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# Water quality measurement by a water sensor

Testing a sample from a peat production area by an optical sensor

Helsinki Metropolia University of Applied Sciences

Bachelor in Engineering

Degree Program in Environmental Engineering

Bachelor's thesis

January 2016

Author	Bharosha Karki
Title	Water quality measurement by a water sensor
Number of Pages	26 pages + 5 appendices
Date	20 January 2016
Degree	Bachelor of Engineering
Degree Programme	Degree Program in Environmental Engineering
Specialisation option	Water, Waste and Environmental Engineering
Instructor(s)	Erkki Rasanen, Project Supervisor Kaj Lindedahl, Lecturer Dr. Minna Paananen-Porkka, Lecturer

Finland is covered by one of the largest areas of peatland in the world. Peat production has both advantage and disadvantage. On the one hand, peat production affects the environment; on the other hand it provides a valuable resource of energy production. Finland has its own rules and regulations for the treatment process of peat water. There are different organisations working for its proper management. With the development of technology and large market, the business sector is in neck-and-neck competition; therefore, good, efficient and reliable product production is necessary. There are many companies producing water quality measurement sensors, and Langis Oy is one of them. It manufactures cost-effective and reliable sensors for a wide array of users.

The purpose of the thesis was to install, calibrate and maintain a water quality measurement sensor for an environmental monitoring and waste water control system as well as to calibrate and test a new water quality sensor developed by Langis Oy. The sample was taken from a peat production area and the main objective was to test the reliability and efficiency of the product before launching it into the market. Different laboratory analyses were carried out with two types of sensors using an autonomic online measurement station with an MQTT network and a 4G gateway. The samples were taken and diluted, and the data generated from the analyses were stored and analysed using the Thing Speak software. Thus, the output voltage value versus the dilution curve was obtained. From the results, it can be concluded that the performance of the sensor was sustainable. Potentially, the sensor could be a versatile device with a good market value.

Keywords	peatland, peat water, water quality measurement sensor, Langis Oy, MQTT network, 4G gateway, Thingspeak software, calibration curve
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## Acknowledgement

Finland was a new environment, with a new university and new culture. It was difficult for me to adapt in the starting weeks, however, the attitude, guidance and patience of the teachers and my classmates helped me to cope up with my difficulties and adapt to the system. It was my pleasure to study in Metropolia as it gave me so much to learn. Now I feel blossomed in every possible way. Studying Environmental Engineering was the right choice on my behalf because this very course shed me light on how can I do my part to conserve the environment. Every person needs to have knowledge related to environment because it can be implemented in practical life as well.

Many thanks to my supervisor Kaj Lindedahl and Erkki Rasanen who gave much effort to guide me through the smallest of tasks in this project. Thank you Kaj for your encouragement, support and push in my theoretical portion, which drove me to give my heart and soul to writing the thesis. On the other hand, Erkki taught me all the laboratory portion because of which I was able to reach my objective. It was your patience and repetitive explanations that were the key to the door of my knowledge. If it was not for you, my tangled processes would not have become smooth and clear.

It is not possible to leave out the Academic English lecturer, Dr. Minna Pannanen-Porkka without whom my thesis would have been incomplete. Your suggestions and feedback helped me to reach my goal. I would also like to thank Dr. Antti Tohka, study coordinator Jenni Merjankaari and all the teachers who helped me during my study period. Last but not the least, thanks to all colleagues, friends and family, who, despite being far, have given me all the support I need. No words can describe how thankful I am towards each and every one of you because of whom I have achieved this position in my life.

Helsinki 20.12.2016

Bharosha Karki

## List of Figures

Figure 1: Use of peatlands in Finland .....	3
Figure 2: Principle of optical measurements .....	8
Figure 3: Suspended solid measuring sensor .....	10
Figure 4: Water quality measurement sensor.....	11
Figure 5: Python code.....	12
Figure 6: PH meter .....	14
Figure 7: Turbidity meter.....	15
Figure 8: Peat water sample before and after dilution .....	15
Figure 9: Calibration curve for data obtained from sensor 1 .....	16
Figure 10: Calibration curve for data obtained from sensor 2.....	18
Figure 11: Turbidity calibration curve .....	20
Figure 12: Voltage Vs measured turbidity .....	21
Figure 13: Sartorius Biostat Fermenter with sensor 1 in decanter .....	22
Figure 14: Calibration curve for fermentation process.....	23

## List of tables

Table 1: Average voltage for certain peat water concentration.....	16
Table 2: Average voltage for certain peat water concentration.....	17
Table 3: Turbidity and pH measurement for certain peat concentration .....	19
Table 4: Turbidity and voltage.....	20
Table 5: Yeast concentration and voltage with each dilution .....	23

## List of abbreviations

A	Absorbance
AC	Alternating current
BAT	Best available techniques
DC	Direct current
DCU	Digital Control Unit
FTU	Formazin Turbidity Units
IR	Infrared radiation
L	litre
LED	Light emitting diode
Log	Logarithmic
min	minute
mL	millilitre(s)
mm	millimetre(s)
MQTT	MQ Telemetry transport
mV	millivolt(s)
N	Nitrogen
nm	nanometre
NTU	Nephelometric Turbidity Units
P	Phosphorus
pH	Potential of hydrogen
PID	Proportional Integral Derivative
SS	Suspended solids
SYKE	Finnish Environmental Institute
T	Transmittance
UV	Ultraviolet radiation
V	Voltage

## Contents

1	Introduction	1
2	Peat in Finland	2
2.1	Uses and Characteristics	2
2.2	Peat Producer	4
2.2.1	Vapo Oy	4
2.2.2	Turveruukki Oy	5
2.3	Water treatment for peat water in practice	5
3	Background	6
3.1	Colorimetry	6
3.2	Beer Lambert law	7
3.3	Optical sensor	7
4	Company and its product	8
4.1	Suspended Solid Sensor	8
4.2	Process Water Analyser	9
4.3	Process Sensor	9
4.4	Low cost sensor	9
5	Sensor in experiment	10
5.1	Sensor 1	10
5.2	Sensor 2	10
6	Experimental Analysis	11
6.1	Aims of study	11
6.2	Sample collection	12
6.3	Methods and Materials	13
6.4	Data collection and result	15
6.4.1	Sensor 1 and sensor 2	15
6.4.2	Turbidity and pH measurement	18
6.4.3	Turbidity and Voltage	20
7	Fermentation experiment	21
7.1	Material and Methods	21
7.2	Data collection and Result	22
8	Comparison between the sensors	24

9	Conclusion	24
10	References	25
Appendices		
Appendix 1. Data from Sensor 1		
Appendix 2. Data from Sensor 2		
Appendix 3. Graph from Fermentation process		

## 1 Introduction

Peat is the decomposed dead organic matter or vegetation in dark brown to murky black colour. It is formed by decaying organic matter in acidic and anaerobic conditions. Peat grows in wet areas; thus, the area of land where peat is gathered is called peatland. There are peatland all over the world covering 400 million hectares of land in 180 countries, which covers almost 3% of the land of the world. Countries covered by large amount of peatland are located in Europe, North America, Africa and Canada.

There are many factors which peat production depends upon, one of the primary factor being climatic condition. The warmer the climate, the higher the decomposition rate. The main factor that alters the decomposition rate is temperature and water. It affects the growth of vegetation and microbes.

Similarly hydrology, geology and geomorphologic play an important role in a peat production. Water supply is either from rainfall or from groundwater. In order for peat to form, the level of nutrient and mineral in the water supply should be low enough. The groundwater supply of water does not act as a favourable condition for peat formation, whereas peat formation occurs only if the water source is from rainfall. Geomorphology affects the peat formation by changes in the physical, chemical or biological processes such as hydrology, soil saturation, surface water movement and surface erosion. Soil conditions such as soil temperature, humidity, microbes, decomposition, and pH play important role in peat formation.

