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ORIGINAL RESEARCH ARTICLE

Removal of contaminants from wastewater by sedimentation in a circular secondary clarifier

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ABSTRACT

In wastewater treatment, a circular clarifier is used to separate wastewater into sludge and effluent in the primary treatment process, and it is one of the core instruments in the secondary treatment process for sludge sedimentation. Since biological sludge sedimentation has strong spatially and temporally non-uniform characteristics and a relative float settling velocity, a separation structure is applied to induce a uniform flow field to improve performance. This clarifier also requires an evacuation system for frequent solid removal. The source of power consumption with the clarifier is the induced flow energy. The result is that the effluent from the clarifier will have low turbidity with a high removal efficiency of contaminants. High removal efficiency is very important to meet the standard 'B' in the Department of Environment's effluent standard. This study will use numerical analysis (CFD) to simulate and validate the results from experimental work. By using CFD, it is hoped that this study can provide a better understanding of the hydraulic behavior and provide a scientific basis for the design process of a circular clarifier for sedimentation. A circular clarifier is crucial equipment in the primary treatment of wastewater. In this study, a circular clarifier with improved structural designs, for which a set of baffle plates with appropriate dimensions and locations generating reduced flow energy, was developed. CFD simulations of contaminant sedimentation were coupled with an Artificial Fish Swarm Algorithm optimization workflow to maximize removal efficiency under operational and hydraulic constraints. This clarifier demonstrated satisfactory performance in sediment separation. Trace back simulations and artificial fish swarm algorithms were applied to determine the optimal design of the clarifier. With these optimal structural dimensions, the clarifier could effectively minimize the sludge volume accumulation rate and shorten the time required for sludge sedimentation in wastewater treatment. Additionally, sediment outlets of different dimensions and various wastewater treatment levels were considered. Both numerical simulations and experimental tests were included for performance evaluation.

Keywords: secondary clarifier; mix the phases; gravity; Sedimentation Processes

1. Introduction

Traditionally, the treatment of sewage was based on the removal of solids from the water of varying sizes and densities. In general, after the primary treatment, the water had around 200-400 mg/L of mineral and organic solids, and the final treatment, in secondary settlement or 4-5 days in lagoons, could remove approximately 25-40% of the solids, reducing its concentration to values around 60-120 mg/L. These primary and secondary treatments did not completely remove some inorganic and organic pollutants, and a tertiary treatment was often necessary[1]. This degraded the quality of water and its reuse. The use of biomass and microorganisms in bioreactors and also the action of flocculants are two key steps in eliminating these contaminants, and the settlement of solid biomass from the water is a necessary step for high bioreactor performance[2]. In recent years, there have been many reports on developing new methods to remove most of the solids and ammonia, phosphorus, heavy metals, xenobiotics, and pathogens directly in an anaerobic/anoxic zone within a circular secondary clarifier, which may be water-covered[3].

Recent advances in water and wastewater treatment have allowed for the improvement of human health and environmental preservation. The drinking of clean water has been established by the United Nations as a basic human right, and most people in developed countries can access clean water[4]. In addition, sanitation systems have been adapted to remove most of the contaminants in sewage and stormwater. The technology to purify wastewater exists; however, see **Figure 1**, especially in developing countries and underprivileged communities, there are still big issues with water supply and contamination. The future of water infrastructure is dependent on different factors - political, economic, and scientific[5]. In developed countries, the pressure for developing different new solutions has also increased, mainly related to the energy and materials used in the processes. The conventional technologies are being changed, and the current trend is to create hybrid systems that use adsorption, oxidation, biological, and physical treatment to complement each other and improve energy efficiency and environmental preservation[6].

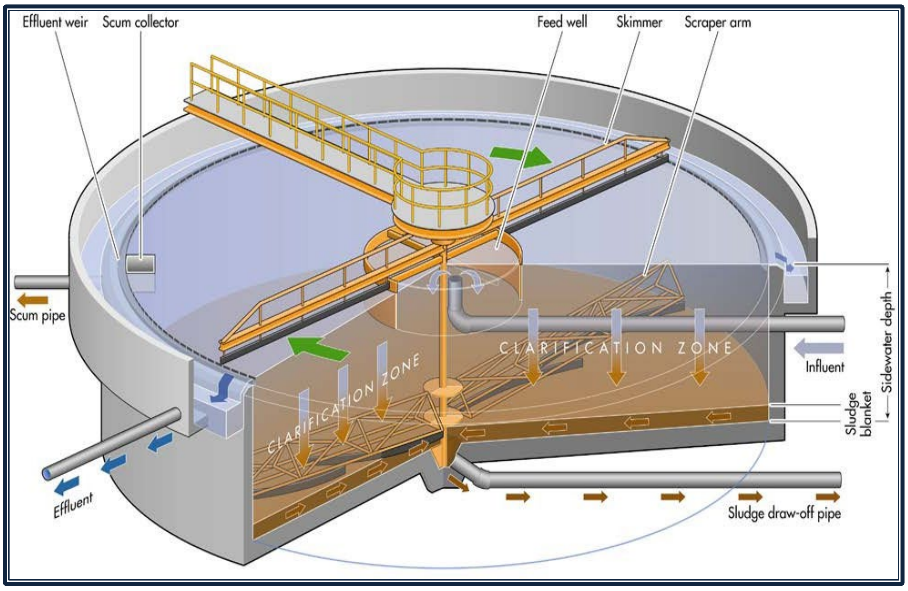


Figure 1. Circular Clarifier[5].

1.1. Purpose of the study

Sedimentation of suspended solids in a secondary clarifier depends on many factors, which is why a great variety of mathematical models has been proposed to simulate the clarifier operation. However, relatively few efforts have been made to model the removal of contaminants from wastewater. These efforts are still at an early stage, as occurred during the development of the design of primary clarifiers in the forties and fifties.

The purpose of the study was to evaluate the sedimentation of six different contaminant particles, whose diameters ranged from 10^-1 to 10^-5 m, in a circular secondary clarifier and to compare the results with experimental data as well as with predictions made using existing models[7]. The particles and their sizes corresponded to those found in secondary effluents. Concentration profiles of the contaminants were measured in a large secondary clarifier at three different water depths, three different influent loads and two different recycle flow rates[8]. The experimental results indicated that removal of contaminants by sedimentation could be explained by allowing for the losses from the bulk of the ratio of the difference between the concentration at any sludge level and that at the outlet of the clarifier to the difference between the concentration in the bulk of the floc and that at the outlet.

1.2. Scope and limitations

If bulk quantities of chemical and biological pollutants are present throughout the entire depth of the water, e.g., if generated by microorganisms from organic materials, then sedimentation in large particles such as sand filter grains or deflocculated, dissolved pollutants are rapidly concentrated into the bottom sludge. Simple gravitational forces are sufficient to separate pollutants from the water. However, if pollutants are present in the upper layers of the water, e.g., if they are formed or carried into the water by an overflow, if they are subject to an underflow across the bottom of the water, or if they are passing from one phase into another, then the forcing mechanism is more complex and generally must be achieved by more sophisticated devices. Thus, the separation of pollutants by sedimentation within a liquid is quite different from the simple separation by sedimentation in a rapidly flowing liquid due to gravitational forces, centrifugal forces, or electrostatic charges.

An important limitation of the sedimentation process and separator is the need for relatively long residence times for effective separation. In its most general sense, sedimentation is the gravitational settling of particulate solids by removal from the suspension by filtration or gravitational settling of non-settling fluids by flotation. In the hydraulic sedimentation unit, the gravitational forces or physicochemical forces acting on the dispersed solids or liquids tend to make the flow separately. Sedimentation is used extensively in wastewater treatment both for the separation of the physical constituents of the liquid (removal of suspended or floating debris, heavy or floating particles and dissolved gases) and for the removal of entrained chemical and biological pollutants. Because of its relatively short execution time, sedimentation is particularly attractive for the removal of bulk quantities of dissolved wastewater contaminants.

2. Theoretical foundations

Governing Equations

The hydrodynamic behavior of wastewater flow in the circular secondary clarifier is described using the incompressible Reynolds-Averaged Navier–Stokes (RANS) equations. The flow is assumed to be isothermal, and density variations are neglected. Under these conditions, the governing equations consist of the continuity and momentum equations.

Continuity equation (mass conservation):

$\nabla \cdot \mathbf{u} = 0$

Momentum equation:

$$\rho\left(\frac{\partial \boldsymbol{u}}{\partial t}+\boldsymbol{u}\cdot\nabla\boldsymbol{u}\right) = -\nabla p + \nabla\cdot\left[\,(\mu+\mu_t)\left(\nabla\boldsymbol{u}+\nabla\boldsymbol{u}^{T}\right)\right] + \rho\boldsymbol{g}$$

Where $\mathbf{u}$ is the mean velocity vector, p is the pressure, ρ is the fluid density, μ is the molecular dynamic viscosity, μ_t is the turbulent eddy viscosity, and $\mathbf{g}$ is the gravitational acceleration vector.

Turbulence effects are represented using a suitable two-equation turbulence model (such as the standard k–ε, RNG k–ε, or SST k–ω model), which provides closure for the Reynolds stresses through the computation of the turbulent viscosity μ_t. The turbulence model is applied exclusively to resolve hydrodynamic mixing and momentum transport within the clarifier.

For a secondary separator operating with a constant influx, q, the solids concentration in sludge withdrawn through the subway, X, yielding sludge drawn per time unit, is:

$$X=(Y*kw1)/(q-w2) \tag{1}$$

Reveals that the equivalent circulating load factor, Cass, were

$$S = cs.ft \,/\, q \tag{2}$$

The equivalent settling area occupied by the flocculated solids[9]. The ratio, S/Y, represents the volume of flocculated sludge flow withdrawn from the lake dependent on the hydrodynamics of the sludge along the pool. The equivalent load factor may be expressed as:

$$C_{ass}=cw1q/ft-q \tag{3}$$

$$Cass=1-(S/Y)/(Y*Css) \tag{4}$$

$$Y = (1 - ns/nt)qcr/Rw10418cm3 \,/\, (s.cm3)\,f = 1.4 * (q) \text{ -0.5 } / \,S = 2.5 * (q) \text{ -0.58} \tag{5}$$

According to the theory of settling column, particles with diameter, d, and density, p, settling at a distance, L, in a fluid with density, pg, and viscosity, g, at Stokes flow conditions, attain a terminal velocity, us, described by the expression:

$$us=\frac{\left[\left(d^2\right)g(pg\text{-}g)\right]}{18gc} \tag{6}$$

$$crc=p/pg \tag{7}$$

For particles with diameter in excess of 0.1% of the distance

$$\text{L, } us=\left(\pi\, d^2\right)g/(18\, g\, c\, c) \tag{8}$$

Representing the Stokes stability criterion in the fluid, with

$$c = (pg - g)/\,p \tag{9}$$

The volumetric sedimentation capacity, Particle turbulent capture parameter, Clear-water residence time may be determined from the mass balance for settling in a column, Volume in gallons of a tank having a diameter of 50 feet and a depth of 9 feet.

$$V=\pi r^2\text{h}= 3.14\; X\; 25\; ft.\; X\; 25\; ft.\; X\; 9\; ft. =17{,}662.5\; ft^3\; X\; 7.48\; gal/ft^3= 132{,}116\; gallons$$

Where primary clarifier is 18 feet wide, 45 feet long, and has a SWD of 9 feet. The clarifier has an effluent trough across the end. The average flow to the clarifier is 0.085 MGD. The weir over flow rate for this clarifier= 9,444 gal/day/ft., Flow, gallons/day =0. 085 MGD X 1,000,000 = 85,000 gal/day (Length of Weir, ft. =Width).

A primary clarifier is 12 foot wide, 40 foot long, and has a SWD of 8 feet. The clarifier has two effluent troughs across the width that allows the water to flow over both sides of each trough. The average flow to the clarifier is 0.41 MGD. Flow, gallons/day=0. 41 MGD X 1,000,000 = 410,000 gal/day Length of Weir, ft. =4 X Width= 4 X 12 ft. =48 ft.

Typical Design Value = ~10,000 gal/day/ft.

1. **Clarifier Geometry and Operating Conditions**

- **Type:** Full-scale circular secondary clarifier
- **Diameter:** 18 m
- **Water depth:** 3.8 m
- **Feed-well diameter:** 2 m
- **Influent flow rate:** 350–500 m^3/h
- **Surface overflow rate:** 20–32 $m^3/m^2 \cdot day$
- **Sludge withdrawal rate:** 2–6% of influent
- **Temperature:** 293 K (assumed isothermal)

2. **Contaminant Particle Properties**

- **Six particle sizes:** 10−1,10−2,10−3,10−4,10−510^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}10−1,10−2,10−3,10−4,10−5 m
- **Density range:** 1050–2650 kg/m^3
- **Shape:** Spherical
- **Settling velocity:** 0.001 – 0.4 m/s (calculated using modified Stokes law with drag correction)

3. **Measurement Locations and Depths**

- Radial locations: 0.25R, 0.5R, 0.75R (R = tank radius)
- Vertical depths: 0.2H, 0.5H, 0.8H (H = water depth)

4. **Sampling Protocol**

- Frequency: every 10 minutes during steady-state operation
- Duration per test: 2 hours per particle size and flow condition
- Replicates: 3 per condition to estimate variability

5. **Analytical Techniques and Uncertainties**

- **Concentration measurements:** Gravimetric filtration (Standard Methods 2540D)
- **Particle size verification:** Laser diffraction
- **Measurement uncertainty:** ±4.5% for concentration, ±2% for flow rate, ±5% for particle size

2.1. Principles of sedimentation

Since the most common design of sedimentation facilities is an open rectangular tank, this design is preferably used for the wastewater. However, the basic principles are equally valid for the design and operation of circular secondary clarifiers which are commonly used in small to moderate size domestic and industrial wastewater treatment plants. The hydraulic loading to the circular clarifier is usually less than 2 m3/m2. d. The large circular clarifiers can be up to 60 meters in diameter and 5 meters deep as **Table 1** and **2**. At the lower end of the size range, a clarifier will typically be 10 to 20 meters in diameter and 2.5 meters deep[10]. Circular clarifiers have only a limited use for large sewage treatment works due to the high land area needed for construction of an array of tanks and the complexity of the inlet and return activated sludge arrangements. In actual fact, it would be rather a rarity to find a big sewage works with only circular tanks. The following principles are explained by reference to a circular clarifier, but with awareness of the limitations of the tank under consideration, the principles are directly applicable to rectangular sedimentation tanks.

First, it should be noted that concentration of heavy solids is not the main purpose of sedimentation in a circular secondary clarifier. The purpose of sedimentation in a wastewater treatment plant is to remove stable colloidal particles from the wastewater. Only non-sediment able elements, with a relative density less than 1.25 kg/m3 and with a diameter less than 100 µm, will remain in the supernatant after 2 to 3 hours in a circular clarifier[11]. This means that the influent to a circular secondary clarifier has to contain a substantial number of sediment able particles, about 40% of the inflow from a conventional activated sludge plant, in order to obtain the benefits of sedimentation[12]. If the incoming particles are larger than 100 micrometers, they are not considered to be colloidally stable and no effective removal of these larger particles will be obtained.

2.2. Design and operation of circular secondary clarifiers

A secondary clarifier is a device used to settle out particulate matter that has settled out biologically in the activated sludge process. The name comes from the fact that the primary application for such clarifiers is to remove the excess biological solids that don't settle out in the aeration tank because the settled solids are returned to the aeration tank to meet the effluent standards, showed in **Figure 2**. These clarifiers may also be open to the atmosphere and be used for primary clarification at a wastewater treatment facility[12]. The small particles that need to be removed in a primary clarifier may also be removed in a secondary clarifier by allowing the floating material to escape, as showed in **Table 3** and **4**. In conventional gravity settlers, the smallest particles need a long hydraulic retention time to allow sedimentation to occur. This concept is not used in activated sludge settlers because the huge required surface area would be very expensive. For the same reason, the residence time in activated sludge clarification is normally 30 minutes or even less.

