Analysis and redesign of structural walls of a Sink-float-tank of a plastic recycling machine

Tianwu Li[1], Raghu Echempati[1], and Roger Fiedler[2]
[1]Kettering University, Flint, MI – 48504
[2]QFD Plastics, Flint, MI – 48507
Email: rechempa@kettering.edu

ABSTRACT
Sink float tank is a structure used to wash the recycled plastic pieces to separate dust from them. One of the main problems is the accumulation of dust at the walls and the corners of the system. This problem was assigned as a final project to a graduate student doing an independent study at Kettering University. The student was asked to do research and view several online YouTube videos to understand the principle behind the operation of the plastic recycle machines, principle of operation of sink float tanks, their process and to analyze the cause of the problem, then to look for a solution and redesign the structure. The study was limited to redesign of sink float tank. Since cost is also important, the student has to design a low cost system. Therefore, some optimization was expected to be carried out. Due to the inherent difficulties to theoretically model and to analyze the dust adhering to the stainless steel walls and the water, a rudimentary experiment was needed to explore which kind of shape is better for the container wall design. The process of the dust sinking also need to be analyzed to guide the design: how much time is needed to keep the pieces in the tank. The learning experience of assigning this real life application as a final project to the graduate student taking the independent study is discussed.

Introduction

The purpose of sink float tanks is to separate dust from plastic pieces by density, using sink-float principle. The heavier dust sinks to the bottom of the tank while the lighter plastic fractions float to the surface of the water contained that should be easily separated to the next phase in operation.

An example of this technology is in the recycling of plastic bottles. Within the Sink-Float Tank the plastic will float, whilst the dust will sink. Figure 1 shows pictures of one of the recycling machines posted on the internet [1]. Some other machines similar to this can be found in online videos: for example reference [2-4]. Depending on the type, size and capacity of these machines, the price ranges from $2,000 to over $50,000 per machine.

The separation container consists of a tank that is filled with liquid (water is usually used) and a screw for material transport, called auger, after separation. Depending on the design of the separation task, the plastic to be separated is transferred to the separation container with a stirrer, or it is transferred from under the surface by screws. There are a number of different designs available for different materials that serve this purpose.

The essential design goal of a separation container is long life, easy to assemble and disassemble and low maintenance requirement. So they need to be carefully designed. Keeping the above views, the purpose of this paper is to discuss the analysis and design of a sink-float-tank machine used in the plastic recycling companies.

Figure 1: The sink float tank from an online reference [1]

The graduate student was assigned this problem as a part of his project in Independent Study. The final learning experiences of doing this project included an understanding of modeling a complex machine structure based on manufacture and assembly process. Differential equation to get sink time has been realized by the student during the course of carrying out this project. Use of modern CAD tool to validate some of the results and to optimize the structure proved to be very challenging for the student.

Some of the course learning objectives (CLOs) identified are as follows:

- Expose the student to real life industrial problems
- Student learns to understand the complexities involved in the product and process
- Student understands how to model the given system using CAE tool for better visualization of the system and for doing any design modifications later
- Student understands and justifies the assumptions made in the simplified model
- Student uses fluid mechanics (laminar flow) principles to model and analyze part of the recycling process, namely, the sink float tank
- Student uses a math tool, and validates some of the important results using a table top model
- Student attempts to validate the lab experiments with real system
- Student understands the limitations of the work done and proposes future work
- Student documents the final learning experiences of undertaking this independent study

Goal: Correct the design of the tank to solve the problem that the dust, which is separated from the fragment of the plastic, stick to the inner surface of the tank.

Current design used in this project

The sink float tank facility is shown in Figure 2 [5]. The lower left one shows two larger size main pipes on the right hand side. The lower one is the dust output mixture from the tank. It contains mostly dirt, gum, etc. The upper tube carries the plastic pieces that were separated due to the auger movement. This subassembly and its various views shown in Figure 3 are modeled using Unigraphics NX 9.0 CAE tool to enhance the student's ability to do solid modeling (visualization skills) and to understand more details about the process. The input to the system contains a mixture of dust (paper, glue, etc.), plastic pieces and water. The goal is to segregate the matter to separate plastic pieces. In the next section preliminary fluid mechanics analysis is presented.

