Final Report

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Abstract

The goals of this summer's Turbidity team were to:

- Finish the testing that the previous team had been working on in order to design a cheap (under $20) Turbidimeter that can easily be transported to potential AguaClara facility locations.
- Find a relationship between depth and Turbidity that is within 50% accuracy for a specific disk design based on line thickness and spacing.
- Fabricate and calibrate 10 turbidimeters that will be ready for shipment by July 28, 2011.

Thus far, the team has managed to improve the design of the original Turbidimeter while lowering cost and increasing portability. All ten prototypes were built, calibrated, and sent to Honduras by the specified date. The only shortcoming was that due to size limitations the Turbidimeter could not measure below 15 NTU, however, this does allow for greater ease of use. The final Turbidimeter design is just over 60 cm in height and costs $4.02 to make.

Introduction

Before Agua Clara builds a water treatment facility in Honduras it must be decided if the community in question has a water supply in need of a plant. Some communities may have water that is so dirty an Agua Clara plant would not be able to help them. Other communities may have water clean enough that no treatment is necessary. The low cost hand held Turbidimeters will be used to gauge the cleanliness of a community's water supply in order to justify building (or not building) a water treatment facility.

The previous team developed a disk design with the words *Agua Clara*, but suggested that a design based on lines or grid patterns might work better. The team believed that there was a greater disparity between eyesights when reading words as opposed to looking for a grid pattern or counting lines. Therefore, it was decided to test multiple grid and line designs by varying thickness and spacing.

Experimental Setup & Methods

Building off of the previous team it was decided to use a pump (with a flow rate of 1.4 L/min) 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. 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. Please refer to Figures 10 and 9 to see how our setup looks in the lab. This program proved extremely useful in that it was possible to write notes directly into the excel file at any given point in time.

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[1]
4. Unplug pump, make a mark in data log as to show when pump was first unplugged
5. Take first depth reading
6. Plug pump in
7. Wait 60 seconds
8. Unplug pump
9. Take second depth reading
10. Plug pump in
11. Repeat steps 7-10 for third reading
12. Wait 60 seconds

[1]Based on flow rate of pump and volume of water present in system the residence time was found to be 127 seconds. Thus the added clay is allowed to cycle through the system twice for thorough mixing.

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

Progression of Turbidimeter Design

Originally the Turbidimeter consisted of a long (about 130cm) clear plastic stick, an LED light, an HDPE circular block, and two screws. Before testing it was decided that there should not be any screws going directly into the LED light; this puts the screws extremely close to the electrical components for the light along with serving to make the light less waterproof. Many ideas to remedy this problem were tested, the first being to duct tape the light to the HDPE and attaching the HDPE to the stick using one screw. This worked well enough for testing purposes, but was obviously not a permanent solution. The next attempt was to use a worm-drive clamp to attach the light to the HDPE (Figure 11). The clamp appeared promising at first, however, it made the Turbidimeter too wide to fit into the PVC pipe used for testing. Another undertaking was to use adhesive, Epoxy 907, to permanently attach the LED light to the HDPE. Unfortunately, when working on manufacturing our final Turbidimeters the glue did not hold as well as originally anticipated. To remedy this problem a piece of metal was bent at a 90º angle, see Figure 12, and fitted between the stick and screws. The disc design and NTU scale were printed on adhesive transparency film and directly applied to the stick and HDPE. Please refer to Figure 15 to view an example of the NTU scale.

Parts/Cost

The table below shows the specific cost of each part and the total cost of our Turbidimeter. The final cost turned out to be well under the given specification of $20 per turbidimeter. Refer to the footnotes on how to acquire each piece.

