Roshi Dahal

Calibration of Water Quality Sensors; Pulp and Paper Mills

Helsinki Metropolia University of Applied Sciences

Bachelor of Engineering

Degree Programme in Environmental Engineering

Bachelor's Thesis

February, 2016

Author(s) Title Number of Pages	Roshi Dahal Calibration of Water Quality Sensors; Pulp and Paper Mills 28 pages + 2 appendices
Degree	Bachelor of Engineering
Degree Programme	Degree Programme in Environmental Engineering
Specialisation option	Water, Waste and Environmental Engineering
Instructor(s)	Kaj Lindedahl, Senior Lecturer Erkki Räsänen, CEO Langis Oy Dr.Minna Paananen Porkka, Academic English Lecturer

This thesis is a study of product prototype and provides an overview for the prospective user. The provided two different sensors were calibrated to check the accuracy of their measurements; results were also compared with the standards. Calibration was done using process water from integrated pulp/paper mill. The comparison of the performance of sensors was made with standard instruments commercial turbidity meter and spectrophotometer. The water sample was provided by the supervisor. Other standard instruments from Metropolia's laboratory were used. The calibration curve method was applied during the result analysis as a mathematical tool. The curve was also analysed on the basis of the Beer-Lambert Law.

The calibration experiment was carried out with the sensor, the turbidity meter and by manual suspended solid measurement. Comparing all three results, the sensor was found to be reliable enough to launch and reach users.

Keywords	Beer-Lambert Law, SS, TU, water quality sensors, pulp and paper mills, accuracy, calibration, calibration curves, dilution experiment

Contents

LIST OF TABLES

LIST OF FIGURES

Abbreviations

A	Absorbance
EMF	Electromagnetic Frequency
EPA	Environmental Protection Agency
GHz	Gigahertz
IR	Infrared
JTU	Jackson Turbidity Unit
NTU	Nephelometric Turbidity Units
PID	Proportional-Intergral-Derivative
SS	Suspended Solid
T	Transmission
TOC	Total Organic Carbon
TU	Turbidity Unit
UV	Ultravoilet rays

1 Theory

1.1 Introduction

Water, the most important constituent of life, makes Earth a hospitable place to live in. A book titled Water Chemistry book describes Water as “a molecule with simple formula H_2O but with remarkable properties making Earth as mother and medium of existence [1]. Three fourths of the Earth consists of water, similarly, a human body consist 60% of water. These are the most common and unforgettable facts we know. This natural resource is found abundant in nature in different forms like sea, oceans, river, and lakes also in atmosphere as vapour. The need and use of water is very vital as the water quality matters for the well-being of human. Although water is abundant in nature, a responsibility has to be established for the protection and to maintain the quality of water bodies. Waste water in enormous amount without proper treatment, misuse of water bodies, no conservation of water resources have led to a decline in quality. In future, we see a threat of water scarcity or less abundance of quality water.

The term *sensor* comes from the word *sense*. A property of device to sense or detect presence of something other than the quality of material/medium defines the term sensor in simple words. Physics defines sensor as a device that converts the chemical into electrical data [2].
Water quality sensors detect the presence of contamination in a water body. They are designed as an online/manual measuring system which provides the information in form of digital signal. They are one of the best tools for the environmental monitoring and saving the water bodies from hazardous pollutants. They could also be very effective in industrial processes. Water sampling was adopted for the detection of any harmful elements, but these days online measuring water quality sensors have been developed to reduce the time consumption and work efficiently.

This thesis was commissioned by a company named Langis Oy. The main idea for the research and experiments was to find the accuracy of the different types of water quality testing sensors produced by the company. The newly made sensors had to be tested to check the reliability before they reached the target groups. It was also planned to get an idea of flexibility and limits when working with these sensors.

Langis Oy is a four-team-membered company, established in 2007, which produces different technical equipment in affordable price for the customers. With the slogan "Water Quality; Its Fundamental", this company produces versatile measurement technologies. Their focus are to produce the optical sensors needed in different fields like water quality measuring, standard sensors, tailored sensors, and sensors with high resolution and measuring capacity. The company aims to reduce the environmental emissions and operating costs for companies providing the proper measurement and controlled systems/application, which is sustainably beneficial. Their products are effective in hospital areas, in hazardous places and for environmental monitoring with low operating costs [3].

1.2 Goals Set

The goal of this thesis work was to check the measurement accuracy of the sensors produced by Langis Oy. It was planned to perform experiments taking the water samples provided and compare the results given by the sensors with the standard measurements/ other available instruments. Comparing the results, the company would decide on the measurement accuracy of sensors before reaching the customers. In the beginning, there was only one sensor provided, followed by another later, for calibration using water samples. It was decided to conduct all the experiments out in Metropolia's laboratory.

After the calibration results, the calibration curves had to be generated and compared; also followed by the generation of the calibration equation. In this thesis, there were 3 precise tasks to be completed. One was the Dilution Experiment using the water sample, Suspended Solid Measurements (SS), and the Turbidity Measurements (TU).

1.3 Water Sample

There were 3 different water samples set for the experiment; river water, peat production water and pulp/paper mills water. The pulp/paper mill sample was chosen with the hope that the results would be interesting due to high suspended solids in the sample.
The sample was provided by thesis supervisor representing Langis Oy. It was taken at a pulp and paper mill situated in northern Finland; because of confidential reasons, the name of the paper mill was not revealed. The sample provided was free of organic or any such harmful chemicals and safe enough to be used in a laboratory. It contained a large amount of suspended solids as well as calcium carbonate ($CaCO_3$) in soluble form as a result of the bleaching of pulp in the process. The pH of the provided sample was 6.91, where carbonate acted as the buffer making the sample a neutral.
Water sample provided from the pulp and paper Mill was collected from the circulation water tower which is the longest loop in the system. The long circulation loop consists of water from the short loop as well as water from the paper machine. This water is used for stock dilution and stock preparation. There is installation of water cleaning equipment and fibre recovery within the long circulation loop. [4]
The loop from where the water was taken for sampling is described in Figure 1 below.

