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Development of a biomass transducer for automated microalgal bioreactors

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DEVELOPMENT OF A BIOMASS TRANSDUCER FOR AUTOMATED MICROALGAL BIOREACTORS

A Thesis

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Abstract

A highly sensitive miniaturized biomass transducer is necessary for continuous and reliable monitoring of the microalgal biomass in a computer controlled, automated microalgal bioreactor. Previous known methods to determine microalgal biomass applicable in these bioreactors are based on single wavelength turbidimetric or fluorescence. The objectives of this research were to (1) determine the light absorption characteristics of some commercially applicable microalgae in the electromagnetic wavelength range of 200-800 nm (2) design and construct a new miniaturized biomass transducer (3) process the transducer output to correlate with the biomass.

Wavelength sensitivity analysis was conducted on the commercially important microalgal species - *Nannochloropsis oculata*, *Isochrysis galbana* and *Thalassiosira weissflogii*, for a growth range of 0-500 mg dry wt L^{-1}. Maximum absorptions were found at UVC, followed by blue and red regions of the electromagnetic spectrum. A new biomass transducer based on UVC measurement was designed and constructed. The measurements were processed for signal conditioning and higher sensitivity. It was followed by further processing in a central control computer to filter the noise present in UVC measurement.

A statistical relationship was developed for signal processing between the individual variables and a new model for the calibration curve was proposed. The new biomass transducer was tested using the developed signal processing algorithm and the calibration with individual microalgal samples as well as the mixed samples independent of calibration curve. The tested results gave an average error < 10% relative to the mean of actual readings.

Chapter 1: Global Introduction

1.1 Introduction

The importance of microalgae has increased in recent years due to the biotechnological potential for producing valuable substances for the aquacultural, nutraceutical, cosmetic and pharmaceutical industries (e.g. Apt and Behrens, 1999; Lee, 2001; Pulz, 2001; Spolaore et al., 2006). Microalgae have also been investigated for/as an alternative and unconventional source of proteins, a photosynthetic gas exchanger for space travel, in the improvement of wastewater quality, carbon dioxide fixation for conversion of biomass and hydrogen production as a renewable energy source (e.g. Cornet, 1995; Borowitzka, 1997; Borowitzka, 1999; Becker, 2004; Spolaore et al., 2006).

Microalgae obtained from natural water sources are not guaranteed for human and animal consumption due to increased contamination risk in these sources (Lee, 2001). Due to the problems associated with harvesting microalgae from natural water sources, researchers developed culture methods such as artificial, raceway ponds and cascading - open systems (Becker, 1994; Richmond, 2000). The production cost for biomass cultured in raceways ranges between US$ 8-15 per kg of dry weight. This is relatively high compared to fishmeal and soy meal, which are marketed at about US$ 1 per kg (Lee, 2001). There are some other major drawbacks related to open systems. Only a limited range of microalgae can be maintained in open-ponds due to the requirement of extreme culture conditions such as high salinity, high alkalinity and high nutritional level. The contamination risk in open systems with respect to bacteria and protozoa is also high (Lee, 2001). The disadvantages of open systems have given way to the development of closed systems (photobioreactors) for the production of high-value products. Closed systems reduce the risk of contamination and loss of CO_2 thereby improving

the cultivation environment (Pulz, 2001). Outdoor, closed photobioreactors, more common than the indoor closed photobioreactors, take advantage of free solar energy (e.g. Tredici and Materassi, 1992; Rusch and Malone 1998; Borowitzka, 1999; Lee, 2001; Pulz, 2001; Fernandez et al., 2003; Molina-Grima et al., 2003).

In recent years, various forms of closed systems have been proposed and several systems are likely to be commercial realities in the near future (Borowitzka, 1999). The two basic designs are the flat plate reactors (Figure 1.1a) (Hu et al., 1996; Pulz, 2001) and the tubular photobioreactors (Figure 1.1b) (Molina Grima et al., 1999; Sanchez Miron et al., 1999).

(a) (b)

Figure 1.1. The two basic designs of closed systems are (a) closed plate photobioreactor fed with high CO_2 levels from a line production plant, Figure adapted from Pulz (2001), and (b) airlift-driven tubular photobioreactors – two reactors are shown with the tubular loops immersed in a pond of cooling water, Figure adapted from Molina Grima et al., (1999).

The fundamental principle in all of these designs is to reduce the light path and thus to increase the amount of light available to each cell (Borowitzka, 1999). The flat plate photobioreactors are usually erected at an angle with the horizontal, and in some cases, vertical to the ground (e.g. Hu et al., 1996; Zou and Richmond, 1999). The tubular photobioreactors have tubes with diameters less than 0.06 - 0.08 m (e.g. Molina Grima et al., 1999; Sanchez Miron et al., 1999; Sanchez Miron et al., 2002). The tubular photobioreactors such as airlift bioreactors has a diameter of 0.06 m and occupies lesser area and are inexpensive and easy to operate (Fernandez et al., 2001; Sanchez Miron et al., 2002). With different approaches in design, the closed systems seem to be more promising for technical advancements (Pulz, 2001). The closed systems mentioned above are not free from drawbacks even though higher productivity and reduced contamination risk is achieved. Productions costs of closed systems are generally higher than open systems due to higher operating costs such as high labor costs, supplies and chemical facilities, and expensive sterilization procedures (Zou and Richmond, 1999; Molina Grima et al, 1999; Ogbonna et al., 1999; Moreno-Garrido and Canavate, 2001). In order to reduce the high operating costs resulting from labor, supplies and sterilization procedures, a new approach in the design of photobioreactors was needed, so that the new photobioreactor can still maintain the same productivity level as the open and closed systems.

According to the results of an international workshop on microalgal culture for aquaculture, the potential solution to the cost of labor, supplies and chemical facilities, and energy was computer control/automation (Fulks and Main, 1991). At present, maximum possible automation is desired in every bioprocess, so that the process can be carried out more efficiently and, at the same time, repetitive and tedious tasks are avoided (Sonnleitner, 1997). With automated systems, it is possible to control the processes safely and reliably, 24 hours a day and 365 days a year,

with minimum errors and maximum safety. The processes turn out to be reproducible, and the products obtained observe quality and standard regulations. System automation requires devices for on-line monitoring of different parameters needed in every process, such as temperature, pH, aeration and biomass (Dorresteijn et al., 1997). Miniaturized transducers for the *in-situ* measurement of pH, temperature, and pO_2 are well developed for biotechnological measurements (Steenkiste et al., 1997). Generally, efficiency of miniaturized transducers in a control loop depends on their speed and accuracy. When designing a transducer, it is important to fully exploit the potential of modern measurement instrumentation and advanced control methods (Cimander et al., 2003). Biomass is a critical parameter in microalgal culture systems (Rusch and Christensen, 2003), and it is difficult to measure with a good degree of accuracy at a low cost (Madrid and Felice, 2005). Therefore, it is not sufficient to have just the automated photobioreactors without the reliable instrumentation to measure parameters such as biomass.

Researchers at Louisiana State University developed the Hydraulically Integrated Serial Turbidostat Algal Reactor (HISTAR), an automated microalgal reactor for commercial microalgal production. HISTAR provides a robust environment that superimposes suspended contaminant control on algal productivity. HISTAR hydraulically links precisely controlled turbidostats with continuous-flow stirred-tank reactors (CFSTRs) into a single production technology (Theegala, 1997; Rusch and Christensen, 2003; Benson and Rusch, 2006). Within the HISTAR system, real-time biomass estimates are made using a density transducer that consists of a 5 V red LED light source emitting a peak wavelength of 635 nm (Figure 1.2). The transducer has a phototransistor on the opposite end of the culture col1ection chamber within the monitoring unit. The transparent tube through which the sample passes has an external diameter of 25.5 mm. The total path length for the LED light travel is 41 mm. Biomass density

estimations are based on relationship between the potential (given in volts) generated by the phototransistor in response to the light output of the light source versus a total suspended solids (TSS) measurement. As an illustration, the TSS measured for a sample of *Nannochloropsis oculata* was 45 mg-dry wt/L. From this sample, concentrations of 10, 20 and 30 mg-dry wt/L were prepared by diluting with a saltwater solution. The density transducer was used on each of these concentrations and the readings were recorded (Table 1.1). AS can be seen, there was no difference between the blank and 30 mg-dry wt/L samples. Even though the difference between the blank and 40 mg-dry wt/L was about 1 mV, the signal gain between the two concentrations is low, making the density transducer highly insensitive for biomass measurements. The density transducer used for HISTAR is not sensitive enough to detect the mg-dry wt/L difference between individual concentrations.

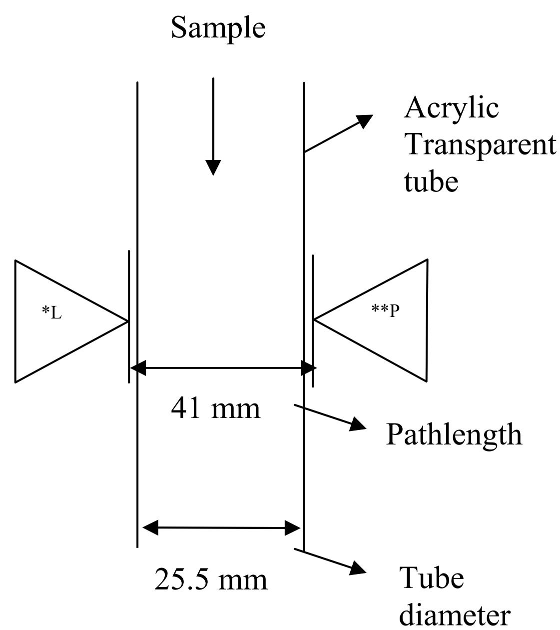

Figure 1.2. The schematic diagram of the microalgal density transducer used for HISTAR system (*L =LED; **P = Phototransistor).

Table 1.1. The readings taken from the density transducer that was used for HISTAR shows insensitivity to increasing biomass.

TSS (mg-dry wt/L)	**Density transducer output (V)**
Blank (Pure salt water)	0.351
10	0.351
20	0.351
30	0.351
40	0.350

While it is vital to make density estimations based on potential (V) versus TSS measurement (mg-dry wt/L), the light sensor design described above does not provide a discerning difference between densities.

The density transducer used in HISTAR is based on the optical density measurement using the absorption spectra due to the presence of chlorophyll *a*. The optical density measurement based transducers are highly insensitive to minor changes in microalgal biomass concentrations, and the measurements are affected due to varying light and nutrient conditions (Nilsson, 2001). On the other hand, the fluorescence transducers to measure microalgal biomass (which are also based on chlorophyll *a* estimations) generate errors into the results when chlorophyll *b* and/or chlorophyll *c* are present in the microalgal species. The main source of error is due to Chlorophyll *b*, which causes slight underestimations of the chlorophyll *a* concentration. The fluorescence based transducers yield only an approximate value of the chlorophyll concentration to be converted into a biomass measurement. This method can be useful where approximate amount of biomass measurement is sufficient instead of accurate measurements such as the method used in a quick assessment of the trophic status of water bodies (Matorin et.al, 2004). Also, the fluorometric transducers are expensive and are difficult to incorporate in an automated microalgal bioreactor due to their large size. The direct determination of microalgal biomass by counting cell numbers under the microscope is both tedious and time consuming. In addition, these methods cannot distinguish viable cells from dead cells. The viable counts method requires elaborate preparations, is laborious, and takes 4-72 hours for the cells to be incubated and counted (Madrid and Felice, 2005).

The demand for commercially available microalgae is increasing, and there have been significant developments in the microalgal reactors with automated control (e.g. Pulz, 2001;

Tredici and Materassi, 1992; Rusch and Malone 1998; Borowitzka, 1999; Molina-Grima et al., 2003). Therefore, in order to maintain the system stability and cost effectiveness, it is important to include highly sensitive, inexpensive and miniature transducers to measure various parameters. Microalgal biomass is a critical operational parameter, thus, advanced techniques are needed to increase their sensitivity when used in automated systems.

1.2 Research Objectives

The overall goal of this research was to develop an inexpensive biomass transducer with greater sensitivity useful for automated microalgal bioreactors. The specific objectives to achieve the goal were:

1. Determine the absorptive wavelength sensitivity for three pure microalgal species, *Nannochlopsis oculata* (*N. oculata), Isochrysis galbana* (*T-ISO*) and *Thalassiosira weissflogii*;
2. Determine the correlation of absorption and microalgal biomass (dry);
3. Design and construct the biomass transducer;
4. Develop an algorithm to process the electrical signal from the transducer;
5. Calibrate the transducer against the measured standard of different microalgal biomass Concentrations; and
6. Test the calibrated transducer with known concentrations of microalgal biomass.

The approach to designing a new microalgal biomass transducer for the automated microalgal bioreactor (i.e. HISTAR) is based on the existing optical density measurement method. The transducer will have two parts, one being the light source that emits appropriate wavelengths to the microalgal sample, and the other being the detector that detects the amount of light passing through the microalgal sample. The light source will have LEDs emitting specific

wavelengths; the selection of which are based on the experimental results obtained in the laboratory using microalgal samples passing through a spectrophotometer. The microalgal samples under investigation will be from three different species belonging to three different classes namely, *Nannochloropsis oculata* (Class: Eustigmatophyte), *Isochrysis galbana* (*T-ISO*) (Class: Prymnesiophytes) and *Thalassiosira weissflogii* (Class: Bacillariophyceae). *Nannochloropsis oculata* (1-2 µm in size) is a photosynthetic, unicellular microalgae, characterized by photosynthetic pigments including chlorophyll *a* and a single parietal yellow – green chloroplast (Anita et al., 1975; Yamamoto et al., 2001). *Isochrysis galbana* belonging to the class of Prymnesiophytes (or haptophyceae) is a small golden/brown flagellate having a width of 2-4 µm and length 4-6 µm. It has chlorophyll *a* and *c* with several other significant characteristics such as moan bearing filiform organelle between the two flagella and calcified scales (Johansson and Graneli, 1999). *Thalassiosira weissflogii* is a pennate diatom (bilaterally symmetric - pennales) with a size of 6-20 µm x 8-15 µm. It has chlorophyll *a* and *c* and varies from brown to green to yellow in color depending on the amount of chlorophyll *a* present in the culture (Friedman and Alberte, 1987; Brown, 1988).

The detection unit will have the same number of silicon photodiodes as the number of LEDs emitting different wavelength. Each of the silicon photodiodes will have uniquely high responsivity for the specific wavelength detected. The size of the transparent tube through which the sample passes will be adjusted according to the distance where highest detection by the photodiode is obtained. The electrical signal given by the photodiodes which is dependent on the absorption spectra for the sample will be proportional to the amount of biomass present in the sample. This will form the basis of correlation between the microalgal biomass and the electrical signal. The microalgal biomass transducer will be calibrated to each species/system specific. The

HISTAR system uses a central control computer (Rugid ™, USA) that will be programmed to accept the biomass transducer signal and process the signal to give a correct biomass measurement.

1.3 Literature Review

1.3.1 Importance of Microalgae

Microalgae grown to the late-logarithmic growth typically contain 30 to 40% protein (Brown et al*.,* 1997; Renaud et al., 1999). The composition of the protein in microalgae is very similar between species (Brown, 1991) and relatively unaffected by the growth phase and light conditions (Brown et al., 1993). Microalgae typically contain 10 to 20% fat and 5 to 15% carbohydrates (Brown et al*.,* 1997; Renaud et al., 1999). There are highlyunsaturated fatty acids (HUFAs) present in microalgae. Highlyunsaturated fatty acids derived from marine microalgae, i.e. docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) and arachidonic acid (AA), are known to be essential for various aquatic larvae (Weers and Gulati, 1997; Sargent et al., 1997). Most marine microalgal species have moderate to high percentages of EPA (7 to 34%). EPA is an established neutraceutical, and evidence is emerging for its therapeutic benefits in disease management (Peet et al., 2001, 2002; Molina Grima et al., 2003). Prymnesiophytes are relatively rich in DHA (0.2 to 11 %), whereas eustigmatophytes such as *N. oculata* and diatoms like *T. weissflogii* have the highest percentages of AA (0 to 4%). Prymnesiophytes such as T-ISO, on average, contain the highest percentages of saturated fats (33% of total fatty acids), followed by diatoms and eustigmatophytes (27%) prasinophytes and chlorophytes (23%) and cryptomonads (18%) (Brown et al., 1997). The content of vitamins can vary between microalgae. Ascorbic acid shows the greatest variation, i.e. 16-fold (1 to 16 mg g^{-1} dry weight) (Brown and Miller, 1992). Concentrations of other vitamins typically show a two- to four-fold difference between species,

i.e. β- carotene 0.5 to 1.1 mg g^{-1}, niacin 0.11 to 0.47 mg g^{-1}, a-tocopherol 0.07 to 0.29 mg g^{-1}, thiamin 29 to 109 μg g^{-1}, riboflavin 25 to 50 μg g^{-1}, pantothenic acid 14 to 38 μg g^{-1}, folates 17 to 24 μg g^{-1}, pyridoxine 3.6 to 17 μg g^{-1}, cobalamin 1.8 to 7.4 μg g^{-1}, biotin 1.1 to 1.9 μg g^{-1}, retinol ≤ 2.2 μg $g^{-1}$and vitamin D < 0.45 μg g^{-1} (Brown et al., 1999). To put the vitamin content of the microalgae into context, data should be compared with the nutritional requirements of the consuming animal.

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Microalgae are a source of various other chemical extracts used in the pharmaceutical and cosmetic industries. On average, about 14 different kinds of carotenoids are found in microalgae, including carotene, canthaxathin and astataxanthin (Leipelt et al., 2001). Microalgae are also extracted for lipids such as phycotene. The lipophilic microalgae with their carotenoid content and tocopherols (vitamin E) are known to increase the catalytic activity in liver and kidneys of animals. Extensive studies have been conducted on the use of these extracts as the dietary supplements to animals such as mice/rats (Abdel-Baky et al., 2002). Microalgae also produce ceramide glucosyltransferases, which consists of ceramides that are widely used as additives to stabilize the skin barrier function to help prevent cancer (Leipelt et al., 2001).

1.3.1.1 Areas Explored for Microalgal Application

The need for human nutritional sources safer than traditional animal products has created renewed interest in microalgae (Feuga, 2000). There are numerous applications from these phototrophic micro-organisms in animal nutrition, human nutrition, disease management and cosmetic industry (Spolaore et. al., 2006). Microalgae are also being examined for their application concerning the water quality, CO_2 fixation for biomass production and renewable sources of energy production (Muller-Feuga et al., 1998; Spolaore et. al., 2006).

Aquaculture: Worldwide aquaculture production is growing, with trends toward intensification and greater control over total nutritional input (Cahu and Infante, 2001; Brown, 2002). The most abundant use of cultured algae is in the aquaculture industry (Cahu and Infante, 2001). Over the last four decades, several hundred microalgal species have been tested as feed, although less than twenty have gained widespread use in aquaculture (Brown, 2002). Microalgal species such as *Isochrysis galbana* and *Nannochloropsis oculata* are utilized in aquaculture as live feeds for all growth stages of bivalve molluscs (e.g. oysters, scallops, clams and mussels), for the larval/early juvenile stages of abalone, crustaceans and some fish species, and for zooplankton used in aquaculture food chains (Brown, 2002). Favored genera of microalgae for larval feeds include *Chaetoceros, Thalassiosira, Tetraselmis, Isochrysis,* and *Nannochloropsis.* These organisms are fed directly and/or indirectly to the cultured larval organism. Indirect means of providing the algae are through *Artemia, Brachionus,* and *Daphnia,* which are, in turn, fed to the target larval organisms (Duerr and Molnar, 1998). *Isochrysis galbana* is the most common species used to feed the larval, early juvenile and broodstock (during hatchery conditioning) stages of bivalve molluscs; these are usually fed together as a mixed diet (O'Connor and Heasman, 1997). Diatoms such as *Thalassiosira weissflogii* are commonly mass-cultured and then settled onto plates as a diet for grazing juvenile abalone.

While microalgae provide food for zooplankton, they also help to stabilize and improve the quality of the culture medium through water quality improvement and stabilization by algal oxygen production (Feuga, 2000). For various freshwater and saltwater animals, the introduction of microalgae to rearing ponds (green-water technique) leads to much better results in terms of survival and growth than that of clear-water techniques (Chuntapa et al., 2003). Some other effects of microalgal presence may include the induction of behavioral processes like initial prey

catching, and the regulation of bacterial population, probiotic effects and the stimulation of immunity (Irianto and Austin, 2002).

Nutritional Supplements: Microalgae are used in human nutrition due to their diverse chemical properties. They act as nutritional supplements or represent a source of natural food colorants and can exist in different forms such as tablets, capsules and liquids. Microalgae can also be incorporated in pastas, snack foods, candy bars or gums and beverages (Borowitzka, 1999). Microalgae for human nutrition are dominated by five strains namely, *Arithrospira, Chlorella, Dunaliella salina* (*D. salina*), *Aphanizomenon flos-aquae* and *Spirulina*. *Arithrospira* is used in human nutrition because of its high protein content and its excellent nutritive value (Spolaore, 2006). In addition, *Arithrospira* has some other health promoting benefits such as the alleviation of hyperlipidemia, suppression of hypertension, protection against renal failure, growth promotion of intestinal lactobacillus and suppression of elevated serum glucose level (Borowitzka, 1999; Apt and Behrens, 1999). *Chlorella* has an important substance called β-1, 3-glucan, which is an immunostimulator, a free radical scavenger and a reducer of blood lipids (Iwamoto, 2004). Various other health-promoting benefits are known to occur such as effectiveness over gastric ulcers, wounds, and constipation; preventive action against atherosclerosis and hypercholesterolemia; and anti-tumor action (Borowitzka, 1999). *D. salina* is exploited for its β-carotene content, which constitutes about 14% of the dry weight of the algal cell. *D. salina* is usually referred to as *Dunaliella* powder, as dietary supplements. *Aphanizomenon flos-aquae* is used alone or in combination with other nutraceuticals or natural food products to promote overall good health (Jensen et al., 2001; Benedetti et al., 2004). *Spirulina* microalgae (*Spirulina platensis, Spirulina maxima, Spirulina fusiformis*) is considered as a valuable additional food source of some macro- and micronutrients including high quality

protein, iron, gamma-linolenic fatty acid, carotenoids, vitamins B_1 and B_{12} (Vieira Costa et al., 2001).

The docosahexaenoic acid, which is rich in oil, is produced from fermented strains of microalgae and is used as an ingredient in several applications including infant formulas, products for pregnant and nursing women, food and beverage products and dietary supplements (Hoffman, 2004). While DHA is a long-chain polyunsaturated omega-3 fatty acid, Arachidonic acid (ARA) is a long-chain polyunsaturated omega-6 fatty acid produced from microalgae (Otero et al., 1997). ARA is naturally available in breast milk and is the primary omega-6 fatty acid in the brain. ARA and DHA together form an important ingredient for infant brain development and physical growth (Birch et al., 2000; Hoffman et al., 2000; Hoffman et al., 2004). Martek Biosciences Corporation (MD, USA) is a premiere organization that produces a variety of microalgal derived nutritional products using fermentation and heterotrophic microalgae in promoting health and wellness through every stage of life.

Terrestrial Animals: Apart from aquatic animals, many other animals such as cats, dogs, ornamental birds, horses, cows and breeding bulls have been administered dietary supplements made up of nutritional extracts from different microalgal species (Certik, 1999; Spolaore et. al., 2006). *Arthrospira* is one such species. It provides a large profile of natural vitamins, minerals, and essential fatty acids; improved immune response and fertility; and better weight control. *Arthrospira* is also known to affect the external appearance resulting in healthy skin and lustrous coat for animals, yields yellow color of broiler skin, shanks and of egg yolk (Certik, 1999; Spolaore et. al., 2006).

Cosmetics, Sun Protection and Hair Care Products*:* Microalgal extracts can be found in face and skin care products such as anti-aging cream, refreshing or regenerant care products,

emollient and as an anti-irritant in peelers (e.g. Certik, 1999; Spolaore et al., 2006). *Arthrospira, Chlorella vulgaris, Nannochloropsis oculata* and *Dunaliella salina* (*D. salina*) are the microalgal species known to be helpful in cosmetics (Spolaore et al., 2006). Protulines® is a product manufactured by a cosmetic company Exsymol (Monte-carlo, Monaco) that uses *Arthrospira* containing gamma-linolenic acid (GLA) that acts as an active ingredient to repair the signs of early skin aging. Cosmetic maker Codif (France) produces a product called Dermochlorella® that uses *Chlorella vulgaris* (natural carotenoid source) in stimulating the collagen synthesis in skin, and hence supports tissue regeneration and wrinkle reduction. PEPHA®– TIGHT manufactured by Pentapharm Ltd. (Switzerland) uses the constituents of *Nannochloropsis oculata* such as the polysaccharides, amino acids and vitamins (especially vitamin C, an effective antioxidant and B_{12}) that have excellent skin-tightening properties with short and long term effects. *D. salina* which is rich in β-carotene has the ability to significantly stimulate cell proliferation and turnover and to positively influence the energy metabolism of skin (Stahl et al., 2000; Spolaore et al., 2006).

Carbon Dioxide Emissions*:* The anthropogenic emissions of carbon dioxide resulting from the combustion of fossil fuels for energy production can have a profound effect on the environment. The increased demand for energy, particularly in the developing world, underlines the projected increase in CO_2 emissions. Meeting this demand without huge increases in CO_2 emissions requires more than merely increasing the efficiency of energy production. Microalgal-based carbon sequestration could be a major tool for reducing atmospheric CO_2 emissions from fossil fuel usage. Microalgae are found to be having higher carbon fixing rates than those of land-based plants by one order of magnitude during photosynthesis (Murakami and Ikenouchi, 1997). Nutrients along with CO_2 from fossil fuel combustion systems are added to the

photobioreactor, where the microalgae photosynthetically convert the CO_2 into compounds of high commercial value. Although microalgal production is expensive, microalgae can produce a variety of high value compounds that can be used to generate revenues as already discussed (Olaizola 2003; Nakamura, 2005). In addition, a few species of microalgae (*Nannochloris atomus,* and *cocolithophorids*) can precipitate CO_2 as calcium carbonate, a potentially long-term sink of carbon (Yates and Robbins, 1998; Zavarzin, 2002).

Hydrogen Production*:* Microalgae are used in hydrogen production as a renewable energy source using just light and water. The fundamental process underlying the hydrogen production is the microalgal photosynthesis. The process of photosynthesis is used to oxidize H_2O and evolve O_2 (PS II reaction), followed by the transport of electrons to ferredoxin (PS I reaction) (Girardi et.al. 2000). The reversible hydrogenase accepts electrons from ferredoxin and generates hydrogen (Peters, 1999). The above phenomenon is observed in some microalgal species such as *Chlamydomonas reinhardtii* (Greenbaum, 1982; Maione and Gibbs, 1986), *Chlorella fusca* (Greenbaum, 1982) and *Seenedesmus obliquus* (Gaffron and Rubins, 1942). Microalgal species such as *Chlamydomonas reinhardtii* can synthesize enzyme hydrogenase that can reduce protons to gaseous hydrogen (Happe and Kaminski 2002). These enzymes can generate hydrogen under appropriate conditions, and can receive the electrons for this process from ferredoxin reduced by PS I (Happe and Kaminski 2002; Tamagnini et al., 2002; Schutz et al., 2004). On a commercial scale, there have been different schemes suggested for generating hydrogen using the photosynthesis process as the basis. Two fundamentally different systems are usually considered to produce hydrogen from microalgae (Prince and Kheshgi, 2005). The first scheme splits water and utilizes hydrogenase as the enzyme to reduce protons, simultaneously evolving oxygen and hydrogen by microalgae. Subsequently, the two gases are separated. This process is known as

direct biophotolysis. The second scheme involves two stages. In the first stage, microalgae fix carbon dioxide and store carbohydrates, evolving oxygen. In the second stage, the carbohydrates are oxidized by light illumination to produce hydrogen. In this way, the hydrogen producing reactions are separated from the oxygen evolving reactions. This process is known as indirect biophotolysis (Melis and Happe 2001; Hallenbeck and Benemann, 2002; Levin et al., 2004; Prince and Kheshgi, 2005; Dutta et al., 2005). Tubular and flat photobioreactors can be used for hydrogen production from microlagae which can address some of the requirements such as: photobioreactors should be enclosed so that the produced hydrogen is not lost, convenient sterilization procedures, high surface to volume ratio to maximize the area of incident light (Dutta et al., 2005).

1.3.2 Commercial Production of Microalgal Biomass

For decades, microalgae were harvested from natural sources for human and animal consumption. Even though there were no cultivation costs, the product quality and higher productivity could not be assured (Lee, 2001). Due to these issues associated with natural water sources, microalgae were later mass cultured in artificial, raceway ponds and cascades (Becker, 1994; Richmond, 2000). The current methods of microalgal culture rely on batch (static containers that are inoculated, grown to a specific density and harvested), semi-continuous or continuous cultures (Pulz, 2001). Major advances in commercial production of microalgal biomass are expected from new production system designs and operations, from batch-run\open tanks to more sophisticated continuously run and closed loop reactors due to the increased importance of microalgae (Fuega, 2000).

1.3.2.1 Open-Culture Systems

Open-culture systems are almost always located outdoors and rely on natural light for illumination (Muller-Feuga et al., 1998). Open systems can be divided into natural waters (lakes, lagoons, ponds) and artificial ponds or containers, erected in very different ways. Raceway-shape culture ponds are used in Israel, the United States, China and other countries (Lee, 2001). Fertilizer is used in the raceway ponds, and the culture is agitated by paddle wheels. A cell concentration of about 0.5 g L^{-1} can be maintained, and a productivity of about 25 g m^{-2} d^{-1} has been widely reported (Richmond et al., 1990).

In the open-pond system, monoculture of algae is usually achieved by maintaining an extreme culture environment, such as high salinity, high alkalinity and high nutritional status (Pulz, 2001). Thus, a limited range of microalgae can be maintained as mono-culture in open ponds during long term operation. It must be noted that such approaches do not necessary exclude bacteria and other biological contaminants (e.g. protozoa) (Lee, 2001). Significant evaporative losses, the diffusion of CO_2 to the atmosphere, as well as the permanent threat of contamination and pollution, are the major drawbacks of open pond systems. For future applications, open pond systems for large scale production seem to have a lower innovative potential than closed systems. For high value products in particular, closed system of photobioreactors seem to be the more promising for technical developments (Pulz, 2001).

1.3.2.2 Closed Photobioreactors

Until recently, open systems were the most important design principle for microalgal production (Richmond, 1990). However, the extraction of high-value products from microalgae for applications in pharmaceutical and cosmetic industries appears to be feasible only on the basis of closed photobioreactors with the ability to reproduce production conditions and to be

GMP-relevant (GMP: good manufacturing practices following ISO and EC guidelines) (Pulz, 2001). The assumption that high cell concentration is necessary to achieve higher biomass productivity, and the need to maintain monoculture for microalgae that grow in mild culture conditions have led to the development of enclosed photobioreactors (Lee, 2001).

Closed photobioreactors are characterized by the regulation and control of nearly all the biotechnologically important parameters as well as by the following fundamental benefits (Pulz 2001): a reduced contamination risk, minimal CO_2 losses, reproducible cultivation conditions, controllable hydrodynamics and temperature, and flexible technical design. Closed photobioreactors may be located indoors or outdoors, but outdoor location is more common because it can make use of free sunlight (e.g. Sanchez et al., 1999; Pulz, 2001). Another advantage of the enclosed photobioreactors is the ability of process control (Pulz, 2001). Closed photobioreactors can be implemented in a process control system, enabling the control and manipulation of various parameters such as pH, temperature and biomass (e.g. Theegala 1997; Theegala et al., 1999; Rusch and Malone 1998; Rusch and Christensen, 2003; Marxen et al., 2005).

Various forms of tubular photobioreactors have been proposed: horizontal straight tubes connected by U-bends (Tredici and Materassi, 1992); α-type photobioreactor with cross tubes arranged at an angle with the horizontal and flexible tubing coiled around a vertical cylindrical frame work (Borowitzka, 1999). There have been a number of other recent advancements in continuous microalgal culture methods; closed tubular photobioreactors made of glass or acrylic tubing (Molina-Grima et al., 1999), closed reactors with integrated internal lighting (Ogbonna et al., 1999) and plastic bag cultures (Moreno-Garrido and Canavate, 2001).

Despite higher biomass concentrations and better control of culture parameters, data accumulated in the past 25 years have shown that the volumetric productivity and cost of production in these enclosed photobioreactors are no better than those achievable in open-pond cultures (Zou and Richmond, 1999; Lee, 2001). The technical difficulty in sterilizing these photobioreactors has hindered their application for the production of high value pharmaceutical products (Lee, 2001). None of the microalgal culture methods including the flat plate glass reactor, closed tubular photobioreactors made of glass or acrylic tubing, closed reactors with integrated internal lighting and plastic bag cultures address the potential for culture collapse due to inadvertent contaminants common to all static and continuous cultures (Moreno-Garrido and Canavate, 2001). The current methods used to reduce contamination problems depend on expensive sterilization procedures, which increase the production costs (Rusch and Christensen, 2003).

1.3.2.3 HISTAR

The hydraulically integrated, serial turbidostat algal reactor (HISTAR) was developed for the mass production of microalgae (Rusch and Malone, 1998). HISTAR, which hydraulically connects precisely controlled turbidostats with continuous-flow stirred-tank reactors (CFSTRs) into a single production technology, was envisaged emphasizing contaminant mitigation at the design stage to maintain system stability. Many contaminants present during microalgal production such as, undesired algae or protozoans, have the same exponential growth as that of the desired microalgae. Doing more at the design level of the microalgal production system to contain the contaminant growth will help in the development of a system that is more tolerant to disturbances caused by contaminants. The factor that controls microalgal production system success or failure is the stability. Stability, which refers to the ability of microalgal bioprocess to

withstand the contamination by undesired algae or protozoans is a major feature of the HISTAR system. HISTAR was the result of a combination of the above philosophy and integrated continuous and open system strategy (Rusch and Malone, 1998). A very high and consistent quality of fresh microalgal innoculum is produced by the enclosed turbidostats. The CFSTRs are open to atmosphere (Figure 1.3). The hydraulic connection from the tubidostats to CFSTRs allows the passage of microalgal innoculum between them (Q_{tb}, m^3 d^{-1}). A solution containing water and other media (nutrients) is injected continuously into the first CFSTR, and it acts as a primary driving force for the continuous flow of microalgae through the system (Q_f, m^3 d^{-1}). The combined effect of Q_{tb} and Q_f forms the total flow through the system, Q_T (m^3 d^{-1}).

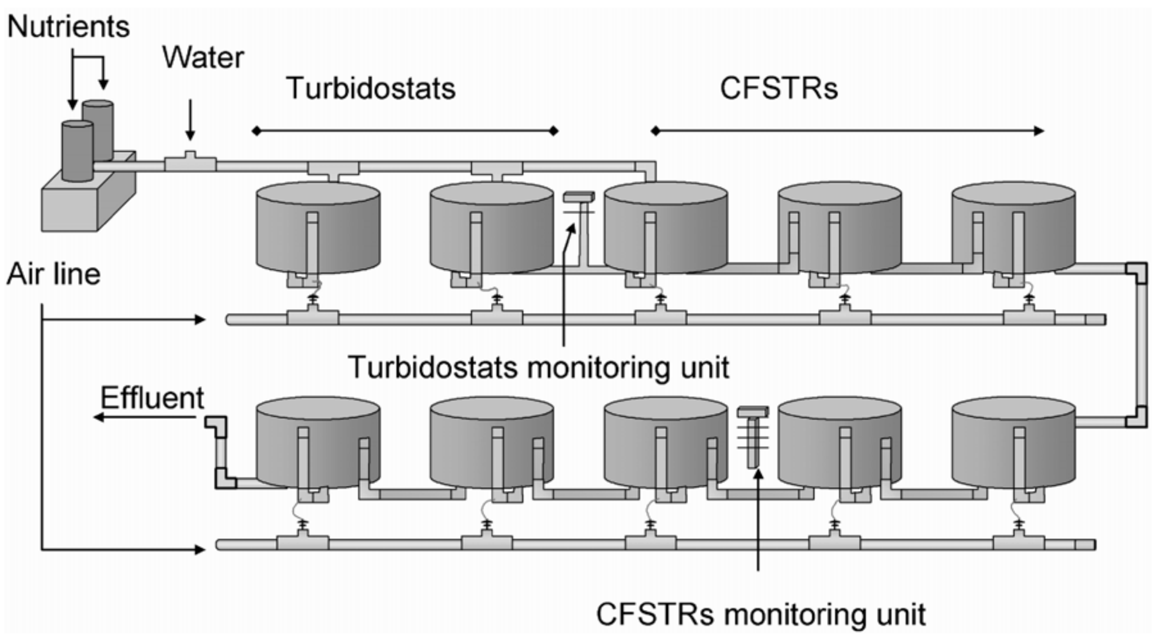


Figure 1.3. The HISTAR system contains two enclosed turbidostats and eight open topped CFSTRs. Figure was adapted from Benson and Rusch (2006).

In order to flush out the contaminants, a local dilution rate (D_n, d^{-1}) is selected for individual CFSTRs that is greater than the growth rate of contaminants (U_c, d^{-1}). The microalgal sample is being driven from one CFSTR to another, and the number of serial CFSTRs (excluding the turbidostat) decides the system dilution (D_s, d^{-1}). System dilution is an important parameter

controlling the daily productivity of the HISTAR system. High D_n and low D_s combined with continuous supply of pure microalgal innoculum from the turbidostats is conducive for microalgal growth while suppressing contaminant growth (Theegala 1997; Theegala et al., 1999; Rusch and Malone 1998; Rusch and Christensen, 2003).

1.3.3 Current Methods to Estimate Microalgal Biomass

Research from the past decade has focused on new reactor designs (Sandnes et al., 2006). However, operational costs are generally higher in the 'new-generation' closed production designs and it is therefore important to maintain the culture at close to optimal culture conditions to maximize the output and reduce production costs. Control over the growing culture is necessary on a time-frame relevant to production rates and, in the case of algal culture, important decisions with respect to fertilizing, harvesting, lighting and temperature may need to be taken on an hourly basis to prevent economical losses. As such, the development of an integrated system for monitoring growth parameters is important for commercial viability, providing the grower with valuable information to optimize production processes and reduce costs (Rusch and Malone, 1998; Gitelson et al., 2000; Sandnes et al., 2006).

A number of methods have been developed to sense and quantify biomass, which are useful in different cases, depending on the application (Madrid and Felice, 2005). At present, the maximum possible automation is desired in every bioprocess, so that the process can be carried out more efficiently and, at the same time, monotonous and boring tasks are avoided (Sonnleitner, 1997). Automation allows us to control processes safely and reliably, 24 hours a day and 365 days a year, with minimum errors and maximum safety. The processes turn out to be reproducible, and the products obtained observe quality and standard regulations. But such an automatic control requires devices for on-line monitoring of different parameters needed in every

process, such as temperature, pH, aeration, or biomass (Dorresteijn et al., 1997). Miniaturized transducers for the in-situ measurement of pH, temperature, pO2 are well developed for biotechnological measurements (Steenkiste et al., 1997). Generally, the faster and more accurate the devices are, the more efficient the control performed in the bioreactor will be. Biomass is a critical parameter in the microalgal harvesting process (Rusch and Christensen, 2003), and it is difficult to measure with a high degree of accuracy (Madrid and Felice, 2005).

1.3.3.1 Dry and Wet Weight

The dry weight method is the most widely applied technique for biomass estimation. The cell density can be quantified as grams of dry or wet weight per liter of sample. The cells in a sample can be separated from the broth and weighed while they are wet, or the cells may be thoroughly dried before weighing. According to Standard Methods (APHA, 1998), the dry weight measurement usually gives a much more consistent result than the wet weight and is usually used as a reference method. However, the dry weight of marine algal samples is affected by the amount of salts absorbed on the cell surface and present in intercellular water. Washing of cell mass is a common technique employed to avert this possible error but the use of the various washing agents has not been subjected to a rigorous verification that gains acceptance. It can be concluded that isotonic solutions of ammonium formate and ammonium bicarbonate are satisfactory washing agents for the dry weight determination of marine algal samples (Lee and Zhu, 1997).

1.3.3.2 Epifluorescence Microscopy

Epifluorescence is a Direct Count (DC) method which is based on the same optical principles of common microscopy. However, it differs in sample handling and in the design and operation of the microscopes used. When designing the generation systems and wave

transmissions of these microscopes, adequate wavelengths for the fluorochromes to be visualized must be taken into account. A fluorochrome is a fluorescent dye used to label biological material. The excitation processes generally require short wavelengths, in the near UV (halogen-quartz lamps, mercury arc lamps, etc.). The lens must be made of a special material (generally fluorite) that is able to transmit these wavelengths. The immersion oil must be non-fluorescent. The most successful technique of this nature is the direct epifluorescence filter technique (DEFT) (Hobson et al*.,* 1996). By using this technique, the microalgae are filtered onto an appropriate membrane. The fluorescent agent is then added (i.e, acridine orange or diamidino-2-phenylindole) to stain the cells. The detection is carried out by fluorescent microscopy or by other methods capable of measuring epifluorescence. The detection limit of the method is 5 X 10^3 microorganisms/mL (Madrid and Felice, 2005).

1.3.3.3 Bioluminescence

Chemiluminescence occurs when a chemical reaction produces an electronically excited species that emits a photon in order to reach the ground state. These reactions are encountered in biological systems, and the effect is called bioluminescence. Bioluminescence is a very rapid and sensitive method for microorganism detection. Assuming that living cells contain a reasonable constant amount of adenosine 5'triphosphate (ATP), which is lost rapidly upon cell death, it can be a good parameter to measure or quantify cells. The reaction of ATP with luciferin catalyzed by the luciferase enzyme is the principle of the bioluminescence method (Billard and DuBow, 1998; Horsburgh et al., 2002; Premkumar et al., 2002; Kim et al., 2003; Kim and Gu, 2003). One photon of light is produced per molecule of hydrolyzed ATP, and this can be measured using a photometer (Hobson et al*.,* 1996), giving a sensitivity of about 10^{-4} mol of ATP. The light emitted is detected, that is proportional to the amount of ATP present (Madrid and Felice, 2005).

1.3.3.4 Photometric Methods

1.3.3.4.1 Fluorescence

Microalgae exhibit fluorescence when a light of particular wavelength is incident on it. The fluorescence, excited by an artificial light source, has been measured in dark-adapted algae in which the PS II reaction centers are open, so that absorbed light energy can be converted into chemical bond energy with maximum efficiency (Berges et al., 1996). The fluorescence technique is used to estimate microalgal biomass by measuring chlorophyll *a* (Honeywill et al., 2002). The electron moves from a high energy state to a lower one, emitting a photon. Absorption of UV radiation by a molecule excites the electron from a vibrational level in the ground state to one of the vibrational levels in the excited state. This excited state is usually the first excited multiplet state by the single component (singlet state). A molecule in a high vibrational level of the excited state will quickly fall to the lowest vibrational level of this state by losing energy to other molecules through collision. The excess energy is divided by the molecule into other possible modes of vibration and rotation. Fluorescence occurs when the molecule returns to the electronic ground state, from the excited singlet state, by emission of a photon. This process distinguishes fluorescence from chemiluminescence, in which the excited state is populated by a chemical reaction (Madrid and Felice, 2005).

Four essential elements of fluorescence detection systems are identified from the preceding discussion: 1) an excitation source, 2) a fluorophore, 3) wavelength filters to separate emission photons from excitation photons, and 4) a detector that registers emission photons and produces an electrical or photographic output. Regardless of the application, compatibility of these four elements is essential for optimizing fluorescence detection (Karsten et al., 1995). Fluorescence is the most popular method for on-line biomass determination in a bioprocess. The intensity of the

fluorescence is affected by the amount of viable biomass concentration and by some abiotic factors such as air bubbles or other fluorescent components in the medium (Gales, 2000; Madrid and Felice, 2005). C-Labeling of chlorophyll *a* and subsequent extraction by HPLC can be adapted for microalgal biomass measurement. The *in-vivo* fluorimetric methods use the technique of monitoring chlorophyll content as a marker for microalgal biomass measurement (Olaizola et al., 1996; Moberg and Karlberg, 2001).

The fluorescence based methods to measure microalgal biomass (which are also based on chlorophyll *a* estimations) generate errors into the results when chlorophyll *b* and/or chlorophyll *c* are present in the microalgal species. The main source of error is due to Chlorophyll *b*, which causes slight underestimations of the chlorophyll *a* concentration. The fluorescence based transducers yield only an approximate value of the chlorophyll concentration to be converted into a biomass measurement. This method can be useful where approximate amount of biomass measurement is sufficient instead of accurate measurements such as the method used in a quick assessment of the trophic status of water bodies (Matorin et.al. 2004). Also, the fluorometric transducers are expensive and are difficult to incorporate in an automated microalgal bioreactor due to their large size. The direct determination of microalgal biomass by counting cell numbers under the microscope is both tedious and time consuming (Madrid and Felice, 2005).

1.3.3.4.2 Nephelometry

Nephelometry is a method for the measurement of scattered light. In this method, the light source and the photodetector are usually but not necessarily 90° with each other. The photodetector detects the intensity of scattered light from the sample. It is based on the principle that a dilute suspension of small particles will scatter light (usually a laser) passed through it rather than simply absorbing it. The signal obtained from the photodetector is directly

proportional to biomass. This technique is widely used in clinical laboratories because it is relatively easily automated (Madrid and Felice, 2005).

Ciaccheri et al. (2002) constructed an optical fiber based nephelometer that performs two-wavelength and multi-angle scattering measurements, the output of which are then being processed by Principal Component Analysis. The instrument was constructed for achieving multi-angular light scattering measurements of a test sample varying the scattering angle. There are two identical optical fibers positioned along the ring. One of the optical fibers is connected to the light source that provides a near-collimated light beam. The other optical fiber is connected to the detector. This fiber can rotate along the ring and identifies a detecting view. The angle identified by the fiber axes is the scattering angle, while the intersection between the illuminating beam and detection view is the area of sensitivity of multi-angular scattering measurements. The output of the nephelometer is the intensity of scattered light as a function of the scattered angle (Ciaccheri et al., 2002).

1.3.3.4.3 Optical Density

The principle behind the optical density measurement to quantify microalgal biomass can be explained as follows. The interaction of light with the microalgae is found to be predominantly for the purpose of photosynthesis. The three classes of photosynthetic pigments (chlorophylls *a*, *b* and *c*) absorb light of different wavelengths: the blue (~430 nm) and the red (650-700 nm) regions of the visible spectrum. The carotenoids and phycobilins absorb in the ranges 400–500 nm and 500-650 nm, respectively (Matorin et al., 2004). The DNA (deoxyribonucleic acid) present in the microalgae absorbs the UVC part of the UV light. The aromatic ring structure of the purine and pyrimidine that make up the nucleoside bases of DNA and RNA present in microalgae are responsible for absorbance of UV (i.e., UVC) light at 260 nm. Although each

specific base has a maximal absorbance at a slightly different wavelength, on average, nucleic acids as a macromolecule will absorb maximally very near 260 nm (Douki et al., 2003). The relationship between absorbance and the concentration of the absorbing species can be explained using the Lambert-Beer law:

$$A=a(\lambda)\ b\ c \tag{1.1}$$

where A is the measured absorbance, $a(\lambda)$ is a wavelength (λ)-dependent absorptivity coefficient, b is the path length, and c is the microalgal biomass concentration. The absorbance measurement is calculated using the following relation:

$$A = -\log T = -\log (I / I_o) \tag{1.2}$$

where T is the light transmission through the sample, I is the light intensity after it passes through the sample and I_o is the initial light intensity. The amount of light absorbed is proportional to the number of molecules responsible for absorption. The Lambert-Beer law is based on three assumptions: (1) the direction of the incident radiation does not change travels across the culture; (2) the incident radiation is monochromatic; and (3) the effect of scattering due to the presence of solid particles is negligible compared to absorption (Fernandez et al., 1997; Nomura et al., 1997; Okuyama et al., 1998; Gore, 2000). Although, the Lambert-Beer's law of light attenuation gives a linear relationship between the absorbance and microalgal biomass concentration, it is not applicable for high biomass concentrations due to the existence of different scattering and selective absorption effects (Fernandez et al., 1997). With regard to scattering effect, the law assumes linear relationship between the absorbance and the biomass concentration. The mathematical model developed by Fernandez et al. (1997) shows that, after a certain concentration of biomass, there is a deviation from the Lambert-Beer's law showing hyperbolic tendency with the absorbance. Cornet et al. (1995) developed a mathematical model

for the microalgal species *spirulina platensis* that assumes light attenuation to be the result of two combined phenomenon, absorption and scattering.

The use of optical density (OD) as a turbidimetric measure of biomass is the most common method of noninvasive biomass estimation. Systems able to continuously measure OD in the bioreactor medium are not difficult to build as they use a simple light source such as an LED and a photodetector. The photodetector is placed in line or 180° from the light source and it detects the intensity of transmitted or the unscattered light passing through the sample. The OD based measurements have a low signal-to-noise ratio (Wilde and Gibbs, 1998). At present, the OD based optical transducers have single light source emitting a specific wavelength for microalgal absorption that is based on Lambert-Beer law (1.1). The transmitted light is detected by a single photodetector which is then correlated with the microalgal biomass. The microalgal absorption of the single wavelength may not be effective for the whole growth range and for more than one species. The microalgal biomass measurement using the light absorption based on Lambert-Beer's law is not applicable for higher microalgal concentrations as discussed before. The OD measurement based transducers could also be affected by varying light conditions (Nilsson, 2001). Proper design of the microalgal biomass transducer that is equipped with signal processing techniques is required in order to accommodate the whole growth range of microalgae and, for more than one species. The OD based transducers have the potential if properly designed with appropriate signal processing techniques, to measure microalgal biomass concentration.

One of the recent techniques to detect microalgal biomass uses the principle of optical density (OD) with light transmittance at/near IR region as a turbidimetric measure to determine biomass (Sandnes et al., 2006). These researchers reported the use of an optical density

transducer for automated control by detecting the light in the near infrared region (880 nm) passing through the microalgal sample. The optical density sensor was constructed with an array of near infrared (NIR) light emitting diodes of wavelength 880 nm and mounted externally on the transparent tube. The transparent tube was reduced locally to approximately l0 mm as illustrated in Figure 1.4, to increase the total transmitted light. The transmitted light was measured by a photodiode positioned on the opposite side of the tube. The number of diodes (five) in the LED array was selected to give high instrument sensitivity over a culture density range suitable for biomass production studies in the system (0.5-2 g L^{-1}). The optical sensors were calibrated to both algal dry weight and cell number counts for the biomass range required for culture experiments. Each sensor/system/species combination must be individually calibrated (Sandnes et al., 2006).

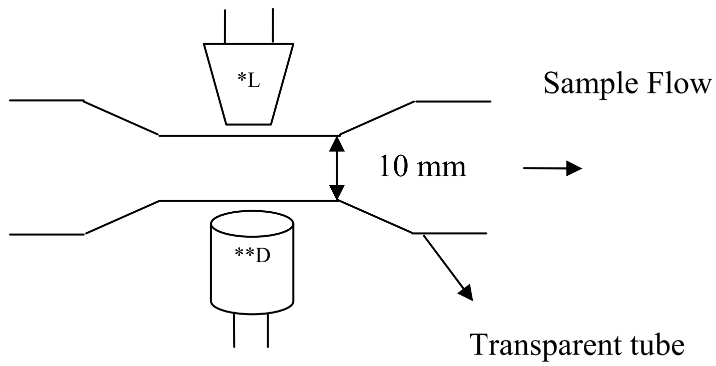


Figure 1.4. The sketch shows the microalgal optical density sensor mounted on the transparent tube with reduced diameter (*L = LED; **D = Photodiode). Figure adapted from Sandnes et al., (2006).

Meireles et al. (2002) used a flow injection analysis technique with the optical density transducer detecting the minimum absorption from microalgal samples at 550 nm. From the several systems available to date for bioreactor control, flow injection analysis (FIA) deserves special attention owing to its low cost, and extremely good reproducibility. FIA allows one to perform automatic dilution. In addition, the carrier fluid stream cleans the detector cell permanently because of its high linear velocities. For these reasons, systems of this type have

already been applied for monitoring; yeast and bacteria biomass, using spectrophotometric and/or fluorimetric detectors, in fermentation processes (Benthin et al., 1990). Furthermore, FIA systems are extremely versatile. Once they are implemented to control one parameter, they can easily be adapted to control others but not yet in microalgal cultures (Meireles et al., 2002).

The FIA device consists of a C22 two-position/eight-channel valve (VICI, USA) with two sample loops, each providing a different dilution of the culture medium. The injection valve is computer controlled via a two-position microelectric actuator interface (VICI), connected through an RS232 serial port. The culture is continuously recirculated from the reactor through the valve with a peristaltic pump at a flow rate of 3.6 mL min $^{-1}$. The carrier fluid is driven by a pump, at a flow rate of 22.0 mL min $^{-1}$. It consisted of sterilized deionized water, which flows from the reservoir through the opposite loop of the culture and then to the detector. The detector was an UV-vis spectrophotometer, equipped with a flow cell. The switching of the detector was also computer-controlled via an RS232 serial port. The wavelength was set to 550 nm because absorption of cellular pigments at this wavelength is at a minimum (Meireles et al., 2002).

The disadvantage with the above device is that there is a divergence in the offline measurement from online measurement. At 550 nm, the cells disrupt rather than absorb the incident light. The divergence found when the cultures reach stationary and death phases can be explained by cell disruption inside the reactor owing to culture conditions. The cell disruption will not interfere as all cellular pigments released will still contribute to that measurement due to the turbidimetric measurement (Meireles et al., 2002). Considering that the microalgal bioreactor system is completely automatic, coupled with the intrinsically high versatility of FIA, the feasibility of this application can be extrapolated to virtually any reactor. This application can also be optimized to measure more than one parameter at a time such as chlorophyll *a.* The

chlorophyll *a* determination is already tested using similar detectors (Eriksen et al., 1998) and could easily be incorporated in the system described here (Meireles et al., 2002).

An optical transducer to measure microalgal biomass consists of a light source made of LEDs and, a light detector made of photodetectors that have high responsitivty to light wavelength emitted by the LEDs.

1.3.3.4.3.1 LED Light Source

Due to their long operating lifetimes, small size, low power consumption, and the fact that they generate little heat, LEDs are the light sources of choice in many applications. When biased in the forward direction (i.e., the anode of LED is connected to positive terminal of the DC source and cathode to the negative terminal), LEDs emit light that is very narrow in spectral bandwidth (light of one color). The color of the light emitted depends on which semiconductor material is used for the LED. There are some ideal characteristics for an LED that should be noted before the device is used in any electronic circuitry. The LED light source should not be affected by frequency of starting. Once switched on, it should stabilize very fast. The LED should not be affected by the high temperature and humid conditions like the ones found in a greenhouse. The life span, which is dependent on a number of factors like heat sinking, wavelength it is emitting, current it is driven by and some other factors, should be acceptable. The life span of the LED that will be used in the biomass transducer is enhanced by the fact that the LED is not always ON. Some of the other characteristics that should be noted while working with the LED include output power, focused emission and power dissipation. A series resistor is necessary if the voltage cannot be regulated to match the LEDs forward supply voltage. Adding resistance to the circuit will help stabilize the voltage across the LED. In a sense, a LED and resistor in series act as a voltage regulator (Pursiainen et al., 2001).

1.3.3.4.3.2 Photodetector

The detection element of the optical transducer is also called the output element. There is a wide variety of detectors that are used in the field of optical detection. Today we find single element detectors and multi – element detector arrays (both linear and two dimensional) that respond from the ultraviolet portion of the spectrum into the far infrared. The detection of optical radiation is accomplished by converting photon energy into an electrical signal through the use of photosensitive materials and thermally conductive materials (Godfrey, 2003).

There are several parameters that characterize a given detector and should be considered when making a selection for sensing applications. These include responsivity, quantum efficiency, linearity, and speed. Responsivity is defined as the detector output per unit of input power. Knowledge of the responsivity will allow the user to determine how much detector signal will be available for a specific application when exposed to discrete light levels. Quantum efficiency is the ratio of photoelectrons produced by photons incident on the detector to the actual number of incident photons. Linearity is another important characteristic of a detector. Photodetectors are characterized by a response that is linear with incident intensity over a broad range, perhaps many orders of magnitude. Response time of a detector is another term that must be considered. If a constant source of light energy is instantaneously turned on and irradiates a photodetector, it will take a finite time for current to appear at the output of the device and reach a steady value (Godfrey, 2003; Bacon et al., 2004).

