Review of Clarifier Technologies

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Abstract

As the South African population grows, so too is the demand for clean water. There are numerous methods that have been developed over the years for cleaning water. Water purification technologies at Veolia Water Technologies The main focus of this study is to use literature to get a fundamental understanding of Clarification technologies. study presents the Finite Element Analysis (FEA) of an Actiflo Clarifier designed by Veolia Wastewater Technologist in Johannesburg, South Africa. Various aspects are investigated in this study. The Actiflo Clarifier stiffeners are assumed to meet the Euler buckling criterion. The maximum deflection occurs at the top of the tank where the actual pressure is far less than the 40kPa at the bottom of the tank which was assumed to be the maximum pressure acting constantly along the walls of the Actiflo. Various parameters such as fatigue failure, design variables, as well as the different stiffener positions and sections used to determine the local bucking points of the rectangular structure are tested in the Finite Element Analysis (FEA) environment using Ansys. The Finite Element Method (FEM) is used to determine the critical zones of large deformations and stresses as well as to test theoretical principles.

Keywords
Finite Element Analysis (FEM), Clarifier, Tensile Stress, Hydrostatic Pressure and Stiffeners

1. Introduction
The main purpose of clarifiers in a treatment scheme is to remove solids from liquids by sedimentation, remove scum from liquid by flotation and thicken solids for removal and further treatment applications. Specific application of clarifier functions will be dependent upon the treatment process employed. This study is a discussion of what has been accounted by prior researchers on wastewater industries as well as the development of clarifiers. This review is focused on five major themes which emerge repeatedly through the literature reviewed. These themes are: wastewater industries, Conventional wastewater treatment processes, Clarifiers, Chambers within a clarifier, rectangular structures of a tank and the application of FEM. Theories and principles behind the different techniques used for designing clarifiers have a role in how designs can be optimized. To effectively optimize the design of an Actiflo clarifier thorough research is required to identify how the thickness of the shell, stiffeners used, and the locations of the stiffeners can affect the Actiflo. The motivation of the research is to gain fundamental knowledge of how clarifiers work and investigate how they have been designed by other researchers.

2. Literature Review
2.1. Wastewater Treatment Industries
Wastewater treatment industries developed in the 19th century, where large cities began to understand that they had to reduce the number of pollutants found in the water that had to discharge into the environment. Despite large supplies of fresh water and the natural ability of water to cleanse itself over time, populations had become so concentrated by 1850 that outbreaks of life-threatening diseases were traced to bacteria in the polluted water (Anon., 2017). Since that time, the practice of wastewater collection and treatment has been developed and perfected, using some of the most

technically sound biological, physical, chemical, and mechanical techniques available. As a result, public health and water quality are protected better today than ever before.

2.2. Generalized Flow of Municipal Wastewater Treatment

Collection systems are put in place by municipal administration. All wastewater is collected and directed into a central point. The water is then directed to a treatment plant using underground drainage systems. During this process pipes and tracks are designed leak proof as well as ensuring odour treatment processes are initiated. The terms used to describe different degrees of treatment in order of increasing treatment level are: preliminary, primary, secondary, and tertiary or advanced wastewater treatment (Asano, 2007). A generalized wastewater treatment block diagram is shown in Figure 1.