Figure 2: The current system used by the QFD plastics division [5]

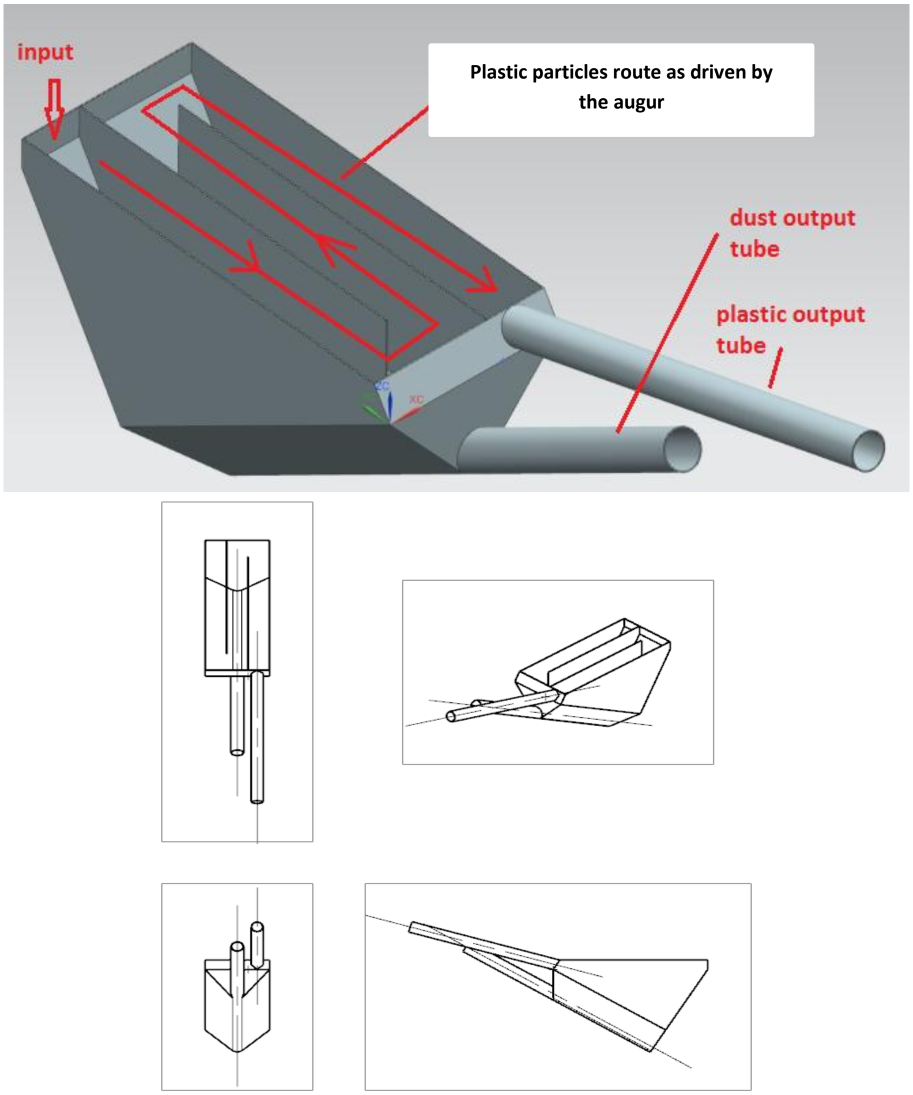


Figure 3: The UG NX 9.0 model with different drafting views of the currently used sink float tank at QFD Plastics [5]

Analysis

Part 1: Sink Time Calculation

In the tank, the separation of the dust and plastic occurs. But the auger also moves the plastic out so it is necessary that before the auger moves the plastic out, the separation and sinking of dust should be completed. The sinking time should be calculated by taking into consideration the time taken for the mixed fluid to travel through length of the tank.

Some of the assumptions made are: (a) the separation occurs once the plastic pieces touch the surface of water, (b) the geometric shape of each dust particle is modeled as a sphere, (c) the density of all dust particles is the same, (d) the water is all pure water and (e) the water is stable (the auger movement just affects the surface of the water).

Few basic equations from Fluid Mechanics are presented below:

From Newton's second law:

$F_{sum}=m\times a$ (1)
$a=dv/dt$ (2)

F_{sum} is the total force the dust surrenders, a is the acceleration of the dust, m is the mass of the dust, v is the velocity of the dust and t is the time.

From the resistance force equation in fluid dynamics [6]:

$f_{resistance}=1/2\times C_d\times A\times \rho_{water}*v^2$ (3)

C_d is the drag coefficient of the dust in water, A is the reference area, ρ_{water} is the density of the water and v is the velocity of the dust.

From the equation of buoyancy [7]:

$F_{buoyancy}=V\times g\times \rho_{water}$ (4)

$F_{buoyancy}$ is the buoyancy force, V is the volume of the dust and g is the gravitational constant.