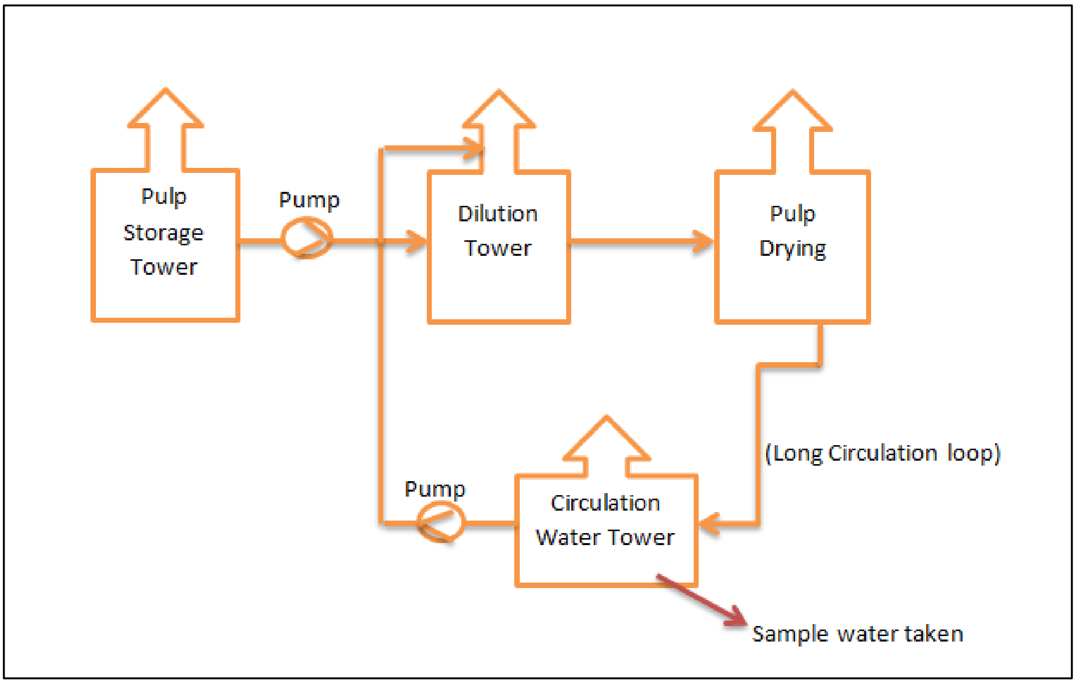


Figure 1. Loop describing the water sampling from pulp mill

1.4 Water Quality Sensors

Water quality sensors monitor different water parameters like pH, dissolved oxygen, suspended solid particles, conductivity and redox. There are generally two types of water quality sensors; conventional water quality sensors detect water quality parameters such as pH, temperature, chlorine (Cl), total organic carbon (TOC) and conductivity whereas advanced water quality sensors can detect in lower concentrations of specific components and are the result of new technologies. [3] These sensors have a data logger system which sends the data in an electronic form as bits or voltage.

1.5 Types of Water Quality Sensors Used

The two different types of Water Quality Sensors were used during the thesis work. Both the sensors had different working phenomenon based on same principle. These are advanced water quality sensors which can detect the amount of impurities also in lower concentrations. The theory behind the sensors is simpler but the sensors have been designed in such a way that they can detect the contaminants as well as other properties in water in multiple ways. One of these sensors has the capacity to detect 4 different responses from the water sample. The best features of the products from this company are that the products are multipurpose devices with multi-combination of technology and also provide data in real time. Online data are the best ways for monitoring the water quality.

1.5.1 Sensor I

The sensor named as Sensor I was a suspended solid sensor; which detects the amount of solid suspension in a water medium. The design of this sensor can be seen in Figure 2.

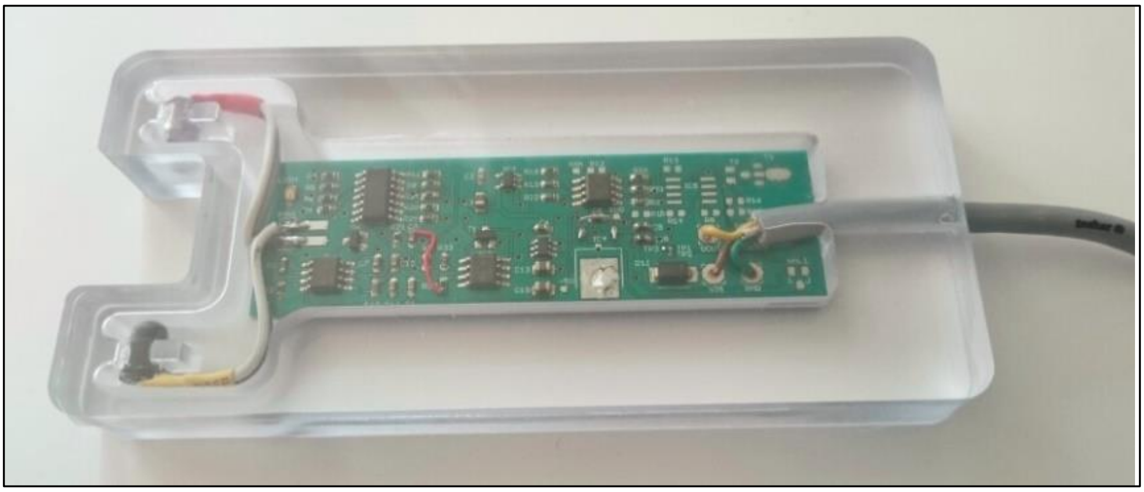


Figure 2. Suspended solid sensor, sensor I

Sensor Specifications

Voltage Output:	0-5 V
Output Range:	10 bits
Resolution:	5mV
Warming time:	Couple of minutes
EMF:	2.4GHz

The sensor gives the reading of voltage as an output along the time interval.

1.5.2 Sensor II

The second sensor used was a 4G Gateway sensor giving the results in the form of four different outputs. The sensor gives the data in four columns; like field 1, field 2, field 3 and field 4 shown in Figure 3 below.

```
field1=77454&field2=5757&field3=112837&field4=87518
field1=77346&field2=5795&field3=112764&field4=87516
field1=77350&field2=5983&field3=112268&field4=87514
```

Figure 3. Readings from python programme, sensor II

Each field denotes different output as follows:

- Field 1 denotes infrared absorbance,
- Field 2 denotes scatter infrared,
- Field 3 denotes UV and
- Field 4 denotes voltage output.

For the data analysis and calibration curve, Field 4 was chosen as it is the range of voltage output given along the change in suspended solid concentration in dilution experiments.

Sensor specifications

Voltage Output: 0-5 V
Output Range: 17 bits
Resolution: 5mV
Data output: Serial data

The design of the sensor can be seen in Figure 4 below.

