Agua Clara Turbidimeter Team

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Abstract

This report will cover all the work that has been done at Cornell's AguaClara Lab on Turbidimeters. Research first started on creating a new low cost turbidimeter Cornell in the Spring of 2011. Since then several different prototypes have been created and 10 turbidimeters have been sent to Honduras for use by communities who are considering getting an AgauClara plant built. The first part of this report will cover why research needs to be done on turbidimeter design and how turbidimeters work. Then past research on turbidimeter designs will be summarized, including details on the latest prototype which was sent to the field in Hondoras this past summer. The current research being done will then be described, including new ideas such as the use of mirrors to lengthen the light path of the LED light and the use of colored cellophane to change the color of the light that reaches the user's eye. Finally, all conclusions that have been made this semester will be discussed and possible ideas on future research will be noted.

Introduction

The turbidimeter is a vital part of the AguaClara design. The turbidimeter helps AguaClara decide if communities need a plant to be built or not. The final goal of the Turbidimeter team is to build a device that can accurately measure turbidities down to $<$5NTU. The device would then be distributed to any community that is looking into having an AguaClara plant built for them. Next, the community would use the device for approximately a month until it can be accurately determined whether or not a plant should be built for them. Some communities may have water that is already clean enough to drink and some may unfortunately have water that is too dirty for AguaClara plants to be able to handle. The turbidimeter should also be user friendly.

There are many different turbidimeters on the market for use by labs and scientific experimentation, however there is no such device available at a low cost for "home" use. It would be impossible to give all the communities in Honduras that are considering building an AguaClara plant a turbidimeter that costs hundreds of dollars. The community would not be willing or able to pay for it. One of the most important design parameters of the turbidimeter we are trying to create is that is can not cost more than $20. The lastest prototype that was built and is currently be used in Hondorus is under $5, it is the hope of the AguaClara that all future designs will remain this afforable. It is possible that in the future one of the turbidimeters we design here at Cornell will make it on to the market so that others can take advantage of this technology as well.

Background

How Traditional Turbidimeters Work

Turbidity is defined as an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through a sample. If light were to travel through "pure" water, the light beam should travel relatively undisturbed, but if there are other particles, such as suspended solids, present then the light will be scattered and absorbed as it interacts with these molecules. Tradtional turbidimeters contain a light source, sample container or cell, and photodetectors to sense the scattered light. The most basic turbidimeter design, seen in Figure 1, consists of a light source that is projected through a sample. The detector is located at a ninty degree angle to the light source. Therefore, the light that is scattered at a ninty degree angle is detected. The amount of light detected is then related to the turbidity of the water.

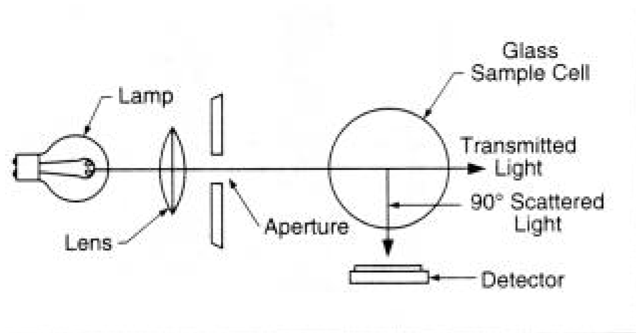

Figure 1: Single Beam Design Turbidimeter

Past Research

Research on the turbidimeter began in the Spring semester of 2011 and was continued during the summer. During the Spring 2011 semester a relationship between depth and turbidity was confirmed and a first prototype with a turbidity scale was designed. During Summer 2011 the turbidimeter design was improved and a more accurate relationship between depth and turbidity was found. A number of different LED designs was tested (See Figure 2 and 3)