Peat has versatile application in different fields such as:

- energy generation
- fertilizer, compost manure in agriculture
- horticulture
- soil improvement
- landfill structure
- crop husbandry cultivation
- animal husbandry
- peat textile
- raw and building material
- providing space for water reservoirs
- urban, industrial, and infrastructure development
- medical purpose

## 2 Peat in Finland

### 2.1 Uses and Characteristics

Finland is regarded as the largest peat producer in the world. Peatland covers almost 30% of land in Finland which is approximately 9.3 million hectares. In addition, the climatic condition of Finland is suitable for peat production. However, the water content in the soil of Nordic countries is very high due to the long snowy winter and short summer. Lapland covers the biggest area for peat production. [1]

About 90% of the peat is used for energy production. It is one of the important energy sources providing about 6.2% of annual energy production. Peat energy is used in heat and electricity generation, resulting in 100 power plants using peat energy. Similarly, 1 million houses are heated by peat and wood. [1]

Peat is a valuable resource which must be protected as it has become a necessity for power plants. Although peat extraction varies with the time and year, peat is not sufficient to meet the demand. Peat and wood are used together so that either peat is used as main fuel or as an additive to wood. Peat production has increased the economy of Finland. There are hundreds of private companies who harvest peat, and it is considered as an

important source of income, especially to farmers and villagers. According to technical research centre Finland, peat production has provided employment for around 12000 person per year. [2] The usage of peatland in different sectors in Finland is shown in Figure 1.

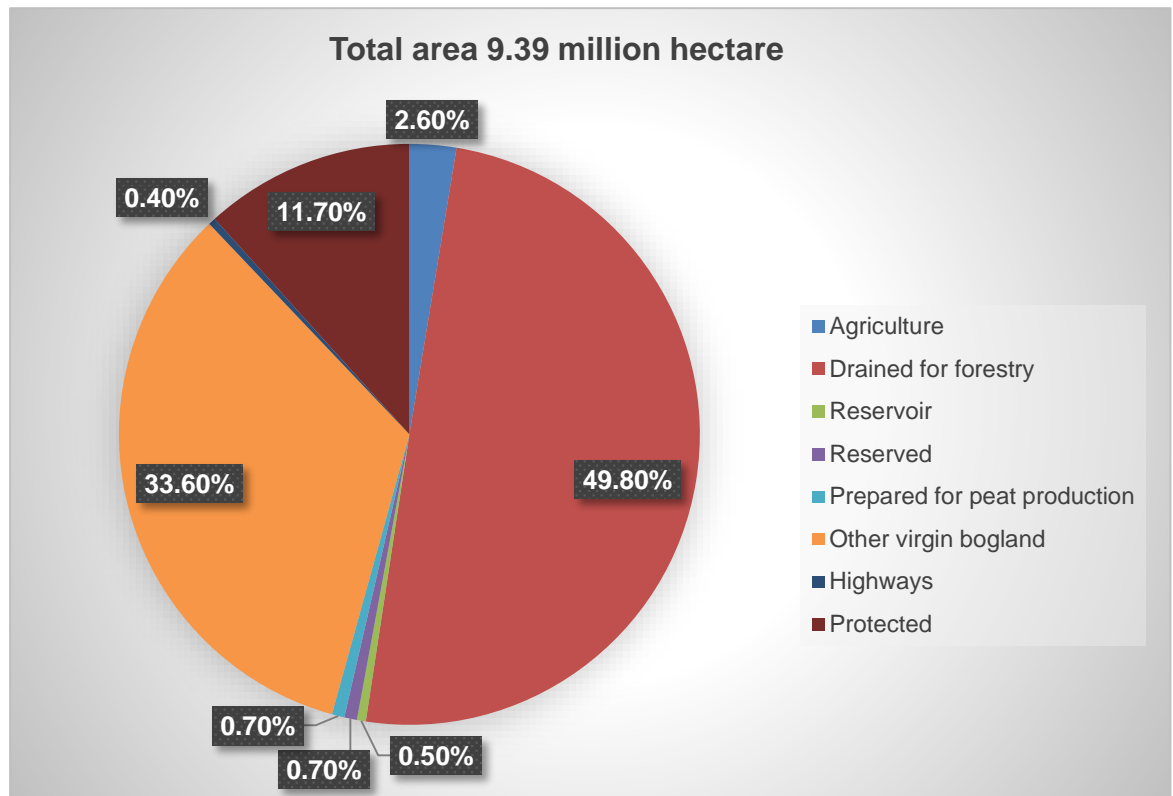


Figure 1: Use of peatlands in Finland [3]

With the positive aspects, peat production also has several negative impacts upon the environment. It affects climate, biodiversity and water quality and is regarded as the leading cause of global warming in Finland. It emits tons of carbon dioxide every year causing greenhouse gas emissions in the environment. It is estimated that the CO<sub>2</sub> emission from peat is equal to CO<sub>2</sub> emission from all the passenger cars in Finland, which is approximately 10 million tons. [1]

Peat production causes water pollution. It contains a high amount of organic acids, toxic metals, nutrients and suspended particles. It also contains phosphorus (P) and nitrogen (N) which effect the colour, pH and quality of water. This pollution leads to eutrophication, loss of biodiversity and destruction of water quality. This may be due to lack of proper monitoring, awareness and carelessness by the government. However, with the change in time, improvements have been made to control water pollution. Nutrient loads have

also decreased in comparison with those in the past. The accident in peat production site in Lestijärvi made people and companies more serious about environmental protection.

Legislation has been introduced by the Finnish environmental authorities to reduce the impacts on water, environment and sustainable development. The Finnish National Board for Water and Environment has marked certain guidelines for water pollution control. There are several organisations and groups working for the proper management of peat. People have become aware about peat management as it is utilized by them. Proper monitoring of production area, appropriate methodology and assessment for water protection has also been made. Finland's Environmental Administration has conducted new projects to focus on water from peat production area. [3]

## 2.2 Peat Producer

There are many peat producing companies in Finland. At the present there are eight large and middle size companies, among which Vapo Oy is the largest producer of peat.

### 2.2.1 Vapo Oy

Located in the heart of Finland, Jyväskylä-based Vapo Oy is the largest peat producer producing about 78% of peat in Finland. It aims to produce peat in such a way that it does not harm the environment. Vapo Oy provides the best available techniques to test the quality and quantity of water. It has installed the first continuous equipment which provides data about the suspended solid and dissolved organic matter every day. It is involved in several projects and research for Environmental and water protection. [2]

One of many projects funded by Vapo Oy is called The Sulka Project, which was implemented by Finnish Environmental Institute and University of Oulu. The major objective of the project was to treat the water load from peat production area. The treatment was done by chemical process and use of passive material. [2]

Likewise, there are other projects being conducted such as SuHE project and theTASO project for water protection from peat production. The SuHE project aimed to reduce acid watercourse load from peat production area. The TASO project worked for the water

protection by different testing and monitoring methods. Similarly, it creates awareness to the peat producer contractor and public about the effects of peat production in water. [2]

### 2.2.2 Turveruukki Oy

Turveruukki Oy is another company located in city of Oulu which produces peat (10%). It supervises the environmental impacts in all the production areas and works according to the environmental permit. It also conducts many projects and public meetings to insure environmental protection. [4]

Similarly, there are other peat producing companies such as Fortum power and heat, Kuopion Energy, and Alholmens Kraft. These companies work under a strict environmental license. They have to follow certain rules and operate according to them. They use different methods for water treatment such as basic methods, chemical methods and advanced methods. [4]

### 2.3 Water treatment for peat water in practice

There are several projects conducted by the companies such as Vapo Oy and Turveruukki Oy concerning the treatment of water from peat production. University of Oulu has been conducting several projects under the supervision of these companies. In Finland, the best available techniques being used for designing construction, maintenance and operation of peat water.

The best methods used by the companies for purification are as follows:

- Overland flow fields  
In overland flow, the discharge water from peat production flows into the surface layer of peat bog. This helps to remove the dissolved nutrients by chemical and biological process. By this process, 55% to 92% of suspended solids, up to 49% of total nitrogen, and up to 46% of total phosphorus are removed. [5]
- Peak runoff control dam  
It controls the flow of water discharge from the peat production area. It helps to decrease the sediments and nutrients load. By this process, 61%-94% of suspended solids, 45%-91% of total nitrogen, 47%-88% of total phosphorus are reduced. [5]

- Chemical treatment.