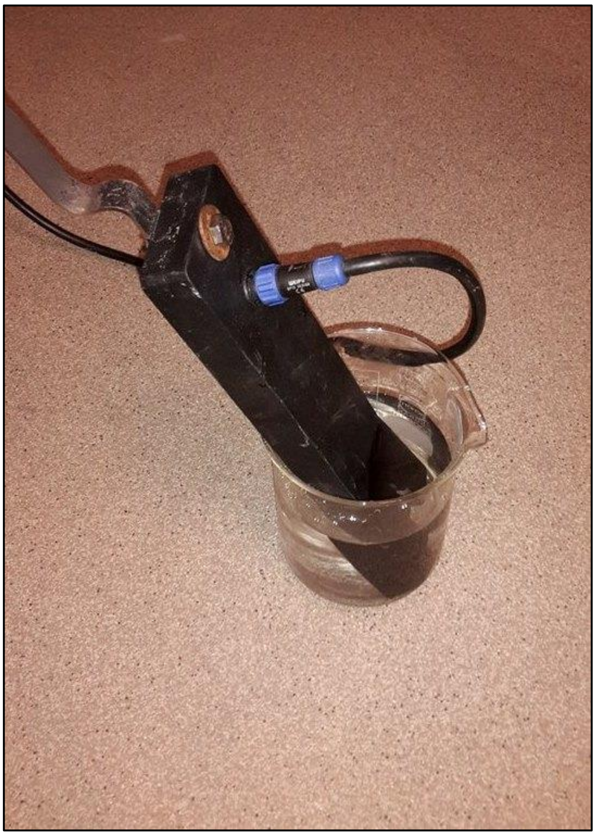


Figure 4. 4G gateway sensor, sensor II dipped in sample water

1.6 Working Principles of Water Quality Sensors

In general, the sensor takes an input as analogue and gives the output in digital form which is a very basic working process of sensor. One physical quantity is taken as an input and the sensor provides another physical quantity as an output.

The sensors were based on the principles of light path and its absorption and the light scatter measurement. There is a led source which lets the light into the medium; on the basis of absorption and diffraction the amount of undefined material in the water medium id derived. The product (sensors) has a sensor board which act as the led source converting the signal process as well as the outputs as voltage or in form of bits. The Python programme is installed in Lenex PC which monitors the sensors to get the online data.[4] The Langis Oy website also shows online measurement data provided by the sensor via thingspeak.com.

The working principle of the sensors/products is shown in Figure 5.

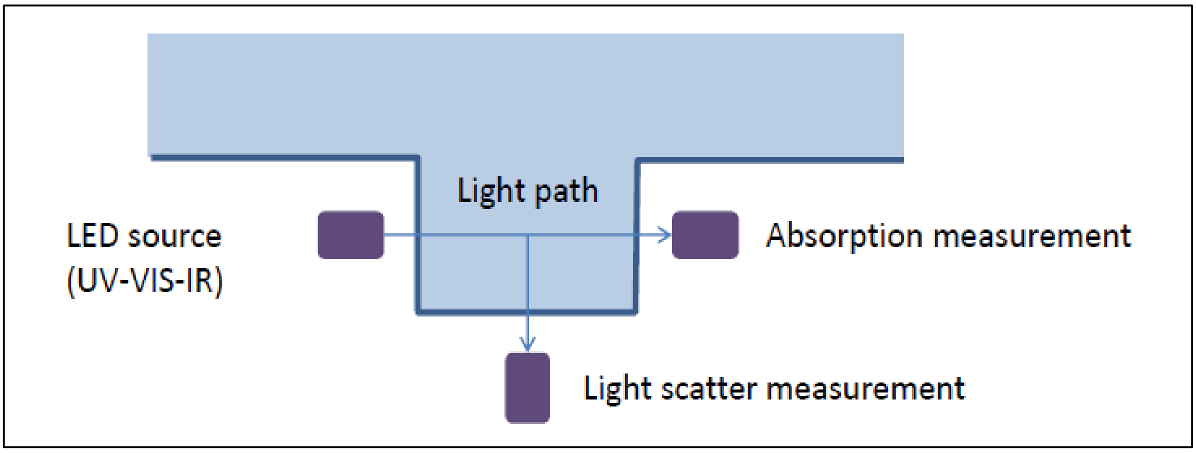


Figure 5. Working Principle of sensor (source: Langis Oy)

The working principle is one of the derivations of the theory of Beer-Lambert Law. The basic idea of the law is related to Absorption of Radiation. The law correlates the transmission, absorbance of light source and concentration of medium. [3]

1.7 The Beer-Lambert Law

Lambert Law

Lambert law states that each layer of equal thickness of an absorbing medium absorbs an equal fraction of the radiant energy that transverses it. If we assume "I_0" as the incident radiant energy and "I" as the transmitted energy, the ratio of them is known as transmittance. This can be expressed as the following equation:

$$\text{Transmittance (T)} = I/I_0$$

Transmittance is generally expressed in terms of percentage (%).

Absorbance is known as logarithmic to the base of reciprocal of transmittance, which can be expressed as follows:

$$\text{Absorbance (A)} = \log_{10} (I_0/I)$$

It is a unit less parameter.

Beer Law

Beer’s law states that the absorption of the light is directly proportional to thickness and the concentration of absorbing medium. That is the intensity decreases with increased thickness and concentration of medium.

The Beer-Lambert Law (as together)

Combining both the laws, the Beer-Lambert law states the relation between absorbance (A), transmittance (T) and concentration of the solution. That is the absorbance (A) is directly proportional to the concentration of solution. It can be stated as follows:

$$\text{Absorbance (A)} = \varepsilon cb,$$

where A is absorbance (unit less), Ɛ is molar absorptivity ($dm^3\ mol^{-1}\ cm^{-1}$), c is molar concentration ($mol\ dm^{-3}$) and b is path length (cm).

Usually, Ɛ is the function of wavelength, so the law is true only when there is light of single wavelength. [5]
The Beer-Lambert law is illustrated in Figure 6.

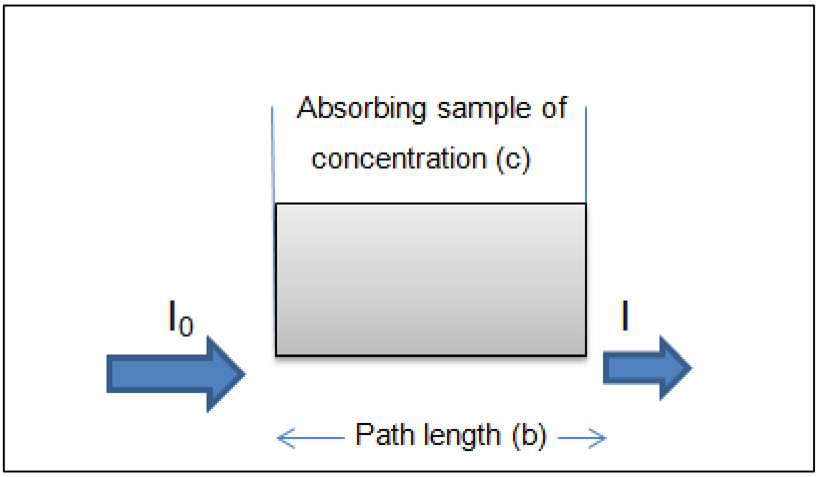


Figure 6. Absorption of light, Beer-Lambert law

1.8 Instrument Calibration Techniques

Measuring by using analytical methods, depending on the necessities calibration of an instrument in order to make sure the measurements are accurate as a whole illustrate an instrument calibration technique.

Calibration

The process of quantitatively defining the system responses to known, controlled signal outputs is known as “calibration” [5]. The most common ways used to calibrate the instruments are:

a. Calibration curve method,
b. Standard Addition Method and
c. Internal Standard Method.