Part	**Cost**
Epoxy 907 [2]	$ 0.04
Metal piece[3]	$0.20
HDPE block[4]	$0.40
Plastic stick[5]	$1.52
Screws[6]	$0.10
LED light[7]	$1.49
Stickers (for scale and design)[8]	$0.27
Total Cost:	**$4.02**

[2] http://www.miller-stephenson.com/epoxy_resins_009.htm
[3] in shop
[4] http://www.mcmaster.com/#8624k29/=dgj9vd

Results

Settling Time

Because the handheld Turbidimeter cannot take measurements every second like the aforementioned Process Controller is was important to note how long an accurate measurement could be made after mixing occurred. Using the dip-and-check method, where the experimenter dips the Turbidimeter into the water sample and slowly raised it up until the design could be seen, for 4 different turbidities, between 80-400 NTU, depth measurements were taken at specific time intervals. As seen in Figure 14 in the Appendix the percent error was found for each measurement assuming that the first measurement was 100% accurate. As can be seen in Figure 1 the rate at which the clay particles settle is approximately linear, however, comparing the R^2 values one can see that this linear approximation breaks down for lower turbidities. It is important to note that the depth readings do not change drastically during the first three to four minutes after shaking. Thus someone using a handheld Turbidimeter has more than enough time to take an accurate measurement.

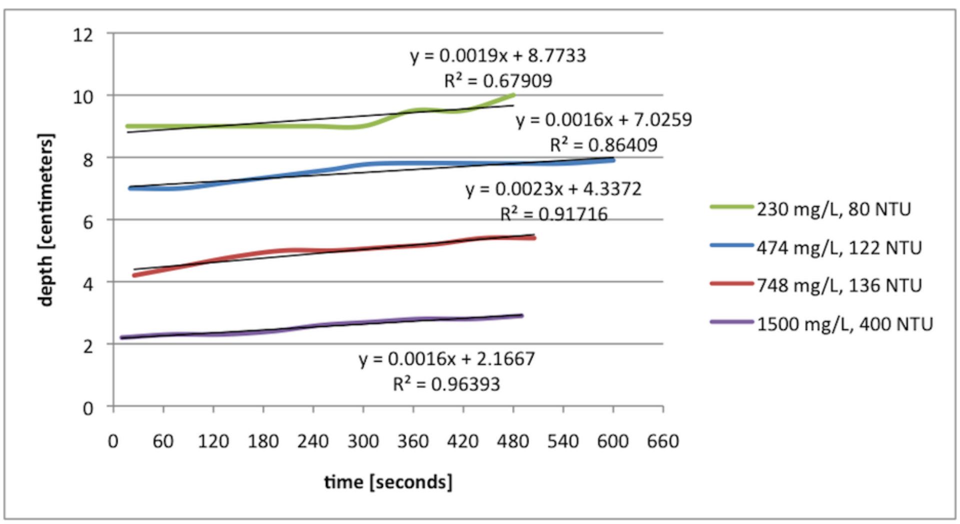

Figure 1: Graph Comparing Settling Times

[5] http://www.mcmaster.com/#8659k37/=dgjal5

[6] in shop

[7] http://www.100candles.com/item.htm/9510/White-Submersible-LED-Light

[8] http://ithaca.citysearch.com/profile/7811598/ithaca_ny/fedex_office.html / Ask for transparent sticky paper

Clay Particle Flow

Based on Figure 2 it can be seen that when a dose of Kaolin Clay is added to the pump system the turbidity fluctuates for 120 - 180 seconds. Because it takes just over two minutes for the turbidity to level out it was decided that after adding a dose of clay four minutes of waiting would be enough for a level out to occur and an accurate measurement to be made.