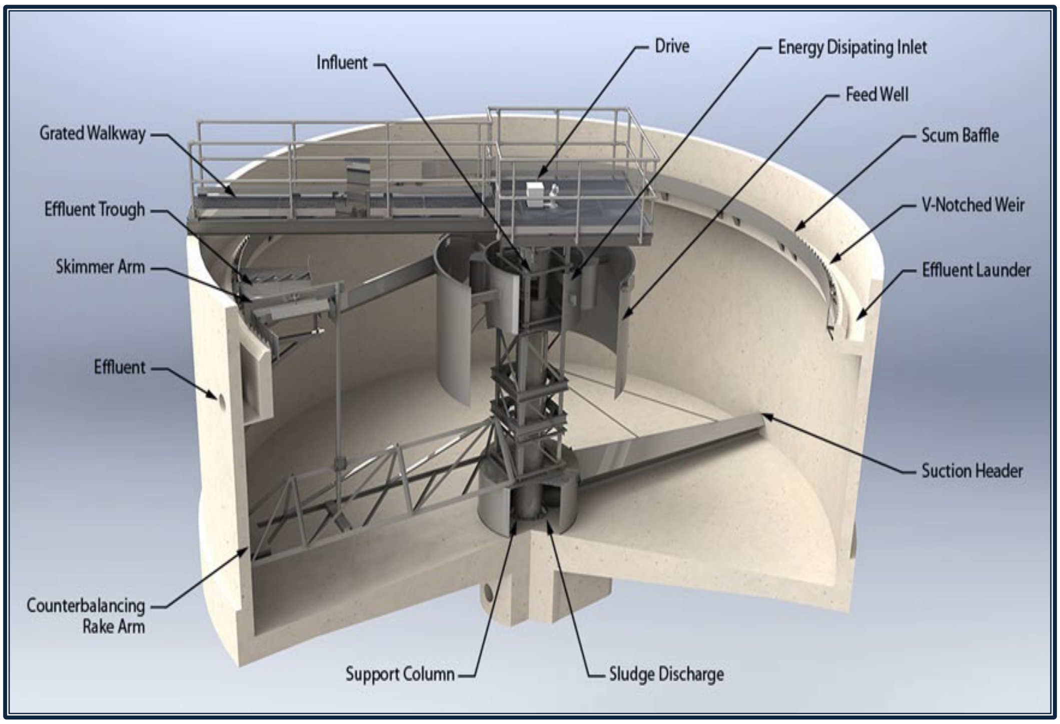


Figure 2. Parts of Circular Clarifiers Secondary Wastewater Treatment[12].

Sand, grit, and other inorganic solids are heavier than water and settle at a higher velocity. Organic solids are lighter than water. Bacteria are aggregates of organic molecules, and flocks of bacteria are hence heavier than water and settle at a velocity between the velocity of the water and the velocity of the inorganic solids. Supernatant is accumulated into the hopper during the settling process. Waste water when treated properly has the potential use in farming, fish farming, and to replenish ground water, see **Table 5**. The organic molecules are digested and used as food by the bacteria during the time that the flocks of bacteria are in suspension. Flock-building and flock-falling is an equilibrium process, determined largely by the balance between the settling velocity of the flocks of bacteria and the upward velocity of the supernatant. The size of the flocks and the relationship between flocks and supernatant are important for the sedimentation process.

Table 1. Boundary Condition.

Region	Boundary Condition	Specification / Justification
Inlet (Influent well)	Velocity inlet	Uniform or radially distributed inflow velocity corresponding to the specified flow rate; turbulence intensity prescribed to represent incoming hydrodynamic mixing
Outlet (Effluent weir)	Free-surface overflow	Fixed water level allowing mass-conservative outflow; pressure-adjusted discharge over the weir
Walls (Clarifier sidewalls)	No-slip wall	Zero velocity at walls with surface roughness representative of concrete clarifier walls
Bottom (Clarifier floor)	No-slip wall	Zero velocity condition with roughness consistent with concrete; enables realistic near-bed flow and sediment deposition
Free surface (Water–air interface)	Shear-free boundary	Zero shear stress and zero normal velocity; neglects wind effects and thermal stratification
Turbulence modeling	Hydrodynamic only	Turbulence model applied solely for momentum transport and mixing; thermal transport effects neglected

2.2.1. Model assumptions

The following assumptions are adopted to simplify the numerical model while preserving the essential physics of sedimentation in a secondary clarifier:

1. The wastewater is treated as an incompressible, Newtonian fluid with constant physical properties.
2. Flow conditions are isothermal; thermal transport, heat transfer, and buoyancy effects are neglected.
3. Turbulence modeling is employed solely for hydrodynamic momentum transfer and mixing, not for thermal or scalar transport.
4. The free surface at the water–air interface is assumed to be flat, stationary, and shear-free, with zero normal velocity.
5. Wind shear, surface waves, and atmospheric interactions are neglected.
6. Clarifier walls and bottom are rigid and impermeable, subject to no-slip boundary conditions with surface roughness representative of concrete.
7. Gravitational acceleration acts in the vertical direction and governs the sedimentation process.
8. Chemical reactions and biological processes are not considered in the hydrodynamic model.
9. Particle–particle interactions and flocculation effects are neglected unless explicitly modeled.

Table 2. Design Variables.

Parameter	Range	Unit	Physical Meaning
Influent flow rate	350 – 500	m³/h	Controls hydraulic loading
Feed-well diameter	1.8 – 3.0	m	Influences flow distribution
Water depth	3.0 – 4.5	m	Affects settling distance
Sludge withdrawal rate	2 – 6	% of QQQ	Prevents sludge accumulation
Particle diameter	10−5–10−110^{-5} – 10^{-1}10−5–10−1	m	Six discrete contaminant sizes

Table 3. Constraints.

Constraint Type	**Symbol**	**Description**	**Limit / Condition**	**Unit**
Hydraulic loading	HLR\text{HLR}HLR	Surface overflow rate	≤ 40	m³/m²·day
Effluent quality	CoutC_{\text{out}}Cout	Maximum effluent concentration	Regulatory limit	mg/L
Shear stress	τb\tau_bτb	Bottom shear stress	<τcr< \tau_{cr}<τcr	N/m²
Mass balance	–	Inlet = outlet + settled mass	≤ 1% error	–
Geometry	–	Fixed tank diameter	18	m

Table 4. Convergence Criteria.

Category	**Parameter**	**Criterion**	**Unit**
CFD solver	Continuity residual	≤ 10−510^{-5}10−5	–
CFD solver	Momentum residuals	≤ 10−510^{-5}10−5	–
Turbulence	kkk, ε\varepsilonε residuals	≤ 10−610^{-6}10−6	–
Particle transport	Concentration variation	≤ 0.1% over 500 iterations	–
Optimization	AFSA iterations	≤ 200	–
Optimization	Objective function change	≤ 10−410^{-4}10−4	–

Table 5. Artificial Fish Swarm Algorithm (AFSA) Parameters.

Parameter	**Value**	**Description**
Population size	30	Number of artificial fish
Visual distance	0.3	Search neighborhood
Step size	0.05	Movement increment
Crowding factor	0.6	Avoids premature convergence
Maximum iterations	200	Termination condition

2.3. Contaminants in wastewater

The approximate concentration of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and ammonium-nitrogen associated with wastewater was approximately 240 kg/1000 m3 (kilograms per 1000 cubic meters), 1000 kg/1000 m3, 100 kg/1000 m3, and 22 kg/1000 m3, respectively. The approximate maxima that were allowable for biochemical oxygen demand, chemical oxygen demand, total suspended solids, and ammonium-nitrogen in the treated wastewater were 15 kg/1000 m3, 75 kg/1000 m3, 10 kg/1000 m3, and 5.0 kg/1000 m3, and possibly 22 kg/1000 m3, for the BOD, COD, TSS, and ammonium-nitrogen, respectively. These contaminants, BOD, COD, TSS, and ammonium-nitrogen, relative to water resources during the secondary treatment processes, were reduced because the microbial metabolism and the microbial population levels increased to maintain the wastewater purification capabilities of the secondary treatment processes. However, microbial lysis and the reduced respiration capacity can cause a build-up of ammonia associated with the effluent during an overloading into the secondary treatment units[13]. Therefore, the removal of organic compounds, either biodegradable or not, will allow the wastewater to be effectively purified.

2.3.1. Types of contaminants

In addition, substances present in cleaning products such as surfactants and detergents, which foam when effluents are agitated, are not easily removed by the normal activated sludge treatment process. Inorganic materials include physical materials such as sand, grit, grease, and other debris. In addition, the most common naturally occurring regulatory standards are nutrients and odorous compounds typically found in pee. These components are generally present in small amounts in urban influents and even smaller amounts in general wastewater treatment plants (WWTPs). However, industrial, agricultural, and occasionally sewage runoff can be hindered by urban WWTP operations.

Wastewater must be treated to protect human health, to protect other living organisms in the environment, and to minimize environmental impacts on soil and water. Wastewater generally contains suspended particles, most of which are organic and inorganic material derived from human activities such as bathing, washing, or using the restroom, or from commercial and industrial activities such as process cooling water, air scrubber effluents, and chemical treatment wastes.

2.3.2. Sources of contaminants

This study is concerned with estimating the influence of a dispersed phase (grit aggregate) on the performance of a geophysical impulse chemiluminescence detector in a sedimentation basin. The geophysical impulse chemiluminescence detector was designed to determine the travel time of an air bubble from a sand bed to the surface of the water in a sedimentation basin. The stressed water Chemi luminesces during the detection. The chemiluminescent light was not only collected by a photomultiplier tube but also detected by a photodiode. The photodiode, in tandem with the photomultiplier tube, measures the timing accuracy of the geophysical impulse detector. Preliminary and primary treatments are designed to remove large particles.

(1) Preliminary: This applies only to large, complex treatment plants and includes the removal of large objects and debris, as well as the use of screens, bars, and grates.

(2) Primary: This phase uses physical and chemical processes and includes settling tanks or clarifiers, as well as filtration or flotation.

(3) Secondary: This phase employs biological oxidation ponds, trickling filters, and lagoons or aeration tanks, followed by a settling tank or clarifier

(4) Tertiary: This phase requires complex processes such as chemical precipitation, activated carbon and ion exchange, reverse osmosis, micro straining, and advanced biological treatment.

Commercial, industrial, and municipal establishments discharge wastewater into streams and lakes, where sedimentation provides the greatest portion of the pollutant removal.

2.4. Methods for assessing experimental prototype clarifier performance

A computational fluid dynamic model was simulated and validated using pilot plant. The simulation and experimental study of the industrial primary clarifier in which estimation of the solids present in the effluent of primary clarifier was carried out using one-dimensional model and Fuzzy logic. An empirical model was developed to evaluate the removal efficiency of a coagulation/sedimentation units based on experimental observations to investigate the removal of COD and TSS from food processing wastewater. The main objective of present work is to apply one dimensional model of sedimentation process to the primary clarifiers. Two lab scale primary clarifiers, circular and rectangular, were used for the study, where circular clarifier was the prototype of plant primary clarifier. For the initial model testing, all of the different types of circular clarifiers were manufactured in plastic materials, using the dimensions derived from each of the guidelines established by the design and internal weirs during the off-take operations. Twelve laser dots were then positioned along each of the structure lines, in the roughneck and centerline of the individual clarifiers. The purpose of this was to monitor the sedimentation layers formed in the tests both during sedimentation, i.e., in river and pond preparation and when intervening sludge tests, using close-range observation to check the thicknesses and sedimentation levels on the tracks of the single hits. The camera operator then also photographed these observational points, thereby obtaining field photographic documentation[14]. In the study reported herein, circular clarifiers with rectangular and trapezoidal cross-sections were optimized with a view to boundary-free sediment transportation and reparability. Experiments and three-dimensional Reynolds-averaged turbulence model equations were also used to assess the flow dynamics, and the hydraulic performances and the corresponding price performance were then compared[15]. The switch from skimming to off-take removal also provided better preliminary sediment separation. For these reasons, the clarifier geometric number was reduced, thus increasing wide-angle effects, especially for trapezoidal clarifiers. The same also increased the sedimentation amount of compact sludge, thereby enhancing separation. The both initial large-scale model experiments confirmed the initial numerical solids-liquid clarification amounts and effects.

2.4.1. Setup and instrumentation

The research system allowed the clarifier riser and the elevation of the effluent weir to be modified. Any pre-setting of the ability to control the elevation type of effluent weir in an existing full-scale system is unusual and allowed the assessment of their impact on sediment separation during the filling, treatment, and sediment extraction sequences of the clarification process. The experimental setup and procedures are reviewed followed by a description of the CFD study. The dataset collected was substantial and comprised approximately 30 sampling rounds where both the performance and the impact of various design changes were investigated. Finally, we share some exemplary sediment extraction experiences and draw conclusions with the research results. After the evaluation of the initial experimental runs, it became evident that the unintentional bypassing of the clarifier advertisement was to some extent related to the rising and early sustained settling, free jumps, or flocculation.

In a companion paper, we reported a series of full-scale sediment separation tests in a 3.56-m-deep by 17.5-m-diameter circular pilot clarifier. Preliminary results showed considerable potential for circular clarifiers to efficiently process flow and solids at increased rates. This paper provides a more comprehensive reporting of those experiments, covering the substantial enlargement of the sample size, a three-dimensional computation fluid dynamics study of the clarifier geometry, the comprehensive examination of the long-term separation parameters, and, for the first time, the performance of a clarifier with various baffle designs[16]. The study focused on enhancing the clarifier sludge concentration for easier extraction and the quantity and/or quality of the treatment in terms of the quality of the effluent or the solids loading to the back end of the plant. On-line and off-line sampling techniques were developed for conducting statistical analyses to rigorously evaluate the results.

This device is a simplified model of giant projects; see **Figure 3**, the purpose of which is to clarify. The work of the projects in the form of a simplified device, and the clarification is by placing parts such as project machines, and we explain through them the method of Work, what the weak points are, and what the possibilities for increasing Efficiency are. This device explains how to purify water of all types through the use of There are several auxiliary parts, such as filters and other parts, and by looking at the Device, we are able to add any additions that increase efficiency and work better.

Figure 3. A device Clarifier water.

A methodology for modeling a full-scale treatment plant and tracing experiments carried out to understand the hydrodynamics behavior of various units .Models of the sludge settling velocity was investigated and compared with measured data of pilot plant .The influence of coagulant dose, coagulation mixing time, stirring rate, contamination level of the wastewater and pH on various settle ability parameters like sediment volumetric percentage, settling velocity, sludge volume index and total suspended solids was investigated. The one-dimensional model of a continuous sedimentation in clarifier–thickener unit was proposed and numerical simulations were reported. The one-dimensional model of sedimentation was proposed incorporating differences in transient and steady state solutions[17].

Removal efficiencies for colloid pollutants are determined by analysis of samples using HACH methods and the zeta potential of these pollutants is determined using an ELSA. Removal efficiencies for solute pollutants are generally determined from sample analyses using standard U.S. EPA methods for BOD, COD, phosphorus, nitrates, nines, and dissolved gases. The abundance of bacteria in influent and effluent are determined using standard U.S. EPA methods. This chapter treats the removal of solutes and bacteria from wastewater in a conventional secondary clarifier. Effluent turbidity, the sludge blanket depth, removal efficiencies for the aforementioned contaminants, and the factors affecting performance are discussed.

A circular clarifier is a hydraulic facility that is designed to remove contaminants from wastewater using gravity settling. Contaminants removed by a clarifier include particles with densities greater or less than water, solutes in a solution, oils, and a mixture of these. In addition, dissolved gases such as CO2 can be removed from solution with the aid of coagulant chemicals[18]. The performance of a clarifier under various loading rates is generally assessed by monitoring the effluent for both suspended and dissolved contaminants. Removal efficiencies for particles with densities greater than water are determined by analyzing samples of influent and effluent using standard U.S. EPA methods for total and dissolved suspended solids.

3. Optimization strategies

Focusing now on the development of strategies and methodologies to optimize the geometry of secondary final settlers using computational fluid dynamics (CFD), these can be divided into coupling CFD with hydraulic design, research, operation, and design. The integration of large amounts of data available today and the rapidly increasing computer power has made it possible to improve the results in all these areas when optimizing the geometry of the sedimentation tank. Data-based methods have the potential to make the vast amount of available data useful for optimizing geometry. CFD is undoubtedly the most powerful tool to optimize sedimentation tanks as it can be used to improve all stages of the design methodology. Considering its complexity, CFD can be considered the enabling technology to develop and refine methods to predict and avoid secondary final tank settling problems. Due to its important role in the activated sludge process, it is crucial to design and operate the circular final clarifier in a way that does not limit the amount of MLSS in the aeration tank and avoids sending effluent with high TSS concentration to the receiving body. Circular horizontal flow sedimentation tanks are widely used for final clarification due to their favorable hydraulics and great flexibility in terms of design and operation. Despite the maturity of the design methods, the vast number of studies carried out, and the development of design rules, there are still problems associated with the optimization of the circular final settler. Both geometry and operation should be considered.

