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Mathematical Modeling & Engineering Design of Wastewater Treatment Unit for Al-Kut Gas Filling Company

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Abstract

New talented treatment method without chemicals and with minimum operational cost was performed to treat industrial waste water discharged by a hydrostatic test performed on the gas bottles maintenance workshops to reuse it. A common method by Tarleton and Wakeman was used to select the general treatment philosophy, The implementation of this study was carried out on three stages, water sample analysis, simulates the proposed preliminary design and detailed engineering designing for the first stage, a sample of waste water was brought from Al-Kut Gas Filling Company - maintenance section and tested for settling, aeration, and filtration. The experiments showed that the most of sediments were insoluble but rather than suspended in water and can be removed by settling. Furthermore, aeration test showed that concentrated Thiophene odor in water was removed at 50 C of water with diffused air bubbling. On the other hand, filtration of using 10 Micron filter paper was achieved to eliminate the rest of tiny sedimentation. Secondly, general dimension of equipment was calculated by engineering design equation according to qualitative and quantitative analyses of waste water. Accordingly, a set of experiments of simulation using ANSYS V19.0 and Eulerian – Eulerian as mathematical model were performed for the 3D two phase flow sedimentation tank with capacity of 5 m³/hr to find the optimum sedimentation performance by testing of the modifications on the tank geometry (baffle depth, distance between baffle and inlet, hooper). Simulation results showed that the optimum tank geometry (0.86 m Baffle depth with inclined part, 2.5m distance between baffle and inlet, hooper within V type geometry W=1.67m/0.29 m, D=1.03 m and tank dimension (L=10m, W=2.5, H=2.5 with slope angle = 2o) with 49.5 volume % in sediment layer with a minimum sediment layer height.

The third stage included an accomplishment of the Preliminary and detailed engineering design of the entire unit by SOLIDWORKS software to be ready for prototyping.

Keywords: CFD, Sedimentation, Industrial Wastewater Treatment, Eulerian – Eulerian Model.

1. Introduction

Al-Kut Gas Filling Company has maintenance and inspection section for defected LPG cylinders. The damaged cylinders enter the maintenance workshop as part of cutting, welding and additions such as clamps and bases and sometimes longitudinal welding of the cylinder if needed according to the type of defect found in cylinder as an initial stage of maintenance. In the second stage, the hydrostatic check is carried out using water and air. The inspection system consists of three lines, with a capacity of 150 cylinders/line with average 6 hours of work per day. Water obtained from one cylinder is 26.2 liters at a pressure of 35 bar, the water is recovered from the cylinder back to the tank that feeds the testing system to be used again in the followed cylinders. The capacity of the feeding tank is approximately 4 cubic meters for each line where the pollutants are accumulated for a period of 22 working days of continuous inspection. After that period, the wastewater is replaced with fresh water from (Raw Water) which is the main source of the plant. In other words, each tank is used to check 3300 cylinders before replacing it with fresh water. Therefore, welding slag, cutting pieces, clay and the remains of the inner lining of the cylinder (iron and metal oxides) are concentrated in this water. Additionally, the strong smell of Thiophene is continuously released to the atmosphere due to open tanks to the environment of maintenance section. As a result, the wastewater is discharge to the channel to pollute the river and therefor, fined is charged by Ministry of Environment representors whenever site is visited. In the last stage, the cylinder is dyed to prepare for filling. This study presents a design proposal for an industrial wastewater treatment Unit for LPG cylinders repair workshop with a production capacity of 5 m³/hr and a simulation of the Unit's work and detailed designs.

2. Material and methods

A proposed prototype for the processing Unit was built based on:

2.1. Finding the best technology to recycle the test water of the cylinders

Based on laboratory experiments and analyses of the test water and the sequence of operations required for the treatment, a common method for selecting the optimal techniques for separating pollutants from water was developed by the two scientists, Wyckman and Tallerton [1]. Through a series of procedures and tests, where a mini-list of the optimal techniques for treatment is selected according to the methodology shown in Figure (1). The figure shows that based on the analyses of the results of sedimentation and filtration tests, the appropriate letters are selected as shown in Figures (2), (3) and (4) respectively. Thus, the mini-list is selected for the optimal treatment from the expanded list of techniques, which includes the mechanism for evaluating the qualitative performance of appropriate techniques [1-3].

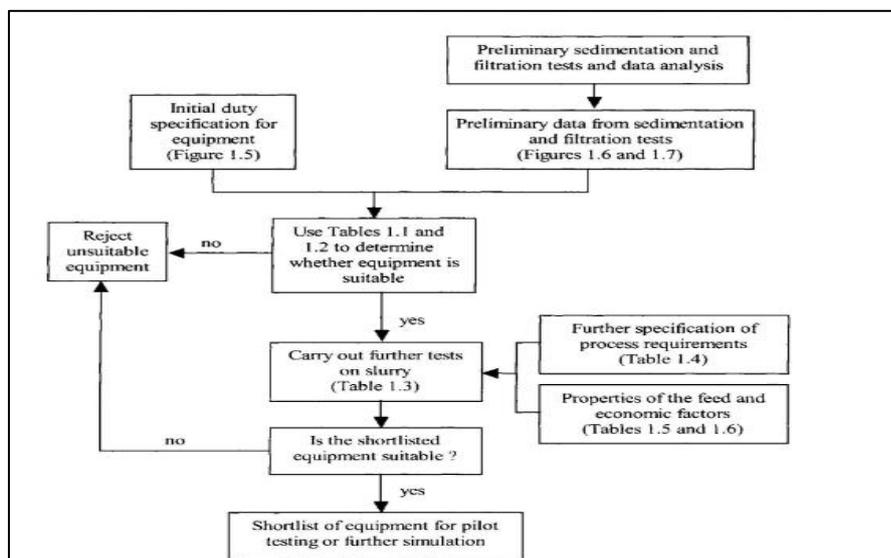


Fig. (1): Shows diagram of the methodology for selecting the optimal equipment for separating pollutants from water