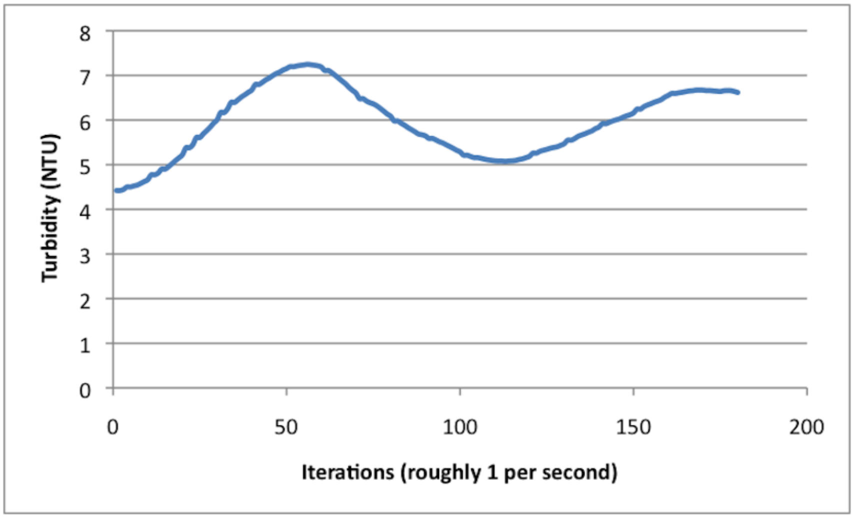

Figure 2: Clay Particle Flow

NTU vs. Clay Concentration

During all experiments the Turbidity and amount of Kaolin clay added at any given time were recorded. Using the dose of clay added and that the pump system held 2.8 L of water the concentration of clay was found. As seen in Figure 3 a formula for Turbidity as a function of clay concentration was found. The best fit line was approximated as linear and has a very good R^2 value of 0.97934, however, as can be seen in Figure 4 when focusing in on the first 100 mg/L the data no longer appears linear. Furthermore, the y-intercept for this data was found to be located at 12.784 which implies that this equation is only useful to someone who is starting an experiment around 12-13 NTU. One problem that was noticed during experimentation is that adding a set amount of clay to the water sample is no gaurantee to get the expected turbidity value. If the clay is added in one large dose as opposed to many small doses spread out over a period of time the turbidity readings are likely to be lower than expected. This discrepancy could occur because when adding a large dose the clay particles are more likely to clump together and stick to the sides and tubing of the apparatus, therefore not making the water any more turbid. This inconsistancy could as be due to the fact that a larger dose may take more time to spread throughout the system and reach a steady state turbidity value.