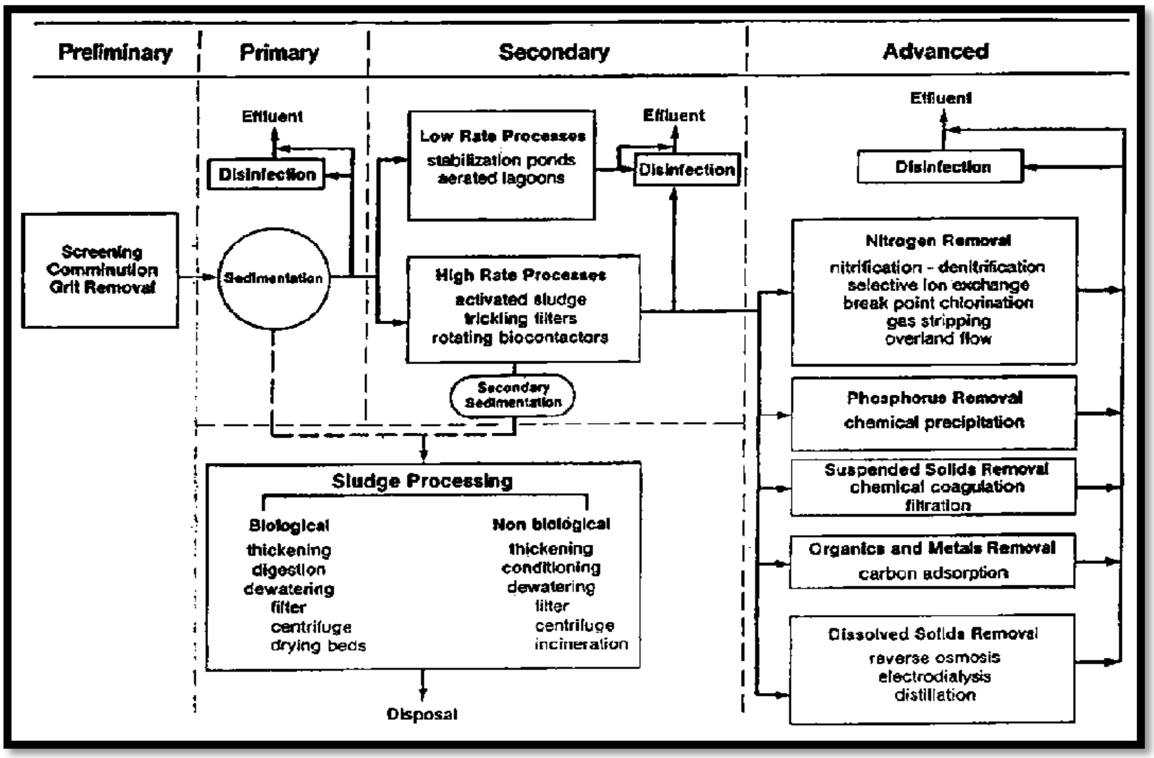

Figure 1. Generalized block diagram for municipal wastewater treatment (Asano, 2007).

2.3. Conventional Wastewater Treatment Processes

Conventional wastewater treatment consists of physical, chemical and biological processes and operations to remove solids and organics from wastewater. The subsections that follow are general terms used to describe the different degrees of treatment, in order of increasing treatment level are preliminary, primary, secondary and tertiary and/or advanced wastewater treatment.

A) Preliminary Treatment

The preliminary treatment stage was designed to remove particulate material and other large materials found in the raw influent. Removal of these material improve the operation and maintenance of the treatment units. The preliminary treatment stage consists of screening and grit removal. The grit chambers allow the raw fed to be maintained moderately high to prevent the settling of most organic solids (Asano, 2007).

B) Primary Treatment
The primary treatment stage is the removal of settleable organic and inorganic solids by settling. This removal of floating material is done by skimming. This stage consists of a primary settling tank and no chemical reaction takes place on this stage (Asano, 2007).

C) Secondary Treatment
The secondary treatment stage is one big chamber divided into aerobic zones, which have varying aeration intensity, depending on the targeted removal compound of interest (Kallon et al, 2020; Maqina et al, 2020; Maqina and Kallon, 2020). Generally, this step (Table 1) comprises of five aeration zones as follows:

Table 1: Secondary Treatment Aerobic Zones **(Asano, 2007).**

Aeration Zones	Description
1	The return sludge from clarifiers mixed with raw feed from the primary treatment stage. This zone maintains the food micro ratio by combining the return sludge which has less organic and high bacteria population with raw effluent from primary treatment stage which is rich in organics.
2	The ammonium nitrite is converted into nitrate due to aeration intensity
3	Aeration is increased two-fold of the intensity of the second zone. Nitrates are converted into ammonia.
4	The aeration is manipulated and Ammonia is converted into nitrogen gas which escapes into atmosphere
5	The phosphorus removal takes place.

D) Tertiary and/or Advanced Treatment
Tertiary treatment stage is the further treatment after second treatment stage. It is commonly used when a specific wastewater constituent which cannot be removed by secondary treatment has to be removed in this stage. Individual treatment has the capacity to treat and remove the following: nitrogen, phosphorus, suspended solids, refectory organics, heavy metals and dissolved solids (Asano, 2007).

2.4. Clarifiers
A clarifier is a mechanical built settling tank that allows for continuous removal of solids being deposited by sedimentation. These type of tanks were designed to exploit laws of physics as they permit solids to exit via settling in a wastewater stream while the stream maintains a certain velocity research proves that the clarifier works similar to oil water separators (Anon., n.d.) Concentrated impurities, discharged from the bottom of the tank are known as sludge, while the particles that float to the surface of the liquid are called scum (J, 1975). The final clarifier was later designed to perform two primary functions namely clarification and thickening. Clarification is the separation of solids from the liquid stream to produce a clarified effluent with low effluent suspended solids (ESS) levels. Thickening is the conveyance of sludge particles to the bottom of the tank, resulting in a slightly concentrated underflow, or return activated sludge (RAS).