During this thesis project, the calibration curve method was used to calibrate the sensors.

Calibration Curve Method

A series of solutions/samples are prepared where the concentrations of those samples are known. Samples are made in a way that they cover the range of interest. A mother solution with the highest concentration or the pure sample solution is analysed. With the reference of the mother solution, concentration of other solutions are plotted to obtain the calibration curve.

The important calculation/analysis of the result in this thesis is based on the calibration curve method. The results are studied by plotting the calibration curve.

Accuracy and Precision

In the field of engineering, the measurement accuracy is the degree of closeness of measurements of a quantity to that quantity's actual (true) value. During the determination of measurement accuracy, a calibration of analytical method with a known standard or a known instrumental reading is done. In this thesis, the measurement results from the sensors are compared with the laboratory standard equipment to check the measurement accuracy.

The precision of a measurement, also known as repeatability and or reproducibility, is the degree to which the repeated measurement under unchanged conditions shows the same results

Range of sensor

The minimum and maximum of readings value that a sensor can collect is known as the range of sensor. The sensors used for this thesis work has two range of outputs; 10 bits and 17 bits. The working ranges of the sensors are presented in Table 1.

Table 1. Range of sensors

Sensor type	Bits	Minimum Range	Maximum Range
I	10	0	1023
II	17	0	13,1072

Bits are the binary representation of digital signal. In the table representation the bits values are converted to numerical value to get the maximum and minimum range values. According to the Table 1 representation, the maximum range of sensor I and II are 1023 and 13,1072 respectively.

Resolution

The smallest change in measurement that sensor can detect is known as resolution. It states about the change in input and output that a sensor can detect.
The resolution of sensor is illustrated in Figure 7.

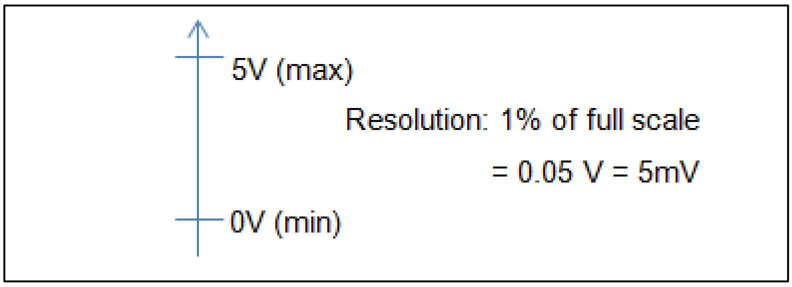


Figure 7. Illustrating resolution of sensor

Error

There are several conditions and factors that can affect an experiment. During the laboratory experiments, errors can occur through sampling methods, analysis techniques or from instruments .Error can be defined as the difference in the measured value and the actual value given. The role of error has to be considered whenever an experiment is carried out. If an experiment is carried out repeatedly under unchanged conditions, the results can show slight variation; which could be due to error during the experiment. The errors can be broadly classified as; Random error and Systematic error.

Random Error

Random error has minimal effect on the results. It could occur due to the measurement technique or other component present in each measurement. One of the examples of random error is noise; which has small magnitude and can be minimized by filtering. During this thesis experiments, the noise signal was neglected from the measurement results

Systematic Error

Systematic error arises from the repetition of same mistake during the experiment. The wrong experimental procedure and incorrect calibration of instrument could lead to systematic error. These errors could be detected and eliminated by following correct analytical procedures.

1.9 Pulp and Paper Mills

Pulp and Paper is a big and mature industry area. From 19th century, the industry has been growing globally and has become one of the dominant areas around the globe. Europe also contributes a major role for the production of pulp and paper. Among the European companies, the Finnish companies are leading in the production of pulp and paper. Metsä Groups and UPM are one of the known and renowned companies in Finland for the paper production.

The pulp and paper mills are one of the sources for global warming, human and ecotoxicity, solid waste, acidification and nitrification. Enforce of strong regulations and controlling the emission, these companies have high technologies for decreasing the pollutants level. The online data measurement in the waste water, air emission or recycling water/materials, the companies have tried to protect the environmental balance. [6]

Wood/Forest is the core raw material for paper and pulp production. Wood is processed and fibres are separated producing pulp. The bleaching of pulp is done and further they are dried. On the basis of pulp nature, fine or coarse, the nature of the paper is determined. There is a use of enormous amount in washing and bleaching of pulp. The inner water circulation is done for washing the pulp, also to minimize the water demand. [7]

The waste water coming out of the pulp mills contain huge amount of suspended solids, colloidal substance and dissolved substances. The mills have internal purification before treating the waste water and releasing them to nature.

The need and use of paper has grown so the paper industry acquires a large area globally. Papers are environmental friendly material that undergoes recycle or decay. With the emerging technologies to control the pollutants and wise use of resources; we can save the nature. These industries should enhance making a balance with the nature and fulfilling the demands from consumers.

2 Experimental Part

The water quality sensors were calibrated as recommended by the company and the results were compared with results from the laboratory instruments commercial turbidity meter and spectrophotometer. Experiments were carried out to check the accuracy of the sensors according to the goals set. The baseline for the experiment and comparison of the results was made with the tap water. The experiments were repeated till the results met the calibration using pulp and paper mills water. Three measurements were carried out during the experiments which described below in sub-headings.

2.1 Dilution Experiment

An experimental set up was made with the samples containing different amount of concentration. The process of dilution was followed to prepare the sample solutions. The first sample solution with the maximum solid was prepared named as “mother solution”. The first sample solution was diluted using deionized water. 5 sample solutions were prepared by the dilution process and measurements were taken from the sensors.

Safety Precautions

- Safety glasses were worn all the time the experiments were done.
- Lab coats were used all the time spent during labs.
- PVC gloves were used during the lab work and the protective gloves were used while using the drying oven.

Equipment and Glassware

- Standard laboratory glassware was used during the experiment: volumetric flask, beakers and pipettes,
- Flask, filtering, 1000mL
- Magnet and magnetic stirrer

Chemicals and Solutions

- Deionized Water

There was no use of any other chemicals during the experiment.

Temperature

The experiments were carried out in the room temperature. The noted laboratory temperature during the experiment was 20.4°C.

pH of Pulp Sample

The pH reading from the pH meter [SevenGo Duo pro, 6V, 75mA] was 6.91. The sample was almost neutral.

2.1.1 Experimental Set Up

A warming up experiment was carried out using a test sample and the measurements were taken from sensor I. The experimental procedure of making the samples and measurements are described below:

- A test sample was made with 30 grams of flour, a table spoon of coffee (Nescafe coffee) and a litre of water (tap water)
- 1000 ml of test sample was taken into a beaker and labelled as mother solution which contained maximum solid suspension.
- The prepared sample solution was well stirred and the sensor was let into the beaker for few minutes to take the measurements.
- 500 ml of the first sample solution poured into another beaker and diluted with tap water of 500 ml. The sample was well stirred and the sensor was let into the beaker to take the measurements.
- Again, 500ml of the second sample solution was taken and diluted with 500 ml of tap water.
- Following the same process of dilution, six samples were prepared.
- Six sets of measurement data were produced from the experiment.