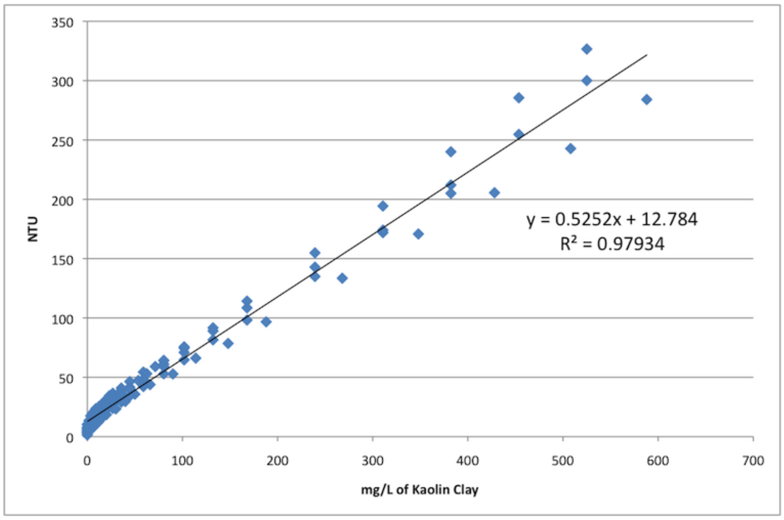

Figure 3: NTU vs. Kaolin Clay Concentration

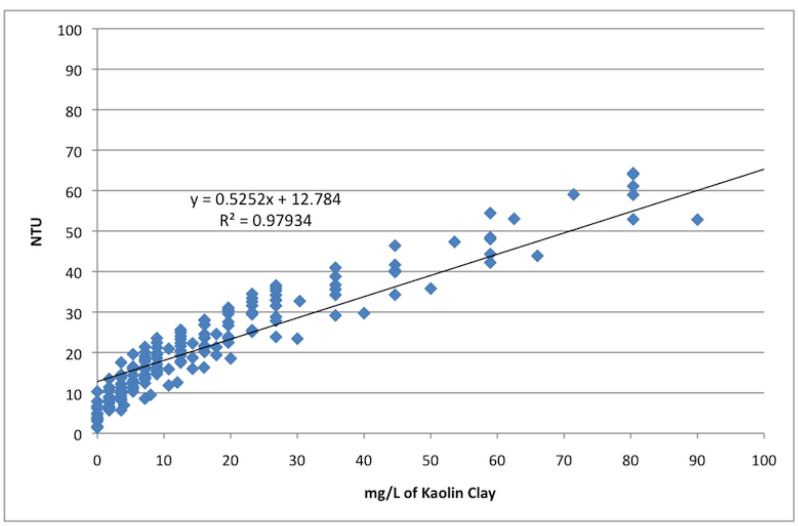

Figure 4: Scaled Down NTU vs. Clay Concentration

Two Designs

During experimentation, one idea that occurred to the team was to have two different designs. This way there would be one design that would be used solely for lower turbidities, less than 40-50 NTU, and another design for everything above that amount. Looking at the following graph it is clear to see why doing this would make sense. To the left of 50 NTU the data follows one line fairly closely, and to the right of 50 NTU the data follows a line with a very different slope. However, when making trying to decide what our final designs would be we realized that having simply one design that would cover almost all turbidities would be best.

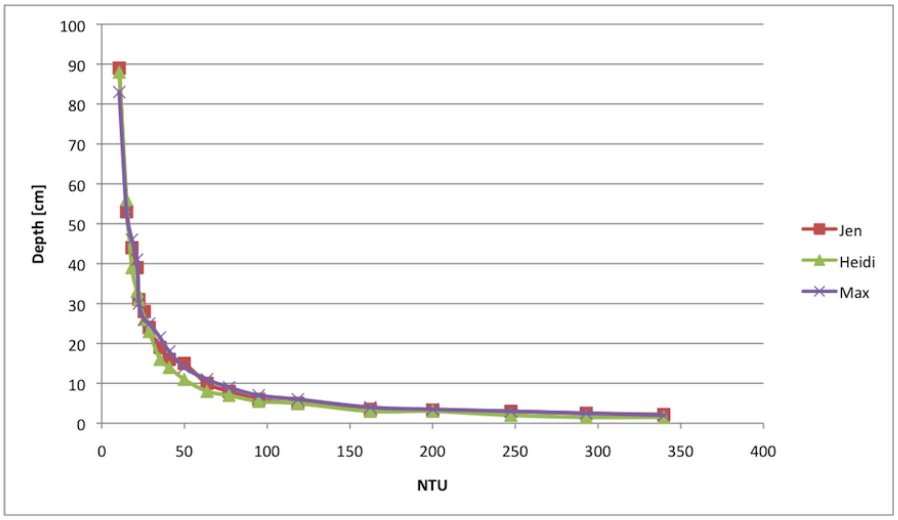

Figure 5: Consideration of Two Designs

Designs

Nine designs, Figures16 & 17, of varying line thickness and spacing were tested using the aforementioned method throughout the summer. The average depth (in cm) for three people was measured for each design at turbidities ranging from 3 NTU to 35 NTU. Plotting the data in a log log format (Figures 6 & 7[9]) allows for easy comparison between designs. The more linear the best fit line for a design is, the more closely the relationship between Depth and Turbidity follows a power function, ie.

$$Depth[cm] = a * Turbidity[NTU]^b \tag{1}$$

It is important to note that depth measurements could only be taken up to 125 cm. This means that if a design could be seen at a depth of 160 cm at an NTU of 6, the data would show the depth to be 125 cm at 6 NTU. This leads to some error in the data, especially when comparing the R^2 values. Future teams may want to take the precaution of throwing out any data that corresponds to a depth reading at the bottom of the PVC tube.

[9]The number corresponding to each best fit line refers to the design with the same number in Figures 16 & 17.