3. Types of Clarifiers
There are different types of clarifier structures used in industry. The hopper-bottomed shaped tank is designed for upward flow, the circular framed tank is used for radial flow and lastly the rectangular structured tank, which is used

for horizontal flow (Kallon et al, 2020; Maqina et al, 2020; Maqina and Kallon, 2020). Figure 2 illustrates the aforementioned clarifiers. The clarifier used in this dissertation is the rectangular tank configuration.

Figure 2. Different types of clarifiers: 1. Lamella, 2. Circular , 3. Rectangular Clarifier (Left to Right) (Menon, 2014).

A) Solid Contact Clarifiers

This type of clarifier works of two basic principles, namely coagulation/flocculation and hydraulic separation. Coagulation and flocculation occur when the raw water feed stream comes into contact with chemical mixtures and suspended sludge particles from previously treated water, this occurs within the flocculent zone. This contact zone promotes floc growth as smaller particles grow into larger heavier particles. The hydraulic separation principle uses an up-flow design to move the water into the settling zone for clarification.

Clarification involves less than 2 percent of the solids that enter the clarifier. A rise in ESS is an indication of clarification failure. Thickening on the other hand involves a relatively larger fraction of the solids (> 98 percent). Thickening failure results in a rise in sludge blanket depth implying that if the clarifier fails in either of these functions, the following would be encountered:

- Effluent TSS permit violations.
- Unintentional wasting of solids with the effluent leading to a reduction of solids retention time (SRT), which could potentially impact the biological process (Jeyanayagam, n.d.).

B) Plate Type Clarifiers

Modern developments of the clarifier design are plates. These plates effectively remove high suspended solids present in the water (Anon., n.d.). Clarity of liquid overflow and density of underflow discharge are the two fundamental process requirements of all gravity settling equipment. In many applications the area needed to provide the desired overflow clarity exceeds that required for thickening of the settled solids. This means that, in a cylindrical settling tank, the lower section including the rakes and drive mechanism is over dimensioned. Pre-treatment is given to water to make it suitable for subsequent treatment, which makes it suitable for use in a particular process.

4. Chambers within a Clarifier

4.1. Coagulation Chamber

In water treatment, coagulation (Figure 3) involves the addition of chemicals that causes small, destabilized particles to stick together into larger aggregates so that they can be more easily separated from the water being treated. The coagulation process involves the addition of the chemical (e.g. alum) and then a rapid mixing to dissolve the chemical and distribute it evenly throughout the water. The earliest use of chemicals that cause coagulation as part of a water treatment process has been observed after approximately 1500 BC, by Egyptians (Veolia, n.d.). They applied the chemical alum for suspended particle settlement, pictures of this purification method have been observed on the wall of the tomb of Amenophis II and Ramses II.

A) Coagulation Techniques

The processes of coagulation can be carried out in the following ways:

- **By electrophoresis:**
  In this method, the colloidal particles are forced to move towards the oppositely charged particles and then they are discharged and collected at the bottom.
- **By mixing two oppositely charged solutions:**
  In this type of coagulation equal amounts of oppositely charged particles are mixed, they cancel out their charges and then precipitate, Figure 3 (Anon., 2018).

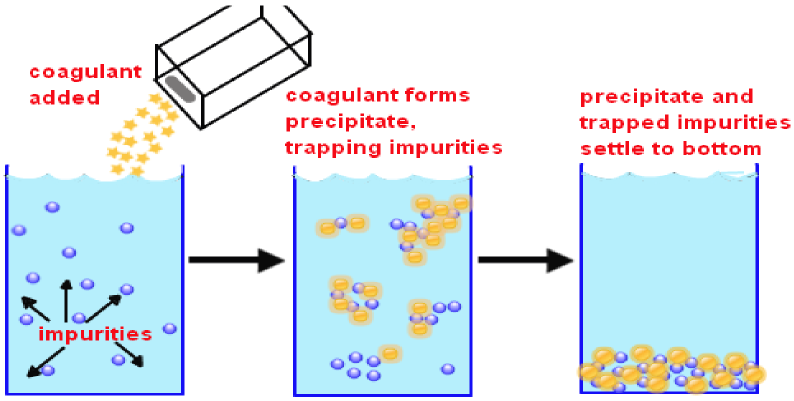

Figure 3. Coagulation by mixing two oppositely charged solutions (Anon., 2018).