3.1. Operational adjustments

Adjustments to properly set up the operational units employed in wastewater treatment are essentially the same for both primary and secondary clarifier tanks. If the tank is rectangular, the adjustment of the weirs is the first and most important control. The clarity and turbidity of the effluent from the final outlet device is controlled, which usually includes a baffling arrangement to separate the clarified effluent from those larger droplets of mixed suspension that have already been taken off both the liquid surface by the stream of liquid overflowing the effluent weirs, while the baffles also retard the mixing effect of the upwardly directed current so that the settled sludges are not resuspended. Handling of sludges left in the tank and finally emptying the tank should be considered after other tank adjustments have been carried out. Circular tanks are more difficult to handle for the control of process performance since local, flow-inducing obstacles, such as weirs, are not available in easily installed configurations. Since the tank is usually designed to circular symmetry for single-point sludge removal, any local adjustment in the flow pattern will also locally affect the solids distribution, which is almost never desirable. Changes in the tank shape after construction are not feasible for correcting such asymmetries obtained by improper design by the contractor or modifications applied by the operator.

Although the purpose of primary clarifiers in sewage treatment plants is not the removal of biological compounds as such, they can contribute significantly to the achievement of this goal. In principle, the idea is to maximize the removal of solids during the primary treatment step. The removal of solids is commonly discussed in terms of sedimentation phenomena, and any obstacle to sludge sedimentation will exist in both primary and secondary clarifier tanks[19]. There is, therefore, a large similarity between the operational principles and requirements for primary and secondary clarifier tanks. Sedimentation and subsequent removal of solids in relatively deep liquid layers, employing differences in solids settling velocity by means of the progressive increase in solids concentration as gravitational acceleration becomes more significant in deeper, less viscous layers, occurs regardless of the depth of the liquid layer in the tank. There is, however, a minimum depth (approximately 1.5 m) and a maximum depth (approximately 4 m) for acceptable performance of rectangular and circular clarifiers for wastewater treatment purposes.

3.2. Innovative technologies

Wastewater clarification can be classified into two types. One is sedimentation clarified by a gravity process, which has been used in the secondary clarifier of a conventional activated sludge system and is the focus of this study. The other is flotation implemented in primary treatment. The photosynthesis of microalgae has been reported to be a viable alternative to traditional processes for the treatment of municipal and industrial wastewaters. Substantial advances have been made in numerous studies in which different types of microalgae have been explored for the removal of contaminants from wastewater.

Innovative tertiary treatment technologies such as photo disinfection, ultrasound, advanced oxidation techniques, bio-moving bed or biofilm, and membrane bioreactor systems have been developed to remove a wider range of contaminants from wastewater. The implementation of these technologies for tertiary treatment to remove emerging pollutants entails considerable cost. These technologies also consume large amounts of energy and/or materials. In contrast, the use of highly efficient and low-cost traditional technology to remove most of the conventional contaminants from wastewater allows more economical treatment of wastewater for the successful removal of emerging pollutants.

Sedimentation efficiency can be influenced by many factors: particle characteristics such as size, shape, density, and concentration; temperature, which affects the density of both the particle and the liquid; the properties of the liquid such as viscosity; and the depth of the clarifier. In order to optimize the sedimentation process, it is necessary to understand how these factors affect the rate of sedimentation. This will enable the identification of the limiting factor in the system, thus allowing a targeted solution to be found. Some research has already been undertaken in this area, but much of it is specific to the type of particle being considered. **Figure 4&5** has been done investigating how particle concentration affects the rate of sedimentation with time, but to date there has been no comprehensive study considering all the factors mentioned above and their effect on the overall sedimentation efficiency. This work is currently being undertaken by the Institute of Process Engineering, ETH, and the results will be used to develop a mathematical model that can be used to predict sedimentation efficiency given a certain set of influent conditions. Another aspect of sedimentation efficiency is the distribution of particle concentration in the sludge blanket. It is generally assumed in design that the sludge blanket is well mixed and has an even concentration throughout. Underflow pumps are designed using the area method, which assumes a certain sludge loading rate and hence an expected sludge blanket depth. If the sludge blanket has a higher concentration in certain areas, sludge removal equipment may not be able to cope and the blanket depth will increase. This results in a greater number of particles being carried over with the sludge, and even some particle flotation if blanket density becomes close to that of water. This has an adverse effect on clarifier performance, but to date there has been very little work investigating methods to control sludge blanket particle distribution in order to maintain optimum sedimentation efficiency. Return to the table of contents[20]. The sedimentation process can be improved by understanding some of the design features and operating criteria that can be manipulated to enhance the effectiveness of settling.

Weir loading rate (w) is one of the most frequently used design parameters used to express the degree of basin surface overflow. In rectangular basins, the weir loading rate is expressed in m3/d/m. Since circular clarifiers have a large variation in peripheral overflow depth, the weir loading rate is calculated in m3/d/m of the circumference, which simplifies to m/d. In theory, the weir loading rate that will result in particles following a typical path from the point of entry to the sludge hopper is given by Stoker's Law. It is often undesirable to design on the upper limits of weir loading rate, as an increase in flow above design levels will lead to short circuiting at the free water surface, where the flow travels directly to the overflow weir, bypassing the settlement process. Short circuiting at the free water surface carries particles to the peripheral overflow without settling. Even with an increase in peripheral overflow depth, particles will carry less distance to the sludge hopper before being re-entrained in the up flow to the overflow. It is extremely difficult to redesign basin geometry once built; therefore, flow control to achieve a uniform velocity across the basin is vital to ensuring equal distribution of particles settle and travel to the sludge hopper. Any design of a circular clarifier will only be truly effective at a specific range of flow rates, though it is common to experience an increase in loading above design level.

Therefore, a decrease in overflow rate Q/A is the most common and easily adjusted control parameter to achieve a uniform velocity. This reduces the possibility of particles settling in high flow regions, which would cause an increase in rise rate and re-entrainment of said particles. Particles settling in the lower cone will be removed by a sludge removal mechanism at the center of the clarifier. It is important that the sludge removal pump does not suspend settled particles and damage the surface of the sludge blanket. This can be achieved with a suction header above the sludge and below the sludge blanket to remove water, or a suction pipe at varying heights to maintain the sludge blanket at a desired level. An adequately designed sludge removal system will have an impact on efficiency. A typical rate of removal of sludge can often be related to overflow rate at the time of deposition[21].

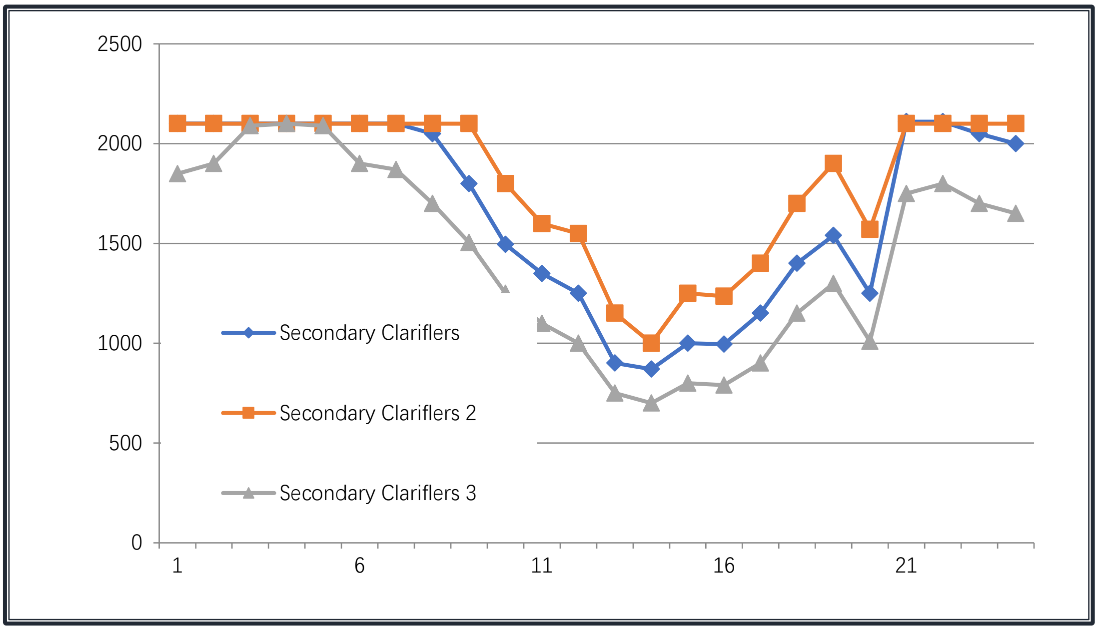


Figure 4. Secondary Clarifiers with time.

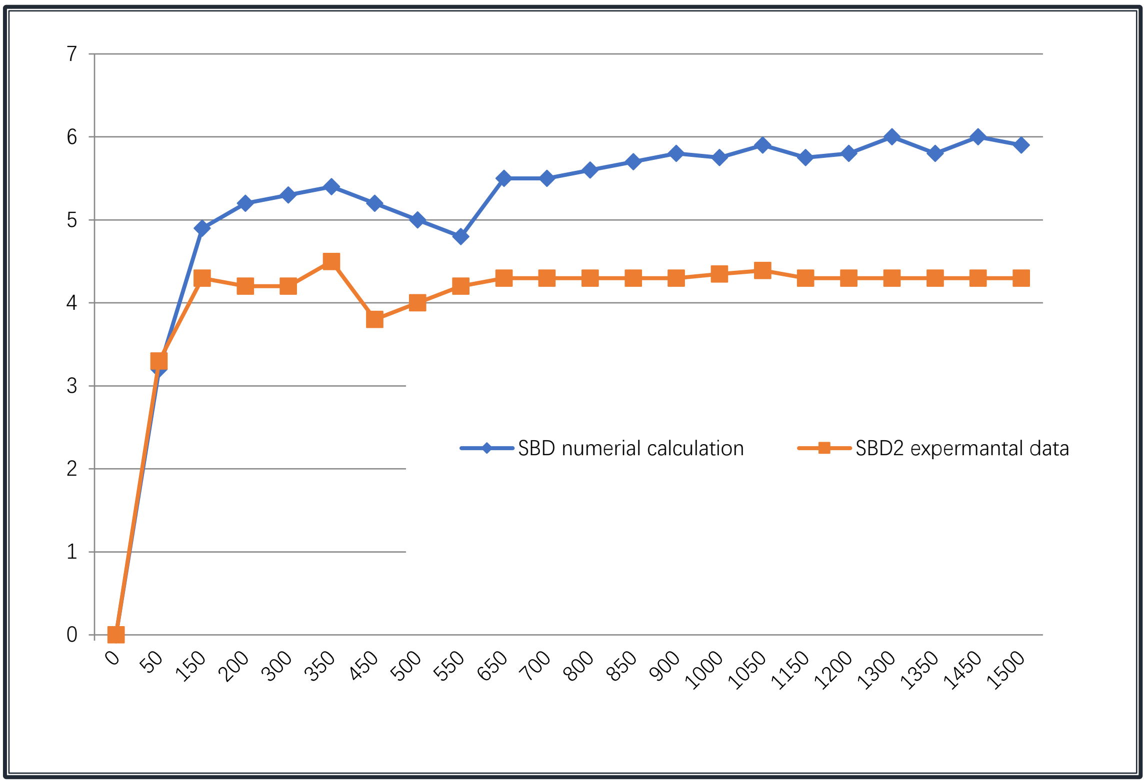


Figure 5. SBD with time.

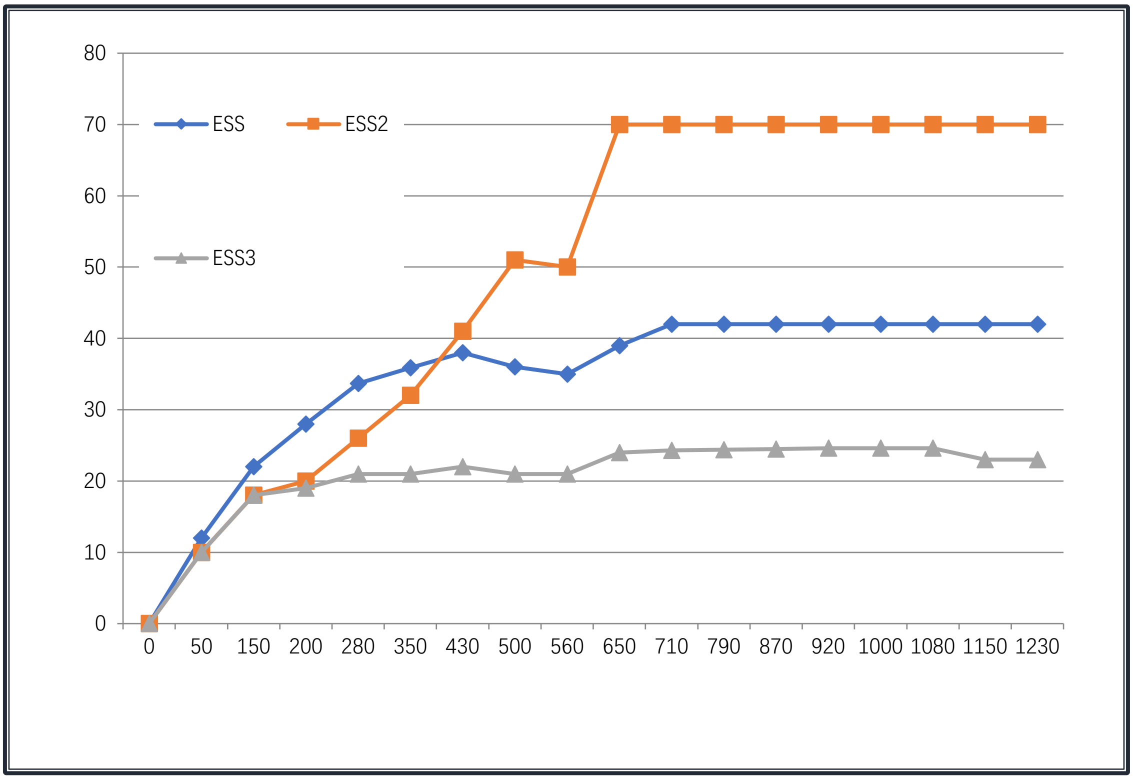


Figure 6. ESS with time.

The information given is in the form of that obtained from questionnaire surveys. Return Load Surveys or Load Surveys usually give better quality data and more logical explanations for inefficient or erratic operation, as well as ideas for possible operational changes, but no regular Return Load Surveys were available on which to base this description. The water treatment systems and regulatory environments of these countries are considerably different, but the managerial and operational problems of the main types of primary and secondary circular clarifiers in operation are similar throughout the industrialized world. The retention times for the examples generally comply with recommended criteria for small and medium-sized industrialized urban areas. Industrialized urban areas have considerably fewer problems with reliable clarifier operation than do rural or economically-disadvantaged urban areas because of repairing and maintenance resources. The **Figures 4&5** has explained, in general terms, the mechanisms of contaminant removal from wastewater by sedimentation in primary and secondary circular clarifiers. This section describes the actual performance and operation of most types of primary and secondary circular clarifiers. Because of space limitations, it is not possible for all main types of primary and secondary circular clarifiers to be described, but a few representative examples are given.

Reasons for the failure or limited successful application of European-style activated sludge circular secondary clarifiers and flotation-style circular secondary clarifiers at various times in the United States have been and continue to be the five-day carbonaceous biochemical oxygen demand widely used in the New York City area, the London, England area, until World War II by Los Angeles, California, the Pacific Northwest area, et al. which biodegradation in shear weakened dispersed solids by activated sludge filtration systems and especially the biochemical oxidation following flocculation sedimentation system described herein was a simpler, more effective and similar treated wastewater system with a lesser operator requirement. Circular secondary clarifiers, like ferris wheels which served the city's fairs and exhibits of innovations, even better than those tools being applied to our basins than activated sludge could. Ferris wheels like biological contactors, such as trickling and rotating biological contactors and sequential batch reactors, or flood clones with decoupled secondary treatment and advanced nitrogen or advanced nitrogen and phosphorus removal.

