Insight to Refinery Secondary Clarifier Operation

The relationship between sludge settling and sludge volume index

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Operators of refinery wastewater treatment facilities routinely measure sludge volume index (SVI), allowing them to detect deteriorating sludge settling quality. This test, however, does not allow the operator to accurately analyze secondary clarifier performance, including clarifier capacity and the required return activated sludge (RAS) flow. A settling flux analysis is required to predict clarifier operation, yet the constants required to generate the settling flux curve are difficult to develop.

For state-point analyses, settling flux curves must be representative of the biomass in the system or use a previously developed relationship between SVI and empirical sludge settling parameters (such as those developed by Daigger and Roper [1985], Daigger [1995], and Wahlberg and Keinath [1988/1995]). These relationships were developed using municipal facilities with varied industrial contributions. Due to the inherent differences in the biomass at both facilities, revised parameters were created for use in the previously developed correlations between SVI and settling parameters for refinery biomass.

METHODOLGY

Zone settling velocities (ZSV) were obtained from settling column tests and used to generate empirical sludge settling constants Vo and K (Vesilind, 1974) at four separate refineries. The facilities that contain two sets of data were analyzed during periods with different biomass settling characteristics (SVI values). The columns were large (4- to 5-feet deep and at least 3 inches in diameter), mechanically stirred, and water-jacketed using a submersible pump located in the effluent lauder to maintain a steady effluent temperature during the tests. An example of a settling apparatus is presented in Figure 1.

Figure 1. Typical column test apparatus

The initial solids concentration, X_i, was varied by dilution with secondary effluent or concentrated by the addition of return activated sludge (RAS) or settling. Settling tests were performed at different mixed liquor concentrations (X_i) to develop the empirical parameters V_o and K of the Vesilind (1974) equation.

$$V_s = V_o \cdot e^{-K \cdot Xi} \qquad (1)$$

Where:
Vs = zone settling velocity (m/hr),
Xi = initial solids concentration (g/L), and
Vo (m/hr) and K (L/g) = sludge specific parameters.

The settling flux, Gs, is defined as the product of the settling velocity and solids concentration.

$$Gs = V_o \cdot X_i \cdot e^{-KXi} \qquad (2)$$

Where:
Gs = settling flux ($kg/m^2 \cdot hr$),
X_i = initial solids concentration (g/L), and
V_o (m/hr) and K (L/g) = sludge specific parameters.

The SVI for each test condition was obtained using a 1-L unstirred settling apparatus. All SVI values fell within the range used by Wahlberg and Keinath (47.9≤SVI≤235) for an SVI performed in a 1-L graduated cylinder not stirred (SVIGN). Table 1 summarizes the data.

Table 1. Summary of refinery Vesilind and SVI data

	Vo	K	SVI	SVI type
	(m/hr)	(L/g)	(L/g)	
A-1	10.0	0.50	110	1-L unstirred graduated cylinder
B-1	9.3	0.40	112	1-L unstirred graduated cylinder
B-2	9.8	0.37	112	1-L unstirred graduated cylinder
C-1	11.9	0.36	89	1-L unstirred graduated cylinder
C-2	12.5	0.33	59	1-L unstirred graduated cylinder
D-1	9.5	0.26	113	1-L unstirred graduated beaker
D-2	15.5	0.35	128	1-L unstirred graduated beaker

The empirical model for predicting setting flux that was developed by Wahlberg and Keinath for the 1-L SVIGN is demonstrated in Equation 3.

$$Gs = X_i \cdot Ύ \cdot e^{[-\delta \cdot SVI - (\alpha + \beta \cdot SVI) \cdot X_i]} \qquad (3)$$

Where:
Gs = solids flux (kg/m²·d).

Average model parameters α, β, δ, and Ύ generated for the SVIGN and their standard deviation was reported as follows:

α = 0.351 ± 0.071 L/g
β = 0.00058 ± 0.00053 L/mL
δ = 0.00602 ± 0.00115 g/mL
Ύ = 18.2 ± 3.2 m/h

Substituting these model parameters into Equation 3 yields the following:

$$Gs = X_i \cdot 18.2 \cdot e^{[-0.00602 \cdot SVI - (0.351 + 0.00058 \cdot SVI) \cdot X_i]} \qquad (4)$$

Using Equation 2, a settling flux curve was generated for each data set in Table 2 by plotting Gs as a function of X_i, Vo, and K. A second flux curve was generated using Equation 3. The model parameters α, β, δ, and Ύ were generated for each of the seven settling runs by adjusting the four parameters to obtain a minimum of squared differences between the two models using the Wahlberg and Keinath parameters as the starting parameters.