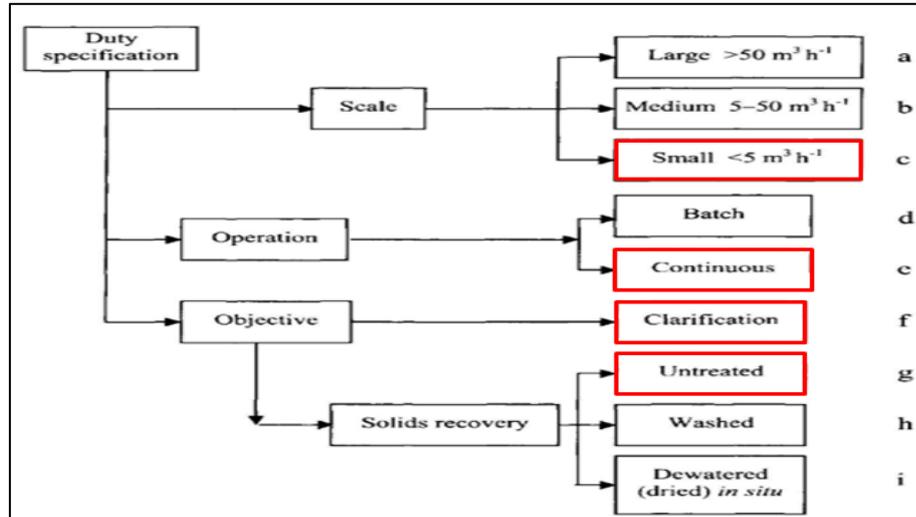


Fig. (2): Shows the quantitative and qualitative data analysis code for processing

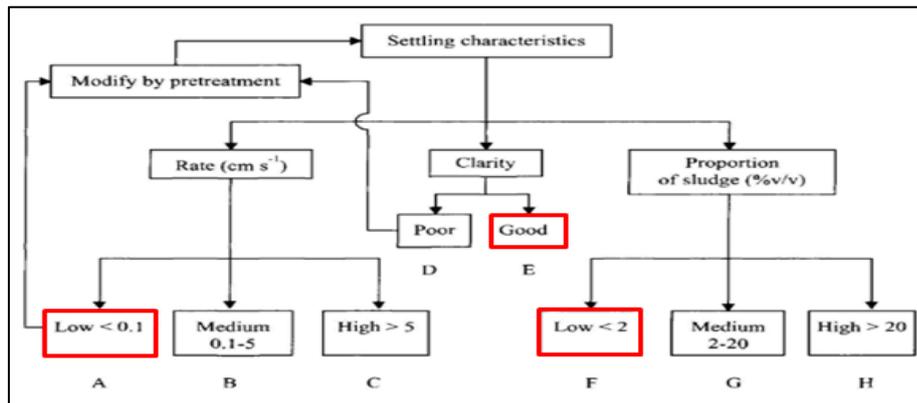


Fig. (3): Shows the sedimentation test results analysis code

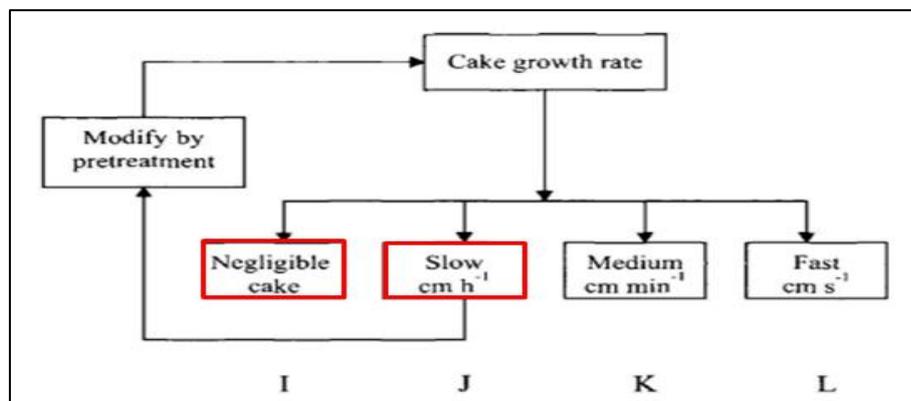


Fig. (4): Shows the code for filtering operations

2.2. Preparing the initial designs for the first stage using Computational Fluid Dynamic simulation programs.

In order to find the best engineering model to send to the final design stage, Computational Fluid Dynamic (CFD) as a Simulation program which is currently used by international design companies to simulate manufactured models using complex programs such as ANSYS was selected for this process. It is considered the pioneer in simulation programs to detect strengths and weaknesses in designs based on fluid flow equations, and by using complex triple differential and integral equations. Therefore, supercomputers are used for this purpose, where the equipment is designed with the required measurements using the drawing part of the Design Modular DM program and then the drawing is converted to the mesh part which is the main part before the simulation process. Then the mathematical model for the solution is selected from a group of models based on criteria of fluid flow, type of flowing, specification of flow....etc. After that, the suitable model to the required simulation to start the simulation process is set with the settings that were previously selected, and then the results are displayed in 2D or 3D [4-9].

2.2.1. Primary calculations of water treatment rate and the dimensions of the sedimentation tank for the treatment system.

The calculations and design capacity of the treatment system were prepared on the basis of 2000 cylinders / day, taking into account the work of 2-3 shifts per day and double production capacity, each cylinder has 26.2 lit capacity.

Production capacity = $26.2 * 2000 = 52,400$ lit/day.

If the Working day = 12 hr and Efficiency = 0.8

So, the capacity = $52400 / (0.8 * 12) = 5458$ lit/hr.

Max tank capacity = $5458 \text{ lit/hr} * 8 \text{ hr (max)} = 43600 \text{ lit}$, ~ 50,000 lit. capacity of sedimentation tank *

Over flow = 20 m^3

Tank Area = $20 \text{ m}^2 = L * W = (4W * W)$,

$W = 2.24 \text{ m}$, $L = 8.96 \text{ m}$,

Suggested depth of tank = 1.5 m, 1 m for the sludge sidementation cone and 0.5 m free board. Total depth of tank = 2.5 m (this is for water simulation with out free board). Water velocity = $5.485 \text{ m}^3/\text{hr} / (2.5*2.5)\text{m}^2 = 0.87 \text{ m/hr}$. According to the literatures calculations, it is an accurate velocity of sedimentation [10-14].

2.2.2. Sedimentation tank simulation experiments using ANSYS V19.0

ANSYS - fluent V19.0 program was used to simulate the sedimentation process with flow rate of 5 m³/hr to find out the optimal geometric dimensions of sedimentation tank as well as the highest sedimentation rate that can occur within selected geometric dimensions based on previous calculations. The rectangular sedimentation tank, according to the available literature and data [1-4], consists of the Inlet Zone, Hooper, Baffle, Precipitator Body, Scum Collector, Weir, Mechanical Scraper, Chains, Scraper board, Gear box, Drive motor, Sprockets, Sludge draw off and Outlet Zone. As shown in Figure (5).