The data was plotted to generate the calibration curve. The calibration curve from the data were plotted and attached in appendix 1. The above experimental procedure was repeated using the pulp and paper mill water sample.

The solution samples prepared during the experiment is shown in Figure 8.

Figure 8.Dilution experiment set up,mother solution starting from left with decreasing concentration solution to the right

Calibration experiment Using Sensor I

Another set of experiments were carried out for the calibration of sensor I using the pulp and paper mill water sample. The same experimental procedure carried during the test sample preparation and measurement was repeated in this experiment too. The experiment was repeated for three times. Each measurements data were used for the generation of the calibration curve. The last experiment results gave the best plot of the calibration curve.

Calibration experiment Using Sensor II

Following the same experimental procedure as above, the pulp and paper mill sample water was used to calibrate the sensor II. Only one experiment was carried out from this sensor, as it stopped functioning.

2.1.2 Fermentation of Yeast (Sensor I)

There was an experiment carried out using Sensor I with Degree Programme of Biotechnology students group. A continuous process to study the growth of the yeast for 6 hours was done in an automated fermenter. The sample was taken from the fermenter by peristaltic pump to a decanter where the sensor was kept and sensor collected the measurement data in PC. The experimental procedures are described as below:

- 9 litres of water was taken initially and 50ml of malt extract as nutrient for the yeast growth.
- 50g of glucose as well as 50g of fresh baking yeast was taken.
- Potassium nitrate and phosphate were taken 0,5g each as P and N.
- During the experiment, the same dilution method was applied. Yeast was taken as the suspended solids for the experiment.
- After certain time interval, water was added to make the solution dilute. About two litres of sample was taken away adding two litres of water to dilute the solution.
- There were four dilutions made during the experiment with the interval time of about five minutes using same process; taking away two litres of sample and adding same amount of water. Normal tap water was used.

It was a continuous experiment of 6 hours; which produced a continuous graph showing the change of voltage in each dilution. The graph of the result is attached in appendix 2.

The automation set for the experiment is as follows:

- Temperature control (PID) set to 37º C,
- pH set to 4.5 (PID control by phosphoric acid and NH_3 solution) and
- Dissolved oxygen control (PID) by stirring speed.
- Automated fermenter Sartorius Biostat, Type 6SM57M-3

2.2 Turbidity Measurement (TU)

The term turbidity comes from the word *turbid*. Turbid refers to the suspended particles in water that restricts the passage of light or even restricts the visual depth. Turbidity is caused by variety of suspended particles in different size; where particles can be random or fixed depending on the surrounding or the system. The suspended particles can be very fine dispersible and homogenous whereas without proper distribution or the heterogeneous. The materials causing turbidity can be in a range from inorganic to largely organic matters.

Standard Unit of Turbidity

A standard has been chosen for the turbidity in order to make water free or with minimal amount of suspended solid particles. The standard chosen was

$$1mg\ SiO_2/1 = 1 \text{ unit of turbidity}$$

where, silica (Si) must meet the certain specifications to particle size. According to U.S. Environmental Protection Agency (EPA), a limit of 1 unit of turbidity is the maximum amount allowed in water supplies. [8]

Measurement Units

There are two standard units of measurement expressed in Nephelometric turbidity units (NTU) and Jackson turbidity units (JTU). NTU is the measurement unit for the instrumental method that comply with EPA method.

JTU is the measurement unit for the visual method, where the visual method involves measuring interference to the passage of light caused by turbidity. JTU comply with ISO 7027, the European drinking-water protocol. [9]

Equipment and Glassware

- ISO Turbidimeter, HI 88713; measurement range: 0-1000 FNU, 0-4000 NTU
- Beakers, glass
- 100ml bottles

Measurements and Results

In the laboratory, the samples were prepared following the dilution experiment and turbidity was measured using the ISO turbid meter.

- A mother sample solution was prepared using the pulp and paper mill water as mentioned in earlier experiments.
- Following same dilution process, five sample solutions were prepared and measurement was taken from turbidity meter for each sample solutions.

The turbidity measurements of all the sample solutions are illustrated in Table 2.

Table 2. Turbidity measurement results

Concentration of pulp sample in solution (%)	Turbidity Measuring Unit (NTU)
100	17.8
50	11.2
25	5.04
12.5	2.62
6.25	1.45
3.125	0.61

There was use of deionized water during each dilution. The sample had to be well stirred and poured carefully in the bottles for measurement.

Result Interpretation

The decreasing turbidity with the decreasing concentration of sample in measurement results shows the result is good and reliable enough. There shows a drop of turbidity from 50% to 25% concentration sample. During the experiment, it was seen that the particles are not homogenous. Transferring sample to a bottle of 100ml was sensitive, as the suspended solid could not enter it with the range in 1litres solution. The pattern seen in the result is positive.

2.3 Suspended Solid Measurement (SS)

The small solid particles which remain as suspension in water is known as suspended solid particles. From the above turbidity results, it can be concluded that there is high amount of suspended amount of particles in sample water.
The pulp and paper mills water contains suspension particles in huge amount and suspended solid measurement a manual way to measure the amount of suspended particles. The measurement is carried out to get the weight of residue amount per litre; mathematically in terms of *mg/L* of solution.

Equipment and Glassware

- Magnet and magnetic stirrer,
- Tongs and plastic tweezers,
- Analytical balance, Libror AEU-210,
- Drying Oven, type T 6120, 50Hz
- Watch glass, 100mm
- Filter paper, Whatman 2, 70mmø
- Filter holder, Filter flask
- Graduated Cylinder

Procedure

- Following the dilution experiment, the samples were prepared and labelled. Samples were levelled as S1, S2, S3, S4 and S5 according to the concentration of solid in ascending order where, S5 was the mother solution with highest amount of solid particles.
- After sample preparation, the 70-mm glass fibre filter was placed in the filter holder using the tweezers.
- Filter holder was placed above filtering flask and about 100ml of deionized water was added. The vacuum was applied to the flask letting all the water to be drawn through filter.
- The filter paper was removed from the filtering disc slowly and transferred to 100-mm watch glass.
- Before the experiment was started, the drying oven was preheated.
- The ready filter paper was placed in the oven for an hour at adjusted temperature of 103ºC.
- After an hour, the filter paper was removed using tongs and allowed to cool in room temperature.
- The weight of the filter paper was taken in analytical balance.
- Again the filter paper was placed in filter holder and wet with deionized water first. After the water filtered, the sample was poured slowly and let to filter using vacuum. Each sample was filtered using same process every time.
- The paper was removed from filter holder and placed in watch glass and let in the drying oven for one hour at 103ºC.
- After an hour, the filter paper was weighed in analytical balance and the weight was recorded.
- In this process, the weight of the filter paper before and after filtration was important to know for the further calculations.