Table 2. Wahlberg and Keinath refinery model parameter estimates

	α	Β	δ	Ύ
	(L/g)	(L/mL)	(g/mL)	(m/h)
A-1	0.428	0.00062	0.00000	10.0
B-1	0.333	0.00057	0.00000	9.26
B-2	0.299	0.00060	0.00000	9.79
C-1	0.310	0.00057	0.00002	11.9
C-2	0.292	0.00057	0.00000	12.5
D-1	0.283	0.00056	0.00000	15.5
D-2	0.198	0.00052	0.00004	9.50
Average	0.306	0.00057	0.000009*	11.2*
Standard deviation	0.068	0.00003	0.000015	2.3

*Outside of mean ± standard deviation of original Wahlberg parameters.

Substituting the revised model parameters in Equation 3 yields the following equation presented by Wahlberg and Keinath:

$$Gs = X_i \cdot 11.2 \cdot e^{[-0.000009 \cdot SVI - (0.306 + 0.00057 \cdot SVI) \cdot X_i]} \quad (5)$$

Daigger developed a best-fit relationship for a combined data set using the following equation suggested by Wahlberg (1988).

$$\ln V_s = \ln V_o - (k_1 + k_2 \cdot SVI) \cdot X_i \quad (6)$$

This equation can also be represented as a settling flux, Gs, by the multiplying the setting velocity and solids concentration.

$$Gs = X_i \cdot Vo \cdot e^{[-(k_1 + k_2 \cdot SVI) \cdot X_i]} \quad (7)$$

Average model parameters ln Vo, k_1, and k_2 generated for the SVI and their standard deviation was reported by Daigger:

$$\ln Vo = 1.871 \pm 0.546 \text{ m/h}$$
$$k_1 = 0.1646 \pm 0.0070 \text{ L/g}$$
$$k_2 = 0.001586 \pm 0.000546 \text{ L/mL}$$

Substituting these model parameters into Equation 6 yields the following:

$$\ln V_s = 1.871 - (0.1646 + 0.001586 \cdot SVI) \cdot X_i \quad (8)$$

Equation 2 was used to generate a settling flux curve for each data set by plotting Gs as a function of Xi, Vo, and K. A second flux curve was generated using Equation 7. The model parameters Vo, k_1, and k_2 were generated for the seven refinery runs by adjusting the three parameters to obtain a minimum of squared differences between the two models using Daigger's original parameters as the starting parameters. Table 3 demonstrates the calculated model parameters for each of the settling test.

Table 3. Daigger refinery model parameter estimates

Refinery-run	Vo	ln Vo	k_1	k_2
	(m/h)	(m/h)	(L/g)	(L/g)
A-1	9.97	2.30	0.2383	0.002339
B-1	9.26	2.23	0.1915	0.002339
B-2	9.79	2.28	0.1767	0.001681
C-1	11.86	2.47	0.1951	0.001862
C-2	12.51	2.53	0.2106	0.001946
D-1	15.53	2.74	0.1633	0.001491
D-2	9.46	2.25	0.1262	0.001153
Average	11.196	2.40*	0.18598*	0.001830
Standard deviation	2.283	0.19	0.03567	0.000434

* Outside mean -± standard deviation of original Daigger parameters.

Substituting the revised model parameters in Equation 7 yields the following:

$$\ln V_s = 2.40 - (0.1860 + 0.00183 \cdot SVI) \cdot X_i \quad (9)$$

A settling flux curve was generated using the original model parameters and the revised model parameters generated with the refinery biomass. Figures 2 and 3 illustrate the flux curve generated for an SVI of 100 mL/g for the original and revised Wahlberg and Keinath and Daigger parameters, respectively.