From the gravity equation, G, the gravitational force, is:

$G=m\times g$ (5)

The load condition of the dust is given by:

$F_{sum}=G – F_{buoyance} – f_{resistance}$ (6)

Regarding the dust as sphere, the volume of the dust can be found to be:

$V=4/3\times \pi\times r^3$ (7)

Here, r is the radius of the dust sphere and π is a dimensionless constant.

The mass of the dust is given by:

$m=\rho_{dust}\times V$ (8)

ρ_{dust} is the mass density of the dust.

The reference area is given by:

$A=\pi\times r^2$ (9)

Setting the drag coefficient as 0.5, the radius of the dust as 30 μm, density of the dust as 2.5 g/cm^3 (mainly for mineral dusts, such as those containing free crystalline silica (e.g., as quartz), coal and cement dusts), the density of water as $1g/cm^3$ (pure water) and the gravity as 9.81 m/s^2 [using references 8-11], equation 2 can be written after simplification as:

$$dv/dt = g(1- (V\times\rho_{water})/m) – 0.5\,(C_d\times A\times\rho_{water})/m\times v^2 \qquad (10)$$

This equation is hard to solve for v, so we can transform it and regard t as being a function of v. this gives:

$$dt/dv=1/(g(1-(V\times\rho_{water})/m)- 0.5(C_d\times A\times\rho_{water})/m\times v^2) \qquad (11)$$

By using the integration routine in MATLAB and substituting the values of all given data, the analytical solution for time t comes out to be:

$$t=0.00824*\text{atanh}\,(20.609v) \qquad (12)$$

Equation (12) is transformed back to express t in terms of v. this gives:

$$v = (1/20.609)\,(1-2/(e^{(t/0.00412)}+1)) \qquad (13)$$

The units of v is m/s and t is sec.

Math tool such as MATLAB has been used to plot the relationship of v and t as shown in Figure 4.

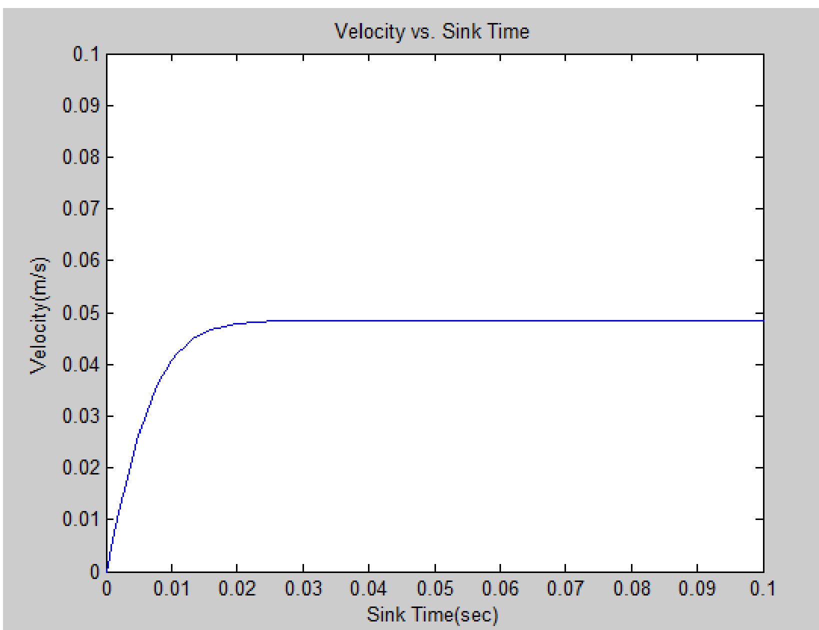


Figure 4: Sink Velocity vs. Time

As shown in Figure 4, the velocity comes to steady state when time is above 0.03s. Actually the limit of velocity is 0.0485m/s when time is 0.027s. It means the dust gets its maximum velocity when sink time is very small.

Since the height of the water table in the tank is not constant, use the maximum height of 80 inch to calculate the time for the dust to settle. This comes out to be around 42 s to reach the bottom. This seems to be reasonable according to the technician from the QFD Plastics Company [5]. This time is much smaller than the time for the dust to go through the tank, which is about 2 min, so there is no need to worry about the sufficiency of the sink time.

Part 2: Rudimentary Sink Float Experiment

A table top experiment shown in Figures 5 to 7 is designed and fabricated to check the proposed new design. This experiment is designed to find the relationship between the amount of the dust stuck to the inclining plate and the angle of the plate. The same fluid brought from QFD Plastics is also used here.