A chemical which causes sedimentation and the dissolved particles to settle down is added to peat water. The coagulants added are such as metal salts, aluminium, silica and lime. By this process, 30%-90% of suspended solids, 30%-60% of total nitrogen and 75%-95% of total phosphorus are removed. [5]

Chemical treatment is expensive as compared to others because it needs high maintenance. Vapo Oy has conducted a project using the chemical coagulants like aluminium sulphate and ferric aluminium sulphate. Likewise, Finnish environmental institute SYKE has reported that they have used the iron based coagulants in their projects.

The most common water treatment technique is base level water treatment which is used by Vapo Oy. Currently, clean waters has been conducting the peat water treatment projects in different places. It is a part of Vapo Oy which works under its supervision. The projects were estimated to be implemented between 2014 and 2015. First project focuses on the planning for peat water treatment in southern Finland, Ahtari. Similarly, the second project aims at reducing the water outflows from the peat area. To this end, investigation and piloting techniques have been used. [2]

### 3 Background

#### 3.1 Colorimetry

Colorimetry is a method used to determine the concentration of a solution based on relative absorption of light with respect to known concentration of solution. The device that is used in the process of colorimetry is known as a colorimeter. [6]

In colorimetry, absorbance and transmission of light plays an important role. It can be described as follows:

Transmittance (T) = Light transmitted (I) / Incident light (I<sub>0</sub>)

Absorbance is the amount of the light absorbed by the sample which is logarithmic function of T.

$$A = \log (1/T) = a \cdot b \cdot c$$

Where, 'a' is the constant, ability of molecule to absorb a particular light  
 'b' is path length  
 'c' is the concentration of particles

### 3.2 Beer Lambert law

When a monochromatic ray of light ( $I_0$ ) passes through a light absorbing solution, the intensity ( $I$ ) exponentially decreases. The attenuation is directly proportional to the length of the absorbing medium ( $l$ ) and the specific absorptivity of the substance ( $k$ ). In other words, the intensity decreases as the depth of the medium increases. This is called Lambert's law. [7]

Mathematically,

$$I = I_0 e^{-k_1 l}$$

Similarly, Beer Lambert law describes the relation between concentration of the light absorbing solution and amount of light absorbed by the solution. Beer's law states that, when a monochromatic ray of light passes through an absorbing solution, the intensity is exponentially opposite as that of the concentration of the solution. In other words, the intensity decreases as the concentration( $c$ ) of the absorbing medium increases. [7]

Mathematically,

$$I = I_0 e^{-k_2 c}$$

Eventually, the combination of these two laws is called Beer-lambert law:

$$I = I_0 e^{-k_3 c}$$

### 3.3 Optical sensor

Optical sensor converts the light rays into electronic signals. The use of optical sensor has been increasing with the years. Water quality measuring optical sensor measures on the basis of absorbance and scattering of light. When the light is absorbed by water sample, the sensor measures the difference in light intensity and solid content of the water. The measurement can be quite challenging sometimes. The IR absorbance arrangement is a classic example of applying Lambert-beer law; the light path length is fixed and the solids have specific absorption at IR wavelength region. [8]

The principle of optical measurement is shown in the Figure 2.

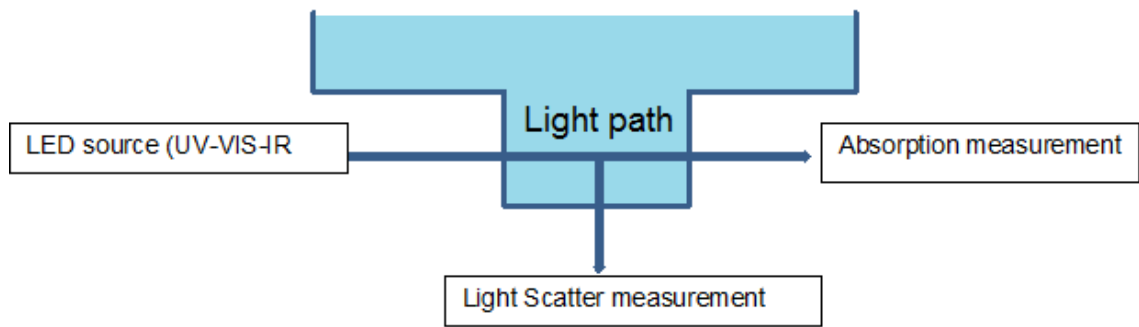


Figure 2: Principle of optical measurements

#### 4 Company and its product

Langis Oy is a technology company established in 2007. It has been building cost effective sensors which are five to ten times cheaper than normal sensor available in the market. The aim of the company to satisfy varieties of users. The sensors can be used in industries, water treatment companies, laboratory analysis, research and analysis and so on. The sensors developed by Langis Oy are efficient and sustainable. They analyse the nutrients, phosphorus and nitrogen in water. The sensor helps to gather large amount of data in the matter of seconds which can be used for analysis. The sensor consist of sensor board which are equipped with programmable LED driver, Amplifier, AC-DC convertor for power supply. The sensors are capable of taking three measurements UV abs, IR abs and IR scatter. [9]

The sensors developed by Langis Oy are cost effective because they are developed by virtual design and manufacturing methods. The materials used are according to physical need. Langis Oy conducts its own workshop regarding the manufacturing of prototype. This helps the effectiveness and efficiency of sensor before launching into the market. Some of the product made by Langis Oy are as follows:

##### 4.1 Suspended Solid Sensor

It is single gap Infrared measurement sensor. It is small and easy to use and is economical and can be used by small waste water treatment plants. It can be equipped with 2.4 GHz radio link for wireless data transmission. Langis will be manufacturing similar UV sensor for monitoring peat water. These are equipped with the sensors, gateway, radio link and controllers utilizing MQTT and MESH protocols. Suspended solid sensor is used

by WWTP in Parikkala, Finland for monitoring the sludge balance measurements. It has been operating since May 2015. [10]

#### 4.2 Process Water Analyser

Process Water Analyser helps to measure the water quality parameters continuously. It consists of two infrared absorption measurement: IR scatter measurement and UV absorption measurement. It has a large vortex chamber to remove air and enable efficient mixing of sample. The automated cleaning is done with detergent and water jet. It is equipped with integrated data server and control unit that helps in the interaction operating system and application. This was used to measure the suspended solids particles in water by Rauma pulp mill. [10]

Langis has developed an online measurement unit to monitor water from peat production area. The measurement units can be used in different production areas. The installation is very easy. It consists long glass fibre which as a radio link and battery attached at the top and sensor at the bottom. The battery is durable and solar cell can be installed to extend the operational time. The data is transferred through radio links.

#### 4.3 Process Sensor

The sensor is installed between two plates. It is cost effective and can remain in high temperature and pressure. It can be cleaned with a wiper or water or air jet. The materials used are steel, sapphire and polycarbonate glass depending upon the process. [10]

#### 4.4 Low cost sensor

It is designed in accordance to the amount of service and sales volume. Langis Oy owns its own technology and digitalized service.

In collaboration with Outotec, Langis gives efficient services and innovative approach, designing and manufacture technology for Outotec. It also provides environmental monitoring service. Outotec have right to sale the built technology. [10]

## 5 Sensor in experiment

There were two types of sensors provided by Langis Oy which were used in this project:

### 5.1 Sensor 1

It is a prototype manufactured by Langis Oy which is used to measure the quality of water. It works similarly as suspended solids measurement sensor that helps in measuring suspended solids by absorbing the IR light of 880nm, with a light path width of 20mm. During one measurement cycle, the intensity of IR emission is increased up to four different levels so that the measurement can be carried out in a wide range. The measurement of suspended solids can be done between 100 milligram per litre and 15 gram per litre. The output of the sensor is analogue voltage signal between 0 and 5 V at 10/8 bit resolution. The sensor gives values in two forms i.e. time and voltage. The sensor 1 used in the thesis project is shown in Figure 3.