Figure 2. Settling flux curves using original and revised Wahlberg and Keinath model parameters

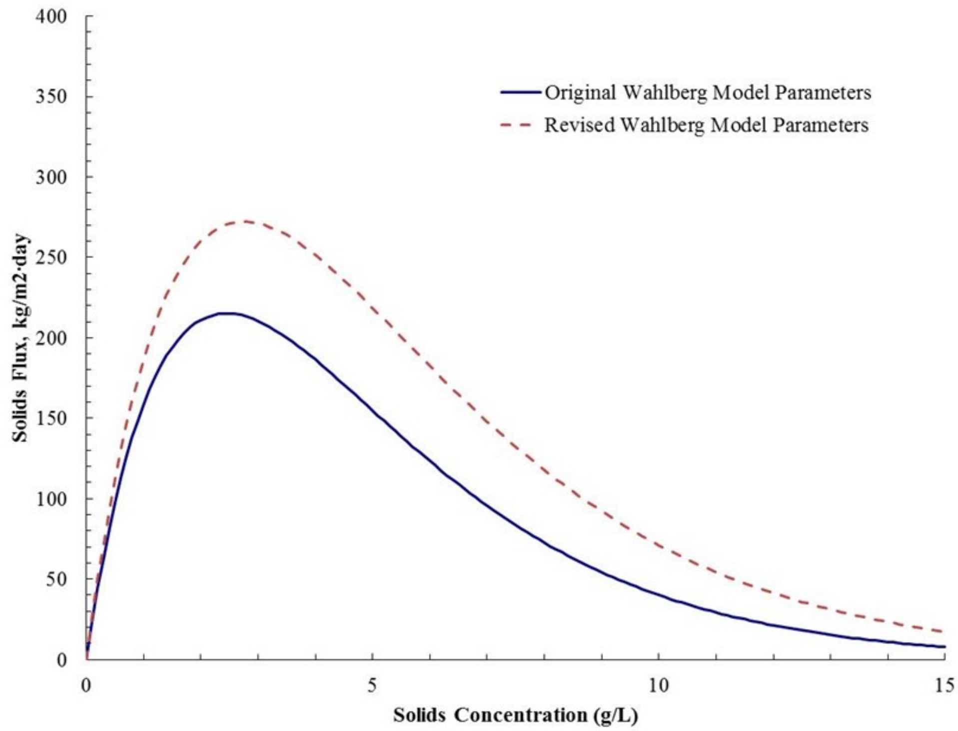
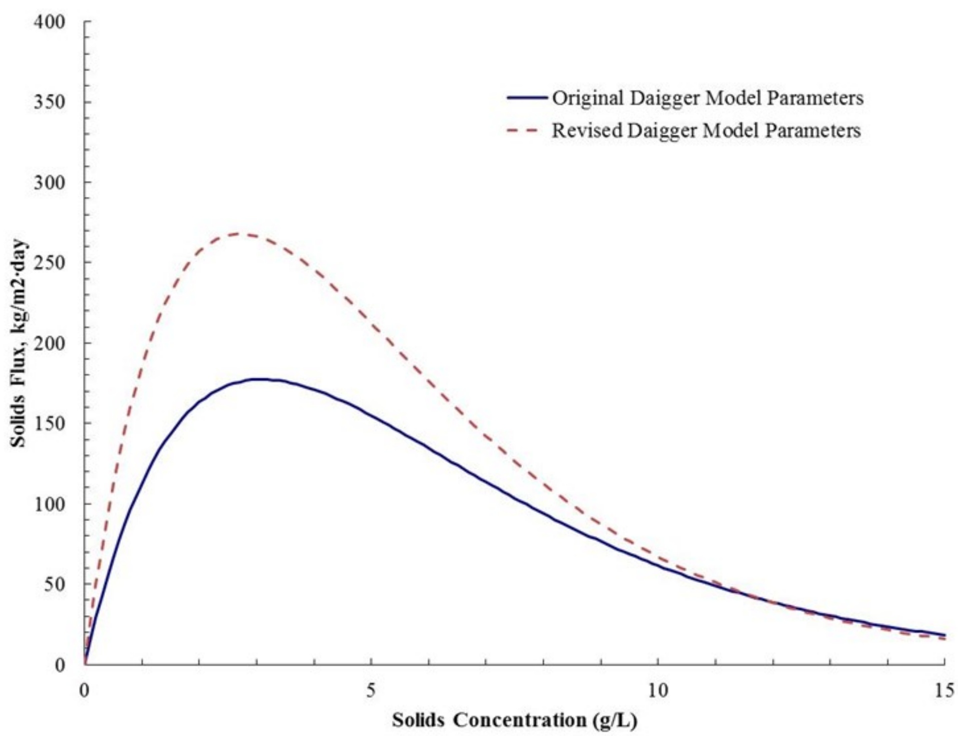