Silicon photodiode: A P-N junction consisting of a positively doped P region and a negatively doped N region forms a silicon photodiode. Between these two regions exists an area of neutral charge known as the depletion region. When light enters the device, electrons in the structure become excited. If the energy of the light is greater than the band gap energy of the

material, electrons will move into the conduction band. The result is the creation of holes throughout the device in the valence band where the electrons were originally located. Electron-hole pairs generated in the depletion region drift to their respective electrodes: N region for electrons and P region for holes, resulting in a positive charge build-up in the P layer and a negative charge build-up in the N layer. The charge is directly proportional to the amount of light falling on the detector. The above principle describes the photovoltaic method of operation. It is also possible to apply a reverse bias to the photodetector, creating the photoconductive mode. This has the effect of increasing the electric field strength between the electrodes and the depth of the depletion region. The advantages of this kind of operation are lower capacitance, and hence higher speed as well as improved linearity. However, dark current is directly dependent on reverse bias voltage, and thus becomes larger with increasing bias voltage.

1.4 Summary

The literature review discussed the importance of microalgae with applications in many different industries such as aquaculture, nutraceutical, pharmaceutical and cosmetic. Commercial production of microalgae was discussed with the techniques achieved from open systems to closed, automated microalgal bioreactors. The need for process controlled systems to achieve high productivity was discussed. The important part of the literature review was the study of unique characteristics of some classes of microalgae such as Eustigmatophyte*,* Prymnesiophytes and Bacillariophyceae. The literature review laid emphasis on the three most important microalgal species belonging to these classes i.e. *Nannochloropsis oculata* (Class: Eustigmatophyte)*, Isochrysis galbana* (*T-ISO*) (Class: Prymnesiophytes) and *Thalassiosira weissflogii* (Class: Bacillariophyceae). Different methods to determine the microalgal biomass were discussed such as dry and wet weight method, epifluorescence microscopy,

bioluminescence and photometric. Under the photometric techniques, fluorescence, nephelometry and optical density based methods were discussed. Some of the recent advances in microalgal biomass transducer designs using optical density measurements such as flow injection and near IR light transmittance techniques were discussed. Finally, the main components of an optical transducer such as the light source made of LEDs and light detectors made of photodetectors were discussed.

Chapter 2: Development of a Biomass Transducer for Automated Microalgal Bioreactors

2.1 Introduction

Microalgae represents one of the most promising sources of new products and applications due to their biotechnological potential to produce valuable substances (e.g. Apt and Behrens, 1999; Pulz, 2001; Lee, 2001; Pulz and Gross, 2004; Spolaore et al., 2006). Some of the valuable substances present in microalgae are proteins (30 to 40%), lipids (10-20%), carbohydrates (5-15%) (Brown et al., 1997; Renaud at al., 1999), anti-oxidants such as β-carotene, vitamin C (Brown and Miller, 1992; Sandnes et al., 2006) and highlyunsaturated fatty acids such as docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) and arachidonic acid (AA) (Sargent et al., 1997; Sandnes et al., 2006). Due to these valuable substances, microalgae are used in feed, food and antibiotics in the aquacultural, nutraceutical, pharmaceutical and cosmetic industries (Pulz, 2001; Lee, 2001; Spolaore et al., 2006). Microalgae have also been explored as a photosynthetic gas exchanger for space travel, in wastewater quality improvement, in CO_2 fixation and as a renewable source of energy (Borowitzka, 1997; Borowitzka, 1999; Becker, 2004; Spolaore et al., 2006). To take advantage of the benefits of microalgae, efficient microalgal bioreactors that produce microalgae in mass quantities without contamination are required (Becker, 1994; Richmond, 2000; Pulz, 2001; Rusch and Christensen, 2003).

The problems associated with harvesting microalgae in natural water sources, such as increased contamination risk, led to the development of culture methods such as artificial, raceway ponds and cascading - open systems (Becker, 1994; Richmond, 2000; Lee, 2001; Sandnes et al., 2006). The open systems also suffered from the risk of contamination and low productivity (Tredici and Materassi, 1992). To overcome the

disadvantages of open systems (e.g. limited production range, contamination), closed system microalagal bioreactors were developed (e.g.; Tredici and Materassi, 1992; Rusch and Malone 1998; Borowitzka, 1999; Molina Grima et al., 1999; Sanchez Miron et al., 1999; Lee, 2001; Pulz, 2001; Sanchez Miron et al., 2002; Molina-Grima et al., 2003; Fernandez et al., 2003; Rusch and Christensen, 2003). Several closed system designs have been investigated including horizontal straight tubes connected by U-bends, α-type photobioreactors and flat plate photobioreactors (Tredici and Materassi, 1992; Borowitzka, 1999; Hu et al., 1996; Molina Grima et al., 1999; Sanchez Miron et al., 1999 and 2002; Molina-Grima et al., 2003).

The efficiency of closed systems can be further enhanced by automation with centralized computer control (Fulks and Main, 1991). By automating the closed systems, the processes can be efficiently carried out, avoiding tedious and repetitive tasks thereby reducing the operating costs (Sonnleitner, 1997). With automated systems, it is possible to control the processes safely and reliably, 24 hours a day and 365 days a year, with minimum errors and maximum safety. The processes turn out to be reproducible, and the products obtained observe quality and standard regulations (Dorresteijn et al., 1997). The Hydraulically Integrated Serial Turbidostat Algal Reactor (HISTAR), developed by the researchers at Louisiana State University is an automated computer controlled microalgal bioreactor that gives robust environment for microalgal production (Theegala, 1997; Rusch and Christensen, 2003; Benson and Rusch, 2006).

HISTAR hydraulically connects precisely controlled turbidostats (enclosed) with continuous-flow stirred-tank reactors (CFSTRs) (open to atmosphere) into a single production technology (Figure 2.1). A very high and consistent quality of fresh

microalgal innoculum is produced by the turbidostats. The hydraulic connection from the tubidostats to CFSTRs allows the passage of the microalgal innoculum.

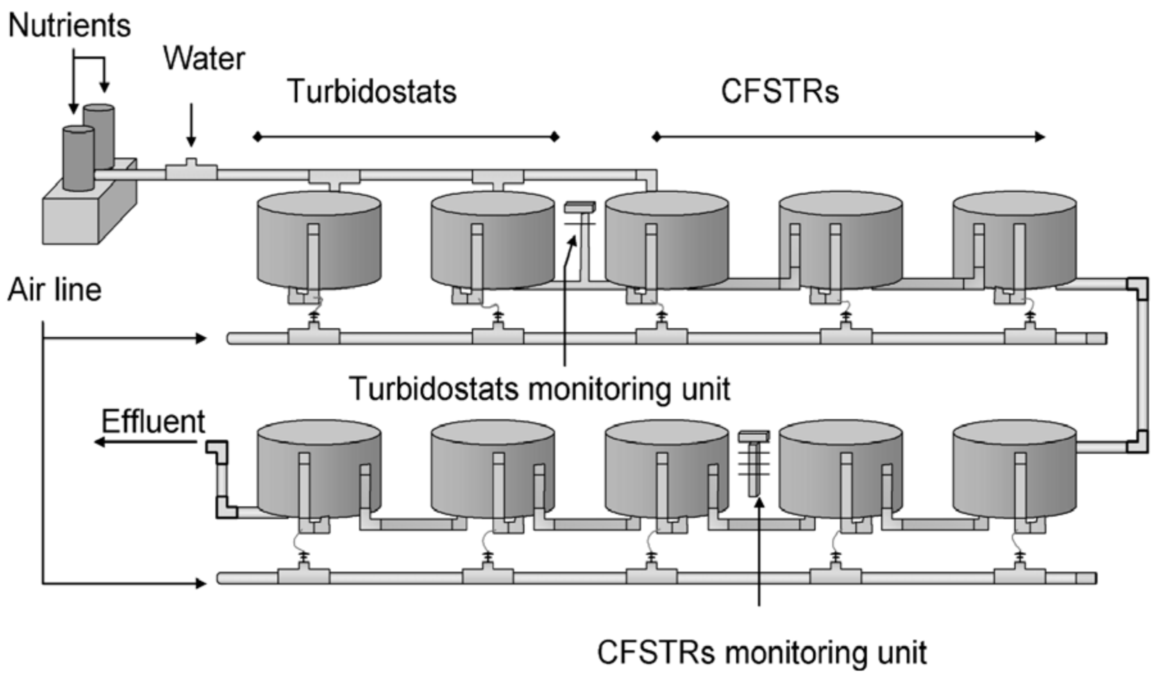


Figure 2.1. The HISTAR system contains two enclosed turbidostats and eight open topped CFSTRs. Figure adapted from Benson and Rusch (2006).

A solution containing water and other media (nutrients) is injected continuously into the first CFSTR, and it acts as a primary driving force for the continuous flow of microalgae through the system (Rusch and Christensen, 2003).

The process control describing the system operation of the HISTAR is shown in Figure 2.2. The system is monitored and controlled with centralized control computer, Rugid (Rugid TM, USA) for input/output control. The Rugid is capable of data collection, storage and trending, and provides full system control. The process control unit collects data from the two monitoring units working with the turbidostats and CFSTRs. For each harvest (every twenty minutes), the turbidostats are monitored, while the CFSTRs are monitored every hour. The data from the two monitoring units include microalgal

biomass, pH, temperature and conductivity. The microalgal biomass concentrations are monitored to maintain stable, steady state cultures. Microalgal biomass estimations from the turbidostats are used by the Rugid to automatically adjust the volume harvested from these reactors to supply for CFSTR1. The pH is monitored to automatically adjust the CO_2 additions within the cultures. Temperature and conductivity are monitored, but not used as an automatic control parameter. Conductivity measurements are converted to salinity and used to make manual adjustments within the saltwater reservoir (Rusch and Christensen, 2003).

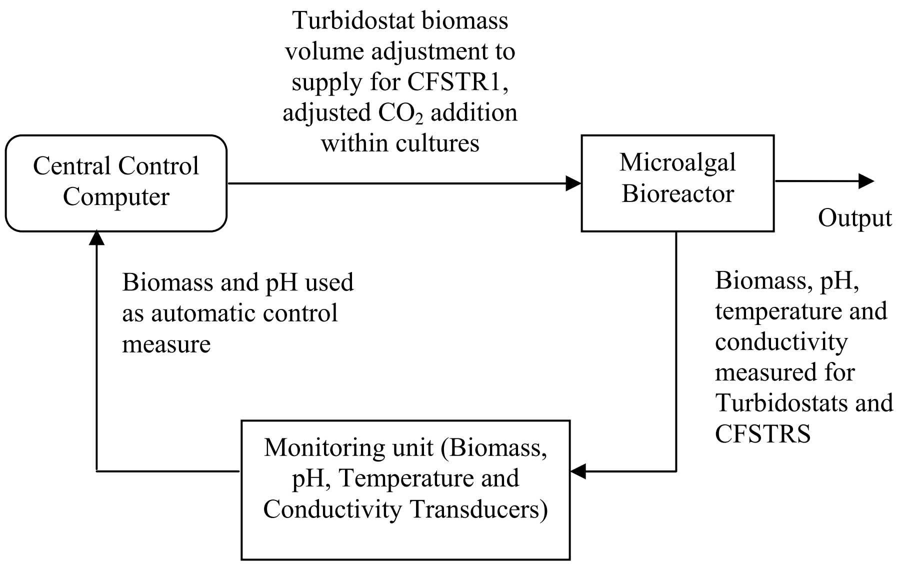


Figure 2.2. The schematic diagram shows the HISTAR process control system with measured parameters and subsequent control action.

Although transducers for the *in-situ* measurement of pH are well developed (Steenkiste et al., 1997), a highly sensitive, cost-effective, miniaturized microalgal biomass transducer is necessary to detect the microalgal biomass accurately and to be a part of successful automated microalgal bioreactor. Over the years, a number of methods have been developed to detect the microalgal biomass. These methods are based on the following two techniques: Turbidometric (Wilde and Gibbs, 1998; Meireles et al., 2002;

Sandnes et al., 2006) and Fluorescence (Honeywill et al., 2002; Madrid and Felice, 2005). The currently available designs for the transducer to measure microalgal biomass based on these techniques have some disadvantages. The transducer designs using turbidometric method does not correlate with the biomass concentration in the whole growth range. And, for increasing cell densities with dead organisms, the detector response is affected, thus failing to give accurate microalgal biomass measurements. Transducer designs using fluorescence techniques are expensive and bulky to be implemented in an automated system. Moreover, the fluorescence methods are not accurate enough to quantify microalgal biomass due to their inherent technology, which is to estimate the amount of chlorophyll *a* before quantifying the microalgal biomass (Nilsson, 2001).

HISTAR uses a simple, real-time microalgal density transducer that has a light source emitting a peak wavelength of 635 nm at one end and a phototransistor at the other to detect the transmitted light. Biomass density readings obtained are based on a linear relationship between the potential generated by the detector in response to the light transmitted versus a total suspended solids measurement. Even though the transducer is inexpensive and suitable for an automated bioreactor system, it is not highly sensitive, leading to biomass estimation errors.

The purpose of this research was to design, construct and test a microalgal biomass variable transducer applicable for a computer controlled automated bioreactor systems. The two main design constraints were cost and sensitivity. The new biomass transducer was connected to HISTAR's central control computer (i.e. Rugid ™), which is equipped with a remote terminal unit that transmits the data to the system and/or altering the state

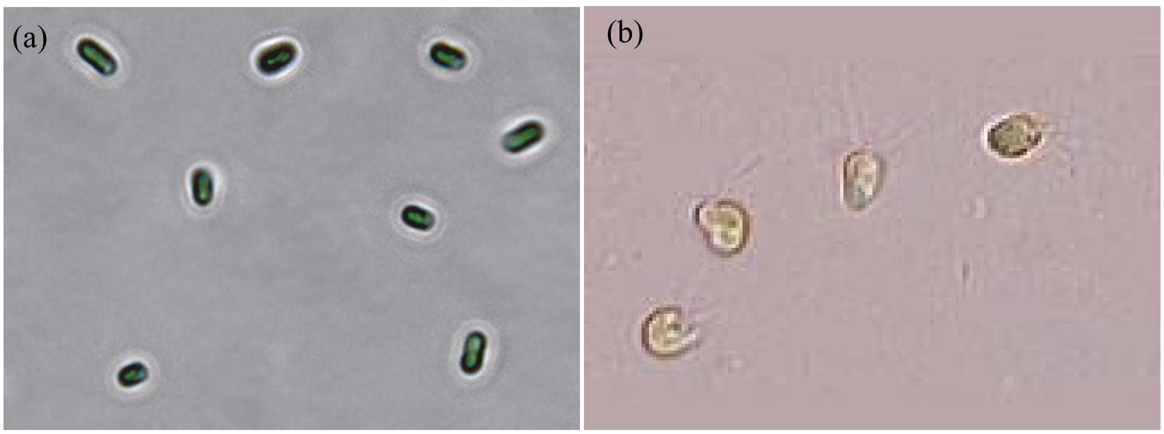
of connected objects based on control messages received from the system. The computer is also equipped with supervisory control, which helps the user to manually change the settings needed according to given specifications. For example, the user can select the calibration curve required for a given microalgal species from a set of different curves available in the control algorithm by just selecting the type of microalgae. If the existing calibration is not desired, the user can re-calibrate by entering own calibration coefficients. In this way, user can change the microalgal type and/or the calibration to adjust the biomass transducer operation.

2.2 Materials and Methods

2.2.1 Microalgal Cultivation

Three microalgal species belonging to three different classes were selected for investigation. The choice of three distinct species of microalgae was to enhance the sensitivity of the transducer that was being designed. *Nannochloropsis oculata* (Class: Eustigmatophyte; Figure 2.3a) is a photosynthetic, unicellular microalgae, characterized by photosynthetic pigments including chlorophyll *a* and a single parietal yellow–green chloroplast. It is a small green algae that is extensively used in the aquaculture industry and has a size of about 1-2 μm. It is nonmotile and live chiefly in fresh water, but also in marine water and in soil. Some of the carotenoid pigments present in *N. oculata* are β-carotene, phycocyanin and violaxanthin (Anita et al., 1975; Yamamoto et al., 2001). *Isochrysis galbana* (Figure 2.3b) belonging to the class of Prymnesiophytes (or haptophyceae) is a small golden/brown flagellate having a width of 2-4 μm and length 4-6 μm. It has chlorophyll *a* and *c* with several other significant characteristics such as moan bearing filiform organelle between the two flagella, equal length, smooth flagella

and calcified organic scales. In this class of microalgae, nonmotile phase alternates with a motile phase. The nonmotile phase is a free-living unicellular organism. In some cases, the alternation between nonmotile and motile phases is mediated by sexual reproduction. *T-ISO* lives primarily in marine water (Johansson and Graneli, 1999). Some of the carotenoid pigments present in *T-ISO* are β-carotene, phycocyanin and fucoxanthin (Evengelista et al., 2006).



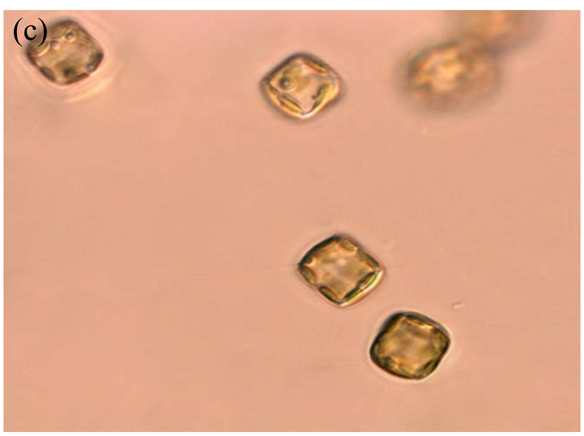


Figure 2.3. The three microalgal species used to determine wavelength sensitivity were (a) *Nannochloropsis oculata* (b) *Isochrysis galbana* (c) *Thalassiosira weissflogii*. Figures have a scale of 5 μm and are adapted from University of Texas at Austin (USA).

Thalassiosira weissflogii (Figure 2.3 c) is a pennate diatom (bilaterally symmetric- pennales) with a size of 6-20 μm x 8-15 μm. It has chlorophyll *a* and *c* and varies from brown to green to yellow in color depending on the amount of chlorophyll present in the culture. Most of the diatoms belonging to the class Bacillariophyceae are unicellular, although some form chains or simple colony. The characteristic feature of diatom cells is that they are encased within a unique cell wall made of silica. These walls

show a wide diversity in form, some quite beautiful and ornate, but usually consist of symmetrical sides with a split between them. Most diatoms are nonmotile, but some are capable of exerting motion (Friedman and Alberte, 1987; Brown, 1988). *T. weissflogii* has fucoxanthin as the main corotenoid pigment (Evengelista et al., 2006).

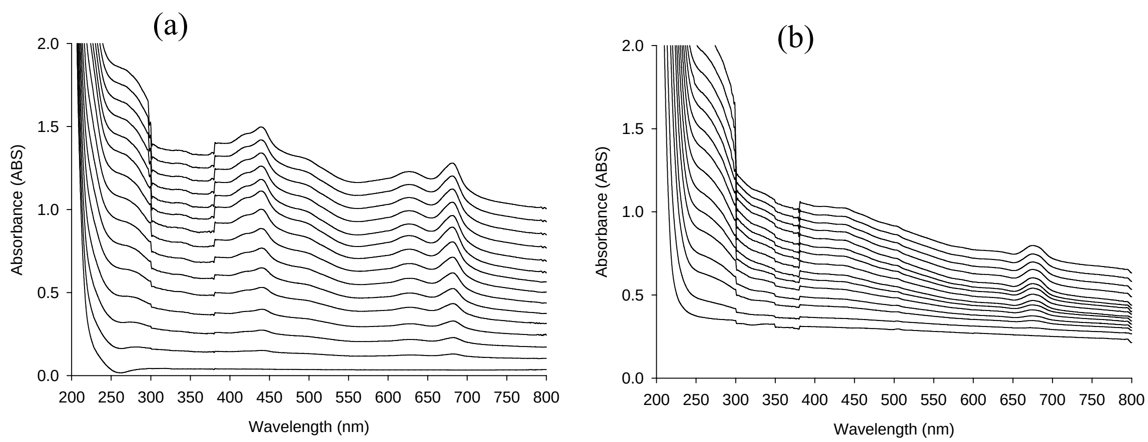
Nannnochloropsis oculata (CCMP525), *Isochrysis galbana* (CCMP1324), *Thalassiosira weissflogii* (CCMP1051) stock cultures were obtained from Bigelow Laboratory for Ocean Sciences (West Boothbay Harbor, Maine, USA). Starter cultures (100 mL) were grown in aerated, 35 ppt artificial saltwater (Crystal Sea®) containing f/2 medium. Sodium metalisilicate was also added to the *T. weissflogii* cultures. The cultures were grown at 24°C and exposed to an average scalar irradiance of 450 µmol s^{-1} m^{-2} from a combination of fluorescent and high pressure sodium lamps. The starter cultures were used to inoculate 11-liter carboys, which were monitored until the biomass concentration reached approximately 500 mg-dry wt/L. Microalgal growth was continually monitored by collecting a sample from the carboy and conducting optical density analyses (λ = 680 nm) using a scanning spectrophotometer (Model No. HachDR/4000). A calibration curve relating optical density to total suspended solids (TSS) was developed and used to correlate optical density to biomass concentration. The TSS procedure was performed in accordance with the Standard Methods (APHA, 1998). However, there were some variations from the normal procedure. Since the microalgal sample contained salts and sodium metasilicates, a 0.5 M ammonia formate rinse was used to dissolve the salts instead of deionized water. The glass microfibre filter used for all of the TSS measurements was GF/F, having a pore size of 0.7 µm. The filters plus microalgae were dried overnight at 65°C.

2.2.2 Wavelength Sensitivity Analysis

The microalgal density transducer that was used for HISTAR was insensitive to different microalgal biomass concentrations as it uses a single light source to detect the biomass concentration in the entire growth range for the three microalgal species. The transmittance level from the single light source emitting wavelength in the red region (635 nm) of the visible spectrum does not correlate linearly with the biomass. To address the issue of absorption insensitivity, wavelength sensitivity analysis was conducted for a commercially applicable (i.e. biomass production) growth range of 0-500 mg dry wt L^{-1}, to determine the wavelengths at which, these three microalgal species had maximum light absorption. The maximum absorption regions would give the wavelengths at which microalgal species are highly sensitive.

Fifteen different concentrations ranging from 0-500 mg dry wt L^{-1} were prepared from the carboy cultures of *N. oculata*, *I. galbana*, *T. weissflogii* for wavelength sensitivity analysis using a scanning spectrophotometer (HachDR/4000). The spectrophotometer has a wavelength range of 190 to 1100 nm and a wavelength accuracy is ±1 nm with a photometric linearity of ±2 nm. The saltwater solution (35 ppt salinity) and the different concentrations of microalgal samples (0-500 mg dry wt L^{-1}) were scanned in replicates for light absorbance characteristics. Considering the photosynthetically active radiation (PAR) range of 400-700 nm, and the germicidal wavelength of ~ 254 nm, a wavelength range of 200-800 nm was selected to determine the microalgal sensitivity. The peak absorption regions were noted and all readings were downloaded onto an excel spreadsheet for further analysis. The absorbance values corresponding to each wavelength from all the replicates along with the date, time and

spectrophotometer model name was tabulated in a spread sheet. The absorbance data for three replicates were averaged to get overall absorbance (ABS) for each concentration (raw data can be found in Appendix A) and plotted as a function of wavelength (Figure 2.4). Maximum absorption among the individual concentrations was found at 265 nm (UVC) followed by 440 nm (blue) and 680 nm (red) for each microalgal species. The wavelength sensitivity analysis recognizes the wavelength at which each of the microalgal species have peak absorptions, and the absorbance is correlated with the concentration. Light emitted with peak wavelengths of 265 nm, 440 nm and 680 nm should undergo absorption when they pass through each of the microalgal samples, and the amount of absorption is given by the absorption curves.



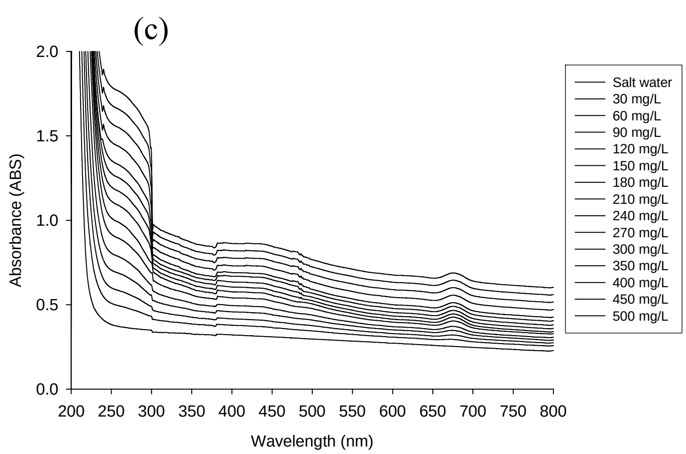


Figure 2.4. The wavelength sensitivity analysis used determine the sensitivity for (a) *N. oculata* (b) *I. galbana* (c) *T. weissflogii* (The bottom most curve in each species is for the pure saltwater and the top most curve is 500 mg-dry wt L^{-1}).

Any living matter having DNA absorbs UVC light in the germicidal wavelength (~254 nm) (Douki et al., 2003), which explains the reason for absorption at 265 nm for the microalgal species. The measurement of microalgal biomass present in the sample by detecting the amount of UVC absorption of the sample forms the basis of the transducer, as there was highest separation among individual microalgal concentrations. The blue (440 nm) and red (680 nm) wavelength energy absorption by the microalgal samples is a function of the chlorophyll pigments present in the microalgae (Matorin et al, 2004). In practice, for a given sample of microalgae, there is some level of contamination by bacteria and zooplankton, which will absorb UVC light due to their own DNA. Subsequently, the biomass measurement given by the transducer detecting UVC absorption not only includes the microalgal absorption, but also any bacterial and zooplankton absorption, if present. The additional UVC absorption given by the bacteria and zooplankton can be termed as “noise”. The blue and red absorptions in bacteria and zooplanktons are absent due to the absence of chlorophyll pigments. Therefore the UVC signal obtained by the transducer needs to be processed and rectified due to the presence of noise. The signals generated at the wavelength of 440 nm and 680 nm were used to filter this noise. The details of signal processing and correction of UVC measurement using the blue and red measurements is given in the section 2.2.5.

2.2.3 Biomass Transducer Design

The new biomass transducer designed consists of a light source made of LEDs and a light detector made of photodetectors that have high responsitivty to light wavelength emitted by the LEDs. Due to their long operating lifetimes, small size, low power consumption, and the fact that they generate little heat, LEDs were the light sources of

choice compared halogen and laser lamps. As there were three absorption peaks in the analysis, three light sources with peak wavelength of 265 nm, 440 nm and 680 nm were required. In other words, the peak absorbance wavelengths obtained from wavelength sensitivity analysis is the same as the peak wavelength for each of the light sources. The light emitter consists of three light sources with each light source having a circuit as shown in Figure 2.5.

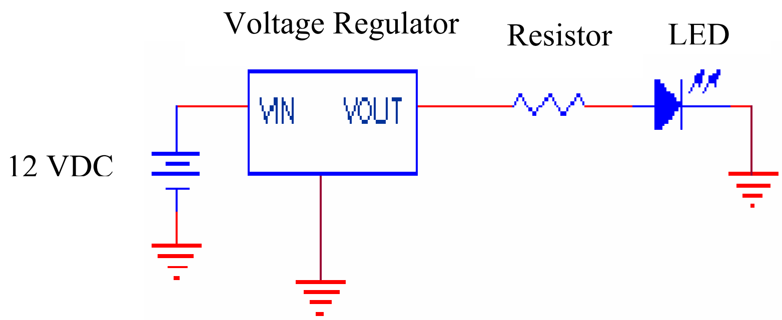


Figure 2.5. A circuit diagram was developed for the construction of a light source in the microalgal biomass transducer

The light emitter consists of an array of three LEDs; a UVC LED (Sensor Electronic Technology Inc., USA) with a peak wavelength of 265 nm; a red LED (Marubeni Corp., Japan) with peak wavelength of 680 nm. A blue LED with a peak wavelength of 440 nm was unavailable in the market. Therefore a blue/violet LED (Lumex, Inc., USA) with a peak wavelength of 430 nm was selected. Of the three LEDs, red has the highest output power (5 mW) and the UVC, the least powerful with a radiation power of about 0.5 mW. Since each of the three LEDs has different forward voltage and forward current requirements, each light source uses a voltage regulator and a resistor with different ratings. The red LED needs a forward voltage of about 2.5 VDC and a forward current of about 25 mA. The blue LED needs a forward voltage of about 4.5 VDC with a forward current of 20 mA. The UVC LED requires a forward voltage of about 7 VDC with a forward current of about 25 mA. A single voltage source of 12 VDC was used to power all the three light sources. An

industrial standard voltage regulator LM7805 (Fairchild Semiconductor, USA), was used for both the red and blue LEDs to regulate the source voltage from 12 VDC to 5 VDC. For the UVC LED, LM7808 (Fairchild Semiconductor, USA) was used to regulate the source voltage to 8 VDC sufficient to provide 7 VDC. To restrict the current passing through the LEDs, each LED was equipped with a series resistor with resistance calculated using ohm's law:

$$R = \left(\frac{V_s - V_f}{I_f} \right) 1000 \tag{2.1}$$

where, R is the series resistance (ohm, Ω), V_s is the source voltage (volts), V_f is the LED forward voltage (volts) and I_f is the LED forward current (milliampere). The resistance values used in the transducer circuit were rated at least 10% higher to the closest resistor available in market as a safety measure. The red and blue LEDs use a resistance of 120 Ω in series while the UVC LED uses 220 Ω in series.

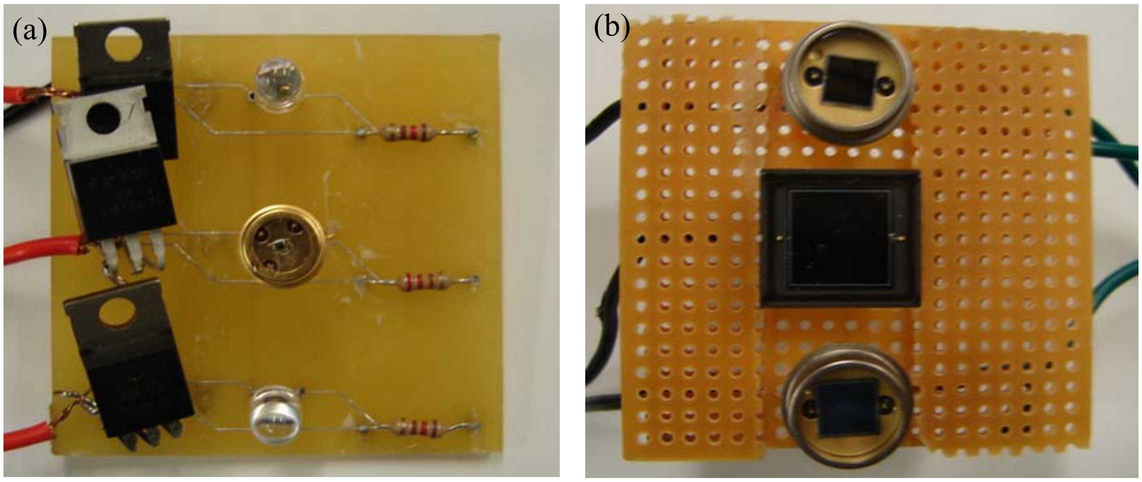
The light detector is comprised of three silicon photodiodes (Hamamatsu Photonics K.K, Japan) having peak wavelength sensitivities corresponding to the peak wavelengths of the light sources. The UVC light sensitive photodiode has an active area of 10 x 10 mm^2 with a quantum efficiency of about 75%. The photosensitivity for the UVC photodiode used is about 0.13 ampere/watt (λ=265 nm). The blue/violet light sensitive photodiode has an active area of 5 x 5 mm^2 with a photosensitivity of about 0.31 ampere/watt (λ=430 nm). The red light sensitive photodiode has an active area of 5.8 x 5.8 mm^2 with a photosensitivity of about 0.48 ampere/watt (λ=680 nm).

Since the current produced by the three photodiodes are in the nanoampere range, the diodes will be operated in the photovoltaic mode which provides higher sensitivity to low current measurements compared to photoconductive mode of operation. Under the

photoconductive mode of operation, there is an issue of noise due to the dark current generated by the photodiode. In case of the photovoltaic mode, the noise is not an issue. One other difference between these two operations is that the photoconductive mode gives a linear response to the input while the photovoltaic mode gives a comparatively non-linear response. Even though the photoconduction mode gives a faster response, photovoltaic mode is better suited for the biomass transducer due to higher sensitivity and low noise requirement.

2.2.4 Construction of Biomass Transducer

In order for the design to be implemented in an automated microalgal bioreactor, a proper housing mechanism for the light emitter and detector is needed. The design constraints for the housing mechanism are: (1) High sensitivity (2) Reduced light path (3) Resistance to high temperature (4) No light leakage from the light emitter (5) No interference with ambient light. The individual light source was designed as illustrated in Figure 2.5, and laid out on a printed circuit board (Sunstone Circuits, USA) (Figure 2.6a). The light detector that includes three photodiodes was soldered to a perforated photoboard as shown in the Figure 2.6 (b). The two light units (emitter and detector) were then mounted in CPVC (K-mac Plastics, USA) housing (Figure 2.6c). The use of CPVC plastic to house the biomass transducer has some advantages. CPVC plastic is a rigid thermoplastic exhibiting similar characteristics as that of PVC, and retaining those characteristics at high temperatures. The light emitter and the light detector were aligned such that, the centers of LEDs and the corresponding photodiodes were in the axis of a straight line. For maximum sensitivity of light detection by the photodiodes, the distance between the two units was kept as small as possible.



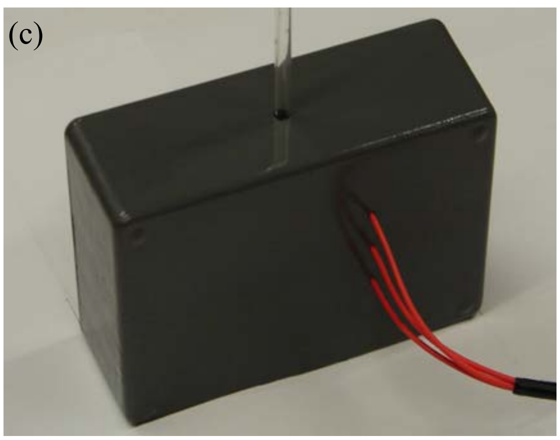


Figure 2.6. The prototype version of the biomass transducer shows the (a) light emitter (b) light detector and (c) overall transducer.

The acrylic transparent tube passing in between the light emission and light detection units has a diameter of about 6.4 mm (Figure 2.7).

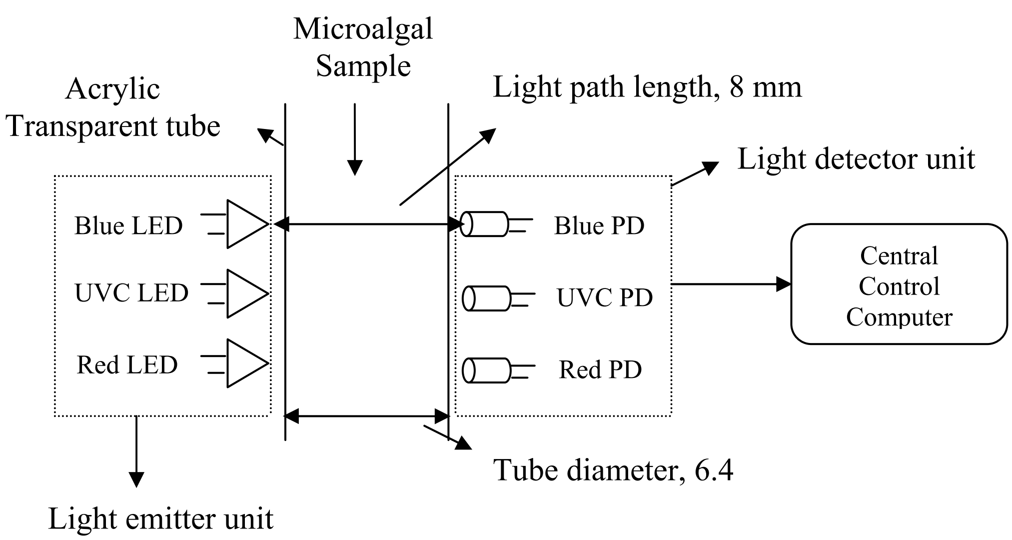


Figure 2.7. The schematic diagram shows the new biomass transducer that was designed for the automated microalgal bioreactor (PD = Photodiode).

The light emitter and the detector, each are separated from the transparent tube by a distance of 0.8 mm making the total length of light as 8 mm. The reduced diameter of the transparent tube decreases the amount of light travel from the LED to the photodiode thereby giving maximum sensitivity for the detector. To block any ambient light from entering the plastic housing of the biomass transducer, rubber gaskets and high temperature black silicone sealant were used to completely close the housing.

2.2.5 Biomass Transducer Operation and Signal Processing

Figure 2.8. The Rugid TM controller was used to monitor and control the operation of HISTAR.

When the biomass transducer is powered through the central control computer, the individual light sources are turned ON and OFF automatically by the program developed in the central control computer. First, the blue LED is turned ON for 7 seconds, followed by red for 5 seconds and UVC LED for 10 seconds. The UVC LED is operated at the last because of the sensitive nature of the germicidal wavelength (265 nm) on microalgae. This order of lightning is followed to protect microalgae from sterilizing before the blue and red LEDs are turned ON. The ON duration of individual LEDs are based on the amount of output power that they generate for the photodiodes to detect the light transmitted through the microalgal sample. As red LED has the highest power (5 mW), it is operated for the least amount of time. The red LED is followed by the blue LED (2.5 mW). The UVC LED is the least powerful (0.5 mW) and hence it is

operated for the highest duration of time enabling the UVC photodiode to detect the light transmitted through the microalgal sample. The individual photodiodes are powered separately with the same duration as their corresponding LEDs. In this way, the readings from the three light detectors are independent of each other.

The nanoampere signals obtained from the detectors were processed to be accepted by the central control computer (Figure 2.8) for further processing. The signal processing circuit for each of the photodiodes is as shown in Figure 2.9. The circuit shows the photodiode operating in the photovoltaic mode, and the current generated by the photodiode is converted to voltage by a current to voltage converter or transimpedance amplifier (OPA380, Texas Instruments Inc.). The transimpedance amplifier which provides high speed operation, extremely high precision, good stability and low noise, helps to give the full rated output voltage (5 VDC). In order for the transducer output to be highly sensitive to the input (i.e. light from the LED), a pull- down resistor (connected to –5 VDC) was added at the output of the transimpedance amplifier. The pull-down resistor helps to swing the output voltage from 0-5 VDC, giving maximum sensitivity to changes in input. The negative supply (–5 VDC) helps to pull the output to 0 V.

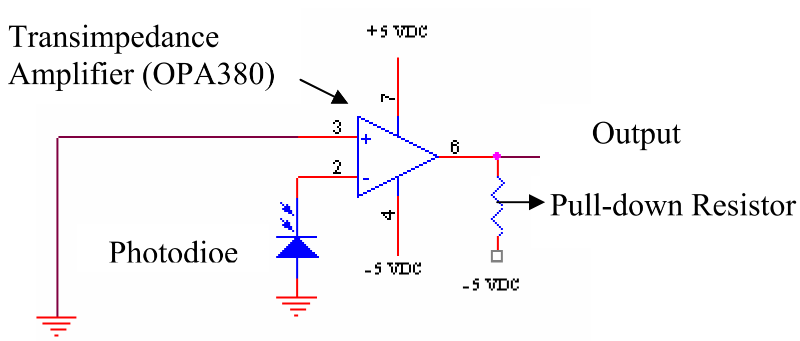


Figure 2.9. A photodiode signal processing circuit was designed for the microalgal biomass transducer.

The readings from the transducer were processed to filter out the noise (i.e. from bacterial and zooplankton absorption) from UVC reading before the transducer can be calibrated. The processing was done in the central control computer by making use of preprogrammed functions known as Configurable Control Functions (CCFs). The CCFs are programmed in the BASIC programming language to perform a certain task and can be configured according to the user specifications. For example, the user can define setpoints by just choosing a setpoint function and specifying the default value, and a trigger input, which tells the microprocessor when the setpoint has to take effect. Another example is, the user can perform a value test between two inputs by choosing the value test function and specifying the two inputs, and a trigger input which tells the processor when to perform the value test. Here the setpoint and value test functions are the CCFs internally created by BASIC language programming. The HISTAR system processes different parameters such as temperature, pH and conductivity using these CCFs generated in the software operating the control computer.

The overall flow chart describing the main steps in the algorithm for noise filtration is shown in Figure 2.10. The transmittance levels detected by the blue and red photodiodes are used to estimate the UVC transmittance level. The estimated UVC transmittance level is then compared with the actual transmittance detected by the UVC photodiode. The mean of estimated and actual transmittance levels are then used to calculate the ratios blue/average UVC and red/average UVC. The ratios are used to re-estimate the UVC transmittance level which is the completely processed measurement that is free from noise. The raw transmittance levels of UVC, blue and red for each microalgal biomass concentration and for each of the three pure microalgal species-

Nannnochloropsis oculata, *Isochrysis galbana* and *Thalassiosira weissflogii* were recorded.

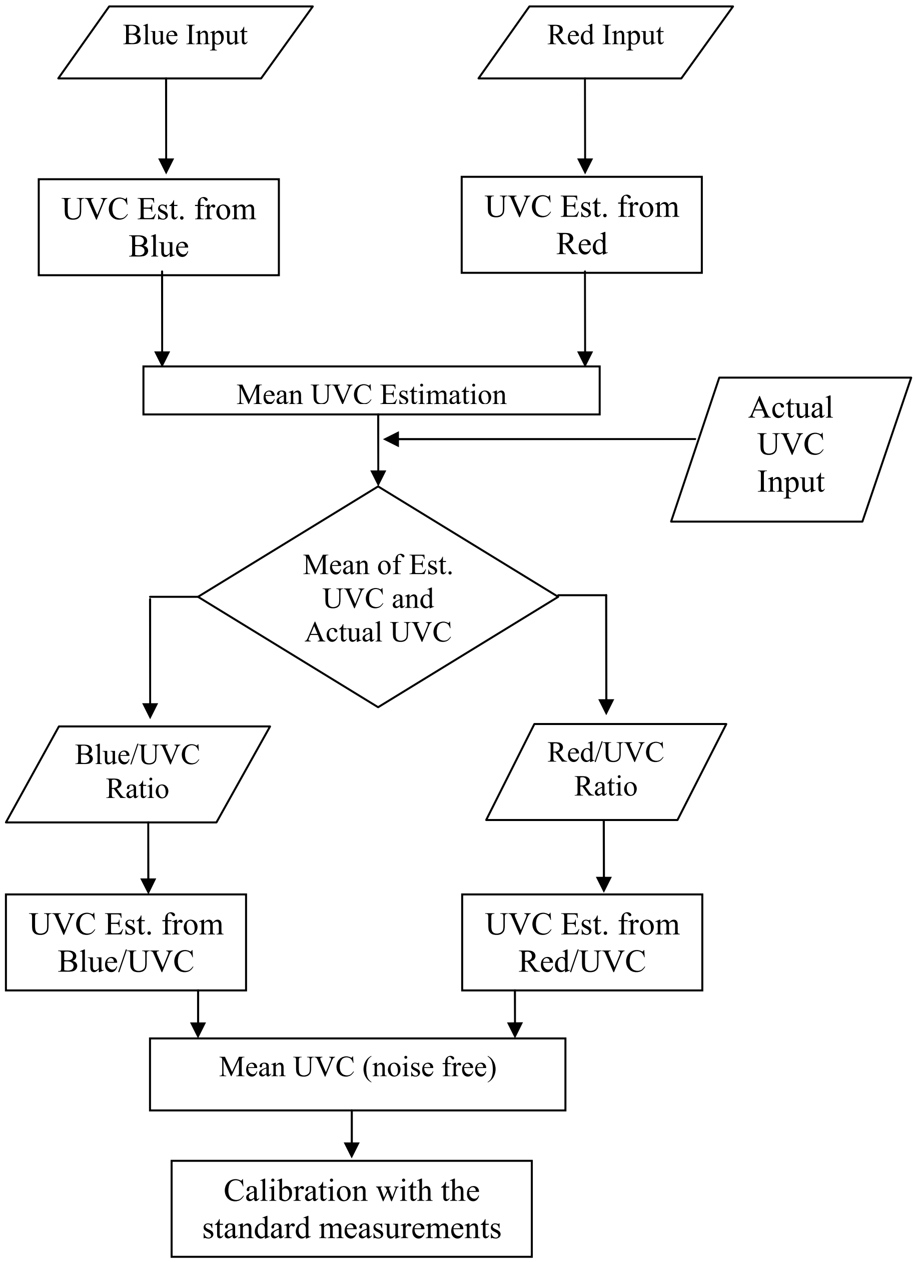


Figure 2.10. The flow chart shows the algorithm flow processing the UVC measurement to filter the noise in the microalgal biomass transducer.

The statistical relationship between the UVC measurement and the corresponding blue and red measurements was described to estimate the UVC measurement for a given sample. A similar procedure was carried out for the UVC measurement and the

corresponding ratios, i.e. blue/UVC and red/UVC for UVC re-estimation in a given sample. Regression analysis on each of these relationships was conducted before developing a relationship between the individual UVC measurement and the corresponding microalgal biomass.

The processed UVC measurement that is free from noise was then correlated with each pure microalgal biomass concentration. The program performing noise filtration and the calibration with the microalgal biomass is given in Appendix F. The biomass transducer testing was performed by taking the microalgal samples of known concentrations for each species. The tested samples were independent of the calibration curve. The biomass estimation given by the transducer was compared with the known concentration.

2.3 Results and Discussion

2.3.1 Signal Processing

The relationships between the UVC measurement and - blue and red measurements, and the ratios blue/UVC (B/U) and red/UVC (R/U) was developed for the three microalgal species as shown in Figures 2.11-2.13. The relationships were described for fifteen different microalgal biomass concentrations in the range of 0-500 mg dry wt L^{-1}. The relationships were linear for all the three species of microalgae. The raw data collected for the individual light readings (i.e. UVC, blue and red) and the ratios of B/U and R/U for all the three species are given in Appendix B, with the necessary statistical measures in Table 2.1. The standard error bars shown in the figures are due to the three replicate measurements taken for each reading.

2.3.1.1 ***Nannochloropsis Oculata***

The UVC reading varied from 1.61 V for a pure saltwater sample (35 ppt) to 1.9 V for 500 mg dry wt L^{-1}. The blue reading varied between 2.35 V for the pure saltwater to 2.42 V for 500 mg dry wt L^{-1}.

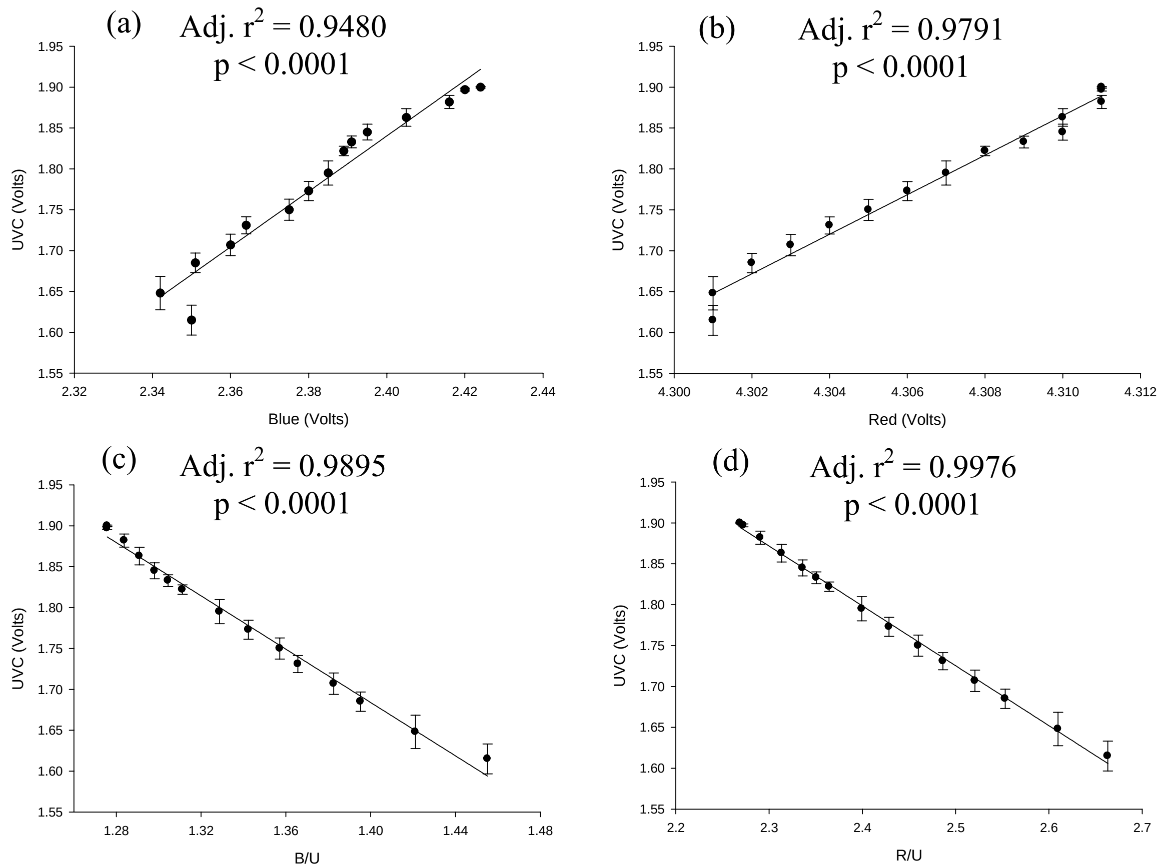


Figure 2.11. The UVC reading obtained from *N. oculata* were plotted against (a) blue reading (b) red reading (c) blue/UVC (d) red/UVC.

The correlation between the UVC measurement and the blue measurement (Figure 2.11a) was linearly described by (2.2):

$$UVC = -6.3 + 3.4\ (blue) \tag{2.2}$$

where -6.3 is the intercept given in volts (V) and 3.4 is the slope. The red measurement varied only between 4.301 V for the pure saltwater to 4.311 V for 500 mg dry wt L^{-1}. The

correlation between the UVC and the red measurement (Figure 2.11b) was also linear given by (2.3):

$$UVC = -102.3 + 24.2\ (red) \tag{2.3}$$

The B/U ratio decreased from 1.45 for pure saltwater to 1.27 for 500 mg dry wt L^{-1}. The correlation between the UVC and B/U ratio (Figure 2.11c) was linearly described by (2.4):

$$UVC = 4 - 1.6\ (B/U) \tag{2.4}$$

The R/U ratio decreased from 2.66 for the pure saltwater to 2.26 for 500 mg dry wt L^{-1}. The correlation between the UVC and R/U ratio (Figure 2.11d) was linearly described by (2.5):

$$UVC = 3.5 - 0.7\ (R/U) \tag{2.5}$$

The UVC reading increases by 3.4 V for change of 1 V in blue reading. The UVC reading is negative when the blue reading shows 0 V. The UVC reading increases by 24.2 V for a change of 1 V in red reading. The UVC reading is negative when red reading is 0 V. The UVC reading decreases by 1.6 V for a unit change in ratio blue/UVC. The UVC reading is about 4 V when the ratio is 0. The UVC reading decreases by 0.7 V when there is a unit change in the ratio red/UVC. The UVC reading is about 3.5 Volts when the ratio is 0.

2.3.1.2 *Isochrysis Galbana*

The UVC reading varied from 1.61 V for a pure saltwater sample (35 ppt) to 1.77 V for 500 mg dry wt L^{-1}. The blue reading varied between 2.35 V for the pure saltwater to 2.59 V for 500 mg dry wt L^{-1}. The correlation between the UVC and blue readings (Figure 2.12a) was linearly described by (2.6):

$$UVC = 0.16 + 0.61\ (\text{blue}) \qquad (2.6)$$

The red reading varied only between 4.302 V for the pure saltwater to 4.310 V for 500 mg dry wt L^{-1}. The correlation between the UVC and the red readings (Figure 2.12b) was linearly described by (2.7):

$$UVC = -93.2 + 22\ (\text{red}) \qquad (2.7)$$

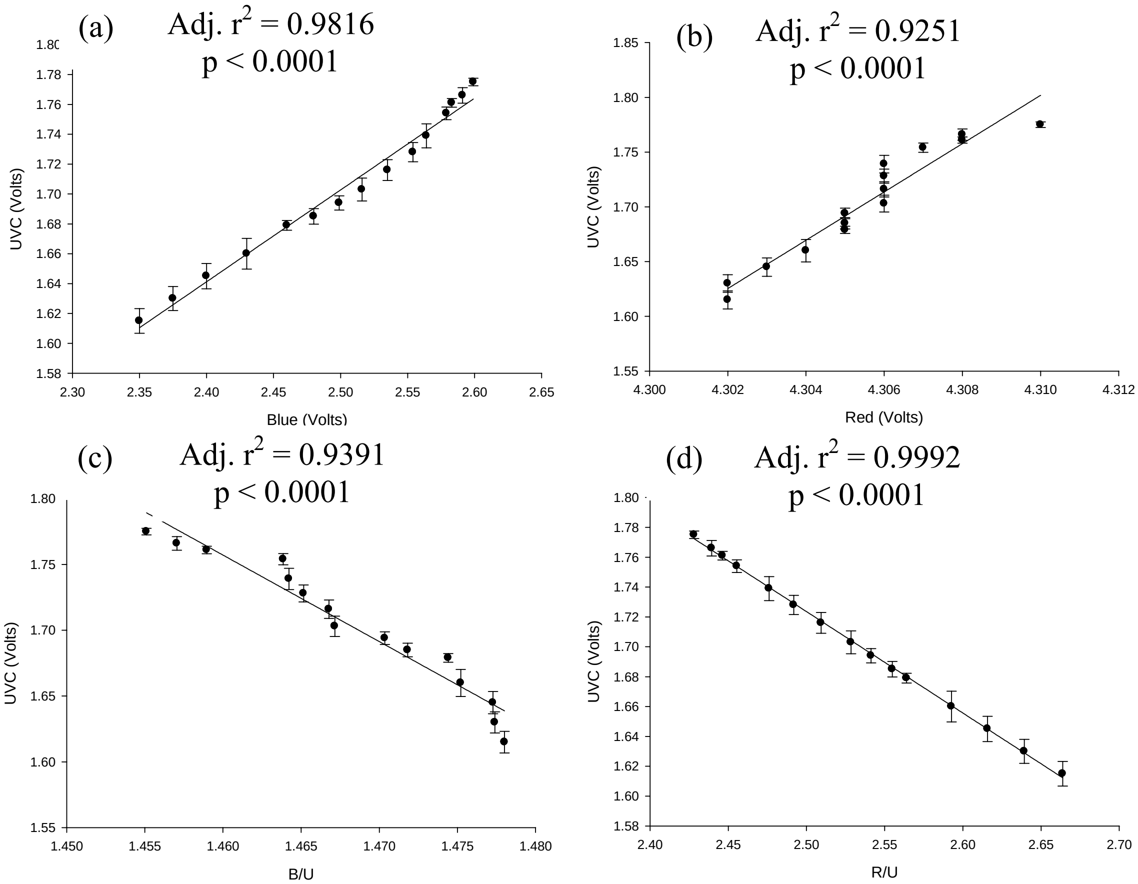


Figure 2.12. The UVC reading obtained from *I.galbana* were plotted against (a) blue reading (b) red reading (c) blue/UVC (d) red/UVC.