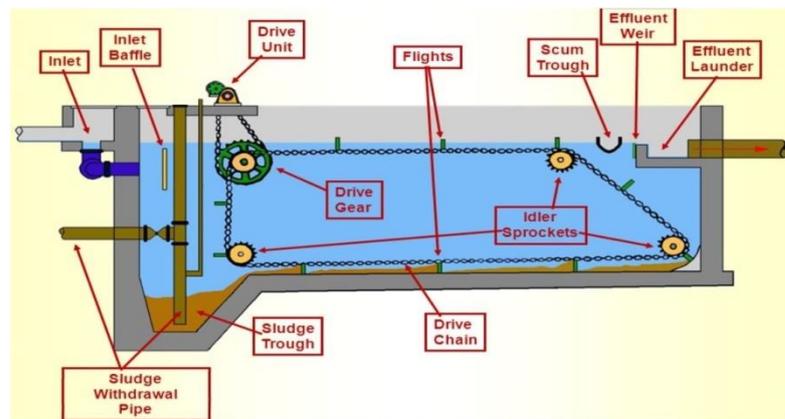


Fig. (5): Shows a simplified image of a rectangular sedimentation tank

** The above calculations are suggested preliminary calculations, and they are a starting point for starting the simulation calculations.*

The simulation was carried out by using Eulerian- Eulerian model with the Standard K- ξ Model. In order to be considered a correct choice for the mathematical model, it must be compatible with the outputs of practical experiments to reduce the percentage of error. A practical experiment was conducted for the sedimentation process by taking

a sample of contaminated water 250 ml in a glass cylinder of 300 ml capacity and observing the sedimentation time, as shown in the Figures (6) and (7).

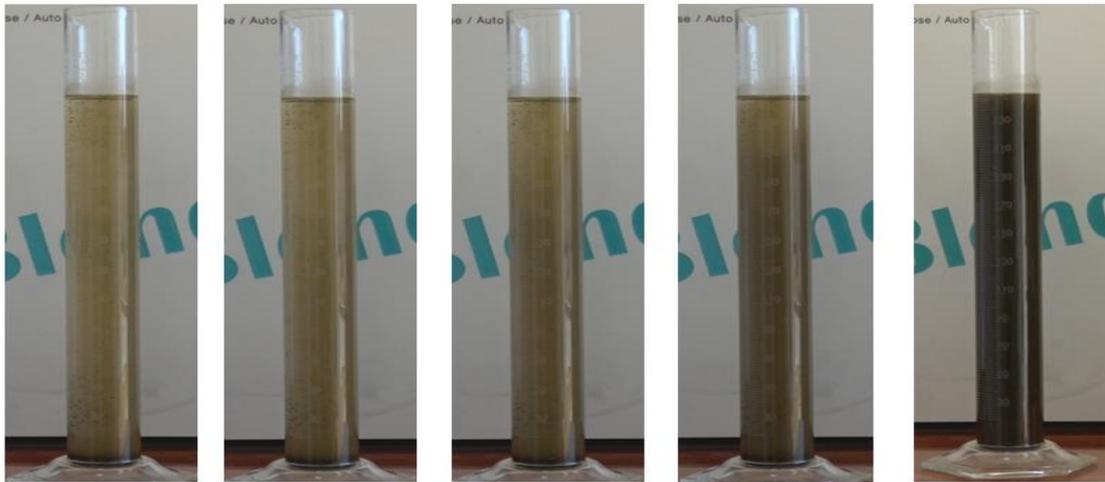


Fig. (6): Shows real sedimentation experiment with time

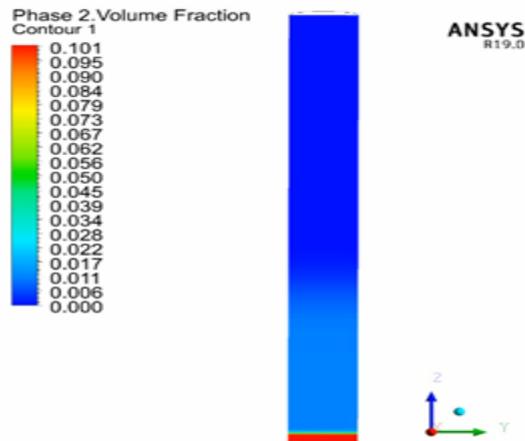


Fig. (7): Shows the simulation of real sedimentation experiment with time

9 sedimentation experiments were simulated with a correction rate of 600,000 iteration, within 0.3-time step per iteration and a physical time of 8 hours per experiment to simulate the same sedimentation time in real experiment. The sedimentation process for the first experiment was without baffle to determine the actual sedimentation rate and compare it with the presence of baffle or other additions to increase the amount of sediment and as shown in Figure (8) [15-18].

2.3. Preparing the final designs using Solid Work program for the outputs of the second stage, in which, the exact details and calculations necessary for implementation on the ground are determined and takes into account the process of automation of total capacity that can be increased when necessary.

2.4. Simulating the initial virtual model of the engineering model mathematically and the changes that may occur to reach the best engineering model for the processing stages through feedback and technically in terms of efficiency and economic cost. The outputs of these tests are reflected to the Solid Work program, which sets the final detailed designs, taking into account the location, operational conditions, automation, ease of installation and maintenance for each part of the processing unit.

3. Results and Discussion

3.1. Sedimentation tank ANSYS simulation results: The sedimentation rate in first simulating experiment (without baffle) was approximately (30.9%) volume of the total volume of sediment as shown in Figure (8). The second experiment was adding baffle that may increase amount of sedimentation.