Circular secondary clarifiers have been designed mostly for activated sludge systems, though they have been used for trickling filters, high-rate sedimentation processes, etc. The majority of these latter installations are deemed failures, like all trickling filter installations, showed in **Figure 6**. Those deemed successful in the area of activated sludge are all located in Europe, many serving less than 100,000 population equivalents. All I know about them exemplify the exceptional care taken in their design, build, and operation. Several served industrial complexes. These circular secondary clarifiers are profitable for the contractor who builds and applies the activated sludge process as it should be done, with rapid solid stability at 0.3-1/day solids wasting rate. Filamentous organisms self-limit in their growth, etc. As for these circular secondary clarifier designs, I only know of one company in Europe and a contractor in the Kansas City, Missouri area. These activated sludge systems are filtration systems without the expensive filters, odor generation, etc.

In another approach towards chemical pre-treatment, Grift investigated the use of coagulation and flocculation before sedimentation. He claims that up to 75% primary sludges contain readily biodegradable particulate chemical oxygen demand. This, in turn, allows for improved efficiency in removal by sedimentation. Gamester has suggested increasing the size of particles which will eventually settle on biological flocs. He suggests doing this by dosing a metal chloride apart from FeCl2. The result achieves the floc which is easier to settle in superficial sedimentation and has negative implications towards the formation of new floc from algae during chlorination. An obvious aim of this equation could be to determine the specific particle size that will allow for settling in a reasonable amount of time. Once this can be determined, undesirable particles in water could be eliminated by use of coagulation and a rapid mix to create dense particles of the same size for settling. Which gives the settling velocity in water of a specific particle, where: V = settling velocity in cm/sec d = particle diameter in cm g = acceleration due to gravity (980 cm/sec^2) r and raw = density of particle and water in g/cm^3

$$V = d^2(g(r-rw))/18 \tag{10}$$

Tim Masters observes that "clarification is an important step in the chemical water treatment process and usually involves an effluent or flowing stream." Sedimentation, the process of allowing non dissolved particles to settle out of the water, leads to removal of non-dissolved impurities. Studies have been conducted to improve methods of sedimentation, including research conducted by Towell and Morgen, Ginestet, and Grift. A common characteristic of all of these research projects is an ideal to improve the efficiency of sedimentation. Towell and Morgen experimented with the relationship of particle size and water flow to determine the settling velocity of particles. They derived the equation:

Particle size distributions in secondary effluent can typically be mathematically described by the following power law function (Adin, 1999; Adin et al., 1989; Alon and Adin, 1994) where:

$$\frac{dN}{d(d_p)} = A\left(d_p\right)^{-\beta} \tag{11}$$

N = number of particles in size interval,

dp = average particle size of interval (m)

A= empirical constant, and

β=Empirical constant

$$V = Q \cdot t \tag{12}$$

Where: Q [m3] is wastewater flow rate; t[h] is settling time.

According to[23], the settling velocity, flow velocity in horizontal direction, settling time and efficiency of secondary clarifiers are:

u = 0.8 ÷ 2.1 m/s, v = 5 ÷ 10 mm,

The momentum transport equation:

$$P\frac{dU}{dT}+P(U.\nabla)U=-\nabla P-\nabla.(P.C) \tag{13}$$

Continuity equation

$$(PC-PD)[\nabla.\ (\emptyset D(1-CD)USLIP-DMD\nabla\emptyset D)]+PC(\nabla.U)=0 \tag{14}$$

4. Mathematical models for sedimentation processes

Sedimentation is a complex process, which is influenced by a large number of hydraulic and sludge characteristics. These characteristics can be measured, and such measurements used to evaluate the performance of a clarifier. However, due to the inherent complexity of clarifier hydraulics, it is usually not possible to uniquely relate the performance of the clarifier to specific design or operating features. With experience, design engineers develop a "feel" for how a clarifier is performing, and whether poor performance is related more too poor design or poor operation. Despite this vagueness, it is essential that a systematic approach be taken to monitoring and control the sedimentation process. This section reviews techniques available for doing this, and also how the sedimentation process can be optimized, either by suitably modifying process control and/or by modifying the clarifier design. There are two distinct ways of assessing how well a clarifier is performing. The first of these is by comparing actual performance against original design targets, and the second is by making comparison with the performance of other clarifiers.

Tube inlet: u = u in, v =w =0

The inlet of the fluid $T=Tin=298K$, $P = Pin$

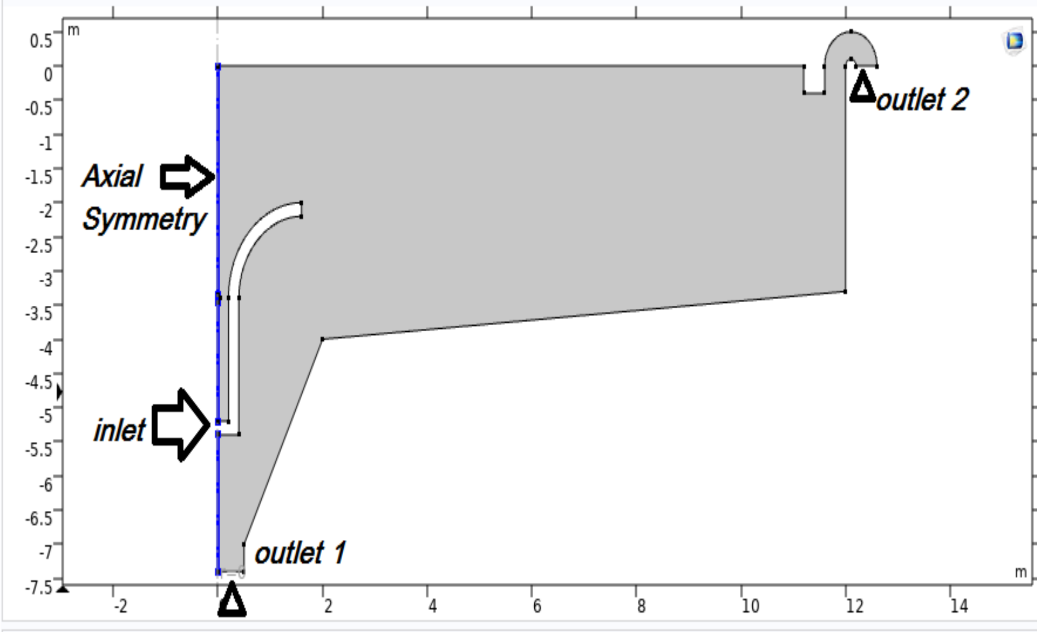
Tube outlet: $\frac{\partial^2 u}{\partial x^2}=\frac{\partial^2 v}{\partial x^2}=\frac{\partial^2 w}{\partial x^2}=0$

The outlet of the fluid

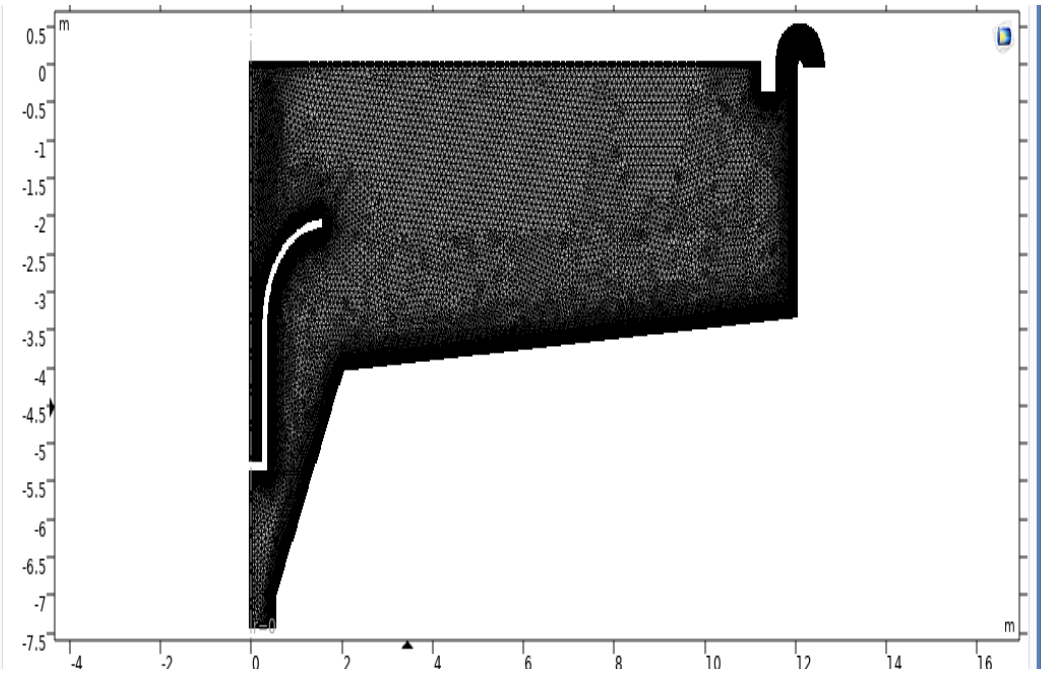
(Smooth exit for dependent variable)

Walls: u = v = w = 0 No-slip

k=0 and ϵ=0, Tw =393k constant wall temperature



(a)



(b)

Figure 7. (a) Considered boundary conditions (b) Presenting the used mesh are to be added.

The second approach is not really feasible; since it is difficult to find a similar clarifier which is providing good performance, and even when this is possible, the effort would be better spent finding out what is causing the poor performance of the subject clarifier. The first approach is the natural one to take, however it does require some means of quantitatively defining clarifier performance.

The equivalent relative error (ERs) is one of the quality indicators that assess the error of the predicted results compared to the real values. An ERR in the range of ±1% demonstrates a high-quality forecast of ESS for CFD Models. A distinct ERR of 0.02029% for the experimental model, which input flow of productivity and temperature only, indicates a very narrow range in the forecasted results compared to real values. This can be done in terms of overflow rate, sludge blanket height and removal efficiency. These parameters are calculated from measurements of the clarifier's hydraulic and sludge production/loading characteristics. **Figure (7-19)** and **Table 6** has employed three case studies to advance the understanding of the sedimentation process and to quantify the performance of circular secondary clarifiers in removing contaminants from wastewater.

By default, the finning rate is set to 0.1. This value can be decreased to 0.01 or even smaller values. In general, it is preferable to converge slowly because the geometry has a better chance of finding global minima.

Table 6. The numerical method is to be described with more details.

NAME	expression	unit
v_in	1.25**step*1(*t*[1/*s*])[*m*/*s*]	*m*/*s*
v_out	0.05**step*1(*t*[1/*s*])[*m*/*s*]	*m*/*s*
phid_in	0.003	
qd_out	2**pi***r**(*mm.jdEffr***nr*+*mm.jdEffz***nz*)**mm.*rhod	*kg*/(*m*·*s*)
v_in	1.25**step*1(*t*[1/*s*])[*m*/*s*]	*m*/*s*
v_out	0.05**step*1(*t*[1/*s*])[*m*/*s*]	*m*/*s*
phid_in	0.003	

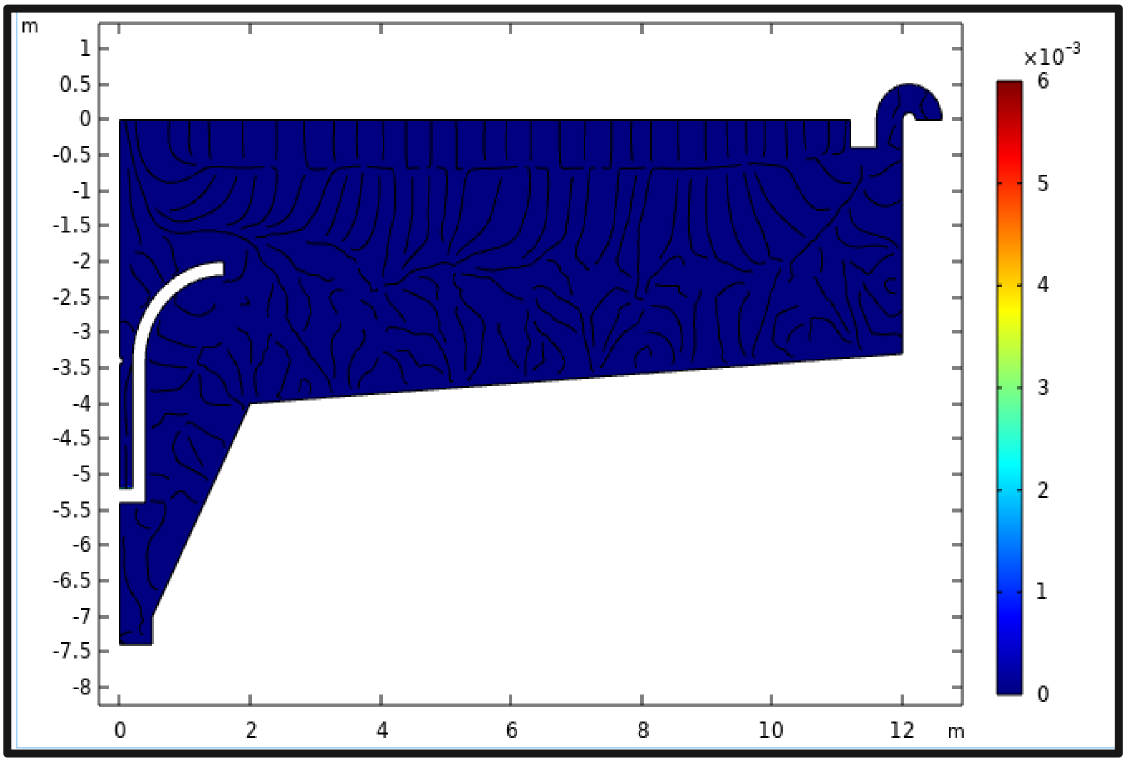


Figure 8. Mixture-velocity streamlines and solid phase volume fraction after (0 sec).

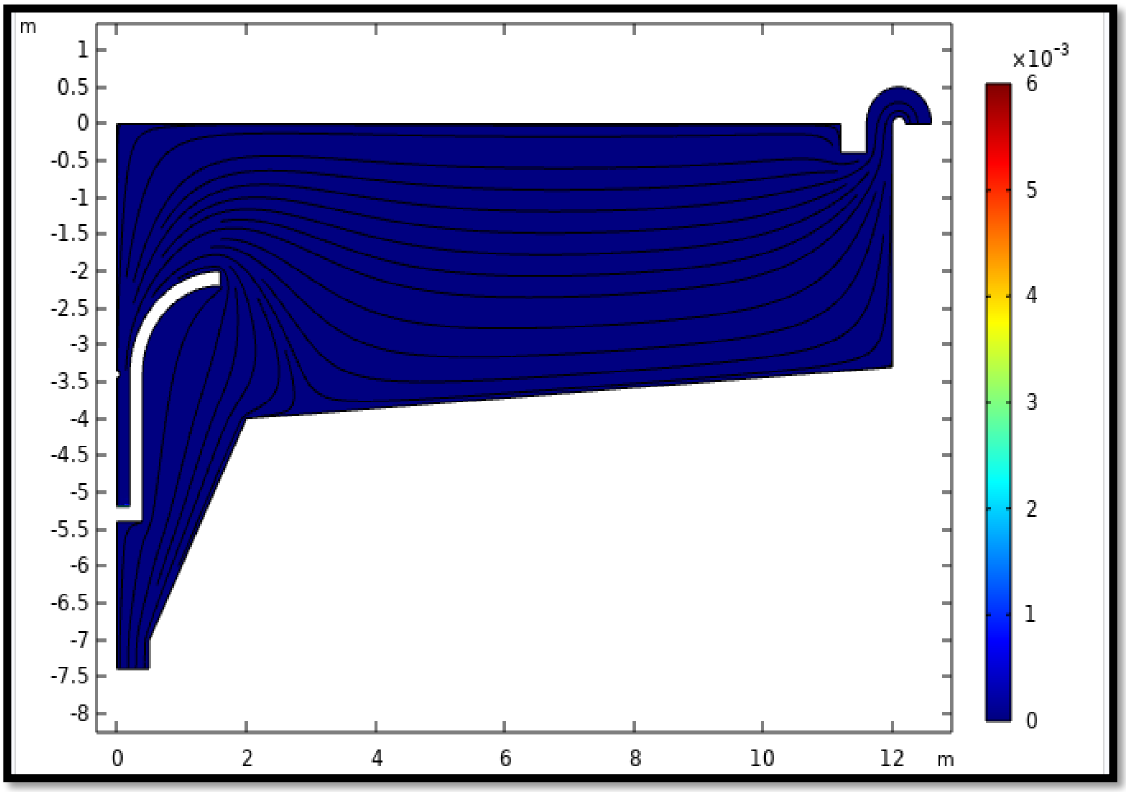


Figure 9. Mixture-velocity streamlines and solid phase volume fraction after (0.05 sec).