Calculations

The weight of each filter paper after and before filtration was noted. The results are presented in Table 3.

Table 3. Calculation of weights of sediments

Sample	Weight of filter paper before filtration Y(g)	Weight of filter paper after filtration X(g)	Weight of sediments (g)
S1	0.3818	0.3838	0.0002
S2	0.3705	0.3719	0.0014
S3	0.3755	0.3782	0.0027
S4	0.3696	0.3734	0.0038
S5	0.361	0.3712	0.0102

The total non-filterable residues are calculated as:

$$\frac{X - Y}{\text{Volume of sample in Litres}} = \text{mg/L}$$

Where, X = weight of filter paper with residue (mg)
Y = weight of filter paper (mg) [10]

The volume of sample made was 500 ml.

Using the formula to calculate the total residue in excel, the result was calculated. The result is presented in Table 4.

Table 4. Suspended solid in mg/L

Sample	Weight of sediments (g)	Weight in mg	Suspended solid in mg/L
S1	0.002	2	0.4
S2	0.0014	1.4	2.8
S3	0.0027	2.7	5.4
S4	0.0038	3.8	7.6
S5	0.0102	10.2	20.4

Result Interpretation

The mother solution contained the highest 20.4 mg/L of suspended solid, which is considerably good one as the sample was turbid.

3 Results and Data Analysis

Mentioned in the Theory, the calibration was made comparing the performance result between the sensor and the provided laboratory instrument. Three different mathematical tools were applied during the analysis.

3.1 Calibration Curve generation

The measurement data given from the sensors were formatted in Microsoft excels. The averages from each result were taken and the calibration curve was generated. The graph was plotted against the voltage and concentration of sample solution. In all experiments' result produced from Sensor I, Sensor II and the fermentation process, the graph was plotted against concentration and sensor response.

Calibration Curve from Sensor I

There were six samples producing six sets of data. The amount of data had to be reduced in order to make the data understandable and for making plots. The average value was provided for each set of data. The values are given in Table 5.

Table 5. Average calculated from sensor I

Sample concentration (%)	Average voltage (mV)
100	517.8761
50	530.8294
25	539.2407
12.5	547.4786
6.25	555.1477
3.175	567.3835

From the averages of each response from Sensor I, the value was plotted against the concentration of data. The calibration curve generated is shown in Figure 9.

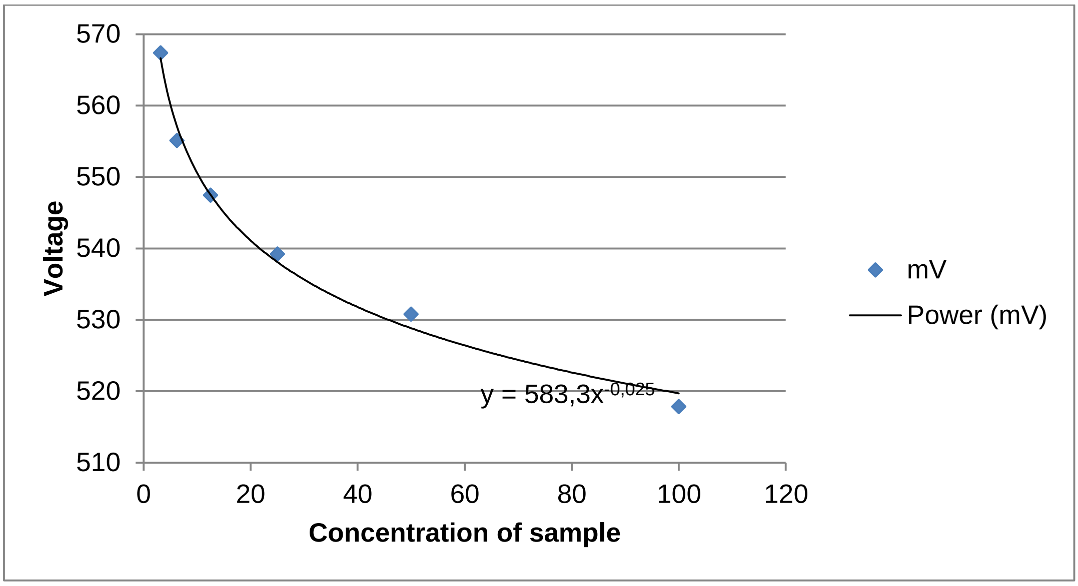


Figure 9. Calibration curve generated from sensor I

The curve obeys the Law of Beer-Lambert. The trend line is plotted against the concentration and voltage output (transmission). Some plots are deviated from the trend line which could be the experimental error. The noise was neglected during the data generation.

Calibration curve from Sensor II

The averages of the response from Sensor II are taken and the graph is plotted against the concentration and bits (as an output response). The averages taken from the response of Sensor II are given in Table 6.

Table 6. Average calculated from sensor II

Sample concentration (%)	Bits
6.25	88195
12.5	87807
25	87252.5
50	87621.92
100	87502.64

The calibration curve plotted from Sensor II is illustrated in Figure 10.

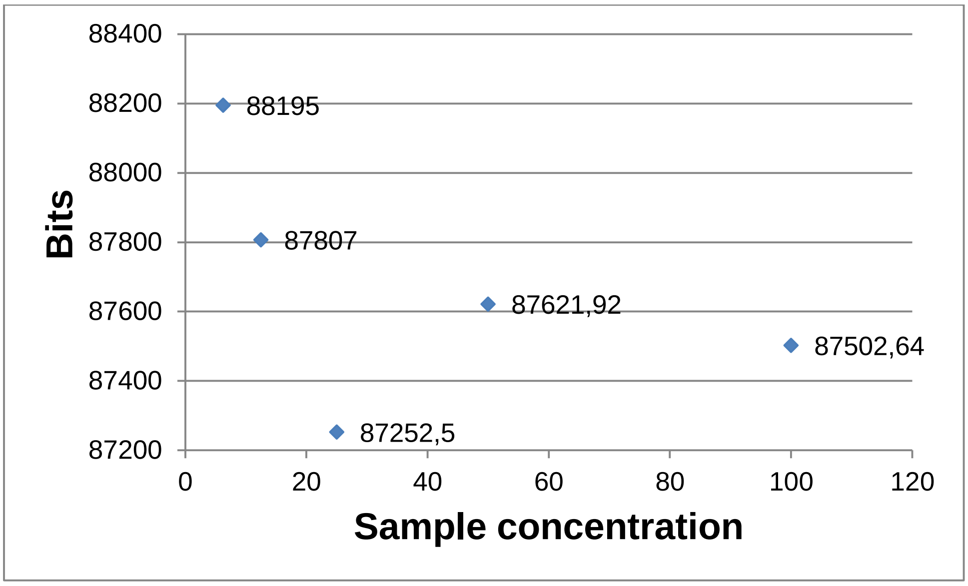


Figure 10. Calibration curve generated from sensor II

Calibration curve from the Fermentation of Yeast

From the yeast fermentation data, the response in every dilution was taken and graph was plotted. The set of data from each dilution is given in Table 7.