Figure 3: Suspended solid measuring sensor

### 5.2 Sensor 2

Sensor 2 is also manufactured by Langis Oy. It is used to measure suspended solids using absorption of IR light of 880nm and light path width of 20mm. If the IR scatter (880 nm) is measured at an angle of 90 degree then it indicates the turbidity of water. Generally, turbidity is the process of testing the clarity of water. Similarly, measuring the UB Blue absorbance (405 nm) through 5 mm light path shows the colour of water for instance

humid substances. The working mechanism of Sensor 2 is completely different than that of Sensor 1. In this sensor, all the measurements are done at constant emission intensity providing the sensor output as a serial data at 16 bit resolution. The sensor provides values in four forms namely, Infrared absorption, Infrared scatter, UV absorption and voltage. Sensor 2 with the power supply can be seen in Figure 4.

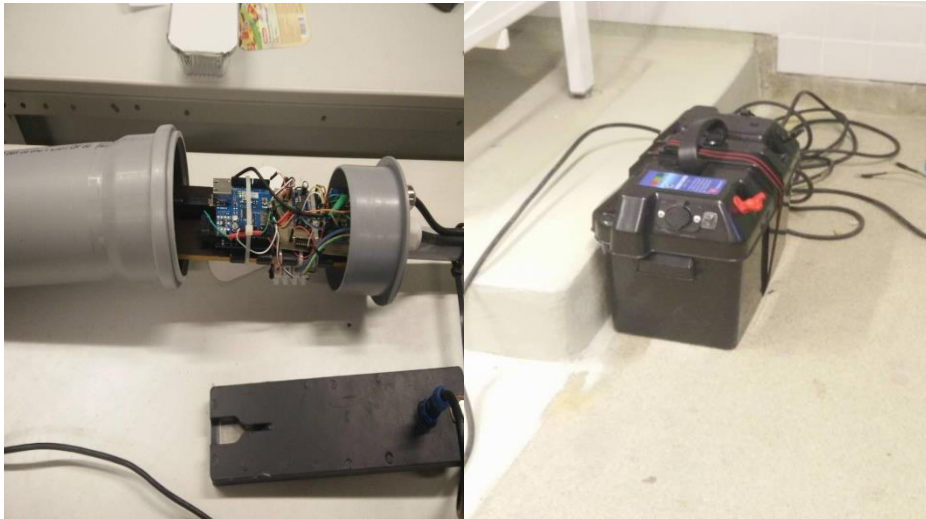


Figure 4: Water quality measurement sensor

## 6 Experimental Analysis

### 6.1 Aims of study

The main task was to install, calibrate and test the water sample taken from peat production area for environmental monitoring and waste water control system. A sensor was used to test the water quality from peat production area. This helped to check the accuracy and reliability of sensor before launching into market. The measurement was carried using an autonomic online measurement station with MQTT network and 4G gateway. Autonomic online measurement station helps to follow the existing water quality and, any change in them and also provide information on continuous basis. The data was analysed using Thingspeak platform. Thingspeak is an open source platform that is used to store and collect the data from sensor. It also helps to analyse and visualised the data and act accordingly. Python program was used to collect the data from sensor which is presented in Figure 5.

```
1  #!/usr/bin/python
2  # -*- coding: utf-8 -*-
3
4  import serial, time
5  import httplib, urllib
6  import sys
7  import ftplib
8  import re
9
10
11
12  start = time.time()
13
14  port = serial.Serial('/dev/ttyACM0', 9600, timeout = 2)
15  #portin lukuparametrit: portti, baudinopeus, timeout
16
17  port.flushInput()
18
19  def writetofile(logdata):
20      f = open('/home/pi/Desktop/datalog.txt', 'a')
21      f.write(logdata)
22      f.closed
23
24  while True:
25
26      data = port.readline().rstrip()
27
28      print(data)
29
30      writetofile(data + "\n")
31
```

Figure 5: Python code

In the laboratory, the samples were diluted and their output voltage dilution curves was measured. The calibration curve was generated, from which, the calibration equation was derived according to the curve fitting method. The measurement was taken multiple time in order to ensure the correct reading.

## 6.2 Sample collection

Peat water sample was taken from swap called Muurainsuo near the city of Lovisa. Muurainsuo is a conservation area which is habitat for bogs and birds. It works under certain law set by government and is operated by Vapo Oy. The brownish coloured sample was brought in a big plastic bottle and kept in the refrigerator.

### 6.3 Methods and Materials

The experiment was carried in Laboratory. The material used are as follows:

- Company Sensor
- Water sample from peat
- Tap water and deionised water
- Beakers -500 ml
- Graduated Cylinder-500ml
- Gloves
- Safety glass
- Pipette
- Glass stirring rod
- PH meter
- Turbidity Meter

All the necessary equipments were collected in the lab. The water sample from peat and sensor was brought in the lab. The dilution was made with the sample in the beaker.

- First sample: 500 ml of mother solution.
- Second sample: From 500 ml 250 ml was taken out. The remaining 250ml of solution was diluted with 250 ml of pure water.
- Third sample: From the second sample 150 ml of solution was taken and diluted with 350 ml of water.
- Fourth sample: From the third sample 62.5ml of solution was taken diluted with 437.5ml of water.
- Fifth sample: From the fourth sample 31.25 ml of solution was taken and diluted with 468.75ml of water.

Basically all the solution were made 500 ml with the addition of water. Graduated cylinder was used for the proper dilution. Each sample were properly mixed with the stirring rod. The sensor was dipped inside the beaker and reading of each sample was taken. Dilution of the sample was done to observe the sensor performance.

The following measurement was taken:

- pH measurement

PH measures the acidity or alkalinity of water. The range of pH is between 0-14 where 7 shows neutral. The solution with pH less than 7 is acidic whereas more than 7 is alkaline or basic. PH can get affected by presents of chemical components in water. PH measurement was done in following ways:

1. PH was calibrated using the instruction provided.
2. Rinse the sensor head with ion exchanged water.
3. PH of the sample was recorded. The sensor head was ringed with ion exchange water before all measurement to avoid the contamination.

PH meter used in the experimental analysis can be seen in Figure 6.



Figure 6: PH meter

- Turbidity measurement

Turbidity measures the clarity of water. Water is turbid due to the presence of suspended particles. Higher amount of suspended solid makes the water cloudier. It is measured in NTU (Nephelometric Turbidity units) or FTU (Formazine turbidity units). The ideal turbidity level for water is 1NTU and above 5 NTU or above the water is highly turbid.

Turbidity machine was calibrated using the instruction provided and measurement was made.

1. Some amount of sample was taken in the measurement bottle.
2. The measurement bottle was kept in the assigned place inside the turbidity meter and the cap was closed.
3. The reading was recorded. The bottle was emptied and rinse.

Figure 7 shows the turbidity meter used in the experiment, and Figure 8 shows the peat water sample.



Figure 7: Turbidity meter



Figure 8: Peat water sample before and after dilution

## 6.4 Data collection and result

### 6.4.1 Sensor 1 and sensor 2

Experimentation and data collection is essential part in any project. The experiment was carried out and the data was collected from each sample. The experiment was repeated with the similar procedure to get the correct result. Thingspeak software was installed and the data was recorded automatically which was then converted into excel file where all the calculation was carried out.

The data from both sensor was transferred in excel. The average of voltage from each sample was calculated and taking all the average calibration curve was made. Same method was carried for both sensor. The table 1 below shows the voltage with certain peat concentration obtained from sensor 1.

Table 1: Average voltage for certain peat water concentration

Peat water concentration(%)	Voltage(Bits)
6.25	569.942
12.5	551.9348
25	539.977
50	520.9454
100	515.9916

Calibration curve is necessary to interpret response for sample. The graph is plotted between average voltage in y-axis and concentration percentage in x-axis. The noise was neglected while producing the graph. The graph obtained by plotting voltage and concentration is presented in Figure 9.