The B/U ratio decreased from 1.478 for pure saltwater to 1.464 for 500 mg dry wt L^{-1}. The correlation between the UVC and B/U ratio (Figure 2.12c) was linearly described by (2.8):

$$UVC = 6.8 - 3.5\ (B/U) \qquad (2.8)$$

The R/U ratio decreased from 2.66 for the pure saltwater to 2.42 for 500 mg dry wt L^{-1}. The correlation between the UVC and R/U ratio (Figure 2.12d) was linearly described by (2.9):

$$UVC = 3.4 - 0.68 \text{ (R/U)} \qquad (2.9)$$

The correlation is good for the ratios (blue/UVC and red/UVC)) compared to the individual readings (blue and red). The UVC reading increases by 0.61 V for change of 1 V in blue reading. The UVC reading is about 0.16 V when the blue reading shows 0 V. The UVC reading increases by 22 V for a change of 1 V in red reading. The UVC reading is negative when red reading is 0 V. The UVC reading decreases by 3.5 V for a unit change in ratio blue/UVC. The UVC reading is about 6.8 V when the ratio is 0. The UVC reading decreases by about 0.7 V when there is a unit change in the ratio red/UVC. The UVC reading is about 3.4 Volts when the ratio is 0.

2.3.1.3 *Thalassiosira Weissflogii*

The UVC reading varied from 1.62 V for a pure saltwater sample (35 ppt) to 1.81 V for 500 mg dry wt L^{-1}. The blue reading varied between 2.4 V for the pure saltwater to 2.491V for 500 mg dry wt L^{-1}. The correlation between the UVC and the blue reading (Figure 2.13a) was linearly described by (2.10):

$$UVC = -4.5 + 2.5 \text{ (blue)} \qquad (2.10)$$

The red reading varied only between 4.307 V for the pure saltwater to 4.313 V for 500 mg dry wt L^{-1}. The correlation between the UVC and red readings (Figure 2.13b) was linearly described by (2.11):

$$UVC = -108.3 + 25.5 \text{ (red)} \qquad (2.11)$$

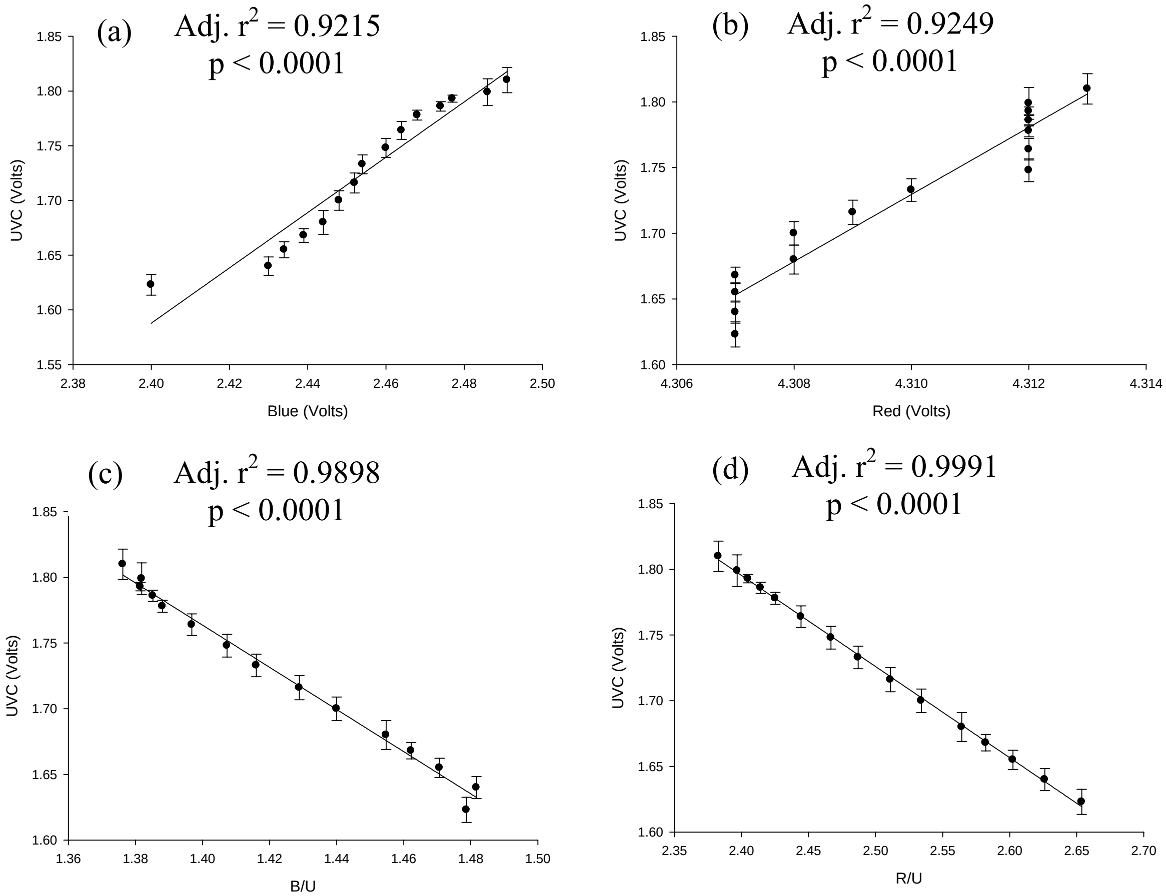


Figure 2.13. The UVC reading obtained from *T. weissflogii* were plotted against (a) blue reading (b) red reading (c) blue/UVC (d) red/UVC.

The B/U ratio decreased from 1.47 for pure saltwater to 1.37 for 500 mg dry wt L^{-1}. The correlation between the UVC reading and the B/U ratio (Figure 2.13c) was linearly described by (2.12):

$$UVC = 4 - 1.6\ (B/U) \qquad (2.12)$$

The R/U ratio decreased from 2.65 for the pure saltwater to 2.38 for 500 mg dry wt L^{-1}. The correlation between the UVC reading and the R/U ratio (Figure 2.13d) was linearly described by (2.13):

$$UVC = 3.4 – 0.7\ (R/U) \qquad (2.13)$$

The UVC reading is 0 V when the blue reading shows 0 V. The UVC reading increases by 25.5 V for a change of 1 V in red reading. The UVC reading is negative when red reading is 0 V. The UVC reading decreases by 1.6 V for a unit change in ratio blue/UVC. The UVC reading is about 4 V when the ratio is 0. The UVC reading decreases by 0.7 V when there is a unit change in the ratio red/UVC. The UVC reading is about 3.4 Volts when the ratio is 0.

The signal processing results for the three microalgal species validate the correlation that was developed between the microalgal biomass concentration and absorbance (i.e. Figure 2.4). The light transmittance readings obtained from UVC, blue and red light sources show a discernible difference between the biomass concentrations in the range, 0-500 mg-dry wt/L. The considerable separation among the concentrations in the UVC and blue regions gives correspondingly different voltage readings from the UVC and blue light emitter/detector combination resulting in a linear curve (i.e. Figures 2.11a, 2.12a and 2.13a). The separation among the different biomass concentrations was less for the red region and hence the voltage reading for the red light source/detector combination was not perfectly linear (i.e. Figures 2.11b, 2.12b and 2.13b). The red transmittance readings are notably insensitive for *Isochrysis galbana* and *Thalassiosira weissflogii* (i.e. Figures 2.12b and 2.13b) as was evident from the correlation developed (i.e. Figures 2.4b-c). As compared to Sandnes et al., (2006), that uses a light emitter made of an array of LEDs emitting same wavelength (880 nm), the sensitivity at 500 mg-dry wt/L of *Nannochloropsis oceanica* was higher. At 500 mg-dry wt/L of *Nannochloropsis oceanica*, Sandnes et al., (2006) shows a voltage reading of 2.9 VDC. At 250 mg-dry wt/L, it was 3.6 VDC. The difference being 0.7 VDC is significantly higher compared to

the results mentioned above which shows a difference of about 0.1 VDC. However as the biomass concentration decreases from 250-0 mg-dry wt/L, the results of Sandnes et al., (2006) is in close agreement with the results mentioned above. Also, Sandnes et al., (2006) designed the optical density sensor for only one species of microalgae (i.e. *Nannochloropsis oceanica*).

The light transmittance levels from each of the light source/detector combination given by volts fell in different range of the overall range 0-5 VDC. For example, the readings from the red were in between 4 – 5 VDC. The readings for blue were in between 2-3 VDC and for UVC it was in between 1-2 VDC. The reason for this different range of voltage readings for different wavelengths can be tied to the output power of each light source. The red LED had the highest output power (5 mW), followed by blue (2.5 mW) and UVC (0.5 mW).

The light transmittance levels obtained for the UVC, blue and red wavelengths can be explained based on the characteristics of microalgal species. As Douki et al. (2003) describes, the different transmittance levels (in volts) obtained for different microalgal biomass concentrations in each of the species at 265 nm is due to the presence of DNA. As the biomass concentration increased, the transmittance level varied accordingly due to the increased amounts of DNA present. The level of transmittance however varied for each of the microalgal species due to the difference in amounts of DNA present. For example, *N. oculata* shows highest transmittance level in the UVC which was 1.9 VDC as compared to *I. galbana* and *T. weissflogii* (Figures 2.11-21.13). Some of the unique characteristics of the microalgal species/class that include size and shape, presence of pigments (i.e. chlorophyll *a*, *b* or *c*, carotenoids), color and motility are responsible for

the light transmittance levels seen in the above results (e.g. Geider, 1987; Herzig and Falkowski 1989; Augusti et al., 1994; Olaizola et al., 1996; Krause-Jensen and Sand-Jensen, 1998; Beutler et al., 2002; Millie et al., 2002; Matorin et al., 2004; Quigg et al., 2006; Evangelista et al., 2006). The transmittance level at peak wavelengths 430 nm and 680 nm confirms the presence of chlorophyll *a* in all the three microalgal species. For the three species, there is an asympototic decrease in light transmittance level with increasing chlorophyll *a* concentration. As the microalgal biomass concentration increased from 0-500 mg-dry wt/L, the chlorophyll *a* density increases giving an asymptotic increase in light absorption in accordance with Augusti et al., (1994). *N. oculata* (Class: Eustigmatophyceae) which was a green microalgae consisting of chlorophyll *a*, β-carotene and phycocyanin, and a single parietal yellow-green chloroplast (Evangelista et al., 2006), has absorption regions in the range of 400-700 nm with peak regions at 430 nm and 680 nm. The absorption seen at 480 nm is due to the presence of β-carotene and the absorption at 630 nm is due to phycocyanin and violaxanthin pigments in accordance with Matorin et al., (2004). *I. galbana* (Class: Prymnesiophyceae), also known as Haptophyceae) and *T. weissflogii* (Class: Bacillariophyceae) showed increased light transmittance levels at the two peak regions, 430 nm and 680 nm (Figures 2.12-2.13) as compared to the correlation results obtained between the absorbance and the biomass concentration (Figure 2.4b-c). The correlation results suggest the decreased light absorption at these two peak regions indicating not just the presence of chlorophyll *c*, but also an increased ratio of Chlorophyll *c/a* according to Geider (1987) and Herzig and Falkowski (1989). The results of the signal processing (Figures 2.12-2.13) however indicate the presence of chlorophyll *c*, but not necessarily the increased ratio of

Chlorophyll *c/a*. The reason for this can be derived from the fact that wavelength sensitivity analysis and the signal processing were conducted at two different times resulting in variation of the microalgal growth according to Quigg et al., (2006). *I. galbana* which was a golden brown flagellated microalgae, consists of a carotenoid pigment called fucoxanthin that is responsible for the light absorption seen at 490 nm according to the results of Evangelista et al., (2006). Fucoxanthin is also responsible for light absorption seen in *T. weissflogii* at 480 nm according to Evangelista et al., (2006). The lower transmittance levels seen in three microalgal species can be explained based on the size and shape of the photosynthetic tissue according to Agusti et al., (1994). The size of *N. oculata* (1-2 µm) is smaller compared to the sizes of *I. galbana* (~ 5 µm) and *T. weissflogii* (15-20 µm) that results in smaller photosynthetic tissues. According to Agusti et al., (1994), the chlorophyll *a* light absorption decreases with the increase in the size of the photosynthetic tissue which explains lower transmittance levels in higher microalgal biomass concentrations for *N. oculata*. The transmittance levels for *I. galbana* and *T. weissflogii* were higher compared to the levels obtained for *N. oculata* for higher biomass concentrations due to their increased size. The transmittance level for *I. galbana* was higher compared to the transmittance seen in *T. weissflogii* (a diatom) even though the cell wall in *T. weissflogii* is covered with silica that reduces the efficiency of light absorption. The reason for this inconsistency can be explained by the presence of sodium metasilicate along with the culture that could have absorbed the light thus reducing the transmittance level seen in *T. weissflogii*. The transmittance levels seen in each of the microalgal species/class can also be explained whether the species are motile or nonmotile to Millie et al., (2002). Among the three species, only *I. galbana* is capable of

moving which probably explains the high transmittance levels in blue readings (Figure 2.12a), but higher absorption in the blue region (Figure 2.4).

2.3.2 Biomass Transducer Calibration

The processed UVC readings (in volts) for each of the pure microalgal species - *Nannnochloropsis oculata, Isochrysis galbana* and *Thalassiosira weissflogii,* were correlated with the corresponding microalgal biomass concentrations (Figures 2.14) with the data mentioned in Appendix C.

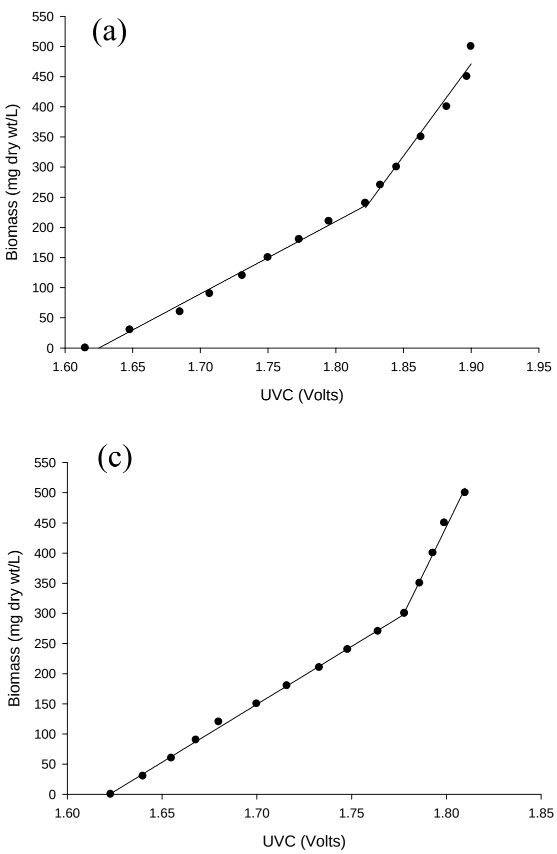


Figure 2.14. The correlation between microalgal biomass and the mean UVC measurement was developed for (a) *N. oculata* (b) *I. galbana* and (c) *T. weissflogii*.

The relation between the microalgal biomass (dependent variable) and UVC reading (independent variable) for all the three microalgal species was described by the two linear curves. The two linear curves were separated by a threshold defined by the UVC reading as described in equations (2.14-21.6). The r^2 and the p values for each curve are also mentioned in these equations.

For *N. oculata*, the relationship between the biomass (mg-dry wt/L) and the UVC (volts) was described by (2.14):

$$\text{Biomass} = \begin{cases} -1948.6 + 1199.1\,(\text{UVC}) \text{ for } 0 \le \text{UVC} < 1.822, \text{ Adj. } r^2 = 0.9900, \text{ p} < 0.0001 \\ -5336.6 + 3056.7\,(\text{UVC}) \text{ for UVC} \ge 1.822, \text{ Adj. } r^2 = 0.9702, \text{ p} < 0.0001 \end{cases}$$

(2.14)

Similarly, for *I. galbana* and *T. weissflogii*, the relationships were described by the linear curves as given by 2.15 and 2.16.

$$\text{Biomass} = \begin{cases} -3987.6 + 2461\,(\text{UVC}) \text{ for } 0 \le \text{UVC} < 1.739, \text{ Adj. } r^2 = 0.9876, \text{ p} < 0.0001 \\ -9665.1 + 5722\,(\text{UVC}) \text{ for UVC} \ge 1.739, \text{ Adj. } r^2 = 0.9484, \text{ p} < 0.0001 \end{cases}$$

(2.15)

$$\text{Biomass} = \begin{cases} -3115.8 + 1920.5\,(\text{UVC}) \text{ for } 0 \le \text{UVC} < 1.778, \text{ Adj. } r^2 = 0.9985, \text{ p} < 0.0001 \\ -11129.4 + 6429.5\,(\text{UVC}) \text{ for UVC} \ge 1.778, \text{ Adj. } r^2 = 0.9869, \text{ p} < 0.0001 \end{cases}$$

(2.16)

The threshold defined by the UVC readings were 1.822 V (*N. oculata*), 1.739 V (*I. galbana*) and 1.778 V (*T. weissflogii*). The standard error estimates for the microalgal biomass concentration with the completely processed UVC measurement for first linear curves were 8.2 mg dry wt L^{-1} (*N. oculata*: $0 \le$ UVC < 1.822 V), 11 mg dry wt L^{-1} (*I. galbana*: $0 \le$ UVC < 1.739 V) and 3.7 mg dry wt L^{-1} (*T. weissflogii*: $0 \le$ UVC < 1.778 V). For the second linear curves, the standard errors were 16.5 mg dry wt L^{-1} (*N. oculata*: UVC $\ge$ 1.822 V), 17.9 mg dry wt L^{-1} (*I. galbana*: UVC $\ge$ 1.739 V) and 9 mg dry wt L^{-1} (*T. weissflogii*: UVC $\ge$ 1.778 V). The standard errors are higher compared to the errors obtained for the calibration curve developed by Sandnes et al., (2006). Sandnes et al., (2006) showed an 8% error in the accuracy for a *Nannochloropsis oceanica* biomass range of 500-2000 mg dry wt L^{-1}. Sandnes et al., (2006) however has not reported the

standard error results for a biomass range less than 500 mg-dry wt/L. The standard error for the biomass transducer calibration is lower compared to the error described by Meireles et al., (2002). Meireles et al., (2002) showed 25% security for different dilutions of *Pavlova lutheri*. Honeywill et al., (2002) reported the use of *in situ* pulse amplitude based fluorescence technique to determine the correlation between fluorescence and chlorophyll *a*. The correlation (R) between the fluorescence and a chlorophyll *a* reported was 0.84 with $p<0.001$. This correlation is lower compared to the correlation (R) obtained for the three species from the new biomass transducer, which had an average value close to 0.99 with $p<0.0001$.

The reason for the linear relation between the microalgal biomass concentration and the UVC reading in the range 0-240 mg-dry wt/L (i.e. *N. oculata*) and 0-300 mg-dry wt/L (i.e. *I. galbana* and *T. weissflogii*) (Figures 2.14) can be explained on the basis of Lambert-Beer law:

$$A = a(\lambda)\ b\ c \qquad (2.17)$$

where A is the measured absorbance, $a(\lambda)$ is a wavelength (λ)-dependent absorptivity coefficient, b is the path length, and c is the microalgal biomass concentration.

The absorbance measurement is calculated using the following relation:

$$A = -\log T = -\log (I / I_o) \qquad (2.18)$$

where T is the light transmission through the sample, I is the light intensity after it passes through the sample and I_o is the initial light intensity. The amount of light absorbed is proportional to the number of molecules responsible for absorption. The Lambert-Beer law is based on three assumptions: (1) the direction of the incident radiation does not change travels across the culture; (2) the incident radiation is monochromatic; and (3) the

effect of scattering due to the presence of solid particles is negligible compared to absorption (Fernandez et al., 1997; Nomura et al., 1997; Okuyama et al., 1998; Gore, 2000). The same linear curve however does not hold after a certain biomass concentration i.e., 240 mg-dry wt/L for *N. oculata*, 300 mg-dry wt/L for. *I. galbana* and *T. weissflogii*. According to Fernandez et al., (1997) and Cornet et al. (1995), the Lambert-Beer's law of light attenuation is not applicable for high biomass concentrations due to the existence of different scattering and selective absorption effects. There is no work in the literature that relates the higher biomass concentration with the UVC absorption for these three microalgal species and hence a linear curve was again used for the concentrations 240-500 mg-dry wt/L for *N. oculata* and 300-500 mg-dry wt/L for *I.galbana* and *T. weissflogii* (Figure 2.14). The hyperbolic model proposed by Fernandez et al. (1997) shows that, after a certain concentration of biomass, there is a deviation from the Lambert-Beer's law showing hyperbolic tendency with the absorbance. According to the results of Fernandez et al. (1997), after 1.3 $g \cdot L^{-1}$ of *Phaeodactylum tricornutum*, the light attenuation by microalgae does not change linearly with concentration, but has an asymptotic tendency, showing a deviation from Lambert-Beer's law. Cornet et al. (1995) developed a mathematical model for the microalgal species *spirulina platensis* that assumes light attenuation to be the result of two combined phenomenon, absorption and scattering. In comparison, the model developed in the 2.3.2 takes only absorption into account and assumes negligible scattering. Sandnes et al., (2006) uses an exponential curve to describe the relationship between the biomass concentrations of *Nannochloropsis oceanica* (0-2000 $g \cdot L^{-1}$) and voltage readings. Meireles et al., (2002) uses a single linear curve to describe the relationship between the optical density and the

ash free dry weight for *Pavlova lutheri*. Comparing the model developed by Sandnes et al., (2006) with the model proposed by Fernandez et al. (1997), the microalgal biomass does not relate exponentially with the voltage readings at higher concentrations. Instead, the hyperbolic model proposed by Fernandez et al. (1997), suggests a more linear model for the higher biomass concentrations.

The reason behind for such high standard errors in the new biomass transducer readings could be traced from the inconsistent and unstable readings obtained from the UVC light source. Assuming that the UVC light source is a perfect emitter with constant output power, inconsistency in the UVC absorption by the microalgal sample (all three species) might have contributed to the problem. As Douki et al. (2003) describes the UVC absorption due the presence of DNA in the living matter, any irregularities in the DNA structure, or if the organism is dead, then there could be inconsistent UVC absorption. The inconsistency results because, even with the dead microalgae, it adds to the biomass concentration, but does not absorb UVC light. This is applicable only if the microalgae are dead for a long time. The irregular shapes and sizes of the microalgae might also contribute to the inconsistent UVC measurements as their DNA structure could vary. One other reason for inconsistent UVC measurements could be the effect of scattering in the microalgal samples (Brogioli et al., 2003). The light transmitted through the sample could vary depending on the effect of scattering. The effect of fluorescence might interfere with the UVC absorption as the microalgae absorb UVC light to emit low energy radiation as described by Madrid and Felice, (2005). The UVC light absorbed by the microalgae and the emitted low energy radiation might underestimate the biomass concentration. The UVC light source being the least powerful among the other two light

sources (blue and red) with an output power of 0.5 mW and being in research grade of manufacturing, it must have contributed for the unstable measurements.

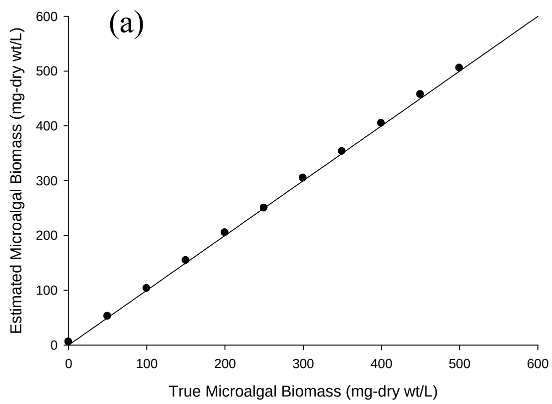
2.3.3 Biomass Transducer Testing

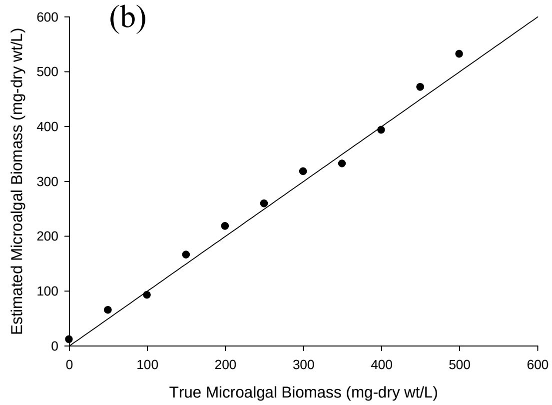
Following the implementation of signal processing (i.e. using the results of section 2.3.1), the processed UVC measurement was calibrated with the microalgal biomass concentrations for all the three species (i.e. using the results of section 2.3.2). The implementation of the calibration process in the central control computer was carried out using the similar procedure described in section 2.2.5. The biomass transducer with the mechanism to filter the noise from the UVC measurement for a given sample of microalgal species and, calibrated to correlate the resulting UVC measurement (completely processed) to the biomass concentration was tested for a microalgal sample independent of the calibration curve. The transducer was tested with known microalgal biomass concentrations for each species to determine the accuracy of measurement. The mean values of the readings obtained from the biomass transducer and the true concentrations (i.e. TSS measurements) for the three species- *Nannnochloropsis oculata*, *Isochrysis galbana* and *Thalassiosira weissflogii* are shown in Figure 2.15 with the data given in Appendix D.

The mean of the microalgal biomass concentrations estimated by the transducer is in close agreement with the prediction line. The standard error of prediction was calculated using the mean of estimated microalgal biomass concentrations and the true microalgal biomass. The relation used to calculate the standard error of prediction is given by (2.19):

$$\text{Standard Error of Prediction} = \sqrt{\left[\frac{\sum_{1}^{n}\left(X_e - X_t\right)^2}{n-1}\right]} \qquad (2.19)$$

Where X_e is the microalgal biomass (mg-dry wt/L) estimated by the transducer, X_t is the true microalgal biomass (mg-dry wt/L) and n is the total number of biomass concentrations tested.





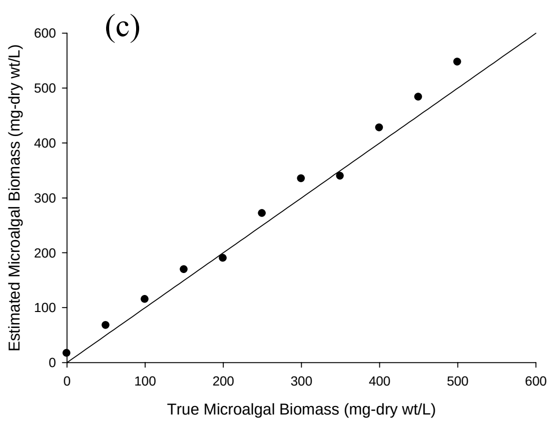


Figure 2.15. The mean of the estimated microalgal biomass was plotted against the true (known) microalgal biomass for (a) *N. oculata* (b) *I. galbana* and (c) *T. weissflogii*.

For a total of 11 different microalgal biomass concentrations that were independent of the biomass concentrations used for calibration, standard errors of predictions were 4.6 mg-dry wt/L (*N. oculata*), 17.8 mg-dry wt/L (*I. galbana*) and 26.7 mg-dry wt/L (*T. weissflogii*). The percentages of average error relative to the overall mean of the actual readings were 1.8 % (*N. oculata*), 6.9 % (*I. galbana*) and 9.9 % (*T. weissflogii*).

Additional testing of the biomass transducer was performed by mixing two or three samples of microalgal species. Equal amounts of *N. oculata* and *I. galbana* (N + I) each with a salinity of 35 ppt were mixed and different dilutions were prepared in the biomass range 0-500 mg-dry wt/L. A similar procedure was carried out for the following combinations - *I. galbana* with *T. weissflogii* (I + T), *N. oculata* with *T. weissflogii* (T + N) and finally all three together (N + I + T). A total of 28 different combinations of mixed samples were tested in replicates for biomass concentration using the new transducer. TSS measurements were conducted on these mixed samples after they were tested for concentration using the biomass transducer. The TSS measurements (i.e. true microalgal biomass) and the mean biomass concentration from the estimated readings by the transducer were compared as shown in Figure 2.16 with the data supplied in Appendix E. Among the different combinations tested, the microalgal biomass concentrations estimated for the combinations, N + I and T + N lie close to the prediction line.

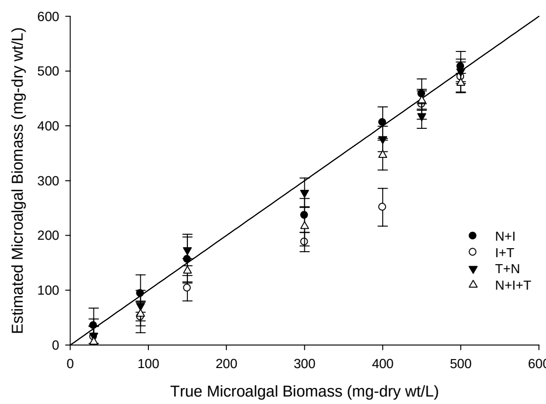


Figure 2.16. The microalgal biomass transducer readings were plotted against the true biomass (TSS measurements) for the combination of microalgal species (N + I = *N. oculata* and *I. galbana*; I + T = *I. galbana* and *T. weissflogii*; T + N = *T. weissflogii* and *N. oculata*; N + I + T = *N. oculata*, *galbana* and *T. weissflogii*

The results of the biomass transducer testing from the section 2.3.3 validate the algorithm developed for the signal processing and the model developed for calibration. The results of additional testing with mixed samples of microalgal species however do

not follow the prediction line for all the combinations tested. Although, the results were good for the combinations of N + I and T + N, the other combinations I + T and N + I + T deviated from the prediction line. The deviations were significant for higher biomass concentrations of the mixed samples (i.e. the combinations, I + T and N + I + T). The reason for these deviations could be due to the change in the relationship that existed before between the biomass concentration and the UVC readings. Although, there were deviations for some mixed samples, the results were good for the rest of the mixed samples indicating a strong potential of the biomass transducer application in the areas where microalgal biomass for the mixed species need to be measured. From the results of additional testing, the biomass transducer has the potential to be a highly sensitive device that can be used in areas where not just one of the microalgal species is used, but many. The estimated cost of the new biomass transducer is about $ 612 which is comparatively less than the cost of some other devices such as a field fluorometer from turner designs (Model no. 10-AU) that has an estimated cost $ 3,000.

2.4 Summary and Conclusions

Wavelength sensitivity analysis for the three microalgal species - *Nannnochloropsis oculata*, *Isochrysis galbana* and *Thalassiosira weissflogii* was conducted for a commercially applicable growth range of 0-500 mg dry wt L^{-1}, to investigate the light absorption characteristics of the microalgal samples. A correlation was developed between the absorbance and the microalgal biomass (mg-dry wt L^{-1}). It was discovered that each of the species had a maximum absorption at UVC, blue and red regions of the electromagnetic spectrum. Accordingly, a new biomass transducer was designed and constructed with a light emitter having three LEDs (UVC, blue and red) and a light

detector having the corresponding photodiodes. The transducer readings were processed using a transimpedance amplifier followed by further processing in the central control computer to filter the noise present in UVC reading. The filtering of noise from the UVC reading was performed using the blue and red readings. The processed UVC reading free of noise was calibrated with the microalgal biomass concentrations for each of the three species and, the transducer was tested for microlagal samples independent of the calibration curve.

The new biomass transducer tested for the individual microalgal species yielded the biomass concentrations in very close agreement with the prediction line and within 10% of the average error relative to the mean of actual readings. The additional testing performed on mixed samples of microalgal species yielded biomass concentrations close to the prediction for the combination: N. *oculata* and *I. galbana* and, *T. weissflogii* and N. *oculata*. However, the results deviated from the predicted line for the combinations: *I. galbana* and *T. weissflogii* and, all three species together.

The calibration developed for the new biomass transducer gave better results as compared to some of the other methods such as the fluorescence technique described by Honeywill et al., (2002) and the turbidimetric based method by Meireles et al., (2002). Sandnes et al., (2006) that uses IR wavelength (880) nm, has reported a better performing transducer than the new biomass transducer. However, Sandnes et al., (2006) has reported the use of such transducer for only single microalgal species. The new biomass transducer was tested for three microalgal species and has the potential to give good results for more than three microalgal species. In the above mentioned literature works,

the tested range was different from 0-500 mg dry wt L^{-1} and the microalgal species were different.

Chapter 3: Global Discussion and Conclusions

3.1 Global Discussion

The scope of this thesis was to develop a highly sensitive, miniaturized and cost effective biomass transducer for automated microalgal bioreactors. The preceding chapter introduces the development of a new biomass transducer for automated microalgal bioreactors. The new transducer developed was designed to be highly sensitive as it can be applied to three microalgal species belonging to different classes and thus having different characteristics.

Wavelength sensitivity analysis was conducted for the three microalgal species - *Nannochloropsis oculata*, *Isochrysis galbana* and *Thalassiosira weissflogii*, to investigate the light absorption characteristics of the microalgae. The biomass growth range was 0-500 mg-dry wt/L and the investigation was extended in the electromagnetic spectrum range of 200-800 nm. A correlation was developed between the absorbance and the biomass concentrations for these three species. The regions where maximum absorption occurs, also known as the peak regions were determined (i.e. UVC = 265 nm, blue = 440 nm and red = 680 nm). The microalgal species were highly sensitive in these regions and hence gave maximum separation between the individual biomass concentrations with the highest separation found in UVC.

A new biomass transducer was designed using a light emitter consisting of three LEDs (i.e. UVC = 265 nm, blue = 430 nm and red = 680 nm) and a light detector having the corresponding photodiodes. The transducer was based on the UVC readings on the microalgal samples. The design was laid out on a printed circuit board and placed in a CPVC plastic housing. A signal processing unit was designed consisting of a

transimpedance amplifier and a pull-down resistor to give highly sensitive readings and an output swing of 0-5 VDC.

The new transducer was connected to the central control computer and an algorithm was developed to further process the readings obtained from the transducer to filter out the noise present in UVC measurement. The blue and red readings from the transducer were used to filter noise present in UVC reading. The statistical relationship developed between the individual readings (i.e. UVC, blue and red) and the ratios (i.e. blue/UVC. Red/UVC) yielded a linear curve. The relationship between the individual readings yielded a positive slope and between UVC and the ratios yielded a negative slope. The processed readings were calibrated with the standard measurements of microalgal biomass concentrations (i.e. TSS measurements conducted in laboratory). The processed UVC readings from the transducer varied linearly up to 240 mg-dry wt/L for *N. oculata* and 300 mg-dry wt/L for *I.galbana* and *T. weissflogii*. For the rest of the concentrations, the UVC readings varied nonliniearly and thus two separate linear curves were used to fit the model.

The newly designed and constructed biomass transducer was tested with the microalgal samples independent of calibration curve to test the validity of the developed design, algorithm and calibration. The estimated biomass readings were compared with the true microalgal biomass readings. The estimated readings were in close agreement with the prediction line and had an average error < 10% relative to the mean of actual readings. Additional testing was performed with the biomass transducer for mixed samples containing combination of microalgal species.

The biomass transducer achieved significantly more sensitivity compared to the density sensor used in HISTAR system. The red measurement in the biomass transducer, which forms the overall density sensor, is highly insensitive to the changes in biomass concentrations. The range of 0-500 mg-dry wt/L of biomass concentration spans only about 10 mV for *N. oculata*, about 8 mV for *I. galbana* and about 6 mV for *T. weissflogii*. The new biomass transducer, which depends on UVC absorption, spans about 300 mV for *N. oculata*, 200 mV for *I. galbana* and about 170 mV for *T. weissflogii* for the same range.

3.2 Global Conclusions and Recommendations

The new biomass transducer tested for the individual microalgal species yielded the biomass concentrations in very close agreement with the prediction The standard errors of prediction were calculated as 4.6 mg-dry wt/L (*N. oculata*), 17.8 mg-dry wt/L (*I. galbana*) and 26.7 mg-dry wt/L (*T. weissflogii*). The percentages of average error relative to the overall mean of the actual readings were 1.8 % (*N. oculata*), 6.9 % (*I. galbana*) and 9.9 % (*T. weissflogii*).

The additional testing performed on mixed samples of microalgal species yielded biomass concentrations close to the prediction for the combination: N. *oculata* and *I. galbana* and, *T. weissflogii* and N. *oculata*. However, the results deviated from the predicted line for the combinations: *I. galbana* and *T. weissflogii* and, all three species together. The calibration developed for the new biomass transducer gave better results as compared to some of the other methods such as the fluorescence technique described by Honeywill et al., (2002) and the turbidimetric based method by Meireles et al., (2002). The new biomass transducer developed has the potential application in automated

microalgal bioreactors with individual species measurement as well as the mixed sample measurement.

Cost Summary*:* The cost of the biomass transducer can be subdivided into costs for the light emitter, light detector, signal processing components and plastic housing. The total cost of the light emitter is estimated to be $ 230, with the bulk coming from UVC LED costing $ 220. The overall cost of the light detector is estimated to be $ 232 with the UVC photodiode costing $100 and blue photodiode, $ 125. The cost of signal processing components such as transimpedance amplifier and service charges for soldering on a DIP package is about **$** 60. The cost of printing the electronic circuit on the board can be estimated to be $ 70. The CPVC plastic housing required for the biomass transducer can cost about $ 10. The other costs such as high temperature silicone sealant and wires would cost another $ 10. The total cost of the biomass transducer can be rounded off to $ 612. The cost summary shows that, the new biomass transducer costs less compared to highly sensitive biomass detecting instruments such as fluorometer, which can cost up to thousands of dollars.

Recommendations: The biomass transducer can be improved in sensitivity and size. The sensitivity can be significantly increased by using a more stable UVC light source that can be incorporated in the biomass transducer. Using a more responsive UVC photodiode with more than 0.13 A/W responsivity, may also increase the sensitivity. One other modification that can be suggested is the elimination of red measurement from the biomass transducer, which might have also caused some error in the UVC measurement processing.

The size of the biomass transducer at present is dictated by the electronic components used for light detector. As the components for the detector reduce in size, the size of the biomass transducer can be further reduced. Currently, the number of wires coming in and out of the biomass transducer is about 10, with 4 being for the light emitter and 6 for the light detector. Improved design with possibly more electronic components inside the transducer can reduce the number of connections.

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Appendix A: Wavelength Sensitivity Analysis

The results of the total suspended solids (TSS) measurements conducted in laboratory for wavelength sensitivity analysis on the three species- *Nannnochloropsis oculata*, *Isochrysis galbana* and *Thalassiosira weissflogii* are shown in Tables A-1, A-5 and A-9 respectively. The TSS measurement is required to find out the microalgal concentration present in the stock cultures present in the carboy. The data to prepare different dilutions to obtain different microalgal concentrations in the range of 0-500 mg dry wt/L for the three species are shown in Tables A-2, A-6 and A-10. The different concentrations were prepared for wavelength sensitivity analysis. The data from the scanning spectrophotometer averaged for each microalgal concentration over the wavelength range 200-800 nm is shown in Tables A-3, A-7 and A-11. The data showing the peak wavelengths (i.e. 265 nm, 430 nm and 680 nm) and their absorbance values for the three regions (i.e. UVC, blue and red) of electromagnetic spectra obtained from wavelength analysis are shown in Tables A-4, A-8 and A-12.

Table A-1. The results of the TSS measurements conducted in laboratory were used for wavelength sensitivity analysis of *N. oculata*.

SAMPLE	PAN NO.	INITIAL WEIGHT (mg)	FINAL WEIGHT (mg)	Vol. (mL)
Blank	142	1109	1109	20
Blank	7	1097.3	1097.3	20
Blank	112	1108.3	1108.3	20
	Average	1104.8	1104.8	
Salt Water	18	1124.4	1125.1	20
Salt Water	10	1109	1110.3	20
Salt Water	143	1099.2	1100.5	20
	Average	1104.1	1105.4	
Nano	6	1110.8	1122.6	20
Nano	2	1098.5	1110.5	20
Nano	4	1102.7	1114.48	20
Nano	20	1108	1119.4	20
	Average	1105	1116.7	

Sample	TSS (mg/L)
Blank	0
SW	65
Nano	587.2
Dry wt	522.2

Table A-2. The different dilutions were used to obtain different microalgal concentrations in the range of 0-500 mg dry wt/L for *N. oculata*.

To prepare 150 mL volume target solutions		
Target Concentration(mg/L)	**Volume of Salt Water (mL)**	**Volume to be added from 522.2 mg/L (mL)**
30	141.3	8.6
60	132.7	17.2
90	124.1	25.8
120	115.5	34.4
150	106.9	43.0
180	98.3	51.6
210	89.6	60.3
240	81.0	68.9
270	72.4	77.5
300	63.8	86.1
350	49.4	100.5
400	35.1	114.8
450	20.7	129.2
500	6.3	143.6

Table A-3. The data from the scanning spectrophotometer was averaged for each microalgal concentration over the wavelength range 200-800 nm to determine the wavelength sensitivity of *N. oculata*.

nm	**Salt water**	**30 mg/L**	**60 mg/L**	**90 mg/L**	**120 mg/L**	**150 mg/L**	**180 mg/L**	**210 mg/L**
800	0.036	0.103	0.171	0.243	0.313	0.374	0.437	0.503
799	0.037	0.104	0.172	0.249	0.314	0.374	0.438	0.502
798	0.036	0.103	0.171	0.245	0.313	0.374	0.438	0.502
797	0.037	0.104	0.171	0.248	0.313	0.374	0.437	0.502
796	0.036	0.103	0.17	0.242	0.315	0.373	0.436	0.501
795	0.036	0.103	0.171	0.244	0.314	0.374	0.436	0.501
794	0.035	0.103	0.171	0.241	0.314	0.374	0.437	0.501
793	0.035	0.102	0.172	0.246	0.313	0.374	0.438	0.501
792	0.035	0.103	0.172	0.244	0.314	0.375	0.439	0.502
791	0.035	0.102	0.172	0.243	0.317	0.376	0.44	0.503
790	0.035	0.102	0.172	0.247	0.313	0.376	0.441	0.502
789	0.035	0.103	0.172	0.247	0.314	0.377	0.441	0.504
788	0.036	0.103	0.172	0.245	0.319	0.378	0.442	0.504
787	0.035	0.103	0.172	0.244	0.314	0.378	0.442	0.505
786	0.035	0.103	0.173	0.244	0.314	0.378	0.443	0.506
785	0.035	0.103	0.173	0.244	0.317	0.378	0.443	0.507
784	0.035	0.104	0.173	0.245	0.318	0.379	0.443	0.508
783	0.035	0.104	0.173	0.244	0.319	0.379	0.443	0.508
782	0.035	0.103	0.173	0.244	0.319	0.38	0.444	0.509
781	0.036	0.104	0.173	0.244	0.32	0.38	0.444	0.509
780	0.036	0.104	0.174	0.245	0.317	0.38	0.445	0.509

779	0.035	0.104	0.174	0.245	0.319	0.38	0.445	0.51
778	0.035	0.104	0.174	0.246	0.319	0.381	0.445	0.51
777	0.035	0.103	0.174	0.246	0.318	0.381	0.446	0.511
776	0.035	0.103	0.174	0.246	0.319	0.381	0.446	0.511
775	0.035	0.104	0.175	0.247	0.319	0.382	0.447	0.512
774	0.035	0.104	0.175	0.247	0.319	0.382	0.447	0.512
773	0.035	0.104	0.175	0.247	0.319	0.383	0.448	0.513
772	0.035	0.104	0.175	0.247	0.319	0.383	0.448	0.513
771	0.035	0.104	0.175	0.247	0.32	0.384	0.449	0.514
770	0.035	0.104	0.175	0.248	0.32	0.384	0.449	0.515
769	0.034	0.104	0.175	0.248	0.321	0.384	0.45	0.515
768	0.034	0.104	0.175	0.248	0.321	0.385	0.45	0.516
767	0.035	0.104	0.175	0.248	0.321	0.385	0.451	0.516
766	0.035	0.105	0.176	0.249	0.322	0.385	0.451	0.517
765	0.034	0.105	0.176	0.249	0.322	0.386	0.452	0.518
764	0.034	0.104	0.176	0.249	0.322	0.386	0.452	0.518
763	0.034	0.105	0.177	0.249	0.323	0.387	0.453	0.519
762	0.034	0.105	0.177	0.249	0.323	0.387	0.453	0.519
761	0.034	0.105	0.177	0.25	0.324	0.388	0.454	0.52
760	0.034	0.105	0.177	0.25	0.324	0.388	0.455	0.521
759	0.035	0.105	0.177	0.25	0.325	0.389	0.456	0.522
758	0.035	0.105	0.177	0.251	0.325	0.389	0.456	0.522
757	0.035	0.105	0.178	0.251	0.325	0.389	0.457	0.523
756	0.035	0.105	0.178	0.251	0.326	0.39	0.457	0.523
755	0.034	0.105	0.178	0.251	0.326	0.39	0.458	0.524
754	0.034	0.106	0.179	0.252	0.327	0.391	0.458	0.525
753	0.034	0.106	0.179	0.252	0.327	0.391	0.459	0.526
752	0.034	0.106	0.179	0.252	0.328	0.392	0.46	0.526
751	0.035	0.106	0.179	0.253	0.328	0.393	0.46	0.527
750	0.034	0.106	0.179	0.253	0.328	0.393	0.461	0.527
749	0.034	0.106	0.179	0.253	0.329	0.393	0.461	0.528
748	0.034	0.106	0.18	0.254	0.329	0.394	0.462	0.529
747	0.034	0.106	0.18	0.254	0.33	0.394	0.463	0.53
746	0.034	0.106	0.18	0.254	0.33	0.395	0.463	0.53
745	0.034	0.106	0.18	0.254	0.331	0.395	0.464	0.531
744	0.034	0.107	0.18	0.255	0.331	0.396	0.464	0.531
743	0.034	0.106	0.181	0.255	0.332	0.396	0.465	0.532
742	0.034	0.107	0.181	0.255	0.332	0.397	0.465	0.533
741	0.034	0.107	0.181	0.256	0.332	0.397	0.466	0.533
740	0.034	0.107	0.181	0.256	0.333	0.398	0.467	0.534
739	0.034	0.107	0.182	0.257	0.333	0.398	0.468	0.535
738	0.034	0.107	0.182	0.257	0.334	0.399	0.468	0.535
737	0.034	0.107	0.182	0.257	0.334	0.399	0.468	0.536
736	0.034	0.107	0.182	0.257	0.335	0.4	0.469	0.537
735	0.034	0.107	0.182	0.258	0.335	0.4	0.47	0.538
734	0.034	0.107	0.183	0.258	0.336	0.401	0.471	0.539
733	0.034	0.108	0.183	0.259	0.337	0.402	0.471	0.54
732	0.034	0.108	0.183	0.259	0.337	0.402	0.472	0.541
731	0.034	0.108	0.184	0.26	0.338	0.403	0.473	0.542
730	0.034	0.108	0.184	0.26	0.338	0.404	0.474	0.543

729	0.034	0.108	0.184	0.261	0.339	0.405	0.475	0.544
728	0.034	0.109	0.185	0.261	0.34	0.406	0.476	0.545
727	0.034	0.109	0.185	0.262	0.34	0.407	0.477	0.546
726	0.034	0.109	0.185	0.262	0.341	0.408	0.478	0.547
725	0.034	0.109	0.186	0.263	0.342	0.409	0.479	0.548
724	0.034	0.109	0.186	0.263	0.343	0.409	0.48	0.55
723	0.034	0.109	0.186	0.264	0.344	0.41	0.481	0.551
722	0.034	0.109	0.187	0.264	0.344	0.411	0.482	0.552
721	0.034	0.11	0.187	0.265	0.345	0.412	0.483	0.553
720	0.034	0.11	0.187	0.266	0.346	0.413	0.484	0.554
719	0.034	0.11	0.188	0.266	0.346	0.414	0.485	0.556
718	0.034	0.11	0.188	0.267	0.347	0.415	0.487	0.557
717	0.034	0.111	0.189	0.268	0.348	0.416	0.488	0.559
716	0.034	0.111	0.189	0.268	0.349	0.418	0.49	0.561
715	0.034	0.111	0.19	0.269	0.35	0.419	0.491	0.562
714	0.034	0.111	0.19	0.27	0.352	0.42	0.493	0.564
713	0.034	0.112	0.191	0.271	0.353	0.422	0.494	0.566
712	0.034	0.112	0.191	0.272	0.354	0.423	0.496	0.568
711	0.034	0.112	0.192	0.273	0.355	0.425	0.498	0.57
710	0.034	0.112	0.192	0.274	0.356	0.426	0.5	0.572
709	0.034	0.113	0.193	0.274	0.358	0.428	0.501	0.574
708	0.034	0.113	0.194	0.276	0.359	0.43	0.504	0.577
707	0.034	0.113	0.194	0.277	0.361	0.432	0.506	0.579
706	0.034	0.114	0.195	0.278	0.363	0.434	0.508	0.582
705	0.034	0.114	0.196	0.279	0.364	0.436	0.511	0.585
704	0.034	0.115	0.197	0.28	0.366	0.438	0.513	0.588
703	0.034	0.115	0.198	0.282	0.368	0.44	0.516	0.591
702	0.034	0.116	0.199	0.283	0.369	0.442	0.518	0.594
701	0.034	0.116	0.199	0.284	0.371	0.444	0.521	0.597
700	0.034	0.116	0.201	0.286	0.373	0.447	0.524	0.601
699	0.034	0.117	0.202	0.288	0.376	0.45	0.528	0.605
698	0.034	0.118	0.203	0.29	0.378	0.453	0.532	0.609
697	0.034	0.118	0.204	0.292	0.381	0.457	0.536	0.614
696	0.034	0.119	0.206	0.294	0.384	0.461	0.541	0.62
695	0.034	0.12	0.208	0.297	0.388	0.465	0.546	0.626
694	0.034	0.121	0.21	0.3	0.392	0.47	0.552	0.633
693	0.034	0.122	0.212	0.303	0.396	0.476	0.559	0.641
692	0.034	0.123	0.214	0.306	0.401	0.481	0.566	0.65
691	0.034	0.124	0.216	0.309	0.405	0.487	0.573	0.658
690	0.034	0.125	0.218	0.312	0.41	0.493	0.58	0.666
689	0.034	0.126	0.22	0.316	0.414	0.498	0.587	0.674
688	0.034	0.127	0.222	0.319	0.419	0.504	0.594	0.683
687	0.034	0.128	0.224	0.321	0.423	0.509	0.6	0.691
686	0.034	0.129	0.226	0.324	0.427	0.514	0.606	0.698
685	0.034	0.129	0.227	0.326	0.43	0.518	0.611	0.704
684	0.034	0.13	0.228	0.328	0.432	0.521	0.615	0.709
683	0.034	0.13	0.228	0.328	0.433	0.523	0.617	0.712
682	0.034	0.13	0.229	0.329	0.433	0.523	0.618	0.713
681	0.034	0.13	0.228	0.328	0.433	0.523	0.618	0.713
680	0.034	0.13	0.228	0.327	0.432	0.522	0.617	0.712

679	0.034	0.129	0.227	0.327	0.431	0.521	0.615	0.71
678	0.034	0.129	0.227	0.325	0.43	0.519	0.613	0.708
677	0.034	0.128	0.225	0.324	0.427	0.516	0.611	0.705
676	0.034	0.128	0.224	0.322	0.425	0.514	0.607	0.701
675	0.034	0.127	0.223	0.32	0.423	0.511	0.604	0.697
674	0.034	0.127	0.222	0.319	0.421	0.509	0.601	0.694
673	0.034	0.126	0.221	0.317	0.419	0.506	0.598	0.69
672	0.034	0.126	0.22	0.316	0.417	0.503	0.595	0.687
671	0.034	0.125	0.219	0.314	0.415	0.5	0.592	0.683
670	0.034	0.125	0.218	0.313	0.412	0.498	0.588	0.679
669	0.034	0.124	0.216	0.311	0.41	0.495	0.585	0.675
668	0.034	0.123	0.215	0.309	0.408	0.492	0.581	0.671
667	0.034	0.123	0.214	0.307	0.405	0.489	0.578	0.666
666	0.034	0.122	0.213	0.306	0.403	0.486	0.574	0.662
665	0.034	0.122	0.212	0.304	0.401	0.484	0.571	0.658
664	0.034	0.121	0.211	0.303	0.399	0.481	0.568	0.655
663	0.034	0.121	0.21	0.301	0.397	0.479	0.566	0.652
662	0.034	0.121	0.21	0.3	0.396	0.477	0.563	0.649
661	0.034	0.12	0.209	0.3	0.395	0.476	0.561	0.646
660	0.034	0.12	0.209	0.299	0.394	0.474	0.56	0.644
659	0.034	0.12	0.208	0.298	0.393	0.473	0.558	0.643
658	0.034	0.12	0.208	0.298	0.392	0.473	0.557	0.641
657	0.034	0.12	0.208	0.298	0.392	0.472	0.557	0.641
656	0.034	0.12	0.208	0.297	0.392	0.472	0.556	0.64
655	0.034	0.12	0.208	0.298	0.392	0.472	0.556	0.64
654	0.034	0.12	0.208	0.298	0.392	0.472	0.557	0.64
653	0.034	0.12	0.208	0.298	0.392	0.472	0.557	0.64
652	0.034	0.12	0.208	0.298	0.393	0.473	0.558	0.641
651	0.035	0.12	0.209	0.299	0.393	0.474	0.558	0.642
650	0.034	0.12	0.209	0.299	0.394	0.475	0.559	0.643
649	0.034	0.12	0.209	0.3	0.395	0.475	0.56	0.644
648	0.035	0.121	0.21	0.3	0.396	0.477	0.562	0.646
647	0.035	0.121	0.21	0.301	0.397	0.478	0.563	0.647
646	0.035	0.121	0.211	0.302	0.398	0.479	0.565	0.65
645	0.035	0.121	0.211	0.303	0.399	0.481	0.567	0.651
644	0.035	0.121	0.212	0.304	0.4	0.482	0.568	0.653
643	0.035	0.122	0.212	0.304	0.401	0.483	0.57	0.655
642	0.034	0.122	0.213	0.305	0.402	0.485	0.571	0.657
641	0.035	0.122	0.213	0.306	0.403	0.486	0.573	0.659
640	0.035	0.122	0.214	0.307	0.404	0.487	0.575	0.661
639	0.035	0.123	0.214	0.307	0.405	0.488	0.576	0.662
638	0.035	0.123	0.215	0.308	0.406	0.49	0.578	0.664
637	0.035	0.123	0.215	0.309	0.407	0.491	0.579	0.666
636	0.035	0.123	0.216	0.309	0.408	0.492	0.581	0.668
635	0.035	0.123	0.216	0.31	0.408	0.493	0.582	0.669
634	0.035	0.124	0.216	0.311	0.409	0.494	0.583	0.671
633	0.035	0.124	0.216	0.311	0.41	0.494	0.584	0.671
632	0.035	0.124	0.217	0.311	0.41	0.495	0.584	0.672
631	0.035	0.124	0.217	0.311	0.41	0.496	0.585	0.673
630	0.035	0.124	0.217	0.312	0.411	0.496	0.585	0.674