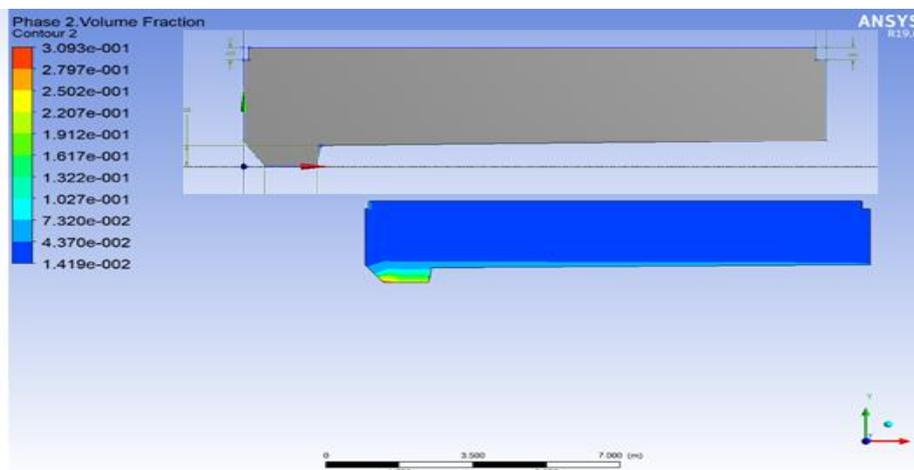


Fig. (8): Shows the Sedimentation process simulation without baffle

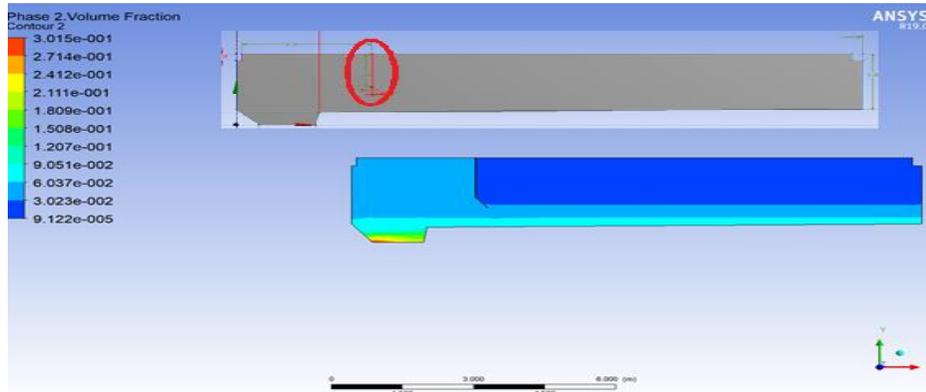


Fig. (9): Shows the sedimentation simulation with baffle

A baffle has been added with the dimensions (height 1.2 meters, distance from the entrance 2.5 meters, angle of inclination 220 degrees) for the purpose of reducing the momentum by reducing the speed of the incoming water to the lowest speed, with the aim of sedimentation of small particles of 10 micron size to the bottom of the tank as shown in Figure (9). Nine experiments have been studied with many variables to reach the largest rate of sediments as shown in Table 1 and Figures (10 to 17).

Table (1) Shows the sediments rates with different variables

No of exp.	Variable	Sedi. Rate	Fig.
1	blank tank without baffle	30.90%	8
2	adding baffle with 1.2m height, 2.5m distance, 220 ° angle	30.10%	9
3	increase the cone angle from 92° to 130°	32.50%	10
4	decrease the height of baffle from 1.2m to 0.8 m	33.60%	11
5	increase the total baffle height to 1.3 m	32.30%	12
6	increase the inclination angle of tank floor to 2° and cone shape	40.30%	13
7	change the cone angles 90° and 152° with 0.5 m cone floor	8%	14
8	change the entrance height to 2.5 m and discharge height to 1.5 m according to exp 6	33%	15
9	change the baffle height to 0.86 according to exp 6	51%	16
10	change the tank length from 12m to 10 m according to exp 6	50%	17

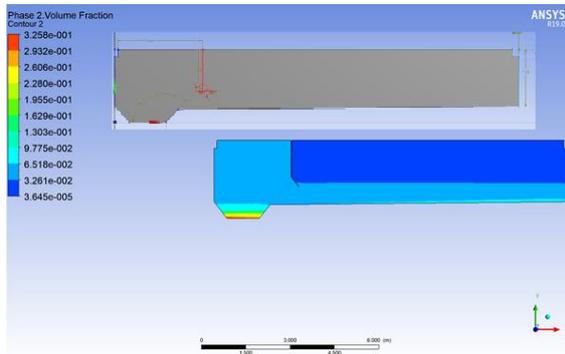


Fig. (10) Sedimentation rate with cone angle

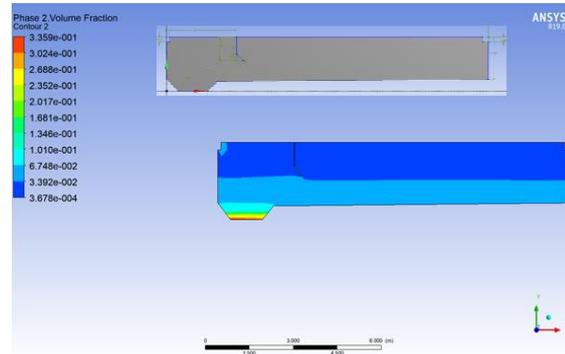


Fig. (11) Sedimentation rate with baffle length

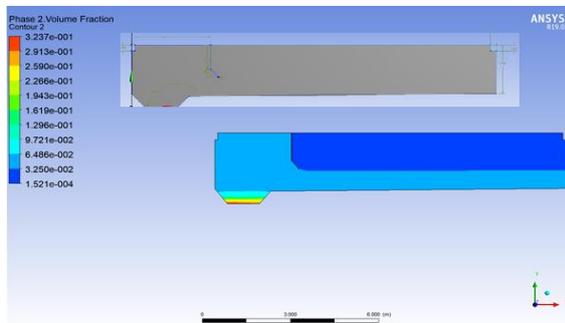


Fig. (12) Sedimentation rate with increasing baffle length

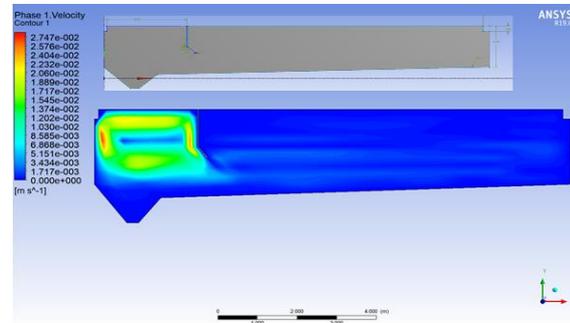


Fig. (13) Sediments velocity with 2° floor & cone shape

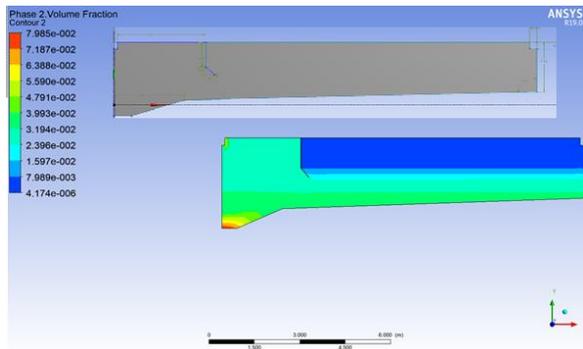


Fig. (14) Sedimentation rate with new cone geometry.