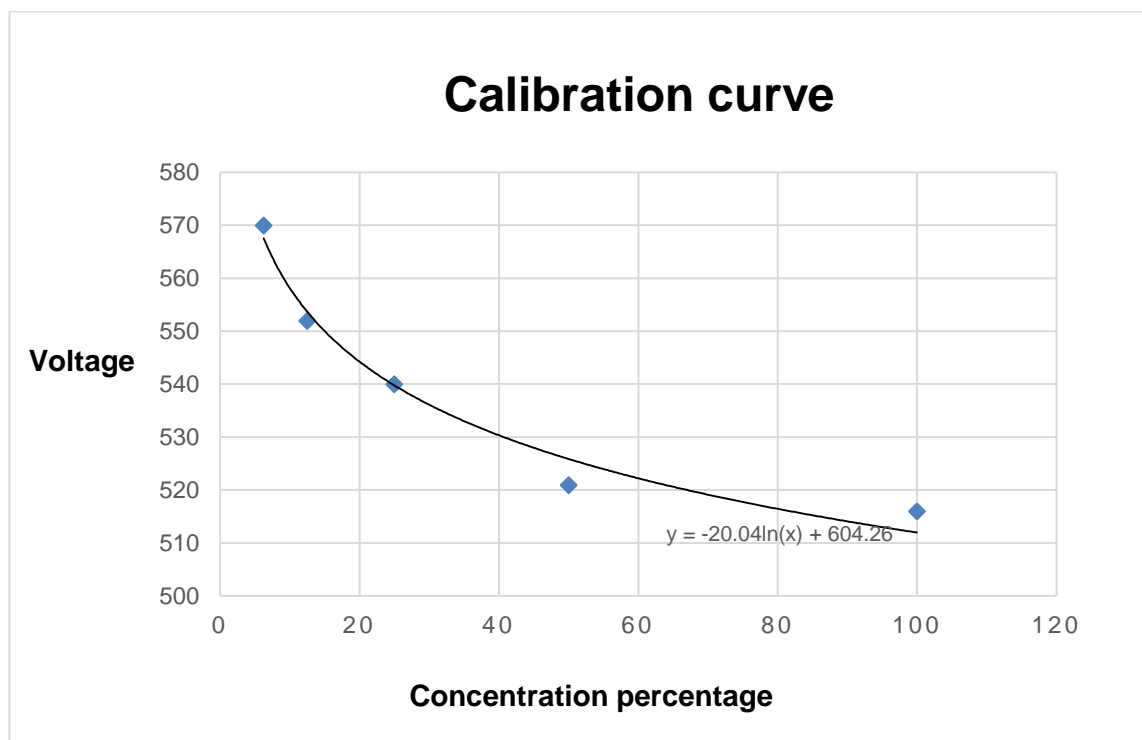


Figure 9: Calibration curve for data obtained from sensor 1

The trends of the line indicate the good pattern. It shows voltage is inversely proportional to concentration which means increasing number of voltage as the concentration of sample decreases. The curve is obeying the rule of Lambert beer law. The performance of sensor 1 is satisfying.

The experiment was repeated for many times with the sensor 1 but the sensor 2 was broken while carrying the experiment so the experiment could not be carried out many times. Regardless of that the result was reasonable. Table 2 shows the different voltage values obtained from different peat concentration.

Table 2: Average voltage for certain peat water concentration

Peat Concentration(%)	Voltage(Bits)
6.25	89421.2963
12.5	89386.34615
25	89178.51515
50	88820.8333
100	88178.51515

The calibration curves obtained from sensor 2 looks worthy. Better results could be obtain if the experiment was carried out several times. There could be possibility of human error as well as sensor error. The relation between voltage and concentration is shown by plotting a calibration curve in Figure 10.

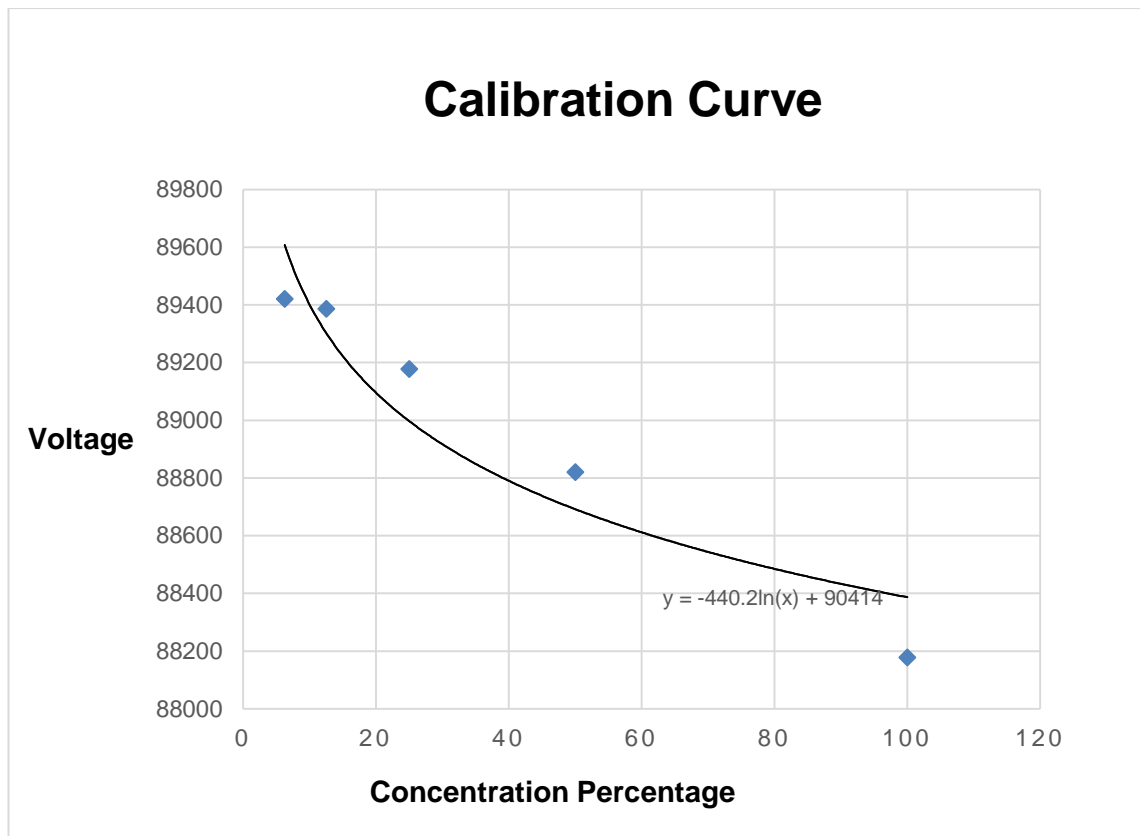


Figure 10: Calibration curve for data obtained from sensor 2

The calibration equation has been derived according to the curve fitting method

This indicates the performance of the sensor 2 is mediocre.

#### 6.4.2 Turbidity and pH measurement

The analysis of turbidity and pH was done in laboratory. While carrying the analysis at the beginning of the project with peat water and standard sample, there was no suspended particles found in the peat water. Therefore, suspended particle analysis was not carried out afterwards.

Turbidity and pH are considered as the water quality indicator which helps to indicate the presence of contaminants in the water. They are very important factors in water quality analysis. Turbidity may be caused by suspended or dissolved particles present in the water that scatter light which makes the water to appear cloudy. It is compared with the intensity of light scatter from the water sample with the turbidity standard values. High intensity of light will give high turbidity and vice versa. Higher turbidity indicates poor water quality. The colour of peat water sample used in the experimental analysis was brownish. This may be due to dissolved organic material such as humus and decayed

plant matter from decomposition. Turbidity can be affected by several factors like dissolved and suspended particles, size and shape of particles and its composition. The instrumental method was used to measure the intensity of light scatter by the particles. The measurement was carried in laboratory. It helped to check the solubility of peat water sample with the water. [11] The temperature of sample was 25°C.