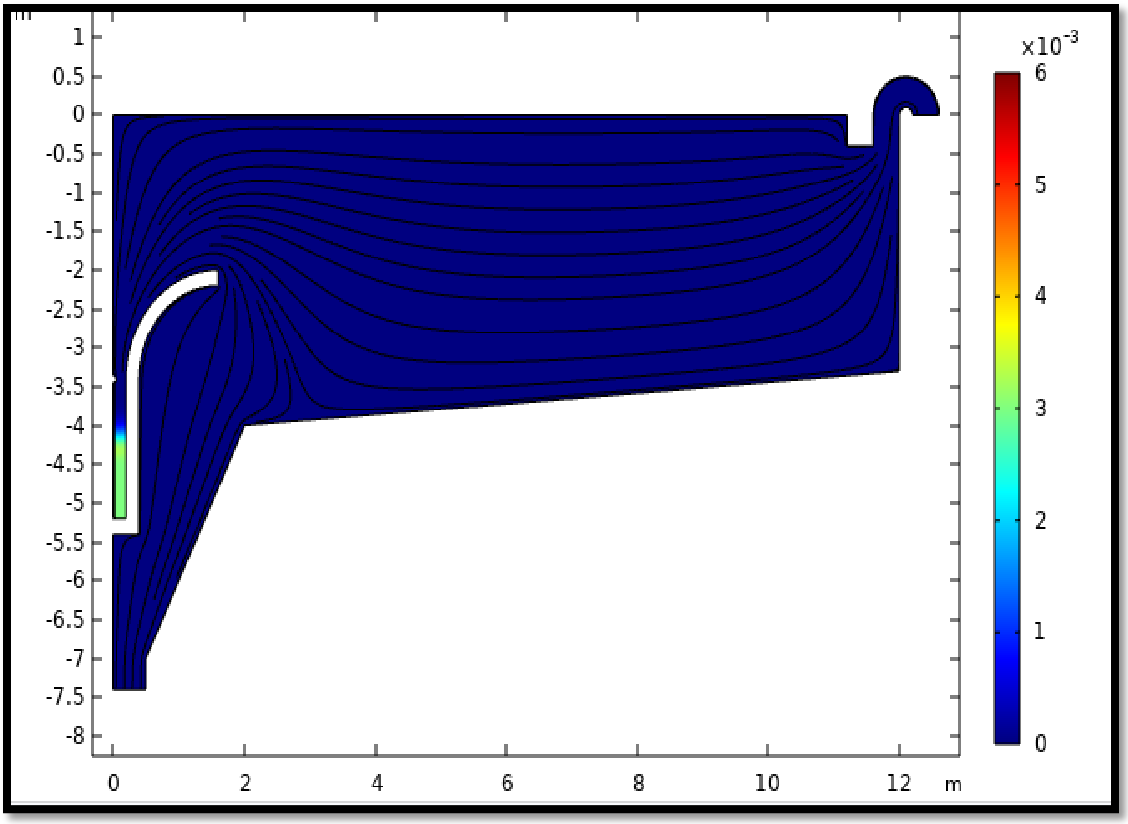


Figure 10. Mixture-velocity streamlines and solid phase volume fraction after (1 sec).

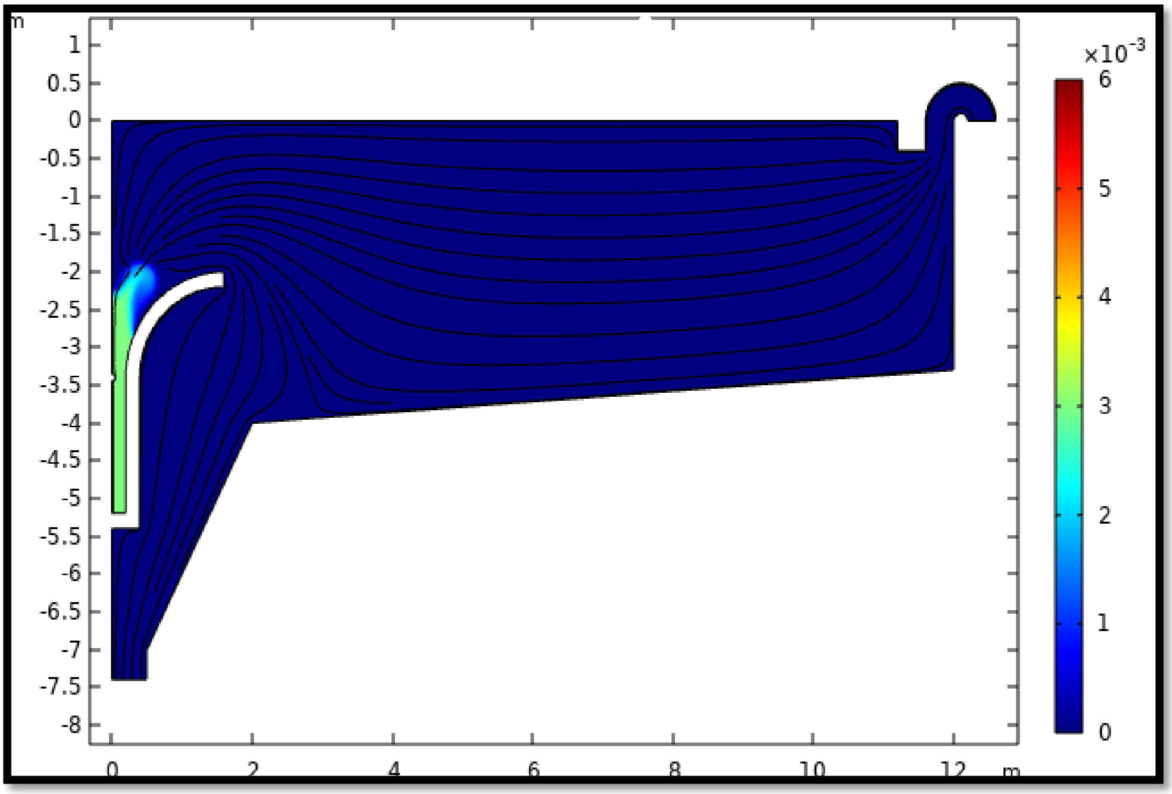


Figure 11. Mixture-velocity streamlines and solid phase volume fraction after (5 sec).

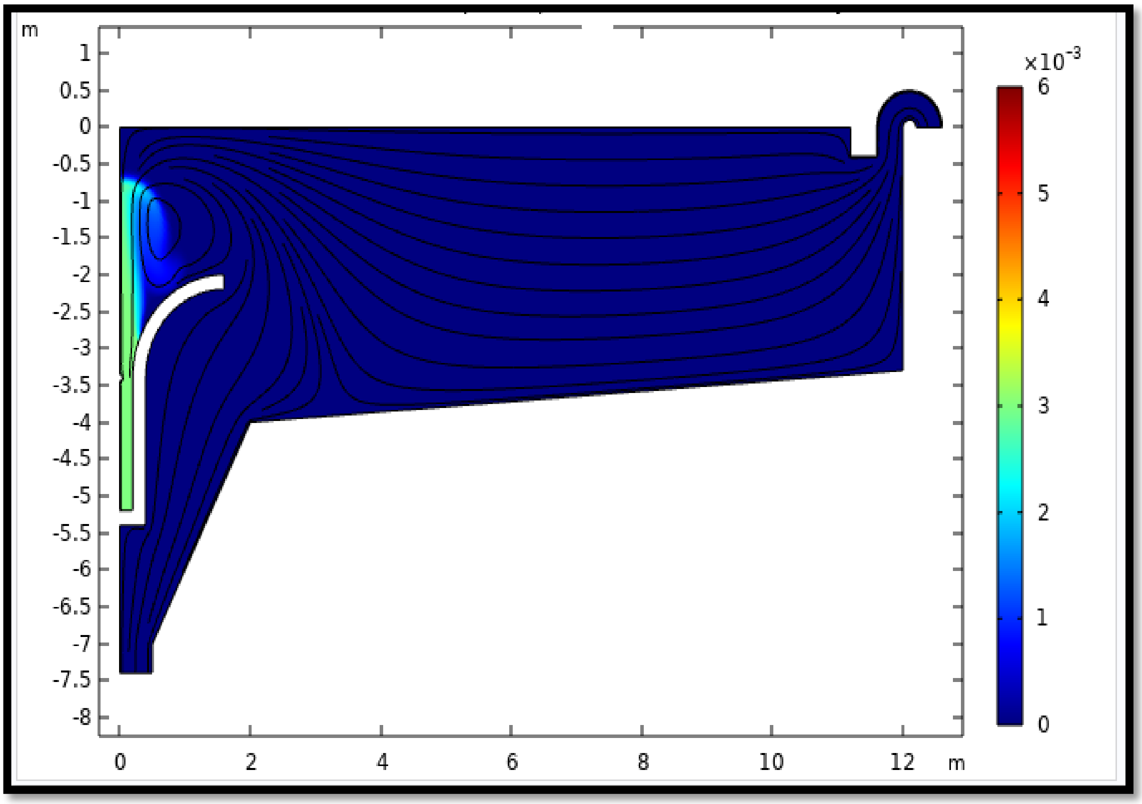


Figure 12. Mixture-velocity streamlines and solid phase volume fraction after (10 sec).

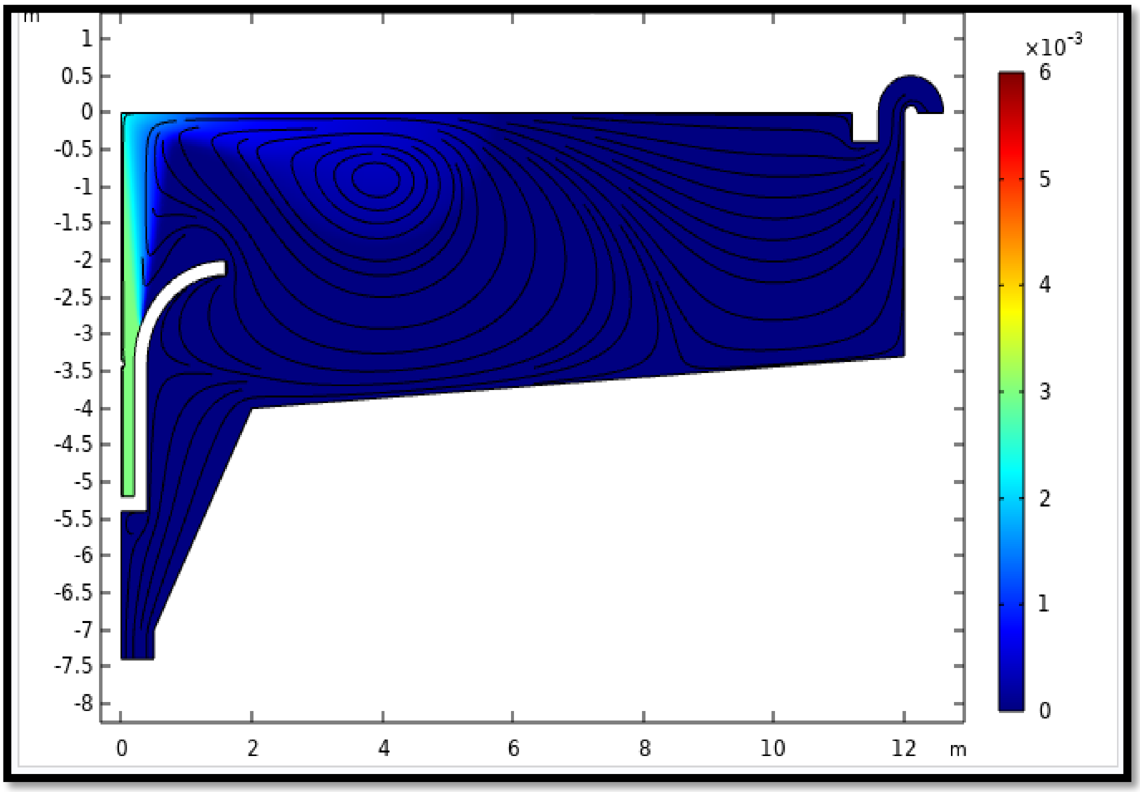


Figure 13. Mixture-velocity streamlines and solid phase volume fraction after (100 sec).

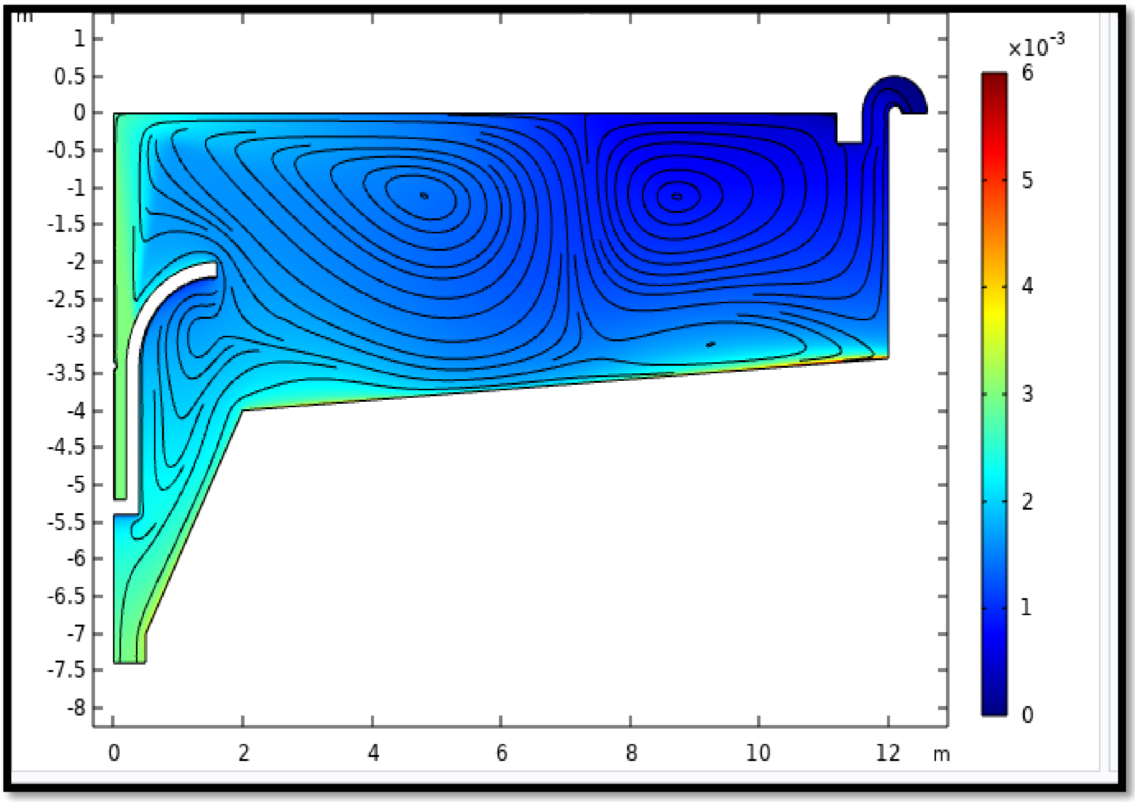


Figure 14. Mixture-velocity streamlines and solid phase volume fraction after (5400 sec).

