Title

Different momentum as main sludge/water separation cause in a secondary sedimentation tank

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Key word

Secondary sedimentation tank; sludge momentum; sludge blanket; density currents; ratio between drag and gravity forces

Abstract

In static conditions, the only mechanism available for sludge/water separation is sludge sedimentation by gravity. In dynamic conditions, both with the gravity, another mechanism is available: at the same speed, the stronger inertia of sludge flocks compared to clear water, at each directional change of the mixed liquid, brings the sludge flocks to go straight on, while the clear water path diverts towards the drainage collection system, or other devices. The measures taken on operating secondary sedimentation tanks have shown this second mechanism to be much more important for sludge/water separation, at least, at the usual loads applied to secondary sedimentation tanks.

a) A new approach to understanding the SST.

In order to improve our understanding of how the SST functions, we must start by analyzing the behavior of an operational SST as observed by various researchers, particularly with regard to the characteristics of the sludge blanket (taking note of the concentration in many directions) as well as the hydrodynamic fields within the SST. These findings can then be interpreted based on hydrodynamic principles:

- Momentum preservation, in case of any energy loss.
- Motion of fluids (as thickened sludge must be considered) from an area with higher potential energy to an area with lower potential energy.
- Ratio between inertia and gravity forces.

What must be taken into consideration is the portion of the SST on the outer part of the central cylinder. It can be surmised here (excluding the rotational movement of the sludge scraper bridge crane upon the liquid mass) that both the hydrodynamic field and the sludge blanket have radial symmetry. In this part of the tank it can be hypothesized that, at least in the initial approximation, the loss of energy is negligible, given the low velocity. Here the potential energy per square meter at a given point of the SST is given by the following formula, reference [1]:

1) $$Ep = (Gs - Gl)/Gs \int_{-}^{H} C(h) * h * dh$$

Where

Gs=specific gravity of solid particles

Gl= clean water specific gravity

C(h)= sludge concentration at a certain height (h) from the bottom

h= height from the bottom

H=height of the SST.

The quantity of said energy, should the loss of energy be negligible, may, according to the circumstances, be transformed into different forms, but will not increase or decrease in absolute value.

b) The hydrodynamic field of an operating SST

Despite numerous studies on hydrodynamics applied to SST based on mathematical models, as in reference [2-4], there are relatively few studies based on the direct measures obtained out in the field. The major drawback of the studies based solely on hydrodynamic mathematical models is that of supposing the sludge to have the same density as the clear water so that the sludge velocity and direction are dependent only on:

- the sludge sedimentation velocity (as in a jar test in static conditions);
- the equations for the conservation of particulate mass (in stationary conditions, the concentration of sludge in each part of the tank remains constant, thus there is no gain or loss of solid mass);
- the boundary conditions;
- the equations for conservation of water mass and momentum.

However, the conservation of the sludge momentum is not taken into account. Moreover, if the density of the water is set equal to that of the sludge, the rate of momentum of the water is no different from that of the sludge particles. For these reasons, in the present study, the hydrodynamic field as directly measured in an operating SST and not as given by mathematical models will be taken into consideration. Despite the results being somewhat similar, it is that minor difference which is so important in explaining the effective functioning of an SST. A typical hydrodynamic field inside an operating circular SST , reference [5] , overlapped to the sludge blanket concentration, is illustrated in figure 1.