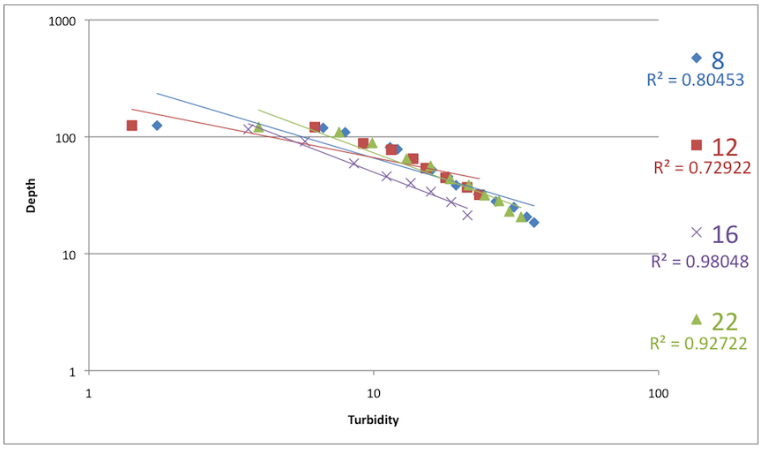

Figure 6: Log Log Plot for designs 8, 12, 16, 22

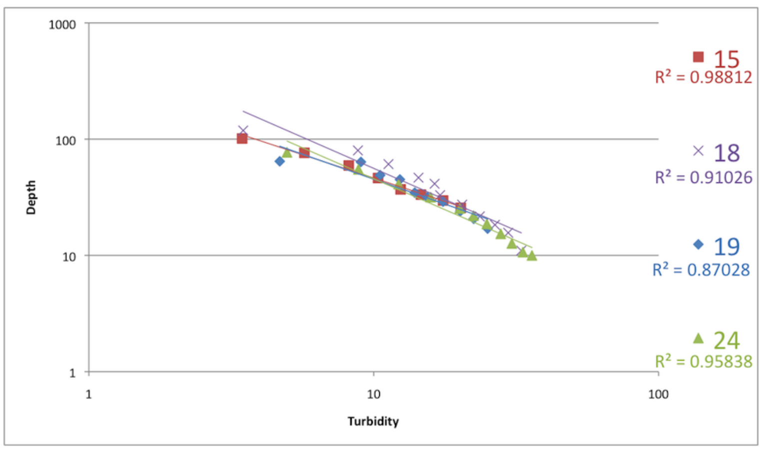

Figure 7: Log Log Plot for designs 15, 18, 19, 24

Final Design

To chose a final design for the turbidimeter two value were used, and R^2 value as well as 'Total Percent Error.' Taking data of depth to NTU and comparing it on a log log plot, the best fit line should be roughly linear if approximated as a power function. As described in the Design section the formula relating depth and turbidity obeys a power law, therefore an R^2 value closer to 1 is a better approximation of a power law fit. The total percent error is a number devised to compare the disparity between people's eyesights for each design. Taking an average depth for each NTU reading and assuming that this average is 100% accurate allows for an individual's percent error between their own depth reading and the average depth reading to be calculated. Summing everyone's percent error for each reading and then dividing by the number of readings done in the experiment gives the Total Percent Error. Essentially the Total Percent Error is the average error for all experimenters. As seen in Table 1 the R^2 values as well as the Total Percent Error values are compared for nine designs. Although design #14 did not have the best total percent error it did have the best fit to a power function, therefore, it was chosen to be the final design. Figure 8 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;

$$Depth = 1463.7 * Turbidity^{-1.219}$$

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.

Design #	**R^2 Value**	**Total Percent Error**
8	0.80453	22.05
12	0.72922	9.86
14	*0.99472*	*25.37*
15	0.98812	40.27
16	0.98048	33.28
18	0.91026	26.17
19	0.87028	23.94
22	0.92722	11.06
24	0.95838	32.47