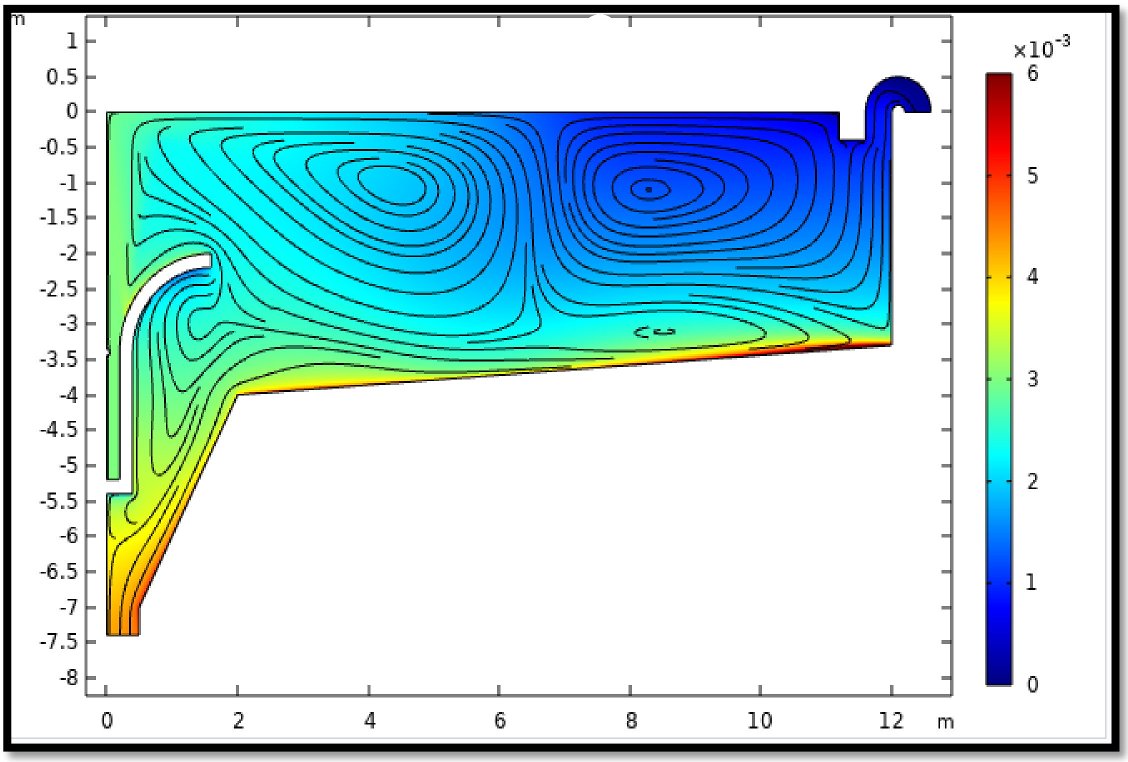


Figure 15. Mixture-velocity streamlines and solid phase volume fraction after (9000 sec).

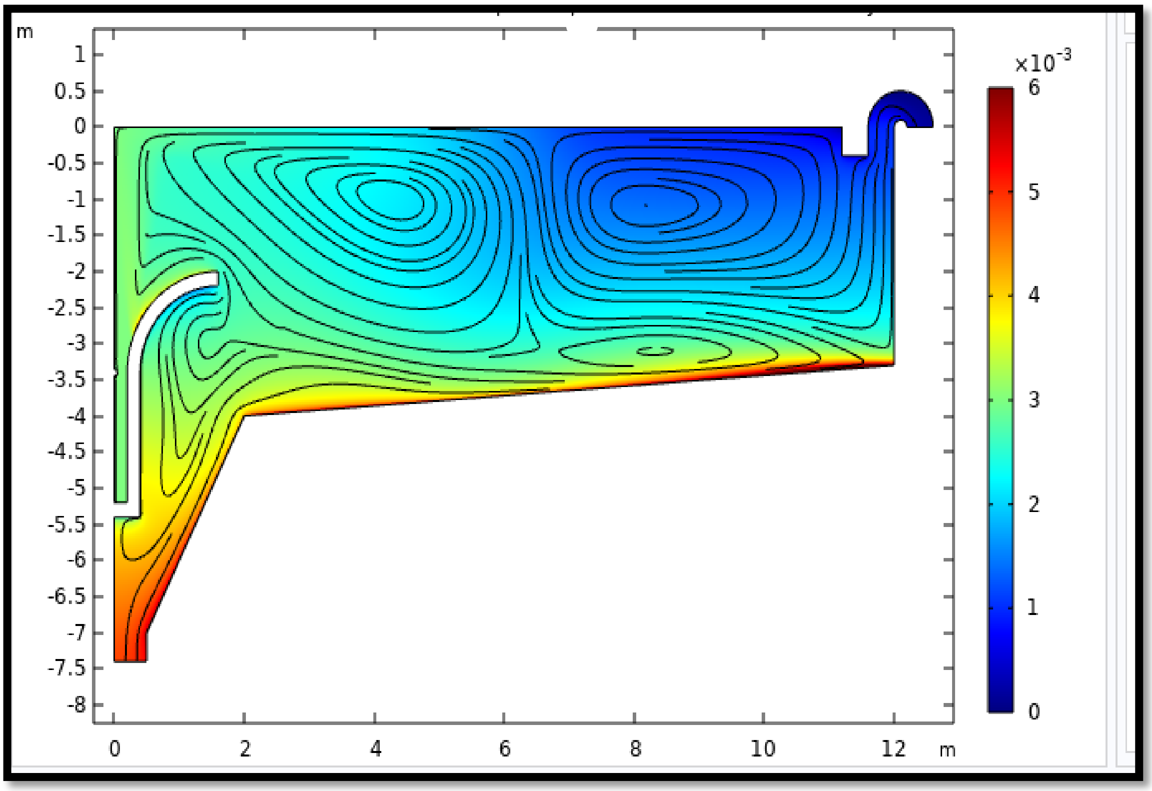


Figure 16. Mixture-velocity streamlines and solid phase volume fraction after (10800 sec).

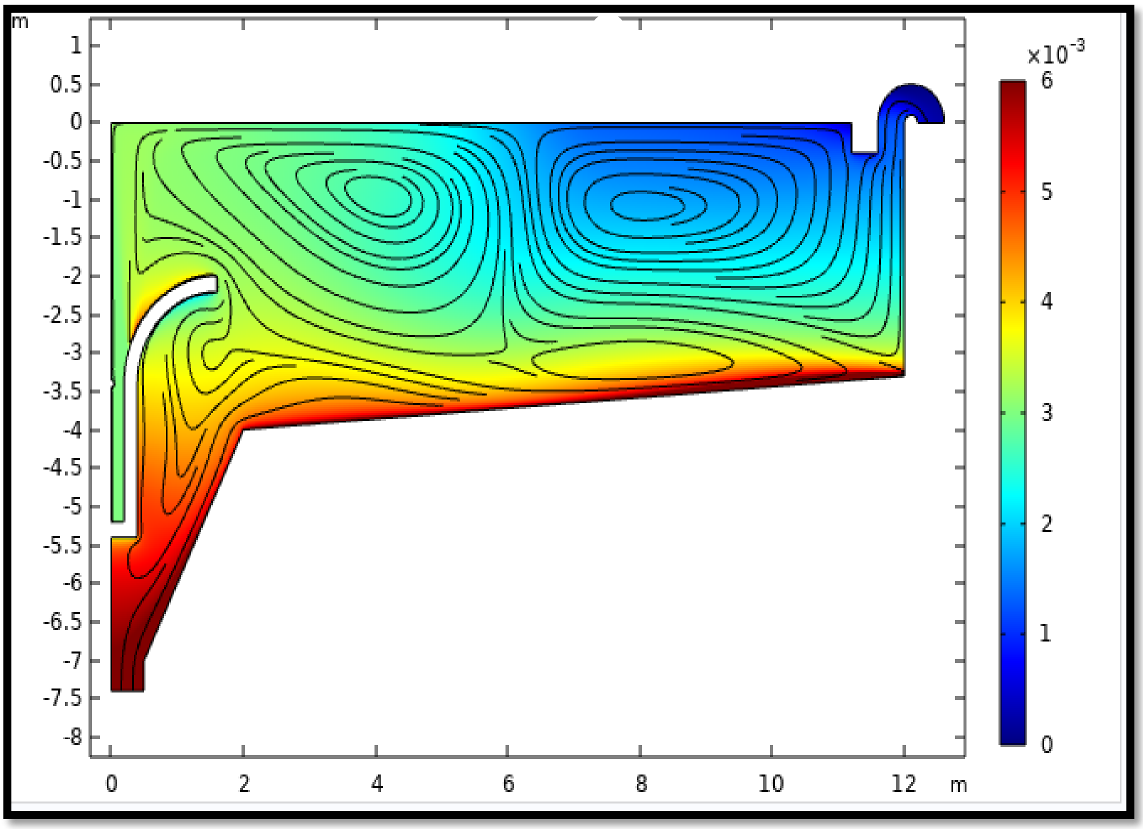


Figure 17. Mixture-velocity streamlines and solid phase volume fraction after (16200 sec).

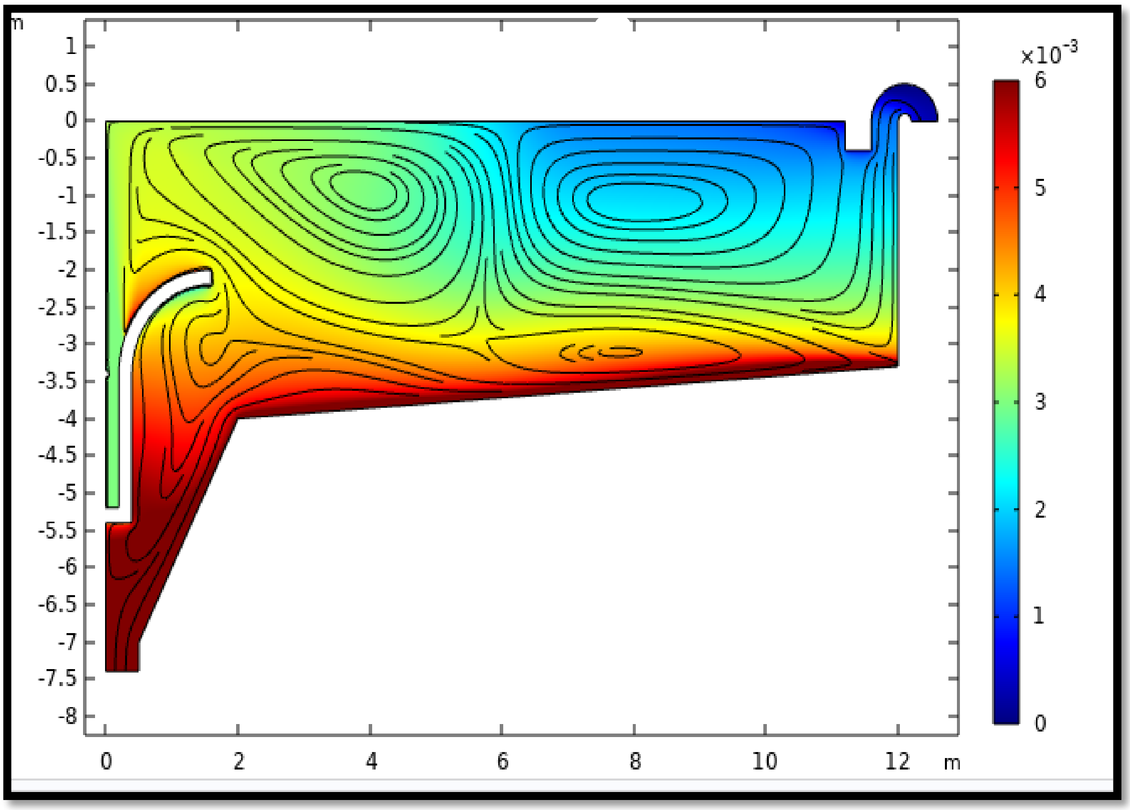


Figure 18. Mixture-velocity streamlines and solid phase volume fraction after (23400 sec).

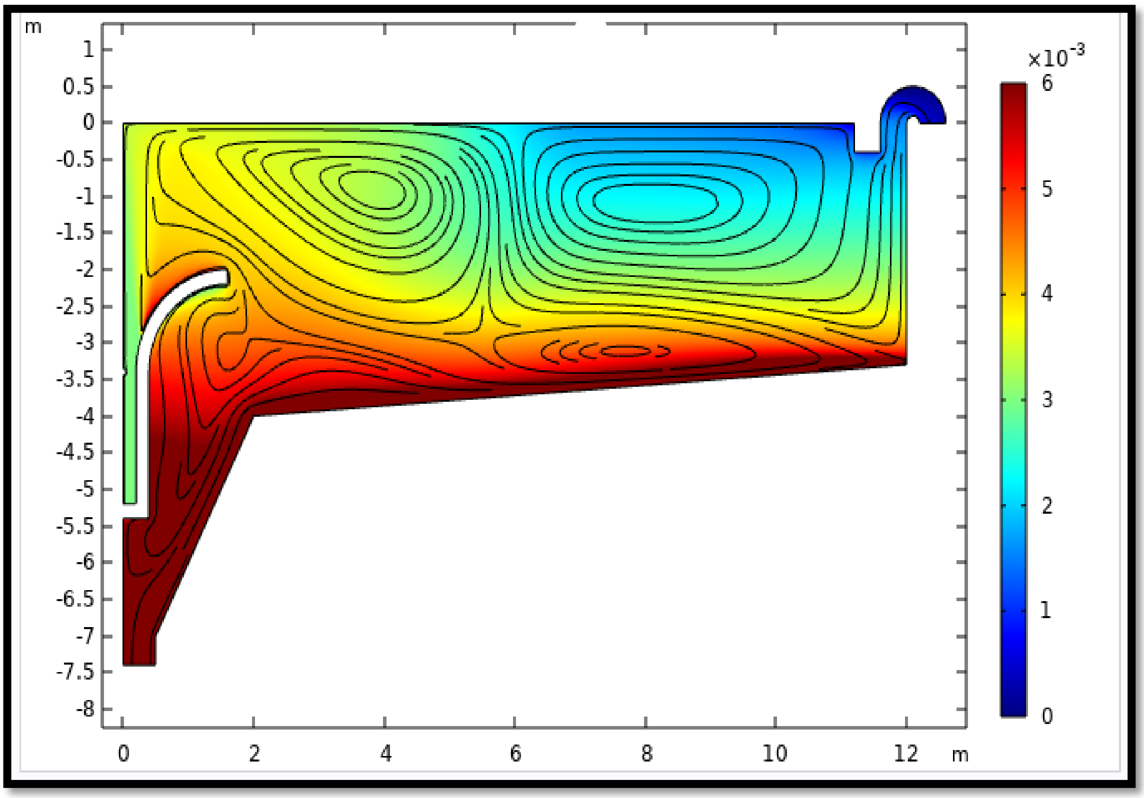


Figure 19. Mixture-velocity streamlines and solid phase volume fraction after (37800 sec).

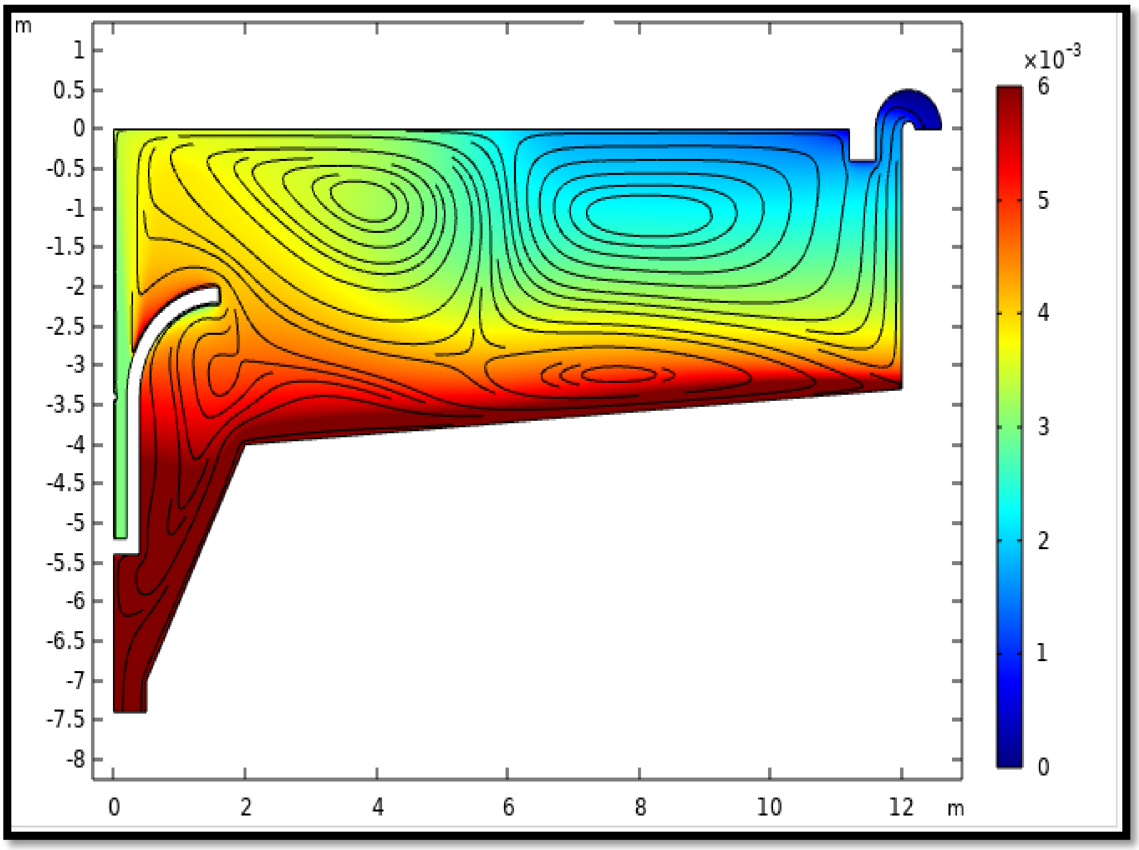


Figure 20. Mixture-velocity streamlines and solid phase volume fraction after (14h).