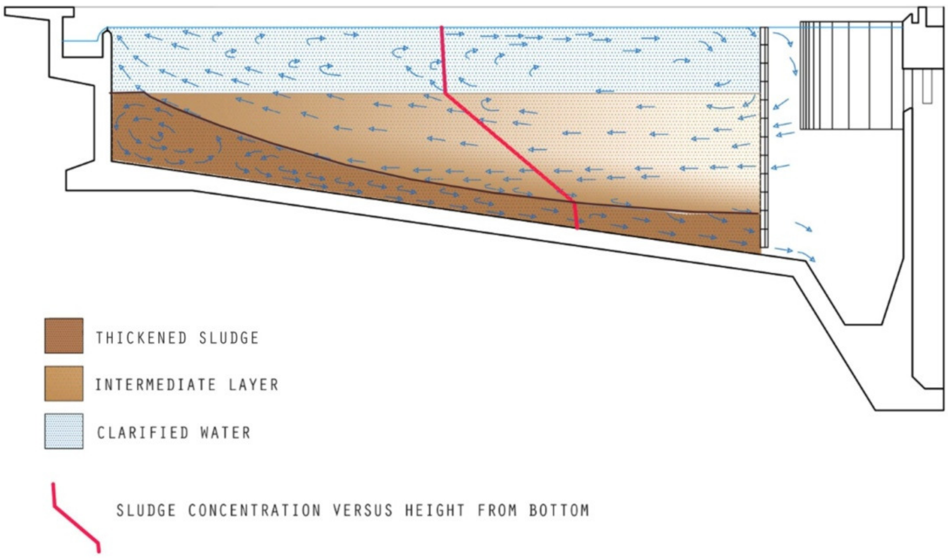


Figure 1 - The hydrodynamic field (represented by the arrows) and the sludge concentration in a circular SST

What is illustrated in this figure complies with the description given in the IAWQ's (International Association on Water Quality) scientific and technical report #6 *"Secondary Settling Tanks: Theory, Modeling, Design and Operation*", chapter 5 "*Hydrodynamic modeling".*

"The flow pattern in the settling zone consists of three layers:

1. *a recirculation zone close the surface of the tank, where the velocities are directed toward the center of the SST;*
2. *a narrow high-velocity flow zone near the top of the sludge blanket interface, where the flow moves as a density current across the top of the blanket until it is turned upwards by the side wall of the SSTs;*
3. *a zone of reverse flow (going toward the center and countering the main direction of flow) located close to the bottom of the SST. This flow reversal occurs due to the influence exerted by the thick sludge layer on the bottom of the tank."*

In examining this picture, the following points appear reasonable:

- The bottom flow, having centripetal direction towards the RAS suction point, is made up of thickened sludge;
- The upper flow immediately above, having a centrifugal direction (which, on arriving close to the peripheral vertical wall of the tank, divides into two streams: one which turns upwards, towards the outlet weir; and anotherwhich turns downwards, towards the thickened sludge,) is made up of MLSS (mixed liquor suspended solids) still not separated into water and sludge. In this layer the significant change of the sludge concentration at different depths is mitigated by the turbulent diffusion phenomenon, which increases as the rate of the two layers increases: the thickened sludge moves towards the central bottom of the tank; the upper layer towards the vertical peripheral wall. Thus, in the central part of the tank, where the velocity of the two layers is very high, no sedimentation can occur at all;

- The uppermost layer is made of clean water and, close to the outlet weir, it divides into two streams: the first goes towards the outlet weir, the second generates a superficial stream which tends to return towards the center of the tank.

The prime issue to achieve in the correct performance of an SST concerns the division of the intermediate stream into two streams going to feed both the bottom flow of thickened sludge and the upper stream of clean water, in other words: the sludge/water separation. This division can be explained as follows:

As long as the peripheral vertical wall (on which the outlet weir is located) is far enough away and the stream speed is high enough, the stream proceeds with a centrifugal direction without any difficulty and without any, or very little, sedimentation hampered by turbulent diffusion. But when the mixed liquor stream gets close to the peripheral wall, the clear water is diverted upstream, towards the drainage channel, but the sludge flocks, for the stronger inertia, to go straight on, until it impacts in the peripheral vertical wall. Why the separation occurs, the ratio between drag and gravity forces affecting the sludge flocks must be low enough.

This impact of the solid particles in the vertical wall generates a stockpile of thickened sludge in the so-called “dead zone” of the decanter. If there is no loss of energy, this impact produces an increase in the potential energy of the sludge blanket. This is equal to the variation of the amount of momentum of the solid mass arriving. This energy is quantified as follows:

$$Ep = K * C * (Q+rQ) * (Q+rQ) = K * C * (Q+rQ)^2 \qquad (2)$$

where:

- K is a constant in the system;
- C*(Q+rQ) is the sludge mass entering the SST in unit time, that we can define as "horizontal solid flux";
- (Q+rQ) for a given SST (that is for an equal peripheral cylindrical surface) is proportionate to the horizontal solid flux velocity noted above which is that pertaining to the middle layer with centrifugal direction.