Figure 5: Prototype of the experiment

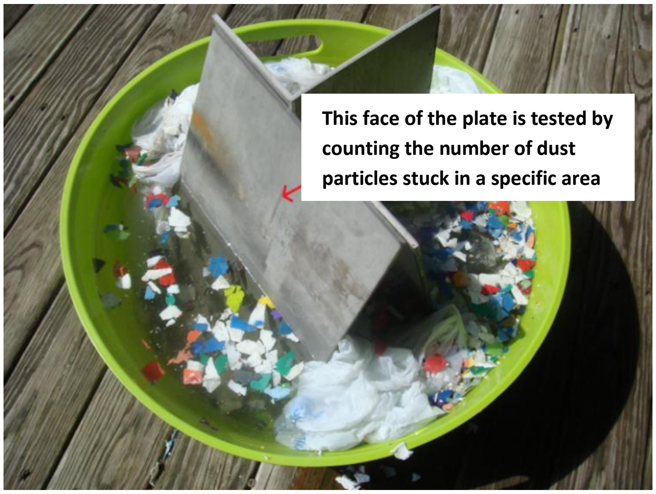


Figure 6: View of the prototype

Figure 7: Close view to the specific area

As can be seen in the picture, it is very hard to count every dust particle in the specific area because: (1) some of the dust is so small that the human eyes cannot distinguish them from the shadow of the little plastic. (2) the specific area is 1 in×1 in and the amount of the dust in that area is very large, so counting one by one might lead to miscalculation and miscounting.

To solve the counting problem, one way is to divide the area in to several smaller segments and count the dust stuck in each of these areas and do some averaging technique get a better approximation. In this experiment, 1/3rd inch wide rectangular areas have been used along each side of the original square area, and multiply the two side numbers to get the final amount of the dust stuck to this area. Figure 8 below and Table 1 on next page show the data collected through this experiment.

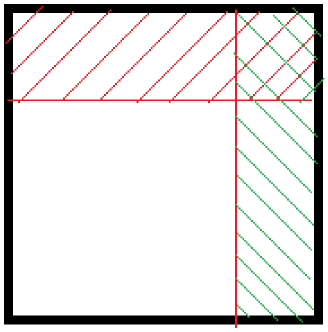


Figure 8: One of the methods to count dust particles

Table 1: Original data and the estimated amount of the dust stuck to the specific area

Angle (deg) of the side wall	area 1		area 2	
	original data	estimated amount	original data	estimated amount
65	8×9	72	9×10	90
74	7×7	49	7×6	42
75	6×4	24	5×5	25
80	3×4	12	4×5	20
83	4×3	12	5×3	15
85	1×1	1	2×2	4

In the original data column, the first number is the number of dust particles in the horizontal direction (red zone) and the second number is the vertical direction number (green zone). For example, for 8×9, 8 is the horizontal direction number and 9 is the vertical one.

In this experiment, there are some errors in the process and some differences with the real sink-float-tank; for example: (1) the 1/3rd inch width rectangular area is the width estimated by the observer; (2) the dust counting might be not so accurate (though the counting way adopted has reduced the difficulty a lot in counting process, it is still not an easy job to count them); (3) the depth of the prototype is not so deep, which might have difference with the real sink-float-tank dimensions; (4) in the prototype, the water is steady although in actuality the water is not so steady since the auger rotates at the surface of the water held in the tank.

It is however important that the relationship between the angle and the amount of the dust stuck to the plate has been found. It is obvious that when the angle is near 90-deg, the number of the dust particles (or amount of dust) is really small. So if in the new design, the plates are all vertical, then such sticking problem will be minimal or may no longer exist. Based on this crude experimental experience, a new design has been proposed to the company. These ideas are being explored for possible patenting opportunities. Brief details about this idea are discussed in the next section.

Part 3: New Design
Requirement of the new design:

1. All side walls of the sink float tank are vertical
   As shown earlier in figures 2 and 3, the bottom is sealed by three declining steel plates. The dust separated from the plastic should fall down to the bottom and moved out by the auger (not shown in the figure, the location is inside the two tubes). But physically the dust will accumulate around the edge of the three plates.