629	0.035	0.124	0.217	0.312	0.411	0.496	0.586	0.674
628	0.035	0.124	0.217	0.312	0.411	0.496	0.586	0.674
627	0.035	0.124	0.217	0.312	0.411	0.496	0.586	0.674
626	0.035	0.124	0.217	0.311	0.411	0.496	0.586	0.674
625	0.035	0.124	0.217	0.311	0.41	0.496	0.586	0.674
624	0.035	0.124	0.217	0.311	0.41	0.496	0.585	0.674
623	0.035	0.124	0.216	0.311	0.41	0.495	0.585	0.673
622	0.035	0.123	0.216	0.311	0.409	0.495	0.584	0.673
621	0.035	0.123	0.216	0.31	0.409	0.494	0.584	0.672
620	0.035	0.123	0.216	0.31	0.408	0.494	0.583	0.671
619	0.035	0.123	0.215	0.309	0.408	0.493	0.582	0.67
618	0.035	0.123	0.215	0.309	0.407	0.492	0.581	0.668
617	0.035	0.123	0.215	0.308	0.406	0.491	0.579	0.667
616	0.035	0.122	0.214	0.307	0.405	0.49	0.578	0.665
615	0.035	0.122	0.214	0.307	0.404	0.489	0.577	0.664
614	0.035	0.122	0.213	0.306	0.403	0.487	0.575	0.662
613	0.035	0.122	0.213	0.305	0.402	0.486	0.574	0.66
612	0.035	0.121	0.212	0.305	0.401	0.485	0.572	0.658
611	0.035	0.121	0.212	0.304	0.4	0.484	0.57	0.656
610	0.035	0.121	0.211	0.303	0.399	0.482	0.569	0.655
609	0.035	0.121	0.211	0.303	0.398	0.481	0.568	0.653
608	0.035	0.121	0.21	0.302	0.398	0.48	0.566	0.652
607	0.035	0.12	0.21	0.301	0.397	0.479	0.565	0.65
606	0.035	0.12	0.21	0.301	0.396	0.478	0.564	0.649
605	0.035	0.12	0.209	0.3	0.396	0.478	0.563	0.648
604	0.035	0.12	0.209	0.3	0.395	0.477	0.562	0.646
603	0.035	0.12	0.209	0.3	0.394	0.476	0.561	0.645
602	0.035	0.12	0.208	0.299	0.394	0.475	0.56	0.644
601	0.035	0.119	0.208	0.299	0.394	0.475	0.56	0.644
600	0.035	0.12	0.208	0.299	0.394	0.475	0.56	0.644
599	0.035	0.119	0.208	0.299	0.393	0.474	0.559	0.643
598	0.035	0.119	0.208	0.298	0.393	0.474	0.559	0.642
597	0.035	0.119	0.208	0.298	0.393	0.474	0.558	0.642
596	0.035	0.119	0.208	0.298	0.393	0.474	0.558	0.642
595	0.035	0.119	0.207	0.298	0.392	0.473	0.557	0.641
594	0.034	0.119	0.207	0.297	0.392	0.473	0.557	0.64
593	0.034	0.119	0.207	0.298	0.392	0.472	0.557	0.64
592	0.035	0.119	0.207	0.297	0.392	0.472	0.556	0.64
591	0.035	0.119	0.207	0.297	0.392	0.472	0.556	0.639
590	0.035	0.119	0.207	0.297	0.391	0.472	0.556	0.639
589	0.035	0.119	0.207	0.297	0.391	0.471	0.555	0.638
588	0.035	0.119	0.207	0.297	0.391	0.471	0.555	0.637
587	0.035	0.118	0.206	0.296	0.39	0.471	0.554	0.637
586	0.034	0.119	0.206	0.296	0.39	0.47	0.554	0.636
585	0.034	0.118	0.206	0.296	0.39	0.47	0.554	0.636
584	0.035	0.118	0.206	0.296	0.39	0.47	0.553	0.635
583	0.035	0.118	0.206	0.296	0.389	0.469	0.553	0.635
582	0.034	0.118	0.206	0.296	0.389	0.469	0.552	0.634
581	0.035	0.118	0.206	0.295	0.389	0.469	0.552	0.634
580	0.035	0.118	0.206	0.295	0.389	0.469	0.552	0.633

579	0.034	0.118	0.205	0.295	0.389	0.468	0.551	0.633
578	0.035	0.118	0.205	0.295	0.388	0.468	0.551	0.633
577	0.035	0.118	0.205	0.295	0.388	0.468	0.551	0.632
576	0.035	0.118	0.205	0.295	0.388	0.468	0.55	0.632
575	0.035	0.118	0.205	0.295	0.388	0.468	0.55	0.631
574	0.035	0.118	0.205	0.295	0.388	0.467	0.55	0.631
573	0.035	0.118	0.205	0.295	0.387	0.467	0.549	0.63
572	0.035	0.118	0.205	0.294	0.387	0.467	0.549	0.63
571	0.035	0.117	0.205	0.294	0.388	0.467	0.549	0.629
570	0.035	0.118	0.205	0.294	0.387	0.467	0.548	0.629
569	0.035	0.118	0.205	0.294	0.387	0.467	0.548	0.629
568	0.035	0.118	0.205	0.294	0.387	0.466	0.548	0.629
567	0.035	0.118	0.205	0.294	0.387	0.466	0.548	0.628
566	0.035	0.118	0.205	0.294	0.387	0.466	0.548	0.628
565	0.035	0.118	0.205	0.294	0.387	0.466	0.548	0.628
564	0.035	0.118	0.205	0.294	0.387	0.466	0.548	0.628
563	0.035	0.118	0.205	0.294	0.387	0.466	0.548	0.628
562	0.035	0.118	0.205	0.295	0.387	0.467	0.548	0.628
561	0.035	0.118	0.205	0.295	0.388	0.467	0.548	0.629
560	0.035	0.118	0.205	0.295	0.388	0.467	0.549	0.629
559	0.035	0.118	0.205	0.295	0.388	0.467	0.549	0.629
558	0.035	0.118	0.205	0.295	0.388	0.468	0.549	0.63
557	0.035	0.118	0.205	0.295	0.388	0.468	0.55	0.63
556	0.035	0.118	0.206	0.296	0.389	0.468	0.55	0.63
555	0.035	0.118	0.206	0.296	0.389	0.469	0.55	0.631
554	0.035	0.118	0.206	0.296	0.389	0.469	0.551	0.631
553	0.035	0.118	0.206	0.297	0.39	0.47	0.552	0.632
552	0.035	0.118	0.206	0.297	0.39	0.471	0.552	0.633
551	0.035	0.118	0.207	0.298	0.391	0.471	0.553	0.633
550	0.035	0.119	0.207	0.298	0.392	0.472	0.554	0.635
549	0.035	0.119	0.207	0.298	0.392	0.473	0.555	0.635
548	0.035	0.119	0.207	0.299	0.393	0.474	0.556	0.636
547	0.035	0.119	0.208	0.299	0.394	0.474	0.557	0.638
546	0.035	0.119	0.208	0.3	0.394	0.475	0.558	0.639
545	0.035	0.119	0.209	0.301	0.395	0.477	0.559	0.64
544	0.035	0.12	0.209	0.301	0.396	0.478	0.561	0.642
543	0.035	0.12	0.21	0.302	0.397	0.479	0.562	0.643
542	0.035	0.12	0.21	0.303	0.398	0.48	0.563	0.645
541	0.035	0.12	0.21	0.303	0.399	0.481	0.564	0.646
540	0.035	0.12	0.211	0.304	0.4	0.482	0.566	0.648
539	0.035	0.121	0.211	0.305	0.401	0.483	0.567	0.65
538	0.035	0.121	0.212	0.306	0.402	0.485	0.569	0.651
537	0.035	0.121	0.212	0.306	0.403	0.486	0.57	0.653
536	0.035	0.121	0.213	0.307	0.404	0.487	0.572	0.655
535	0.035	0.122	0.213	0.308	0.405	0.489	0.574	0.657
534	0.035	0.122	0.214	0.309	0.407	0.491	0.576	0.659
533	0.035	0.122	0.215	0.31	0.408	0.492	0.577	0.661
532	0.035	0.122	0.215	0.311	0.409	0.494	0.579	0.663
531	0.035	0.123	0.216	0.312	0.41	0.495	0.581	0.666
530	0.035	0.123	0.217	0.313	0.412	0.497	0.583	0.668

529	0.035	0.124	0.217	0.314	0.413	0.499	0.585	0.671
528	0.035	0.124	0.218	0.315	0.415	0.5	0.587	0.673
527	0.035	0.124	0.219	0.316	0.416	0.502	0.589	0.675
526	0.035	0.124	0.219	0.317	0.417	0.504	0.591	0.677
525	0.035	0.124	0.22	0.318	0.418	0.505	0.593	0.68
524	0.035	0.125	0.22	0.319	0.42	0.507	0.595	0.682
523	0.035	0.125	0.221	0.32	0.421	0.508	0.597	0.684
522	0.035	0.125	0.222	0.32	0.422	0.51	0.599	0.687
521	0.035	0.126	0.222	0.321	0.424	0.512	0.601	0.689
520	0.035	0.126	0.223	0.322	0.425	0.513	0.603	0.691
519	0.035	0.126	0.224	0.323	0.426	0.515	0.605	0.694
518	0.035	0.127	0.224	0.324	0.428	0.517	0.607	0.696
517	0.035	0.127	0.225	0.325	0.429	0.518	0.609	0.698
516	0.036	0.127	0.225	0.326	0.43	0.52	0.611	0.7
515	0.035	0.128	0.226	0.327	0.431	0.521	0.612	0.702
514	0.036	0.128	0.226	0.328	0.432	0.522	0.614	0.704
513	0.036	0.128	0.227	0.328	0.433	0.524	0.616	0.706
512	0.036	0.128	0.228	0.329	0.435	0.526	0.618	0.709
511	0.036	0.129	0.228	0.33	0.436	0.527	0.62	0.711
510	0.036	0.129	0.229	0.331	0.437	0.529	0.622	0.713
509	0.036	0.129	0.229	0.332	0.439	0.531	0.624	0.716
508	0.036	0.13	0.23	0.333	0.44	0.532	0.626	0.718
507	0.036	0.13	0.23	0.334	0.441	0.534	0.628	0.721
506	0.036	0.13	0.231	0.335	0.442	0.536	0.63	0.723
505	0.036	0.13	0.232	0.336	0.444	0.537	0.632	0.725
504	0.036	0.131	0.232	0.337	0.445	0.539	0.634	0.728
503	0.036	0.131	0.233	0.338	0.447	0.541	0.636	0.73
502	0.036	0.132	0.234	0.339	0.448	0.542	0.638	0.732
501	0.036	0.132	0.234	0.34	0.449	0.544	0.64	0.734
500	0.036	0.132	0.235	0.341	0.45	0.545	0.641	0.736
499	0.036	0.132	0.235	0.341	0.451	0.546	0.643	0.737
498	0.036	0.133	0.236	0.342	0.452	0.547	0.644	0.739
497	0.036	0.133	0.236	0.342	0.452	0.548	0.645	0.74
496	0.036	0.133	0.236	0.343	0.453	0.549	0.646	0.742
495	0.036	0.133	0.237	0.343	0.454	0.55	0.647	0.743
494	0.036	0.133	0.237	0.344	0.454	0.551	0.648	0.744
493	0.037	0.134	0.237	0.344	0.455	0.551	0.649	0.745
492	0.036	0.134	0.238	0.344	0.456	0.552	0.65	0.746
491	0.036	0.134	0.238	0.345	0.456	0.553	0.651	0.747
490	0.037	0.134	0.238	0.345	0.457	0.554	0.652	0.748
489	0.037	0.134	0.238	0.346	0.457	0.554	0.653	0.749
488	0.037	0.134	0.239	0.346	0.458	0.555	0.654	0.75
487	0.037	0.134	0.239	0.347	0.458	0.556	0.654	0.751
486	0.037	0.134	0.239	0.347	0.459	0.556	0.655	0.752
485	0.037	0.134	0.239	0.347	0.459	0.556	0.655	0.753
484	0.037	0.134	0.24	0.347	0.46	0.557	0.656	0.754
483	0.037	0.135	0.24	0.348	0.46	0.558	0.657	0.754
482	0.037	0.135	0.24	0.348	0.461	0.558	0.658	0.755
481	0.037	0.135	0.24	0.349	0.461	0.559	0.658	0.756
480	0.037	0.135	0.241	0.349	0.462	0.56	0.659	0.757

479	0.037	0.135	0.241	0.35	0.462	0.561	0.66	0.758
478	0.037	0.135	0.241	0.35	0.463	0.561	0.661	0.759
477	0.037	0.136	0.241	0.351	0.464	0.562	0.662	0.761
476	0.037	0.136	0.242	0.351	0.465	0.563	0.663	0.762
475	0.037	0.136	0.242	0.352	0.465	0.564	0.665	0.763
474	0.037	0.136	0.243	0.352	0.466	0.565	0.666	0.764
473	0.037	0.136	0.243	0.353	0.467	0.566	0.667	0.765
472	0.037	0.137	0.243	0.354	0.468	0.567	0.668	0.767
471	0.037	0.137	0.244	0.354	0.469	0.569	0.67	0.769
470	0.037	0.137	0.244	0.355	0.47	0.57	0.671	0.771
469	0.037	0.137	0.245	0.356	0.471	0.571	0.673	0.772
468	0.037	0.138	0.246	0.357	0.472	0.573	0.675	0.774
467	0.037	0.138	0.246	0.357	0.473	0.574	0.676	0.776
466	0.037	0.138	0.247	0.358	0.474	0.575	0.678	0.778
465	0.037	0.138	0.247	0.359	0.475	0.577	0.679	0.78
464	0.038	0.139	0.248	0.36	0.476	0.578	0.681	0.782
463	0.038	0.139	0.248	0.36	0.478	0.58	0.683	0.784
462	0.038	0.139	0.249	0.361	0.479	0.581	0.685	0.786
461	0.038	0.14	0.25	0.363	0.48	0.583	0.687	0.789
460	0.038	0.14	0.25	0.364	0.482	0.585	0.689	0.791
459	0.038	0.14	0.251	0.365	0.484	0.587	0.692	0.795
458	0.038	0.141	0.252	0.366	0.485	0.589	0.695	0.798
457	0.038	0.141	0.253	0.368	0.488	0.592	0.698	0.801
456	0.038	0.142	0.254	0.369	0.49	0.595	0.701	0.805
455	0.038	0.142	0.255	0.371	0.492	0.598	0.705	0.81
454	0.038	0.143	0.257	0.373	0.495	0.601	0.709	0.814
453	0.038	0.144	0.258	0.375	0.497	0.605	0.713	0.82
452	0.038	0.144	0.259	0.377	0.501	0.608	0.718	0.825
451	0.038	0.145	0.261	0.379	0.504	0.612	0.723	0.831
450	0.038	0.147	0.263	0.383	0.508	0.618	0.729	0.839
449	0.038	0.147	0.265	0.385	0.512	0.623	0.735	0.846
448	0.038	0.148	0.267	0.388	0.516	0.627	0.741	0.852
447	0.038	0.149	0.268	0.39	0.519	0.632	0.746	0.859
446	0.038	0.15	0.27	0.392	0.522	0.636	0.752	0.865
445	0.038	0.15	0.271	0.395	0.525	0.64	0.756	0.872
444	0.038	0.151	0.272	0.397	0.527	0.643	0.761	0.877
443	0.038	0.151	0.273	0.398	0.529	0.646	0.764	0.881
442	0.038	0.151	0.273	0.399	0.53	0.647	0.766	0.883
441	0.038	0.151	0.273	0.399	0.531	0.648	0.767	0.884
440	0.039	0.152	0.274	0.399	0.531	0.648	0.768	0.885
439	0.039	0.151	0.273	0.398	0.531	0.648	0.767	0.886
438	0.039	0.151	0.273	0.398	0.53	0.647	0.766	0.884
437	0.039	0.151	0.273	0.397	0.529	0.646	0.765	0.883
436	0.039	0.151	0.272	0.396	0.527	0.644	0.762	0.88
435	0.039	0.15	0.271	0.395	0.526	0.642	0.759	0.877
434	0.039	0.15	0.27	0.394	0.524	0.64	0.757	0.875
433	0.039	0.149	0.269	0.393	0.523	0.638	0.755	0.871
432	0.039	0.149	0.269	0.392	0.521	0.636	0.753	0.869
431	0.039	0.149	0.268	0.391	0.52	0.634	0.751	0.866
430	0.039	0.149	0.268	0.39	0.519	0.633	0.749	0.864

429	0.039	0.149	0.267	0.39	0.518	0.632	0.748	0.863
428	0.039	0.148	0.267	0.389	0.517	0.631	0.747	0.861
427	0.039	0.148	0.266	0.388	0.516	0.63	0.746	0.859
426	0.039	0.148	0.266	0.388	0.516	0.629	0.745	0.858
425	0.039	0.148	0.266	0.388	0.516	0.628	0.744	0.857
424	0.039	0.148	0.266	0.387	0.515	0.628	0.743	0.856
423	0.039	0.148	0.266	0.387	0.515	0.628	0.743	0.856
422	0.039	0.148	0.266	0.387	0.515	0.628	0.742	0.856
421	0.04	0.148	0.265	0.387	0.514	0.627	0.742	0.855
420	0.039	0.148	0.265	0.386	0.514	0.627	0.741	0.855
419	0.039	0.148	0.265	0.386	0.513	0.626	0.741	0.853
418	0.04	0.148	0.265	0.386	0.513	0.625	0.739	0.852
417	0.04	0.147	0.264	0.385	0.512	0.624	0.738	0.851
416	0.04	0.147	0.264	0.385	0.511	0.623	0.737	0.849
415	0.039	0.147	0.263	0.384	0.51	0.622	0.735	0.847
414	0.039	0.147	0.263	0.383	0.509	0.62	0.734	0.845
413	0.039	0.146	0.262	0.382	0.508	0.619	0.732	0.843
412	0.039	0.146	0.262	0.381	0.507	0.617	0.729	0.84
411	0.039	0.146	0.261	0.38	0.505	0.616	0.728	0.838
410	0.039	0.145	0.26	0.38	0.504	0.614	0.725	0.835
409	0.039	0.145	0.26	0.379	0.503	0.613	0.724	0.833
408	0.039	0.145	0.259	0.378	0.502	0.611	0.722	0.83
407	0.039	0.145	0.259	0.377	0.5	0.609	0.719	0.828
406	0.04	0.145	0.259	0.377	0.499	0.608	0.718	0.826
405	0.04	0.144	0.258	0.376	0.499	0.607	0.716	0.824
404	0.04	0.144	0.258	0.375	0.498	0.606	0.715	0.822
403	0.04	0.144	0.258	0.375	0.497	0.605	0.713	0.82
402	0.04	0.144	0.257	0.374	0.496	0.604	0.712	0.819
401	0.04	0.144	0.257	0.374	0.496	0.603	0.711	0.817
400	0.04	0.144	0.257	0.374	0.496	0.602	0.71	0.817
399	0.04	0.144	0.257	0.374	0.496	0.603	0.71	0.816
398	0.04	0.144	0.257	0.374	0.496	0.602	0.71	0.816
397	0.04	0.144	0.257	0.374	0.496	0.602	0.71	0.815
396	0.04	0.145	0.258	0.374	0.496	0.603	0.71	0.815
395	0.04	0.144	0.257	0.374	0.496	0.603	0.71	0.815
394	0.04	0.144	0.257	0.374	0.496	0.603	0.71	0.815
393	0.04	0.144	0.258	0.375	0.496	0.603	0.711	0.815
392	0.04	0.144	0.258	0.375	0.497	0.603	0.711	0.816
391	0.04	0.145	0.258	0.375	0.497	0.604	0.711	0.816
390	0.04	0.145	0.258	0.375	0.497	0.604	0.711	0.817
389	0.04	0.145	0.259	0.376	0.498	0.605	0.712	0.817
388	0.04	0.145	0.259	0.376	0.498	0.605	0.712	0.817
387	0.041	0.145	0.259	0.376	0.498	0.605	0.712	0.817
386	0.041	0.145	0.259	0.377	0.498	0.606	0.713	0.818
385	0.041	0.145	0.259	0.377	0.498	0.606	0.713	0.818
384	0.04	0.145	0.259	0.377	0.499	0.606	0.713	0.818
383	0.041	0.145	0.26	0.377	0.499	0.606	0.713	0.817
382	0.041	0.146	0.259	0.377	0.499	0.605	0.712	0.817
381	0.041	0.145	0.259	0.377	0.499	0.606	0.713	0.817
380	0.036	0.139	0.251	0.361	0.48	0.582	0.683	0.782

379	0.038	0.144	0.254	0.368	0.484	0.583	0.686	0.782
378	0.04	0.143	0.254	0.367	0.484	0.586	0.688	0.781
377	0.04	0.143	0.254	0.368	0.485	0.588	0.687	0.779
376	0.039	0.142	0.254	0.365	0.483	0.585	0.685	0.779
375	0.039	0.143	0.253	0.366	0.485	0.585	0.683	0.78
374	0.04	0.143	0.254	0.367	0.484	0.585	0.682	0.779
373	0.039	0.142	0.254	0.366	0.484	0.584	0.683	0.777
372	0.04	0.143	0.254	0.367	0.483	0.585	0.682	0.775
371	0.039	0.141	0.251	0.366	0.483	0.585	0.682	0.776
370	0.04	0.142	0.253	0.367	0.482	0.585	0.682	0.777
369	0.039	0.142	0.252	0.367	0.483	0.585	0.682	0.776
368	0.04	0.142	0.253	0.367	0.484	0.584	0.683	0.775
367	0.041	0.142	0.253	0.367	0.483	0.584	0.683	0.775
366	0.04	0.142	0.253	0.367	0.484	0.585	0.683	0.776
365	0.04	0.142	0.254	0.367	0.483	0.584	0.682	0.776
364	0.04	0.143	0.254	0.369	0.484	0.584	0.682	0.777
363	0.041	0.143	0.254	0.368	0.483	0.584	0.681	0.776
362	0.041	0.143	0.255	0.369	0.484	0.586	0.683	0.777
361	0.04	0.143	0.255	0.369	0.485	0.585	0.684	0.776
360	0.041	0.144	0.255	0.369	0.485	0.587	0.684	0.777
359	0.04	0.143	0.255	0.369	0.485	0.587	0.683	0.777
358	0.04	0.143	0.256	0.37	0.486	0.588	0.682	0.778
357	0.04	0.143	0.256	0.371	0.487	0.587	0.684	0.778
356	0.041	0.144	0.256	0.371	0.488	0.589	0.684	0.779
355	0.039	0.143	0.255	0.37	0.488	0.587	0.684	0.778
354	0.04	0.144	0.257	0.371	0.489	0.589	0.686	0.779
353	0.041	0.144	0.258	0.373	0.49	0.59	0.688	0.78
352	0.04	0.145	0.258	0.373	0.491	0.592	0.689	0.784
351	0.041	0.146	0.259	0.374	0.493	0.595	0.69	0.784
350	0.041	0.145	0.259	0.374	0.493	0.595	0.692	0.786
349	0.04	0.145	0.258	0.376	0.493	0.596	0.694	0.787
348	0.041	0.147	0.261	0.378	0.496	0.597	0.695	0.79
347	0.041	0.147	0.262	0.379	0.497	0.599	0.697	0.793
346	0.04	0.146	0.261	0.379	0.497	0.599	0.698	0.793
345	0.04	0.147	0.262	0.38	0.499	0.601	0.7	0.796
344	0.04	0.147	0.263	0.38	0.5	0.602	0.7	0.797
343	0.04	0.147	0.264	0.381	0.501	0.602	0.703	0.798
342	0.04	0.148	0.264	0.382	0.502	0.604	0.704	0.798
341	0.041	0.148	0.264	0.383	0.503	0.606	0.706	0.799
340	0.041	0.148	0.265	0.383	0.503	0.607	0.706	0.801
339	0.04	0.149	0.266	0.384	0.505	0.608	0.707	0.802
338	0.041	0.149	0.266	0.384	0.505	0.608	0.707	0.804
337	0.041	0.149	0.266	0.384	0.505	0.609	0.707	0.803
336	0.041	0.149	0.267	0.385	0.506	0.609	0.707	0.803
335	0.04	0.149	0.267	0.385	0.505	0.609	0.707	0.803
334	0.041	0.149	0.267	0.385	0.507	0.609	0.708	0.804
333	0.041	0.149	0.267	0.385	0.506	0.61	0.709	0.803
332	0.04	0.149	0.267	0.386	0.506	0.61	0.709	0.804
331	0.041	0.15	0.268	0.387	0.506	0.609	0.709	0.804
330	0.041	0.15	0.268	0.387	0.507	0.61	0.71	0.804

329	0.041	0.15	0.268	0.388	0.507	0.609	0.71	0.804
328	0.041	0.15	0.268	0.388	0.508	0.61	0.71	0.805
327	0.041	0.15	0.269	0.389	0.509	0.611	0.71	0.804
326	0.041	0.151	0.269	0.389	0.51	0.612	0.713	0.805
325	0.041	0.151	0.269	0.39	0.511	0.613	0.713	0.805
324	0.042	0.152	0.27	0.39	0.512	0.614	0.714	0.807
323	0.042	0.152	0.272	0.391	0.512	0.616	0.714	0.809
322	0.042	0.153	0.272	0.392	0.512	0.616	0.715	0.809
321	0.043	0.153	0.273	0.393	0.513	0.617	0.715	0.81
320	0.043	0.154	0.273	0.394	0.514	0.617	0.717	0.81
319	0.043	0.154	0.274	0.395	0.516	0.619	0.718	0.813
318	0.044	0.154	0.274	0.395	0.517	0.62	0.72	0.813
317	0.043	0.155	0.274	0.396	0.518	0.621	0.72	0.814
316	0.043	0.155	0.275	0.397	0.518	0.622	0.721	0.815
315	0.043	0.155	0.276	0.398	0.518	0.623	0.724	0.817
314	0.043	0.155	0.277	0.399	0.52	0.624	0.724	0.819
313	0.043	0.156	0.276	0.4	0.522	0.624	0.724	0.819
312	0.043	0.156	0.278	0.401	0.523	0.627	0.727	0.821
311	0.043	0.157	0.279	0.402	0.524	0.629	0.727	0.821
310	0.042	0.156	0.279	0.402	0.525	0.629	0.73	0.824
309	0.043	0.157	0.28	0.403	0.527	0.631	0.731	0.828
308	0.043	0.158	0.281	0.404	0.527	0.632	0.733	0.828
307	0.042	0.157	0.281	0.406	0.528	0.634	0.735	0.832
306	0.043	0.158	0.283	0.407	0.53	0.638	0.74	0.834
305	0.042	0.158	0.283	0.409	0.533	0.639	0.742	0.838
304	0.043	0.159	0.284	0.409	0.535	0.641	0.742	0.839
303	0.042	0.159	0.284	0.41	0.536	0.643	0.745	0.841
302	0.041	0.159	0.284	0.411	0.536	0.646	0.747	0.843
301	0.042	0.16	0.286	0.413	0.538	0.647	0.749	0.844
300	0.043	0.164	0.296	0.43	0.566	0.685	0.801	0.915
299	0.043	0.164	0.297	0.431	0.568	0.687	0.806	0.92
298	0.043	0.165	0.298	0.433	0.57	0.69	0.809	0.923
297	0.043	0.165	0.299	0.434	0.573	0.693	0.813	0.927
296	0.042	0.166	0.3	0.437	0.576	0.698	0.818	0.934
295	0.042	0.166	0.302	0.439	0.58	0.703	0.823	0.94
294	0.041	0.167	0.303	0.442	0.583	0.707	0.829	0.947
293	0.041	0.168	0.305	0.444	0.587	0.711	0.835	0.955
292	0.041	0.168	0.307	0.446	0.59	0.716	0.841	0.962
291	0.041	0.169	0.308	0.449	0.594	0.72	0.845	0.968
290	0.04	0.169	0.309	0.451	0.597	0.724	0.851	0.974
289	0.04	0.169	0.311	0.453	0.6	0.729	0.855	0.979
288	0.039	0.17	0.312	0.456	0.603	0.733	0.861	0.986
287	0.039	0.17	0.313	0.458	0.607	0.737	0.867	0.993
286	0.039	0.171	0.315	0.46	0.611	0.742	0.873	0.999
285	0.038	0.172	0.316	0.463	0.614	0.746	0.878	1.006
284	0.037	0.172	0.317	0.465	0.617	0.75	0.883	1.012
283	0.037	0.172	0.318	0.467	0.619	0.753	0.886	1.017
282	0.036	0.172	0.319	0.468	0.622	0.756	0.89	1.021
281	0.035	0.172	0.32	0.469	0.623	0.76	0.894	1.026
280	0.035	0.172	0.32	0.47	0.625	0.762	0.897	1.03

279	0.034	0.172	0.321	0.472	0.627	0.765	0.9	1.033
278	0.033	0.171	0.321	0.473	0.628	0.766	0.903	1.036
277	0.032	0.171	0.321	0.474	0.63	0.769	0.906	1.04
276	0.031	0.171	0.322	0.474	0.632	0.77	0.909	1.043
275	0.03	0.17	0.322	0.475	0.633	0.773	0.912	1.048
274	0.029	0.17	0.322	0.476	0.635	0.775	0.914	1.051
273	0.028	0.169	0.322	0.476	0.636	0.777	0.917	1.054
272	0.026	0.168	0.322	0.477	0.637	0.779	0.919	1.056
271	0.025	0.168	0.321	0.477	0.638	0.78	0.921	1.059
270	0.024	0.167	0.322	0.478	0.639	0.782	0.924	1.062
269	0.022	0.166	0.321	0.478	0.639	0.783	0.925	1.064
268	0.021	0.165	0.32	0.477	0.64	0.784	0.926	1.066
267	0.02	0.164	0.32	0.478	0.64	0.784	0.928	1.068
266	0.019	0.163	0.32	0.478	0.641	0.785	0.929	1.069
265	0.018	0.163	0.32	0.478	0.641	0.786	0.93	1.071
264	0.017	0.163	0.32	0.478	0.642	0.787	0.931	1.072
263	0.017	0.162	0.32	0.479	0.643	0.788	0.932	1.074
262	0.017	0.163	0.32	0.48	0.644	0.791	0.934	1.076
261	0.017	0.163	0.321	0.48	0.645	0.791	0.935	1.077
260	0.017	0.163	0.322	0.481	0.646	0.792	0.937	1.078
259	0.018	0.164	0.323	0.482	0.648	0.794	0.939	1.08
258	0.018	0.165	0.324	0.484	0.65	0.796	0.941	1.082
257	0.02	0.167	0.326	0.485	0.651	0.797	0.943	1.084
256	0.021	0.168	0.327	0.487	0.653	0.8	0.945	1.086
255	0.022	0.17	0.329	0.49	0.656	0.802	0.947	1.089
254	0.024	0.172	0.332	0.492	0.658	0.805	0.951	1.092
253	0.027	0.175	0.334	0.495	0.661	0.808	0.953	1.095
252	0.029	0.177	0.337	0.498	0.664	0.811	0.956	1.098
251	0.032	0.181	0.34	0.502	0.668	0.816	0.961	1.102
250	0.036	0.184	0.345	0.506	0.672	0.82	0.965	1.107
249	0.04	0.189	0.349	0.511	0.677	0.825	0.971	1.112
248	0.044	0.193	0.354	0.515	0.682	0.83	0.976	1.117
247	0.048	0.198	0.359	0.52	0.688	0.836	0.981	1.123
246	0.052	0.202	0.364	0.526	0.693	0.842	0.988	1.13
245	0.057	0.208	0.369	0.532	0.7	0.849	0.995	1.137
244	0.061	0.213	0.375	0.539	0.707	0.857	1.003	1.146
243	0.066	0.219	0.382	0.546	0.715	0.866	1.013	1.156
242	0.072	0.225	0.389	0.554	0.725	0.876	1.024	1.168
241	0.077	0.232	0.397	0.563	0.734	0.886	1.036	1.181
240	0.083	0.239	0.405	0.572	0.745	0.898	1.049	1.196
239	0.089	0.246	0.414	0.582	0.757	0.912	1.064	1.213
238	0.095	0.254	0.423	0.593	0.77	0.926	1.081	1.232
237	0.102	0.262	0.433	0.605	0.784	0.943	1.1	1.254
236	0.108	0.271	0.444	0.618	0.8	0.962	1.121	1.278
235	0.115	0.28	0.455	0.632	0.815	0.98	1.142	1.303
234	0.122	0.289	0.466	0.645	0.832	1	1.165	1.329
233	0.129	0.298	0.478	0.659	0.849	1.021	1.188	1.356
232	0.136	0.308	0.49	0.674	0.867	1.042	1.213	1.384
231	0.145	0.319	0.503	0.689	0.885	1.065	1.238	1.413
230	0.153	0.329	0.515	0.704	0.903	1.085	1.261	1.44

229	0.162	0.34	0.528	0.719	0.92	1.106	1.285	1.468
228	0.171	0.351	0.541	0.735	0.938	1.126	1.307	1.493
227	0.185	0.367	0.559	0.755	0.961	1.152	1.336	1.525
226	0.2	0.383	0.577	0.775	0.983	1.176	1.362	1.555
225	0.215	0.4	0.595	0.795	1.005	1.2	1.388	1.585
224	0.233	0.419	0.616	0.817	1.028	1.227	1.415	1.615
223	0.252	0.44	0.638	0.841	1.054	1.252	1.443	1.644
222	0.274	0.463	0.663	0.867	1.081	1.281	1.472	1.676
221	0.299	0.49	0.69	0.896	1.112	1.313	1.505	1.71
220	0.33	0.522	0.724	0.931	1.148	1.35	1.543	1.749
219	0.368	0.562	0.765	0.973	1.192	1.394	1.588	1.796
218	0.416	0.611	0.815	1.025	1.244	1.447	1.641	1.85
217	0.476	0.671	0.877	1.087	1.308	1.51	1.708	1.921
216	0.552	0.749	0.955	1.167	1.389	1.59	1.787	2.008
215	0.632	0.829	1.037	1.25	1.473	1.674	1.874	2.09
214	0.727	0.925	1.133	1.346	1.57	1.771	1.967	2.189
213	0.838	1.036	1.245	1.457	1.682	1.882	2.075	2.295
212	0.968	1.166	1.377	1.588	1.812	2.013	2.2	2.424
211	1.117	1.315	1.527	1.738	1.958	2.156	2.341	2.569
210	1.282	1.479	1.688	1.9	2.117	2.313	2.491	2.698
209	1.454	1.651	1.857	2.065	2.279	2.476	2.662	2.85
208	1.665	1.859	2.063	2.267	2.483	2.66	2.842	3.032
207	1.93	2.119	2.313	2.506	2.699	2.904	3.056	3.213
206	2.201	2.381	2.571	2.736	2.942	3.122	3.244	3.393
205	2.401	2.577	2.742	2.924	3.082	3.257	3.398	3.606
204	2.514	2.702	2.863	3.036	3.206	3.281	3.567	3.753
203	2.572	2.732	2.921	3.067	3.188	3.36	3.554	3.744
202	2.599	2.77	2.888	3.101	3.257	3.364	3.522	3.733
201	2.607	2.756	2.923	3.076	3.162	3.347	3.46	3.681
200	2.604	2.76	2.909	3.096	3.185	3.36	3.426	3.543

nm	**240 mg/L**	**270 mg/L**	**300 mg/L**	**350 mg/L**	**400 mg/L**	**450 mg/L**	**500 mg/L**
800	0.564	0.618	0.688	0.768	0.847	0.926	1.004
799	0.565	0.623	0.693	0.773	0.852	0.931	1.009
798	0.564	0.626	0.696	0.776	0.855	0.933	1.011
797	0.565	0.626	0.696	0.776	0.855	0.933	1.011
796	0.563	0.619	0.689	0.769	0.848	0.927	1.005
795	0.562	0.622	0.692	0.772	0.851	0.929	1.007
794	0.562	0.627	0.697	0.777	0.856	0.935	1.013
793	0.562	0.629	0.699	0.779	0.858	0.937	1.015
792	0.564	0.627	0.697	0.777	0.856	0.935	1.013
791	0.565	0.626	0.696	0.776	0.855	0.934	1.012
790	0.566	0.626	0.696	0.776	0.855	0.934	1.012
789	0.567	0.627	0.697	0.777	0.856	0.934	1.012
788	0.567	0.627	0.697	0.777	0.856	0.934	1.012
787	0.568	0.627	0.697	0.777	0.856	0.935	1.013
786	0.568	0.628	0.698	0.778	0.857	0.935	1.013

785	0.568	0.628	0.698	0.778	0.857	0.935	1.013
784	0.57	0.629	0.699	0.779	0.858	0.937	1.015
783	0.569	0.629	0.699	0.779	0.858	0.937	1.015
782	0.571	0.63	0.7	0.78	0.859	0.938	1.016
781	0.571	0.631	0.701	0.781	0.86	0.939	1.017
780	0.571	0.631	0.701	0.781	0.86	0.939	1.017
779	0.572	0.63	0.7	0.78	0.859	0.938	1.016
778	0.572	0.631	0.701	0.781	0.86	0.939	1.017
777	0.573	0.631	0.701	0.781	0.86	0.939	1.017
776	0.573	0.632	0.702	0.782	0.861	0.94	1.018
775	0.574	0.633	0.703	0.783	0.862	0.941	1.019
774	0.575	0.633	0.703	0.783	0.862	0.941	1.019
773	0.576	0.634	0.704	0.784	0.863	0.942	1.02
772	0.576	0.635	0.705	0.785	0.864	0.943	1.021
771	0.577	0.635	0.705	0.785	0.864	0.943	1.021
770	0.577	0.636	0.706	0.786	0.865	0.944	1.022
769	0.578	0.637	0.707	0.787	0.866	0.945	1.023
768	0.578	0.638	0.708	0.788	0.867	0.946	1.024
767	0.579	0.638	0.708	0.788	0.867	0.946	1.024
766	0.579	0.639	0.709	0.789	0.868	0.947	1.025
765	0.58	0.64	0.71	0.79	0.869	0.948	1.026
764	0.581	0.64	0.71	0.79	0.869	0.948	1.026
763	0.581	0.641	0.711	0.791	0.87	0.949	1.027
762	0.582	0.642	0.712	0.792	0.871	0.95	1.028
761	0.583	0.643	0.713	0.793	0.872	0.951	1.029
760	0.584	0.644	0.714	0.794	0.873	0.952	1.03
759	0.585	0.644	0.714	0.794	0.873	0.952	1.03
758	0.585	0.645	0.715	0.795	0.874	0.953	1.031
757	0.586	0.646	0.716	0.796	0.875	0.954	1.032
756	0.587	0.647	0.717	0.797	0.876	0.955	1.033
755	0.588	0.648	0.718	0.798	0.877	0.956	1.034
754	0.588	0.648	0.718	0.798	0.877	0.956	1.034
753	0.589	0.649	0.719	0.799	0.878	0.957	1.035
752	0.59	0.65	0.72	0.8	0.879	0.958	1.036
751	0.591	0.651	0.721	0.801	0.88	0.959	1.037
750	0.591	0.651	0.721	0.801	0.88	0.959	1.037
749	0.592	0.652	0.722	0.802	0.881	0.96	1.038
748	0.593	0.653	0.723	0.803	0.882	0.961	1.039
747	0.593	0.654	0.724	0.804	0.883	0.962	1.04
746	0.594	0.654	0.724	0.804	0.883	0.962	1.04
745	0.595	0.655	0.725	0.805	0.884	0.963	1.041
744	0.596	0.656	0.726	0.806	0.885	0.964	1.042
743	0.596	0.657	0.727	0.807	0.886	0.965	1.043
742	0.597	0.658	0.728	0.808	0.887	0.966	1.044
741	0.598	0.658	0.728	0.808	0.887	0.966	1.044
740	0.599	0.659	0.729	0.809	0.888	0.967	1.045
739	0.599	0.66	0.73	0.81	0.889	0.968	1.046
738	0.6	0.661	0.731	0.811	0.89	0.969	1.047

737	0.601	0.662	0.732	0.812	0.891	0.97	1.048
736	0.602	0.663	0.733	0.813	0.892	0.971	1.049
735	0.603	0.663	0.733	0.813	0.892	0.971	1.049
734	0.604	0.664	0.734	0.814	0.893	0.972	1.05
733	0.605	0.666	0.736	0.816	0.895	0.974	1.052
732	0.606	0.667	0.737	0.817	0.896	0.975	1.053
731	0.607	0.668	0.738	0.818	0.897	0.976	1.054
730	0.608	0.669	0.739	0.819	0.898	0.977	1.055
729	0.609	0.67	0.74	0.82	0.899	0.978	1.056
728	0.61	0.672	0.742	0.822	0.901	0.98	1.058
727	0.611	0.673	0.743	0.823	0.902	0.981	1.059
726	0.613	0.675	0.745	0.825	0.904	0.983	1.061
725	0.614	0.676	0.746	0.826	0.905	0.984	1.062
724	0.616	0.678	0.748	0.828	0.907	0.986	1.064
723	0.617	0.679	0.749	0.829	0.908	0.987	1.065
722	0.618	0.681	0.751	0.831	0.91	0.989	1.067
721	0.62	0.682	0.752	0.832	0.911	0.99	1.068
720	0.621	0.684	0.754	0.834	0.913	0.992	1.07
719	0.623	0.685	0.755	0.835	0.914	0.993	1.071
718	0.624	0.687	0.757	0.837	0.916	0.995	1.073
717	0.626	0.689	0.759	0.839	0.918	0.997	1.075
716	0.628	0.691	0.761	0.841	0.92	0.999	1.077
715	0.63	0.693	0.763	0.843	0.922	1.001	1.079
714	0.632	0.696	0.766	0.846	0.925	1.004	1.082
713	0.634	0.698	0.768	0.848	0.927	1.006	1.084
712	0.636	0.7	0.77	0.85	0.929	1.008	1.086
711	0.639	0.703	0.773	0.853	0.932	1.011	1.089
710	0.641	0.706	0.776	0.856	0.935	1.014	1.092
709	0.644	0.708	0.778	0.858	0.937	1.016	1.094
708	0.646	0.712	0.782	0.862	0.941	1.02	1.098
707	0.65	0.715	0.785	0.865	0.944	1.023	1.101
706	0.653	0.718	0.788	0.868	0.947	1.026	1.104
705	0.656	0.722	0.792	0.872	0.951	1.03	1.108
704	0.659	0.725	0.795	0.875	0.954	1.033	1.111
703	0.662	0.729	0.799	0.879	0.958	1.037	1.115
702	0.666	0.733	0.803	0.883	0.962	1.041	1.119
701	0.67	0.737	0.807	0.887	0.966	1.045	1.123
700	0.674	0.742	0.812	0.892	0.971	1.05	1.128
699	0.678	0.747	0.817	0.897	0.976	1.055	1.133
698	0.684	0.753	0.823	0.903	0.982	1.061	1.139
697	0.689	0.76	0.83	0.91	0.989	1.067	1.145
696	0.696	0.767	0.837	0.917	0.996	1.074	1.152
695	0.703	0.775	0.845	0.925	1.004	1.083	1.161
694	0.711	0.784	0.854	0.934	1.013	1.092	1.17
693	0.72	0.795	0.865	0.945	1.024	1.102	1.18
692	0.73	0.806	0.876	0.956	1.035	1.113	1.191
691	0.739	0.816	0.886	0.966	1.045	1.124	1.202
690	0.749	0.827	0.897	0.977	1.056	1.135	1.213

689	0.759	0.839	0.909	0.989	1.068	1.146	1.224
688	0.769	0.851	0.921	1.001	1.08	1.158	1.236
687	0.778	0.861	0.931	1.011	1.09	1.168	1.246
686	0.787	0.871	0.941	1.021	1.1	1.179	1.257
685	0.794	0.88	0.95	1.03	1.109	1.187	1.265
684	0.799	0.886	0.956	1.036	1.115	1.194	1.272
683	0.803	0.891	0.961	1.041	1.12	1.198	1.276
682	0.805	0.893	0.963	1.043	1.122	1.201	1.279
681	0.805	0.893	0.963	1.043	1.122	1.201	1.279
680	0.804	0.893	0.963	1.043	1.122	1.2	1.278
679	0.802	0.891	0.961	1.041	1.12	1.199	1.277
678	0.8	0.888	0.958	1.038	1.117	1.196	1.274
677	0.796	0.884	0.954	1.034	1.113	1.192	1.27
676	0.792	0.88	0.95	1.03	1.109	1.187	1.265
675	0.788	0.875	0.945	1.025	1.104	1.183	1.261
674	0.784	0.871	0.941	1.021	1.1	1.178	1.256
673	0.78	0.866	0.936	1.016	1.095	1.174	1.252
672	0.776	0.862	0.932	1.012	1.091	1.169	1.247
671	0.772	0.857	0.927	1.007	1.086	1.164	1.242
670	0.767	0.852	0.922	1.002	1.081	1.159	1.237
669	0.762	0.846	0.916	0.996	1.075	1.153	1.231
668	0.758	0.841	0.911	0.991	1.07	1.148	1.226
667	0.753	0.835	0.905	0.985	1.064	1.142	1.22
666	0.748	0.83	0.9	0.98	1.059	1.137	1.215
665	0.743	0.824	0.894	0.974	1.053	1.132	1.21
664	0.739	0.82	0.89	0.97	1.049	1.127	1.205
663	0.735	0.815	0.885	0.965	1.044	1.123	1.201
662	0.732	0.811	0.881	0.961	1.04	1.119	1.197
661	0.729	0.808	0.878	0.958	1.037	1.116	1.194
660	0.727	0.805	0.875	0.955	1.034	1.113	1.191
659	0.725	0.803	0.873	0.953	1.032	1.111	1.189
658	0.723	0.801	0.871	0.951	1.03	1.109	1.187
657	0.722	0.8	0.87	0.95	1.029	1.108	1.186
656	0.721	0.799	0.869	0.949	1.028	1.107	1.185
655	0.721	0.799	0.869	0.949	1.028	1.106	1.184
654	0.721	0.799	0.869	0.949	1.028	1.106	1.184
653	0.721	0.799	0.869	0.949	1.028	1.107	1.185
652	0.722	0.8	0.87	0.95	1.029	1.107	1.185
651	0.723	0.801	0.871	0.951	1.03	1.108	1.186
650	0.724	0.802	0.872	0.952	1.031	1.109	1.187
649	0.725	0.803	0.873	0.953	1.032	1.111	1.189
648	0.727	0.805	0.875	0.955	1.034	1.113	1.191
647	0.729	0.807	0.877	0.957	1.036	1.115	1.193
646	0.731	0.81	0.88	0.96	1.039	1.117	1.195
645	0.733	0.812	0.882	0.962	1.041	1.12	1.198
644	0.735	0.814	0.884	0.964	1.043	1.122	1.2
643	0.738	0.817	0.887	0.967	1.046	1.125	1.203
642	0.74	0.819	0.889	0.969	1.048	1.127	1.205

641	0.742	0.822	0.892	0.972	1.051	1.129	1.207
640	0.744	0.824	0.894	0.974	1.053	1.132	1.21
639	0.746	0.826	0.896	0.976	1.055	1.134	1.212
638	0.748	0.829	0.899	0.979	1.058	1.136	1.214
637	0.75	0.831	0.901	0.981	1.06	1.139	1.217
636	0.752	0.833	0.903	0.983	1.062	1.141	1.219
635	0.754	0.835	0.905	0.985	1.064	1.143	1.221
634	0.755	0.837	0.907	0.987	1.066	1.145	1.223
633	0.757	0.838	0.908	0.988	1.067	1.146	1.224
632	0.758	0.84	0.91	0.99	1.069	1.147	1.225
631	0.758	0.841	0.911	0.991	1.07	1.148	1.226
630	0.759	0.841	0.911	0.991	1.07	1.149	1.227
629	0.76	0.842	0.912	0.992	1.071	1.149	1.227
628	0.76	0.842	0.912	0.992	1.071	1.15	1.228
627	0.76	0.843	0.913	0.993	1.072	1.15	1.228
626	0.76	0.843	0.913	0.993	1.072	1.15	1.228
625	0.76	0.842	0.912	0.992	1.071	1.15	1.228
624	0.76	0.842	0.912	0.992	1.071	1.149	1.227
623	0.759	0.841	0.911	0.991	1.07	1.149	1.227
622	0.758	0.84	0.91	0.99	1.069	1.148	1.226
621	0.757	0.84	0.91	0.99	1.069	1.147	1.225
620	0.756	0.838	0.908	0.988	1.067	1.146	1.224
619	0.755	0.837	0.907	0.987	1.066	1.144	1.222
618	0.753	0.835	0.905	0.985	1.064	1.143	1.221
617	0.752	0.833	0.903	0.983	1.062	1.141	1.219
616	0.75	0.832	0.902	0.982	1.061	1.139	1.217
615	0.748	0.829	0.899	0.979	1.058	1.137	1.215
614	0.746	0.827	0.897	0.977	1.056	1.135	1.213
613	0.744	0.824	0.894	0.974	1.053	1.132	1.21
612	0.742	0.822	0.892	0.972	1.051	1.129	1.207
611	0.74	0.82	0.89	0.97	1.049	1.127	1.205
610	0.738	0.817	0.887	0.967	1.046	1.125	1.203
609	0.736	0.815	0.885	0.965	1.044	1.123	1.201
608	0.734	0.813	0.883	0.963	1.042	1.121	1.199
607	0.732	0.811	0.881	0.961	1.04	1.119	1.197
606	0.73	0.809	0.879	0.959	1.038	1.117	1.195
605	0.729	0.807	0.877	0.957	1.036	1.115	1.193
604	0.728	0.805	0.875	0.955	1.034	1.113	1.191
603	0.726	0.804	0.874	0.954	1.033	1.112	1.19
602	0.725	0.803	0.873	0.953	1.032	1.111	1.189
601	0.724	0.802	0.872	0.952	1.031	1.11	1.188
600	0.724	0.802	0.872	0.952	1.031	1.109	1.187
599	0.723	0.801	0.871	0.951	1.03	1.109	1.187
598	0.723	0.8	0.87	0.95	1.029	1.108	1.186
597	0.722	0.8	0.87	0.95	1.029	1.108	1.186
596	0.722	0.799	0.869	0.949	1.028	1.107	1.185
595	0.721	0.798	0.868	0.948	1.027	1.105	1.183
594	0.72	0.797	0.867	0.947	1.026	1.104	1.182

593	0.719	0.796	0.866	0.946	1.025	1.104	1.182
592	0.719	0.795	0.865	0.945	1.024	1.103	1.181
591	0.719	0.795	0.865	0.945	1.024	1.103	1.181
590	0.718	0.794	0.864	0.944	1.023	1.101	1.179
589	0.717	0.793	0.863	0.943	1.022	1.101	1.179
588	0.717	0.792	0.862	0.942	1.021	1.1	1.178
587	0.716	0.791	0.861	0.941	1.02	1.099	1.177
586	0.715	0.791	0.861	0.941	1.02	1.099	1.177
585	0.714	0.79	0.86	0.94	1.019	1.098	1.176
584	0.714	0.789	0.859	0.939	1.018	1.097	1.175
583	0.713	0.788	0.858	0.938	1.017	1.096	1.174
582	0.713	0.788	0.858	0.938	1.017	1.096	1.174
581	0.712	0.787	0.857	0.937	1.016	1.095	1.173
580	0.712	0.786	0.856	0.936	1.015	1.094	1.172
579	0.711	0.785	0.855	0.935	1.014	1.093	1.171
578	0.71	0.785	0.855	0.935	1.014	1.093	1.171
577	0.71	0.784	0.854	0.934	1.013	1.092	1.17
576	0.709	0.784	0.854	0.934	1.013	1.092	1.17
575	0.709	0.783	0.853	0.933	1.012	1.091	1.169
574	0.708	0.782	0.852	0.932	1.011	1.09	1.168
573	0.708	0.781	0.851	0.931	1.01	1.089	1.167
572	0.707	0.78	0.85	0.93	1.009	1.088	1.166
571	0.706	0.78	0.85	0.93	1.009	1.088	1.166
570	0.706	0.779	0.849	0.929	1.008	1.087	1.165
569	0.706	0.779	0.849	0.929	1.008	1.087	1.165
568	0.705	0.778	0.848	0.928	1.007	1.086	1.164
567	0.705	0.778	0.848	0.928	1.007	1.086	1.164
566	0.705	0.777	0.847	0.927	1.006	1.085	1.163
565	0.705	0.777	0.847	0.927	1.006	1.085	1.163
564	0.705	0.777	0.847	0.927	1.006	1.085	1.163
563	0.705	0.777	0.847	0.927	1.006	1.085	1.163
562	0.705	0.777	0.847	0.927	1.006	1.085	1.163
561	0.705	0.777	0.847	0.927	1.006	1.085	1.163
560	0.705	0.777	0.847	0.927	1.006	1.085	1.163
559	0.705	0.777	0.847	0.927	1.006	1.085	1.163
558	0.705	0.777	0.847	0.927	1.006	1.085	1.163
557	0.706	0.778	0.848	0.928	1.007	1.086	1.164
556	0.706	0.778	0.848	0.928	1.007	1.086	1.164
555	0.707	0.778	0.848	0.928	1.007	1.086	1.164
554	0.707	0.779	0.849	0.929	1.008	1.087	1.165
553	0.708	0.78	0.85	0.93	1.009	1.088	1.166
552	0.709	0.781	0.851	0.931	1.01	1.089	1.167
551	0.709	0.781	0.851	0.931	1.01	1.089	1.167
550	0.711	0.783	0.853	0.933	1.012	1.091	1.169
549	0.712	0.784	0.854	0.934	1.013	1.092	1.17
548	0.713	0.785	0.855	0.935	1.014	1.093	1.171
547	0.714	0.786	0.856	0.936	1.015	1.094	1.172
546	0.715	0.788	0.858	0.938	1.017	1.096	1.174

545	0.717	0.789	0.859	0.939	1.018	1.097	1.175
544	0.719	0.791	0.861	0.941	1.02	1.099	1.177
543	0.72	0.793	0.863	0.943	1.022	1.101	1.179
542	0.722	0.795	0.865	0.945	1.024	1.103	1.181
541	0.724	0.797	0.867	0.947	1.026	1.105	1.183
540	0.725	0.799	0.869	0.949	1.028	1.107	1.185
539	0.727	0.801	0.871	0.951	1.03	1.109	1.187
538	0.729	0.803	0.873	0.953	1.032	1.111	1.189
537	0.731	0.805	0.875	0.955	1.034	1.113	1.191
536	0.733	0.807	0.877	0.957	1.036	1.115	1.193
535	0.736	0.81	0.88	0.96	1.039	1.118	1.196
534	0.738	0.813	0.883	0.963	1.042	1.121	1.199
533	0.74	0.815	0.885	0.965	1.044	1.123	1.201
532	0.743	0.818	0.888	0.968	1.047	1.126	1.204
531	0.746	0.821	0.891	0.971	1.05	1.129	1.207
530	0.748	0.824	0.894	0.974	1.053	1.132	1.21
529	0.751	0.828	0.898	0.978	1.057	1.135	1.213
528	0.754	0.83	0.9	0.98	1.059	1.138	1.216
527	0.757	0.833	0.903	0.983	1.062	1.141	1.219
526	0.759	0.836	0.906	0.986	1.065	1.144	1.222
525	0.762	0.839	0.909	0.989	1.068	1.147	1.225
524	0.764	0.842	0.912	0.992	1.071	1.15	1.228
523	0.767	0.845	0.915	0.995	1.074	1.153	1.231
522	0.77	0.848	0.918	0.998	1.077	1.156	1.234
521	0.772	0.851	0.921	1.001	1.08	1.159	1.237
520	0.775	0.854	0.924	1.004	1.083	1.162	1.24
519	0.778	0.857	0.927	1.007	1.086	1.165	1.243
518	0.78	0.86	0.93	1.01	1.089	1.168	1.246
517	0.783	0.863	0.933	1.013	1.092	1.17	1.248
516	0.785	0.865	0.935	1.015	1.094	1.173	1.251
515	0.787	0.868	0.938	1.018	1.097	1.175	1.253
514	0.789	0.87	0.94	1.02	1.099	1.178	1.256
513	0.792	0.873	0.943	1.023	1.102	1.181	1.259
512	0.795	0.876	0.946	1.026	1.105	1.184	1.262
511	0.798	0.879	0.949	1.029	1.108	1.187	1.265
510	0.8	0.883	0.953	1.033	1.112	1.19	1.268
509	0.803	0.886	0.956	1.036	1.115	1.193	1.271
508	0.806	0.889	0.959	1.039	1.118	1.196	1.274
507	0.809	0.892	0.962	1.042	1.121	1.2	1.278
506	0.812	0.895	0.965	1.045	1.124	1.203	1.281
505	0.815	0.899	0.969	1.049	1.128	1.206	1.284
504	0.817	0.902	0.972	1.052	1.131	1.209	1.287
503	0.82	0.905	0.975	1.055	1.134	1.213	1.291
502	0.822	0.908	0.978	1.058	1.137	1.215	1.293
501	0.825	0.91	0.98	1.06	1.139	1.218	1.296
500	0.827	0.913	0.983	1.063	1.142	1.22	1.298
499	0.829	0.915	0.985	1.065	1.144	1.222	1.3
498	0.83	0.917	0.987	1.067	1.146	1.224	1.302