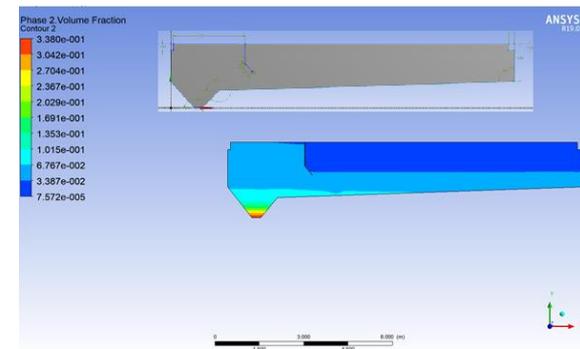


Fig. (15) Sedimentation rate with entrance height to 2.5m and discharge height to 1.5m

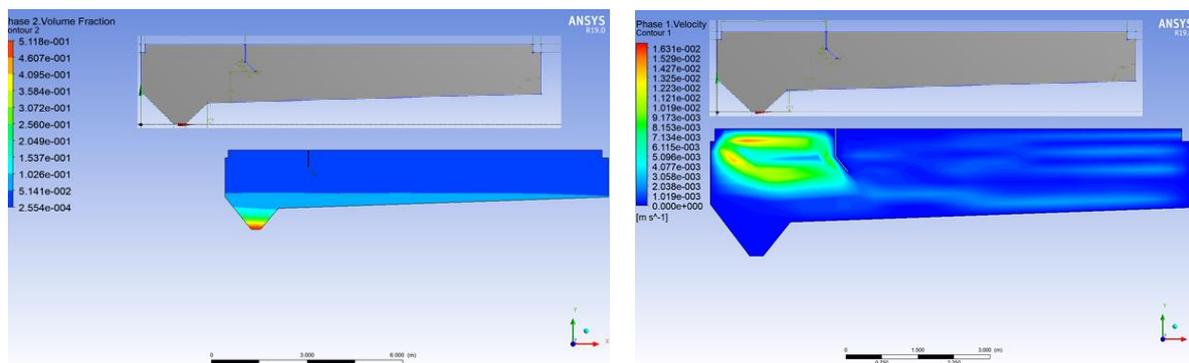


Fig. (16) Sedimentation rate with baffle height to 0.86m Fig. (17) Sediments velocity with 10 m tank length

3.2. Heating Tank ANSYS Results

The simulation of heat transfer in second part of treatment Unit was carried out eliminate thiophene odor based on laboratory experiments. The mathematical model for heat transfer sitting of double precision system, laminar fluid flow rate, and copper for 8 heaters metal were selected. The difficult part of heat transfer in the ANSYS program is the complexity of choosing the MESH in the heat transfer area between the metal of heater and the water surrounding it. Therefore, a special type of MESH is used, which is the type of Contact Region. The simulation was conducted for half of the heating tank to reduce the load on the processor of the computer for the simulation process due to using equations for heat transfer between metal and water of conduction and convection within the simulation program.

The initial experiments were using 8 heaters, 4 heaters on each side, with the initial design of the fenders inside the heating tank. After simulation process, the results of experiments reveal that the temperature of the water leaving the heating tank does not match the required temperature (50°C) as shown in Figures (18) and (19). This was because of bad distribution of heating inside the tank reflect the bad efficiency of 8 heaters due to the geometry of baffles inside the heating tank.

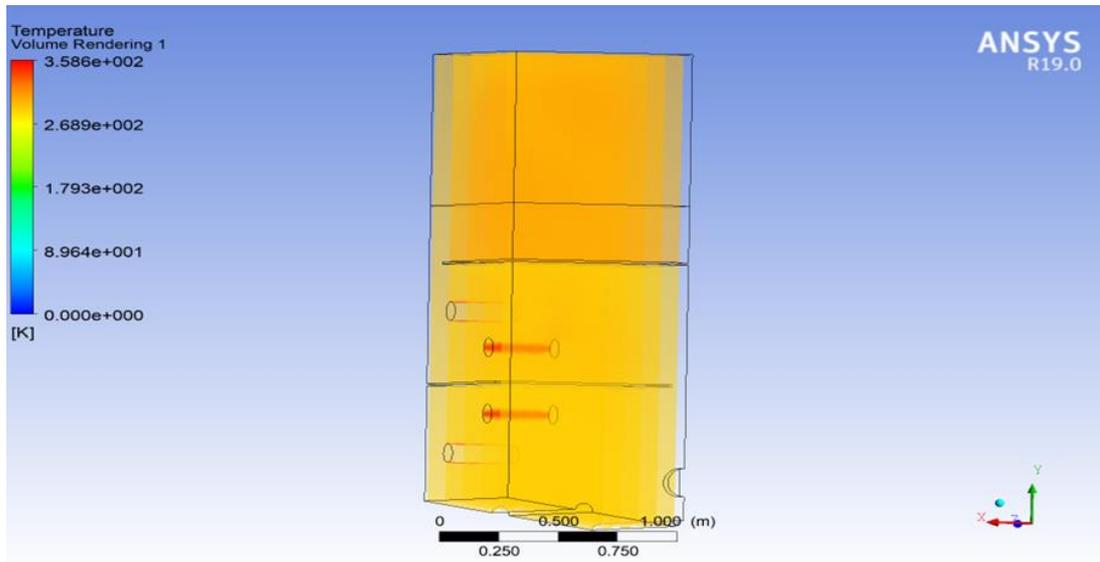


Fig. (18): A cross-sectional figure shows volume rendering the heat distribution on half of the aeration tank

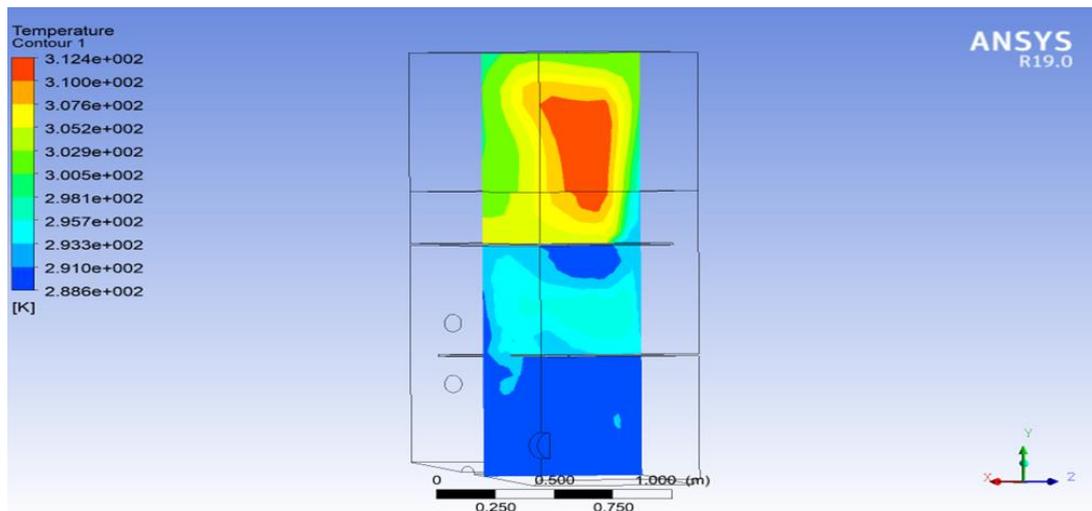


Fig. (19): A cross-sectional figure shows Velocity contour the heat distribution on half of the aeration tank

Based on the previous results, the geometry of the heating tank was changed, including changing the internal fenders and their number, in addition to increasing the heaters to 18 heaters (9 heaters on each side) to heat the required amount (5 m³) as shown in Figure (20). After that, simulation experiments were conducted for the heating

tank, using the same mathematical equations for flow and heat transfer by (Conduction and Convection), and the results indicated excellent heat transfer distribution and obstruction flow in terms of reaching the temperature of the water leaving the upper part to the required heat as shown in Figure (21).