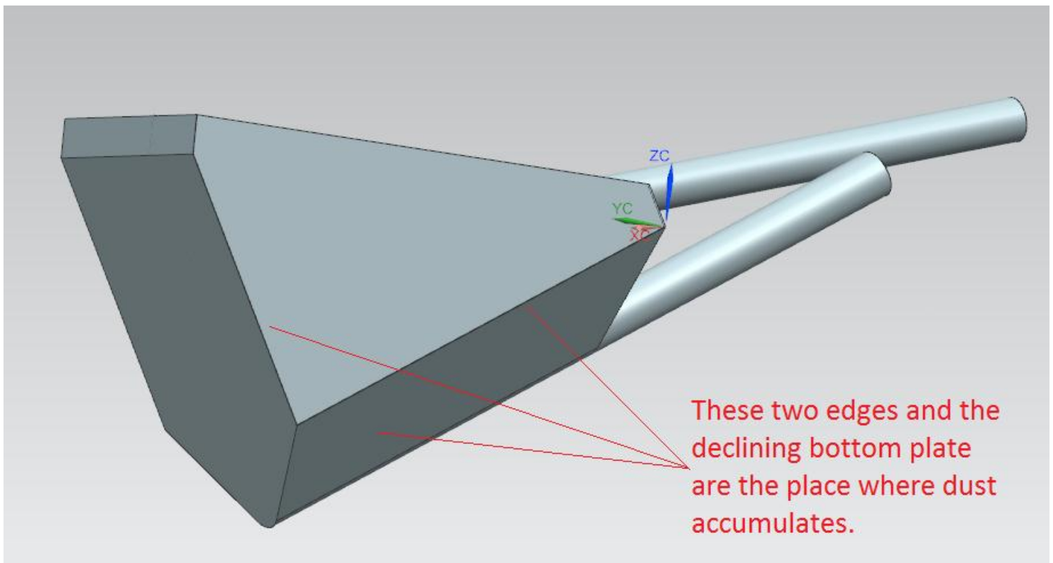


Figure 9: Original design showing the location where the dust accumulates

2. Less volume
   Less volume means that less water contained. In order to separate the dust from the plastic efficiently and the requirement of the next process to deal with the plastic, the water should be kept warm. So less water need less heat and it will save money.
3. Enough time for separation
   Settlement of dust from plastic needs enough time. Based on the calculations in Part 1, the result shows that the dust need no more than 1min to sink to the bottom, but the time for separation is not considered. To make the separation efficiently, more time is needed.

Based on the above requirements for a new design, several ideas have been thought of, but only three of these promising ones are presented and discussed as given below.

First Design:
The first design shown in Figure 10 is based on the idea to fulfill the second requirement, namely, less volume. There is a huge advantage of the two-stage design for which much less water usage is anticipated. One of the tanks is designed for separation and the water in another tank will be kept cleaner than the first stage due to less dust sinking down and this tank will need less water loop to keep the water contained in it clean. Figure 10 shows the conceptual CAD design of the tank.