Likewise, pH is an important indicator of chemical properties of water. pH can be affected by several factors: both natural and man-made. The intensity of pH determines the corrosiveness of the water. The presence of metals and material makes the water corrosive.

#### 6.4.2.1 Interpretation of results

The result obtained from the turbidity and pH measurement is shown in the table 3.

Table 3: Turbidity and pH measurement for certain peat concentration

Peat Concentration(mL)	Turbidity(NTU)	pH
500	3.18	6.50
250	1.72	6.10
125	0.85	5.95
62.5	0.77	5.2
31.5	0.26	5

The slight difference has been found in the turbidity measurement of sample with each dilution. Peat water has a very little suspended solid particles, thus turbidity is low. The turbidity of mother solution obtained from experiment was 3.18 NTU, which means water was less turbid. After dilution with each sample, the turbidity seems to be decreasing.

Likewise, pH of mother solution was 6.50 which was acidic. After dilution, no significant difference has been found. At times, the value of pH may be high in peat water due to presence of calcium carbonate. Calcium carbonate can be naturally present in peat production area which has made the water alkaline. A retest was held since the value of pH was higher during first analysis. However, in this experiment, the pH was decreasing after each dilution. Figure 11 below shows how the turbidity decreases with each dilution.

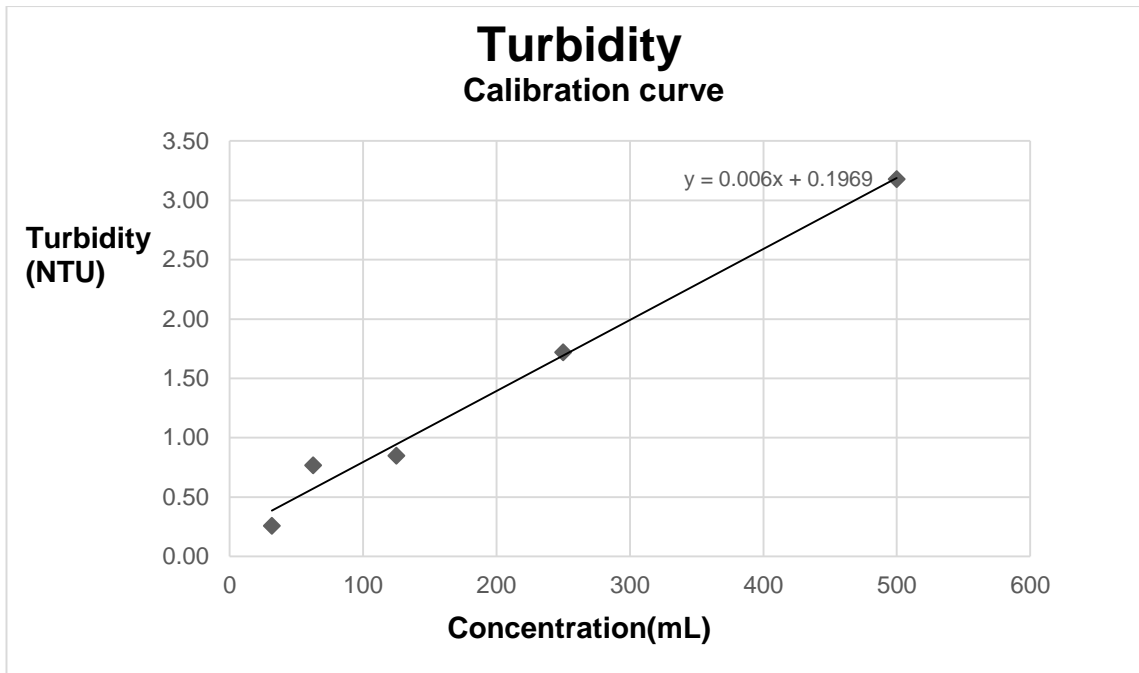


Figure 11: Turbidity calibration curve

The graph shows high concentration of peat water in which the turbidity is higher. With the concentration point 250, the graph is in nonlinear part of the assay whereas other follows the linear pattern. The turbidity has been declined with each dilution.

#### 6.4.3 Turbidity and Voltage

The turbidity measured with the lab device and voltage from sensor 1 was compared. The result from sensor 1 was reliable and better than sensor 2, thus it was taken for comparison. The table 4 below shows the data from the results.

Table 4: Turbidity and voltage

Turbidity (NTU)	Voltage (Bits)
3,18	515,9916
1,72	520,9454
0,85	539,977
0,77	551,9348
0,26	569,942

It shows that the turbidity (with lab device) has inverse relation to IR absorbance; the absorbance (voltage) decreases with increasing solids but the scatter light (turbidity) increases up to specific point. This is presented graphically below in Figure 12.

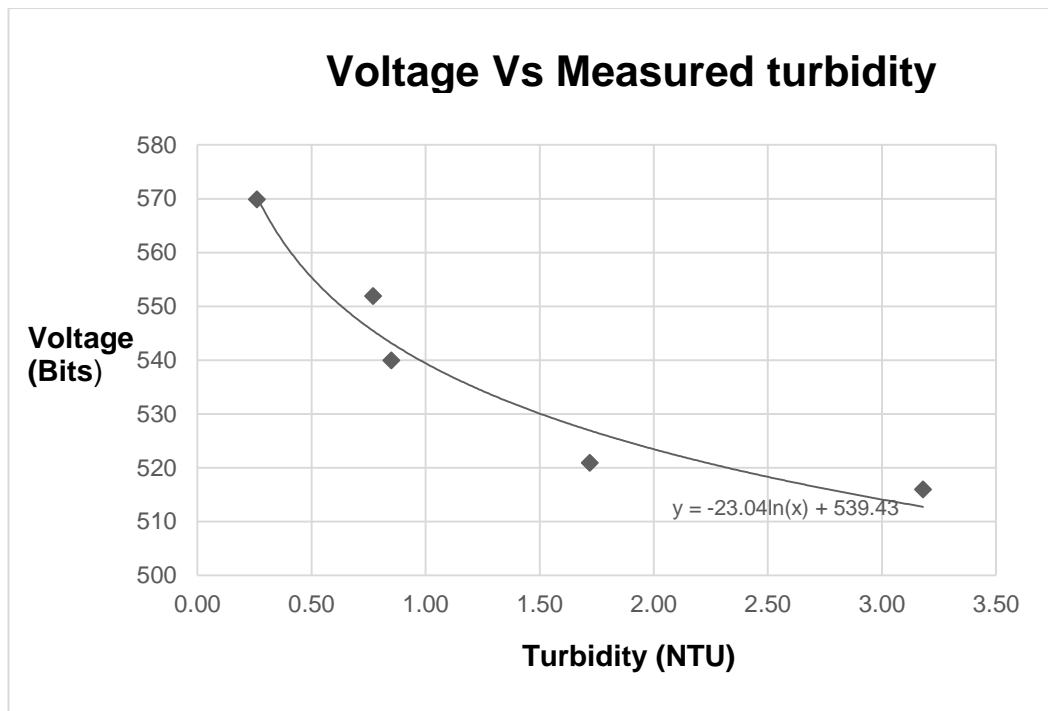


Figure 12: Voltage Vs measured turbidity

The y-axis is voltage (bits) and x-axis is scattered lights. All the points are not in a linear pattern. The voltage is gradually decreasing whereas the turbidity is increasing. It shows a proper transfer function between voltage and turbidity.

## 7 Fermentation experiment

### 7.1 Material and Methods

The experiment was carried out in bioprocess laboratory to study the growth of yeast in automated fermenter. The automated fermenter used was Sartorius Biostat C-DCU. It is a fully qualified system with in-situ sterilisable culture vessel having capacity up to 30 litre working volume. It performs various applications. The modular design of fermenter looks complex but it's quite simple and easy to use. It consists of culture vessel, the supply unit, control cabinet and DCU 3 (Automated digital controllers).