4.2. Flocculation Chamber

Flocculation is the turbulent mixing phase technique that promotes agglomeration and assists in the settling in particles. Flocculation is affected by several parameters, including mixing speeds, intensity and mixing time (Hubbard, 2007-11-13). Flocculation is also defined as the turbulent mixing phase of the coagulant in the rapid mix (Hudson, 1981). Figure 4 indicates flocculation tank designs.

Figure 4. Flocculation Designs: Maze flocculation, Rotating horizontal Pickets, Draft tube flocculent (Left to Right) (Mpholo, 2017).

The Draft tube flocculent is used within the Actiflo where, very fine sand is mixed in rapid mix with the coagulant. Floc forms with the sand as a nucleus, providing ballast to enhance settling. After settling, pumps draw the sand/floc mixture from the bottom of the settling basin and return it to cyclone separators where a significant portion of the sand is recovered and recycled (Engelhardt, 2010).

4.3. Clear Well Chamber

This chamber is also known as the clarification chamber. This is where flow is equalized and only clear odourless liquids exits the system as shown in Figure 5.

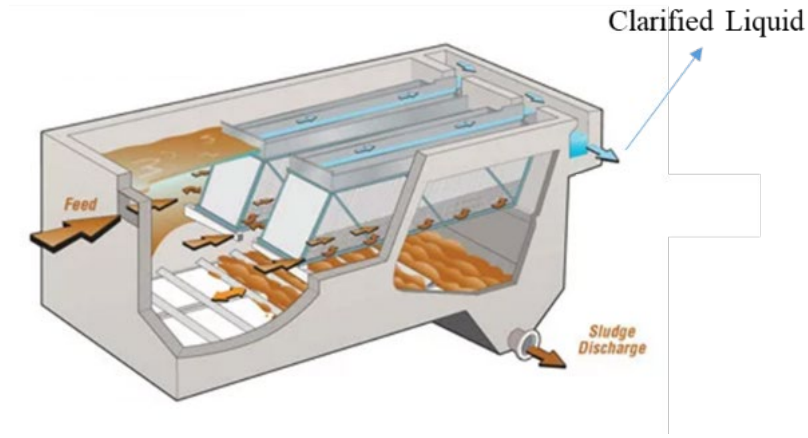

Figure 5. Clarifier Configuration (Anon., 2018).

5. Lamella Settling Tank

Clarifier performance with flocculent sedimentation is mainly dependent on the hydraulic loading rate (HLR). Depth and hydraulic retention time are generally considered as second-order factors, according to the most common models of sedimentation processes analysis (López, 2013). The common strategy used to improve performance in clarifiers is the horizontal settling surface enlargement, which leads to a decrease in hydraulic loading rate at equal flow rate. This increase can be attained in different ways. Figure 6 shows the flow split supported by each horizontal surface.

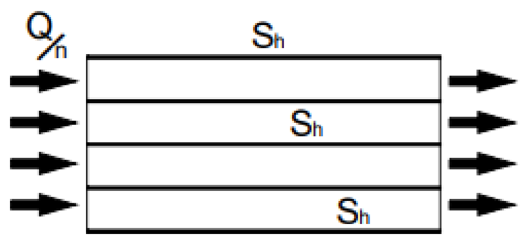

Figure 6. The effect of introducing different levels in a settling tank (McGraw-Hill, 2005).

The hydraulic loading rate can be achieved through Equation 1.

$$HLR = \frac{Q}{n.S_h} \quad (1)$$

Where n is the number of false bottoms and S_h is the true horizontal surface. The factor f does not grow just as n. "f" factor may vary between 0.5 and 1, being normally between 0.9 and 1 (López, 2013). Figure 7 shows "Multilevel" clarifier with parallel flow.