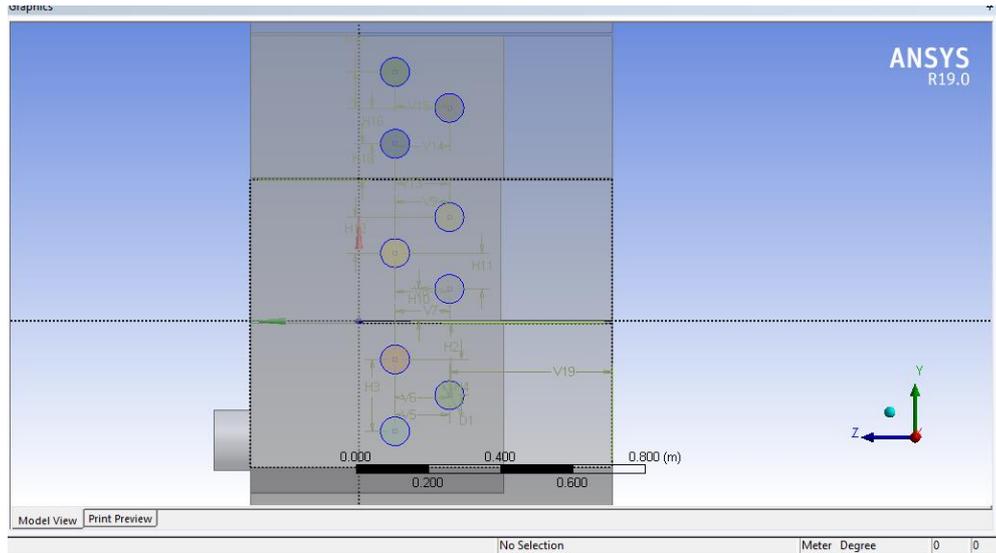


Fig. (20): Shows the heaters and fenders geometry

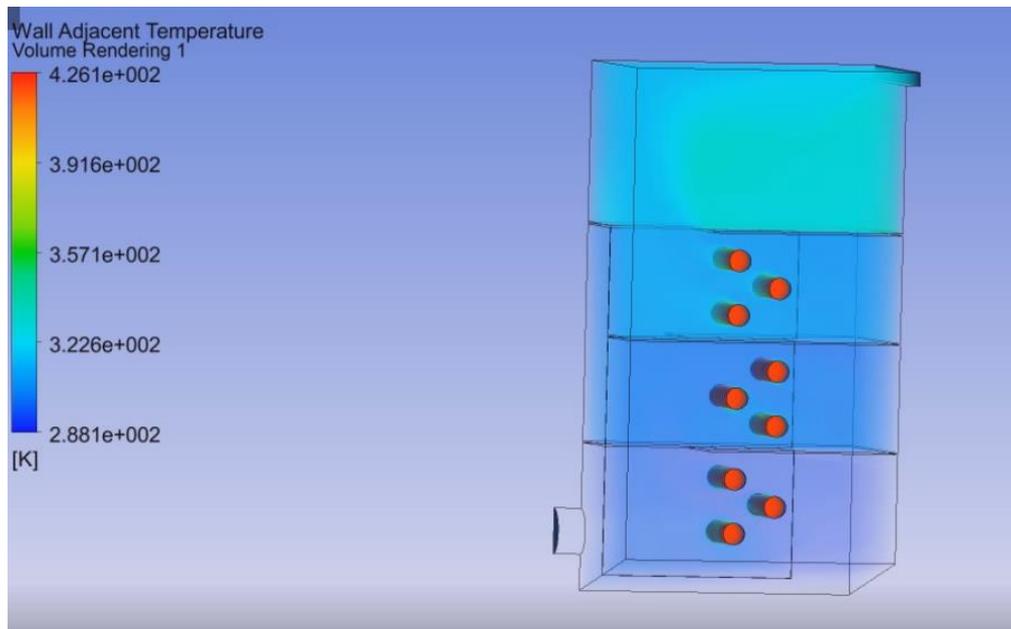


Fig. (21): Shows the volume rendering of heating

3.3. Aeration tank results

Aeration section is the largest part of the tank, and it is open to atmosphere and according to the design, it is either exposed to the air or attached with activated Carbon filters to absorb the Thiophene from the polluted water. The compressed air is distributed inside the tank by means of distribution discs (diffusers), which are spread along the length of the tank and work to transform the flowing air into small bubbles to increase the surface area of contact between air and water as depicted in Figure (22).

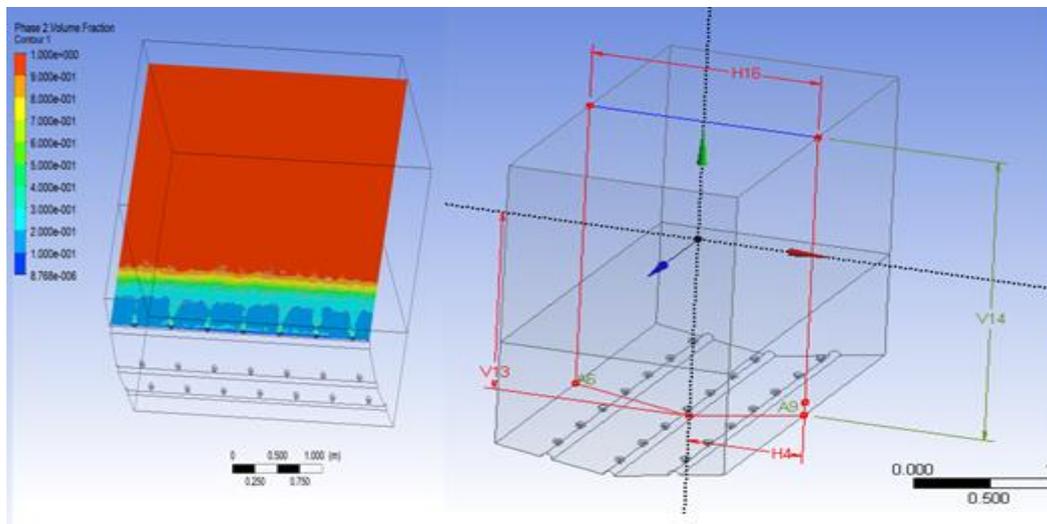


Fig. (22): Shows the distribution on diffusers on the aeration tank length

More than a hundred aeration tank simulation experiments have been conducted using mathematical models of fluid flow by using the models (VOF, Mixture and Eulerian Model) and the Implicit models system at each stage. Several constants were changed to reach the best result for the contacting area between water and incoming air and the results reflected to phase volume fraction for each phase on the graphs as shown in Figure (23).