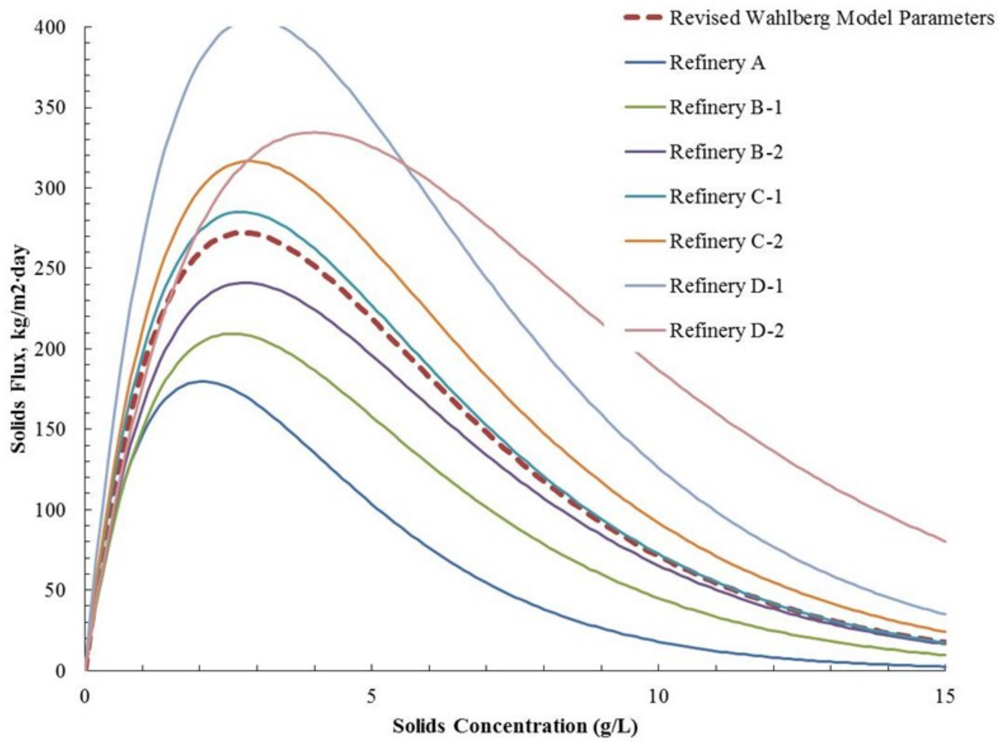
Figure 3. Settling flux curves using original and revised Daigger model parameters



Both curves indicate the refinery biomass has greater settling properties compared to the settling properties the previous models indicated.

Figure 4 presents the individual derived Wahlberg and Keinath model parameters plotted at an SVI of 100 mL/g (Table 2) as well as the combined revised Wahlberg and Keinath parameters for the same SVI (Equation 5).

Figure 4. Settling flux curves using refinery-specific derived Wahlberg model parameters and revised combined model parameters



As demonstrated, there is a significant variation in the settling flux curves generated for each refinery compared to the combined parameters.

SUMMARY AND CONCLUSIONS

Seven separate model runs using biomass from refinery wastewater treatment facilities were used to evaluate the existing relationships for generating settling flux curves from SVI data. This comparison developed revised model parameters for refinery biomass, as expressed in Equation 5:

$$Gs = X_i \cdot 11.2 \cdot e\text{^}[- 0.000009 \cdot SVI - (0.306 + 0.00057 \cdot SVI) \cdot X_i]$$

This revised correlation can be used for better insight on clarifier capacity and operation at a refinery activated sludge treatment facility than could be discerned with prior published correlations. However, the variation in refinery model predicted settling flux data and actual data is significant and warrants careful consideration when using a correlation.

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