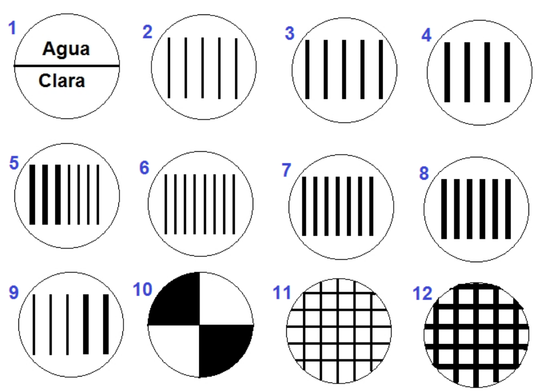

Figure 2: First 12 Designs

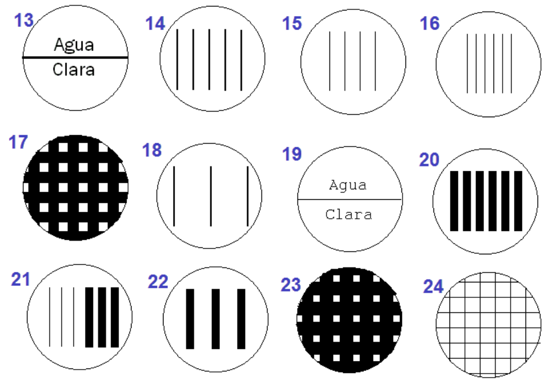

Figure 3: Last 12 Designs

Design #14 did not have the best total percent error but it did have the best fit to a power function, therefore, it was chosen to be the final design. Figure 4 is a Log Log plot of Depth vs Turbidity for the final design. As can be seen a very good fit for the data was achieved. The power law function for this set of data was as follows:

$$Depth = 1463.7 * Turbidity^{-1.29}$$

Using this formula the scale for the final turbidimeter stick was developed by inputting desired Turbidities such as 15, 16, 50, 100, 400 NTU etc. and marking the given depth that many cm above the light on the stick.

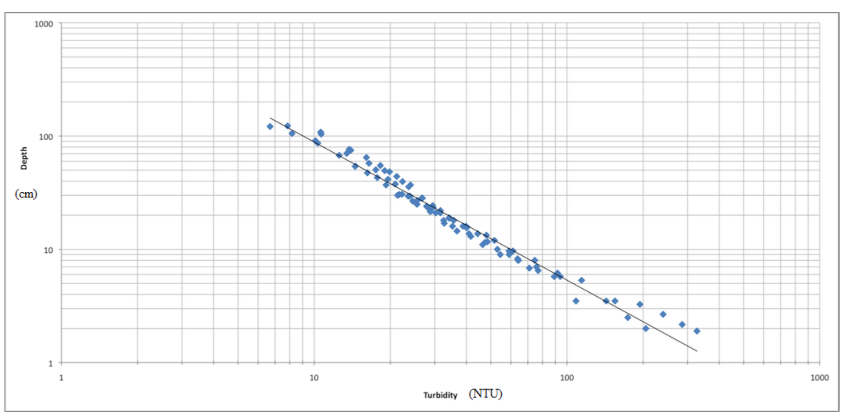

Figure 4: Log-log plot for Design 14

The latest design for the turbidimeter can be seen below in Figure 5. Ten of these turbidimeters were sent to Honduras to be used as seen in Figure 6.

Figure 5: Latest Turbidimeter Design

Figure 6: Turbidimeter being used in Honduras

Methods

Mirror Component Design

The team wants the turbidimeter to be able to measure turbidity as low as 5 NTU. One idea to achieve this was to extend the range of the turbidimeter by placing the light source at the top of the water column (facing down) and then attaching a mirror to the end of the lowering rod.The team's first design task was to figure out how to attach the LED (light source) at the top of the PVC pipe (water column) facing down. The team screwed the LED light (including light diffuser and pattern) to the inside of a PVC coupling, as seen in Figure 7. There is a slit in the coupling so that the operator can attach and remove it as needed. The mirror is glued to a L-shaped piece of metal (see Figure 7). The L-shaped piece of metal is then attached to the end of a lowering rod.

Figure 7: Mirror Component Design

Colored LED Design

The team did not have any colored LED lights but wanted to start testing to see if color will help to measure lower turbidities. Therefore the team bought colored cellophane at a local craft store (blue, green, red). A small piece of cellophane was cut and placed between the LED light and the light diffuser as seen in Figure 8. To get the cellophane to the right size we simply placed a large piece of cellophane between the light and the HDPE block and then cut around the edges of the block.

Figure 8: LED light with colored cellophane

Colored LED lights have been ordered and recieved. The team now has 3 Blue, 3 Green, and 3 Red LED lights. Testing with the blue LED light (seen in Figure 9) has begun. The blue LED light is attached to the lowering rod in the same way that the colorless LED light is attached in Figure 5.

Figure 9: Blue LED light

Experimental Design

Just like in previous semesters a pump (with a flow rate of 1.4 L/min) was used to continuously stir the water sample. A PVC pipe with holes drilled at the top and bottom was used to hold the water. Using tubing the bottom hole connects to an electronic turbidimeter, from there to a pump and finally to the top of the PVC (See Figure 10). The electronic turbidimeter is connected to a computer in the lab room and using a Process Controller program the NTU at every second was recorded into an excel file. This program proved extremely useful in that it was possible to write notes directly into the excel file at any given point in time.