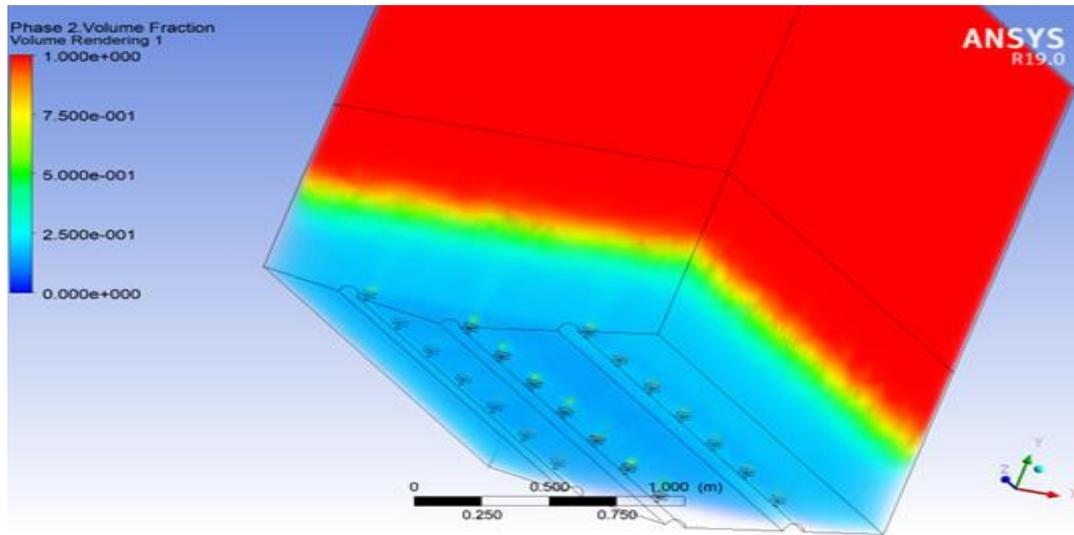


Fig. (23): Shows the volume fraction of air in aeration tank

4. Unit Design Using SOLIDWORKS

Preparing the final designs using SOLIDWORKS program, in which the exact details and calculations necessary for implementation on the ground are determined. Thus, it is easy to use and take into account the automation process of total capacity that can be increased when necessary depending on the simulation output. The processing unit consists of the following main procedures: -

- 1- Sedimentation unit for clays, minerals, iron slag and its accessories.
- 2- Thiophene removal unit (ventilation) and its accessories.
- 3- Filtration unit and its accessories.
- 4- Control unit and its accessories.

As shown in Figures (24, 25)

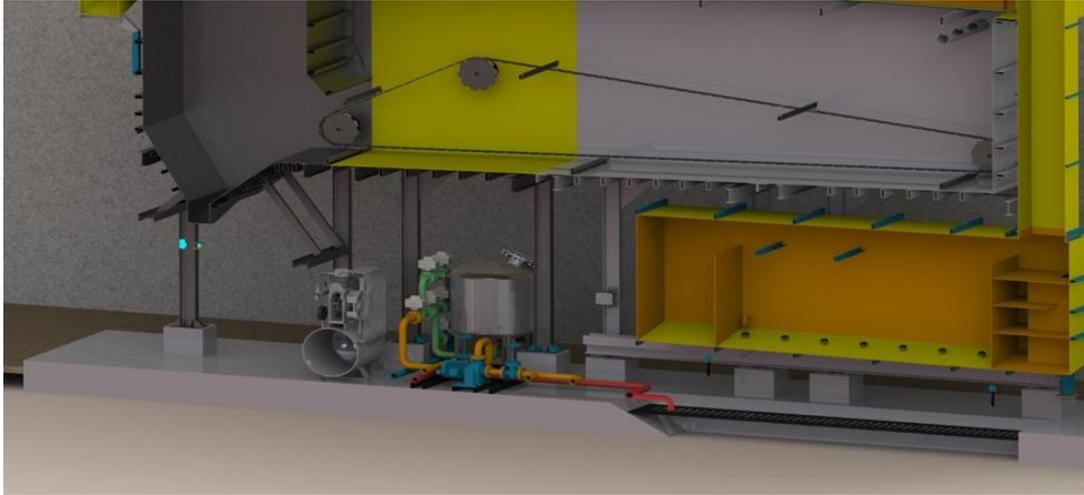


Fig. (24): Shows a cross section of the entire treatment unit



Fig. (25): Shows a transparency view of the entire unit

The design of the main parts was taken into consideration that it consists of small parts (Skid Mounted) that are easy to install and dismantle in the transportation to another site or maintenance as shown in fig (26). Accordingly, the whole precipitator tank includes the followings:

- 1- Precipitator Tank.
- 2- Mechanical Skimmer.
- 3- Gear Box Complex.
- 4- Sludge Withdrawal Valve.
- 5- Water Outlet Valve.



Fig. (26): Shows the water treatment site

4.1. Filtration Unit Design

The filter unit consists of the following parts shown in Figure (27):

- 1- Two multi-layer filters that activate by feedback when the pressure drop increases inside them as a result of the deposition of particles inside them.
- 2- Opening and closing solenoid valves for each filter, operating in one direction, filtering and washing in the reverse direction.
- 3- Two water pumps.

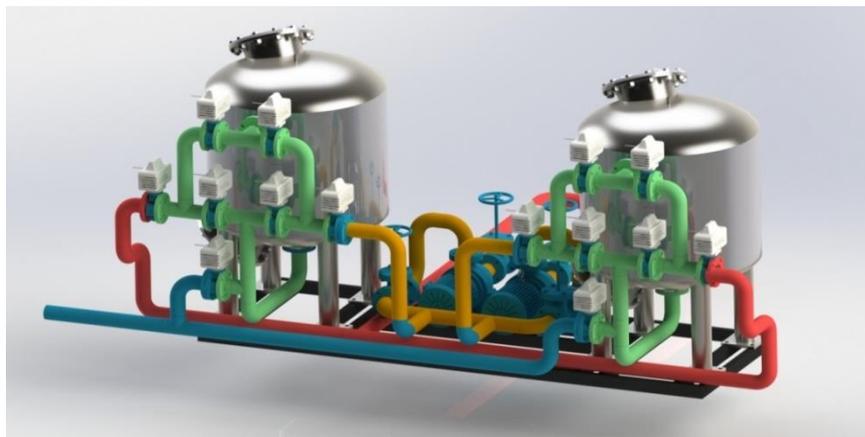


Fig. (27): Shows the filtration unit design of influent, effluent and backwashing pipes

The effluent water after the filtration process is come out to use again and represented by blue-colored tube as shown in Figure (27). However the red-colored pipes are used in the backwashing process when the pressure drops to specific levels is reached as a result of the accumulation of polluted particles and granules, then the water filtration process takes place by itself for the second filter while the first filter is in a state of backwashing from the bottom up direction and that is through the valves connected to each filter. The green pipes represent the flow of feed polluted water from aeration part. Each filter consists of several layers as shown in Figure (28) and as follows:

- 1- Activated Carbon layer, which is used to remove the residual sulfur or thiophene odor, as well as any residual chemical substances especially organic compounds from the water when filtering as first layer in the filter.
- 2- Anthracite layer is used to remove the turbidity of water and to purify water from small particles.
- 3- Sand layer is used to purify water from small particles in size.
- 4- Garnet layer, which has a small granular size with a high density and used to purify the remaining minutes in the water.
- 5- Gravel layer is used to prevent clogging of the pipes at the bottom of the filter by sand from the upper layers.