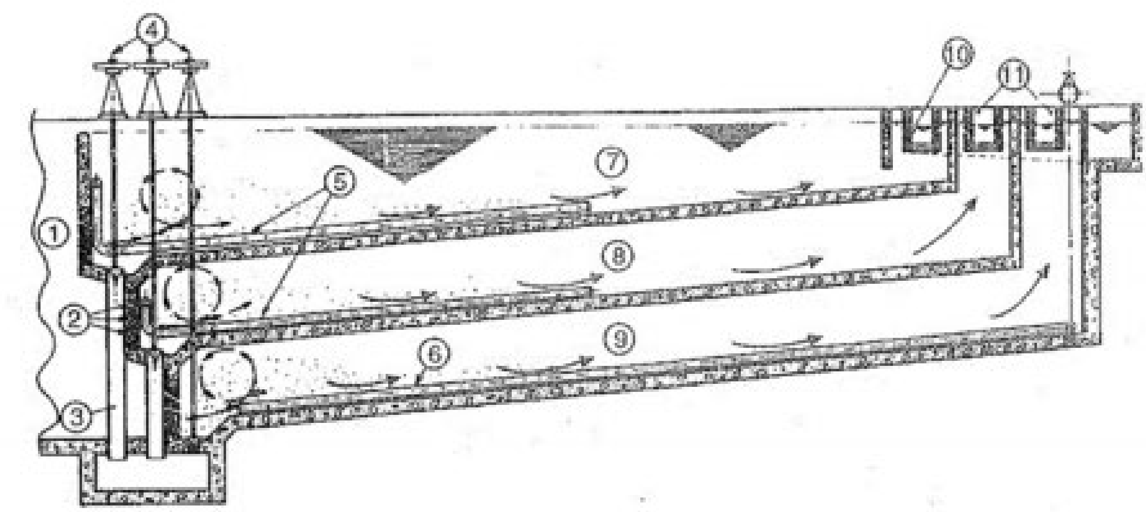

Figure 7. "Multilevel" clarifier with parallel flow (McGraw-Hill, 2005).

The volume of building site with various levels clarifiers can be reduced to half. Different experiences in this way led to settling tanks with 3 to 5 levels. This arrangement creates problems sludge removal problems, so enhanced systems should be developed (McGraw-Hill, 2005). The different levels are labelled in Table 2.

Table 2: "Multilevel Stages" clarifier with parallel flow.

1. Flocculation Tank	7. Upper Clarification Level
2. Split-Roll Entries	1. Medium Clarification Level
2. Sludge Drainage	2. Lower Clarification Level
3. Manual Controlled Superior Valve	3. Effluent Weirs
4. Sludge Extraction System (Optional)	4. Clarifier Water Channels
5. Water Cleaning System	

An alternative to facilitate sludge removal would be to increase the steepness of the settling unit levels, in order to force the sludge to go down and deposit on a single surface, generating a single extraction system. Figure 8 illustrates the basic concept of the lamella or laminar plate clarifiers.

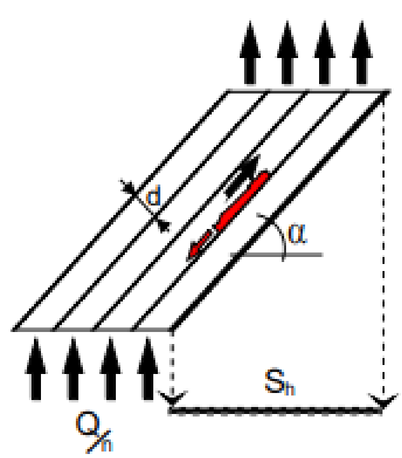

Figure 8. Diagram of a lamella clarifier basic operation (y, 2003).

The spacing between the plates is generally between 2.5 and 5 cm for drinking water facilities and 5 to 10 cm in wastewater treatments. The effective horizontal surface is the horizontal projection of each plate multiplied by plates number. This total projected surface value is used to calculate the hydraulic loading rate. An important factor to take into consideration is the critical scour velocity (y, 2003). The hydraulic loading rate can be achieved through Equation 2.

$$\boldsymbol{HLR} = \frac{\boldsymbol{Q}}{\boldsymbol{n.S_h Cos\alpha}} \tag{2}$$

The foregoing results in more compact equipment and with surface requirements considerably lower than in conventional circular and rectangular clarifiers. Laminar or tubular clarifiers are also called high rate settling units (D., 2007).

6. Conclusion

The aim of this study was to effectively investigate methods of optimizing the Actiflos stiffeners. This could not be done without thorough research of how parameters such as the Actiflo wall thickness, stiffener configurations used, optimal stiffener locations as well as identifying local buckling points. The Actiflo was designed in accordance to the volume required per chamber which covers the most important aspect of an Actiflo operation however no structural analysis was done to investigate the number of stiffeners required to resist the internal hydrostatic forces, the type of stiffeners to be used and ideal locations to place stiffeners. This structure was therefore classified as statically indeterminate beam with a VDL (varying distributed load). Simulating software's such as ANSYS are power tools that can give any organization massive upgrades cutting time of applying manual theoretical calculations, solving complex structures, mitigating any risks by identifying failures prematurely before they occur, this may also cut any manufacturing costs.

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