AguaClara Turbidimeter Team

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Abstract

This report will cover all the work that has been done by Cornell's AguaClara program on turbidimeters. Research first started on creating a new, low cost turbidimeter at Cornell in the Spring of 2011. Since then several different prototypes have been created and ten turbidimeters have been sent to Honduras for use by communities who are considering building an AguaClara plant. The reason that a low cost turbidimeter needs to be developed is so that communities who may be in need of water treatment facilities can test their water without incurring the high expense of other turbidimeters currently on the market. The most current complete turbidimeter prototype can read NTU values down to 15 NTU. The research discussed in this report details new turbidimeter designs with which it may be possible to read NTU values down to approximately seven NTU. The most promising design includes the use of a blue LED light and a large HDPE block, which is used for diffusing the light. However, this design will need to be tested more thoroughly for accuracy before it can be fabricated for use in the field. In the future if research continues to be done to try to create a turbidimeter that can read turbidity values below 5 NTU the length of the lowering rod may have to be made longer than the current prototype, which is only 60 cm long. Without adding length to the lowering rod current research suggests that it may be impossible to read the turbidity of any water with an NTU value lower than seven.

Introduction

The turbidimeter is a vital part of the AguaClara design. The turbidimeter helps AguaClara determine the type of water treatment processes that are needed for a particular source water. The final goal of the Turbidimeter team is to build a device that can accurately measure turbidities down to <5NTU. The device will be distributed to any community that is looking into having an AguaClara plant built. 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 only require chlorination, while others may need the flocculation, sedimentation, filtration, and chlorination. 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 impractical 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 is that it can not cost more than \$20. The latest prototype that was built and is currently be used in Honduras is under \$5; it is the hope of AguaClara that all future designs will remain this affordable. It is possible that in the future one of the turbidimeters designed at Cornell will make it onto 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. Traditional 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[1], consists of a light source that is projected through a sample. The detector is located at a ninety degree angle to the light source. Therefore, the light that is scattered at a ninety degree angle is detected. The amount of light detected is then related to the turbidity of the water.

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[1] Basic Nephelometer. 1999. Graphic. EPA Guidance Web. 6 Dec 2011. <http://water.epa.gov/lawsregs/rulesregs/sdwa/mdbp/upload/2001_01_12_mdbp_turbidity_chap_11.pdf>.

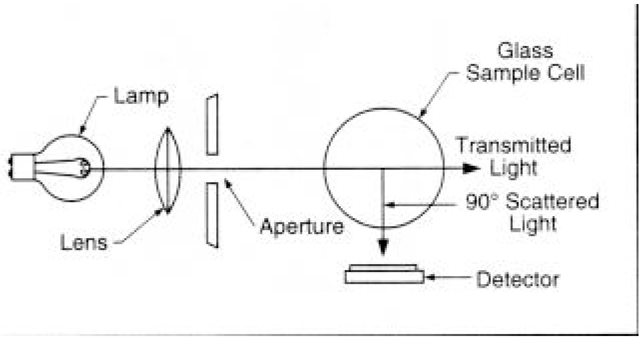

Figure 1: Single Beam Design Turbidimeter

Past Research

Research on the turbidimeter began in the spring of 2011 and was continued during the summer. During the spring of 2011 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 were tested (See Figure 2 and 3)

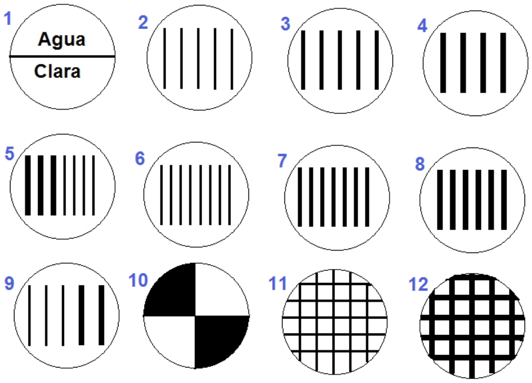

Figure 2: First set of 12 Designs

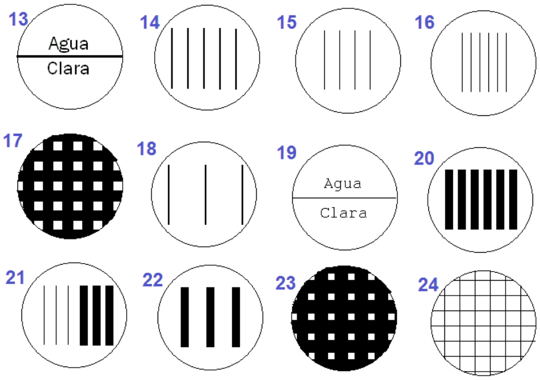

Figure 3: Second set of 12 Designs

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 seen in this plot, an excellent fit for the data was achieved; the R^2value for this fit was 0.99472. The power law function for this set of data was as follows:

$$Depth = 1463.7 * Turbidity^{-1.29} \tag{1}$$

Using this formula, the scale for the final turbidimeter was developed by marking desired turbidities such as 15, 16, 50, 100, 400 NTU etc. on the rod at the distance specified by Equation 1 above the light source.

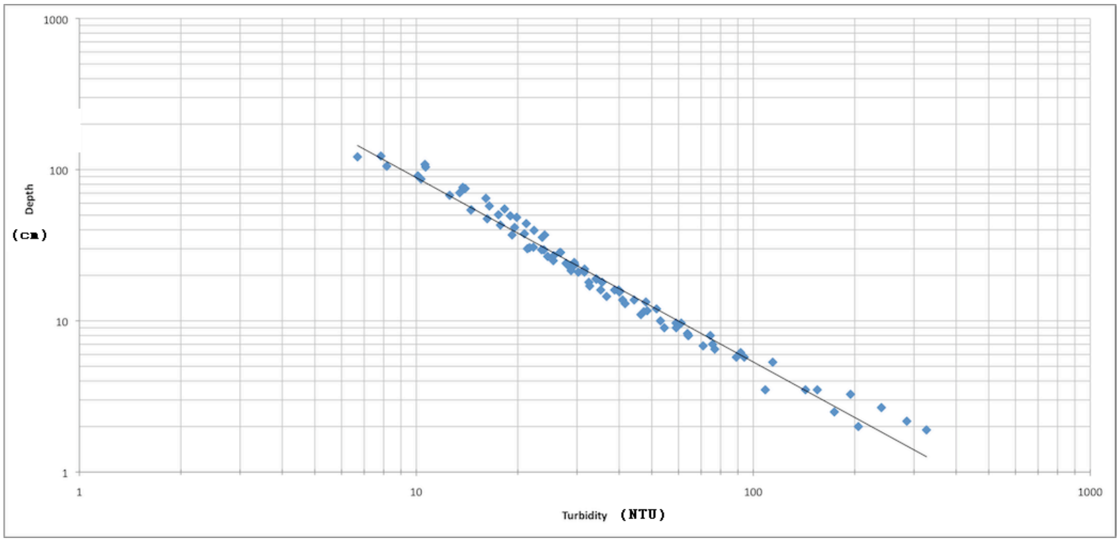

Figure 4: Log-log plot for Design 14

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

Current research focuses on creating a turbidimeter which can measure turbidities 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 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 LED light was secured with a screw (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 metal attachment piece (again as seen in Figure7) is then attached to the end of a lowering rod.

Figure 7: Mirror Component Design

Colored LED Design

The next design idea for possibly extending the range of NTU values that could be measured was to use colored LED lights, however none were immediately available. Therefore colored cellophane was bought at a local craft store (blue, green, red) to be used as a replacement for colored LED lights. A small piece of cellophane was cut and placed between the LED light and the light diffuser (HDPE block) 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

For more accurate testing colored LED lights were ordered and received; the colors ordered were red, green and blue. Testing with the blue LED light (seen in Figure 9) has proved most successful. The blue LED light was attached to the lowering rod in the same way that the colorless LED light was attached in Figure 5.

Figure 9: Blue LED light

Double HDPE Block

It was decided to try to increase the thickness of the HDPE block to see if a lower NTU could be measured. When first using the double HDPE block, it was noticed that a large quantity of light was escaping from the sides of the block. Therefore, black electrical tape was wrapped around the HDPE to block out as much light as possible. Tests were done using two different patterns (Design 14 from Figure 3 and light slit design made from electrical tape) and two different color LEDs (blue and white). Both of these designs can be seen in Figure 10.

Figure 10: Design for the double HDPE block. First two pictures are of the light slits pattern and the third picture contains the original pattern.

Experimental Design

As 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 11). The electronic turbidimeter is connected to a computer in the lab and using a Process Controller the NTU was recorded into an excel file every second. This program proved extremely useful in that it was possible to write notes directly into the excel file at any given point in time.