Table 1: Comparison of Designs

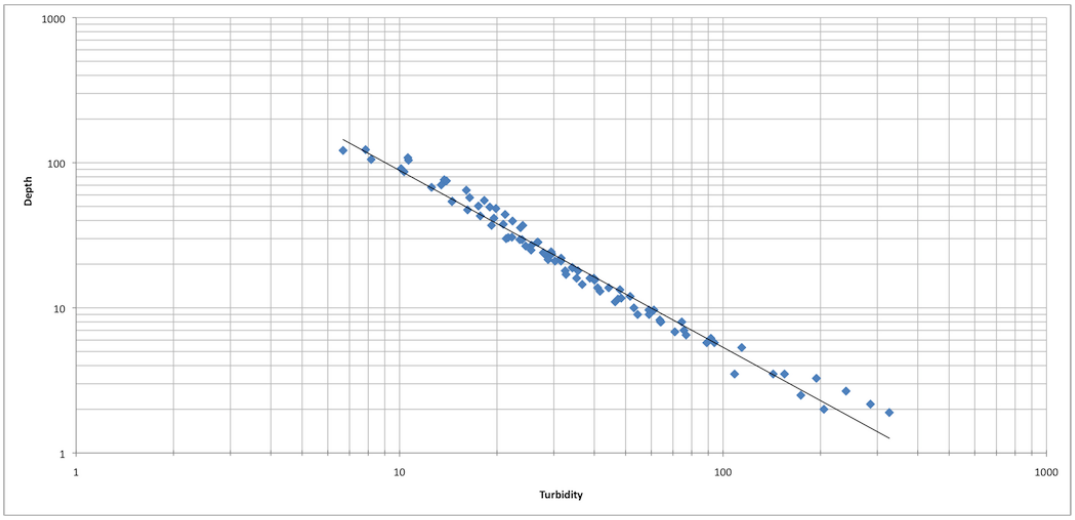

Figure 8: Log Log Plot for design 14

Future Research

There were many research topics that are related to the turbidimeter that our team did not get a chance to look into. It was decided to use the HDPE block that the previous team had used exactly as they had it. The size (thickness) of this block was never experimented on, it was simply taken as it had been provided by the previous team. The size of this block would almost certainly have an effect on how much light can be seen through the block. Varying the size of this block in future experiments could possibly help to give less disparity in results based on eyesight, though this is not certain.

The screws in the present turbidimeter were simply chosen based on availability from the shop, and worked great as they were needed. For future designs, stainless steel screws might be chosen as these would be less likely to rust in the long run. Any other materials that may be useful as screws or any other alternatives can also be looked into for future designs.

In the test done this summer many different sticker patterns were tested; however, there is no way to know if the design we found is actually the optimal design. More designs should be tested in the future to try and optimize the accuracy and minimize the difference between readings based on personal eyesights.

The use of humic acid was something that was originally suggested to the team to experiment within the challenges document. Humic acid would add color to the water without adding more particles, and therefore without raising the NTU level of the water. This is something that happens naturally often and can easily cause confusion over how "dirty" a sample of water. There is a clear difference between turbidity and color of a water sample and testing with humic acid would help to show this difference.

Most of the tests done this semester used a turbidimeter with only 1 battery installed in the light, making the light dimmer. This way, lower turbidities could be measured with the 124cm height that was available. This choice was only based on the fact that it was too easy to see the pattern at the bottom, rather than based on actual experimental data. In the future, this issue could be explored in order to determine the optimal brightness for the light.

One suggestion for future research from the previous Turbidimeter team was to try using different colored LED lights. It is still unknown whether or not this would make a difference for viewing the Turbidimeter underwater. Using different colored lights would be helpful if it would cut down on the error that arises from differing eyesights when taking turbidity readings.