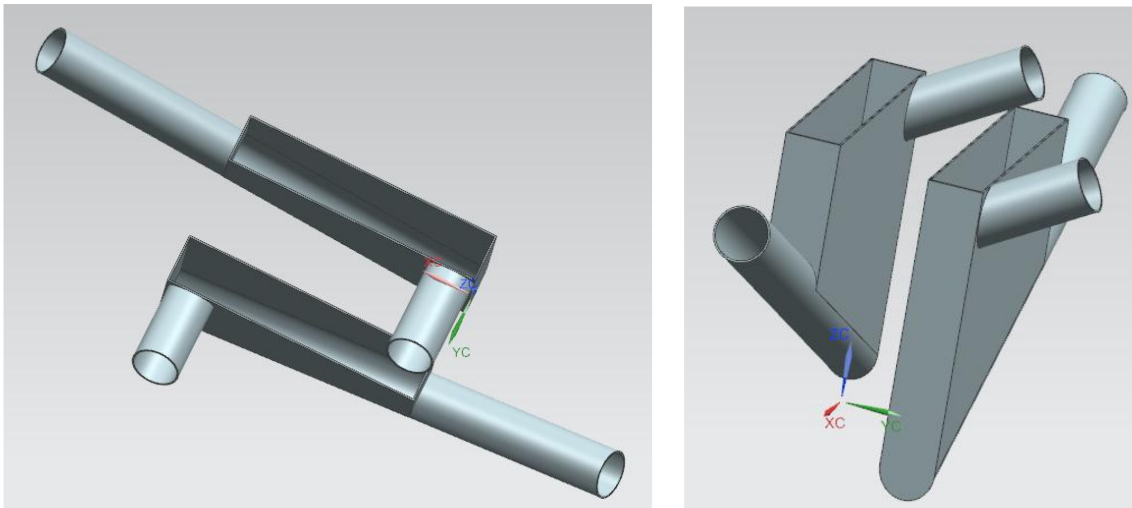
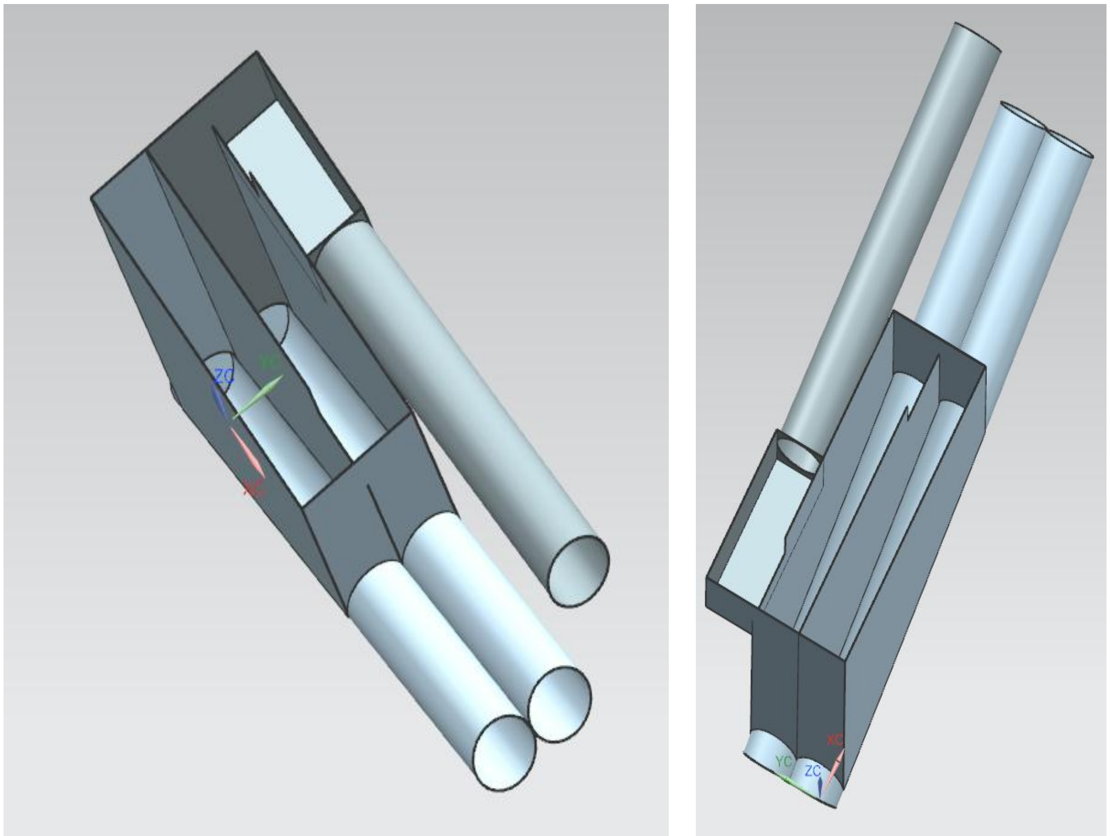


Figure 10: The first design showing a two-stage process

However, after discussing with the technical manager of the QFD Plastics, this design was not accepted because the overall space needed is bigger than what is available, which is 80 in (length) x 200 in (width) x 75 in (height). Also the two drop-out auger pipe needs two containers to collect the dust that drop out of the units. A second idea and design is worked out as proposed.

Second Design:
The second idea and conceptual design shown in Figure 11 on the next page is the compromise of the first design and the currently used design. The second design can fulfill all the requirements so it is the basis for the next design idea. If the water line is 4 in below the top edge, the total water it holds will not be more than 500 gal, while in the currently used tank, the water volume is about 800 gal, which means the second design almost cuts the water needed by 38% nearly, which will save a lot of money. Still the space limitations precluded this design being further carried on. Many other design ideas have been explored and discarded due to not satisfying one or two requirements specified above. One of the last design ideas is presented in the next section.

Third and final Design:
The third conceptual design shown in Figures (12 to 14) is the final design which fulfills almost all the requirements and satisfies the needs of the company. As mentioned, the third design is based on the second design in which more accessories have been added. The main part, namely the tank, has some modifications, however.