Table 7. Yeast fermentation dilution responses

Yeast concentration (%)	mV	Dilution steps
100	76	Mother solution
77.77	103	1st dilution
55.55	142	2nd dilution
33.33	202	3rd dilution
11.11	266	4th dilution

The calibration curve generated from the above data is illustrated in Figure 11.

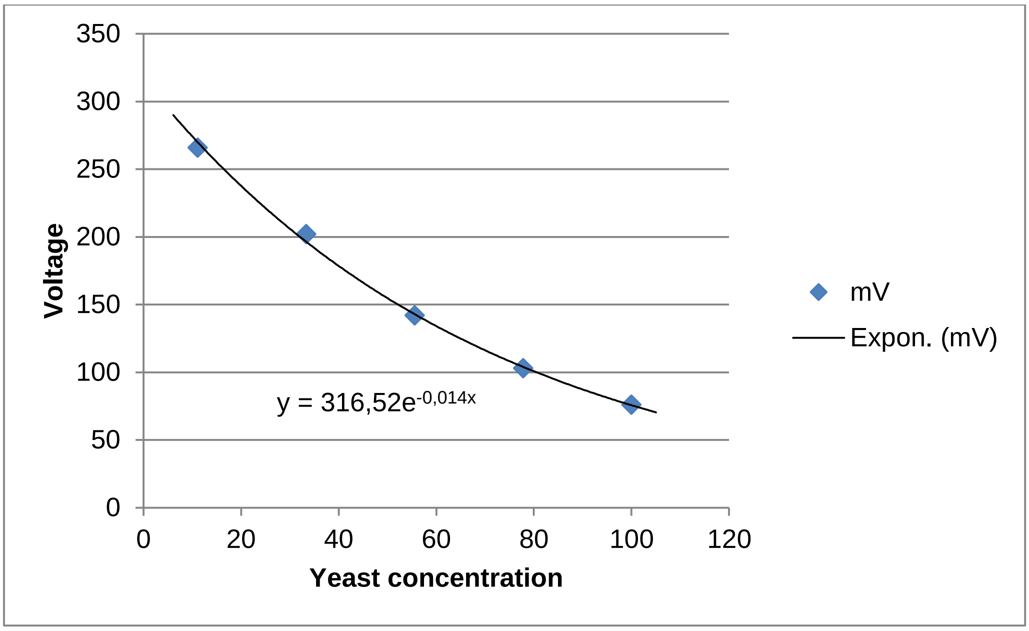


Figure 11. Calibration curve generated from the fermentation experiment

Graph plotted from the Turbidity Measurement

The results from the turbidity measurements have been provided above. The curve generated from the data is illustrated in Figure 12.

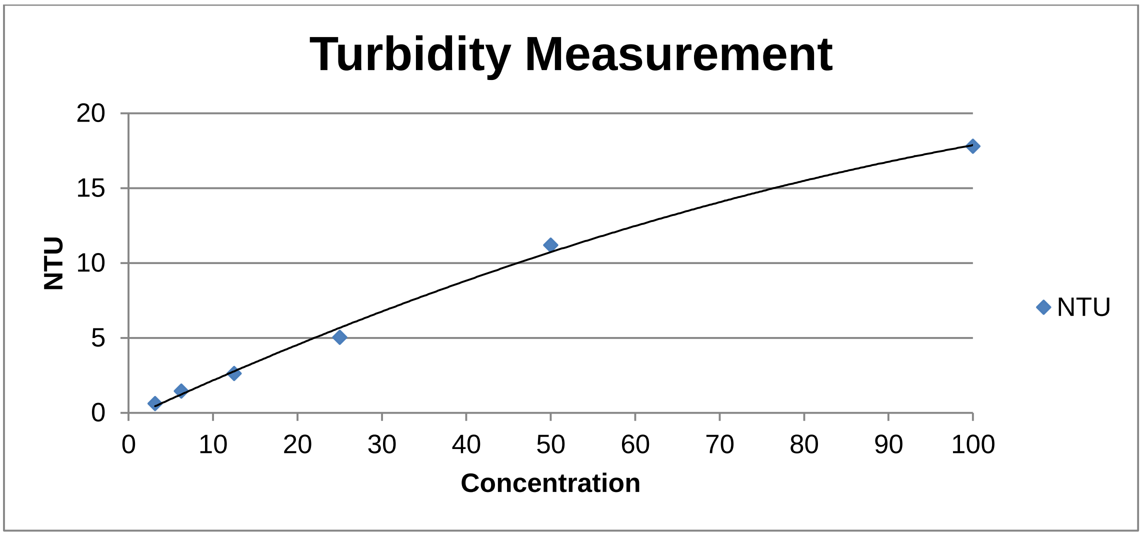


Figure 12. Curve generated from turbidity measurement result

Graph plotted from Suspended Solid Measurement

From the measurement results of SS the graph plotted is illustrated in Figure 13.

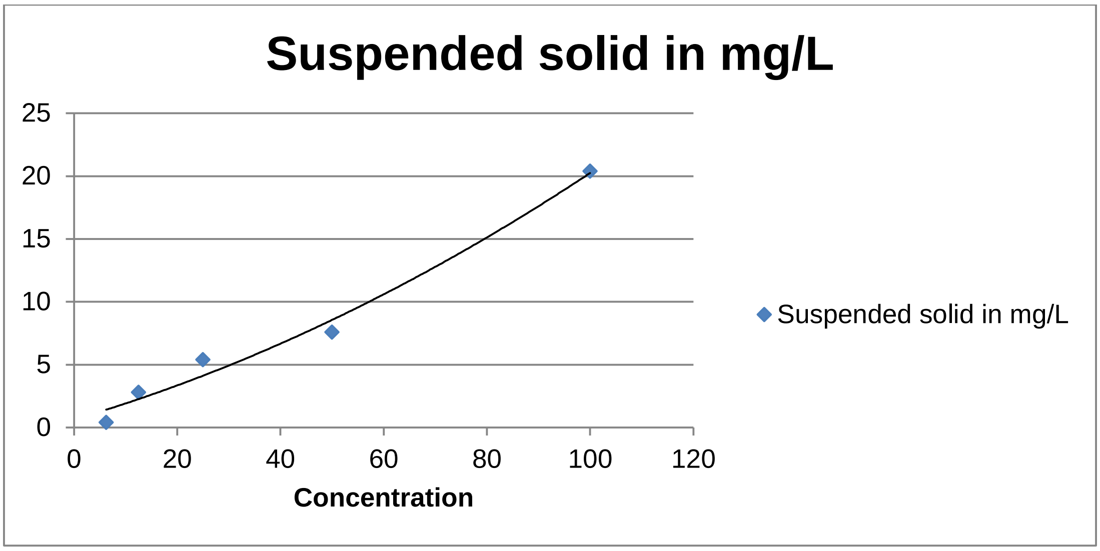


Figure 13. Curve generated from suspended solid measurement result

3.2 Calibration curve comparison

Comparing the nature of the curves, the analysis is made for the accuracy of sensors with the reference standard.