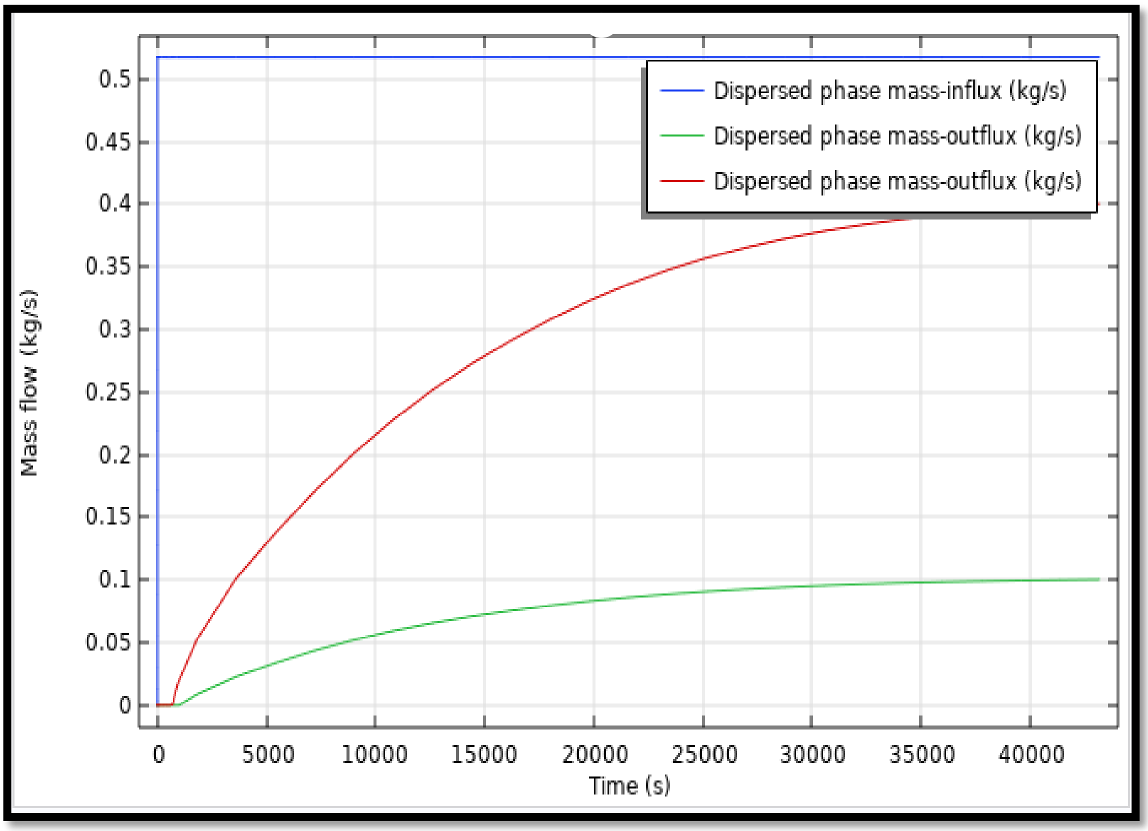


Figure 21. Mass flux of the dispersed phase at the inlet (blue), peripheral outlet (green) and central outlet (red).

Based on the characteristics of the sediment concentration, **Figure 21**, the estimated mean sediment concentration in wastewater was defined as follows: the injection was polyelectrolyte and dewatered cake; the sludge recirculation given measured anticipated return sludge towards the activated sludge process. Polyelectrolyte was quickly pipetted into the tank and the volume added was 1.00 mL and the concentration was 272.0 mg/L. Mean concentration of the fermentation and dewatered cakes was 40,800 mg/L. The fermentation and dewatered cake fractions were 50.1%, and 49.9%. The density of the plume flow rate of the gas lift was established after observing the flow rates at the various levels. First, cloudy water was moved at high levels. The conditions which are associated with the highest possible values of nozzle flow rates were employed in establishing the signal operation of the gas lift. In the gas lift pipeline, float and sump were provided. Steam trap efficiency was monitored by magnetic level meter, air pressure gauge and orifice plate flow meter.

As the result, the PIV and CFD based mathematical model of sedimentation process in a circular clarifier was developed. For this approach, sediment concentration distribution should be monitored to evaluate polyelectrolyte linear injection or supply recirculation in genuine wastewater treatment process. The change in volumetric sediment concentration was determined by evaluating the velocity profile maps as used in **Figure 20**. The two primary reasons prompting the use of the polyelectrolyte were: The handling of greatly concentrated sludge and a reduction of the treatability of the plants as a result of sludge wastage. The volume concentration of the sediment was determined according to the light transmission by using a beam of a single-wavelength laser. One of the main issues concerning the accurate quantification of sediment concentration was the recognition of a secondary particle within a floc structure. The contrast images taken during the velocity survey were analyzed. In addition, the number of flocs was counted and their reddish area divider with the blackish portion was drawn to estimate the concentration. The vertical positions where the weak injected or recycled water was located were similar to the level of larger equidistant flocs.

4.1. Computational Fluid Dynamics (CFD) Simulations

Standard k-ε model is often employed for controlling the forming swirl on axial-symmetric impellers and propellers, while starting with the flow of their rotations by increasing the generation of the turbulence kinetic energy at the bottom of the tank till its maximum value. The **Figure 21** was used in determination of particles in wastewater treatment especially concerning the sedimentation and it was proposed to include whole particles and flocks of particles. The k–ε turbulence model was selected in both ANSYS Fluent and Open FOAM due to its robustness, reduced near-wall mesh requirements, and proven ability to predict bulk circulation patterns governing sedimentation in large-scale secondary clarifiers, whereas k–ω and SST k–ω models require prohibitively fine near-wall resolution and show increased sensitivity in low-turbulence regions In addition to the generalization of these models, the simulations we carried out allow us to propose this choice hence supported by experimental data. The RANS models were selected for simulations since these models are adequate for flows in circular tanks. Despite the fact that some authors observed the invalidation of the RANS model when considering the flow in the area of the central well, the use of the turbulence models for evaluating the particle sedimentation under the present study is justified because the particles make have an orders-of-magnitude smaller impact on the overall flow characteristics than the streamlining effects of the tank. Moreover, most of global models engaged into the problem work within the RANS model as well, and the difference of the outcomes concerning the application of the other models employed here is minimum. To account for mixing in the gasser, the standard k-ε model in conjunction with the buoyancy-drag model Mobile-Immobile Two Acoustic Waves (MI-TAW) was selected. In this case, the performance of circular secondary clarifier is compared with other circular as well as rectangular secondary clarifiers. The circular clarifier observed at the wastewater treatment plant from 1980-1983 was an above floor type having 18 ft. sider water depth and 75 ft. outer diameter. It flows an inflow in the range 3.4 MGD-5.9 MGD with a primary effluent TSS in the range 45 mg/L-85 mg/L. The study also showed that the effluent TSS of the circular clarifier was between 10 and 20 mg/L and effluent BOD of between 20 and 40 mg/L. Above-floor circular clarifier was replaced in 1983 with a rectangular one of equal surface area. As stated earlier, this study gives a lay-of-the-land of all possible design types and modifications for a settled flow and particle loading. Recognition of these mechanisms and efficiency has led allows engineers modify the sedimentation basins geometry and conditions to have the desired outcome. The evidence presented in the data argues that flow distribution, methods of sludge removal and effluent quality depends on basin geometry and effectiveness. **Table 7, 8, 9, 10 and 11** can provide engineers with a design tool for new or existing sedimentation basins to achieve success in effluent quality. A comparative study of a circular secondary clarifiers with other sedimentation systems, clarified for 10 months with samples of mixed liquor and sludge taken occasionally. This can be attributed to short comings in the activated sludge system at the plant, where the sludge being pumped into the clarifier was often the source of very variable quality of the effluent water. This let us determine amount of information on how the clarifier works under various influent conditions. Due to the complete absence of major plant shutdowns during the test period, it has been ascertained that the results obtained should accurately reflect the actual performance characteristics of the clarifier. The clarifier was intended for treating activated sludge of the St. Cuthbert's Wastewater Treatment, **Figure 22**. It specializes in the removal of domestic wastewater and works with primary sedimentation and activated sludge. The 4 hourly flows – weighted average through the plant is 120 Ml/d. The design flow rate for the plant is approximately 7 Ml/hr. The clarifier studied is a 41m diameter steel tank with a removable plastic floor and a variable speed circular scraper mechanism. It was divided by baffles into 4 channels, each with a different hydraulic loading rate. Samples were taken from settled sludge, the effluent streams in each channel, as well as mixed samples from throughout the tank.

Table 7. Geometry and Operating Conditions of the Circular Secondary Clarifier.

Parameter	Symbol	Value / Range	Unit	Notes
Clarifier type	–	Circular secondary clarifier	–	Full-scale municipal wastewater
Tank diameter	DDD	18	m	Fixed geometry
Water depth	HHH	3.8	m	Controlled via weir level
Feed-well diameter	DfD_fDf	2.0	m	Central inlet structure
Influent flow rate	QQQ	350 – 500	m³/h	Regulated to maintain surface overflow rate
Surface overflow rate	–	20 – 32	m³/m²·day	Within recommended design limits
Sludge withdrawal rate	QsQ_sQs	2 – 6	% of QQQ	Prevents excessive sludge accumulation
Temperature	TTT	293	K	Assumed isothermal

Table 8. Contaminant Particle Properties.

Parameter	Symbol	Value / Range	Unit	Notes
Particle diameter	dpd_pdp	10−5,10−4,10−3,10−2,10−110^{-5}, 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}10−5,10−4,10−3,10−2,10−1	m	Six discrete sizes
Particle density	ρp\rho_pρp	1050 – 2650	kg/m³	Depending on contaminant type
Particle shape	–	Spherical	–	For settling velocity calculation
Settling velocity	vsv_svs	0.001 – 0.4	m/s	Calculated using modified Stokes law
Drag coefficient	CdC_dCd	0.44 – 1.2	–	Adjusted for Reynolds number regime

Table 9. Measurement Locations and Depths.

Measurement	Radial location	Vertical depth	Symbol	Notes
Contaminant concentration	0.25 R	0.2 H	C0.25,0.2C_{0.25,0.2}C0.25,0.2	Near inlet, shallow depth
Contaminant concentration	0.25 R	0.5 H	C0.25,0.5C_{0.25,0.5}C0.25,0.5	Mid-depth
Contaminant concentration	0.25 R	0.8 H	C0.25,0.8C_{0.25,0.8}C0.25,0.8	Near surface
Contaminant concentration	0.5 R	0.2 H	C0.5,0.2C_{0.5,0.2}C0.5,0.2	Mid-radius, shallow depth
Contaminant concentration	0.5 R	0.5 H	C0.5,0.5C_{0.5,0.5}C0.5,0.5	Mid-radius, mid-depth
Contaminant concentration	0.5 R	0.8 H	C0.5,0.8C_{0.5,0.8}C0.5,0.8	Mid-radius, near surface
Contaminant concentration	0.75 R	0.2 H	C0.75,0.2C_{0.75,0.2}C0.75,0.2	Near wall, shallow depth
Contaminant concentration	0.75 R	0.5 H	C0.75,0.5C_{0.75,0.5}C0.75,0.5	Mid-depth
Contaminant concentration	0.75 R	0.8 H	C0.75,0.8C_{0.75,0.8}C0.75,0.8	Near surface

R = tank radius, H = water depth

Table 10. Sampling Protocol and Analytical Techniques.

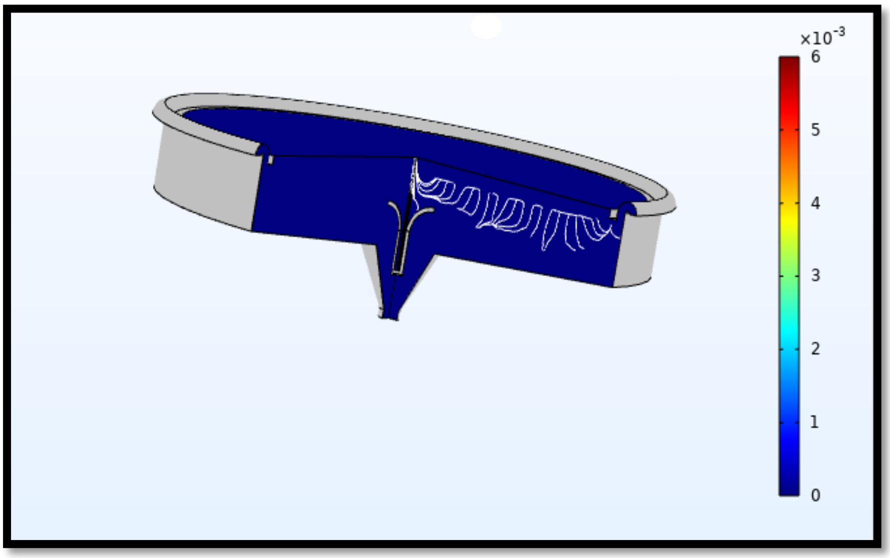
Parameter	Value / Range	Unit	Notes
Sampling frequency	Every 10	min	During steady-state operation
Test duration	2	h	Per particle size and flow condition
Replicates	3	–	To estimate measurement uncertainty

Parameter	Value / Range	Unit	Notes
Measurement method	Gravimetric filtration	–	Standard Methods 2540D
Particle size verification	Laser diffraction	–	Ensures monodispersity
Concentration measurement uncertainty	±4.5	%	From replicate analysis
Flow measurement uncertainty	±2	%	Based on flowmeter calibration
Particle size tolerance	±5	%	Laser diffraction instrument

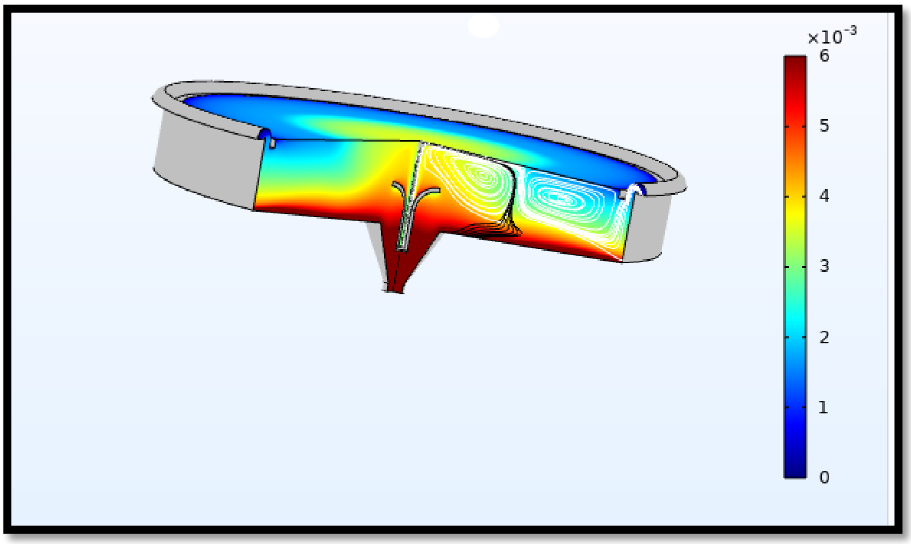
Table 10. (*Continued*)

Table 11. Summary of CFD + Experimental Validation Parameters.