497	0.832	0.919	0.989	1.069	1.148	1.226	1.304
496	0.834	0.921	0.991	1.071	1.15	1.228	1.306
495	0.835	0.922	0.992	1.072	1.151	1.23	1.308
494	0.837	0.924	0.994	1.074	1.153	1.231	1.309
493	0.838	0.925	0.995	1.075	1.154	1.233	1.311
492	0.839	0.927	0.997	1.077	1.156	1.234	1.312
491	0.84	0.928	0.998	1.078	1.157	1.235	1.313
490	0.841	0.929	0.999	1.079	1.158	1.237	1.315
489	0.842	0.931	1.001	1.081	1.16	1.238	1.316
488	0.843	0.932	1.002	1.082	1.161	1.239	1.317
487	0.845	0.933	1.003	1.083	1.162	1.24	1.318
486	0.845	0.934	1.004	1.084	1.163	1.241	1.319
485	0.846	0.934	1.004	1.084	1.163	1.242	1.32
484	0.847	0.935	1.005	1.085	1.164	1.243	1.321
483	0.848	0.936	1.006	1.086	1.165	1.244	1.322
482	0.849	0.937	1.007	1.087	1.166	1.245	1.323
481	0.85	0.939	1.009	1.089	1.168	1.246	1.324
480	0.851	0.94	1.01	1.09	1.169	1.247	1.325
479	0.852	0.941	1.011	1.091	1.17	1.248	1.326
478	0.853	0.942	1.012	1.092	1.171	1.25	1.328
477	0.855	0.944	1.014	1.094	1.173	1.251	1.329
476	0.856	0.945	1.015	1.095	1.174	1.252	1.33
475	0.857	0.947	1.017	1.097	1.176	1.254	1.332
474	0.859	0.949	1.019	1.099	1.178	1.256	1.334
473	0.86	0.95	1.02	1.1	1.179	1.257	1.335
472	0.862	0.952	1.022	1.102	1.181	1.259	1.337
471	0.864	0.954	1.024	1.104	1.183	1.261	1.339
470	0.866	0.956	1.026	1.106	1.185	1.264	1.342
469	0.868	0.958	1.028	1.108	1.187	1.266	1.344
468	0.87	0.961	1.031	1.111	1.19	1.268	1.346
467	0.872	0.963	1.033	1.113	1.192	1.271	1.349
466	0.875	0.966	1.036	1.116	1.195	1.273	1.351
465	0.877	0.968	1.038	1.118	1.197	1.275	1.353
464	0.879	0.971	1.041	1.121	1.2	1.278	1.356
463	0.881	0.973	1.043	1.123	1.202	1.28	1.358
462	0.884	0.976	1.046	1.126	1.205	1.283	1.361
461	0.887	0.98	1.05	1.13	1.209	1.287	1.365
460	0.89	0.983	1.053	1.133	1.212	1.29	1.368
459	0.893	0.987	1.057	1.137	1.216	1.294	1.372
458	0.897	0.991	1.061	1.141	1.22	1.298	1.376
457	0.901	0.995	1.065	1.145	1.224	1.303	1.381
456	0.906	1.001	1.071	1.151	1.23	1.308	1.386
455	0.911	1.007	1.077	1.157	1.236	1.314	1.392
454	0.917	1.013	1.083	1.163	1.242	1.32	1.398
453	0.923	1.019	1.089	1.169	1.248	1.327	1.405
452	0.929	1.027	1.097	1.177	1.256	1.334	1.412
451	0.936	1.035	1.105	1.185	1.264	1.342	1.42
450	0.944	1.043	1.113	1.193	1.272	1.351	1.429

449	0.951	1.053	1.123	1.203	1.282	1.36	1.438
448	0.961	1.062	1.132	1.212	1.291	1.37	1.448
447	0.969	1.072	1.142	1.222	1.301	1.38	1.458
446	0.976	1.081	1.151	1.231	1.31	1.389	1.467
445	0.984	1.09	1.16	1.24	1.319	1.398	1.476
444	0.989	1.098	1.168	1.248	1.327	1.405	1.483
443	0.996	1.103	1.173	1.253	1.332	1.41	1.488
442	0.998	1.107	1.177	1.257	1.336	1.415	1.493
441	1	1.11	1.18	1.26	1.339	1.417	1.495
440	1.001	1.111	1.181	1.261	1.34	1.418	1.496
439	1.001	1.111	1.181	1.261	1.34	1.418	1.496
438	1	1.11	1.18	1.26	1.339	1.417	1.495
437	0.998	1.108	1.178	1.258	1.337	1.416	1.494
436	0.994	1.104	1.174	1.254	1.333	1.411	1.489
435	0.992	1.1	1.17	1.25	1.329	1.408	1.486
434	0.988	1.097	1.167	1.247	1.326	1.405	1.483
433	0.985	1.093	1.163	1.243	1.322	1.401	1.479
432	0.982	1.089	1.159	1.239	1.318	1.397	1.475
431	0.979	1.086	1.156	1.236	1.315	1.394	1.472
430	0.977	1.083	1.153	1.233	1.312	1.391	1.469
429	0.975	1.081	1.151	1.231	1.31	1.389	1.467
428	0.973	1.079	1.149	1.229	1.308	1.386	1.464
427	0.971	1.077	1.147	1.227	1.306	1.385	1.463
426	0.97	1.074	1.144	1.224	1.303	1.382	1.46
425	0.969	1.073	1.143	1.223	1.302	1.381	1.459
424	0.968	1.073	1.143	1.223	1.302	1.38	1.458
423	0.968	1.072	1.142	1.222	1.301	1.379	1.457
422	0.967	1.071	1.141	1.221	1.3	1.379	1.457
421	0.966	1.071	1.141	1.221	1.3	1.378	1.456
420	0.965	1.069	1.139	1.219	1.298	1.377	1.455
419	0.963	1.068	1.138	1.218	1.297	1.376	1.454
418	0.963	1.066	1.136	1.216	1.295	1.374	1.452
417	0.961	1.064	1.134	1.214	1.293	1.372	1.45
416	0.959	1.062	1.132	1.212	1.291	1.37	1.448
415	0.957	1.06	1.13	1.21	1.289	1.368	1.446
414	0.954	1.057	1.127	1.207	1.286	1.365	1.443
413	0.951	1.053	1.123	1.203	1.282	1.361	1.439
412	0.948	1.05	1.12	1.2	1.279	1.357	1.435
411	0.946	1.047	1.117	1.197	1.276	1.354	1.432
410	0.943	1.044	1.114	1.194	1.273	1.351	1.429
409	0.94	1.039	1.109	1.189	1.268	1.347	1.425
408	0.936	1.036	1.106	1.186	1.265	1.343	1.421
407	0.933	1.032	1.102	1.182	1.261	1.34	1.418
406	0.931	1.03	1.1	1.18	1.259	1.338	1.416
405	0.928	1.027	1.097	1.177	1.256	1.334	1.412
404	0.926	1.024	1.094	1.174	1.253	1.332	1.41
403	0.923	1.021	1.091	1.171	1.25	1.328	1.406
402	0.921	1.018	1.088	1.168	1.247	1.326	1.404

401	0.92	1.016	1.086	1.166	1.245	1.324	1.402
400	0.919	1.015	1.085	1.165	1.244	1.322	1.4
399	0.919	1.014	1.084	1.164	1.243	1.321	1.399
398	0.918	1.014	1.084	1.164	1.243	1.321	1.399
397	0.917	1.013	1.083	1.163	1.242	1.32	1.398
396	0.918	1.013	1.083	1.163	1.242	1.321	1.399
395	0.918	1.012	1.082	1.162	1.241	1.32	1.398
394	0.917	1.013	1.083	1.163	1.242	1.32	1.398
393	0.918	1.012	1.082	1.162	1.241	1.32	1.398
392	0.917	1.013	1.083	1.163	1.242	1.32	1.398
391	0.917	1.013	1.083	1.163	1.242	1.32	1.398
390	0.918	1.013	1.083	1.163	1.242	1.32	1.398
389	0.918	1.013	1.083	1.163	1.242	1.321	1.399
388	0.918	1.013	1.083	1.163	1.242	1.321	1.399
387	0.919	1.014	1.084	1.164	1.243	1.321	1.399
386	0.918	1.014	1.084	1.164	1.243	1.321	1.399
385	0.919	1.014	1.084	1.164	1.243	1.322	1.4
384	0.919	1.013	1.083	1.163	1.242	1.321	1.399
383	0.919	1.013	1.083	1.163	1.242	1.321	1.399
382	0.92	1.012	1.082	1.162	1.241	1.32	1.398
381	0.919	1.012	1.082	1.162	1.241	1.319	1.397
380	0.867	0.954	1.024	1.104	1.183	1.262	1.34
379	0.869	0.954	1.024	1.104	1.183	1.262	1.34
378	0.87	0.958	1.028	1.108	1.187	1.265	1.343
377	0.868	0.957	1.027	1.107	1.186	1.265	1.343
376	0.86	0.951	1.021	1.101	1.18	1.259	1.337
375	0.864	0.947	1.017	1.097	1.176	1.255	1.333
374	0.869	0.946	1.016	1.096	1.175	1.254	1.332
373	0.867	0.944	1.014	1.094	1.173	1.251	1.329
372	0.866	0.942	1.012	1.092	1.171	1.25	1.328
371	0.863	0.943	1.013	1.093	1.172	1.25	1.328
370	0.865	0.942	1.012	1.092	1.171	1.25	1.328
369	0.866	0.943	1.013	1.093	1.172	1.251	1.329
368	0.866	0.942	1.012	1.092	1.171	1.25	1.328
367	0.865	0.942	1.012	1.092	1.171	1.25	1.328
366	0.863	0.943	1.013	1.093	1.172	1.25	1.328
365	0.865	0.944	1.014	1.094	1.173	1.251	1.329
364	0.863	0.943	1.013	1.093	1.172	1.251	1.329
363	0.865	0.944	1.014	1.094	1.173	1.251	1.329
362	0.862	0.943	1.013	1.093	1.172	1.25	1.328
361	0.86	0.944	1.014	1.094	1.173	1.252	1.33
360	0.864	0.943	1.013	1.093	1.172	1.25	1.328
359	0.862	0.944	1.014	1.094	1.173	1.252	1.33
358	0.864	0.947	1.017	1.097	1.176	1.255	1.333
357	0.866	0.945	1.015	1.095	1.174	1.253	1.331
356	0.866	0.947	1.017	1.097	1.176	1.255	1.333
355	0.866	0.945	1.015	1.095	1.174	1.253	1.331
354	0.867	0.946	1.016	1.096	1.175	1.254	1.332

353	0.869	0.945	1.015	1.095	1.174	1.253	1.331
352	0.871	0.947	1.017	1.097	1.176	1.255	1.333
351	0.871	0.951	1.021	1.101	1.18	1.259	1.337
350	0.873	0.951	1.021	1.101	1.18	1.258	1.336
349	0.873	0.953	1.023	1.103	1.182	1.261	1.339
348	0.877	0.956	1.026	1.106	1.185	1.264	1.342
347	0.878	0.958	1.028	1.108	1.187	1.266	1.344
346	0.88	0.96	1.03	1.11	1.189	1.268	1.346
345	0.881	0.963	1.033	1.113	1.192	1.271	1.349
344	0.883	0.964	1.034	1.114	1.193	1.272	1.35
343	0.885	0.965	1.035	1.115	1.194	1.272	1.35
342	0.884	0.964	1.034	1.114	1.193	1.272	1.35
341	0.887	0.965	1.035	1.115	1.194	1.273	1.351
340	0.888	0.968	1.038	1.118	1.197	1.276	1.354
339	0.888	0.969	1.039	1.119	1.198	1.276	1.354
338	0.889	0.969	1.039	1.119	1.198	1.277	1.355
337	0.89	0.97	1.04	1.12	1.199	1.278	1.356
336	0.89	0.97	1.04	1.12	1.199	1.278	1.356
335	0.889	0.971	1.041	1.121	1.2	1.279	1.357
334	0.889	0.97	1.04	1.12	1.199	1.277	1.355
333	0.892	0.971	1.041	1.121	1.2	1.278	1.356
332	0.892	0.972	1.042	1.122	1.201	1.28	1.358
331	0.893	0.97	1.04	1.12	1.199	1.278	1.356
330	0.893	0.971	1.041	1.121	1.2	1.278	1.356
329	0.893	0.969	1.039	1.119	1.198	1.277	1.355
328	0.892	0.969	1.039	1.119	1.198	1.276	1.354
327	0.892	0.969	1.039	1.119	1.198	1.277	1.355
326	0.892	0.97	1.04	1.12	1.199	1.278	1.356
325	0.893	0.969	1.039	1.119	1.198	1.277	1.355
324	0.894	0.972	1.042	1.122	1.201	1.28	1.358
323	0.894	0.972	1.042	1.122	1.201	1.28	1.358
322	0.893	0.974	1.044	1.124	1.203	1.281	1.359
321	0.894	0.974	1.044	1.124	1.203	1.281	1.359
320	0.895	0.974	1.044	1.124	1.203	1.282	1.36
319	0.899	0.974	1.044	1.124	1.203	1.282	1.36
318	0.9	0.976	1.046	1.126	1.205	1.284	1.362
317	0.899	0.977	1.047	1.127	1.206	1.285	1.363
316	0.901	0.977	1.047	1.127	1.206	1.285	1.363
315	0.903	0.981	1.051	1.131	1.21	1.289	1.367
314	0.905	0.98	1.05	1.13	1.209	1.288	1.366
313	0.908	0.981	1.051	1.131	1.21	1.289	1.367
312	0.907	0.982	1.052	1.132	1.211	1.29	1.368
311	0.911	0.985	1.055	1.135	1.214	1.293	1.371
310	0.909	0.986	1.056	1.136	1.215	1.294	1.372
309	0.914	0.986	1.056	1.136	1.215	1.294	1.372
308	0.916	0.992	1.062	1.142	1.221	1.3	1.378
307	0.916	0.995	1.065	1.145	1.224	1.303	1.381
306	0.921	0.998	1.068	1.148	1.227	1.306	1.384

305	0.923	1.001	1.071	1.151	1.23	1.308	1.386
304	0.927	1.005	1.075	1.155	1.234	1.313	1.391
303	0.929	1.006	1.076	1.156	1.235	1.314	1.392
302	0.931	1.007	1.077	1.157	1.236	1.314	1.392
301	0.933	1.008	1.078	1.158	1.237	1.316	1.394
300	1.024	1.125	1.195	1.275	1.354	1.433	1.511
299	1.03	1.13	1.2	1.28	1.359	1.438	1.516
298	1.034	1.135	1.205	1.285	1.364	1.443	1.521
297	1.04	1.14	1.24	1.35	1.45	1.529	1.628
296	1.046	1.148	1.248	1.358	1.458	1.56	1.659
295	1.054	1.157	1.257	1.367	1.467	1.569	1.668
294	1.063	1.167	1.267	1.377	1.477	1.579	1.678
293	1.071	1.176	1.276	1.386	1.486	1.588	1.687
292	1.078	1.186	1.286	1.396	1.496	1.598	1.697
291	1.085	1.195	1.295	1.405	1.505	1.607	1.706
290	1.091	1.202	1.302	1.412	1.512	1.614	1.713
289	1.099	1.21	1.31	1.42	1.52	1.622	1.721
288	1.107	1.22	1.32	1.43	1.53	1.632	1.731
287	1.115	1.228	1.328	1.438	1.538	1.64	1.739
286	1.123	1.237	1.337	1.447	1.547	1.649	1.748
285	1.13	1.246	1.346	1.456	1.556	1.658	1.757
284	1.138	1.253	1.353	1.463	1.563	1.665	1.764
283	1.144	1.26	1.36	1.47	1.57	1.672	1.771
282	1.149	1.267	1.367	1.477	1.577	1.679	1.778
281	1.154	1.272	1.372	1.482	1.582	1.684	1.783
280	1.159	1.278	1.378	1.488	1.588	1.69	1.789
279	1.163	1.283	1.383	1.493	1.593	1.695	1.794
278	1.167	1.289	1.389	1.499	1.599	1.701	1.8
277	1.171	1.294	1.394	1.504	1.604	1.706	1.805
276	1.175	1.296	1.396	1.506	1.606	1.708	1.807
275	1.18	1.302	1.402	1.512	1.612	1.714	1.813
274	1.183	1.307	1.407	1.517	1.617	1.719	1.818
273	1.187	1.311	1.411	1.521	1.621	1.723	1.822
272	1.191	1.316	1.416	1.526	1.626	1.728	1.827
271	1.195	1.32	1.42	1.53	1.63	1.732	1.831
270	1.197	1.325	1.425	1.535	1.635	1.737	1.836
269	1.2	1.328	1.428	1.538	1.638	1.74	1.839
268	1.202	1.33	1.43	1.54	1.64	1.742	1.841
267	1.204	1.332	1.432	1.542	1.642	1.744	1.843
266	1.207	1.335	1.435	1.545	1.645	1.747	1.846
265	1.209	1.336	1.436	1.546	1.646	1.748	1.847
264	1.21	1.337	1.437	1.547	1.647	1.749	1.848
263	1.212	1.34	1.44	1.55	1.65	1.752	1.851
262	1.214	1.342	1.442	1.552	1.652	1.754	1.853
261	1.216	1.344	1.444	1.554	1.654	1.756	1.855
260	1.218	1.346	1.446	1.556	1.656	1.758	1.857
259	1.22	1.348	1.448	1.558	1.658	1.76	1.859
258	1.221	1.35	1.45	1.56	1.66	1.762	1.861

257	1.222	1.353	1.453	1.563	1.663	1.765	1.864
256	1.225	1.354	1.454	1.564	1.664	1.766	1.865
255	1.227	1.356	1.456	1.566	1.666	1.768	1.867
254	1.231	1.358	1.458	1.568	1.668	1.77	1.869
253	1.234	1.361	1.461	1.571	1.671	1.773	1.872
252	1.237	1.365	1.465	1.575	1.675	1.777	1.876
251	1.241	1.369	1.469	1.579	1.679	1.781	1.88
250	1.246	1.374	1.474	1.584	1.684	1.786	1.885
249	1.251	1.378	1.478	1.588	1.688	1.79	1.889
248	1.257	1.384	1.484	1.594	1.694	1.796	1.895
247	1.263	1.389	1.489	1.599	1.699	1.801	1.9
246	1.269	1.397	1.497	1.607	1.707	1.809	1.908
245	1.278	1.406	1.506	1.616	1.716	1.818	1.917
244	1.287	1.416	1.516	1.626	1.726	1.828	1.927
243	1.298	1.428	1.528	1.638	1.738	1.84	1.939
242	1.311	1.44	1.54	1.65	1.75	1.852	1.951
241	1.326	1.455	1.555	1.665	1.765	1.867	1.966
240	1.342	1.473	1.573	1.683	1.783	1.885	1.984
239	1.36	1.495	1.595	1.705	1.805	1.907	2.006
238	1.381	1.518	1.618	1.728	1.828	1.93	2.029
237	1.406	1.547	1.647	1.757	1.857	1.959	2.058
236	1.433	1.576	1.676	1.786	1.886	1.988	2.087
235	1.462	1.609	1.709	1.819	1.919	2.021	2.12
234	1.492	1.642	1.742	1.852	1.952	2.054	2.153
233	1.523	1.676	1.776	1.886	1.986	2.088	2.187
232	1.555	1.713	1.813	1.923	2.023	2.125	2.224
231	1.589	1.75	1.85	1.96	2.06	2.162	2.261
230	1.62	1.788	1.888	1.998	2.098	2.2	2.299
229	1.651	1.821	1.921	2.031	2.131	2.233	2.332
228	1.681	1.854	1.954	2.064	2.164	2.266	2.365
227	1.717	1.895	1.995	2.105	2.205	2.307	2.406
226	1.75	1.931	2.031	2.141	2.241	2.343	2.442
225	1.78	1.965	2.065	2.175	2.275	2.377	2.476
224	1.812	2	2.1	2.21	2.31	2.412	2.511
223	1.845	2.035	2.135	2.245	2.345	2.447	2.546
222	1.881	2.076	2.176	2.286	2.386	2.488	2.587
221	1.918	2.116	2.216	2.326	2.426	2.528	2.627
220	1.961	2.167	2.267	2.377	2.477	2.579	2.678
219	2.012	2.218	2.318	2.428	2.528	2.63	2.729
218	2.067	2.278	2.378	2.488	2.588	2.69	2.789
217	2.138	2.347	2.447	2.557	2.657	2.759	2.858
216	2.228	2.436	2.536	2.646	2.746	2.848	2.947
215	2.305	2.518	2.618	2.728	2.828	2.93	3.029
214	2.4	2.632	2.732	2.842	2.942	3.044	3.143
213	2.509	2.719	2.819	2.929	3.029	3.131	3.23
212	2.646	2.829	2.929	3.039	3.139	3.241	3.34
211	2.821	2.961	3.061	3.171	3.271	3.373	3.472
210	2.952	3.124	3.224	3.334	3.434	3.536	3.635

209	3.078	3.234	3.334	3.444	3.544	3.646	3.745
208	3.232	3.503	3.603	3.713	3.813	3.915	4.014
207	3.316	3.8	3.9	4.01	4.11	4.212	4.311
206	3.473	3.863	3.963	4.073	4.173	4.275	4.374
205	3.647	3.808	3.908	4.018	4.118	4.22	4.319
204	3.528	3.599	3.699	3.809	3.909	4.011	4.11
203	3.652	3.682	3.782	3.892	3.992	4.094	4.193
202	3.841	3.784	3.884	3.994	4.094	4.196	4.295
201	3.999	3.928	4.028	4.138	4.238	4.34	4.439
200	3.822	4	4.1	4.21	4.31	4.412	4.511

Table A-4. The peak wavelengths and their absorbance values for the three regions of electromagnetic spectra were obtained from wavelength sensitivity analysis of *N. oculata*.

Concentration (mg/L)	**Wavelength (nm)**	**Color**	**ABS**
0 (SW)	265	UVC	0.018
	430	Blue/Violet	0.039
	680	Red	0.033
30	265	UVC	0.163
	430	Blue/Violet	0.148
	680	Red	0.129
60	265	UVC	0.319
	430	Blue/Violet	0.267
	680	Red	0.227
90	265	UVC	0.477
	430	Blue/Violet	0.39
	680	Red	0.327
120	265	UVC	0.641
	430	Blue/Violet	0.519
	680	Red	0.431
150	265	UVC	0.786
	430	Blue/Violet	0.633
	680	Red	0.522
180	265	UVC	0.929
	430	Blue/Violet	0.749
	680	Red	0.617
210	265	UVC	1.07
	430	Blue/Violet	0.864
	680	Red	0.711
240	265	UVC	1.209
	430	Blue/Violet	0.976
	680	Red	0.804
270	265	UVC	1.336
	430	Blue/Violet	1.083

	680	Red	0.892
300	265	UVC	1.436
	430	Blue/Violet	1.153
	680	Red	0.962
350	265	UVC	1.546
	430	Blue/Violet	1.233
	680	Red	1.042
400	265	UVC	1.646
	430	Blue/Violet	1.312
	680	Red	1.121
450	265	UVC	1.748
	430	Blue/Violet	1.39
	680	Red	1.2
500	265	UVC	1.847
	430	Blue/Violet	1.468
	680	Red	1.278

Table A-5. The results of the TSS measurements conducted in laboratory were used for wavelength sensitivity analysis of *I. galbana*.

SAMPLE	INITIAL WEIGHT (mg)	FINAL WEIGHT (mg)	Average Diff (mg)	Filter Type
Blank	1102.7	1102.7	0	GF/F
SW	1101.5	1103	1.5	GF/F
ISO	1103.3	1119	15.7	GF/F

Sample	Avg. Diff	Sample Vol. (mL)	TSS (mg/L)
Blank	0	20	0
SW	1.5	20	75
ISO	15.7	20	785
		Dry Wt	710

Table A-6. The different dilutions were used to obtain different microalgal concentrations in the range of 0-500 mg dry wt/L for *I. galbana*.

To prepare 150 mL volume target solutions		
Target Concentration(mg/L)	**Volume of Salt Water (mL)**	**Volume to be added from 710 mg/L (mL)**
30	143.6	6.3
60	137.3	12.6
90	130.9	19.0
120	124.6	25.3
150	118.3	31.6
180	111.9	38.0
210	105.6	44.3
240	99.2	50.7
270	92.9	57.0

300	86.6	63.3
350	76.0	73.9
400	65.4	84.5
450	54.9	95.0
500	44.3	105.6

Table A-7. The data from the scanning spectrophotometer was averaged for each microalgal concentration over the wavelength range 200-800 nm to determine the wavelength sensitivity of *I. galbana*.

nm	Salt water	30 mg/L	60 mg/L	90 mg/L	120 mg/L	150 mg/L	180 mg/L	210 mg/L
800	0.214	0.266	0.287	0.305	0.325	0.344	0.365	0.385
799	0.214	0.266	0.288	0.305	0.326	0.344	0.366	0.385
798	0.22	0.267	0.29	0.309	0.329	0.35	0.367	0.39
797	0.224	0.27	0.296	0.313	0.334	0.354	0.37	0.394
796	0.23	0.271	0.299	0.318	0.339	0.358	0.373	0.398
795	0.235	0.272	0.302	0.32	0.342	0.361	0.373	0.4
794	0.235	0.271	0.301	0.32	0.342	0.361	0.374	0.399
793	0.235	0.272	0.302	0.32	0.342	0.361	0.373	0.399
792	0.234	0.272	0.302	0.319	0.342	0.361	0.373	0.399
791	0.233	0.272	0.302	0.319	0.342	0.362	0.373	0.399
790	0.233	0.272	0.302	0.32	0.341	0.361	0.374	0.4
789	0.233	0.272	0.302	0.32	0.343	0.362	0.374	0.4
788	0.234	0.273	0.302	0.321	0.342	0.362	0.374	0.401
787	0.234	0.272	0.303	0.321	0.343	0.363	0.375	0.402
786	0.234	0.273	0.303	0.322	0.344	0.363	0.375	0.402
785	0.235	0.273	0.303	0.321	0.344	0.364	0.375	0.403
784	0.235	0.273	0.304	0.322	0.344	0.364	0.375	0.404
783	0.235	0.273	0.304	0.322	0.345	0.365	0.376	0.402
782	0.236	0.273	0.305	0.322	0.345	0.366	0.376	0.403
781	0.236	0.274	0.305	0.322	0.346	0.366	0.376	0.403
780	0.236	0.274	0.305	0.323	0.346	0.366	0.377	0.404
779	0.236	0.274	0.305	0.324	0.346	0.366	0.377	0.405
778	0.236	0.275	0.305	0.324	0.347	0.367	0.378	0.405
777	0.236	0.275	0.305	0.324	0.347	0.367	0.378	0.406
776	0.236	0.276	0.305	0.324	0.347	0.367	0.379	0.406
775	0.237	0.276	0.306	0.325	0.348	0.368	0.379	0.407
774	0.237	0.276	0.306	0.325	0.348	0.368	0.379	0.407
773	0.237	0.276	0.306	0.325	0.349	0.369	0.38	0.407
772	0.238	0.276	0.307	0.326	0.349	0.369	0.38	0.408
771	0.238	0.277	0.307	0.326	0.349	0.369	0.381	0.408
770	0.238	0.277	0.307	0.327	0.35	0.37	0.381	0.409
769	0.239	0.277	0.308	0.327	0.35	0.37	0.382	0.409
768	0.239	0.277	0.308	0.327	0.35	0.371	0.382	0.41
767	0.239	0.278	0.308	0.327	0.351	0.371	0.383	0.41
766	0.239	0.278	0.308	0.328	0.351	0.371	0.383	0.411
765	0.24	0.278	0.309	0.328	0.351	0.372	0.384	0.411
764	0.24	0.278	0.309	0.329	0.352	0.372	0.384	0.411
763	0.24	0.279	0.309	0.329	0.352	0.372	0.384	0.412

762	0.24	0.279	0.309	0.329	0.352	0.373	0.385	0.412
761	0.241	0.279	0.309	0.33	0.353	0.373	0.385	0.413
760	0.24	0.279	0.309	0.329	0.353	0.373	0.385	0.413
759	0.24	0.279	0.31	0.33	0.353	0.374	0.386	0.414
758	0.24	0.279	0.31	0.33	0.353	0.374	0.386	0.414
757	0.241	0.279	0.31	0.33	0.353	0.374	0.387	0.414
756	0.241	0.28	0.31	0.33	0.354	0.374	0.387	0.415
755	0.241	0.28	0.31	0.331	0.354	0.374	0.388	0.415
754	0.241	0.28	0.311	0.331	0.354	0.375	0.387	0.415
753	0.241	0.28	0.311	0.331	0.355	0.375	0.388	0.416
752	0.241	0.281	0.311	0.331	0.355	0.375	0.389	0.416
751	0.242	0.281	0.311	0.332	0.355	0.376	0.389	0.417
750	0.241	0.281	0.312	0.332	0.355	0.376	0.389	0.417
749	0.242	0.281	0.312	0.332	0.356	0.376	0.39	0.417
748	0.242	0.281	0.312	0.332	0.356	0.377	0.39	0.418
747	0.242	0.282	0.312	0.333	0.356	0.377	0.39	0.418
746	0.242	0.282	0.313	0.333	0.357	0.377	0.391	0.419
745	0.243	0.282	0.313	0.333	0.357	0.378	0.391	0.419
744	0.243	0.282	0.313	0.333	0.357	0.378	0.391	0.42
743	0.243	0.282	0.313	0.333	0.358	0.378	0.392	0.42
742	0.243	0.283	0.314	0.334	0.358	0.379	0.392	0.42
741	0.243	0.283	0.314	0.334	0.358	0.379	0.392	0.421
740	0.243	0.283	0.314	0.334	0.358	0.379	0.393	0.421
739	0.243	0.283	0.314	0.334	0.358	0.379	0.393	0.422
738	0.244	0.283	0.314	0.335	0.359	0.38	0.394	0.422
737	0.244	0.283	0.315	0.335	0.359	0.38	0.394	0.422
736	0.244	0.283	0.315	0.335	0.36	0.381	0.394	0.423
735	0.244	0.284	0.315	0.336	0.36	0.381	0.395	0.423
734	0.244	0.284	0.316	0.336	0.36	0.381	0.395	0.424
733	0.245	0.284	0.316	0.336	0.361	0.382	0.396	0.424
732	0.245	0.284	0.316	0.336	0.361	0.382	0.396	0.425
731	0.245	0.285	0.316	0.337	0.362	0.383	0.397	0.425
730	0.245	0.285	0.317	0.337	0.362	0.383	0.397	0.426
729	0.245	0.285	0.317	0.337	0.362	0.383	0.398	0.426
728	0.246	0.285	0.317	0.338	0.363	0.384	0.398	0.427
727	0.246	0.285	0.317	0.338	0.363	0.384	0.399	0.428
726	0.246	0.286	0.318	0.338	0.363	0.385	0.399	0.428
725	0.246	0.286	0.318	0.339	0.364	0.385	0.4	0.429
724	0.247	0.286	0.318	0.339	0.364	0.386	0.4	0.429
723	0.247	0.286	0.319	0.339	0.365	0.386	0.401	0.43
722	0.247	0.287	0.319	0.34	0.365	0.386	0.401	0.43
721	0.247	0.287	0.319	0.34	0.365	0.387	0.402	0.431
720	0.247	0.287	0.319	0.34	0.366	0.387	0.402	0.431
719	0.247	0.287	0.32	0.341	0.366	0.388	0.403	0.432
718	0.247	0.287	0.32	0.341	0.366	0.388	0.403	0.432
717	0.248	0.288	0.32	0.341	0.367	0.389	0.404	0.433
716	0.248	0.288	0.321	0.342	0.367	0.389	0.405	0.434
715	0.248	0.288	0.321	0.342	0.368	0.39	0.405	0.435
714	0.248	0.288	0.321	0.342	0.368	0.39	0.406	0.435
713	0.248	0.288	0.322	0.343	0.369	0.391	0.407	0.436

712	0.249	0.289	0.322	0.343	0.369	0.391	0.407	0.437
711	0.249	0.289	0.322	0.344	0.37	0.392	0.408	0.437
710	0.249	0.289	0.323	0.344	0.37	0.392	0.409	0.438
709	0.249	0.289	0.323	0.345	0.371	0.393	0.409	0.439
708	0.249	0.29	0.324	0.345	0.372	0.394	0.41	0.44
707	0.25	0.29	0.324	0.346	0.372	0.394	0.411	0.441
706	0.25	0.29	0.324	0.346	0.373	0.395	0.412	0.442
705	0.25	0.291	0.325	0.347	0.373	0.396	0.413	0.443
704	0.25	0.291	0.325	0.347	0.374	0.397	0.414	0.444
703	0.25	0.291	0.326	0.348	0.375	0.398	0.415	0.446
702	0.25	0.291	0.326	0.348	0.375	0.398	0.416	0.447
701	0.251	0.292	0.327	0.349	0.376	0.399	0.417	0.448
700	0.251	0.292	0.327	0.35	0.377	0.4	0.419	0.449
699	0.251	0.292	0.328	0.35	0.378	0.402	0.42	0.451
698	0.251	0.293	0.328	0.351	0.379	0.403	0.422	0.453
697	0.251	0.293	0.329	0.352	0.381	0.404	0.424	0.455
696	0.252	0.293	0.33	0.353	0.382	0.406	0.426	0.458
695	0.252	0.294	0.331	0.354	0.383	0.408	0.428	0.46
694	0.252	0.295	0.332	0.356	0.385	0.41	0.431	0.463
693	0.252	0.295	0.333	0.357	0.387	0.412	0.434	0.466
692	0.253	0.296	0.334	0.359	0.389	0.415	0.437	0.47
691	0.253	0.296	0.335	0.36	0.391	0.417	0.439	0.473
690	0.253	0.297	0.336	0.361	0.393	0.419	0.442	0.477
689	0.253	0.297	0.337	0.363	0.395	0.422	0.445	0.48
688	0.253	0.298	0.338	0.364	0.397	0.424	0.448	0.484
687	0.253	0.298	0.339	0.366	0.399	0.427	0.451	0.487
686	0.254	0.299	0.34	0.367	0.4	0.429	0.454	0.49
685	0.254	0.3	0.341	0.368	0.402	0.431	0.456	0.493
684	0.254	0.3	0.342	0.369	0.404	0.432	0.458	0.495
683	0.254	0.3	0.343	0.371	0.405	0.434	0.46	0.497
682	0.254	0.301	0.343	0.371	0.406	0.435	0.461	0.499
681	0.254	0.301	0.344	0.372	0.407	0.436	0.462	0.5
680	0.255	0.301	0.344	0.372	0.408	0.437	0.463	0.501
679	0.255	0.301	0.345	0.373	0.408	0.438	0.464	0.502
678	0.255	0.302	0.345	0.374	0.409	0.439	0.465	0.503
677	0.255	0.302	0.345	0.374	0.409	0.439	0.466	0.504
676	0.255	0.302	0.346	0.374	0.41	0.44	0.466	0.505
675	0.256	0.302	0.346	0.375	0.41	0.44	0.466	0.505
674	0.256	0.303	0.346	0.375	0.41	0.44	0.466	0.505
673	0.256	0.303	0.346	0.375	0.41	0.44	0.466	0.504
672	0.256	0.303	0.346	0.375	0.41	0.439	0.465	0.503
671	0.257	0.303	0.346	0.374	0.409	0.438	0.464	0.502
670	0.257	0.303	0.346	0.374	0.408	0.438	0.462	0.5
669	0.257	0.302	0.345	0.373	0.407	0.436	0.46	0.498
668	0.257	0.302	0.345	0.372	0.406	0.435	0.459	0.496
667	0.257	0.302	0.344	0.372	0.405	0.433	0.457	0.494
666	0.258	0.302	0.344	0.371	0.404	0.432	0.455	0.492
665	0.258	0.302	0.343	0.37	0.403	0.43	0.453	0.489
664	0.258	0.302	0.343	0.369	0.402	0.429	0.451	0.487
663	0.258	0.302	0.342	0.368	0.4	0.427	0.449	0.485

662	0.258	0.302	0.342	0.368	0.399	0.426	0.447	0.482
661	0.259	0.302	0.341	0.367	0.398	0.425	0.445	0.48
660	0.259	0.301	0.341	0.366	0.397	0.423	0.444	0.478
659	0.259	0.301	0.34	0.366	0.396	0.422	0.442	0.477
658	0.259	0.301	0.34	0.365	0.396	0.421	0.441	0.475
657	0.259	0.301	0.34	0.365	0.395	0.42	0.44	0.474
656	0.259	0.301	0.339	0.364	0.394	0.419	0.439	0.472
655	0.259	0.302	0.339	0.364	0.394	0.419	0.438	0.471
654	0.26	0.302	0.339	0.364	0.394	0.418	0.438	0.471
653	0.26	0.302	0.339	0.364	0.393	0.418	0.437	0.47
652	0.26	0.302	0.34	0.364	0.393	0.418	0.437	0.47
651	0.26	0.302	0.34	0.364	0.393	0.418	0.437	0.47
650	0.261	0.302	0.34	0.364	0.394	0.418	0.438	0.47
649	0.261	0.303	0.34	0.365	0.394	0.419	0.438	0.471
648	0.261	0.303	0.34	0.365	0.394	0.419	0.439	0.471
647	0.261	0.303	0.341	0.366	0.395	0.42	0.439	0.472
646	0.262	0.303	0.341	0.366	0.395	0.42	0.44	0.473
645	0.262	0.304	0.342	0.366	0.396	0.421	0.441	0.474
644	0.262	0.304	0.342	0.367	0.396	0.422	0.442	0.475
643	0.262	0.304	0.343	0.367	0.397	0.422	0.442	0.475
642	0.262	0.304	0.343	0.368	0.398	0.423	0.443	0.476
641	0.263	0.305	0.343	0.368	0.398	0.423	0.444	0.477
640	0.263	0.305	0.343	0.369	0.399	0.424	0.444	0.478
639	0.263	0.305	0.344	0.369	0.399	0.424	0.445	0.478
638	0.263	0.305	0.344	0.369	0.4	0.425	0.446	0.479
637	0.263	0.306	0.344	0.37	0.4	0.426	0.446	0.48
636	0.264	0.306	0.345	0.37	0.401	0.426	0.447	0.481
635	0.264	0.306	0.345	0.371	0.401	0.427	0.447	0.481
634	0.264	0.306	0.345	0.371	0.401	0.427	0.448	0.482
633	0.264	0.306	0.346	0.371	0.402	0.428	0.448	0.482
632	0.265	0.307	0.346	0.372	0.402	0.428	0.449	0.483
631	0.265	0.307	0.346	0.372	0.403	0.428	0.449	0.483
630	0.265	0.307	0.346	0.372	0.403	0.429	0.449	0.483
629	0.265	0.307	0.347	0.372	0.403	0.429	0.45	0.484
628	0.266	0.308	0.347	0.372	0.403	0.429	0.45	0.484
627	0.266	0.308	0.347	0.373	0.404	0.43	0.45	0.484
626	0.266	0.308	0.347	0.373	0.404	0.43	0.45	0.485
625	0.266	0.308	0.348	0.373	0.404	0.43	0.451	0.485
624	0.266	0.308	0.348	0.374	0.405	0.43	0.451	0.485
623	0.267	0.308	0.348	0.374	0.405	0.431	0.451	0.486
622	0.267	0.309	0.348	0.374	0.405	0.431	0.452	0.486
621	0.267	0.309	0.349	0.374	0.405	0.431	0.452	0.486
620	0.267	0.309	0.349	0.374	0.406	0.432	0.452	0.487
619	0.267	0.309	0.349	0.375	0.406	0.432	0.452	0.487
618	0.268	0.309	0.349	0.375	0.406	0.432	0.453	0.487
617	0.268	0.31	0.349	0.375	0.406	0.432	0.453	0.487
616	0.268	0.31	0.35	0.376	0.407	0.433	0.453	0.488
615	0.268	0.31	0.35	0.376	0.407	0.433	0.453	0.488
614	0.269	0.31	0.35	0.376	0.407	0.433	0.453	0.488
613	0.269	0.31	0.35	0.376	0.407	0.433	0.454	0.488

612	0.269	0.31	0.351	0.377	0.408	0.434	0.454	0.488
611	0.269	0.311	0.351	0.377	0.408	0.434	0.454	0.489
610	0.269	0.311	0.351	0.377	0.408	0.434	0.454	0.489
609	0.27	0.311	0.351	0.377	0.408	0.434	0.455	0.489
608	0.27	0.311	0.352	0.378	0.409	0.435	0.455	0.489
607	0.27	0.312	0.352	0.378	0.409	0.435	0.455	0.49
606	0.27	0.312	0.352	0.378	0.409	0.435	0.456	0.49
605	0.271	0.312	0.352	0.378	0.41	0.436	0.456	0.49
604	0.271	0.312	0.353	0.379	0.41	0.436	0.456	0.491
603	0.271	0.312	0.353	0.379	0.41	0.436	0.457	0.491
602	0.271	0.313	0.353	0.379	0.411	0.437	0.458	0.492
601	0.271	0.313	0.354	0.38	0.411	0.437	0.458	0.493
600	0.269	0.313	0.352	0.379	0.41	0.436	0.458	0.492
599	0.269	0.313	0.353	0.379	0.411	0.437	0.459	0.493
598	0.27	0.313	0.353	0.379	0.411	0.437	0.459	0.494
597	0.27	0.313	0.353	0.38	0.412	0.438	0.46	0.495
596	0.27	0.314	0.354	0.381	0.412	0.439	0.461	0.495
595	0.27	0.314	0.354	0.381	0.413	0.439	0.462	0.496
594	0.271	0.314	0.355	0.382	0.414	0.441	0.462	0.498
593	0.271	0.314	0.355	0.382	0.414	0.44	0.463	0.498
592	0.272	0.315	0.355	0.382	0.415	0.441	0.464	0.499
591	0.271	0.315	0.355	0.383	0.415	0.442	0.464	0.499
590	0.272	0.315	0.356	0.383	0.416	0.442	0.465	0.5
589	0.272	0.315	0.356	0.383	0.416	0.443	0.465	0.501
588	0.272	0.315	0.357	0.384	0.417	0.444	0.466	0.501
587	0.273	0.316	0.357	0.385	0.417	0.444	0.467	0.502
586	0.273	0.316	0.358	0.385	0.418	0.445	0.467	0.503
585	0.273	0.316	0.358	0.385	0.418	0.445	0.468	0.503
584	0.273	0.317	0.358	0.386	0.419	0.446	0.469	0.504
583	0.273	0.317	0.359	0.386	0.419	0.446	0.469	0.505
582	0.274	0.317	0.359	0.386	0.419	0.447	0.469	0.505
581	0.274	0.317	0.359	0.387	0.42	0.447	0.47	0.506
580	0.274	0.318	0.36	0.387	0.42	0.448	0.471	0.506
579	0.274	0.318	0.36	0.387	0.421	0.448	0.471	0.507
578	0.275	0.318	0.36	0.388	0.421	0.449	0.472	0.508
577	0.275	0.318	0.36	0.388	0.422	0.449	0.472	0.508
576	0.275	0.319	0.361	0.389	0.422	0.45	0.473	0.509
575	0.275	0.319	0.361	0.389	0.423	0.45	0.473	0.509
574	0.276	0.319	0.361	0.389	0.423	0.451	0.474	0.51
573	0.276	0.319	0.362	0.39	0.424	0.451	0.475	0.511
572	0.276	0.319	0.362	0.39	0.424	0.452	0.475	0.512
571	0.276	0.32	0.362	0.391	0.425	0.453	0.476	0.512
570	0.277	0.32	0.363	0.391	0.426	0.454	0.477	0.513
569	0.277	0.32	0.363	0.392	0.426	0.454	0.477	0.514
568	0.277	0.321	0.364	0.392	0.427	0.455	0.478	0.515
567	0.277	0.321	0.364	0.393	0.427	0.456	0.479	0.516
566	0.278	0.321	0.365	0.394	0.428	0.456	0.48	0.517
565	0.278	0.322	0.365	0.394	0.429	0.457	0.481	0.518
564	0.278	0.322	0.366	0.395	0.43	0.458	0.482	0.519
563	0.279	0.322	0.366	0.396	0.431	0.459	0.483	0.521

562	0.279	0.322	0.366	0.396	0.431	0.46	0.484	0.522
561	0.279	0.323	0.367	0.397	0.432	0.461	0.485	0.523
560	0.279	0.323	0.367	0.397	0.433	0.462	0.486	0.524
559	0.279	0.323	0.368	0.398	0.433	0.462	0.487	0.525
558	0.28	0.324	0.368	0.398	0.434	0.463	0.488	0.526
557	0.28	0.324	0.369	0.399	0.435	0.464	0.489	0.527
556	0.28	0.324	0.369	0.399	0.436	0.465	0.49	0.528
555	0.28	0.325	0.37	0.4	0.437	0.466	0.491	0.529
554	0.28	0.325	0.37	0.401	0.437	0.467	0.492	0.53
553	0.281	0.325	0.37	0.401	0.438	0.468	0.493	0.532
552	0.281	0.325	0.371	0.402	0.439	0.469	0.494	0.533
551	0.281	0.326	0.371	0.403	0.44	0.47	0.495	0.534
550	0.281	0.326	0.372	0.403	0.441	0.471	0.496	0.536
549	0.281	0.326	0.373	0.404	0.441	0.472	0.497	0.537
548	0.282	0.326	0.373	0.404	0.442	0.473	0.498	0.538
547	0.282	0.327	0.373	0.405	0.443	0.473	0.499	0.539
546	0.282	0.327	0.374	0.406	0.444	0.475	0.5	0.54
545	0.283	0.328	0.375	0.406	0.445	0.475	0.501	0.542
544	0.283	0.328	0.375	0.407	0.445	0.476	0.503	0.543
543	0.283	0.328	0.376	0.408	0.446	0.477	0.504	0.544
542	0.283	0.329	0.376	0.408	0.447	0.478	0.505	0.545
541	0.283	0.329	0.377	0.409	0.448	0.479	0.506	0.546
540	0.284	0.329	0.377	0.41	0.449	0.48	0.507	0.547
539	0.284	0.329	0.377	0.41	0.449	0.481	0.507	0.548
538	0.284	0.33	0.378	0.411	0.45	0.482	0.509	0.55
537	0.284	0.33	0.378	0.411	0.451	0.482	0.51	0.551
536	0.284	0.33	0.379	0.412	0.451	0.483	0.51	0.552
535	0.285	0.331	0.379	0.412	0.452	0.484	0.512	0.553
534	0.285	0.331	0.38	0.413	0.453	0.485	0.513	0.554
533	0.285	0.331	0.38	0.414	0.454	0.486	0.514	0.555
532	0.285	0.332	0.381	0.414	0.454	0.487	0.515	0.557
531	0.286	0.332	0.381	0.415	0.455	0.488	0.516	0.558
530	0.286	0.332	0.382	0.416	0.456	0.489	0.517	0.559
529	0.286	0.333	0.382	0.416	0.457	0.49	0.518	0.561
528	0.286	0.333	0.383	0.417	0.458	0.491	0.519	0.562
527	0.287	0.333	0.383	0.418	0.459	0.492	0.52	0.563
526	0.287	0.333	0.384	0.418	0.459	0.493	0.521	0.564
525	0.287	0.334	0.384	0.419	0.46	0.494	0.523	0.566
524	0.287	0.334	0.385	0.42	0.461	0.495	0.524	0.567
523	0.288	0.334	0.386	0.42	0.462	0.496	0.525	0.568
522	0.288	0.335	0.386	0.421	0.463	0.497	0.526	0.569
521	0.288	0.335	0.387	0.422	0.464	0.498	0.527	0.571
520	0.288	0.335	0.387	0.422	0.464	0.499	0.528	0.572
519	0.288	0.336	0.388	0.423	0.465	0.5	0.53	0.573
518	0.288	0.336	0.388	0.424	0.466	0.501	0.531	0.575
517	0.289	0.336	0.389	0.424	0.467	0.502	0.532	0.576
516	0.289	0.336	0.389	0.425	0.468	0.502	0.533	0.577
515	0.289	0.337	0.39	0.425	0.468	0.503	0.534	0.578
514	0.289	0.337	0.39	0.426	0.469	0.504	0.535	0.579
513	0.289	0.337	0.391	0.427	0.47	0.505	0.536	0.581

512	0.29	0.338	0.391	0.428	0.471	0.506	0.537	0.582
511	0.29	0.338	0.392	0.429	0.472	0.508	0.539	0.584
510	0.291	0.339	0.393	0.43	0.474	0.509	0.54	0.586
509	0.292	0.34	0.394	0.431	0.475	0.511	0.542	0.588
508	0.293	0.341	0.396	0.433	0.477	0.514	0.544	0.591
507	0.295	0.341	0.397	0.435	0.479	0.516	0.546	0.593
506	0.296	0.342	0.398	0.436	0.481	0.517	0.547	0.595
505	0.296	0.342	0.399	0.437	0.483	0.519	0.548	0.597
504	0.296	0.342	0.399	0.438	0.483	0.52	0.549	0.598
503	0.295	0.342	0.399	0.438	0.483	0.52	0.55	0.598
502	0.294	0.342	0.399	0.437	0.483	0.52	0.551	0.599
501	0.294	0.342	0.399	0.437	0.483	0.52	0.551	0.599
500	0.293	0.342	0.399	0.437	0.483	0.521	0.552	0.6
499	0.292	0.342	0.398	0.437	0.483	0.521	0.552	0.6
498	0.292	0.342	0.399	0.437	0.484	0.521	0.553	0.601
497	0.292	0.342	0.399	0.437	0.484	0.521	0.554	0.602
496	0.292	0.342	0.399	0.438	0.484	0.522	0.555	0.603
495	0.292	0.342	0.399	0.439	0.485	0.523	0.556	0.604
494	0.293	0.343	0.4	0.439	0.486	0.524	0.557	0.605
493	0.293	0.343	0.401	0.44	0.487	0.525	0.558	0.606
492	0.293	0.343	0.401	0.441	0.488	0.526	0.559	0.607
491	0.294	0.344	0.402	0.441	0.489	0.527	0.56	0.608
490	0.294	0.344	0.402	0.442	0.489	0.528	0.56	0.609
489	0.294	0.344	0.403	0.442	0.49	0.529	0.561	0.61
488	0.295	0.345	0.403	0.443	0.491	0.53	0.562	0.611
487	0.295	0.345	0.404	0.443	0.492	0.53	0.562	0.612
486	0.295	0.345	0.404	0.444	0.492	0.531	0.563	0.613
485	0.296	0.346	0.404	0.444	0.493	0.532	0.564	0.614
484	0.296	0.346	0.405	0.445	0.493	0.532	0.565	0.614
483	0.296	0.346	0.405	0.445	0.494	0.533	0.566	0.615
482	0.296	0.346	0.406	0.446	0.495	0.534	0.567	0.616
481	0.297	0.347	0.406	0.446	0.495	0.535	0.568	0.618
480	0.297	0.347	0.407	0.447	0.496	0.536	0.569	0.619
479	0.297	0.347	0.407	0.448	0.497	0.537	0.57	0.62
478	0.297	0.348	0.408	0.448	0.498	0.538	0.571	0.622
477	0.298	0.348	0.408	0.449	0.499	0.538	0.572	0.623
476	0.298	0.348	0.409	0.45	0.5	0.54	0.573	0.624
475	0.298	0.348	0.409	0.45	0.5	0.541	0.575	0.626
474	0.298	0.349	0.41	0.451	0.501	0.541	0.576	0.627
473	0.298	0.349	0.41	0.452	0.502	0.543	0.577	0.628
472	0.298	0.349	0.411	0.452	0.503	0.544	0.578	0.63
471	0.298	0.35	0.411	0.453	0.504	0.545	0.58	0.631
470	0.299	0.35	0.412	0.454	0.505	0.546	0.581	0.633
469	0.299	0.35	0.413	0.454	0.506	0.547	0.583	0.635
468	0.299	0.35	0.413	0.455	0.507	0.549	0.584	0.637
467	0.3	0.351	0.414	0.456	0.508	0.55	0.586	0.638
466	0.3	0.351	0.414	0.457	0.509	0.551	0.587	0.64
465	0.3	0.352	0.415	0.458	0.51	0.552	0.588	0.641
464	0.3	0.352	0.415	0.458	0.511	0.553	0.589	0.643
463	0.3	0.352	0.416	0.459	0.512	0.554	0.59	0.644

462	0.301	0.353	0.417	0.46	0.513	0.555	0.592	0.645
461	0.301	0.353	0.417	0.46	0.514	0.557	0.593	0.647
460	0.301	0.353	0.417	0.461	0.515	0.558	0.594	0.648
459	0.301	0.353	0.418	0.462	0.515	0.559	0.595	0.649
458	0.301	0.354	0.418	0.462	0.516	0.559	0.596	0.651
457	0.301	0.354	0.419	0.463	0.517	0.56	0.597	0.652
456	0.302	0.354	0.419	0.463	0.518	0.561	0.598	0.653
455	0.302	0.354	0.419	0.464	0.518	0.562	0.599	0.654
454	0.302	0.355	0.42	0.465	0.519	0.563	0.6	0.655
453	0.302	0.355	0.421	0.465	0.52	0.564	0.601	0.657
452	0.302	0.355	0.421	0.466	0.521	0.565	0.602	0.658
451	0.302	0.355	0.421	0.466	0.522	0.566	0.604	0.659
450	0.302	0.355	0.422	0.466	0.522	0.566	0.604	0.66
449	0.302	0.356	0.422	0.467	0.523	0.567	0.606	0.662
448	0.302	0.356	0.423	0.468	0.524	0.568	0.607	0.664
447	0.301	0.356	0.423	0.468	0.525	0.569	0.608	0.665
446	0.302	0.356	0.424	0.47	0.526	0.571	0.61	0.667
445	0.302	0.357	0.424	0.47	0.527	0.572	0.611	0.668
444	0.302	0.357	0.425	0.471	0.528	0.573	0.612	0.67
443	0.302	0.357	0.425	0.471	0.528	0.574	0.614	0.671
442	0.303	0.358	0.426	0.472	0.53	0.576	0.615	0.673
441	0.302	0.358	0.427	0.473	0.53	0.577	0.616	0.674
440	0.303	0.358	0.427	0.474	0.531	0.577	0.617	0.675
439	0.303	0.358	0.427	0.474	0.532	0.578	0.618	0.676
438	0.304	0.359	0.428	0.475	0.532	0.579	0.618	0.677
437	0.304	0.359	0.428	0.475	0.533	0.579	0.619	0.678
436	0.304	0.359	0.428	0.475	0.533	0.579	0.619	0.678
435	0.304	0.359	0.428	0.475	0.534	0.58	0.619	0.679
434	0.304	0.359	0.429	0.476	0.534	0.58	0.619	0.679
433	0.305	0.36	0.429	0.476	0.534	0.581	0.62	0.679
432	0.305	0.359	0.429	0.476	0.534	0.581	0.62	0.679
431	0.305	0.359	0.429	0.476	0.534	0.581	0.62	0.679
430	0.305	0.36	0.429	0.476	0.535	0.581	0.62	0.679
429	0.305	0.36	0.43	0.476	0.535	0.581	0.62	0.679
428	0.305	0.36	0.429	0.476	0.535	0.581	0.621	0.679
427	0.305	0.36	0.43	0.477	0.535	0.582	0.621	0.679
426	0.306	0.36	0.429	0.477	0.535	0.582	0.621	0.68
425	0.306	0.36	0.43	0.477	0.536	0.582	0.622	0.681
424	0.306	0.361	0.43	0.477	0.536	0.582	0.622	0.681
423	0.306	0.361	0.43	0.478	0.536	0.583	0.623	0.681
422	0.306	0.361	0.431	0.478	0.537	0.583	0.623	0.682
421	0.307	0.361	0.431	0.478	0.537	0.584	0.623	0.682
420	0.306	0.361	0.431	0.478	0.538	0.584	0.624	0.683
419	0.307	0.361	0.431	0.479	0.538	0.585	0.624	0.683
418	0.307	0.362	0.432	0.48	0.539	0.585	0.625	0.684
417	0.307	0.361	0.432	0.48	0.539	0.586	0.625	0.685
416	0.307	0.362	0.432	0.48	0.539	0.586	0.626	0.686
415	0.307	0.362	0.433	0.48	0.54	0.587	0.626	0.685
414	0.307	0.362	0.433	0.48	0.54	0.587	0.626	0.685
413	0.308	0.362	0.433	0.481	0.54	0.587	0.627	0.686