The flow of thickened sludge which heads towards the RAS suction point comes from the stockpile of thickened sludge found at the back of the peripheral walls.

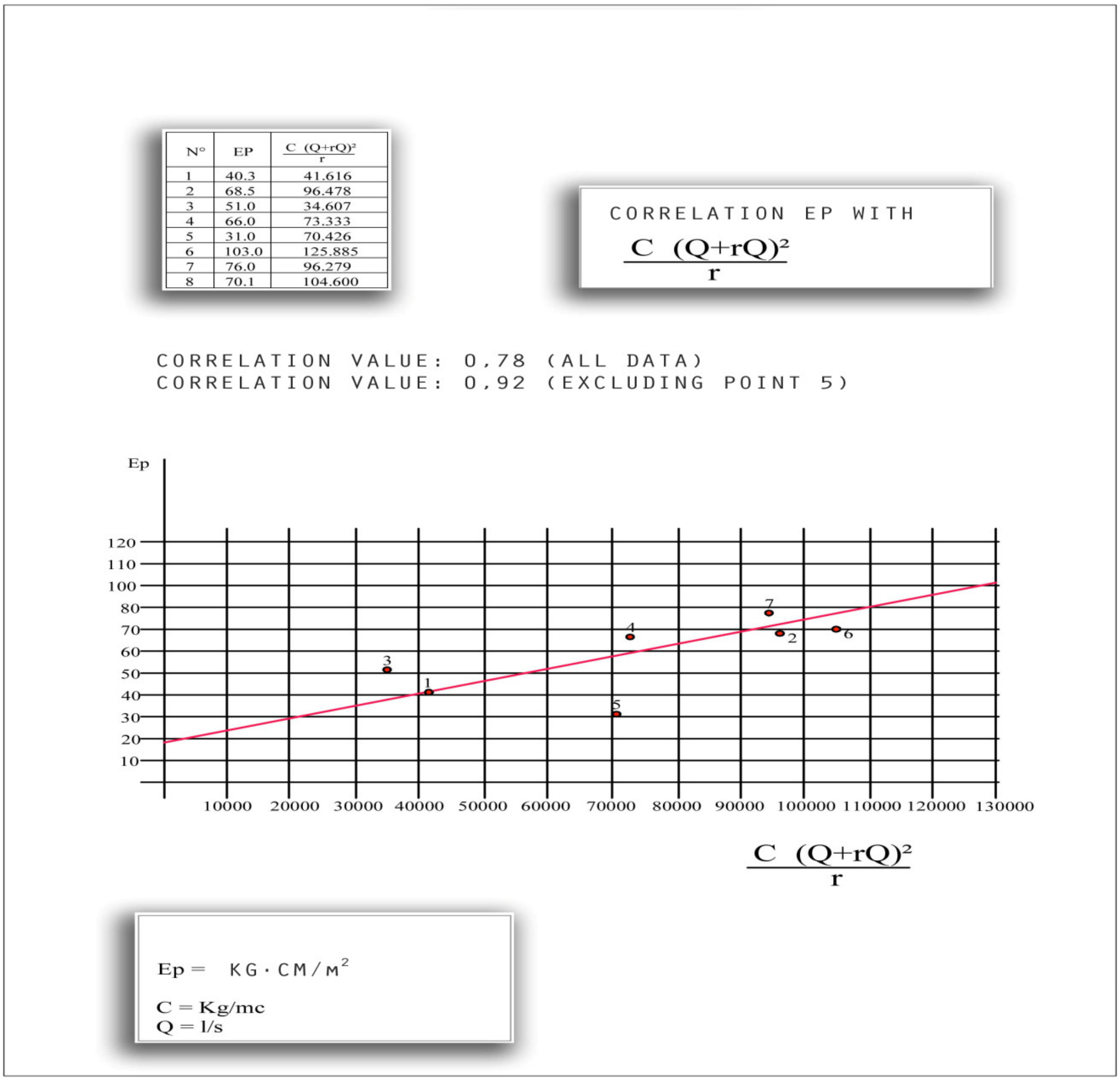
From the above it can be hypothesized that the potential energy from the sludge blanket at the periphery of the tank is:

- directly proportional to the term: $C * (Q+rQ)^2$;
- and inversely proportionate to r, the ratio between RAS flow and Q, incoming flow;

That is :

$$Ep = K * C/r * (Q+rQ)^2 \qquad (3)$$

This expression has been confirmed by the measures taken by the author (see apendix 1) .



N°	EP	$\frac{C}{r}(Q+rQ)^2$
1	40.3	41.616
2	68.5	96.478
3	51.0	34.607
4	66.0	73.333
5	31.0	70.426
6	103.0	125.885
7	76.0	96.279
8	70.1	104.600

Figure 2 - Correlation between the potential energy of the sludge blanket and the expression: C/r * (Q+rQ)^2

The expression 3 can be applied only if the inlet load to the secondary sedimentation tank (as overflow rate, recycle ratio, MLSS concentration and SVI) is inside a certain range. In fact: If the applied load is too high, the sludge flocks are dragged in the outlet weir ;if the applied load is too low, the sludge mass does not reach the peripheral wall, and no impact occurs on sludge flocks on the wall. However, this seems to be the normal status of a correctly performing secondary sedimentation tank. The author has also given another expression to evaluate the correct ratio between drag and gravity forces on sludge flocks, to achieve a correctly performing secondary sedimentation tank. But this matter has been discussed in other papers (see reference 6).

c) Exsisting design strategies that comply with the given explanation of the SST operation

c.1) Peripheral feed decanter

In a secondary sedimentation tank with the flow of liquid aerated from the periphery and collected in the sludge from the center, the hydrodynamic flows are those represented in figure 3.

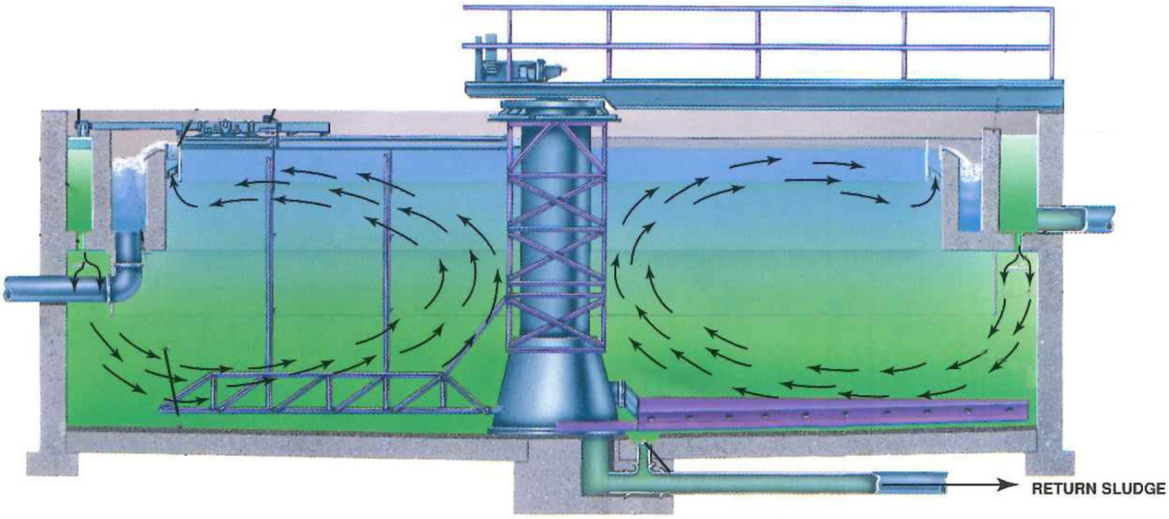


Figure 3 - The hydrodynamic field (represented by the arrows) in a peripheral feed decanter