The experiment was carried for almost six hours. The solution was prepared by adding following quantity of nutrients:

- 9 litres of water
- 50 ml of malt extract as nutrient
- 50 gram glucose was added at 9 am and later on 1 pm approximately
- Potassium nitrate and phosphates, 0.5 g of each as P and N
- 50 gram of baking yeast

The temperature was adjusted to 37 C. Similarly, PH was set to be 4.5 (PID control by phosphoric acid and NH<sub>3</sub> solution) and dissolved oxygen control (PID) by stirring speed. The fermentation process was carried out.

Sensor 1 for suspended solid measurement was used to measure the yeast sample. The nine litres of sample was prepared. Then two litres was taken out and diluted with two litre of water. Similarly again two was taken out and added two litres of water. The sample was diluted for four times and data was recorded with each dilution. Yeast sample was taken from fermenter by peristaltic pump to a decanter where sensor was placed. The sample was passed back to fermenter through a pipe as overflow from decanter. The pumping speed was 100ml/min. The Fermenter and the sensor during analysis is shown in Figure 13.



Figure 13: Sartorius Biostat Fermenter with sensor 1 in decanter

## 7.2 Data collection and Result

Sensor 1 was used to test the sample. The sample was diluted and data was obtained in single series with each dilution. The values can be seen below in the table 5.

Table 5: Yeast concentration and voltage with each dilution

Yeast Concentration (%)	mV	Dilution
100	76	Mother solution
77.778	103	First dilution
55.56	142	Second dilution
33.33	202	Third dilution
11.11	266	Fourth dilution

The calibration curve plotted between yeast concentration and voltage is presented below in Figure 14.

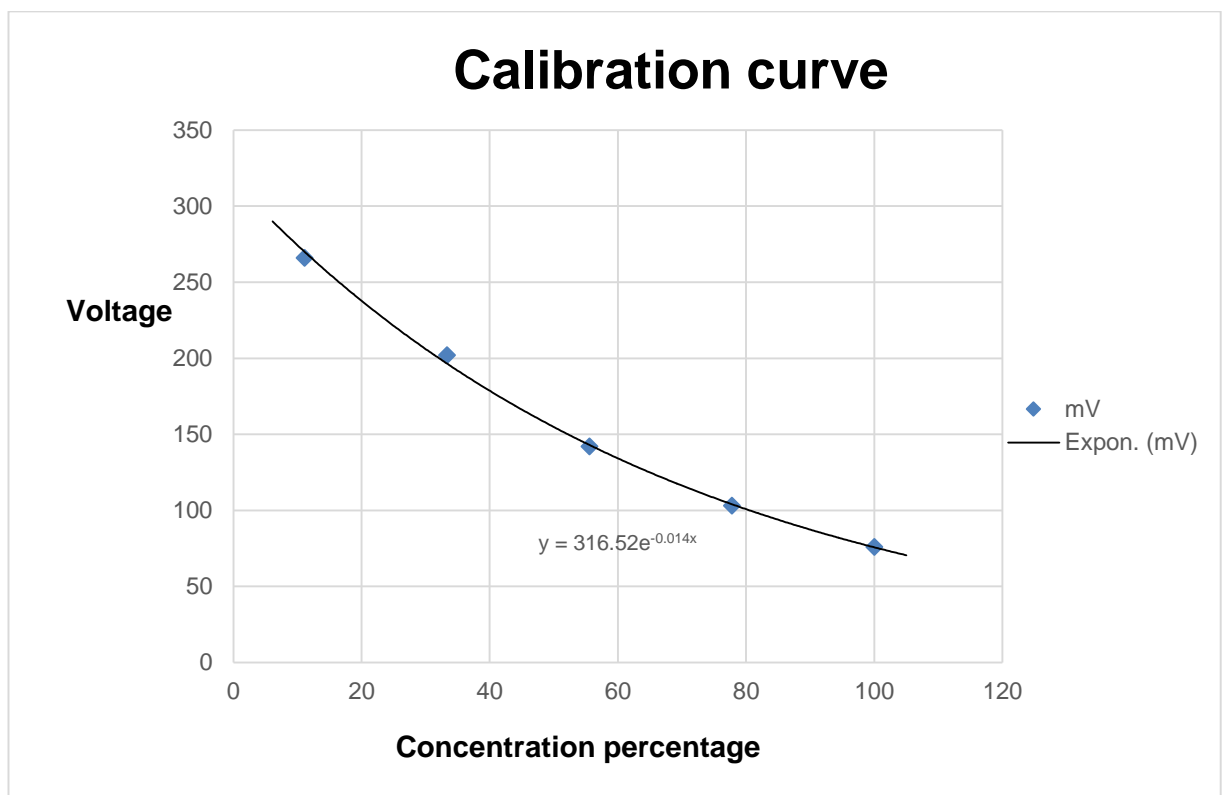


Figure 14: Calibration curve for fermentation process

The curve is obeying the rule of Lambert Beer law. The sensor 1 gave a good series of data. This shows the good performance of sensor 1.

## 8 Comparison between the sensors

Both the sensors are used for water quality measurement, but their working mechanism are completely different from each. Sensor 1 is small and easy to carry, whereas Sensor 2 is bigger and is connected to a big power supply battery. Sensor 1 gives single series of data in one measurement cycle, but sensor 2 gives data in four different levels during one measurement cycle. Sensor 1 allows measurement in a certain range, while sensor 2 measures emission at a continuous rate. Both the sensors have the ability to repeat the experiment again and again giving good and accurate results. They are responsive and fast can give the result in a few seconds. Sensor 1 is long-lasting, 2 broke down while carrying out the experimental analysis. This may be because it was just a prototype, not so strong and well-equipped. The performance of sensor 1 is better than sensor 2. Sensor 1 is precise, durable and productive as compared to sensor 2.

## 9 Conclusion

With the advancement of technology, newer and better products are available in the market. These products compete against themselves. The prototypes developed by Langis Oy are sustainable and reliable. The result obtained from the sensors and the experimental analysis was satisfactory. However, few artificial error and experimental error may be present due to the efficiency of device. The only problem encountered during the project was failure of sensor 2 because of which the experiment could not be repeated numerous times. Never the less, it was a prototype.

On the brighter side, the sensors are easy to use, efficient, concise, affordable and versatile. They can be used from small to large industries, environmental monitoring, laboratory, water treatment plants as well as common users. Hence is beneficial to any end user.