412	0.308	0.362	0.433	0.481	0.54	0.587	0.627	0.686
411	0.308	0.362	0.433	0.481	0.54	0.587	0.627	0.686
410	0.308	0.362	0.433	0.481	0.54	0.587	0.627	0.686
409	0.308	0.362	0.433	0.481	0.54	0.587	0.627	0.686
408	0.308	0.363	0.434	0.481	0.541	0.587	0.627	0.686
407	0.309	0.363	0.434	0.481	0.541	0.587	0.627	0.686
406	0.308	0.363	0.434	0.481	0.541	0.587	0.627	0.686
405	0.309	0.363	0.434	0.482	0.541	0.588	0.628	0.686
404	0.309	0.363	0.434	0.482	0.541	0.588	0.627	0.686
403	0.309	0.363	0.434	0.482	0.541	0.588	0.628	0.687
402	0.309	0.364	0.435	0.482	0.541	0.588	0.628	0.687
401	0.309	0.364	0.435	0.483	0.542	0.589	0.629	0.687
400	0.309	0.364	0.435	0.483	0.542	0.589	0.629	0.688
399	0.309	0.364	0.435	0.483	0.543	0.59	0.63	0.688
398	0.31	0.365	0.436	0.484	0.543	0.59	0.63	0.689
397	0.31	0.365	0.436	0.484	0.544	0.591	0.631	0.69
396	0.31	0.365	0.437	0.484	0.544	0.591	0.632	0.691
395	0.31	0.365	0.437	0.485	0.545	0.592	0.633	0.692
394	0.31	0.366	0.437	0.485	0.546	0.593	0.634	0.693
393	0.31	0.366	0.437	0.485	0.546	0.593	0.635	0.693
392	0.31	0.366	0.438	0.486	0.547	0.594	0.635	0.694
391	0.31	0.366	0.438	0.487	0.547	0.595	0.636	0.695
390	0.311	0.367	0.438	0.487	0.548	0.596	0.637	0.696
389	0.311	0.367	0.439	0.487	0.549	0.596	0.638	0.697
388	0.311	0.367	0.439	0.488	0.549	0.597	0.639	0.697
387	0.311	0.367	0.439	0.488	0.55	0.597	0.639	0.698
386	0.311	0.367	0.439	0.489	0.55	0.598	0.64	0.699
385	0.311	0.367	0.44	0.489	0.551	0.598	0.641	0.7
384	0.311	0.367	0.44	0.49	0.551	0.599	0.641	0.702
383	0.311	0.367	0.441	0.49	0.552	0.6	0.642	0.704
382	0.311	0.368	0.441	0.491	0.553	0.601	0.643	0.704
381	0.312	0.368	0.441	0.49	0.553	0.601	0.644	0.706
380	0.296	0.355	0.425	0.472	0.53	0.575	0.612	0.665
379	0.296	0.358	0.426	0.474	0.531	0.577	0.609	0.666
378	0.297	0.358	0.426	0.473	0.53	0.576	0.612	0.67
377	0.299	0.357	0.425	0.474	0.531	0.576	0.615	0.669
376	0.298	0.357	0.427	0.475	0.533	0.577	0.615	0.667
375	0.299	0.358	0.43	0.475	0.535	0.579	0.616	0.671
374	0.3	0.361	0.431	0.478	0.536	0.583	0.615	0.669
373	0.3	0.36	0.43	0.477	0.536	0.582	0.615	0.67
372	0.305	0.36	0.432	0.48	0.538	0.586	0.622	0.678
371	0.304	0.359	0.43	0.479	0.536	0.584	0.622	0.676
370	0.304	0.361	0.431	0.479	0.538	0.585	0.623	0.678
369	0.304	0.36	0.432	0.479	0.539	0.586	0.622	0.679
368	0.303	0.361	0.432	0.48	0.54	0.586	0.621	0.679
367	0.304	0.36	0.432	0.48	0.54	0.586	0.624	0.679
366	0.305	0.362	0.434	0.482	0.541	0.588	0.624	0.681
365	0.306	0.361	0.433	0.482	0.541	0.588	0.626	0.681
364	0.304	0.361	0.433	0.481	0.541	0.588	0.627	0.683
363	0.305	0.361	0.434	0.483	0.543	0.59	0.628	0.685

362	0.304	0.362	0.435	0.484	0.544	0.591	0.629	0.685
361	0.304	0.362	0.436	0.484	0.545	0.591	0.629	0.684
360	0.304	0.362	0.436	0.485	0.545	0.592	0.629	0.686
359	0.305	0.363	0.436	0.486	0.547	0.594	0.631	0.687
358	0.305	0.364	0.437	0.486	0.547	0.595	0.632	0.689
357	0.307	0.363	0.437	0.486	0.548	0.595	0.635	0.692
356	0.306	0.363	0.438	0.488	0.549	0.597	0.637	0.694
355	0.305	0.362	0.438	0.488	0.55	0.597	0.637	0.695
354	0.306	0.365	0.44	0.49	0.551	0.599	0.639	0.697
353	0.307	0.365	0.439	0.49	0.552	0.6	0.641	0.698
352	0.307	0.365	0.44	0.491	0.552	0.602	0.642	0.701
351	0.307	0.364	0.44	0.492	0.554	0.603	0.642	0.701
350	0.306	0.366	0.442	0.493	0.556	0.605	0.643	0.701
349	0.324	0.372	0.452	0.505	0.569	0.618	0.654	0.716
348	0.324	0.374	0.454	0.508	0.572	0.622	0.658	0.72
347	0.324	0.375	0.455	0.509	0.574	0.624	0.658	0.721
346	0.324	0.376	0.456	0.51	0.576	0.626	0.661	0.723
345	0.325	0.376	0.457	0.512	0.578	0.629	0.664	0.726
344	0.324	0.376	0.458	0.512	0.578	0.629	0.665	0.727
343	0.324	0.376	0.459	0.514	0.579	0.63	0.666	0.729
342	0.324	0.376	0.459	0.514	0.581	0.632	0.668	0.732
341	0.326	0.378	0.461	0.516	0.583	0.634	0.67	0.734
340	0.326	0.379	0.462	0.517	0.584	0.636	0.673	0.736
339	0.326	0.378	0.462	0.518	0.585	0.636	0.673	0.738
338	0.326	0.378	0.463	0.519	0.587	0.638	0.675	0.742
337	0.326	0.379	0.463	0.519	0.587	0.64	0.678	0.744
336	0.326	0.38	0.464	0.52	0.59	0.643	0.68	0.745
335	0.324	0.379	0.464	0.521	0.59	0.643	0.681	0.746
334	0.325	0.38	0.465	0.522	0.592	0.645	0.683	0.748
333	0.324	0.379	0.465	0.522	0.592	0.645	0.685	0.749
332	0.325	0.38	0.466	0.523	0.593	0.646	0.686	0.752
331	0.324	0.38	0.466	0.522	0.594	0.647	0.688	0.752
330	0.323	0.38	0.466	0.523	0.594	0.649	0.689	0.754
329	0.323	0.38	0.467	0.524	0.595	0.649	0.69	0.755
328	0.322	0.38	0.467	0.524	0.596	0.65	0.691	0.757
327	0.322	0.38	0.467	0.525	0.596	0.651	0.693	0.76
326	0.321	0.381	0.467	0.525	0.597	0.652	0.695	0.761
325	0.32	0.38	0.468	0.526	0.598	0.654	0.696	0.763
324	0.32	0.381	0.468	0.526	0.599	0.654	0.698	0.764
323	0.32	0.381	0.468	0.527	0.599	0.655	0.701	0.766
322	0.319	0.382	0.469	0.529	0.602	0.658	0.703	0.767
321	0.32	0.382	0.47	0.529	0.602	0.659	0.704	0.77
320	0.319	0.382	0.47	0.53	0.603	0.66	0.706	0.771
319	0.32	0.383	0.471	0.532	0.605	0.663	0.708	0.774
318	0.32	0.384	0.473	0.533	0.607	0.665	0.711	0.778
317	0.321	0.383	0.474	0.534	0.608	0.667	0.713	0.78
316	0.322	0.385	0.475	0.536	0.611	0.669	0.716	0.783
315	0.321	0.386	0.477	0.539	0.615	0.673	0.719	0.786
314	0.323	0.387	0.479	0.541	0.618	0.676	0.721	0.791
313	0.324	0.388	0.481	0.543	0.621	0.679	0.725	0.794

312	0.325	0.387	0.482	0.544	0.623	0.682	0.728	0.796
311	0.326	0.389	0.485	0.547	0.627	0.686	0.733	0.799
310	0.327	0.39	0.486	0.55	0.629	0.688	0.735	0.804
309	0.328	0.39	0.487	0.552	0.631	0.691	0.74	0.808
308	0.327	0.391	0.488	0.553	0.634	0.694	0.742	0.813
307	0.327	0.392	0.489	0.556	0.637	0.699	0.747	0.816
306	0.328	0.393	0.492	0.558	0.64	0.702	0.75	0.82
305	0.328	0.393	0.494	0.56	0.643	0.706	0.755	0.826
304	0.328	0.394	0.496	0.563	0.645	0.709	0.758	0.829
303	0.329	0.395	0.498	0.565	0.648	0.712	0.762	0.836
302	0.328	0.396	0.498	0.567	0.651	0.716	0.766	0.839
301	0.329	0.396	0.5	0.569	0.654	0.72	0.771	0.845
300	0.346	0.417	0.531	0.607	0.705	0.781	0.853	0.944
299	0.346	0.418	0.533	0.61	0.709	0.786	0.858	0.95
298	0.347	0.42	0.535	0.614	0.714	0.791	0.864	0.958
297	0.348	0.421	0.538	0.617	0.719	0.797	0.872	0.967
296	0.349	0.422	0.541	0.622	0.725	0.805	0.88	0.978
295	0.349	0.424	0.545	0.627	0.731	0.812	0.889	0.988
294	0.35	0.425	0.548	0.631	0.739	0.82	0.899	0.999
293	0.35	0.427	0.551	0.636	0.744	0.828	0.909	1.01
292	0.35	0.428	0.555	0.64	0.75	0.835	0.917	1.019
291	0.351	0.43	0.557	0.644	0.756	0.842	0.926	1.029
290	0.351	0.431	0.561	0.648	0.761	0.848	0.934	1.039
289	0.35	0.432	0.563	0.652	0.767	0.855	0.942	1.049
288	0.351	0.433	0.567	0.656	0.773	0.862	0.95	1.058
287	0.351	0.435	0.569	0.66	0.778	0.869	0.959	1.069
286	0.351	0.437	0.573	0.665	0.784	0.877	0.968	1.079
285	0.352	0.438	0.576	0.669	0.791	0.884	0.978	1.09
284	0.352	0.44	0.579	0.673	0.796	0.891	0.985	1.099
283	0.353	0.441	0.581	0.676	0.801	0.897	0.992	1.107
282	0.353	0.442	0.584	0.679	0.806	0.902	0.998	1.115
281	0.353	0.444	0.586	0.683	0.809	0.907	1.005	1.122
280	0.353	0.445	0.588	0.685	0.814	0.912	1.011	1.129
279	0.354	0.445	0.59	0.688	0.817	0.917	1.017	1.136
278	0.354	0.446	0.592	0.691	0.821	0.921	1.023	1.143
277	0.354	0.448	0.595	0.694	0.825	0.926	1.028	1.149
276	0.355	0.449	0.597	0.697	0.829	0.931	1.034	1.156
275	0.355	0.45	0.599	0.7	0.833	0.936	1.04	1.164
274	0.356	0.451	0.601	0.703	0.837	0.941	1.045	1.17
273	0.356	0.453	0.603	0.705	0.841	0.945	1.051	1.177
272	0.357	0.454	0.606	0.708	0.844	0.95	1.057	1.183
271	0.357	0.455	0.608	0.711	0.848	0.954	1.062	1.188
270	0.358	0.456	0.609	0.714	0.851	0.958	1.067	1.194
269	0.359	0.458	0.612	0.716	0.855	0.962	1.072	1.2
268	0.359	0.459	0.613	0.719	0.858	0.966	1.076	1.204
267	0.36	0.459	0.615	0.721	0.861	0.97	1.08	1.21
266	0.36	0.461	0.617	0.723	0.864	0.973	1.084	1.215
265	0.361	0.462	0.619	0.725	0.867	0.977	1.088	1.219
264	0.361	0.463	0.621	0.727	0.87	0.98	1.092	1.224
263	0.362	0.464	0.622	0.73	0.873	0.984	1.096	1.228

262	0.363	0.465	0.624	0.732	0.875	0.987	1.1	1.233
261	0.364	0.467	0.626	0.734	0.878	0.991	1.104	1.237
260	0.365	0.468	0.628	0.736	0.881	0.993	1.108	1.241
259	0.365	0.47	0.629	0.738	0.883	0.996	1.111	1.245
258	0.366	0.471	0.631	0.74	0.885	0.999	1.114	1.249
257	0.367	0.472	0.632	0.741	0.888	1.001	1.117	1.252
256	0.367	0.474	0.634	0.743	0.89	1.004	1.12	1.255
255	0.368	0.475	0.636	0.745	0.892	1.007	1.124	1.259
254	0.369	0.476	0.637	0.747	0.895	1.009	1.127	1.263
253	0.37	0.478	0.639	0.75	0.898	1.013	1.132	1.267
252	0.371	0.48	0.641	0.753	0.901	1.017	1.136	1.272
251	0.373	0.482	0.644	0.756	0.905	1.021	1.142	1.278
250	0.374	0.485	0.647	0.759	0.909	1.026	1.148	1.284
249	0.376	0.487	0.651	0.764	0.914	1.031	1.154	1.291
248	0.378	0.49	0.654	0.768	0.92	1.037	1.162	1.299
247	0.379	0.493	0.658	0.772	0.925	1.044	1.17	1.308
246	0.381	0.497	0.662	0.777	0.932	1.051	1.179	1.318
245	0.383	0.5	0.667	0.783	0.939	1.06	1.19	1.33
244	0.385	0.504	0.672	0.789	0.948	1.069	1.202	1.343
243	0.387	0.509	0.679	0.798	0.959	1.082	1.217	1.359
242	0.39	0.515	0.687	0.808	0.971	1.097	1.236	1.379
241	0.392	0.52	0.696	0.818	0.984	1.113	1.257	1.401
240	0.395	0.527	0.706	0.831	1.001	1.133	1.28	1.427
239	0.399	0.535	0.718	0.846	1.021	1.155	1.308	1.458
238	0.403	0.543	0.731	0.863	1.043	1.181	1.34	1.494
237	0.407	0.553	0.747	0.883	1.069	1.212	1.379	1.536
236	0.412	0.563	0.765	0.904	1.098	1.246	1.42	1.58
235	0.417	0.575	0.784	0.929	1.13	1.284	1.465	1.632
234	0.422	0.588	0.806	0.958	1.168	1.33	1.518	1.69
233	0.428	0.602	0.831	0.989	1.208	1.378	1.577	1.758
232	0.435	0.618	0.859	1.026	1.257	1.434	1.646	1.831
231	0.442	0.635	0.888	1.063	1.306	1.494	1.715	1.91
230	0.45	0.655	0.923	1.107	1.365	1.564	1.798	1.999
229	0.458	0.675	0.959	1.154	1.426	1.637	1.885	2.096
228	0.467	0.699	1.001	1.207	1.497	1.72	1.981	2.202
227	0.48	0.733	1.06	1.284	1.598	1.839	2.119	2.354
226	0.495	0.769	1.123	1.363	1.702	1.962	2.259	2.514
225	0.511	0.808	1.192	1.45	1.815	2.094	2.406	2.677
224	0.53	0.854	1.27	1.549	1.945	2.241	2.581	2.864
223	0.552	0.903	1.354	1.655	2.081	2.399	2.752	3.022
222	0.578	0.96	1.447	1.771	2.229	2.567	2.931	3.2
221	0.61	1.026	1.552	1.9	2.387	2.728	3.103	3.42
220	0.649	1.1	1.667	2.041	2.552	2.899	3.253	3.498
219	0.702	1.193	1.808	2.208	2.742	3.081	3.356	3.542
218	0.769	1.305	1.966	2.392	2.925	3.234	3.564	3.568
217	0.854	1.436	2.136	2.581	3.091	3.377	3.53	3.625
216	0.961	1.591	2.323	2.77	3.186	3.474	3.565	3.526
215	1.079	1.744	2.493	2.934	3.303	3.552	3.67	3.822
214	1.212	1.918	2.654	3.067	3.369	3.533	3.669	3.661
213	1.374	2.107	2.824	3.209	3.409	3.647	3.637	3.733

212	1.559	2.313	2.988	3.321	3.394	3.58	3.69	3.752
211	1.76	2.51	3.101	3.312	3.485	3.687	3.774	3.923
210	1.972	2.707	3.204	3.366	3.505	3.603	3.727	3.931
209	2.195	2.885	3.294	3.414	3.511	3.58	3.726	3.767
208	2.443	2.997	3.309	3.428	3.475	3.604	3.693	3.881
207	2.669	3.062	3.288	3.449	3.537	3.62	3.665	3.9
206	2.852	3.111	3.291	3.417	3.55	3.636	3.8	3.793
205	2.938	3.153	3.311	3.399	3.492	3.673	3.82	3.968
204	2.939	3.152	3.303	3.424	3.493	3.608	3.819	3.913
203	2.955	3.187	3.286	3.398	3.615	3.583	3.702	3.925
202	2.956	3.152	3.349	3.43	3.523	3.546	3.798	3.877
201	2.959	3.139	3.304	3.497	3.575	3.531	3.782	3.707
200	2.948	3.136	3.333	3.368	3.54	3.508	3.685	3.821

nm	**240 mg/L**	**270 mg/L**	**300 mg/L**	**350 mg/L**	**400 mg/L**	**450 mg/L**	**500 mg/L**
800	0.403	0.42	0.439	0.489	0.534	0.582	0.633
799	0.399	0.421	0.44	0.49	0.535	0.583	0.634
798	0.406	0.426	0.445	0.495	0.54	0.588	0.639
797	0.413	0.431	0.451	0.501	0.546	0.594	0.645
796	0.419	0.435	0.456	0.506	0.551	0.599	0.65
795	0.423	0.439	0.459	0.509	0.554	0.602	0.653
794	0.424	0.44	0.46	0.51	0.555	0.603	0.654
793	0.424	0.439	0.46	0.51	0.555	0.603	0.654
792	0.423	0.439	0.46	0.51	0.555	0.603	0.654
791	0.423	0.44	0.46	0.51	0.555	0.603	0.654
790	0.424	0.44	0.461	0.511	0.556	0.604	0.655
789	0.423	0.441	0.463	0.513	0.558	0.606	0.657
788	0.424	0.441	0.464	0.514	0.559	0.607	0.658
787	0.424	0.442	0.463	0.513	0.558	0.606	0.657
786	0.424	0.442	0.464	0.514	0.559	0.607	0.658
785	0.424	0.443	0.464	0.514	0.559	0.607	0.658
784	0.424	0.443	0.465	0.515	0.56	0.608	0.659
783	0.425	0.443	0.466	0.516	0.561	0.609	0.66
782	0.426	0.444	0.467	0.517	0.562	0.61	0.661
781	0.427	0.444	0.467	0.517	0.562	0.61	0.661
780	0.427	0.445	0.468	0.518	0.563	0.611	0.662
779	0.428	0.445	0.469	0.519	0.564	0.612	0.663
778	0.429	0.446	0.469	0.519	0.564	0.612	0.663
777	0.429	0.446	0.47	0.52	0.565	0.613	0.664
776	0.429	0.447	0.47	0.52	0.565	0.613	0.664
775	0.43	0.447	0.471	0.521	0.566	0.614	0.665
774	0.43	0.447	0.471	0.521	0.566	0.614	0.665
773	0.431	0.448	0.472	0.522	0.567	0.615	0.666
772	0.431	0.448	0.472	0.522	0.567	0.615	0.666
771	0.432	0.449	0.473	0.523	0.568	0.616	0.667
770	0.432	0.45	0.474	0.524	0.569	0.617	0.668
769	0.433	0.45	0.474	0.524	0.569	0.617	0.668

768	0.433	0.451	0.474	0.524	0.569	0.617	0.668
767	0.434	0.451	0.475	0.525	0.57	0.618	0.669
766	0.434	0.452	0.475	0.525	0.57	0.618	0.669
765	0.435	0.452	0.476	0.526	0.571	0.619	0.67
764	0.435	0.453	0.477	0.527	0.572	0.62	0.671
763	0.436	0.453	0.477	0.527	0.572	0.62	0.671
762	0.436	0.454	0.478	0.528	0.573	0.621	0.672
761	0.437	0.454	0.478	0.528	0.573	0.621	0.672
760	0.436	0.454	0.479	0.529	0.574	0.622	0.673
759	0.437	0.455	0.479	0.529	0.574	0.622	0.673
758	0.437	0.455	0.48	0.53	0.575	0.623	0.674
757	0.438	0.456	0.48	0.53	0.575	0.623	0.674
756	0.438	0.456	0.481	0.531	0.576	0.624	0.675
755	0.439	0.456	0.481	0.531	0.576	0.624	0.675
754	0.439	0.457	0.481	0.531	0.576	0.624	0.675
753	0.44	0.457	0.482	0.532	0.577	0.625	0.676
752	0.44	0.458	0.482	0.532	0.577	0.625	0.676
751	0.44	0.458	0.483	0.533	0.578	0.626	0.677
750	0.44	0.459	0.483	0.533	0.578	0.626	0.677
749	0.441	0.459	0.483	0.533	0.578	0.626	0.677
748	0.442	0.46	0.484	0.534	0.579	0.627	0.678
747	0.442	0.46	0.484	0.534	0.579	0.627	0.678
746	0.443	0.461	0.485	0.535	0.58	0.628	0.679
745	0.443	0.461	0.485	0.535	0.58	0.628	0.679
744	0.444	0.462	0.486	0.536	0.581	0.629	0.68
743	0.444	0.462	0.486	0.536	0.581	0.629	0.68
742	0.444	0.462	0.486	0.536	0.581	0.629	0.68
741	0.445	0.463	0.487	0.537	0.582	0.63	0.681
740	0.445	0.463	0.487	0.537	0.582	0.63	0.681
739	0.446	0.464	0.488	0.538	0.583	0.631	0.682
738	0.446	0.464	0.488	0.538	0.583	0.631	0.682
737	0.447	0.465	0.489	0.539	0.584	0.632	0.683
736	0.447	0.465	0.489	0.539	0.584	0.632	0.683
735	0.448	0.466	0.49	0.54	0.585	0.633	0.684
734	0.448	0.466	0.491	0.541	0.586	0.634	0.685
733	0.449	0.467	0.492	0.542	0.587	0.635	0.686
732	0.449	0.468	0.492	0.542	0.587	0.635	0.686
731	0.45	0.468	0.493	0.543	0.588	0.636	0.687
730	0.45	0.469	0.494	0.544	0.589	0.637	0.688
729	0.451	0.47	0.494	0.544	0.589	0.637	0.688
728	0.452	0.47	0.495	0.545	0.59	0.638	0.689
727	0.452	0.471	0.496	0.546	0.591	0.639	0.69
726	0.453	0.472	0.496	0.546	0.591	0.639	0.69
725	0.454	0.472	0.497	0.547	0.592	0.64	0.691
724	0.454	0.473	0.498	0.548	0.593	0.641	0.692
723	0.455	0.474	0.498	0.548	0.593	0.641	0.692
722	0.455	0.474	0.499	0.549	0.594	0.642	0.693
721	0.456	0.475	0.5	0.55	0.595	0.643	0.694

720	0.456	0.476	0.5	0.55	0.595	0.643	0.694
719	0.457	0.476	0.501	0.551	0.596	0.644	0.695
718	0.458	0.477	0.502	0.552	0.597	0.645	0.696
717	0.458	0.478	0.503	0.553	0.598	0.646	0.697
716	0.459	0.478	0.504	0.554	0.599	0.647	0.698
715	0.46	0.479	0.505	0.555	0.6	0.648	0.699
714	0.461	0.48	0.506	0.556	0.601	0.649	0.7
713	0.462	0.481	0.507	0.557	0.602	0.65	0.701
712	0.462	0.482	0.507	0.557	0.602	0.65	0.701
711	0.463	0.483	0.508	0.558	0.603	0.651	0.702
710	0.464	0.484	0.51	0.56	0.605	0.653	0.704
709	0.465	0.485	0.511	0.561	0.606	0.654	0.705
708	0.466	0.486	0.513	0.563	0.608	0.656	0.707
707	0.468	0.488	0.514	0.564	0.609	0.657	0.708
706	0.468	0.489	0.515	0.565	0.61	0.658	0.709
705	0.47	0.49	0.517	0.567	0.612	0.66	0.711
704	0.471	0.491	0.518	0.568	0.613	0.661	0.712
703	0.472	0.493	0.52	0.57	0.615	0.663	0.714
702	0.474	0.494	0.522	0.572	0.617	0.665	0.716
701	0.475	0.496	0.523	0.573	0.618	0.666	0.717
700	0.477	0.498	0.526	0.576	0.621	0.669	0.72
699	0.479	0.5	0.528	0.578	0.623	0.671	0.722
698	0.481	0.502	0.531	0.581	0.626	0.674	0.725
697	0.483	0.505	0.534	0.584	0.629	0.677	0.728
696	0.486	0.508	0.537	0.587	0.632	0.68	0.731
695	0.489	0.511	0.54	0.59	0.635	0.683	0.734
694	0.492	0.515	0.544	0.594	0.639	0.687	0.738
693	0.496	0.519	0.549	0.599	0.644	0.692	0.743
692	0.5	0.523	0.554	0.604	0.649	0.697	0.748
691	0.504	0.527	0.558	0.608	0.653	0.701	0.752
690	0.508	0.532	0.563	0.613	0.658	0.706	0.757
689	0.512	0.536	0.568	0.618	0.663	0.711	0.762
688	0.516	0.541	0.573	0.623	0.668	0.716	0.767
687	0.519	0.545	0.578	0.628	0.673	0.721	0.772
686	0.523	0.549	0.582	0.632	0.677	0.725	0.776
685	0.526	0.552	0.586	0.636	0.681	0.729	0.78
684	0.529	0.556	0.59	0.64	0.685	0.733	0.784
683	0.532	0.558	0.593	0.643	0.688	0.736	0.787
682	0.533	0.56	0.595	0.645	0.69	0.738	0.789
681	0.535	0.562	0.597	0.647	0.692	0.74	0.791
680	0.537	0.564	0.599	0.649	0.694	0.742	0.793
679	0.538	0.565	0.6	0.65	0.695	0.743	0.794
678	0.539	0.566	0.601	0.651	0.696	0.744	0.795
677	0.54	0.567	0.602	0.652	0.697	0.745	0.796
676	0.541	0.568	0.603	0.653	0.698	0.746	0.797
675	0.541	0.568	0.604	0.654	0.699	0.747	0.798
674	0.54	0.568	0.603	0.653	0.698	0.746	0.797
673	0.54	0.567	0.602	0.652	0.697	0.745	0.796

672	0.539	0.566	0.601	0.651	0.696	0.744	0.795
671	0.537	0.564	0.599	0.649	0.694	0.742	0.793
670	0.535	0.562	0.597	0.647	0.692	0.74	0.791
669	0.533	0.56	0.594	0.644	0.689	0.737	0.788
668	0.531	0.557	0.591	0.641	0.686	0.734	0.785
667	0.528	0.554	0.587	0.637	0.682	0.73	0.781
666	0.525	0.551	0.584	0.634	0.679	0.727	0.778
665	0.523	0.548	0.581	0.631	0.676	0.724	0.775
664	0.52	0.545	0.577	0.627	0.672	0.72	0.771
663	0.517	0.542	0.574	0.624	0.669	0.717	0.768
662	0.515	0.539	0.571	0.621	0.666	0.714	0.765
661	0.512	0.536	0.568	0.618	0.663	0.711	0.762
660	0.51	0.534	0.565	0.615	0.66	0.708	0.759
659	0.508	0.531	0.562	0.612	0.657	0.705	0.756
658	0.506	0.529	0.56	0.61	0.655	0.703	0.754
657	0.504	0.527	0.557	0.607	0.652	0.7	0.751
656	0.503	0.526	0.555	0.605	0.65	0.698	0.749
655	0.502	0.524	0.554	0.604	0.649	0.697	0.748
654	0.501	0.523	0.552	0.602	0.647	0.695	0.746
653	0.5	0.522	0.552	0.602	0.647	0.695	0.746
652	0.5	0.522	0.551	0.601	0.646	0.694	0.745
651	0.5	0.522	0.551	0.601	0.646	0.694	0.745
650	0.5	0.522	0.551	0.601	0.646	0.694	0.745
649	0.5	0.523	0.552	0.602	0.647	0.695	0.746
648	0.501	0.523	0.553	0.603	0.648	0.696	0.747
647	0.502	0.524	0.554	0.604	0.649	0.697	0.748
646	0.503	0.525	0.555	0.605	0.65	0.698	0.749
645	0.504	0.526	0.556	0.606	0.651	0.699	0.75
644	0.505	0.527	0.557	0.607	0.652	0.7	0.751
643	0.506	0.528	0.558	0.608	0.653	0.701	0.752
642	0.507	0.529	0.559	0.609	0.654	0.702	0.753
641	0.508	0.53	0.56	0.61	0.655	0.703	0.754
640	0.508	0.531	0.561	0.611	0.656	0.704	0.755
639	0.509	0.532	0.562	0.612	0.657	0.705	0.756
638	0.51	0.533	0.563	0.613	0.658	0.706	0.757
637	0.511	0.534	0.564	0.614	0.659	0.707	0.758
636	0.512	0.535	0.565	0.615	0.66	0.708	0.759
635	0.512	0.535	0.566	0.616	0.661	0.709	0.76
634	0.513	0.536	0.566	0.616	0.661	0.709	0.76
633	0.513	0.536	0.567	0.617	0.662	0.71	0.761
632	0.514	0.537	0.567	0.617	0.662	0.71	0.761
631	0.514	0.537	0.568	0.618	0.663	0.711	0.762
630	0.515	0.538	0.568	0.618	0.663	0.711	0.762
629	0.515	0.538	0.569	0.619	0.664	0.712	0.763
628	0.515	0.538	0.569	0.619	0.664	0.712	0.763
627	0.516	0.539	0.569	0.619	0.664	0.712	0.763
626	0.516	0.539	0.57	0.62	0.665	0.713	0.764
625	0.516	0.54	0.57	0.62	0.665	0.713	0.764

624	0.517	0.54	0.571	0.621	0.666	0.714	0.765
623	0.517	0.54	0.571	0.621	0.666	0.714	0.765
622	0.517	0.541	0.571	0.621	0.666	0.714	0.765
621	0.518	0.541	0.572	0.622	0.667	0.715	0.766
620	0.518	0.542	0.572	0.622	0.667	0.715	0.766
619	0.518	0.542	0.572	0.622	0.667	0.715	0.766
618	0.519	0.542	0.573	0.623	0.668	0.716	0.767
617	0.519	0.542	0.573	0.623	0.668	0.716	0.767
616	0.519	0.543	0.573	0.623	0.668	0.716	0.767
615	0.519	0.543	0.573	0.623	0.668	0.716	0.767
614	0.52	0.543	0.574	0.624	0.669	0.717	0.768
613	0.52	0.543	0.574	0.624	0.669	0.717	0.768
612	0.52	0.543	0.574	0.624	0.669	0.717	0.768
611	0.52	0.544	0.574	0.624	0.669	0.717	0.768
610	0.52	0.544	0.574	0.624	0.669	0.717	0.768
609	0.521	0.544	0.575	0.625	0.67	0.718	0.769
608	0.521	0.544	0.575	0.625	0.67	0.718	0.769
607	0.521	0.545	0.575	0.625	0.67	0.718	0.769
606	0.522	0.545	0.575	0.625	0.67	0.718	0.769
605	0.522	0.546	0.576	0.626	0.671	0.719	0.77
604	0.522	0.546	0.576	0.626	0.671	0.719	0.77
603	0.523	0.547	0.577	0.627	0.672	0.72	0.771
602	0.524	0.547	0.578	0.628	0.673	0.721	0.772
601	0.524	0.548	0.578	0.628	0.673	0.721	0.772
600	0.523	0.547	0.577	0.627	0.672	0.72	0.771
599	0.524	0.548	0.579	0.629	0.674	0.722	0.773
598	0.525	0.549	0.579	0.629	0.674	0.722	0.773
597	0.526	0.55	0.581	0.631	0.676	0.724	0.775
596	0.527	0.551	0.582	0.632	0.677	0.725	0.776
595	0.527	0.551	0.582	0.632	0.677	0.725	0.776
594	0.529	0.553	0.584	0.634	0.679	0.727	0.778
593	0.529	0.554	0.585	0.635	0.68	0.728	0.779
592	0.53	0.555	0.586	0.636	0.681	0.729	0.78
591	0.531	0.555	0.586	0.636	0.681	0.729	0.78
590	0.532	0.557	0.588	0.638	0.683	0.731	0.782
589	0.532	0.557	0.588	0.638	0.683	0.731	0.782
588	0.533	0.558	0.59	0.64	0.685	0.733	0.784
587	0.534	0.559	0.591	0.641	0.686	0.734	0.785
586	0.535	0.56	0.592	0.642	0.687	0.735	0.786
585	0.536	0.561	0.592	0.642	0.687	0.735	0.786
584	0.536	0.561	0.593	0.643	0.688	0.736	0.787
583	0.537	0.562	0.594	0.644	0.689	0.737	0.788
582	0.537	0.562	0.594	0.644	0.689	0.737	0.788
581	0.538	0.563	0.595	0.645	0.69	0.738	0.789
580	0.538	0.564	0.596	0.646	0.691	0.739	0.79
579	0.539	0.564	0.596	0.646	0.691	0.739	0.79
578	0.54	0.565	0.597	0.647	0.692	0.74	0.791
577	0.54	0.566	0.598	0.648	0.693	0.741	0.792

576	0.541	0.567	0.599	0.649	0.694	0.742	0.793
575	0.542	0.567	0.599	0.649	0.694	0.742	0.793
574	0.542	0.568	0.6	0.65	0.695	0.743	0.794
573	0.544	0.569	0.601	0.651	0.696	0.744	0.795
572	0.544	0.57	0.602	0.652	0.697	0.745	0.796
571	0.545	0.571	0.603	0.653	0.698	0.746	0.797
570	0.546	0.572	0.604	0.654	0.699	0.747	0.798
569	0.547	0.573	0.606	0.656	0.701	0.749	0.8
568	0.548	0.574	0.607	0.657	0.702	0.75	0.801
567	0.55	0.575	0.608	0.658	0.703	0.751	0.802
566	0.551	0.577	0.61	0.66	0.705	0.753	0.804
565	0.552	0.578	0.611	0.661	0.706	0.754	0.805
564	0.553	0.58	0.613	0.663	0.708	0.756	0.807
563	0.555	0.581	0.614	0.664	0.709	0.757	0.808
562	0.556	0.582	0.616	0.666	0.711	0.759	0.81
561	0.557	0.584	0.618	0.668	0.713	0.761	0.812
560	0.558	0.585	0.619	0.669	0.714	0.762	0.813
559	0.559	0.587	0.62	0.67	0.715	0.763	0.814
558	0.56	0.588	0.622	0.672	0.717	0.765	0.816
557	0.562	0.589	0.623	0.673	0.718	0.766	0.817
556	0.563	0.59	0.624	0.674	0.719	0.767	0.818
555	0.564	0.592	0.626	0.676	0.721	0.769	0.82
554	0.566	0.594	0.628	0.678	0.723	0.771	0.822
553	0.567	0.595	0.63	0.68	0.725	0.773	0.824
552	0.569	0.597	0.631	0.681	0.726	0.774	0.825
551	0.57	0.598	0.633	0.683	0.728	0.776	0.827
550	0.572	0.6	0.635	0.685	0.73	0.778	0.829
549	0.573	0.601	0.636	0.686	0.731	0.779	0.83
548	0.574	0.603	0.638	0.688	0.733	0.781	0.832
547	0.576	0.604	0.639	0.689	0.734	0.782	0.833
546	0.577	0.606	0.641	0.691	0.736	0.784	0.835
545	0.578	0.607	0.643	0.693	0.738	0.786	0.837
544	0.58	0.609	0.645	0.695	0.74	0.788	0.839
543	0.581	0.611	0.646	0.696	0.741	0.789	0.84
542	0.583	0.612	0.648	0.698	0.743	0.791	0.842
541	0.584	0.613	0.65	0.7	0.745	0.793	0.844
540	0.585	0.615	0.651	0.701	0.746	0.794	0.845
539	0.586	0.616	0.652	0.702	0.747	0.795	0.846
538	0.588	0.618	0.654	0.704	0.749	0.797	0.848
537	0.589	0.619	0.655	0.705	0.75	0.798	0.849
536	0.59	0.62	0.657	0.707	0.752	0.8	0.851
535	0.592	0.622	0.658	0.708	0.753	0.801	0.852
534	0.593	0.623	0.66	0.71	0.755	0.803	0.854
533	0.594	0.625	0.662	0.712	0.757	0.805	0.856
532	0.595	0.626	0.663	0.713	0.758	0.806	0.857
531	0.597	0.628	0.665	0.715	0.76	0.808	0.859
530	0.598	0.629	0.667	0.717	0.762	0.81	0.861
529	0.6	0.631	0.669	0.719	0.764	0.812	0.863

528	0.601	0.633	0.67	0.72	0.765	0.813	0.864
527	0.603	0.634	0.672	0.722	0.767	0.815	0.866
526	0.604	0.636	0.674	0.724	0.769	0.817	0.868
525	0.606	0.637	0.675	0.725	0.77	0.818	0.869
524	0.607	0.639	0.677	0.727	0.772	0.82	0.871
523	0.609	0.64	0.678	0.728	0.773	0.821	0.872
522	0.61	0.642	0.68	0.73	0.775	0.823	0.874
521	0.612	0.644	0.682	0.732	0.777	0.825	0.876
520	0.613	0.645	0.684	0.734	0.779	0.827	0.878
519	0.615	0.647	0.686	0.736	0.781	0.829	0.88
518	0.616	0.649	0.688	0.738	0.783	0.831	0.882
517	0.617	0.65	0.689	0.739	0.784	0.832	0.883
516	0.618	0.651	0.69	0.74	0.785	0.833	0.884
515	0.62	0.653	0.692	0.742	0.787	0.835	0.886
514	0.621	0.654	0.694	0.744	0.789	0.837	0.888
513	0.623	0.656	0.696	0.746	0.791	0.839	0.89
512	0.624	0.658	0.697	0.747	0.792	0.84	0.891
511	0.626	0.66	0.7	0.75	0.795	0.843	0.894
510	0.628	0.662	0.702	0.752	0.797	0.845	0.896
509	0.631	0.665	0.705	0.755	0.8	0.848	0.899
508	0.634	0.668	0.708	0.758	0.803	0.851	0.902
507	0.636	0.671	0.711	0.761	0.806	0.854	0.905
506	0.639	0.673	0.714	0.764	0.809	0.857	0.908
505	0.641	0.676	0.717	0.767	0.812	0.86	0.911
504	0.642	0.677	0.719	0.769	0.814	0.862	0.913
503	0.642	0.678	0.72	0.77	0.815	0.863	0.914
502	0.643	0.678	0.72	0.77	0.815	0.863	0.914
501	0.643	0.679	0.721	0.771	0.816	0.864	0.915
500	0.644	0.679	0.721	0.771	0.816	0.864	0.915
499	0.644	0.68	0.722	0.772	0.817	0.865	0.916
498	0.645	0.681	0.724	0.774	0.819	0.867	0.918
497	0.646	0.682	0.725	0.775	0.82	0.868	0.919
496	0.647	0.683	0.726	0.776	0.821	0.869	0.92
495	0.648	0.684	0.727	0.777	0.822	0.87	0.921
494	0.65	0.686	0.729	0.779	0.824	0.872	0.923
493	0.651	0.688	0.731	0.781	0.826	0.874	0.925
492	0.652	0.689	0.732	0.782	0.827	0.875	0.926
491	0.653	0.69	0.733	0.783	0.828	0.876	0.927
490	0.655	0.691	0.735	0.785	0.83	0.878	0.929
489	0.656	0.693	0.736	0.786	0.831	0.879	0.93
488	0.657	0.694	0.737	0.787	0.832	0.88	0.931
487	0.658	0.695	0.739	0.789	0.834	0.882	0.933
486	0.659	0.696	0.74	0.79	0.835	0.883	0.934
485	0.66	0.697	0.741	0.791	0.836	0.884	0.935
484	0.661	0.698	0.742	0.792	0.837	0.885	0.936
483	0.662	0.699	0.743	0.793	0.838	0.886	0.937
482	0.663	0.701	0.745	0.795	0.84	0.888	0.939
481	0.664	0.702	0.746	0.796	0.841	0.889	0.94

480	0.666	0.703	0.748	0.798	0.843	0.891	0.942
479	0.667	0.705	0.75	0.8	0.845	0.893	0.944
478	0.669	0.707	0.752	0.802	0.847	0.895	0.946
477	0.67	0.708	0.753	0.803	0.848	0.896	0.947
476	0.672	0.71	0.755	0.805	0.85	0.898	0.949
475	0.673	0.712	0.757	0.807	0.852	0.9	0.951
474	0.675	0.714	0.759	0.809	0.854	0.902	0.953
473	0.676	0.715	0.761	0.811	0.856	0.904	0.955
472	0.678	0.717	0.763	0.813	0.858	0.906	0.957
471	0.68	0.719	0.765	0.815	0.86	0.908	0.959
470	0.682	0.721	0.768	0.818	0.863	0.911	0.962
469	0.684	0.724	0.77	0.82	0.865	0.913	0.964
468	0.686	0.726	0.772	0.822	0.867	0.915	0.966
467	0.688	0.728	0.775	0.825	0.87	0.918	0.969
466	0.69	0.73	0.777	0.827	0.872	0.92	0.971
465	0.691	0.732	0.779	0.829	0.874	0.922	0.973
464	0.693	0.733	0.781	0.831	0.876	0.924	0.975
463	0.694	0.735	0.783	0.833	0.878	0.926	0.977
462	0.696	0.737	0.785	0.835	0.88	0.928	0.979
461	0.698	0.739	0.787	0.837	0.882	0.93	0.981
460	0.699	0.74	0.789	0.839	0.884	0.932	0.983
459	0.701	0.742	0.79	0.84	0.885	0.933	0.984
458	0.702	0.743	0.792	0.842	0.887	0.935	0.986
457	0.703	0.745	0.793	0.843	0.888	0.936	0.987
456	0.705	0.746	0.795	0.845	0.89	0.938	0.989
455	0.706	0.748	0.797	0.847	0.892	0.94	0.991
454	0.708	0.749	0.798	0.848	0.893	0.941	0.992
453	0.709	0.751	0.8	0.85	0.895	0.943	0.994
452	0.71	0.752	0.802	0.852	0.897	0.945	0.996
451	0.712	0.754	0.804	0.854	0.899	0.947	0.998
450	0.714	0.756	0.805	0.855	0.9	0.948	0.999
449	0.716	0.758	0.807	0.857	0.902	0.95	1.001
448	0.718	0.76	0.81	0.86	0.905	0.953	1.004
447	0.72	0.762	0.812	0.862	0.907	0.955	1.006
446	0.72	0.764	0.814	0.864	0.909	0.957	1.008
445	0.722	0.767	0.817	0.867	0.912	0.96	1.011
444	0.724	0.769	0.819	0.869	0.914	0.962	1.013
443	0.726	0.769	0.821	0.871	0.916	0.964	1.015
442	0.727	0.771	0.823	0.873	0.918	0.966	1.017
441	0.728	0.772	0.825	0.875	0.92	0.968	1.019
440	0.73	0.774	0.826	0.876	0.921	0.969	1.02
439	0.731	0.775	0.828	0.878	0.923	0.971	1.022
438	0.732	0.776	0.829	0.879	0.924	0.972	1.023
437	0.733	0.777	0.828	0.878	0.923	0.971	1.022
436	0.734	0.778	0.829	0.879	0.924	0.972	1.023
435	0.734	0.778	0.83	0.88	0.925	0.973	1.024
434	0.734	0.778	0.83	0.88	0.925	0.973	1.024
433	0.734	0.778	0.83	0.88	0.925	0.973	1.024

432	0.734	0.778	0.83	0.88	0.925	0.973	1.024
431	0.734	0.779	0.83	0.88	0.925	0.973	1.024
430	0.734	0.778	0.83	0.88	0.925	0.973	1.024
429	0.735	0.778	0.83	0.88	0.925	0.973	1.024
428	0.735	0.779	0.83	0.88	0.925	0.973	1.024
427	0.735	0.779	0.83	0.88	0.925	0.973	1.024
426	0.735	0.78	0.831	0.881	0.926	0.974	1.025
425	0.736	0.781	0.831	0.881	0.926	0.974	1.025
424	0.736	0.781	0.832	0.882	0.927	0.975	1.026
423	0.737	0.781	0.833	0.883	0.928	0.976	1.027
422	0.737	0.782	0.833	0.883	0.928	0.976	1.027
421	0.738	0.782	0.834	0.884	0.929	0.977	1.028
420	0.739	0.783	0.835	0.885	0.93	0.978	1.029
419	0.739	0.784	0.836	0.886	0.931	0.979	1.03
418	0.74	0.785	0.836	0.886	0.931	0.979	1.03
417	0.74	0.785	0.837	0.887	0.932	0.98	1.031
416	0.741	0.786	0.838	0.888	0.933	0.981	1.032
415	0.741	0.786	0.838	0.888	0.933	0.981	1.032
414	0.741	0.786	0.838	0.888	0.933	0.981	1.032
413	0.742	0.786	0.838	0.888	0.933	0.981	1.032
412	0.742	0.786	0.839	0.889	0.934	0.982	1.033
411	0.742	0.787	0.838	0.888	0.933	0.981	1.032
410	0.742	0.787	0.838	0.888	0.933	0.981	1.032
409	0.742	0.786	0.838	0.888	0.933	0.981	1.032
408	0.742	0.786	0.838	0.888	0.933	0.981	1.032
407	0.742	0.787	0.838	0.888	0.933	0.981	1.032
406	0.742	0.786	0.838	0.888	0.933	0.981	1.032
405	0.742	0.786	0.838	0.888	0.933	0.981	1.032
404	0.742	0.786	0.838	0.888	0.933	0.981	1.032
403	0.742	0.787	0.839	0.889	0.934	0.982	1.033
402	0.743	0.787	0.839	0.889	0.934	0.982	1.033
401	0.743	0.788	0.839	0.889	0.934	0.982	1.033
400	0.744	0.788	0.839	0.889	0.934	0.982	1.033
399	0.744	0.788	0.84	0.89	0.935	0.983	1.034
398	0.745	0.789	0.841	0.891	0.936	0.984	1.035
397	0.746	0.79	0.843	0.893	0.938	0.986	1.037
396	0.747	0.792	0.844	0.894	0.939	0.987	1.038
395	0.747	0.792	0.845	0.895	0.94	0.988	1.039
394	0.749	0.794	0.847	0.897	0.942	0.99	1.041
393	0.75	0.795	0.848	0.898	0.943	0.991	1.042
392	0.751	0.797	0.849	0.899	0.944	0.992	1.043
391	0.752	0.798	0.85	0.9	0.945	0.993	1.044
390	0.753	0.799	0.851	0.901	0.946	0.994	1.045
389	0.754	0.8	0.853	0.903	0.948	0.996	1.047
388	0.756	0.801	0.854	0.904	0.949	0.997	1.048
387	0.757	0.802	0.855	0.905	0.95	0.998	1.049
386	0.758	0.803	0.856	0.906	0.951	0.999	1.05
385	0.759	0.804	0.858	0.908	0.953	1.001	1.052

384	0.76	0.806	0.859	0.909	0.954	1.002	1.053
383	0.761	0.807	0.86	0.91	0.955	1.003	1.054
382	0.761	0.808	0.861	0.911	0.956	1.004	1.055
381	0.762	0.809	0.862	0.912	0.957	1.005	1.056
380	0.711	0.755	0.802	0.852	0.897	0.945	0.996
379	0.715	0.758	0.809	0.874	0.919	0.967	1.018
378	0.718	0.757	0.806	0.871	0.916	0.964	1.015
377	0.72	0.758	0.808	0.873	0.918	0.966	1.017
376	0.72	0.759	0.805	0.87	0.915	0.963	1.014
375	0.721	0.761	0.808	0.873	0.918	0.966	1.017
374	0.721	0.761	0.807	0.872	0.917	0.965	1.016
373	0.722	0.762	0.806	0.871	0.916	0.964	1.015
372	0.73	0.768	0.815	0.88	0.925	0.973	1.024
371	0.73	0.769	0.816	0.881	0.926	0.974	1.025
370	0.728	0.77	0.815	0.88	0.925	0.973	1.024
369	0.73	0.77	0.817	0.882	0.927	0.975	1.026
368	0.73	0.771	0.817	0.882	0.927	0.975	1.026
367	0.731	0.774	0.819	0.884	0.929	0.977	1.028
366	0.732	0.774	0.82	0.885	0.93	0.978	1.029
365	0.734	0.776	0.822	0.887	0.932	0.98	1.031
364	0.734	0.776	0.821	0.886	0.931	0.979	1.03
363	0.735	0.777	0.823	0.888	0.933	0.981	1.032
362	0.736	0.779	0.824	0.889	0.934	0.982	1.033
361	0.737	0.78	0.827	0.892	0.937	0.985	1.036
360	0.738	0.781	0.827	0.892	0.937	0.985	1.036
359	0.741	0.78	0.828	0.893	0.938	0.986	1.037
358	0.743	0.783	0.83	0.895	0.94	0.988	1.039
357	0.745	0.786	0.834	0.899	0.944	0.992	1.043
356	0.746	0.789	0.835	0.9	0.945	0.993	1.044
355	0.747	0.79	0.838	0.903	0.948	0.996	1.047
354	0.75	0.792	0.838	0.903	0.948	0.996	1.047
353	0.752	0.793	0.839	0.904	0.949	0.997	1.048
352	0.754	0.796	0.844	0.909	0.954	1.002	1.053
351	0.755	0.797	0.845	0.91	0.955	1.003	1.054
350	0.756	0.798	0.849	0.914	0.959	1.007	1.058
349	0.772	0.816	0.863	0.928	0.973	1.021	1.072
348	0.774	0.82	0.867	0.932	0.977	1.025	1.076
347	0.778	0.822	0.869	0.934	0.979	1.027	1.078
346	0.781	0.825	0.873	0.938	0.983	1.031	1.082
345	0.785	0.828	0.876	0.941	0.986	1.034	1.085
344	0.786	0.83	0.878	0.943	0.988	1.036	1.087
343	0.786	0.831	0.881	0.946	0.991	1.039	1.09
342	0.79	0.835	0.884	0.949	0.994	1.042	1.093
341	0.792	0.838	0.887	0.952	0.997	1.045	1.096
340	0.795	0.84	0.891	0.956	1.001	1.049	1.1
339	0.798	0.841	0.892	0.957	1.002	1.05	1.101
338	0.801	0.845	0.896	0.961	1.006	1.054	1.105
337	0.802	0.847	0.899	0.964	1.009	1.057	1.108

336	0.803	0.849	0.901	0.966	1.011	1.059	1.11
335	0.805	0.852	0.902	0.967	1.012	1.06	1.111
334	0.808	0.854	0.904	0.969	1.014	1.062	1.113
333	0.809	0.855	0.906	0.971	1.016	1.064	1.115
332	0.811	0.857	0.909	0.974	1.019	1.067	1.118
331	0.812	0.86	0.91	0.975	1.02	1.068	1.119
330	0.814	0.861	0.912	0.977	1.022	1.07	1.121
329	0.816	0.864	0.914	0.979	1.024	1.072	1.123
328	0.818	0.865	0.916	0.981	1.026	1.074	1.125
327	0.82	0.866	0.918	0.983	1.028	1.076	1.127
326	0.823	0.868	0.92	0.985	1.03	1.078	1.129
325	0.823	0.87	0.921	0.986	1.031	1.079	1.13
324	0.824	0.871	0.922	0.987	1.032	1.08	1.131
323	0.827	0.876	0.925	0.99	1.035	1.083	1.134
322	0.827	0.876	0.926	0.991	1.036	1.084	1.135
321	0.83	0.877	0.929	0.994	1.039	1.087	1.138
320	0.833	0.881	0.93	0.995	1.04	1.088	1.139
319	0.836	0.884	0.935	1	1.045	1.093	1.144
318	0.838	0.888	0.939	1.004	1.049	1.097	1.148
317	0.84	0.89	0.942	1.007	1.052	1.1	1.151
316	0.844	0.894	0.947	1.012	1.057	1.105	1.156
315	0.848	0.899	0.95	1.015	1.06	1.108	1.159
314	0.853	0.902	0.953	1.018	1.063	1.111	1.162
313	0.857	0.908	0.959	1.024	1.069	1.117	1.168
312	0.861	0.91	0.964	1.029	1.074	1.122	1.173
311	0.865	0.915	0.968	1.033	1.078	1.126	1.177
310	0.87	0.921	0.974	1.039	1.084	1.132	1.183
309	0.875	0.924	0.977	1.042	1.087	1.135	1.186
308	0.879	0.928	0.984	1.049	1.094	1.142	1.193
307	0.884	0.932	0.988	1.053	1.098	1.146	1.197
306	0.888	0.939	0.994	1.059	1.104	1.152	1.203
305	0.892	0.945	0.999	1.064	1.109	1.157	1.208
304	0.897	0.95	1.002	1.067	1.112	1.16	1.211
303	0.902	0.956	1.007	1.072	1.117	1.165	1.216
302	0.908	0.961	1.016	1.081	1.126	1.174	1.225
301	0.914	0.967	1.02	1.085	1.13	1.178	1.229
300	1.033	1.107	1.186	1.236	1.281	1.329	1.38
299	1.041	1.115	1.195	1.245	1.365	1.495	1.636
298	1.05	1.123	1.206	1.256	1.376	1.506	1.647
297	1.059	1.134	1.219	1.299	1.419	1.549	1.69
296	1.071	1.147	1.233	1.313	1.433	1.563	1.704
295	1.084	1.161	1.248	1.328	1.448	1.578	1.719
294	1.097	1.176	1.264	1.364	1.484	1.614	1.755
293	1.108	1.19	1.279	1.379	1.499	1.629	1.77
292	1.12	1.203	1.293	1.393	1.513	1.643	1.784
291	1.132	1.216	1.307	1.407	1.527	1.657	1.798
290	1.143	1.228	1.321	1.421	1.541	1.671	1.812
289	1.154	1.241	1.335	1.435	1.555	1.685	1.826

288	1.166	1.253	1.349	1.449	1.569	1.699	1.84
287	1.178	1.266	1.364	1.464	1.584	1.714	1.855
286	1.189	1.28	1.379	1.479	1.599	1.729	1.87
285	1.202	1.294	1.395	1.495	1.615	1.745	1.886
284	1.213	1.306	1.409	1.509	1.629	1.759	1.9
283	1.223	1.317	1.419	1.519	1.639	1.769	1.91
282	1.231	1.327	1.431	1.531	1.651	1.781	1.922
281	1.24	1.336	1.441	1.541	1.661	1.791	1.932
280	1.248	1.344	1.45	1.55	1.67	1.8	1.941
279	1.256	1.352	1.461	1.561	1.681	1.811	1.952
278	1.263	1.361	1.469	1.569	1.689	1.819	1.96
277	1.269	1.37	1.479	1.579	1.699	1.829	1.97
276	1.277	1.379	1.487	1.587	1.707	1.837	1.978
275	1.285	1.388	1.499	1.599	1.719	1.849	1.99
274	1.294	1.397	1.508	1.608	1.728	1.858	1.999
273	1.302	1.404	1.518	1.618	1.738	1.868	2.009
272	1.308	1.414	1.525	1.625	1.745	1.875	2.016
271	1.315	1.42	1.534	1.634	1.754	1.884	2.025
270	1.321	1.427	1.543	1.643	1.763	1.893	2.034
269	1.328	1.434	1.551	1.651	1.771	1.901	2.042
268	1.334	1.44	1.557	1.657	1.777	1.907	2.048
267	1.34	1.448	1.563	1.663	1.783	1.913	2.054
266	1.345	1.454	1.569	1.669	1.789	1.919	2.06
265	1.35	1.459	1.577	1.677	1.797	1.927	2.068
264	1.354	1.464	1.583	1.683	1.803	1.933	2.074
263	1.36	1.469	1.589	1.689	1.809	1.939	2.08
262	1.365	1.476	1.595	1.695	1.815	1.945	2.086
261	1.37	1.481	1.6	1.7	1.82	1.95	2.091
260	1.375	1.486	1.605	1.705	1.825	1.955	2.096
259	1.379	1.49	1.61	1.71	1.83	1.96	2.101
258	1.382	1.494	1.615	1.715	1.835	1.965	2.106
257	1.386	1.498	1.619	1.719	1.839	1.969	2.11
256	1.39	1.502	1.621	1.721	1.841	1.971	2.112
255	1.394	1.506	1.627	1.727	1.847	1.977	2.118
254	1.398	1.51	1.632	1.732	1.852	1.982	2.123
253	1.403	1.516	1.637	1.737	1.857	1.987	2.128
252	1.408	1.521	1.644	1.744	1.864	1.994	2.135
251	1.414	1.528	1.65	1.75	1.87	2	2.141
250	1.422	1.535	1.658	1.758	1.878	2.008	2.149
249	1.429	1.543	1.666	1.766	1.886	2.016	2.157
248	1.437	1.553	1.676	1.776	1.896	2.026	2.167
247	1.446	1.563	1.686	1.806	1.906	2.036	2.177
246	1.456	1.574	1.699	1.819	1.919	2.049	2.19
245	1.47	1.588	1.713	1.833	1.933	2.063	2.204
244	1.484	1.602	1.729	1.849	1.949	2.079	2.22
243	1.502	1.622	1.751	1.871	1.971	2.101	2.242
242	1.524	1.646	1.776	1.896	1.996	2.126	2.267
241	1.548	1.671	1.805	1.925	2.025	2.155	2.296

240	1.576	1.703	1.838	1.958	2.058	2.188	2.329
239	1.609	1.739	1.879	1.999	2.099	2.229	2.37
238	1.649	1.781	1.925	2.045	2.145	2.275	2.416
237	1.697	1.833	1.981	2.101	2.201	2.331	2.472
236	1.747	1.888	2.04	2.16	2.26	2.39	2.531
235	1.803	1.95	2.108	2.228	2.328	2.458	2.599
234	1.867	2.02	2.181	2.301	2.401	2.531	2.672
233	1.94	2.101	2.272	2.392	2.492	2.622	2.763
232	2.021	2.193	2.375	2.495	2.595	2.725	2.866
231	2.111	2.282	2.477	2.597	2.697	2.827	2.968
230	2.212	2.393	2.595	2.715	2.815	2.945	3.086
229	2.318	2.502	2.713	2.833	2.933	3.063	3.204
228	2.438	2.638	2.856	2.976	3.076	3.206	3.347
227	2.599	2.813	3.048	3.168	3.268	3.398	3.539
226	2.766	2.98	3.26	3.38	3.48	3.61	3.751
225	2.932	3.154	3.416	3.536	3.636	3.766	3.907
224	3.12	3.355	3.519	3.639	3.739	3.869	4.01
223	3.313	3.584	3.649	3.769	3.869	3.999	4.14
222	3.49	3.726	3.72	3.84	3.94	4.07	4.211
221	3.528	3.897	3.814	3.934	4.034	4.164	4.305
220	3.699	3.777	3.868	3.988	4.088	4.218	4.359
219	3.711	3.911	3.836	3.956	4.056	4.186	4.327
218	3.797	3.923	3.783	3.903	4.003	4.133	4.274
217	3.918	3.868	3.911	4.031	4.131	4.261	4.402
216	3.869	3.852	3.845	3.965	4.065	4.195	4.336
215	3.939	3.796	3.986	4.106	4.206	4.336	4.477
214	3.923	3.874	3.956	4.076	4.176	4.306	4.447
213	3.857	3.869	3.932	4.052	4.152	4.282	4.423
212	3.736	3.833	3.936	4.056	4.156	4.286	4.427
211	3.777	3.904	3.889	4.009	4.109	4.239	4.38
210	3.897	3.895	3.934	4.054	4.154	4.284	4.425
209	3.876	3.833	3.908	4.028	4.128	4.258	4.399
208	3.926	3.965	3.854	3.974	4.074	4.204	4.345
207	3.841	3.951	3.914	4.034	4.134	4.264	4.405
206	3.779	3.851	3.939	4.059	4.159	4.289	4.43
205	3.851	3.908	4.004	4.124	4.224	4.354	4.495
204	3.806	3.915	4.004	4.124	4.224	4.354	4.495
203	3.912	3.925	3.91	4.03	4.13	4.26	4.401
202	3.908	3.881	3.998	4.118	4.218	4.348	4.489
201	3.789	3.96	3.964	4.084	4.184	4.314	4.455
200	3.81	3.984	4.004	4.124	4.224	4.354	4.495

Table A-8. The peak wavelengths and their absorbance values for the three regions in electromagnetic spectra were obtained from wavelength sensitivity analysis of *I. galbana*.