Category	Parameter	Symbol	Value / Notes
CFD domain	Geometry	–	Full-scale circular clarifier
CFD grid	Mesh	2 million cells	Refined near inlet and bottom
Boundary conditions	Inlet	Uniform velocity	Based on measured flow
Boundary conditions	Outlet	Fixed water level	Surface overflow weir
Boundary conditions	Walls	No-slip	Concrete walls
Particle tracking	Method	Lagrangian	Settling with drag correction
Validation	Comparison	Concentration profiles	Radial & depth-wise
Optimization	Algorithm	AFSA	Artificial Fish Swarm Algorithm



(a)



(b)

Figure 22. This example studies the removal of contaminants from wastewater by sedimentation in a circular secondary clarifier. The example uses the k-epsilon turbulence model at (a) time=0 &(b) time=14hr.

5. Challenges and future directions

This research was carried out with the aim of helping in developing a method of quantifying the sensitivity of the model for the comparison of the relative significance of design and operating conditions to obtain the needed performance characteristics. There are several disadvantages associated with the macroscopic model, such as inability to evaluate interceptor efficiency, inability to determine all sources of short-term change monitoring program interference, and its practical application at best at pilot scale where effects on phosphate removal through kinetics might be better understood. Further, field sites that had good performance may be unable to adopt, the design modifications that form the model, without large capital investment. As such, the model might be more effective when addressing specific countermeasures to design and reactor problems.

Substantial studies have been conducted on the design and efficiency of secondary clarifiers in order to determine the feasibility of modifying these solids-contact tanks with conventional secondary clarifiers by adding an inclined plate or some other feature. To examine the impact of introducing element/s in the final sedimentation zone of the secondary clarifier, the final suspended activated sludge does not rely on its initial settling behaviors. To this date, advancements on the technology of the conventional secondary clarifiers improved for proper separation of the sludge have not been driven by basic data for the improved rapidity and efficiency of the secondary treatment of domestic wastewater.

5.1. Current challenges in sedimentation processes

In the last three decades, the growth of the world population, the changes in lifestyle, urbanization, and industrialization have led to high rise in the amount of wastewater produced and have thereby raised growing concerns all over the world about the impacts of contaminated water on the health of human beings and the environment. This increased volume of wastewater together with limited treatment capacities offered by majority of current treatment plants may be detrimental to the environment. It is challenging to address the wastewater to the necessary degree in current treatment plants to meet the stringent requirements, see **Table 12** that exist in many countries, and it is almost impossible in a very short time. The governments have set some parameters that effluent can be reused or discharge, which means that the treatment facilities have challenges in attaining such high effluent quality.

Table 12. Quantitative Comparison with Literature and Design Standards for Circular Secondary Clarifiers.

Typical Design Standards	Parameter
20–40	Surface overflow rate ($m^3/m^2 \cdot d$)
1.5–3.0	Hydraulic retention time (h)
85–95	Suspended solids removal efficiency (%)
0.5–1.5	Sludge blanket depth (m)
2–6	Solids loading rate ($kg/m^2 \cdot h$)
< 30	Effluent TSS (mg/L)

Due to population growth and industrialization and urbanization, water consumption as well as wastewater production has been on the increase. Treatment plants are being erected in many cities and towns for the domestic sewage and industrial effluents; though ninety percent population of this world resides in the developing countries, among them a significant proportion do not have proper sanitation or regular water supply. Well established city areas having large populations are now seeking and adopting decentralized treatment systems. Waste water when treated properly has the potential use in farming, fish farming, and to replenish ground water. However, only when the treated water is to be reused or discharged, it is necessary to achieve a certain level of treatment, which is often not achieved and this is a disadvantage of the treatment plants.

5.2. Emerging technologies and research areas

Novel methods of nutrient recovery are also under development today. Thermal methods appear to be the preferred choice because they enable the recovery of all phosphates. In order to create stable application of these secondary phosphates, efforts are being made to reclaim them in the agricultural and horticultural industry. Wet extraction of struvite appears to be a feasible method of enhancing the physicochemical phosphate and ammonia recovery processes and generating a product that has viability for higher added-value uses. In summary, the practice of using the recovered nutrients as fertilizers has provided a new area of research that can still be developed. No investigations have been made yet about the effects that a market implementation has on flora & fauna of urban streams. It is also unclear the possible effect it could have on microbiological and heavy metal loads in the production system.

In the case of biological nutrient removal processes, additional processes and the least dependency on external sources are closure of cycles. The last decades have not yet provided adequate answers and there is still a lack for a deeper understanding of the fundamental mechanisms associated with nutrient removal and for development of new or other well-identified engineered process and hydraulic configurations. These new requirements and improvements in the membrane separation processes did offer some very interesting ideas and problems. This is due to the coupling with biological nutrient removal processes which ensures that the energy demand is comparatively lower than with some of the other phosphate removal processes. To scale up the membrane bioreactors and to maintain a stable bioprocess lasting for a longer duration is a very tricky and innovative area in the research, which has earned much attention all over the world.

6. Conclusion and recommendations

The following research activities are recommended to further establish the design and operational guidelines: This manuscript will also explore the factors that affect the performance of a secondary circular clarifier when mixing. The objective of this study will be to assess the impact of weir loading rate on efficiency of the circular clarifier secondary. Determine the influence of some structures inherent in the CSTR design on the sludge density of a biological system. Research on how other forms of organic matters apart from the activated sludge affect the operation of a secondary circular clarifier. First specific objective: Understand role of BVH in TSS removal Thus it is suggested that the costs of various designs should be built and the environmental outcomes that will accrue from each design must be also compared. The design cost can currently not be drawn to a parallel due to several unexplained parameters. There is thus a need for full-scale measurements and laboratory investigations. As for the operational cost, the author of the report offered some conclusions in this report; however, these grants funded study is not yet final. Thus, it is suggested that a grant application should be made in order to do "cost analysis of design, operating & Maintenance of existing & envisioned arrangements".

Therefore, it holds true that by increasing the GT or indeed a longer detention time will decrease the depth of the sludge blanket, SVI and TSS, in the effluent. However, the increase in the GT will nullify the energy savings which can be realized when the detention time is reduced. Temporary report: The design flow of 5 Ml/d in dry weather flow has been chosen for this project the cross-sectional area of half bridge is greater than that of a full bridge design. To draw precise conclusion further investigations should be made further to explore the capability of half bridge design. It is also suggested that the findings of this study be replicated in a thoroughly managed full scale secondary circular clarifier.

6.1. Conclusion

Based on the experimental measurements and mathematical modeling findings of this study, it will facilitate efficient contaminant elimination in the secondary clarifiers that can serve to both manage the quality of the activated sludge process and function as an added layer of safety against the discharge of pollutants into the water systems. The operational guidelines derived from this study consist of various operating conditions which are influenced by primary treated wastewater characteristics, return activated sludge flow, and size of secondary clarifier, and not the previous or current activated sludge effluent quality. Due to the enhanced legislation that has been placed on emission of pollutants into the aquatic environment and also due to advancement in laboratory analysis for the presence of low concentration of contaminants in trace and ultra-trace level, the first objective of this research therefore compares the ability of the primary and secondary effluent samples to detect the occurrence frequency of the selected trace and ultra-trace contaminants in a time series analysis.

In this study, separation and removal of the contaminants from highly treated wastewater in a secondary clarifier is studied comprehensively. The performance of the secondary clarifier was determined using the correlation between the settled solids in the primary influent and return activated sludge flow and the important influent operating parameters such as the surface overflow rate, sludge blanket depth, excess recycle activated sludge, and influent total suspended solids concentration (TSSin). The collected effluent sample was also analyzed for estrogen hormones, estrone, β-estradiol, estriol, antimicrobial compound triclosan, and pharmaceutically active compound carbamazepine using SPE HPLC-MS/MS.

The presence of contaminants in highly treated effluent from a typical domestic wastewater treatment plant is analyzed. A second clarifier meanwhile is one of the most important unit processes in treating activated sludge mixed with primary treated wastewater. It eliminates the biological solids that form in the activated sludge process. It will be very important if one has full details of the characteristics of the final effluent discharges from secondary clarifiers if they will meet the expected standard of effluent discharge into the aquatic systems.

6.2. Scope of study

- To identify the efficiency of the sedimentation process in removing the contaminants from wastewater before further treatment.

- To determine the state of flow in the tank and how it affects the performance of the sedimentation process.
- To identify the concentration of different contaminants at every sampling point across the tank during the sedimentation process.
- To determine the efficiency of sludge collection and compare the sludge blanket depth with the tank requirement.
- To provide an analysis of the particles approaching the tank floor under the current state of flow and their trajectory.
- To predict the performance of the sedimentation process through simulation and recommend any improvements to the design of the tank and the sedimentation process.
- To have a better understanding of the sedimentation process in wastewater treatment through a clear representation of the particles and the flow.

6.3. Recommendations for future research

Fifth, a multiple regression equation of plant size or raw and treated sewage flow rate versus percent efficiencies can offer the empirical means of evaluating the magnitude of the removal percentage of the tractive compounds in circular secondary clarifiers having design flow rates. Such a method could have a great practical application since these compounds are most unwanted in the clarified water. Of less importance, but still important, would-be analytical expressions for the v5 versus SVI relationships. It also suggests that such a set of tests could be conducted in larger tanks than the 1.5-meter tank used in this research. Sixth, the role of the physics of the important or controlling sedimentation phenomena are still unidentified and a vast amount of work should still be focused on coming up with an acceptable theoretical model.

There are a lot of recommendations that can be given in connection with the findings outlined in this report for further research. First, the methodology, including the special test procedures used, might be employed on a greater number of circular secondary clarifiers installed at different municipalities. Second, about the difficulties in algae removal from the influent stream it may be suggested to use coagulants or try some other type of flocculants. Third, future tests should be conducted at overflow rates and mixed liquor suspended solids concentrations higher and lower than those used in this study. Ideally, the results from such broader conditions should be provided in one report to enable a relevant comparison of the performances of the pollutant removal in both the types of operation. Fourth, if the influent pollution measuring method is satisfactorily developed, it greatly improves the value of the product of the research to wastewater treatment plant operators and design engineers.

Conflict of interest

The authors declare no conflict of interest.

References

1. Thomas E. Wilson Water- Pollution Control Federation (WEF), Manual of Practice FD-8, Clarifier Design, Second Edition (2005)-FD-8.
2. Hamood, H. M., Mansour, M. M., Lafta, A. M., & Nashee, S. R. (2023b). Numerical Investigation to Study the Effect of Three Height of Triangular Obstacles on Heat Transfer of Nanofluids in a Microchannel. International Review of Mechanical Engineering (IREME), 17(11), 533. https://doi.org/10.15866/ireme.v17i11.23627 .
3. Mustafa M. Mansour, Kamaal Sahib M. Al-hamdani.(2024). Tabu Search Algorithm to Optimize Layout Design for a Multi Objective Plant Function.Passer Journal,Passer 6 (Issue 2) (2024) 446-452. https://doi.org/10.24271/psr.2024.450554.1554

4. Silvestro Damiani -Journal of Environmental Management- Treatments for color removal from wastewater: State of the art- Volume 236, 15 April 2019.
5. Abdulhasan, M. J., Abdulaali, H. S., Al-Doori, Q. L., Dakheel, H. S., Al-Abdan, R. H., Alhachami, F. R., Hameed, A. J., Shoia, S. J., & Mansour, M. M. (2022b). Physicochemical and Heavy Metal Properties of Soil Samples in Waste Disposal Site, Suq Al-Shyokh, Iraq. 2022 International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT). https://doi.org/10.1109/ismsit56059.2022.9932750
6. Vanitha Katheresan and Jibrail Kansedo Journal of Environmental Chemical Engineering-Efficiency of various recent wastewater dye removal methods: A review -Volume 6, August 2018, Issue 4.
7. Bao Lee Phoon- Journal of Hazardous Materials-Conventional and emerging technologies for removal of antibiotics from wastewater-5 December 2020.
8. Ramy H. Mohammed -Removal of heavy metal ions from wastewater: a comprehensive and critical review-n 07 December 2021
9. Mansour, M. M., & Doos, Q. M. (2025). Developing expert system for defects diagnostic for specific oil refinery pipelines via using artificial neural network. AIP Conference Proceedings, 3303, 060010. https://doi.org/10.1063/5.0261530
10. Min-Kyu Ji, Reda A.I. Abou-Shanab, Seong-Heon Kim, El-Sayed Salama, Sang-Hun Lee, Akhil N. Kabra, Youn-Suk Lee, Sungwoo Hong, Byong-Hun Jeon, Cultivation of microalgae species in tertiary municipal wastewater supplemented with CO2 for nutrient removal and biomass production, Ecological Engineering, Volume 58,2013,Pages 142-148, ISSN 0925-8574, https://doi.org/10.1016/j.ecoleng.2013.06.020. (https://www.sciencedirect.com/science/article/pii/S0925857413002218).
11. P.A Brown- Water Research-Metal removal from wastewater using peat-1 November 2000.
12. Rakesh Shrestha- Journal of Environmental Chemical Engineering-Technological trends in heavy metals removal from industrial wastewater: A review-August 2021.
13. Barrera Bernal, C., Vázquez, G., Barceló Quintal, I. et al. Microalgal Dynamics in Batch Reactors for Municipal Wastewater Treatment Containing Dairy Sewage Water. Water Air Soil Pollut 190, 259–270 (2008). https://doi.org/10.1007/s11270-007-9598-3
14. M. Pomiès -Science of The Total Environment-Modelling of micropollutant removal in biological wastewater treatments: A review-15 January 2013.
15. A. khalidi-idrissi-International Journal of Environmental Science and Technology -Recent advances in the biological treatment of wastewater rich in emerging pollutants produced by pharmaceutical industrial discharges-16 March 2023.
16. Mansour, M., & Al-hamdani, K. (2024). Key Performance Indicators for Evaluating the Efficiency of Production Processes in Food Industry. Passer Journal of Basic and Applied Sciences, 6(2), 494-504. https://doi.org/10.24271/psr.2024.450557.1555
17. Mansour, M. M., & Ugla, A. A. (2024). EMPLOYING GENETIC ALGORITHM TO OPTIMIZE MANUFACTURING CELLS DESIGN. ACADEMIC JOURNAL OF MANUFACTURING ENGINEERING, 22(3).
18. Michał Bodzek and Alina Pohl -Archives of Environmental Protection-Removal of microplastics in unit processes used in water and wastewater treatment: a review/aep.2022-10.24425.
19. Noor Najm, Mansour, M.M. (2024). The Role of Waste Reduction Technology in Sustainable Recycling of Waste Paper at Thi-Qar University. International Journal of Sustainable Development and Planning, Vol. 19, No. 8, pp.
20. Mansour, M. M. (2024). Assessing the role of circular economy principles in reducing waste by sustainable manufacturing practices: A review. Sigma Journal of Engineering and Natural Sciences – Sigma Mühendislik Ve Fen Bilimleri Dergisi. https://doi.org/10.14744/sigma.2024.00155 .
21. Mac Phee, J.; Tyson, B.; Ferraro, C.; Roberts, P.; Parsons, S. A.; Jefferson, B. Factors Affecting the Sedimentation of Particles in Primary Settling Tanks. Water Res. 2008, 42, 339-349.
22. Lilly, D. R.; Russell, A. H. Inclined sedimentation tanks. J. Sanit. Eng. Div. 1958, 85, 43-85.
23. Ghoniem, A. M. An Equilibrium Theory for Settling Slurry-Wake and Implications for Clarifier Design and Collection Efficiency. J. Environ. Public Health 2018, 2018, 1-24.
24. Bing, Z.; Wang, X.; Guo, H.; Yuan, Q. Simplified modeling for discretely sized particle settling in full-scale circular sedimentation tanks. Water Res. 2014, 67, 112-121.
25. Mansour, M.M., Erabee, I.K., Lafta, A.M. (2024). Comprehensive analysis of water based emulsion drilling fluids in GHARRAF oil field in southern Iraq: Properties, specifications, and practical applications. International Journal of Computational Methods and Experimental Measurements, Vol. 12, No. 3, pp. 297-307. https://doi.org/10.18280/ijcmem.120310