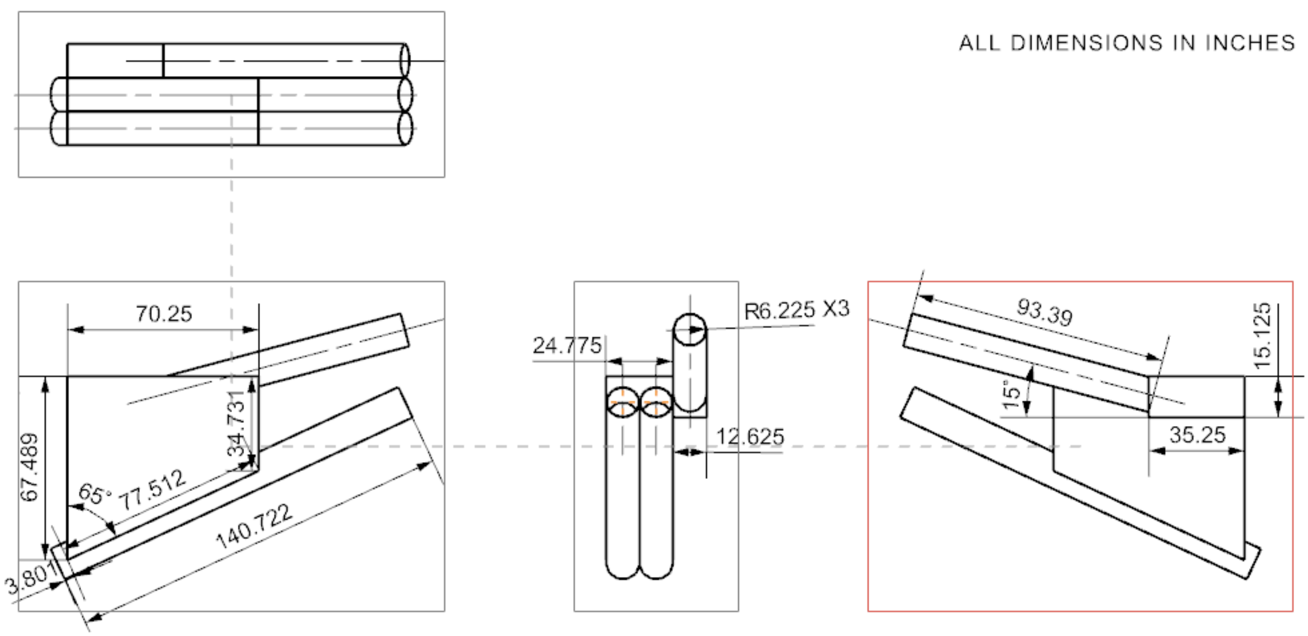


Figure 11: The second design idea with water pipe lowered by few inches

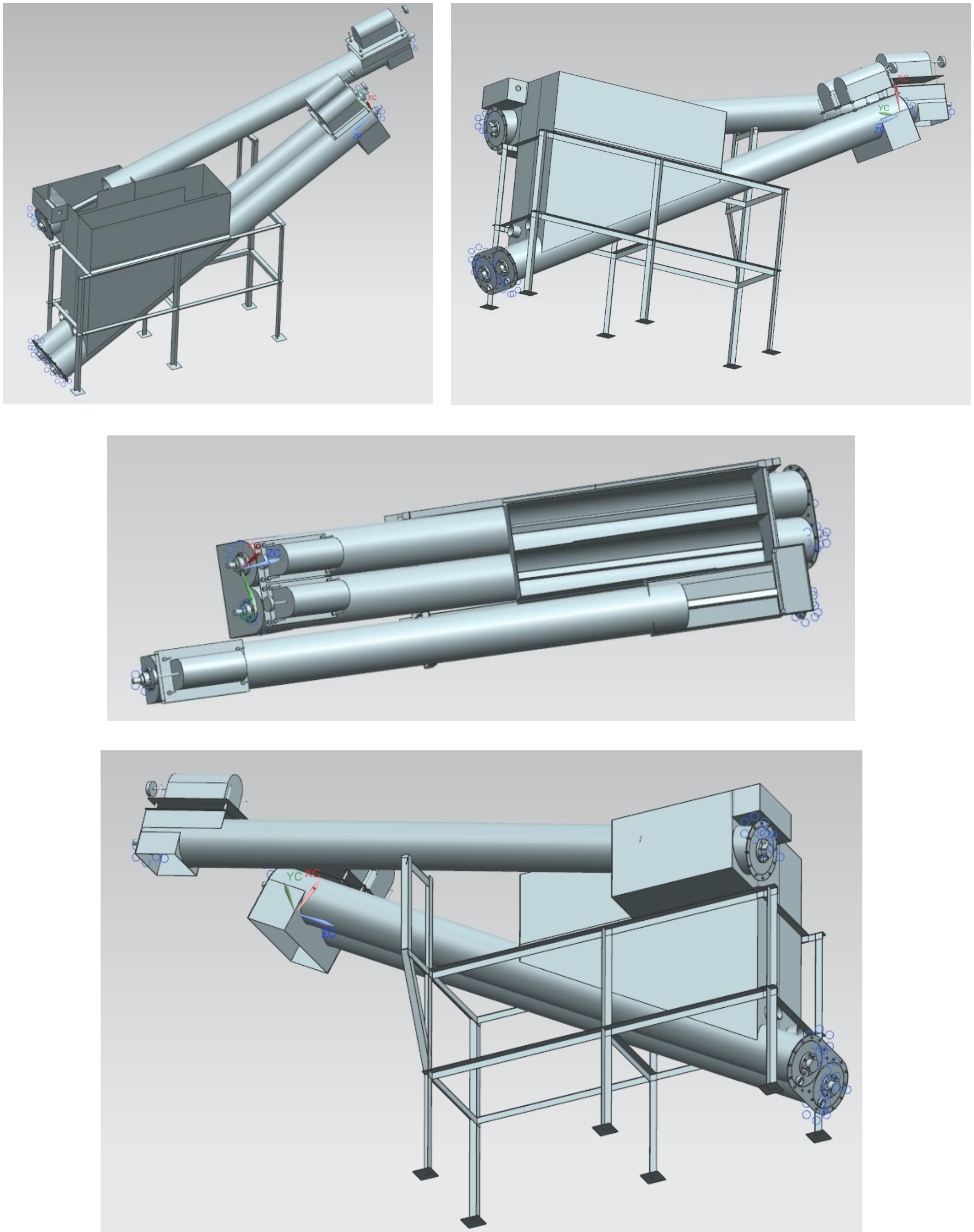


Figure 12: The third and final design effort

The final design incorporates some or all of the following:

1. The heads were added to the end of the drop-out pipe in order to make the drop-outs fall down directly.
2. The additional cube was added in order to link to the filter system. There would be a net (shown in figure 3-5) fixed there to clean the out flow and after filtration, the clean inlet flow will supply the water needed.
3. The additional bar on the side wall is for the support.
4. The bottom was made open for installing the auger.

The design of the motor uses the bolt to adjust the height of the motor to fit the length of the belt which links the auger and the motor. Actual cost analysis to make necessary changes in the design is not yet performed. However, the company can, and will do cost analysis when they are serious and ready to implement the new design ideas.

Summary

This real life project based problem has relationship with many academic and research areas: functional design, fluid dynamics, manufacture, and experiment. When the knowledge needed is not shown or given in a book, the most efficient and the only way should be to model the system the best one can, and then perform simplified experiments. The mathematical equations and the tool used for the solution, especially the differential equation, are so powerful to address the physics of the problem. The design is a complex process that so many things should be taken into consideration simultaneously: maximum efficiency for energy savings, low cost, easy to manufacture, easy assembly and disassembly, fit for the space in the plant, and security, just to mention a few. In this project, the student was able to use project-based learning to assimilate the collective knowledge gained in different courses to try and attempt to solve a real life industry problem.

Acknowledgements

The authors wish to sincerely acknowledge the support and help provided by QFD Tiles Division of Flint, MI and for their constant guidance, particularly to the President of the company. Acknowledgements are also due to the Indian Institute of Technology, Gandhinagar, Ahmedabad, India for the sabbatical appointment they gave during which time final manuscript of the paper is written.

Bibliography

1. http://moogetech.en.made-in-china.com/product/nSKEVuJvvzcm/China-Classical-Type-PET-Flakes-Sink-Float-Tank.html
2. http://www.youtube.com/watch?v=9cZtO4O9Ls0
3. http://www.youtube.com/watch?v=GtlihM9m08Y
4. http://www.youtube.com/watch?v=NnGgbParOQg
5. QFD Plastics Division, 4450 Linden Creek Parkway, Flint, MI
6. http://en.wikipedia.org/wiki/Drag_coefficient
7. http://en.wikipedia.org/wiki/Buoyancy
8. Wikipedia on Answers.com: Drag coefficient, http://www.answers.com/topic/drag-coefficient-1
9. World Health Organization, Hazard Prevention and Control in the Work Environment: Airborne Dust

10. Erwin Kreyszig, Advanced Engineering Mathematics, Edition: 10th, Wiley, ISBN-10: 1118007409, ISBN-13: 978-1118007402
11. Pedro Lilienfeld, HIGH CONCENTRATION DUST MASS MONITOR, Particulate Science and Technology: An International Journal, pages 91-100, Volume 1, Issue 1, 1983.