The water in these tanks is forced to undergo a reversal in direction, while the sludge enters from the periphery and exits from the center, without undergoing any reversal in direction. This performance is exactly the opposite of that of a traditional sedimentation decanter (figure 1) in which the sludge is forced to undergo a reversal in direction while the water enters from the center and exits from the periphery. With the interpretation of a secondary sedimentation tank as indicated above, it is obvious why the peripheral feed tank, with equal dimensions, guarantees a much better performance than the traditional sedimentation decanter. In fact, it requires much less energy to invert the flow of the clarified water than that required to invert the flow of thickened sludge.

c.2) Conversion of longitudinal flow rectangular clarifier to transverse flow.

The manual issued by the Water Enviromental Federation (USA) "Clarifier Design, second edition" reports the case of the Guinett County Yellow River/Sweet Water Creek Wastewater Treatment Plant, in which four rectangular decanters with the following dimensions: 36.6 m length, 9.2 m width, 3.9 m useful depth, were transformed realizing a longitudinal distribution canal for the entire length of one of the two long sides, with the collection of the clarified water along the entire length of the same side, in order to have the same hydrodynamic conditions in each transversal section of the decanter. Essentially, the rectangular clarifier conversion was designed to duplicate the pattern of a peripheral feed, peripheral overflow circular clarifiers. This transformation not only ensured that the inversion of flow took place for the clarified water and not for the thickened sludge (as in the previous case of the peripheral feed decanter) but it ensured a drastic reduction of the sludge momentum near the drainage canal of the clarified liquid, thus guaranteeing a more favorable ratio between the gravitational forces and the dragging forces that act on the sludge flocks in the vicinity of the drainage canal. The author applied the same strategy measures on a secondary decanter of a treatment water of Waste Water Treatment Plant in Lido di Camaiore (Lucca, Tuscany), with excellent results (see figure 4). Precise measurements have not yet been taken but, in substance, the load applicable to the decanter more than doubled.

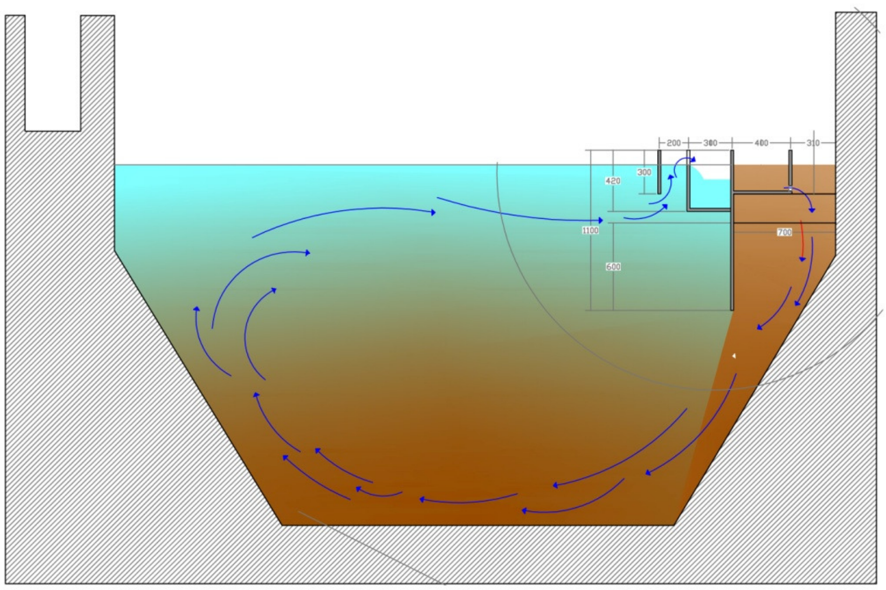


Figure 4 - Cross section of a rectangular clarifier with longitudinal distribution of incoming MLSS for the entire length of one of the two long sides

c.3) Recommended placement of transverse weir away from effluent end

The previously mentioned WEF manual recommends that the terminal drainage canals of a rectangular and longitudinal flow sedimentation tank be arranged at a larger depth distance from the back wall of the tank and, in any case, not less than 5 meters. This recommendation derives from the interpretation of the functioning of a secondary decanter indicated above. Although the trials were run on circular decanters, it is clear that the fundamental physical principles are the same, whether for a circular decanter or for a rectangular one.