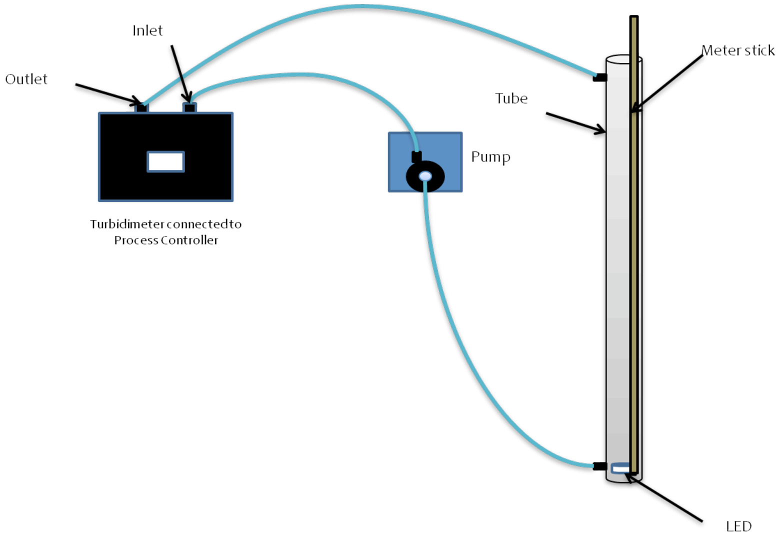

Figure 11: Continuous-mix experimental schematic

1. Turn on Process Controller
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 with the new total amount of clay in the system
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 it was determined 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, it was decided to reject the mirror concept and focus solely on improving the LED design.

Colored LED Tests

Blue Cellophane Covered LED

The first colored LED light tests were run 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. In general the goal is 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). Tests on the blue cellophane covered light were continued and more data points were aquirred. Following these tests the R-squared value increased to 0.9409. Using the equation of the line given in the log-log plot (see Figure 12) a relationship was found between turbidity and depth using a LED light covered with blue cellophane. This relationship can be seen below:

$$Depth = 385.56 * Turbidity^{-0.824}$$

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

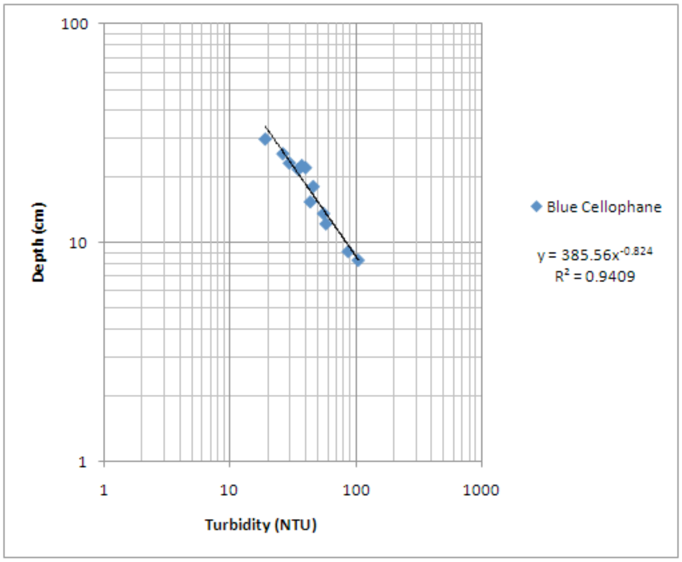

Figure 12: Log-log plot of depth as a function of turbidity for the blue cellophane covered LED light

Blue Colored LED

After the blue LED lights were acquired, testing using these lights began immediately. The turbidities tested with the blue LED ranged from about 7 NTU to 53 NTU, as seen in Table 2. The log-log plot regression analysis produced an R-squared value of 0.9964 (See Figure 13). Because this value is higher than the R-squared value found with the blue cellophane covered LED data, the relationship between turbidity and depth using the blue LED light is more accurate. Therefore, 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 trend line equation given in the log-log plot a relationship between turbidity and depth was determined. This relationship can be seen below:

$$Depth = 715.22 * Turbidity^{-1.112}$$

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

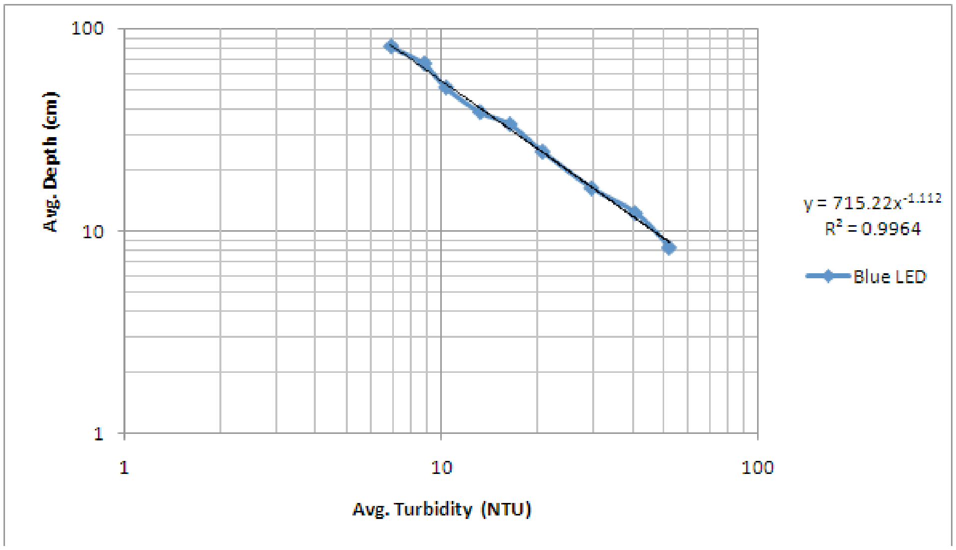

Figure 13: Log-log plot of depth as a function of turbidity using blue LED light

Double HDPE Block

Three different tests were done using a HDPE block that is double the length of the original HDPE block. A log log plot of these tests can be see in Figure 14. Using the equations given by a power law fit to the data, a minimum NTU value can be determined for a turbidimeter length of 60 cm. It was found that for the white LED and light slit pattern, the minimum turbidity that can be measured (at 60 cm) is 8.233 NTU. For the blue LED and light slit pattern, a minimum turbidity of 7.73 NTU can be measured. For the blue LED and original design, a minimum turbidity of 5.89 NTU can be measured. Therefore, if the turbidimeter was to be redesigned, the double HDPE block with the blue LED and the original design (Design 14) would be used. Though the white LED and light slit pattern had a better R-squared value, the blue LED and original design was chosen because a lower NTU value can be measured and it had less variability between user readings.

The goal this semester was to be able to measure turbidities down to 5 NTU. Based on the double HDPE block tests, if the turbidimeter was lengthened from 60 to 65 cm, it may be possible to accomplish this goal. Further testing with the double HDPE, blue LED, and original design should be done to verify this result.

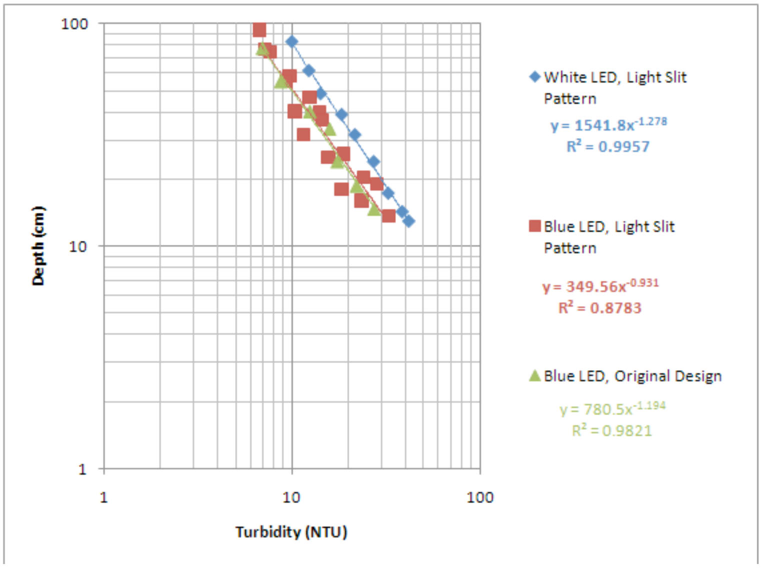

Figure 14: Log log plot of all double HDPE block designs

Future Work

There are 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. To get the mirrors to work well, the design would need more specialized components and most likely be more expensive.

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.

Using lights other than LEDs is another possibility. This could possibly reduce the disparity 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 somewhere 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 accuracy of readings if the user did not realize the change in brightness. More research needs to be done into substitutes for LED tea-candle type lights.

In past semesters the idea of using humic acid had been discussed. It would be a good idea to experiment with humic acid because it would better estimate natural waters. Humic acid would change the color of the water without changing its turbidity. 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.