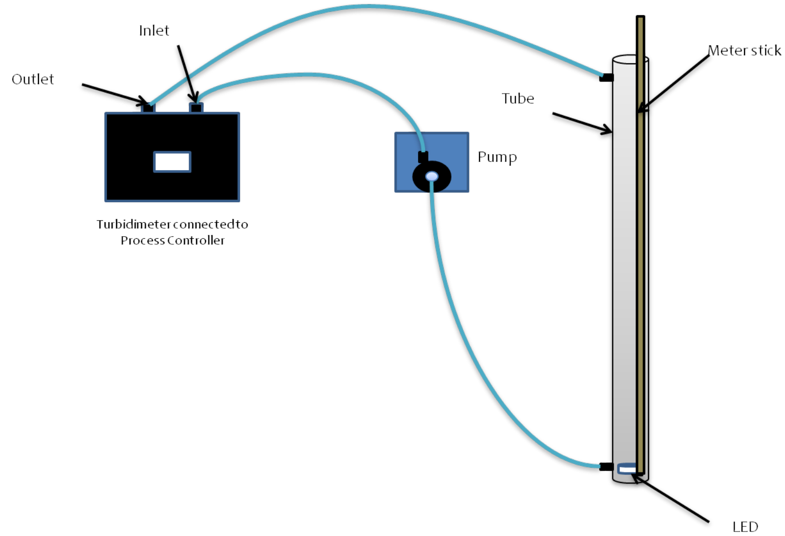

Figure 10: Contiuous-mix experimental schematic

1. Turn on data log i.e. the process controller on the computer
2. Add initial amount of clay
3. Run pump system for four minutes
4. Unplug pump, make a mark in data log as to show when pump was first unplugged
5. First team member takes depth reading
6. Plug pump in
7. Wait 60 seconds
8. Unplug pump
9. Second team member takes depth reading
10. Repeat steps 6-8
11. Third team member takes depth reading
12. Wait 60 seconds
13. Add the next amount of clay, make mark in data log as to show what the new total amount of clay in the system is
14. Repeat steps 3-13 until you reach the final amount of clay/NTU desired

Results and Conclusions

Mirror Component Design

After first testing out the mirror design the team found that aligning the mirror so the operator could see the reflection of the LED light pattern was very difficult. Even after brainstorming a few ideas to improve the design, the team decided that it would be best to reject the mirror concept and focus solely on improving the LED design. The team then decided to try using different colored LED lights.

Colored LED Tests

Blue Cellophane Covered LED

The team ran its first colored LED light test, using the blue cellophane covered LED. After the first test, the relationship found resulted in a R-squared value of 0.6419. This value was too low. The team hopes to achieve an R-squared value in the 0.9 range. This low R-squared value was probably due to the fact that our range of turbidity was not large enough (13-30 NTU) and that only a few measurements have been taken (see Table 2). The team continued to test the blue cellophane covered light and aquired a few more data points. The R-squared value increased to 0.9409. Using the equation of the line given in the log-log plot (see Figure 11) a relationship was found between turbidity and depth using a LED light covered with blue cellophane. This relationship can be seen below:

$$Depth = 1204.8 * Turbidity^{-1.142}$$

Mass of Clay (mg)	Average Height (cm)	Average Turbidity (NTU)
0	Bottom (120 cm)	3.9
0	55.7	13.6
5	105.7	8.3
5	46	18.1
10	87.7	9.1
10	40	22.1
15	37.3	22.6
20	58.3	12.2
20	35	21.7
30	43.7	15.4
30	29.7	23.2
50	26.3	25.6
100	19	29.9

Table 1: Blue cellophane covered LED light test data

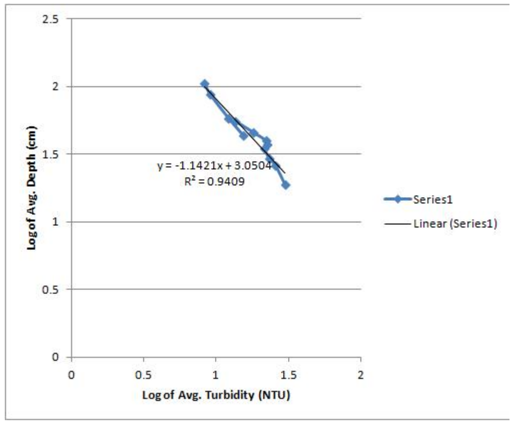

Figure 11: Log-log plot of depth as a function of turbidity for the blue cellophane covered LED light