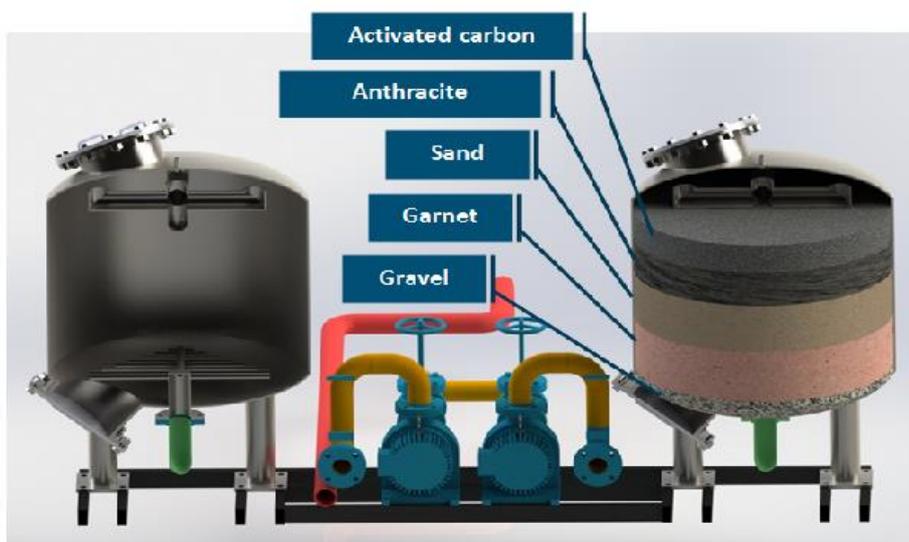


Fig. (28): Shows the layers type of filters

4.2. The design details of the proposed treatment maintenance unit

Table (2) shows the specification with sheet No.

No	Sheet No.	Specification
1-	A-001	Basic Engineering Specification Data
2-	A-002	Process Main Equipment
3-	A-003	Precipitation Equipment Main Components
4-	A-004	Precipitation Tank Inlet Zone
5-	A-005	1 st Basin Section Steel Structure Details
6-	A-006	1 st Basin Section Design
7-	B-001	Aeration Tank Main Components
8-	B-002	Precipitation Tank Inlet Zone
9-	C-001	Filtration Unit Demonstration

All design sheets will be attached.

5. Conclusion

Recycling wastewater of maintenance section in the LPG Gas filling company by designing, simulation and engineering Unit for treatment was suggested. Firstly, selecting path processing technology for treatment based on performing water analysis in the laboratory. Thus, configure out that the Unit is consist of three main parts Precipitators, Aeration, Filtration. Secondly, simulation of the preliminary design Unit using Ansys fluent V.19 (Computational Fluid Dynamic) to mimic the process of sedimentation of particles according to high rate of precipitation that means multi-modification geometry of precipitator and heating zone of the first and second part of Unit to reach best configuration. Eventually, the last part is to engineering Unit on the ground by using Solid work program software to determine the practical work as cost and reliable execution steps fitted with area available and issues may raise as obstacles.

References

- [1] E. S. Tarleton and R. Wakeman, *Solid / Liquid Separation: Scale-up of Industrial Equipment*. 2005.
- [2] A. Y. Madala, “Effluent Treatment in LPG Bottling Plants A Study on Mysore LPG Bottling Plant,” vol. 3, no. 7, pp. 638–642, 2018.
- [3] J. K. Farmer, “Wastewater treatment technologies,” *Pollut. Eng.*, vol. 23, no. 9, pp. 66–70, 1991, doi: 10.1016/b978-0-12-811989-1.00012-9.
- [4] T. Lemmer and Cg. du Toik, *Modelling of Rectangular Sedimentation Tanks*, no. 998.
- [5] A. M. Karpinska and J. Bridgeman, “CFD-aided modelling of activated sludge systems - A critical review,” *Water Res.*, vol. 88, pp. 861–879, 2016, doi: 10.1016/j.watres.2015.11.008.
- [6] A. Zhang, “CFD Modeling and Optimization of Primary sedimentation tank,” 2017.
- [7] S. Meshing, “Introduction to ANSYS Meshing,” *Workbench*, no. December, pp. 1–37, 2010.
- [8] C. T. Material, “Meshing g Methods Introduction to ANSYS Meshing Meshing Methods,” *Methods*, no. February, pp. 1–68, 2011.
- [9] C. T. Material, “Lecture Introduction to ANSYS Meshing Introduction to ANSYS Meshing Introduction to ANSYS Meshing What you will learn from this presentation :,” no. February, pp. 1–53, 2011.
- [10] J. S. Rodríguez, L. A. Jácome, and B. P. Ures, “Primary clarifier,” no. October, 2014.
- [11] “Sedimentation Basin Design and Problems Designing a Rectangular Sedimentation Tank Introduction Overview of Calculations.”
- [12] N. Voutchkov, “Settling Tanks,” *Water Encycl.*, no. November, 2005, doi: 10.1002/047147844x.mw506.
- [13] P. By, “Clarifier Calculations Clarifier Calculations Hydraulic Loading Solids Loading.”

- [14] G. Criteria *et al.*, “CHAPTER 5 Clarifiers,” no. January, pp. 1–10, 2016.
- [15] “Chapter 4 3D Geometry,” pp. 1–60, 2007.
- [16] F. X. Giraldo, “Time-Integrators,” pp. 1–14.
- [17] M. Hassanien, E. S. Elmolla, and U. F. Mahmoud, “Modeling the effect of inlet baffle longitudinal and vertical positions on the settling tank performance with computational fluid dynamics,” no. 40, 2018.
- [18] “Candidate : Achini Weerasooriya Title : Simulation of Flow in Sedimentation Tank Using Fluent,” 2013.