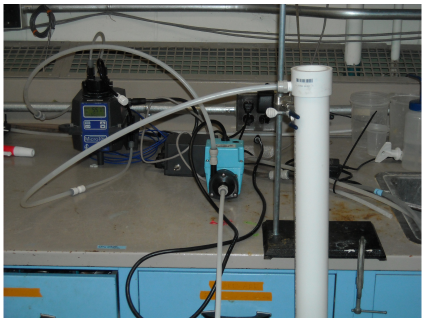

Figure 9: Close up of Pump Setup

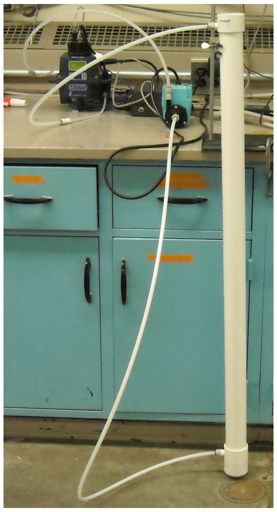

Figure 10: Experimental Setup

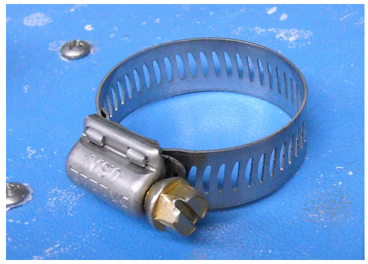

Figure 11: Worm Drive Clamp

Figure 12: Metal Piece

Figure 13: Final Turbidimeter

Concentration (mg/L)	Time after shake (s)	Depth (cm)	% Error
230	17	9	–
	60	9	0%
	120	9	0%
	180	9	0%
	240	9	0%
	300	9	0%
	360	9.5	5.56%
	420	9.5	5.56%
	480	10	11.11%
474	20	7	–
	80	7	0.00%
	140	7.2	2.86%
	200	7.4	5.71%
	260	7.6	8.57%
	320	7.8	11.43%
	480	7.8	11.43%
	540	7.8	11.43%
	600	7.9	11.43%
748	25	4.2	–
	85	4.5	7.14%
	145	4.8	14.29%
	205	5	19.05%
	265	5	19.05%
	325	5.1	21.43%
	385	5.2	23.81%
	445	5.4	28.57%
	505	5.4	28.57%
1500	10	2.2	–
	70	2.3	4.55%
	130	2.3	4.55%
	190	2.4	9.09%
	250	2.6	18.18%
	310	2.7	22.73%
	370	2.8	27.27%
	430	2.8	27.27%
	490	2.9	31.82%