4) Conclusions

A new approach has been developed for studying secondary sedimentation tank operations. This study covers the basic physical principles applying to suspended sludge in an SST – preservation of momentum, the ratio of drag to gravity, and the potential energy variations of the sludge blanket under changing hydrodynamic conditions. Tests carried out have demonstrated that the approach is correct, and that it is possible to define new design and verification criteria for SSTs.

Appendix 1

The sludge blanket structure analysis (sludge concentration gradient under different operating conditions) was performed at various WWTPs between July and December 1993:

1. Castel Giubileo, Rome, Lazio region, Italy. (Rectangular SST)
2. Bracciano, Lazio region, Italy. (Circular SST)
3. Avellino Est, Campania region, Italy. (Circular SST)

The WWTPs operating conditions are as shown in Table AI:

Table A1 Operating conditions at the SSTs studied

	Castel Giubileo	**Bracciano**	**Avellino**
Population equivalent (pe)	12,500	34,000	35,000
Primary sedimentation	no	yes	yes
Average flow (L/s)	40	100	92.5
Denitrification	yes	no	no
MLSS concentration (kg/m^3)	> 3	>3	6
Organic load (kg-BOD_5/d/kg-MLSS)	<0.1	< 0.25	< 0.1
Operating units (number)	4	2	2
Length/diameter (m)	22	22.5	29.0
Width (m)	5.0		
Height (m)	1.9	1.8	2.0

Sludge samples were taken by stopping the sludge scraper, using a special sampler that enabled calibration of the depth of sampling. TSS analyses were done by a specialized laboratory.

It was clear quite early on that the results from the Bracciano and Avellino WWTPs were similar, and it was decided to continue only with Bracciano WWTP.

During the test period the operating characteristics of the remaining two SSTs changed as follows:

Castel Giubileo

- Clarified water flow: from 6.0 to 20.0 L/s
- r (RAS ratio): 0.6 to 1.2

Bracciano

- Clarified water flow: from 26.5 to 47.5 L/s
- r (RAS ratio): 0.29 to 1.0

References

1. Water Practice and Technology, [1]:Pezza L. (2016) **"A new approach for studing the operation of a secondary sedimentation tank"**, Vol. 11. N°1; IWA Publishing 2016
2. Journal of Hydraulic Engineering, [2]: Djamel Lakehal; Peter Krebs; Johan Krijgsman; Wolfgang Rodi (1999). **"Computing Shear Flow and Sludge Blanket in Secondary Clarifiers"**, ASCE - March. 1999, pp. 253-262
3. Water Research, [3]: Ekama G.A., Marais P.(2004).**"Assessing the applicability of the 1D flux theory to a full-scale secondary settling tank design with a 2D hydrodynamic model** *" 2004; pp 495-506; Elsevier* (Corporate Office) Radarweg 29, **Amsterdam** 1043 NX
4. Water Science Technology [4] Vanrolleghem P.A.; Clercq B.D.; Clercq J.D.; Devisscher M.; Kinnear D.J.; Nopens I. (2006).**"New measurement techniques for secondary settlers: a review"**; Vol. 53; N° 4-5; pp 419-429; IWA publishing 2006
5. Ingegneria Sanitaria [5] Bertola P. (1980)."**Campo di velocità e distribuzione della concentrazione del fango nella vasca di sedimentazione finale di un impianto di depurazione"**, N°06/1980, pp. 318- 332,Organo dell' Associazione Nazionale di Ingegneria Sanitaria ANDIS, Piazza Sallustio , 24 - Roma