Sensor I obeys the absorption and transmittance of light. As the concentration of solution increases, the intensity of light decreases; giving the output range in smaller value and with the decreasing concentration it gives higher output range.

Turbidity measurement results were good enough. The turbid meter gives an increasing result with increasing concentration.

The suspended solid measurement was the manual way for calculation of solid in samples. The results from the table and graph plotted show an increasing suspended solid with high concentration. During this experiment, the result from mother solution was a keen interested one which is adequate as assorted from the graph.

Comparing with the data values, the sensor results are inverse to the turbidity and suspended solid results. Mathematically, a good correlation can be seen with both the measurement results.

Even Sensor II follows the same pattern although the plots are deviated from the trend line.

4 Discussion and Limitations

The sample was provided only once and used for all the experiments. There was no new and fresh samples in order to compare the results. As mentioned earlier, one of the sensors did not function well, and the experiment had to be ended.

During the suspended solid particles experiment, there were first negative readings with the weight of the filter paper with and without residual. That means the weight of the filter paper with residual was less than the weight of the filter paper without residual. No such error was detected with experiment or with the instruments used; repeating the experiment gave good measurement results.

There was no replicated experiment in order to carry out any statistical analysis.

5 Conclusion

With respect to the goals set, the accuracy of the measurement data give provided by Sensor I was very good. It functions well with its working principle. When its results are compared with those given by the turbidity meter, there is accuracy in the measurements.

Sensor II gave a good pattern of curve on the basis of working principles, but only one experiment result is not enough to rely on the accuracy of the sensor.

In conclusion, Sensor I gives accurate measurement readings, is reliable enough to use for measurements and reach the customer. Due to insufficient number of experiments Sensor II, cannot be claimed to be accurate.

6 References

1 Stanley EM. Water Chemistry, Green Science and Technology of Nature's Most Renewable Resource. Boca Raton, FL:CRC Press; 2011

2 Che H, Liu S. Contamination Detection Using Multiple Convectional Water Quality Sensors in an Early Warning System. Procedia Engineering [Internet] 2014. [cited 5 Jan, 2016]; Volume 89:479-487. Available from http://www.sciencedirect.com/science/article/pii/S1877705814023546

3 Langis. Water Quality. It's Fundamental, [Internet] 2015 [cited on 8 Jan, 2016]. Available from www.langis.fi

4 U. Weise, J. Terho, H. Paulapuro, Stock and water systems of paper machine, Paper Making Part 1, Stock Preparation and Wet End, Ch.1, p.1 [Intenet] 2000, [cited on Dec 18, 2015] Availble from http://www.fing.edu.uy/iq/maestrias/icp/materiales/2010/06_Papermaking/book8chapter5.pdf

5 R.S. Khandpur, Handbook of Analytical Instruments, Laws Relating to Absorption of Radiation, p. 31, The McGraw Hills Companies, Inc. Copyright, 2007

6 Onno Kuik, Environmental Innovation Dynamics in the Pulp and Paper Industry, Commisioned by European, DG Environment [Internet] 2006 [cited on 29 Dec, 2015], Available from http://ec.europa.eu/environment/enveco/policy/pdf/2007_pulp_paper.pdf

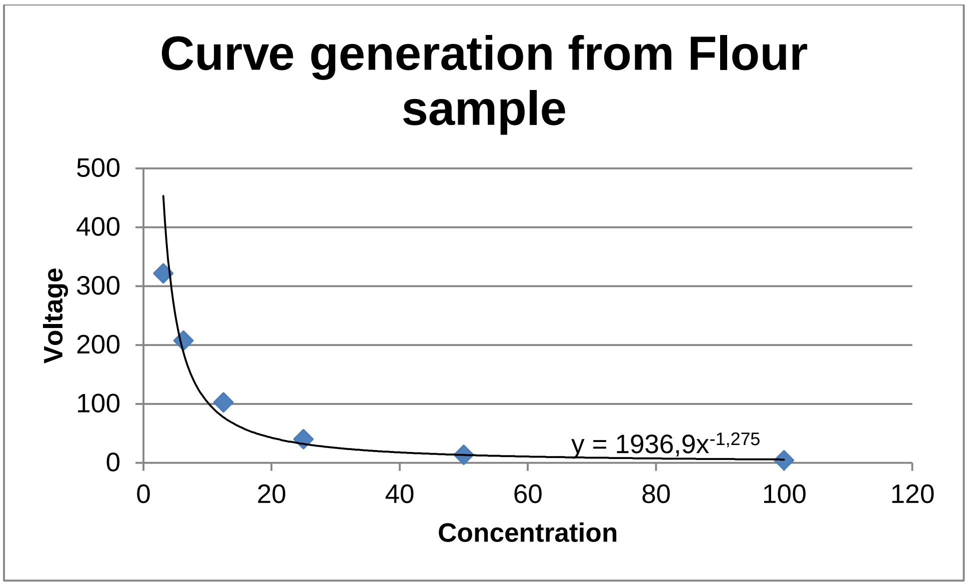
7 J. Nuortila-Jokinen, Wastewater Recycle, Reuse and Reclamation- Vol I-Fresh Water Minimization by Membrane Filtration in the Pulp and Paper Industry, Lappeenranta University of Technology, Lappeenranta, Finland, Cleantech [Internet] 2000 [cited on 15 Jan, 2016] , Available from http://www.eolss.net/sample-chapters/c07/e2-14-02-07.pdf

8 Sawyer/McCarty, Chemistry for Environmental Engineering, Third Edition, Copyright McGraw Hill 1978, Chapter: Turbidity, p.331

9 Michael J Sadar, Turbidity Science, Technical Information Series—Booklet no. 11, Copyright Hach Company USA, [Internet] 1998, cited on [9 Jan, 2016] Available from http://www.hach.com/asset-get.download-en.jsa?code=61792

10 Solids, Non filterable Suspended Solids; Total and Volatile, USEPA Gravimetric Method, Edition 8, [Internet] Copyright Hach Company USA, 2015 [cited on 5 Nov 2015], Available from http://www.hach.com/asset-get.download-en.jsa?code=56432

Appendix 1. Curve generation from 1st experiment (sample of coffee, water and flour)



Appendix2. Graph showing change in voltage in every dilution during Fermentation process