Figure 14: Settling Time Data

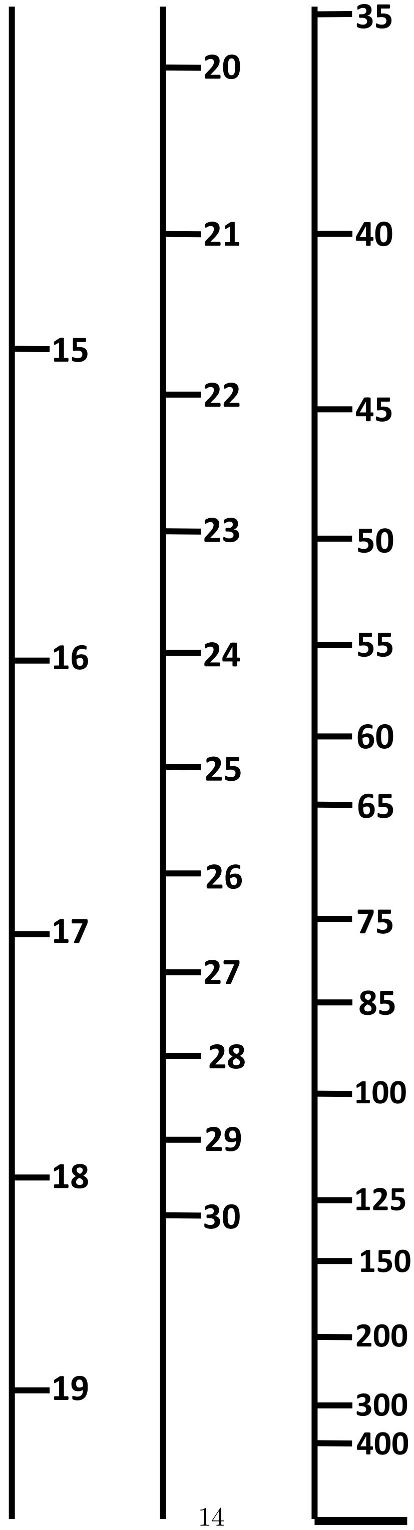

Figure 15: NTU scale

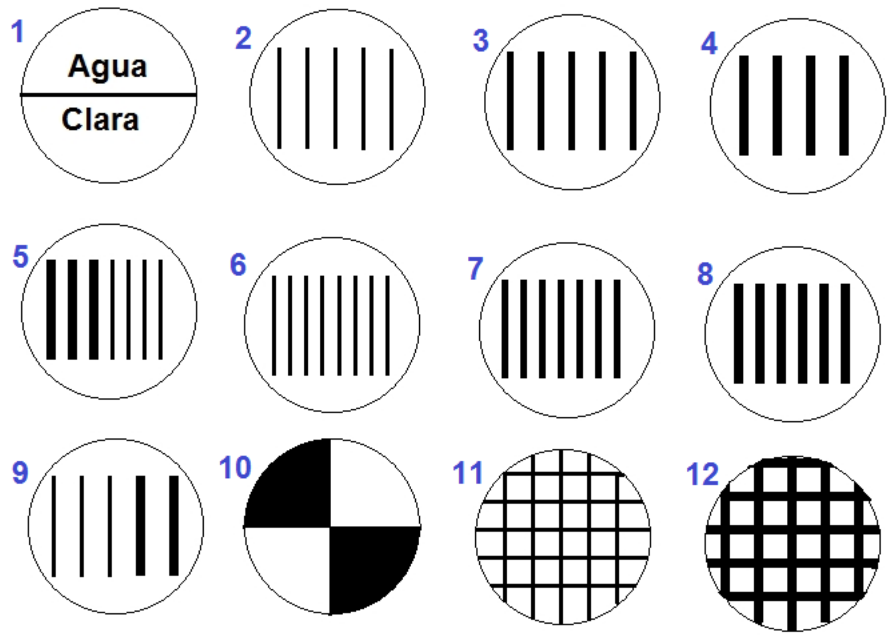

Figure 16: First 12 Designs

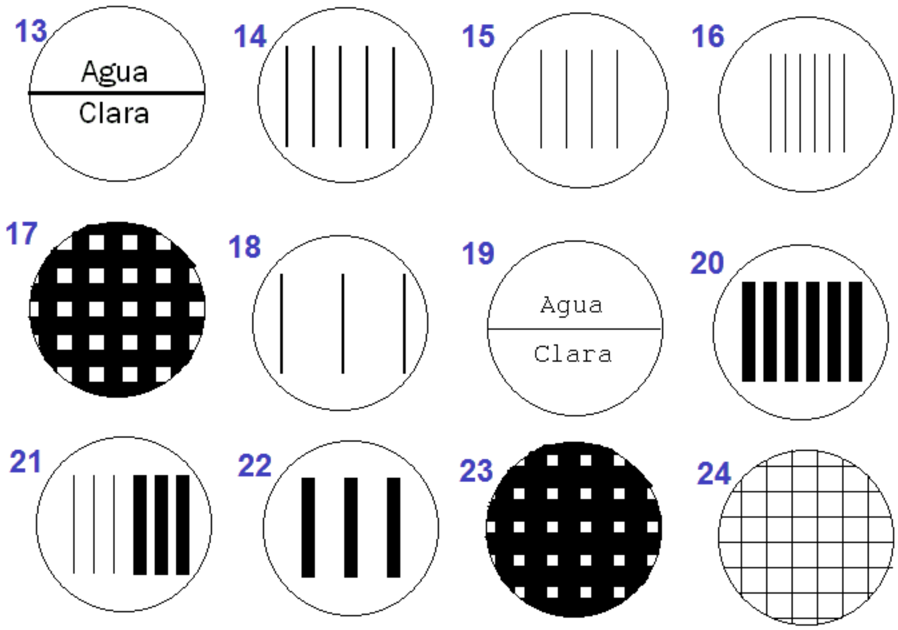

Figure 17: Second 12 Designs