Concentration (mg/L)	**Wavelength (nm)**	**Color**	**ABS**
0 (SW)	265	UVC	0.36
	430	Blue/Violet	0.302
	680	Red	0.254
30	265	UVC	0.461
	430	Blue/Violet	0.358
	680	Red	0.301
60	265	UVC	0.618
	430	Blue/Violet	0.427
	680	Red	0.344
90	265	UVC	0.725
	430	Blue/Violet	0.474
	680	Red	0.372
120	265	UVC	0.86
	430	Blue/Violet	0.531
	680	Red	0.407
150	265	UVC	0.977
	430	Blue/Violet	0.577
	680	Red	0.437
180	265	UVC	1.088
	430	Blue/Violet	0.617
	680	Red	0.463
210	265	UVC	1.218
	430	Blue/Violet	0.675
	680	Red	0.500
240	265	UVC	1.35
	430	Blue/Violet	0.73
	680	Red	0.537
270	265	UVC	1.459
	430	Blue/Violet	0.774
	680	Red	0.563
300	265	UVC	1.576
	430	Blue/Violet	0.826
	680	Red	0.598
350	265	UVC	1.676
	430	Blue/Violet	0.876
	680	Red	0.648
400	265	UVC	1.796
	430	Blue/Violet	0.921
	680	Red	0.693
450	265	UVC	1.926

	430	Blue/Violet	0.969
	680	Red	0.741
500	265	UVC	2.067
	430	Blue/Violet	1.020
	680	Red	0.792

Table A-9. The results of the TSS measurements conducted in laboratory were used for wavelength sensitivity analysis of *T. weissflogii*.

SAMPLE	INITIAL WEIGHT (mg)	FINAL WEIGHT (mg)	Average Diff (mg)	Filter Type
Blank	1094.2	1094.2	0	GF/F
SW	1100.7	1102.15	1.45	GF/F
TW	1099.6	1106.5	6.9	GF/F

Sample	Avg. Diff	Sample Vol. (mL)	TSS (mg/L)
Blank	0	10	0
SW	1.45	10	145
TW	6.9	10	690
		Dry Wt	545

Table A-10. The different dilutions were used to obtain different microalgal concentrations in the range of 0-500 mg dry wt/L for *T. weissflogii*.

To prepare 150 mL volume target solutions		
Target Concentration(mg/L)	**Volume of Salt Water (mL)**	**Volume to be added from 545 mg/L (mL)**
30	141.7	8.2
60	133.4	16.5
90	125.2	24.7
120	116.9	33.0
150	108.7	41.2
180	100.4	49.5
210	92.2	57.7
240	83.9	66.0
270	75.6	74.3
300	67.4	82.5
350	53.6	96.3
400	39.9	110.0
450	26.1	123.8
500	12.3	137.6

Table A-11. The data from the scanning spectrophotometer was averaged for each microalgal concentration over the wavelength range 200-800 nm to determine the wavelength sensitivity of *T. weissflogii*.

nm	Salt water	30 mg/L	60 mg/L	90 mg/L	120 mg/L	150 mg/L	180 mg/L	210 mg/L
800	0.229	0.258	0.275	0.291	0.307	0.329	0.341	0.36
799	0.228	0.256	0.274	0.29	0.306	0.328	0.341	0.36
798	0.228	0.256	0.273	0.291	0.307	0.327	0.339	0.358
797	0.226	0.257	0.273	0.29	0.305	0.327	0.338	0.357
796	0.225	0.255	0.273	0.289	0.305	0.326	0.339	0.358
795	0.227	0.256	0.273	0.288	0.304	0.327	0.338	0.357
794	0.225	0.256	0.273	0.288	0.304	0.327	0.339	0.358
793	0.226	0.256	0.273	0.288	0.305	0.327	0.339	0.358
792	0.226	0.257	0.273	0.289	0.306	0.328	0.34	0.359
791	0.227	0.257	0.273	0.29	0.305	0.329	0.34	0.359
790	0.227	0.257	0.273	0.291	0.307	0.329	0.34	0.359
789	0.227	0.257	0.274	0.29	0.306	0.328	0.34	0.359
788	0.227	0.257	0.274	0.291	0.307	0.328	0.34	0.359
787	0.228	0.257	0.274	0.291	0.307	0.329	0.341	0.36
786	0.227	0.258	0.275	0.291	0.307	0.329	0.342	0.361
785	0.228	0.258	0.275	0.292	0.307	0.33	0.342	0.361
784	0.228	0.258	0.275	0.292	0.307	0.33	0.342	0.361
783	0.227	0.258	0.276	0.293	0.308	0.33	0.342	0.361
782	0.228	0.259	0.276	0.293	0.308	0.33	0.342	0.361
781	0.228	0.258	0.276	0.293	0.308	0.33	0.342	0.361
780	0.228	0.259	0.276	0.293	0.308	0.33	0.343	0.362
779	0.228	0.259	0.276	0.294	0.308	0.33	0.343	0.362
778	0.229	0.259	0.277	0.294	0.308	0.331	0.343	0.362
777	0.229	0.259	0.277	0.294	0.309	0.331	0.344	0.363
776	0.229	0.26	0.277	0.295	0.309	0.331	0.344	0.363
775	0.231	0.26	0.277	0.295	0.309	0.332	0.344	0.363
774	0.23	0.26	0.278	0.295	0.31	0.332	0.345	0.364
773	0.23	0.26	0.278	0.296	0.31	0.332	0.345	0.364
772	0.229	0.26	0.278	0.296	0.311	0.333	0.345	0.364
771	0.23	0.261	0.279	0.296	0.311	0.333	0.346	0.365
770	0.23	0.261	0.279	0.297	0.311	0.333	0.346	0.365
769	0.23	0.261	0.279	0.297	0.312	0.334	0.346	0.365
768	0.231	0.261	0.279	0.297	0.312	0.334	0.346	0.365
767	0.231	0.261	0.28	0.297	0.312	0.334	0.347	0.366
766	0.231	0.261	0.28	0.298	0.312	0.335	0.347	0.366
765	0.231	0.262	0.28	0.298	0.313	0.335	0.348	0.367
764	0.231	0.262	0.281	0.298	0.313	0.335	0.348	0.367
763	0.232	0.263	0.281	0.299	0.313	0.335	0.349	0.368
762	0.232	0.263	0.281	0.299	0.314	0.336	0.349	0.368
761	0.232	0.263	0.282	0.299	0.314	0.336	0.349	0.368
760	0.233	0.264	0.282	0.299	0.314	0.337	0.349	0.368
759	0.233	0.264	0.283	0.3	0.315	0.337	0.35	0.369
758	0.234	0.265	0.283	0.3	0.315	0.337	0.35	0.369
757	0.234	0.265	0.283	0.3	0.315	0.337	0.351	0.37
756	0.234	0.265	0.283	0.3	0.316	0.338	0.351	0.37

755	0.234	0.265	0.284	0.301	0.316	0.338	0.351	0.37
754	0.234	0.265	0.284	0.301	0.316	0.338	0.351	0.37
753	0.236	0.266	0.284	0.301	0.316	0.339	0.352	0.371
752	0.235	0.266	0.284	0.302	0.317	0.339	0.352	0.371
751	0.235	0.266	0.285	0.302	0.317	0.339	0.353	0.372
750	0.236	0.266	0.285	0.302	0.317	0.339	0.353	0.372
749	0.236	0.266	0.285	0.302	0.317	0.34	0.353	0.372
748	0.236	0.266	0.285	0.303	0.318	0.34	0.354	0.373
747	0.237	0.267	0.286	0.303	0.318	0.341	0.354	0.373
746	0.237	0.267	0.286	0.303	0.318	0.341	0.354	0.373
745	0.236	0.267	0.286	0.304	0.319	0.341	0.354	0.373
744	0.237	0.268	0.286	0.304	0.319	0.341	0.355	0.374
743	0.237	0.268	0.286	0.304	0.319	0.342	0.355	0.374
742	0.238	0.268	0.287	0.304	0.32	0.342	0.355	0.374
741	0.238	0.268	0.287	0.305	0.32	0.342	0.356	0.375
740	0.238	0.268	0.287	0.305	0.32	0.343	0.356	0.375
739	0.238	0.268	0.287	0.305	0.32	0.343	0.356	0.375
738	0.238	0.269	0.288	0.305	0.321	0.343	0.356	0.375
737	0.238	0.269	0.288	0.306	0.321	0.343	0.357	0.376
736	0.239	0.269	0.288	0.306	0.321	0.344	0.357	0.376
735	0.239	0.269	0.288	0.306	0.321	0.344	0.358	0.377
734	0.24	0.27	0.289	0.307	0.322	0.345	0.358	0.377
733	0.24	0.27	0.289	0.307	0.322	0.345	0.358	0.377
732	0.24	0.27	0.289	0.307	0.323	0.345	0.359	0.378
731	0.24	0.271	0.289	0.307	0.323	0.346	0.359	0.378
730	0.24	0.271	0.29	0.308	0.323	0.346	0.36	0.379
729	0.241	0.271	0.29	0.308	0.324	0.346	0.36	0.379
728	0.241	0.271	0.291	0.309	0.324	0.347	0.361	0.38
727	0.241	0.272	0.291	0.309	0.325	0.347	0.361	0.38
726	0.242	0.272	0.291	0.309	0.325	0.348	0.362	0.381
725	0.242	0.273	0.291	0.31	0.325	0.348	0.362	0.381
724	0.242	0.273	0.292	0.31	0.326	0.348	0.362	0.381
723	0.242	0.273	0.292	0.31	0.326	0.349	0.363	0.382
722	0.243	0.273	0.293	0.311	0.326	0.349	0.363	0.382
721	0.243	0.274	0.293	0.311	0.327	0.35	0.364	0.383
720	0.243	0.274	0.293	0.311	0.327	0.35	0.364	0.383
719	0.243	0.274	0.293	0.312	0.328	0.351	0.365	0.384
718	0.243	0.274	0.294	0.312	0.328	0.351	0.365	0.384
717	0.244	0.274	0.294	0.313	0.328	0.352	0.366	0.385
716	0.244	0.275	0.294	0.313	0.329	0.352	0.366	0.385
715	0.244	0.275	0.295	0.313	0.329	0.353	0.367	0.386
714	0.244	0.276	0.295	0.314	0.33	0.353	0.367	0.386
713	0.244	0.276	0.295	0.314	0.33	0.354	0.368	0.387
712	0.245	0.276	0.296	0.314	0.331	0.354	0.368	0.387
711	0.245	0.276	0.296	0.315	0.331	0.355	0.369	0.388
710	0.245	0.277	0.296	0.315	0.332	0.355	0.37	0.389
709	0.245	0.277	0.297	0.316	0.332	0.356	0.37	0.389
708	0.246	0.277	0.297	0.316	0.333	0.356	0.371	0.39
707	0.246	0.278	0.298	0.316	0.333	0.357	0.372	0.391
706	0.246	0.278	0.298	0.317	0.334	0.358	0.373	0.392

705	0.246	0.278	0.298	0.318	0.335	0.359	0.373	0.392
704	0.246	0.279	0.299	0.318	0.335	0.359	0.374	0.393
703	0.247	0.279	0.299	0.319	0.336	0.36	0.375	0.394
702	0.247	0.279	0.3	0.319	0.336	0.361	0.376	0.395
701	0.247	0.28	0.3	0.32	0.337	0.362	0.377	0.396
700	0.247	0.28	0.301	0.32	0.338	0.363	0.378	0.397
699	0.248	0.281	0.301	0.321	0.339	0.364	0.38	0.399
698	0.248	0.281	0.302	0.322	0.34	0.365	0.381	0.4
697	0.248	0.282	0.303	0.323	0.341	0.367	0.383	0.402
696	0.248	0.282	0.304	0.324	0.342	0.369	0.385	0.404
695	0.249	0.283	0.304	0.325	0.344	0.371	0.387	0.406
694	0.249	0.283	0.305	0.326	0.345	0.373	0.389	0.408
693	0.249	0.284	0.306	0.328	0.347	0.375	0.392	0.411
692	0.249	0.285	0.307	0.329	0.349	0.377	0.394	0.413
691	0.25	0.285	0.308	0.33	0.351	0.379	0.397	0.416
690	0.25	0.286	0.309	0.332	0.353	0.382	0.4	0.419
689	0.25	0.287	0.31	0.334	0.355	0.384	0.403	0.422
688	0.25	0.288	0.311	0.335	0.357	0.387	0.406	0.425
687	0.251	0.288	0.313	0.337	0.359	0.389	0.408	0.427
686	0.251	0.289	0.314	0.338	0.361	0.392	0.411	0.43
685	0.251	0.29	0.315	0.34	0.363	0.394	0.414	0.433
684	0.251	0.29	0.316	0.341	0.364	0.396	0.416	0.435
683	0.252	0.291	0.317	0.342	0.366	0.397	0.418	0.437
682	0.252	0.292	0.317	0.343	0.367	0.398	0.42	0.439
681	0.252	0.292	0.318	0.344	0.368	0.4	0.421	0.44
680	0.252	0.293	0.319	0.345	0.369	0.401	0.422	0.441
679	0.252	0.293	0.319	0.346	0.37	0.402	0.424	0.443
678	0.253	0.293	0.32	0.347	0.371	0.403	0.425	0.444
677	0.253	0.294	0.32	0.347	0.371	0.403	0.425	0.444
676	0.253	0.294	0.321	0.348	0.371	0.404	0.426	0.445
675	0.254	0.295	0.321	0.348	0.372	0.404	0.426	0.445
674	0.254	0.295	0.321	0.348	0.372	0.403	0.426	0.445
673	0.254	0.295	0.321	0.348	0.372	0.403	0.425	0.444
672	0.254	0.295	0.321	0.348	0.371	0.402	0.424	0.443
671	0.255	0.295	0.32	0.347	0.37	0.4	0.423	0.442
670	0.255	0.295	0.32	0.347	0.369	0.399	0.421	0.44
669	0.255	0.295	0.319	0.346	0.368	0.397	0.419	0.438
668	0.255	0.294	0.319	0.345	0.367	0.396	0.417	0.436
667	0.255	0.294	0.318	0.344	0.366	0.394	0.415	0.434
666	0.256	0.294	0.318	0.343	0.364	0.392	0.413	0.432
665	0.256	0.294	0.317	0.342	0.363	0.391	0.411	0.43
664	0.256	0.294	0.317	0.341	0.362	0.389	0.409	0.428
663	0.256	0.294	0.316	0.34	0.36	0.387	0.407	0.426
662	0.257	0.293	0.316	0.34	0.359	0.386	0.405	0.424
661	0.257	0.293	0.315	0.339	0.358	0.385	0.403	0.422
660	0.257	0.293	0.315	0.338	0.357	0.383	0.402	0.421
659	0.257	0.293	0.315	0.337	0.356	0.382	0.4	0.419
658	0.257	0.293	0.314	0.337	0.355	0.381	0.399	0.418
657	0.258	0.293	0.314	0.336	0.354	0.38	0.398	0.417
656	0.258	0.293	0.314	0.336	0.354	0.379	0.397	0.416

655	0.258	0.293	0.314	0.335	0.353	0.379	0.396	0.415
654	0.259	0.293	0.314	0.335	0.353	0.378	0.395	0.414
653	0.259	0.293	0.314	0.335	0.353	0.378	0.395	0.414
652	0.259	0.294	0.314	0.335	0.353	0.378	0.395	0.414
651	0.259	0.294	0.315	0.335	0.353	0.378	0.395	0.414
650	0.26	0.294	0.315	0.335	0.353	0.379	0.395	0.414
649	0.26	0.294	0.315	0.336	0.354	0.379	0.395	0.414
648	0.26	0.294	0.315	0.336	0.354	0.38	0.396	0.415
647	0.261	0.295	0.316	0.336	0.355	0.38	0.396	0.415
646	0.261	0.295	0.316	0.337	0.355	0.381	0.397	0.416
645	0.261	0.296	0.317	0.337	0.356	0.381	0.398	0.417
644	0.261	0.296	0.317	0.338	0.356	0.382	0.398	0.417
643	0.262	0.296	0.317	0.338	0.357	0.382	0.399	0.418
642	0.262	0.297	0.318	0.339	0.357	0.383	0.4	0.419
641	0.262	0.297	0.318	0.339	0.358	0.383	0.4	0.419
640	0.262	0.297	0.318	0.339	0.358	0.384	0.401	0.42
639	0.262	0.297	0.319	0.34	0.359	0.385	0.402	0.421
638	0.263	0.298	0.319	0.34	0.359	0.385	0.402	0.421
637	0.263	0.298	0.32	0.341	0.36	0.386	0.403	0.422
636	0.263	0.299	0.32	0.341	0.36	0.386	0.403	0.422
635	0.264	0.299	0.32	0.342	0.361	0.387	0.404	0.423
634	0.264	0.299	0.321	0.342	0.361	0.387	0.404	0.423
633	0.264	0.3	0.321	0.342	0.362	0.387	0.405	0.424
632	0.264	0.3	0.321	0.343	0.362	0.388	0.405	0.424
631	0.265	0.3	0.322	0.343	0.362	0.388	0.405	0.424
630	0.265	0.301	0.322	0.343	0.362	0.389	0.406	0.425
629	0.265	0.301	0.322	0.344	0.363	0.389	0.406	0.425
628	0.265	0.301	0.322	0.344	0.363	0.389	0.407	0.426
627	0.266	0.301	0.323	0.344	0.363	0.39	0.407	0.426
626	0.266	0.302	0.323	0.345	0.364	0.39	0.407	0.426
625	0.266	0.302	0.323	0.345	0.364	0.39	0.408	0.427
624	0.267	0.302	0.324	0.345	0.365	0.391	0.408	0.427
623	0.267	0.303	0.324	0.346	0.365	0.391	0.408	0.427
622	0.267	0.303	0.324	0.346	0.365	0.391	0.409	0.428
621	0.267	0.303	0.324	0.346	0.365	0.391	0.409	0.428
620	0.268	0.303	0.325	0.346	0.366	0.392	0.409	0.428
619	0.268	0.303	0.325	0.347	0.366	0.392	0.409	0.428
618	0.268	0.304	0.325	0.347	0.366	0.392	0.41	0.429
617	0.268	0.304	0.325	0.347	0.366	0.392	0.41	0.429
616	0.269	0.304	0.325	0.347	0.367	0.393	0.41	0.429
615	0.269	0.304	0.326	0.347	0.367	0.393	0.41	0.429
614	0.269	0.305	0.326	0.348	0.367	0.393	0.411	0.43
613	0.269	0.305	0.326	0.348	0.367	0.393	0.411	0.43
612	0.27	0.305	0.326	0.348	0.367	0.393	0.411	0.43
611	0.27	0.305	0.327	0.348	0.368	0.393	0.411	0.43
610	0.27	0.306	0.327	0.349	0.368	0.394	0.411	0.43
609	0.27	0.306	0.327	0.349	0.368	0.394	0.411	0.43
608	0.271	0.306	0.327	0.349	0.368	0.394	0.411	0.43
607	0.271	0.306	0.327	0.349	0.368	0.394	0.412	0.431
606	0.271	0.306	0.328	0.349	0.368	0.394	0.412	0.431

605	0.271	0.307	0.328	0.35	0.369	0.395	0.412	0.431
604	0.272	0.307	0.328	0.35	0.369	0.395	0.412	0.431
603	0.272	0.307	0.329	0.35	0.369	0.395	0.413	0.432
602	0.272	0.307	0.329	0.351	0.37	0.396	0.413	0.432
601	0.272	0.308	0.329	0.351	0.37	0.396	0.414	0.433
600	0.271	0.307	0.329	0.351	0.37	0.396	0.414	0.433
599	0.272	0.308	0.329	0.351	0.37	0.397	0.414	0.433
598	0.272	0.308	0.33	0.351	0.371	0.397	0.415	0.434
597	0.272	0.308	0.33	0.352	0.371	0.398	0.415	0.434
596	0.272	0.308	0.33	0.352	0.372	0.398	0.416	0.435
595	0.273	0.309	0.331	0.353	0.372	0.399	0.417	0.436
594	0.273	0.309	0.331	0.353	0.373	0.399	0.417	0.436
593	0.274	0.309	0.331	0.353	0.373	0.4	0.418	0.437
592	0.275	0.31	0.332	0.354	0.374	0.4	0.418	0.437
591	0.275	0.311	0.332	0.354	0.374	0.401	0.419	0.438
590	0.275	0.311	0.334	0.355	0.374	0.401	0.419	0.438
589	0.275	0.312	0.334	0.356	0.375	0.402	0.42	0.439
588	0.275	0.312	0.334	0.356	0.375	0.402	0.42	0.439
587	0.276	0.312	0.334	0.357	0.377	0.404	0.421	0.44
586	0.276	0.312	0.335	0.357	0.377	0.404	0.421	0.44
585	0.276	0.313	0.335	0.358	0.377	0.405	0.423	0.442
584	0.277	0.313	0.335	0.358	0.378	0.405	0.424	0.443
583	0.277	0.313	0.335	0.358	0.378	0.405	0.424	0.443
582	0.277	0.313	0.336	0.358	0.379	0.406	0.424	0.443
581	0.277	0.314	0.336	0.359	0.379	0.406	0.425	0.444
580	0.277	0.314	0.336	0.359	0.379	0.407	0.425	0.444
579	0.278	0.314	0.337	0.359	0.38	0.407	0.425	0.444
578	0.278	0.314	0.337	0.36	0.38	0.407	0.426	0.445
577	0.278	0.315	0.337	0.36	0.38	0.408	0.426	0.445
576	0.279	0.315	0.338	0.36	0.381	0.408	0.427	0.446
575	0.279	0.315	0.338	0.361	0.381	0.409	0.427	0.446
574	0.279	0.316	0.338	0.361	0.381	0.409	0.428	0.447
573	0.279	0.316	0.339	0.362	0.382	0.41	0.428	0.447
572	0.28	0.316	0.339	0.362	0.382	0.41	0.429	0.448
571	0.28	0.316	0.34	0.362	0.383	0.411	0.43	0.449
570	0.28	0.317	0.34	0.363	0.384	0.412	0.43	0.449
569	0.28	0.317	0.34	0.364	0.384	0.412	0.431	0.45
568	0.28	0.317	0.341	0.364	0.385	0.413	0.432	0.451
567	0.281	0.318	0.341	0.365	0.385	0.414	0.433	0.452
566	0.281	0.318	0.342	0.365	0.386	0.415	0.434	0.453
565	0.281	0.319	0.342	0.366	0.387	0.415	0.434	0.453
564	0.282	0.319	0.343	0.366	0.387	0.416	0.435	0.454
563	0.282	0.319	0.343	0.367	0.388	0.417	0.436	0.455
562	0.282	0.32	0.344	0.368	0.389	0.418	0.437	0.456
561	0.282	0.32	0.344	0.368	0.389	0.418	0.438	0.457
560	0.282	0.32	0.344	0.369	0.39	0.419	0.439	0.458
559	0.283	0.321	0.345	0.369	0.39	0.42	0.439	0.458
558	0.283	0.321	0.345	0.37	0.391	0.421	0.44	0.459
557	0.283	0.321	0.346	0.37	0.392	0.421	0.441	0.46
556	0.283	0.322	0.346	0.371	0.393	0.422	0.442	0.461

555	0.284	0.322	0.347	0.371	0.393	0.423	0.443	0.462
554	0.284	0.322	0.347	0.372	0.394	0.424	0.444	0.463
553	0.284	0.323	0.348	0.373	0.395	0.425	0.445	0.464
552	0.284	0.323	0.348	0.373	0.395	0.426	0.446	0.465
551	0.285	0.324	0.349	0.374	0.396	0.427	0.447	0.466
550	0.285	0.324	0.349	0.375	0.397	0.427	0.448	0.467
549	0.285	0.324	0.35	0.375	0.398	0.428	0.449	0.468
548	0.285	0.325	0.35	0.376	0.398	0.429	0.45	0.469
547	0.285	0.325	0.35	0.376	0.399	0.43	0.451	0.47
546	0.286	0.326	0.351	0.377	0.4	0.431	0.452	0.471
545	0.286	0.326	0.351	0.378	0.401	0.432	0.453	0.472
544	0.286	0.326	0.352	0.378	0.401	0.433	0.454	0.473
543	0.286	0.327	0.352	0.379	0.402	0.433	0.455	0.474
542	0.287	0.327	0.353	0.379	0.403	0.434	0.456	0.475
541	0.287	0.327	0.353	0.38	0.403	0.435	0.457	0.476
540	0.287	0.328	0.354	0.381	0.404	0.436	0.457	0.476
539	0.287	0.328	0.354	0.381	0.405	0.437	0.458	0.477
538	0.288	0.329	0.355	0.382	0.405	0.437	0.459	0.478
537	0.288	0.329	0.355	0.382	0.406	0.438	0.46	0.479
536	0.288	0.329	0.356	0.383	0.407	0.439	0.461	0.48
535	0.288	0.33	0.356	0.383	0.407	0.439	0.462	0.481
534	0.289	0.33	0.357	0.384	0.408	0.44	0.463	0.482
533	0.289	0.33	0.357	0.385	0.409	0.441	0.464	0.483
532	0.289	0.331	0.357	0.385	0.409	0.442	0.465	0.484
531	0.289	0.331	0.358	0.386	0.41	0.443	0.466	0.485
530	0.29	0.332	0.358	0.386	0.411	0.444	0.467	0.486
529	0.29	0.332	0.359	0.387	0.412	0.445	0.468	0.487
528	0.29	0.332	0.359	0.388	0.413	0.446	0.469	0.488
527	0.291	0.333	0.36	0.388	0.413	0.446	0.47	0.489
526	0.291	0.333	0.36	0.389	0.414	0.448	0.471	0.49
525	0.291	0.334	0.361	0.39	0.415	0.448	0.472	0.491
524	0.291	0.334	0.362	0.39	0.416	0.449	0.473	0.492
523	0.291	0.335	0.362	0.391	0.417	0.451	0.475	0.494
522	0.292	0.335	0.363	0.392	0.418	0.452	0.476	0.495
521	0.292	0.335	0.363	0.393	0.419	0.453	0.477	0.496
520	0.292	0.336	0.364	0.394	0.42	0.454	0.478	0.497
519	0.293	0.337	0.365	0.394	0.421	0.455	0.48	0.499
518	0.293	0.337	0.365	0.395	0.421	0.456	0.481	0.5
517	0.293	0.337	0.366	0.396	0.422	0.457	0.482	0.501
516	0.293	0.338	0.366	0.397	0.423	0.458	0.483	0.502
515	0.294	0.338	0.367	0.397	0.424	0.459	0.485	0.504
514	0.294	0.339	0.367	0.398	0.425	0.46	0.486	0.505
513	0.294	0.339	0.368	0.399	0.426	0.462	0.487	0.506
512	0.294	0.34	0.369	0.4	0.427	0.463	0.489	0.508
511	0.295	0.34	0.37	0.401	0.428	0.464	0.49	0.509
510	0.295	0.341	0.37	0.401	0.429	0.465	0.492	0.511
509	0.295	0.341	0.371	0.402	0.43	0.467	0.493	0.512
508	0.295	0.342	0.372	0.403	0.431	0.468	0.494	0.513
507	0.295	0.342	0.372	0.404	0.432	0.469	0.496	0.515
506	0.295	0.342	0.372	0.404	0.433	0.47	0.497	0.516

505	0.296	0.343	0.373	0.405	0.434	0.471	0.498	0.517
504	0.296	0.343	0.374	0.406	0.435	0.472	0.499	0.518
503	0.296	0.344	0.374	0.406	0.436	0.473	0.501	0.52
502	0.296	0.344	0.375	0.407	0.437	0.474	0.502	0.521
501	0.297	0.345	0.375	0.408	0.438	0.476	0.504	0.523
500	0.297	0.345	0.376	0.409	0.439	0.477	0.505	0.524
499	0.297	0.345	0.377	0.41	0.439	0.478	0.506	0.525
498	0.298	0.346	0.377	0.41	0.44	0.479	0.507	0.526
497	0.298	0.346	0.378	0.411	0.441	0.48	0.508	0.527
496	0.298	0.346	0.378	0.412	0.442	0.48	0.509	0.528
495	0.298	0.347	0.379	0.412	0.442	0.481	0.51	0.529
494	0.299	0.347	0.379	0.413	0.443	0.482	0.511	0.53
493	0.299	0.347	0.379	0.413	0.444	0.483	0.511	0.53
492	0.299	0.348	0.38	0.414	0.444	0.483	0.512	0.531
491	0.299	0.348	0.38	0.414	0.445	0.484	0.513	0.532
490	0.3	0.348	0.381	0.415	0.445	0.484	0.514	0.533
489	0.3	0.349	0.381	0.415	0.446	0.485	0.514	0.533
488	0.3	0.349	0.381	0.416	0.446	0.485	0.514	0.535
487	0.3	0.35	0.382	0.416	0.447	0.486	0.515	0.536
486	0.301	0.35	0.382	0.416	0.447	0.486	0.516	0.544
485	0.301	0.35	0.382	0.417	0.447	0.487	0.516	0.538
484	0.301	0.35	0.383	0.417	0.448	0.487	0.516	0.539
483	0.302	0.351	0.383	0.418	0.448	0.487	0.516	0.544
482	0.302	0.351	0.383	0.418	0.449	0.488	0.516	0.544
481	0.302	0.352	0.384	0.419	0.45	0.489	0.517	0.545
480	0.302	0.352	0.384	0.419	0.45	0.489	0.518	0.546
479	0.303	0.352	0.385	0.42	0.451	0.489	0.519	0.547
478	0.303	0.353	0.385	0.42	0.452	0.49	0.52	0.548
477	0.303	0.353	0.386	0.421	0.453	0.491	0.521	0.549
476	0.303	0.353	0.386	0.422	0.453	0.492	0.522	0.55
475	0.304	0.354	0.387	0.422	0.454	0.493	0.523	0.551
474	0.304	0.354	0.388	0.423	0.455	0.494	0.525	0.553
473	0.304	0.355	0.388	0.424	0.456	0.495	0.526	0.554
472	0.305	0.355	0.389	0.425	0.456	0.497	0.527	0.555
471	0.305	0.356	0.389	0.425	0.457	0.498	0.529	0.557
470	0.305	0.356	0.39	0.426	0.458	0.5	0.531	0.559
469	0.305	0.357	0.391	0.427	0.459	0.501	0.532	0.56
468	0.306	0.357	0.391	0.428	0.46	0.502	0.534	0.562
467	0.306	0.358	0.392	0.429	0.461	0.503	0.535	0.563
466	0.306	0.358	0.392	0.429	0.462	0.505	0.537	0.565
465	0.306	0.359	0.393	0.429	0.463	0.506	0.538	0.566
464	0.307	0.359	0.394	0.43	0.464	0.507	0.539	0.567
463	0.307	0.359	0.394	0.431	0.465	0.508	0.54	0.568
462	0.307	0.36	0.395	0.432	0.466	0.509	0.542	0.57
461	0.307	0.36	0.395	0.433	0.467	0.51	0.543	0.571
460	0.307	0.361	0.395	0.433	0.468	0.511	0.544	0.572
459	0.308	0.361	0.395	0.434	0.469	0.512	0.545	0.573
458	0.308	0.362	0.396	0.435	0.469	0.513	0.546	0.574
457	0.308	0.362	0.396	0.435	0.47	0.514	0.547	0.575
456	0.309	0.361	0.397	0.436	0.471	0.515	0.548	0.576

455	0.309	0.362	0.397	0.437	0.472	0.515	0.549	0.577
454	0.309	0.362	0.398	0.437	0.472	0.516	0.55	0.578
453	0.309	0.362	0.398	0.438	0.473	0.517	0.551	0.579
452	0.31	0.363	0.399	0.438	0.474	0.518	0.552	0.58
451	0.31	0.363	0.4	0.439	0.474	0.52	0.554	0.582
450	0.31	0.365	0.401	0.441	0.477	0.522	0.556	0.584
449	0.31	0.365	0.402	0.442	0.478	0.523	0.557	0.585
448	0.31	0.366	0.403	0.443	0.479	0.524	0.558	0.586
447	0.311	0.366	0.403	0.443	0.48	0.525	0.56	0.588
446	0.311	0.366	0.404	0.444	0.481	0.526	0.561	0.589
445	0.311	0.367	0.404	0.445	0.482	0.528	0.563	0.591
444	0.311	0.368	0.405	0.446	0.483	0.529	0.564	0.592
443	0.312	0.368	0.406	0.447	0.484	0.53	0.565	0.593
442	0.312	0.368	0.406	0.448	0.485	0.531	0.566	0.594
441	0.312	0.369	0.407	0.448	0.486	0.532	0.567	0.595
440	0.312	0.369	0.407	0.449	0.486	0.533	0.568	0.596
439	0.313	0.37	0.408	0.449	0.487	0.533	0.569	0.597
438	0.313	0.37	0.408	0.45	0.487	0.534	0.57	0.598
437	0.313	0.37	0.408	0.45	0.488	0.534	0.57	0.598
436	0.313	0.37	0.409	0.451	0.488	0.535	0.57	0.598
435	0.313	0.371	0.409	0.451	0.488	0.534	0.571	0.599
434	0.314	0.371	0.409	0.451	0.488	0.535	0.571	0.599
433	0.314	0.371	0.41	0.451	0.489	0.535	0.571	0.599
432	0.314	0.371	0.41	0.451	0.489	0.535	0.571	0.599
431	0.314	0.371	0.41	0.452	0.489	0.535	0.571	0.599
430	0.315	0.372	0.41	0.452	0.489	0.535	0.571	0.599
429	0.315	0.372	0.41	0.452	0.489	0.535	0.571	0.599
428	0.315	0.372	0.411	0.452	0.489	0.536	0.571	0.599
427	0.315	0.373	0.411	0.452	0.489	0.536	0.571	0.599
426	0.316	0.373	0.411	0.452	0.49	0.536	0.572	0.6
425	0.316	0.373	0.411	0.453	0.49	0.536	0.572	0.6
424	0.316	0.373	0.411	0.453	0.49	0.536	0.572	0.6
423	0.317	0.373	0.412	0.453	0.491	0.537	0.573	0.601
422	0.317	0.374	0.412	0.454	0.491	0.537	0.573	0.601
421	0.317	0.374	0.412	0.454	0.492	0.538	0.573	0.601
420	0.317	0.374	0.412	0.454	0.492	0.538	0.574	0.602
419	0.317	0.374	0.413	0.454	0.492	0.538	0.574	0.602
418	0.318	0.375	0.413	0.455	0.492	0.539	0.575	0.603
417	0.318	0.375	0.413	0.455	0.493	0.539	0.575	0.603
416	0.318	0.375	0.414	0.455	0.493	0.539	0.575	0.603
415	0.318	0.376	0.414	0.456	0.493	0.539	0.575	0.603
414	0.319	0.376	0.414	0.456	0.494	0.54	0.575	0.603
413	0.319	0.376	0.414	0.456	0.493	0.539	0.575	0.603
412	0.319	0.376	0.414	0.456	0.493	0.539	0.576	0.604
411	0.319	0.376	0.414	0.456	0.494	0.539	0.576	0.604
410	0.319	0.376	0.415	0.456	0.494	0.539	0.576	0.604
409	0.319	0.377	0.415	0.456	0.494	0.54	0.576	0.604
408	0.32	0.377	0.415	0.456	0.494	0.54	0.576	0.604
407	0.32	0.377	0.415	0.457	0.494	0.54	0.576	0.604
406	0.32	0.377	0.415	0.457	0.494	0.54	0.576	0.604

405	0.32	0.377	0.415	0.457	0.494	0.54	0.576	0.604
404	0.32	0.377	0.415	0.457	0.494	0.54	0.576	0.604
403	0.321	0.378	0.416	0.457	0.494	0.54	0.576	0.604
402	0.321	0.378	0.416	0.457	0.494	0.54	0.576	0.604
401	0.321	0.378	0.416	0.457	0.495	0.54	0.576	0.604
400	0.322	0.378	0.416	0.458	0.495	0.54	0.576	0.604
399	0.322	0.379	0.416	0.458	0.495	0.541	0.577	0.605
398	0.322	0.379	0.417	0.458	0.495	0.541	0.578	0.606
397	0.322	0.379	0.417	0.458	0.496	0.542	0.578	0.606
396	0.322	0.38	0.417	0.459	0.496	0.542	0.578	0.606
395	0.323	0.38	0.418	0.46	0.497	0.543	0.579	0.607
394	0.323	0.38	0.418	0.46	0.497	0.543	0.579	0.607
393	0.323	0.38	0.419	0.46	0.498	0.544	0.58	0.608
392	0.323	0.381	0.419	0.461	0.498	0.544	0.581	0.609
391	0.324	0.381	0.42	0.461	0.499	0.545	0.581	0.609
390	0.324	0.381	0.42	0.461	0.499	0.545	0.582	0.61
389	0.324	0.382	0.42	0.462	0.5	0.546	0.582	0.61
388	0.325	0.382	0.42	0.462	0.5	0.547	0.583	0.611
387	0.325	0.382	0.421	0.463	0.501	0.547	0.583	0.611
386	0.325	0.382	0.421	0.463	0.501	0.547	0.583	0.611
385	0.325	0.382	0.421	0.463	0.501	0.548	0.584	0.612
384	0.325	0.383	0.422	0.464	0.502	0.548	0.585	0.613
383	0.325	0.383	0.422	0.464	0.502	0.549	0.585	0.613
382	0.325	0.383	0.422	0.464	0.502	0.549	0.586	0.614
381	0.325	0.384	0.417	0.464	0.498	0.534	0.574	0.602
380	0.317	0.374	0.411	0.454	0.49	0.533	0.564	0.592
379	0.318	0.373	0.411	0.451	0.489	0.532	0.565	0.59
378	0.319	0.372	0.411	0.45	0.492	0.534	0.567	0.592
377	0.321	0.375	0.412	0.454	0.49	0.534	0.568	0.593
376	0.319	0.376	0.412	0.453	0.492	0.536	0.57	0.595
375	0.321	0.377	0.415	0.455	0.492	0.536	0.571	0.596
374	0.322	0.378	0.414	0.453	0.492	0.536	0.572	0.597
373	0.322	0.376	0.415	0.454	0.493	0.537	0.571	0.596
372	0.322	0.378	0.417	0.456	0.493	0.538	0.572	0.597
371	0.322	0.379	0.416	0.457	0.493	0.539	0.574	0.599
370	0.323	0.38	0.417	0.458	0.495	0.539	0.574	0.599
369	0.323	0.379	0.416	0.457	0.495	0.539	0.574	0.599
368	0.322	0.379	0.416	0.457	0.495	0.539	0.573	0.598
367	0.322	0.379	0.418	0.457	0.496	0.542	0.574	0.599
366	0.323	0.381	0.418	0.459	0.498	0.541	0.576	0.601
365	0.324	0.382	0.42	0.46	0.497	0.542	0.577	0.602
364	0.324	0.382	0.419	0.46	0.498	0.542	0.577	0.602
363	0.324	0.382	0.418	0.46	0.498	0.543	0.579	0.604
362	0.324	0.382	0.42	0.461	0.498	0.544	0.579	0.604
361	0.324	0.382	0.419	0.461	0.499	0.543	0.58	0.605
360	0.324	0.381	0.42	0.461	0.498	0.545	0.581	0.606
359	0.324	0.382	0.42	0.461	0.5	0.546	0.582	0.607
358	0.325	0.383	0.42	0.462	0.501	0.547	0.583	0.608
357	0.326	0.383	0.422	0.464	0.502	0.548	0.583	0.608
356	0.325	0.383	0.423	0.463	0.502	0.548	0.584	0.609

355	0.324	0.383	0.423	0.464	0.504	0.551	0.585	0.61
354	0.325	0.385	0.423	0.465	0.505	0.551	0.587	0.612
353	0.325	0.385	0.424	0.466	0.506	0.553	0.589	0.614
352	0.325	0.385	0.425	0.467	0.507	0.555	0.591	0.616
351	0.326	0.386	0.425	0.469	0.507	0.555	0.593	0.618
350	0.326	0.386	0.426	0.469	0.509	0.558	0.593	0.618
349	0.328	0.387	0.426	0.471	0.512	0.56	0.596	0.621
348	0.329	0.387	0.427	0.472	0.513	0.561	0.598	0.623
347	0.329	0.387	0.428	0.473	0.514	0.563	0.6	0.625
346	0.33	0.389	0.429	0.475	0.515	0.565	0.602	0.627
345	0.329	0.389	0.43	0.475	0.516	0.566	0.604	0.629
344	0.329	0.389	0.431	0.476	0.517	0.568	0.605	0.63
343	0.33	0.389	0.432	0.477	0.519	0.57	0.607	0.632
342	0.332	0.392	0.433	0.479	0.52	0.57	0.609	0.634
341	0.332	0.392	0.433	0.479	0.522	0.571	0.61	0.635
340	0.331	0.391	0.433	0.48	0.522	0.573	0.612	0.637
339	0.33	0.392	0.434	0.48	0.523	0.574	0.614	0.639
338	0.331	0.392	0.435	0.481	0.524	0.576	0.615	0.64
337	0.332	0.393	0.436	0.482	0.526	0.578	0.618	0.643
336	0.332	0.393	0.436	0.483	0.527	0.579	0.618	0.643
335	0.332	0.394	0.437	0.484	0.528	0.579	0.62	0.645
334	0.331	0.394	0.437	0.485	0.529	0.582	0.62	0.645
333	0.332	0.395	0.438	0.485	0.53	0.583	0.623	0.648
332	0.332	0.396	0.439	0.487	0.531	0.584	0.624	0.649
331	0.332	0.396	0.439	0.488	0.532	0.584	0.625	0.65
330	0.332	0.395	0.44	0.489	0.533	0.585	0.626	0.651
329	0.332	0.395	0.44	0.488	0.534	0.587	0.628	0.653
328	0.333	0.397	0.441	0.49	0.535	0.589	0.63	0.655
327	0.333	0.397	0.442	0.491	0.537	0.59	0.632	0.657
326	0.334	0.398	0.443	0.492	0.538	0.591	0.634	0.659
325	0.333	0.398	0.443	0.493	0.539	0.593	0.635	0.66
324	0.333	0.398	0.444	0.494	0.54	0.593	0.636	0.661
323	0.333	0.398	0.445	0.494	0.542	0.596	0.638	0.663
322	0.334	0.399	0.446	0.496	0.543	0.597	0.64	0.665
321	0.334	0.4	0.446	0.498	0.544	0.6	0.642	0.667
320	0.335	0.402	0.448	0.498	0.546	0.601	0.644	0.669
319	0.335	0.402	0.449	0.499	0.547	0.603	0.647	0.672
318	0.336	0.402	0.449	0.501	0.549	0.605	0.648	0.673
317	0.336	0.403	0.451	0.502	0.55	0.606	0.65	0.675
316	0.336	0.404	0.452	0.503	0.552	0.608	0.652	0.677
315	0.335	0.403	0.451	0.503	0.553	0.61	0.655	0.68
314	0.335	0.404	0.452	0.505	0.555	0.612	0.657	0.682
313	0.336	0.405	0.454	0.507	0.557	0.614	0.659	0.684
312	0.336	0.406	0.454	0.509	0.558	0.616	0.66	0.685
311	0.336	0.406	0.455	0.51	0.559	0.618	0.663	0.688
310	0.335	0.406	0.456	0.511	0.561	0.622	0.667	0.692
309	0.336	0.407	0.457	0.512	0.563	0.622	0.669	0.694
308	0.336	0.409	0.458	0.514	0.566	0.626	0.673	0.698
307	0.336	0.409	0.46	0.515	0.569	0.629	0.678	0.703
306	0.338	0.41	0.461	0.517	0.571	0.632	0.68	0.705

305	0.338	0.411	0.463	0.52	0.574	0.635	0.683	0.708
304	0.337	0.412	0.463	0.521	0.576	0.637	0.686	0.711
303	0.337	0.413	0.464	0.524	0.578	0.642	0.69	0.715
302	0.337	0.414	0.466	0.525	0.581	0.644	0.694	0.719
301	0.338	0.414	0.475	0.527	0.593	0.683	0.728	0.753
300	0.349	0.431	0.489	0.554	0.616	0.688	0.747	0.792
299	0.35	0.432	0.491	0.557	0.619	0.692	0.752	0.831
298	0.351	0.434	0.493	0.559	0.623	0.697	0.757	0.844
297	0.351	0.435	0.495	0.563	0.627	0.703	0.764	0.864
296	0.351	0.436	0.498	0.566	0.632	0.71	0.772	0.872
295	0.351	0.438	0.501	0.571	0.638	0.717	0.78	0.88
294	0.352	0.44	0.504	0.575	0.644	0.725	0.789	0.889
293	0.352	0.442	0.507	0.579	0.649	0.732	0.797	0.897
292	0.353	0.444	0.51	0.584	0.654	0.739	0.805	0.905
291	0.353	0.446	0.513	0.588	0.66	0.745	0.813	0.913
290	0.353	0.448	0.516	0.592	0.665	0.752	0.821	0.921
289	0.354	0.449	0.519	0.596	0.671	0.759	0.829	0.929
288	0.354	0.451	0.522	0.6	0.676	0.767	0.837	0.937
287	0.355	0.453	0.525	0.605	0.683	0.774	0.846	0.946
286	0.355	0.455	0.528	0.609	0.688	0.782	0.855	0.955
285	0.356	0.457	0.531	0.614	0.695	0.788	0.863	0.963
284	0.356	0.459	0.534	0.618	0.7	0.794	0.871	0.971
283	0.357	0.461	0.536	0.622	0.704	0.799	0.877	0.977
282	0.357	0.462	0.539	0.625	0.709	0.804	0.884	0.984
281	0.357	0.464	0.541	0.629	0.713	0.809	0.89	0.99
280	0.358	0.465	0.543	0.632	0.717	0.814	0.895	0.995
279	0.358	0.466	0.546	0.635	0.721	0.818	0.9	1
278	0.359	0.468	0.548	0.638	0.724	0.823	0.906	1.006
277	0.359	0.469	0.55	0.641	0.729	0.827	0.912	1.012
276	0.36	0.471	0.552	0.644	0.732	0.833	0.918	1.018
275	0.361	0.472	0.554	0.647	0.737	0.838	0.924	1.024
274	0.361	0.474	0.557	0.651	0.741	0.843	0.93	1.03
273	0.362	0.476	0.559	0.653	0.745	0.848	0.936	1.036
272	0.362	0.477	0.561	0.657	0.748	0.852	0.941	1.041
271	0.363	0.478	0.563	0.659	0.752	0.856	0.946	1.046
270	0.364	0.48	0.565	0.662	0.756	0.86	0.951	1.051
269	0.365	0.482	0.567	0.665	0.759	0.864	0.955	1.055
268	0.365	0.483	0.569	0.668	0.762	0.868	0.959	1.059
267	0.366	0.485	0.571	0.671	0.765	0.871	0.963	1.063
266	0.367	0.486	0.573	0.673	0.768	0.874	0.966	1.066
265	0.367	0.487	0.575	0.675	0.771	0.878	0.97	1.07
264	0.368	0.489	0.577	0.678	0.774	0.881	0.973	1.073
263	0.369	0.49	0.578	0.68	0.776	0.883	0.976	1.076
262	0.368	0.49	0.579	0.681	0.778	0.886	0.979	1.079
261	0.369	0.492	0.58	0.683	0.78	0.889	0.983	1.083
260	0.371	0.493	0.582	0.685	0.783	0.892	0.986	1.086
259	0.372	0.494	0.584	0.687	0.785	0.893	0.988	1.088
258	0.373	0.496	0.585	0.688	0.787	0.896	0.991	1.091
257	0.374	0.497	0.587	0.69	0.789	0.898	0.993	1.093
256	0.375	0.498	0.588	0.692	0.79	0.9	0.994	1.094

255	0.376	0.499	0.59	0.693	0.792	0.902	0.997	1.097
254	0.377	0.501	0.591	0.695	0.794	0.904	1	1.1
253	0.378	0.503	0.593	0.697	0.797	0.907	1.002	1.102
252	0.379	0.504	0.595	0.699	0.799	0.91	1.006	1.106
251	0.381	0.506	0.598	0.702	0.802	0.914	1.01	1.11
250	0.383	0.508	0.6	0.705	0.805	0.917	1.014	1.114
249	0.385	0.511	0.603	0.708	0.809	0.922	1.018	1.118
248	0.387	0.513	0.606	0.711	0.813	0.927	1.023	1.123
247	0.389	0.516	0.609	0.715	0.818	0.933	1.029	1.129
246	0.391	0.519	0.613	0.72	0.823	0.939	1.037	1.137
245	0.394	0.523	0.618	0.725	0.829	0.947	1.045	1.145
244	0.396	0.527	0.623	0.73	0.837	0.957	1.055	1.155
243	0.4	0.531	0.629	0.738	0.846	0.968	1.068	1.168
242	0.403	0.537	0.636	0.746	0.856	0.981	1.081	1.181
241	0.406	0.542	0.643	0.755	0.867	0.996	1.098	1.198
240	0.41	0.548	0.652	0.766	0.881	1.014	1.117	1.217
239	0.414	0.556	0.662	0.778	0.897	1.035	1.139	1.239
238	0.419	0.563	0.674	0.792	0.915	1.058	1.166	1.266
237	0.423	0.572	0.687	0.809	0.936	1.086	1.198	1.298
236	0.429	0.583	0.702	0.828	0.96	1.116	1.232	1.332
235	0.434	0.594	0.718	0.848	0.986	1.149	1.27	1.37
234	0.439	0.605	0.736	0.871	1.015	1.189	1.311	1.411
233	0.446	0.619	0.756	0.897	1.047	1.231	1.358	1.458
232	0.452	0.633	0.778	0.926	1.084	1.277	1.41	1.51
231	0.46	0.649	0.802	0.957	1.125	1.329	1.469	1.569
230	0.468	0.667	0.829	0.992	1.171	1.386	1.533	1.633
229	0.476	0.687	0.859	1.031	1.221	1.451	1.606	1.706
228	0.486	0.709	0.895	1.074	1.28	1.536	1.697	1.797
227	0.499	0.739	0.939	1.133	1.354	1.629	1.801	1.901
226	0.515	0.772	0.988	1.197	1.435	1.73	1.916	2.016
225	0.531	0.808	1.04	1.265	1.521	1.837	2.037	2.137
224	0.55	0.847	1.099	1.338	1.616	1.958	2.169	2.269
223	0.573	0.893	1.166	1.423	1.723	2.09	2.313	2.413
222	0.6	0.945	1.238	1.513	1.837	2.229	2.466	2.566
221	0.633	1.003	1.32	1.614	1.964	2.393	2.636	2.736
220	0.675	1.076	1.418	1.732	2.111	2.566	2.813	2.913
219	0.731	1.163	1.533	1.868	2.271	2.742	3.004	3.104
218	0.8	1.264	1.666	2.018	2.446	2.92	3.159	3.259
217	0.894	1.39	1.821	2.19	2.634	3.111	3.228	3.328
216	1.003	1.531	1.988	2.371	2.806	3.213	3.36	3.46
215	1.133	1.683	2.159	2.548	2.96	3.348	3.398	3.498
214	1.274	1.846	2.338	2.726	3.095	3.415	3.455	3.555
213	1.439	2.032	2.528	2.899	3.184	3.428	3.437	3.537
212	1.635	2.235	2.701	3.067	3.278	3.493	3.542	3.642
211	1.843	2.437	2.871	3.179	3.339	3.504	3.61	3.71
210	2.051	2.635	3.008	3.229	3.351	3.46	3.658	3.758
209	2.278	2.817	3.107	3.301	3.436	3.496	3.579	3.679
208	2.525	2.981	3.174	3.375	3.449	3.517	3.572	3.672
207	2.751	3.092	3.239	3.373	3.486	3.501	3.555	3.655
206	2.884	3.162	3.272	3.385	3.492	3.451	3.558	3.658