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## Appendices

### Appendix 1. Data obtained from Sensor 1

62.5		125.00		500		250		Mother solution								
531	1013	0	1013	1011	1012	746	1013	0	1012							
532	1013	0	1013	1012	1012	972	1013	0	1012							
532	1013	0	1013	1010	1012	1010	1013	0	1012							
535	1013	0	1013	1011	1012	1010	1013	2	1012							
535	1013	1	1013	1011	1012	1011	1013	0	1012							
531	1013	0	1013	1011	1012	1010	1013	0	1012							
534	1013	0	1013	1011	1012	1011	1013	2	1012							
532	1013	0	1013	1010	1012	1010	1013	0	1012							
534	1013	0	1013	1008	1012	1010	1013	0	1012							
536	1013	1	1013	1011	1012	1009	1013	0	1012							
763	1013	0	1013	1011	1012	1010	1013	0	1012							
783	1013	0	1013	1012	1012	1011	1013	0	1012							
783	1013	487	1013	1009	1012	1008	1013	0	1012			515.99	100			
784	1013	493	1013	1012	1012	1012	1013	1	1012			520.95	50			
784	1013	569.94	490	1013	551.93	794	1012	520.95	1008	1013	539.98	0	1012	515.99	539.98	25
786	1013		492	1013		0	1012		1008	1013		2	1012		551.93	12.5
784	1013		491	1013		0	1012		1008	1013		1	1012		569.94	6.25
783	1013		495	1013		0	1012		1011	1013		471	1012			
785	1013		493	1013		0	1012		1010	1013		502	1012			
785	1013		490	1013		0	1012		1008	1013		500	1012			
783	1013		496	1013		1	1012		1011	1013		506	1012			
787	1013		494	1013		0	1012		1010	1013		505	1012			
1009	1013		495	1013		1	1012		1008	1013		504	1012			
1010	1013		624	1013		0	1012		1010	1013		506	1012			
1012	1013		725	1013		1	1012		1012	1013		506	1012			
1011	1013		723	1013		0	1012		4	1013		508	1012			
1008	1013		724	1013		2	1012		0	1013		507	1012			
1010	1013		723	1013		0	1012		2	1013		507	1012			
1012	1013		722	1013		0	1012		0	1013		507	1012			
1011	1013		726	1013		0	1012		0	1013		739	1012			
1011	1013		722	1013		0	1012		2	1013		740	1012			
1010	1013		725	1013		0	1012		0	1013		739	1012			
1012	1013		723	1013		0	1012		0	1013		744	1012			
1010	1013		722	1013		0	1012		0	1013		742	1012			
1010	1013		721	1013		1	1012		0	1013		741	1012			
1012	1013		987	1013		0	1012		0	1013		742	1012			
1008	1013		1012	1013		0	1012		0	1013		743	1012			
1011	1013		1010	1013		491	1012		0	1013		741	1012			
1011	1013		1010	1013		497	1012		0	1013		743	1012			
1010	1013		1010	1013		495	1012		1	1013		743	1012			
1011	1013		1010	1013		494	1012		2	1013		816	1012			
1010	1013		1010	1013		498	1012		0	1013		1009	1012			
1009	1013		1011	1013		493	1012		0	1013		1009	1012			
1011	1013		1012	1013		496	1012		0	1013		1008	1012			
1011	1013		1011	1013		498	1012		1	1013		1011	1012			
53	1013		1009	1013		496	1012		0	1013		1012	1012			
0	1013		1011	1013		495	1012		0	1013		1012	1012			
2	1013		1008	1013		494	1012		505	1013		1010	1012			
0	1013		1012	1013		602	1012		508	1013		1010	1012			
1	1013		1010	1013		726	1012		515	1013		1011	1012			
0	1013		1008	1013		725	1012		512	1013		1011	1012			
0	1013		1011	1013		726	1012		510	1013		1008	1012			
0	1013		1009	1013		724	1012		512	1013		1010	1012			

## Appendix 2. Data obtained from Sensor 2

75562	-131072	-131072	87298	88178.5	-61513	-131072	-131072	88874	88874	
				88178.5					88867	
68918	-131072	-131072	87293	88178.5	-66170	-131072	-131072	88867	88867	
				88178.5					88861	
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				88178.5					88856	
63350	-131072	-131072	87295	88178.5	-68979	-131072	-131072	88856	88856	
				88178.5					88849	
65058	-131072	-131072	87297	88178.5	-70028	-131072	-131072	88849	88849	
				88178.5					88844	
64902	-131072	-131072	87298	88178.5	-71940	-131072	-131072	88844	88844	
				88178.5					88836	
65406	-131072	-131072	87300	88178.5	-74233	-131072	-131072	88836	88836	
				88178.5					88830	
66186	-131072	-131072	87300	88178.5	-74644	-131072	-131072	88830	88830	
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				88178.5					88820.83	
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				88178.5					88820.83	
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				88178.5					88820.83	
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				88178.5					88820.83	
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66976	-131072	-131072	88178.51515						88820.83	

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-52642	-131072	-131072	89188	89188	66782	-131072	-131072	89401	89401
				89178.52					89396
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				89178.52					89390
-57771	-131072	-131072	89155	89178.52	66438	-131072	-131072	89390	89390
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				89178.52					89386.3
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				89178.52					89386.3
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				89178.52					89386.3
-65134	-131072	-131072	89077	89178.52	65406	-131072	-131072	89367	89386.3
				89178.52					89386.3
-64452	-131072	-131072	89070	89178.52	65458	-131072	-131072	89363	89386.3
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-62544	-131072	-131072	89064	89178.52	64750	-131072	-131072	89362	89386.3
				89178.52					89386.3
-60340	-131072	-131072	89056	89178.52	64558	-131072	-131072	89358	89386.3
				89178.52					89386.3
-60807	-131072	-131072	89049	89178.52	64510	-131072	-131072	89356	89386.3
				89178.52					89386.3
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				89178.52					89386.3
				89178.52	64510	-131072	-131072	89356	89386.3
				89178.52					89386.3
-32631.5	-131072	-131072	89178.52	89178.52	66460.154	-131072	-131072	89386.34615	89386.3

				Max	average
73226	-131072	-131072	89394	89444	89444
73110	-131072	-131072	89399	89444	
72758	-131072	-131072	89398	89444	
73278	-131072	-131072	89403	89444	
72998	-131072	-131072	89406	89444	
73106	-131072	-131072	89406	89444	
73182	-131072	-131072	89412	89444	
73350	-131072	-131072	89410	89444	
73306	-131072	-131072	89414	89444	
73214	-131072	-131072	89414	89444	
73318	-131072	-131072	89419	89444	
73174	-131072	-131072	89416	89444	
73282	-131072	-131072	89421	89444	
73102	-131072	-131072	89423	89444	
73194	-131072	-131072	89423	89444	
73098	-131072	-131072	89426	89444	
73086	-131072	-131072	89428	89444	
73226	-131072	-131072	89427	89444	
73130	-131072	-131072	89431	89444	
72914	-131072	-131072	89431	89444	
73054	-131072	-131072	89435	89444	
73114	-131072	-131072	89436	89444	
72918	-131072	-131072	89437	89444	
73006	-131072	-131072	89440	89444	
73158	-131072	-131072	89440	89444	
72878	-131072	-131072	89442	89444	
72998	-131072	-131072	89444	89444	
73117.7037	-131072	-131072	89421.2963	89444	

## Appendix 3. Graph From Fermentation Process

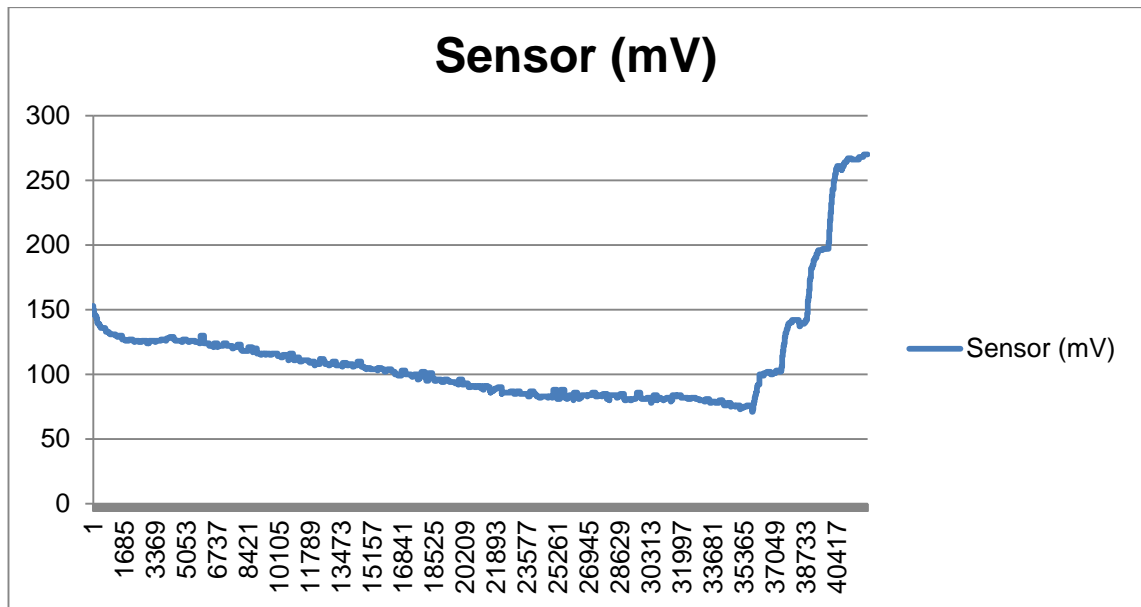


Figure 1: Voltage on sensor 1