Blue Colored LED

Testing using a blue colored LED light was started. The turbidites tested presently range from about 7 NTU to 53 NTU, as seen in Table 2. The log-log plot regression analysis produces an R-squared value of 0.9964 (See Figure 12). Because this value is higher than the R-squared value found of the blue cellophane covered LED data, the relationship between turbidity and depth using the blue LED light is more accurate. Therefore, it is most likely that testing using the cellophane covered LED light design will cease and only further testing with the colored LED lights will continue. Whether the colored LED light will be able to measure turbidities less than 5 NTU accurately has yet to be determined.

Using the trendline equation given in the log-log plot a relationship between turbidity and depth was determined. This relationship can be seen below:

$$Depth = 715.2 * Turbidity^{-1.1119}$$

Using this equation, theoretically, a turbidity of 5 NTU could be measured at a depth of 119 cm. Currently, the turbidimeter being used to do testing is 120 cm. Therefore, measuring turbidity less than 5 NTU might not be possible. Further testing, will either prove or nullify this hypothesis.

Mass of Clay (mg)	Average Depth (cm)	Average Turbidity (NTU)
0	81.7	6.9
5	67.3	8.8
10	51.3	10.3
20	38.7	13.2
30	33.7	16.4
50	24.7	20.8
100	16.3	29.7
150	12.3	40.8
200	8.3	52.3

Table 2: Blue LED light test data

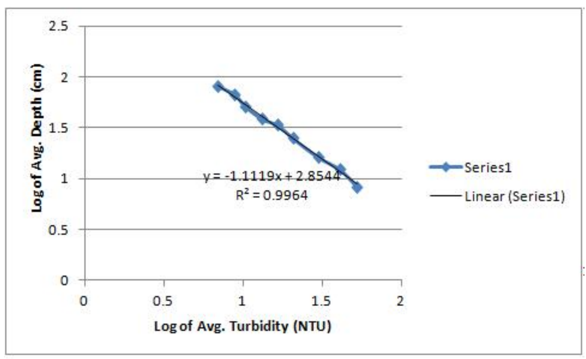

Figure 12: Log-log plot of depth as a function of turbidity using blue LED light

Future Work

There is still many different options that can be tested to improve the accuracy of the turbidimeter. Though we have already dismissed the idea of using mirrors for the design this semester the use of mirrors could be revisited in the future. The problem with the mirrors idea is that aligning the mirror with the LED was difficult and the only solutions the team could come up with did not work well with the low cost parameter. To get the mirrors to work well the design work need more components that would be more specialized and most likely more expensive than the parts we are currently using.

This semester experiments in which the color of the light has been changed have been performed. Due to the inaccuracy of the cellophane covered lights, the team will only continue using the colored LED lights. For the rest of this research period the team will continue to try more colors (blue, red, green) and more or less saturation of color.

An idea that has recently come up is the idea of using lights other than LEDs. This could possibly help to solve the problem of great disparities between different users readings. The LEDs have proved to be a problem as they often turn off with the slightest movement. Sometimes a light could be on and then after setting down the light on the counter it will suddenly turn off. Another situation that has happened many times is that a user will be attempting to take a reading but the light will go dim; this could clearly influence the accurarcy of readings if the user did not realize the change in the light brightness. More research needs to be done into what could possibly be reasonable subsitutes for LED tea-candle type lights.

Another suggestion that had been made by previous teams would be to try a different size of the HDPE block. This could potentially effect the amount of light which reaches the users eye and therefore the reading that the user would make. This could mean that the device could possibly read down to 5 NTU or less. Changing the size of the block could also lead to less disparity between different users readings, therefore making the turbidimeter more accurate.

In past semesters the idea of using humic acid had been brought up to the team. This would be a good idea to experiment with because it may make the water more like how it would actually appear in nature. Humic acid would change the color of the water without changing the turbidity of the water. This is something that people are often confused about, the idea of turbidity vs color. Running experiments where we could change both would help to clear up this confusion.

References

"Basic Turbidimeter Design and Concepts." U.S. EPA. EPA Guidance Manual Turbidity Provisions, April 1999. Web. 29 Sep 2011. <http://water.epa.gov/lawsregs/rulesregs/sdwa/mdbp/upload/20