205	2.947	3.212	3.268	3.361	3.427	3.458	3.668	3.768
204	2.949	3.185	3.253	3.387	3.518	3.497	3.694	3.794
203	2.978	3.176	3.25	3.379	3.466	3.468	3.82	3.92
202	2.993	3.181	3.275	3.402	3.481	3.471	3.684	3.784
201	2.981	3.141	3.266	3.395	3.419	3.47	3.73	3.83
200	3.027	3.151	2.154	3.343	2.347	0.005	1.21	1.31

nm	**240 mg/L**	**270 mg/L**	**300 mg/L**	**350 mg/L**	**400 mg/L**	**450 mg/L**	**500 mg/L**
800	0.381	0.405	0.427	0.471	0.516	0.56	0.603
799	0.381	0.405	0.427	0.471	0.516	0.56	0.603
798	0.379	0.403	0.425	0.469	0.514	0.558	0.601
797	0.378	0.402	0.424	0.468	0.513	0.557	0.6
796	0.379	0.403	0.425	0.469	0.514	0.558	0.601
795	0.378	0.402	0.424	0.468	0.513	0.557	0.6
794	0.379	0.403	0.425	0.469	0.514	0.558	0.601
793	0.379	0.403	0.425	0.469	0.514	0.558	0.601
792	0.38	0.404	0.426	0.47	0.515	0.559	0.602
791	0.38	0.404	0.426	0.47	0.515	0.559	0.602
790	0.38	0.404	0.426	0.47	0.515	0.559	0.602
789	0.38	0.404	0.426	0.47	0.515	0.559	0.602
788	0.38	0.404	0.426	0.47	0.515	0.559	0.602
787	0.381	0.405	0.427	0.471	0.516	0.56	0.603
786	0.382	0.406	0.428	0.472	0.517	0.561	0.604
785	0.382	0.406	0.428	0.472	0.517	0.561	0.604
784	0.382	0.406	0.428	0.472	0.517	0.561	0.604
783	0.382	0.406	0.428	0.472	0.517	0.561	0.604
782	0.382	0.406	0.428	0.472	0.517	0.561	0.604
781	0.382	0.406	0.428	0.472	0.517	0.561	0.604
780	0.383	0.407	0.429	0.473	0.518	0.562	0.605
779	0.383	0.407	0.429	0.473	0.518	0.562	0.605
778	0.383	0.407	0.429	0.473	0.518	0.562	0.605
777	0.384	0.408	0.43	0.474	0.519	0.563	0.606
776	0.384	0.408	0.43	0.474	0.519	0.563	0.606
775	0.384	0.408	0.43	0.474	0.519	0.563	0.606
774	0.385	0.409	0.431	0.475	0.52	0.564	0.607
773	0.385	0.409	0.431	0.475	0.52	0.564	0.607
772	0.385	0.409	0.431	0.475	0.52	0.564	0.607
771	0.386	0.41	0.432	0.476	0.521	0.565	0.608
770	0.386	0.41	0.432	0.476	0.521	0.565	0.608
769	0.386	0.41	0.432	0.476	0.521	0.565	0.608
768	0.386	0.41	0.432	0.476	0.521	0.565	0.608
767	0.387	0.411	0.433	0.477	0.522	0.566	0.609
766	0.387	0.411	0.433	0.477	0.522	0.566	0.609
765	0.388	0.412	0.434	0.478	0.523	0.567	0.61
764	0.388	0.412	0.434	0.478	0.523	0.567	0.61
763	0.389	0.413	0.435	0.479	0.524	0.568	0.611
762	0.389	0.413	0.435	0.479	0.524	0.568	0.611
761	0.389	0.413	0.435	0.479	0.524	0.568	0.611

760	0.389	0.413	0.435	0.479	0.524	0.568	0.611
759	0.39	0.414	0.436	0.48	0.525	0.569	0.612
758	0.39	0.414	0.436	0.48	0.525	0.569	0.612
757	0.391	0.415	0.437	0.481	0.526	0.57	0.613
756	0.391	0.415	0.437	0.481	0.526	0.57	0.613
755	0.391	0.415	0.437	0.481	0.526	0.57	0.613
754	0.391	0.415	0.437	0.481	0.526	0.57	0.613
753	0.392	0.416	0.438	0.482	0.527	0.571	0.614
752	0.392	0.416	0.438	0.482	0.527	0.571	0.614
751	0.393	0.417	0.439	0.483	0.528	0.572	0.615
750	0.393	0.417	0.439	0.483	0.528	0.572	0.615
749	0.393	0.417	0.439	0.483	0.528	0.572	0.615
748	0.394	0.418	0.44	0.484	0.529	0.573	0.616
747	0.394	0.418	0.44	0.484	0.529	0.573	0.616
746	0.394	0.418	0.44	0.484	0.529	0.573	0.616
745	0.394	0.418	0.44	0.484	0.529	0.573	0.616
744	0.395	0.419	0.441	0.485	0.53	0.574	0.617
743	0.395	0.419	0.441	0.485	0.53	0.574	0.617
742	0.395	0.419	0.441	0.485	0.53	0.574	0.617
741	0.396	0.42	0.442	0.486	0.531	0.575	0.618
740	0.396	0.42	0.442	0.486	0.531	0.575	0.618
739	0.396	0.42	0.442	0.486	0.531	0.575	0.618
738	0.396	0.42	0.442	0.486	0.531	0.575	0.618
737	0.397	0.421	0.443	0.487	0.532	0.576	0.619
736	0.397	0.421	0.443	0.487	0.532	0.576	0.619
735	0.398	0.422	0.444	0.488	0.533	0.577	0.62
734	0.398	0.422	0.444	0.488	0.533	0.577	0.62
733	0.398	0.422	0.444	0.488	0.533	0.577	0.62
732	0.399	0.423	0.445	0.489	0.534	0.578	0.621
731	0.399	0.423	0.445	0.489	0.534	0.578	0.621
730	0.4	0.424	0.446	0.49	0.535	0.579	0.622
729	0.4	0.424	0.446	0.49	0.535	0.579	0.622
728	0.401	0.425	0.447	0.491	0.536	0.58	0.623
727	0.401	0.425	0.447	0.491	0.536	0.58	0.623
726	0.402	0.426	0.448	0.492	0.537	0.581	0.624
725	0.402	0.426	0.448	0.492	0.537	0.581	0.624
724	0.402	0.426	0.448	0.492	0.537	0.581	0.624
723	0.403	0.427	0.449	0.493	0.538	0.582	0.625
722	0.403	0.427	0.449	0.493	0.538	0.582	0.625
721	0.404	0.428	0.45	0.494	0.539	0.583	0.626
720	0.404	0.428	0.45	0.494	0.539	0.583	0.626
719	0.405	0.429	0.451	0.495	0.54	0.584	0.627
718	0.405	0.429	0.451	0.495	0.54	0.584	0.627
717	0.406	0.43	0.452	0.496	0.541	0.585	0.628
716	0.406	0.43	0.452	0.496	0.541	0.585	0.628
715	0.407	0.431	0.453	0.497	0.542	0.586	0.629
714	0.407	0.431	0.453	0.497	0.542	0.586	0.629
713	0.408	0.432	0.454	0.498	0.543	0.587	0.63
712	0.408	0.432	0.454	0.498	0.543	0.587	0.63
711	0.409	0.433	0.455	0.499	0.544	0.588	0.631

710	0.41	0.434	0.456	0.5	0.545	0.589	0.632
709	0.41	0.434	0.456	0.5	0.545	0.589	0.632
708	0.411	0.435	0.457	0.501	0.546	0.59	0.633
707	0.412	0.436	0.458	0.502	0.547	0.591	0.634
706	0.413	0.437	0.459	0.503	0.548	0.592	0.635
705	0.413	0.437	0.459	0.503	0.548	0.592	0.635
704	0.414	0.438	0.46	0.504	0.549	0.593	0.636
703	0.415	0.439	0.461	0.505	0.55	0.594	0.637
702	0.416	0.44	0.462	0.506	0.551	0.595	0.638
701	0.417	0.441	0.463	0.507	0.552	0.596	0.639
700	0.418	0.442	0.464	0.508	0.553	0.597	0.64
699	0.42	0.444	0.466	0.51	0.555	0.599	0.642
698	0.421	0.445	0.467	0.511	0.556	0.6	0.643
697	0.423	0.447	0.469	0.513	0.558	0.602	0.645
696	0.425	0.449	0.471	0.515	0.56	0.604	0.647
695	0.427	0.451	0.473	0.517	0.562	0.606	0.649
694	0.429	0.453	0.475	0.519	0.564	0.608	0.651
693	0.432	0.456	0.478	0.522	0.567	0.611	0.654
692	0.434	0.458	0.48	0.524	0.569	0.613	0.656
691	0.437	0.461	0.483	0.527	0.572	0.616	0.659
690	0.44	0.464	0.486	0.53	0.575	0.619	0.662
689	0.443	0.467	0.489	0.533	0.578	0.622	0.665
688	0.446	0.47	0.492	0.536	0.581	0.625	0.668
687	0.448	0.472	0.494	0.538	0.583	0.627	0.67
686	0.451	0.475	0.497	0.541	0.586	0.63	0.673
685	0.454	0.478	0.5	0.544	0.589	0.633	0.676
684	0.456	0.48	0.502	0.546	0.591	0.635	0.678
683	0.458	0.482	0.504	0.548	0.593	0.637	0.68
682	0.46	0.484	0.506	0.55	0.595	0.639	0.682
681	0.461	0.485	0.507	0.551	0.596	0.64	0.683
680	0.462	0.486	0.508	0.552	0.597	0.641	0.684
679	0.464	0.488	0.51	0.554	0.599	0.643	0.686
678	0.465	0.489	0.511	0.555	0.6	0.644	0.687
677	0.465	0.489	0.511	0.555	0.6	0.644	0.687
676	0.466	0.49	0.512	0.556	0.601	0.645	0.688
675	0.466	0.49	0.512	0.556	0.601	0.645	0.688
674	0.466	0.49	0.512	0.556	0.601	0.645	0.688
673	0.465	0.489	0.511	0.555	0.6	0.644	0.687
672	0.464	0.488	0.51	0.554	0.599	0.643	0.686
671	0.463	0.487	0.509	0.553	0.598	0.642	0.685
670	0.461	0.485	0.507	0.551	0.596	0.64	0.683
669	0.459	0.483	0.505	0.549	0.594	0.638	0.681
668	0.457	0.481	0.503	0.547	0.592	0.636	0.679
667	0.455	0.479	0.501	0.545	0.59	0.634	0.677
666	0.453	0.477	0.499	0.543	0.588	0.632	0.675
665	0.451	0.475	0.497	0.541	0.586	0.63	0.673
664	0.449	0.473	0.495	0.539	0.584	0.628	0.671
663	0.447	0.471	0.493	0.537	0.582	0.626	0.669
662	0.445	0.469	0.491	0.535	0.58	0.624	0.667
661	0.443	0.467	0.489	0.533	0.578	0.622	0.665

660	0.442	0.466	0.488	0.532	0.577	0.621	0.664
659	0.44	0.464	0.486	0.53	0.575	0.619	0.662
658	0.439	0.463	0.485	0.529	0.574	0.618	0.661
657	0.438	0.462	0.484	0.528	0.573	0.617	0.66
656	0.437	0.461	0.483	0.527	0.572	0.616	0.659
655	0.436	0.46	0.482	0.526	0.571	0.615	0.658
654	0.435	0.459	0.481	0.525	0.57	0.614	0.657
653	0.435	0.459	0.481	0.525	0.57	0.614	0.657
652	0.435	0.459	0.481	0.525	0.57	0.614	0.657
651	0.435	0.459	0.481	0.525	0.57	0.614	0.657
650	0.435	0.459	0.481	0.525	0.57	0.614	0.657
649	0.435	0.459	0.481	0.525	0.57	0.614	0.657
648	0.436	0.46	0.482	0.526	0.571	0.615	0.658
647	0.436	0.46	0.482	0.526	0.571	0.615	0.658
646	0.437	0.461	0.483	0.527	0.572	0.616	0.659
645	0.438	0.462	0.484	0.528	0.573	0.617	0.66
644	0.438	0.462	0.484	0.528	0.573	0.617	0.66
643	0.439	0.463	0.485	0.529	0.574	0.618	0.661
642	0.44	0.464	0.486	0.53	0.575	0.619	0.662
641	0.44	0.464	0.486	0.53	0.575	0.619	0.662
640	0.441	0.465	0.487	0.531	0.576	0.62	0.663
639	0.442	0.466	0.488	0.532	0.577	0.621	0.664
638	0.442	0.466	0.488	0.532	0.577	0.621	0.664
637	0.443	0.467	0.489	0.533	0.578	0.622	0.665
636	0.443	0.467	0.489	0.533	0.578	0.622	0.665
635	0.444	0.468	0.49	0.534	0.579	0.623	0.666
634	0.444	0.468	0.49	0.534	0.579	0.623	0.666
633	0.445	0.469	0.491	0.535	0.58	0.624	0.667
632	0.445	0.469	0.491	0.535	0.58	0.624	0.667
631	0.445	0.469	0.491	0.535	0.58	0.624	0.667
630	0.446	0.47	0.492	0.536	0.581	0.625	0.668
629	0.446	0.47	0.492	0.536	0.581	0.625	0.668
628	0.447	0.471	0.493	0.537	0.582	0.626	0.669
627	0.447	0.471	0.493	0.537	0.582	0.626	0.669
626	0.447	0.471	0.493	0.537	0.582	0.626	0.669
625	0.448	0.472	0.494	0.538	0.583	0.627	0.67
624	0.448	0.472	0.494	0.538	0.583	0.627	0.67
623	0.448	0.472	0.494	0.538	0.583	0.627	0.67
622	0.449	0.473	0.495	0.539	0.584	0.628	0.671
621	0.449	0.473	0.495	0.539	0.584	0.628	0.671
620	0.449	0.473	0.495	0.539	0.584	0.628	0.671
619	0.449	0.473	0.495	0.539	0.584	0.628	0.671
618	0.45	0.474	0.496	0.54	0.585	0.629	0.672
617	0.45	0.474	0.496	0.54	0.585	0.629	0.672
616	0.45	0.474	0.496	0.54	0.585	0.629	0.672
615	0.45	0.474	0.496	0.54	0.585	0.629	0.672
614	0.451	0.475	0.497	0.541	0.586	0.63	0.673
613	0.451	0.475	0.497	0.541	0.586	0.63	0.673
612	0.451	0.475	0.497	0.541	0.586	0.63	0.673
611	0.451	0.475	0.497	0.541	0.586	0.63	0.673

610	0.451	0.475	0.497	0.541	0.586	0.63	0.673
609	0.451	0.475	0.497	0.541	0.586	0.63	0.673
608	0.451	0.475	0.497	0.541	0.586	0.63	0.673
607	0.452	0.476	0.498	0.542	0.587	0.631	0.674
606	0.452	0.476	0.498	0.542	0.587	0.631	0.674
605	0.452	0.476	0.498	0.542	0.587	0.631	0.674
604	0.452	0.476	0.498	0.542	0.587	0.631	0.674
603	0.453	0.477	0.499	0.543	0.588	0.632	0.675
602	0.453	0.477	0.499	0.543	0.588	0.632	0.675
601	0.454	0.478	0.5	0.544	0.589	0.633	0.676
600	0.454	0.478	0.5	0.544	0.589	0.633	0.676
599	0.454	0.478	0.5	0.544	0.589	0.633	0.676
598	0.455	0.479	0.501	0.545	0.59	0.634	0.677
597	0.455	0.479	0.501	0.545	0.59	0.634	0.677
596	0.456	0.48	0.502	0.546	0.591	0.635	0.678
595	0.457	0.481	0.503	0.547	0.592	0.636	0.679
594	0.457	0.481	0.503	0.547	0.592	0.636	0.679
593	0.458	0.482	0.504	0.548	0.593	0.637	0.68
592	0.458	0.482	0.504	0.548	0.593	0.637	0.68
591	0.459	0.483	0.505	0.549	0.594	0.638	0.681
590	0.459	0.483	0.505	0.549	0.594	0.638	0.681
589	0.46	0.484	0.506	0.55	0.595	0.639	0.682
588	0.46	0.484	0.506	0.55	0.595	0.639	0.682
587	0.461	0.485	0.507	0.551	0.596	0.64	0.683
586	0.461	0.485	0.507	0.551	0.596	0.64	0.683
585	0.463	0.487	0.509	0.553	0.598	0.642	0.685
584	0.464	0.488	0.51	0.554	0.599	0.643	0.686
583	0.464	0.488	0.51	0.554	0.599	0.643	0.686
582	0.464	0.488	0.51	0.554	0.599	0.643	0.686
581	0.465	0.489	0.511	0.555	0.6	0.644	0.687
580	0.465	0.489	0.511	0.555	0.6	0.644	0.687
579	0.465	0.489	0.511	0.555	0.6	0.644	0.687
578	0.466	0.49	0.512	0.556	0.601	0.645	0.688
577	0.466	0.49	0.512	0.556	0.601	0.645	0.688
576	0.467	0.491	0.513	0.557	0.602	0.646	0.689
575	0.467	0.491	0.513	0.557	0.602	0.646	0.689
574	0.468	0.492	0.514	0.558	0.603	0.647	0.69
573	0.468	0.492	0.514	0.558	0.603	0.647	0.69
572	0.469	0.493	0.515	0.559	0.604	0.648	0.691
571	0.47	0.494	0.516	0.56	0.605	0.649	0.692
570	0.47	0.494	0.516	0.56	0.605	0.649	0.692
569	0.471	0.495	0.517	0.561	0.606	0.65	0.693
568	0.472	0.496	0.518	0.562	0.607	0.651	0.694
567	0.473	0.497	0.519	0.563	0.608	0.652	0.695
566	0.474	0.498	0.52	0.564	0.609	0.653	0.696
565	0.474	0.498	0.52	0.564	0.609	0.653	0.696
564	0.475	0.499	0.521	0.565	0.61	0.654	0.697
563	0.476	0.5	0.522	0.566	0.611	0.655	0.698
562	0.477	0.501	0.523	0.567	0.612	0.656	0.699
561	0.478	0.502	0.524	0.568	0.613	0.657	0.7

560	0.479	0.503	0.525	0.569	0.614	0.658	0.701
559	0.479	0.503	0.525	0.569	0.614	0.658	0.701
558	0.48	0.504	0.526	0.57	0.615	0.659	0.702
557	0.481	0.505	0.527	0.571	0.616	0.66	0.703
556	0.482	0.506	0.528	0.572	0.617	0.661	0.704
555	0.483	0.507	0.529	0.573	0.618	0.662	0.705
554	0.484	0.508	0.53	0.574	0.619	0.663	0.706
553	0.485	0.509	0.531	0.575	0.62	0.664	0.707
552	0.486	0.51	0.532	0.576	0.621	0.665	0.708
551	0.487	0.511	0.533	0.577	0.622	0.666	0.709
550	0.488	0.512	0.534	0.578	0.623	0.667	0.71
549	0.489	0.513	0.535	0.579	0.624	0.668	0.711
548	0.49	0.514	0.536	0.58	0.625	0.669	0.712
547	0.491	0.515	0.537	0.581	0.626	0.67	0.713
546	0.492	0.516	0.538	0.582	0.627	0.671	0.714
545	0.493	0.517	0.539	0.583	0.628	0.672	0.715
544	0.494	0.518	0.54	0.584	0.629	0.673	0.716
543	0.495	0.519	0.541	0.585	0.63	0.674	0.717
542	0.496	0.52	0.542	0.586	0.631	0.675	0.718
541	0.497	0.521	0.543	0.587	0.632	0.676	0.719
540	0.497	0.521	0.543	0.587	0.632	0.676	0.719
539	0.498	0.522	0.544	0.588	0.633	0.677	0.72
538	0.499	0.523	0.545	0.589	0.634	0.678	0.721
537	0.5	0.524	0.546	0.59	0.635	0.679	0.722
536	0.501	0.525	0.547	0.591	0.636	0.68	0.723
535	0.502	0.526	0.548	0.592	0.637	0.681	0.724
534	0.503	0.527	0.549	0.593	0.638	0.682	0.725
533	0.504	0.528	0.55	0.594	0.639	0.683	0.726
532	0.505	0.529	0.551	0.595	0.64	0.684	0.727
531	0.506	0.53	0.552	0.596	0.641	0.685	0.728
530	0.507	0.531	0.553	0.597	0.642	0.686	0.729
529	0.508	0.532	0.554	0.598	0.643	0.687	0.73
528	0.509	0.533	0.555	0.599	0.644	0.688	0.731
527	0.51	0.534	0.556	0.6	0.645	0.689	0.732
526	0.511	0.535	0.557	0.601	0.646	0.69	0.733
525	0.512	0.536	0.558	0.602	0.647	0.691	0.734
524	0.513	0.537	0.559	0.603	0.648	0.692	0.735
523	0.515	0.539	0.561	0.605	0.65	0.694	0.737
522	0.516	0.54	0.562	0.606	0.651	0.695	0.738
521	0.517	0.541	0.563	0.607	0.652	0.696	0.739
520	0.518	0.542	0.564	0.608	0.653	0.697	0.74
519	0.52	0.544	0.566	0.61	0.655	0.699	0.742
518	0.521	0.545	0.567	0.611	0.656	0.7	0.743
517	0.522	0.546	0.568	0.612	0.657	0.701	0.744
516	0.523	0.547	0.569	0.613	0.658	0.702	0.745
515	0.525	0.549	0.571	0.615	0.66	0.704	0.747
514	0.526	0.55	0.572	0.616	0.661	0.705	0.748
513	0.527	0.551	0.573	0.617	0.662	0.706	0.749
512	0.529	0.553	0.575	0.619	0.664	0.708	0.751
511	0.53	0.554	0.576	0.62	0.665	0.709	0.752

510	0.532	0.556	0.578	0.622	0.667	0.711	0.754
509	0.533	0.557	0.579	0.623	0.668	0.712	0.755
508	0.534	0.558	0.58	0.624	0.669	0.713	0.756
507	0.536	0.56	0.582	0.626	0.671	0.715	0.758
506	0.537	0.561	0.583	0.627	0.672	0.716	0.759
505	0.538	0.562	0.584	0.628	0.673	0.717	0.76
504	0.539	0.563	0.585	0.629	0.674	0.718	0.761
503	0.541	0.565	0.587	0.631	0.676	0.72	0.763
502	0.542	0.566	0.588	0.632	0.677	0.721	0.764
501	0.544	0.568	0.59	0.634	0.679	0.723	0.766
500	0.545	0.569	0.591	0.635	0.68	0.724	0.767
499	0.546	0.57	0.592	0.636	0.681	0.725	0.768
498	0.547	0.571	0.593	0.637	0.682	0.726	0.769
497	0.548	0.572	0.594	0.638	0.683	0.727	0.77
496	0.549	0.573	0.6	0.644	0.689	0.733	0.776
495	0.55	0.574	0.601	0.645	0.69	0.734	0.777
494	0.551	0.575	0.602	0.646	0.691	0.735	0.778
493	0.551	0.575	0.602	0.646	0.691	0.735	0.778
492	0.552	0.576	0.606	0.65	0.695	0.739	0.782
491	0.553	0.577	0.607	0.651	0.696	0.74	0.783
490	0.554	0.578	0.608	0.652	0.697	0.741	0.784
489	0.554	0.578	0.608	0.652	0.697	0.741	0.784
488	0.559	0.586	0.616	0.66	0.705	0.749	0.792
487	0.56	0.586	0.616	0.66	0.705	0.749	0.792
486	0.57	0.596	0.626	0.67	0.715	0.759	0.802
485	0.565	0.591	0.619	0.663	0.708	0.752	0.795
484	0.568	0.594	0.622	0.666	0.711	0.755	0.798
483	0.574	0.6	0.628	0.672	0.717	0.761	0.804
482	0.574	0.608	0.636	0.68	0.725	0.769	0.812
481	0.575	0.609	0.637	0.681	0.726	0.77	0.813
480	0.576	0.61	0.637	0.681	0.726	0.77	0.813
479	0.577	0.611	0.638	0.682	0.727	0.771	0.814
478	0.578	0.612	0.639	0.683	0.728	0.772	0.815
477	0.579	0.613	0.64	0.684	0.729	0.773	0.816
476	0.58	0.614	0.641	0.685	0.73	0.774	0.817
475	0.581	0.615	0.637	0.681	0.726	0.77	0.813
474	0.583	0.617	0.639	0.683	0.728	0.772	0.815
473	0.584	0.618	0.64	0.684	0.729	0.773	0.816
472	0.585	0.619	0.641	0.685	0.73	0.774	0.817
471	0.587	0.621	0.643	0.687	0.732	0.776	0.819
470	0.589	0.623	0.645	0.689	0.734	0.778	0.821
469	0.59	0.624	0.646	0.69	0.735	0.779	0.822
468	0.592	0.626	0.648	0.692	0.737	0.781	0.824
467	0.593	0.627	0.649	0.693	0.738	0.782	0.825
466	0.595	0.629	0.651	0.695	0.74	0.784	0.827
465	0.596	0.63	0.652	0.696	0.741	0.785	0.828
464	0.597	0.631	0.653	0.697	0.742	0.786	0.829
463	0.598	0.632	0.654	0.698	0.743	0.787	0.83
462	0.6	0.634	0.656	0.7	0.745	0.789	0.832
461	0.601	0.635	0.657	0.701	0.746	0.79	0.833

460	0.602	0.636	0.658	0.702	0.747	0.791	0.834
459	0.603	0.637	0.659	0.703	0.748	0.792	0.835
458	0.604	0.638	0.66	0.704	0.749	0.793	0.836
457	0.605	0.639	0.661	0.705	0.75	0.794	0.837
456	0.606	0.64	0.662	0.706	0.751	0.795	0.838
455	0.607	0.641	0.663	0.707	0.752	0.796	0.839
454	0.608	0.642	0.664	0.708	0.753	0.797	0.84
453	0.609	0.643	0.665	0.709	0.754	0.798	0.841
452	0.61	0.644	0.666	0.71	0.755	0.799	0.842
451	0.612	0.646	0.668	0.712	0.757	0.801	0.844
450	0.614	0.648	0.67	0.714	0.759	0.803	0.846
449	0.615	0.649	0.671	0.715	0.76	0.804	0.847
448	0.616	0.65	0.672	0.716	0.761	0.805	0.848
447	0.618	0.652	0.674	0.718	0.763	0.807	0.85
446	0.619	0.653	0.675	0.719	0.764	0.808	0.851
445	0.621	0.655	0.677	0.721	0.766	0.81	0.853
444	0.622	0.656	0.678	0.722	0.767	0.811	0.854
443	0.623	0.657	0.679	0.723	0.768	0.812	0.855
442	0.624	0.658	0.68	0.724	0.769	0.813	0.856
441	0.625	0.659	0.681	0.725	0.77	0.814	0.857
440	0.626	0.66	0.682	0.726	0.771	0.815	0.858
439	0.627	0.661	0.683	0.727	0.772	0.816	0.859
438	0.628	0.662	0.684	0.728	0.773	0.817	0.86
437	0.628	0.662	0.684	0.728	0.773	0.817	0.86
436	0.628	0.662	0.684	0.728	0.773	0.817	0.86
435	0.629	0.663	0.685	0.729	0.774	0.818	0.861
434	0.629	0.663	0.685	0.729	0.774	0.818	0.861
433	0.629	0.663	0.685	0.729	0.774	0.818	0.861
432	0.629	0.663	0.685	0.729	0.774	0.818	0.861
431	0.629	0.663	0.685	0.729	0.774	0.818	0.861
430	0.629	0.663	0.685	0.729	0.774	0.818	0.861
429	0.629	0.663	0.685	0.729	0.774	0.818	0.861
428	0.629	0.663	0.685	0.729	0.774	0.818	0.861
427	0.629	0.663	0.685	0.729	0.774	0.818	0.861
426	0.63	0.664	0.686	0.73	0.775	0.819	0.862
425	0.63	0.664	0.686	0.73	0.775	0.819	0.862
424	0.63	0.664	0.686	0.73	0.775	0.819	0.862
423	0.631	0.665	0.687	0.731	0.776	0.82	0.863
422	0.631	0.665	0.687	0.731	0.776	0.82	0.863
421	0.631	0.665	0.687	0.731	0.776	0.82	0.863
420	0.632	0.666	0.688	0.732	0.777	0.821	0.864
419	0.632	0.666	0.688	0.732	0.777	0.821	0.864
418	0.633	0.667	0.689	0.733	0.778	0.822	0.865
417	0.633	0.667	0.689	0.733	0.778	0.822	0.865
416	0.633	0.667	0.689	0.729	0.774	0.818	0.861
415	0.633	0.667	0.689	0.729	0.774	0.818	0.861
414	0.633	0.667	0.689	0.729	0.774	0.818	0.861
413	0.633	0.667	0.689	0.729	0.774	0.818	0.861
412	0.634	0.668	0.69	0.73	0.775	0.819	0.862
411	0.634	0.668	0.69	0.73	0.775	0.819	0.862

410	0.634	0.668	0.69	0.73	0.775	0.819	0.862
409	0.634	0.668	0.69	0.73	0.775	0.819	0.862
408	0.634	0.668	0.69	0.73	0.775	0.819	0.862
407	0.634	0.668	0.69	0.73	0.775	0.819	0.862
406	0.634	0.668	0.69	0.73	0.775	0.819	0.862
405	0.634	0.668	0.69	0.73	0.775	0.819	0.862
404	0.634	0.668	0.69	0.73	0.775	0.819	0.862
403	0.634	0.668	0.69	0.73	0.775	0.819	0.862
402	0.634	0.668	0.69	0.73	0.775	0.819	0.862
401	0.634	0.668	0.69	0.73	0.775	0.819	0.862
400	0.634	0.668	0.69	0.73	0.775	0.819	0.862
399	0.635	0.669	0.691	0.731	0.776	0.82	0.863
398	0.636	0.67	0.692	0.732	0.777	0.821	0.864
397	0.636	0.67	0.692	0.732	0.777	0.821	0.864
396	0.636	0.67	0.692	0.732	0.777	0.821	0.864
395	0.637	0.671	0.693	0.733	0.778	0.822	0.865
394	0.637	0.671	0.693	0.733	0.778	0.822	0.865
393	0.638	0.672	0.694	0.734	0.779	0.823	0.866
392	0.639	0.673	0.695	0.735	0.78	0.824	0.867
391	0.639	0.673	0.695	0.735	0.78	0.824	0.867
390	0.64	0.674	0.696	0.736	0.781	0.825	0.868
389	0.64	0.671	0.693	0.733	0.778	0.822	0.865
388	0.641	0.672	0.694	0.734	0.779	0.823	0.866
387	0.641	0.67	0.692	0.732	0.777	0.821	0.864
386	0.641	0.67	0.692	0.732	0.777	0.821	0.864
385	0.642	0.671	0.693	0.733	0.778	0.822	0.865
384	0.643	0.67	0.692	0.732	0.777	0.821	0.864
383	0.643	0.67	0.692	0.732	0.777	0.821	0.864
382	0.644	0.671	0.693	0.733	0.778	0.822	0.865
381	0.632	0.659	0.681	0.721	0.766	0.81	0.853
380	0.622	0.649	0.671	0.711	0.756	0.8	0.843
379	0.617	0.644	0.666	0.706	0.751	0.795	0.838
378	0.619	0.643	0.665	0.705	0.75	0.794	0.837
377	0.62	0.644	0.666	0.706	0.751	0.795	0.838
376	0.622	0.646	0.668	0.712	0.757	0.801	0.844
375	0.623	0.647	0.669	0.713	0.758	0.802	0.845
374	0.624	0.648	0.67	0.714	0.759	0.803	0.846
373	0.623	0.647	0.669	0.713	0.758	0.802	0.845
372	0.624	0.648	0.67	0.714	0.759	0.803	0.846
371	0.626	0.65	0.672	0.716	0.761	0.805	0.848
370	0.626	0.65	0.672	0.716	0.761	0.805	0.848
369	0.626	0.65	0.672	0.716	0.761	0.805	0.848
368	0.625	0.649	0.671	0.715	0.76	0.804	0.847
367	0.626	0.65	0.672	0.716	0.761	0.805	0.848
366	0.628	0.652	0.674	0.718	0.763	0.807	0.85
365	0.629	0.653	0.675	0.719	0.764	0.808	0.851
364	0.629	0.653	0.675	0.719	0.764	0.808	0.851
363	0.631	0.655	0.677	0.721	0.766	0.81	0.853
362	0.631	0.655	0.677	0.721	0.766	0.81	0.853
361	0.632	0.656	0.678	0.722	0.767	0.811	0.854

360	0.633	0.657	0.679	0.723	0.768	0.812	0.855
359	0.634	0.658	0.68	0.724	0.769	0.813	0.856
358	0.635	0.659	0.681	0.725	0.77	0.814	0.857
357	0.635	0.659	0.681	0.725	0.77	0.814	0.857
356	0.636	0.66	0.682	0.726	0.771	0.815	0.858
355	0.637	0.661	0.683	0.727	0.772	0.816	0.859
354	0.639	0.663	0.685	0.729	0.774	0.818	0.861
353	0.641	0.665	0.687	0.731	0.776	0.82	0.863
352	0.643	0.667	0.689	0.733	0.778	0.822	0.865
351	0.645	0.669	0.691	0.735	0.78	0.824	0.867
350	0.645	0.669	0.691	0.735	0.78	0.824	0.867
349	0.648	0.672	0.694	0.738	0.783	0.827	0.87
348	0.65	0.674	0.696	0.74	0.785	0.829	0.872
347	0.652	0.676	0.698	0.742	0.787	0.831	0.874
346	0.654	0.678	0.7	0.744	0.789	0.833	0.876
345	0.656	0.68	0.702	0.746	0.791	0.835	0.878
344	0.657	0.681	0.703	0.747	0.792	0.836	0.879
343	0.659	0.683	0.705	0.749	0.794	0.838	0.881
342	0.661	0.685	0.707	0.751	0.796	0.84	0.883
341	0.662	0.686	0.708	0.752	0.797	0.841	0.884
340	0.664	0.688	0.71	0.754	0.799	0.843	0.886
339	0.666	0.69	0.712	0.756	0.801	0.845	0.888
338	0.667	0.691	0.713	0.757	0.802	0.846	0.889
337	0.67	0.694	0.716	0.76	0.805	0.849	0.892
336	0.67	0.694	0.716	0.76	0.805	0.849	0.892
335	0.672	0.696	0.724	0.768	0.813	0.857	0.9
334	0.672	0.696	0.724	0.768	0.813	0.857	0.9
333	0.675	0.699	0.727	0.771	0.816	0.86	0.903
332	0.676	0.7	0.728	0.772	0.817	0.861	0.904
331	0.677	0.701	0.729	0.773	0.818	0.862	0.905
330	0.678	0.702	0.73	0.774	0.819	0.863	0.906
329	0.68	0.704	0.732	0.776	0.821	0.865	0.908
328	0.682	0.706	0.734	0.778	0.823	0.867	0.91
327	0.684	0.708	0.736	0.78	0.825	0.869	0.912
326	0.686	0.71	0.738	0.782	0.827	0.871	0.914
325	0.687	0.711	0.739	0.783	0.828	0.872	0.915
324	0.688	0.712	0.74	0.784	0.829	0.873	0.916
323	0.69	0.714	0.742	0.786	0.831	0.875	0.918
322	0.692	0.716	0.744	0.788	0.833	0.877	0.92
321	0.694	0.718	0.746	0.79	0.835	0.879	0.922
320	0.696	0.72	0.748	0.792	0.837	0.881	0.924
319	0.699	0.723	0.751	0.795	0.84	0.884	0.927
318	0.7	0.724	0.752	0.796	0.841	0.885	0.928
317	0.702	0.726	0.754	0.798	0.843	0.887	0.93
316	0.704	0.728	0.756	0.8	0.845	0.889	0.932
315	0.707	0.731	0.759	0.803	0.848	0.892	0.935
314	0.709	0.733	0.761	0.805	0.85	0.894	0.937
313	0.711	0.735	0.763	0.807	0.852	0.896	0.939
312	0.712	0.736	0.764	0.808	0.853	0.897	0.94
311	0.715	0.739	0.767	0.811	0.856	0.9	0.943

310	0.719	0.743	0.771	0.815	0.86	0.904	0.947
309	0.721	0.745	0.773	0.817	0.862	0.906	0.949
308	0.725	0.749	0.777	0.821	0.866	0.91	0.953
307	0.73	0.754	0.782	0.826	0.871	0.915	0.958
306	0.732	0.756	0.784	0.828	0.873	0.917	0.96
305	0.735	0.759	0.787	0.831	0.876	0.92	0.963
304	0.738	0.762	0.79	0.834	0.879	0.923	0.966
303	0.742	0.766	0.794	0.838	0.883	0.927	0.97
302	0.746	0.77	0.792	0.836	0.881	0.925	0.968
301	0.78	0.804	0.826	0.87	0.915	0.959	1.002
300	0.827	0.858	0.935	1.044	1.155	1.264	1.371
299	0.875	0.914	0.991	1.1	1.211	1.32	1.427
298	0.915	0.964	1.041	1.15	1.261	1.37	1.477
297	0.942	1.009	1.086	1.195	1.306	1.415	1.522
296	0.956	1.03	1.107	1.216	1.327	1.436	1.543
295	0.964	1.044	1.121	1.23	1.341	1.45	1.557
294	0.973	1.053	1.13	1.239	1.35	1.459	1.566
293	0.981	1.061	1.138	1.247	1.358	1.467	1.574
292	0.989	1.069	1.146	1.255	1.366	1.475	1.582
291	0.997	1.077	1.154	1.263	1.374	1.483	1.59
290	1.005	1.085	1.162	1.271	1.382	1.491	1.598
289	1.013	1.093	1.17	1.279	1.39	1.499	1.606
288	1.021	1.101	1.178	1.287	1.398	1.507	1.614
287	1.03	1.11	1.187	1.296	1.407	1.516	1.623
286	1.039	1.119	1.196	1.305	1.416	1.525	1.632
285	1.047	1.127	1.204	1.313	1.424	1.533	1.64
284	1.055	1.135	1.212	1.321	1.432	1.541	1.648
283	1.061	1.141	1.218	1.327	1.438	1.547	1.654
282	1.068	1.148	1.225	1.334	1.445	1.554	1.661
281	1.074	1.154	1.231	1.34	1.451	1.56	1.667
280	1.079	1.159	1.236	1.345	1.456	1.565	1.672
279	1.084	1.164	1.241	1.35	1.461	1.57	1.677
278	1.09	1.17	1.247	1.356	1.467	1.576	1.683
277	1.096	1.176	1.253	1.362	1.473	1.582	1.689
276	1.102	1.182	1.259	1.368	1.479	1.588	1.695
275	1.108	1.188	1.265	1.374	1.485	1.594	1.701
274	1.114	1.194	1.271	1.38	1.491	1.6	1.707
273	1.12	1.2	1.277	1.386	1.497	1.606	1.713
272	1.125	1.205	1.282	1.391	1.502	1.611	1.718
271	1.13	1.21	1.287	1.396	1.507	1.616	1.723
270	1.135	1.215	1.292	1.401	1.512	1.621	1.728
269	1.139	1.219	1.296	1.405	1.516	1.625	1.732
268	1.143	1.223	1.3	1.409	1.52	1.629	1.736
267	1.147	1.227	1.304	1.413	1.524	1.633	1.74
266	1.15	1.23	1.307	1.416	1.527	1.636	1.743
265	1.154	1.234	1.311	1.42	1.531	1.64	1.747
264	1.157	1.237	1.314	1.423	1.534	1.643	1.75
263	1.16	1.24	1.317	1.426	1.537	1.646	1.753
262	1.163	1.243	1.32	1.429	1.54	1.649	1.756
261	1.167	1.247	1.324	1.433	1.544	1.653	1.76

260	1.17	1.25	1.327	1.436	1.547	1.656	1.763
259	1.172	1.252	1.329	1.438	1.549	1.658	1.765
258	1.175	1.255	1.332	1.441	1.552	1.661	1.768
257	1.177	1.257	1.334	1.443	1.554	1.663	1.77
256	1.178	1.258	1.335	1.444	1.555	1.664	1.771
255	1.181	1.261	1.338	1.447	1.558	1.667	1.774
254	1.184	1.264	1.341	1.45	1.561	1.67	1.777
253	1.186	1.266	1.343	1.452	1.563	1.672	1.779
252	1.19	1.27	1.347	1.456	1.567	1.676	1.783
251	1.194	1.274	1.351	1.46	1.571	1.68	1.787
250	1.198	1.278	1.355	1.464	1.575	1.684	1.791
249	1.202	1.282	1.359	1.468	1.579	1.688	1.795
248	1.207	1.287	1.364	1.473	1.584	1.693	1.8
247	1.213	1.293	1.37	1.479	1.59	1.699	1.806
246	1.221	1.301	1.378	1.487	1.598	1.707	1.814
245	1.229	1.309	1.386	1.495	1.606	1.715	1.822
244	1.239	1.319	1.396	1.505	1.616	1.725	1.832
243	1.252	1.332	1.409	1.518	1.629	1.738	1.845
242	1.265	1.345	1.422	1.531	1.642	1.751	1.858
241	1.282	1.362	1.439	1.548	1.659	1.768	1.875
240	1.301	1.381	1.458	1.567	1.678	1.787	1.894
239	1.323	1.403	1.478	1.534	1.645	1.754	1.861
238	1.35	1.43	1.481	1.561	1.672	1.781	1.888
237	1.382	1.462	1.484	1.593	1.704	1.813	1.92
236	1.416	1.496	1.518	1.627	1.738	1.847	1.954
235	1.454	1.534	1.556	1.665	1.776	1.885	1.992
234	1.495	1.575	1.597	1.706	1.817	1.926	2.033
233	1.542	1.622	1.644	1.753	1.864	1.973	2.08
232	1.594	1.674	1.696	1.805	1.916	2.025	2.132
231	1.653	1.733	1.755	1.864	1.975	2.084	2.191
230	1.717	1.797	1.819	1.928	2.039	2.148	2.255
229	1.79	1.87	1.892	2.001	2.112	2.221	2.328
228	1.881	1.961	1.983	2.092	2.203	2.312	2.419
227	1.985	2.065	2.087	2.196	2.307	2.416	2.523
226	2.1	2.18	2.202	2.311	2.422	2.531	2.638
225	2.221	2.301	2.323	2.432	2.543	2.652	2.759
224	2.353	2.433	2.455	2.564	2.675	2.784	2.891
223	2.497	2.577	2.599	2.708	2.819	2.928	3.035
222	2.65	2.73	2.752	2.861	2.972	3.081	3.188
221	2.82	2.9	2.922	3.031	3.142	3.251	3.358
220	2.997	3.077	3.099	3.208	3.319	3.428	3.535
219	3.188	3.268	3.29	3.399	3.51	3.619	3.726
218	3.343	3.423	3.445	3.554	3.665	3.774	3.881
217	3.412	3.492	3.514	3.623	3.734	3.843	3.95
216	3.544	3.624	3.646	3.755	3.866	3.975	4.082
215	3.582	3.662	3.684	3.793	3.904	4.013	4.12
214	3.639	3.719	3.741	3.85	3.961	4.07	4.177
213	3.621	3.701	3.723	3.832	3.943	4.052	4.159
212	3.726	3.806	3.828	3.937	4.048	4.157	4.264
211	3.794	3.874	3.896	4.005	4.116	4.225	4.332

210	3.842	3.922	3.944	4.053	4.164	4.273	4.38
209	3.763	3.843	3.865	3.974	4.085	4.194	4.301
208	3.756	3.836	3.858	3.967	4.078	4.187	4.294
207	3.739	3.819	3.841	3.95	4.061	4.17	4.277
206	3.742	3.822	3.844	3.953	4.064	4.173	4.28
205	3.852	3.932	3.954	4.063	4.174	4.283	4.39
204	3.878	3.958	3.98	4.089	4.2	4.309	4.416
203	4.004	4.084	4.106	4.215	4.326	4.435	4.542
202	3.868	3.948	3.97	4.079	4.19	4.299	4.406
201	3.914	3.994	4.016	4.125	4.236	4.345	4.452
200	1.394	1.474	1.496	1.605	1.716	1.825	1.932

Table A-12. The peak wavelengths and their absorbance values for the three regions in electromagnetic spectra were obtained from wavelength sensitivity analysis of *T. weissflogii*.

Concentration (mg/L)	**Wavelength (nm)**	**Color**	**ABS**
0 (SW)	265	UVC	0.367
	430	Blue/Violet	0.312
	680	Red	0.252
30	265	UVC	0.486
	430	Blue/Violet	0.369
	680	Red	0.292
60	265	UVC	0.575
	430	Blue/Violet	0.407
	680	Red	0.318
90	265	UVC	0.675
	430	Blue/Violet	0.449
	680	Red	0.345
120	265	UVC	0.77
	430	Blue/Violet	0.486
	680	Red	0.368
150	265	UVC	0.878
	430	Blue/Violet	0.532
	680	Red	0.4
180	265	UVC	0.97
	430	Blue/Violet	0.568
	680	Red	0.422
210	265	UVC	1.07
	430	Blue/Violet	0.596
	680	Red	0.441
240	265	UVC	1.154
	430	Blue/Violet	0.626
	680	Red	0.462
270	265	UVC	1.234

	430	Blue/Violet	0.66
	680	Red	0.486
300	265	UVC	1.311
	430	Blue/Violet	0.685
	680	Red	0.508
350	265	UVC	1.42
	430	Blue/Violet	0.729
	680	Red	0.552
400	265	UVC	1.531
	430	Blue/Violet	0.774
	680	Red	0.597
450	265	UVC	1.64
	430	Blue/Violet	0.818
	680	Red	0.641
500	265	UVC	1.747
	430	Blue/Violet	0.861
	680	Red	0.684

Appendix B: Signal Processing Data

The raw data collected for the individual light readings (i.e. UVC, blue and red, in volts) and the ratios of B/U and R/U for *N. oculata*, *I.galbana* and *T.weissflogii* are shown in Table B-1, B-2 and B-3 respectively. The data was collected for pure microalgal samples to develop a statistical relationship among the individual readings in order to process the UVC reading.

Table B-1. The raw data for the individual light measurements (i.e. UVC, blue and red) and the ratios of B/U and R/U were obtained for different biomass concentrations of *N. oculata*.

Concn. (mg/L)	**Blue (V)**	**Red (V)**	**UVC (V)**	**B/U**	**R/U**
0	2.350	4.301	1.615	1.455	2.663
30	2.342	4.301	1.648	1.421	2.609
60	2.351	4.302	1.685	1.395	2.553
90	2.360	4.303	1.707	1.382	2.520
120	2.364	4.304	1.731	1.365	2.486
150	2.375	4.305	1.750	1.357	2.460
180	2.380	4.306	1.773	1.342	2.428
210	2.385	4.307	1.795	1.328	2.399
240	2.389	4.308	1.822	1.311	2.364
270	2.391	4.309	1.833	1.304	2.350
300	2.395	4.310	1.845	1.298	2.336
350	2.405	4.310	1.863	1.290	2.313
400	2.416	4.311	1.882	1.283	2.290
450	2.420	4.311	1.897	1.275	2.272
500	2.424	4.311	1.9	1.275	2.268

Table B-2. The raw data for the individual light measurements (i.e. UVC, blue and red) and the ratios of B/U and R/U were obtained for different biomass concentrations of *I. galbana*.

Concn. (mg/L)	**Blue (V)**	**Red (V)**	**UVC (V)**	**B/U**	**R/U**
0	2.35	4.302	1.615	1.478	2.663
30	2.375	4.302	1.63	1.477	2.639
60	2.4	4.303	1.645	1.477	2.615
90	2.43	4.304	1.66	1.475	2.592
120	2.46	4.305	1.679	1.474	2.564
150	2.48	4.305	1.685	1.471	2.554
180	2.499	4.305	1.694	1.470	2.541
210	2.516	4.306	1.703	1.467	2.528
240	2.535	4.306	1.716	1.466	2.509
270	2.554	4.306	1.728	1.465	2.491
300	2.564	4.306	1.739	1.464	2.476
350	2.579	4.307	1.754	1.463	2.455
400	2.583	4.308	1.761	1.458	2.446
450	2.591	4.308	1.766	1.457	2.439
500	2.599	4.31	1.775	1.455	2.428

Table B-3. The raw data for the individual light measurements (i.e. UVC, blue and red) and the ratios of B/U and R/U were obtained for different biomass concentrations of *T. weissflogii*.

Concn. (mg/L)	**Blue (V)**	**Red (V)**	**UVC (V)**	**B/U**	**R/U**
0	2.4	4.307	1.623	1.478	2.653
30	2.43	4.307	1.64	1.481	2.626
60	2.434	4.307	1.655	1.470	2.602
90	2.439	4.307	1.668	1.462	2.582
120	2.444	4.308	1.68	1.454	2.564
150	2.448	4.308	1.7	1.44	2.534
180	2.452	4.309	1.716	1.428	2.511
210	2.454	4.31	1.733	1.416	2.487
240	2.46	4.312	1.748	1.407	2.466
270	2.464	4.312	1.764	1.396	2.444
300	2.468	4.312	1.778	1.388	2.425
350	2.474	4.312	1.786	1.385	2.414
400	2.477	4.312	1.793	1.381	2.404
450	2.486	4.312	1.799	1.381	2.396
500	2.491	4.313	1.81	1.376	2.382

Appendix C: Biomass Transducer Calibration Data

The completely processed UVC readings (volts) for each of the pure microalgal species - *Nannnochloropsis oculata*, *Isochrysis galbana and Thalassiosira weissflogii,* were correlated with the corresponding microalgal biomass concentrations as shown in Tables C-1, C-2 and C-3. The completely processed UVC reading will use the regression coefficients generated from the calibration curve to give the correct the microalgal biomass reading in mg-dry wt/L.

Table C-1. The completely processed UVC measurements were obtained for the different microalgal biomass concentrations of *N. oculata*.

Concn. (mg/L)	**UVC (V)**
0	1.615
30	1.648
60	1.685
90	1.707
120	1.731
150	1.750
180	1.773
210	1.795
240	1.822
270	1.833
300	1.845
350	1.863
400	1.882
450	1.897
500	1.9

Table C-2. The completely processed UVC measurements were obtained for the different microalgal biomass concentrations of *I. galbana*.

Concn. (mg/L)	**UVC (V)**
0	1.615
30	1.63
60	1.645
90	1.66
120	1.679
150	1.685
180	1.694
210	1.703
240	1.716
270	1.728
300	1.739
350	1.754
400	1.761
450	1.766
500	1.775

Table C-3. The completely processed UVC measurements were obtained for the different microalgal biomass concentrations of *T. weissflogii*.

Concn. (mg/L)	**UVC (V)**
0	1.623
30	1.64
60	1.655
90	1.668
120	1.68
150	1.7
180	1.716
210	1.733
240	1.748
270	1.764
300	1.778
350	1.786
400	1.793
450	1.799
500	1.81

Appendix D: Biomass Transducer Testing Data

The data for the biomass transducer test for all the three species- *Nannnochloropsis oculata*, *Isochrysis galbana* and *Thalassiosira weissflogii* is given in the Tables D-1, D-2 and D-3. The data was collected after the statistical relationships were developed among the individual readings followed by UVC reading processing and development of the calibration curve. The tested samples were independent of the calibration curve. The transducer was tested for microalgal biomass estimation and compared with the true concentration.

Table D-1. The results of the biomass transducer testing were obtained after the transducer was calibrated with the different microalgal biomass concentrations of *N. oculata*.

True Concn. (mg/L)	**Est. Biomass (mg/L)**
0	5.5
50	52.3
100	103.2
150	154.2
200	205
250	249.8
300	304.5
350	353.2
400	404.7
450	457.1
500	505.3

Table D-2. The results of the biomass transducer testing were obtained after the transducer was calibrated with the different microalgal biomass concentrations of *I. galbana*.

True Concn. (mg/L)	**Est. Biomass (mg/L)**
0	11.3
50	64.8
100	92.1
150	165.6
200	217.8
250	258.9
300	317.4
350	331.6
400	393
450	471.3
500	531.6

Table D-3. The results of the biomass transducer testing were obtained after the transducer was calibrated with the different microalgal biomass concentrations of *T.weissflogii*.

True Concn. (mg/L)	**Est. Biomass (mg/L)**
0	16.6
50	67.4
100	114.7
150	169.1
200	189.7
250	271.3
300	334.7
350	339.4
400	427.5
450	483.4
500	547.3

Appendix E: Mixed Samples Test Data

The three microalgal species- *Nannnochloropsis oculata*, *Isochrysis galbana* and *Thalassiosira weissflogii* were mixed in different combinations and tested for microalgal biomass concentrations. The test was later compared with the TSS measurements (i.e. true biomass). The data for the TSS measurements conducted in laboratory is shown in Table E-1, and the data from the transducer with the TSS measurement is shown in shown in table E-2. A total of 28 different concentrations belonging to different combinations were run in replicates.The different combinations tested were:

N+I = *N. oculata* and *I. galbana*

I+T = *I. galbana* and *T. weissflogii*

N+T = *N. oculata* and *T. weissflogii*

N+I+T = *N. oculata*, *I. galbana* and *T. weissflogii*

Table E-1. The TSS results obtained in the laboratory were used for comparison with the transducer readings for different combinations of microalgal species.

SAMPLE	**PAN NO.**	**INITIAL WEIGHT (mg)**	**FINAL WEIGHT (mg)**	**Vol.**	**Avg TSS**
N+I	20	1109.4	1114.1	5	940
N+I	4	1101.3	1105.9	5	920
N+I	7	1107.8	1112.4	5	920
				Avg	920
I+T	11	1101.3	1108.6	5	1460
I+T	112	1112.2	1119.7	5	1500
I+T	10	1424.5	1432.6	5	1620
				Avg	1560
T+N	7	1107.6	1115.1	5	1500
T+N	12	1405.6	1412.2	5	1320
T+N	10	1424.6	1432.6	5	1600
				Avg	1460
N+I+T	6	1107.4	1115.8	5	1680
N+I+T	12	1405.7	1413.7	5	1600
N+I+T	7	1107.7	1116	5	1660
				Avg	1630

Sample	**TSS (mg/L)**
Blank	0
SW	70
N + I	920
Dry wt	**850**
Blank	0
SW	140
I + T	1560
Dry wt	**1420**
Blank	0
SW	140
T + N	1460
Dry wt	**1320**
Blank	0
SW	140
N + I + T	1630
Dry wt	**1490**

Table E-2. The biomass transducer readings and the TSS measurements of mixed species were tabulated for comparison.

Concn. (mg/L)	Estimated Biomass (mg/L)
N + I	
30	35.2
90	93.9
150	156.1
230	236.5
400	405.8
450	458.1
500	508.1
I + T	
10	14.9
50	51.4
100	103.6
180	187.8
250	251.3
430	439.3
480	489.1
T + N	
15	17.4
75	72
160	173.4
270	278.1
375	376
410	417.9
490	499.4
N + I + T	
0	5.5
60	56.6
130	135.3
210	216.6
340	346.6
440	446.1
470	478

Vita

Amar Shivaram Hegde was born on December 10, 1981, in Bangalore, India. He grew up in Bangalore, where he graduated from U.A.S Campus School in May 1997. He attended Seshadripuram Main College, Bangalore, where he earned Pre-university degree majoring in physics, chemistry and math. Following the Pre-university College, he attended R. V. College of Engineering, Bangalore, to earn a Bachelor of Engineering in Instrumentation Technology in July 2003. He became a full-time graduate student in January, 2004 at the Department of Electrical Engineering before changing the department to Engineering Science. Presently, he is a candidate for the degree of Master of Science in Engineering Science.