Hydrodynamic evaluation of the influence of outlet configuration for mechanical flocculation facilities
J. L. Cestari, T. Matsumoto, D. Gebara, M. Dall’Aglio Sobrinho and M. Libânio

ABSTRACT
This paper focuses on hydrodynamic research aiming at the short-circuit evaluation of five different outlet configurations through the compartments of a mechanical flocculation unit of vertical shaft with mixing paddles at pilot scale. The tests were carried out with two, three and four compartments, variable and constant velocity gradients, including alternating senses of paddle rotation (clockwise in the first compartment, anticlockwise in the following one and so on). The research pointed out that the relevance of outlet configuration increases with the reduction of the number of compartments. In opposite, the velocity gradient and the sense of the paddle rotation seem less significant features. These results suggest the possibility of a viable increasing of performance, with low financial investments, mainly for flocculation units with three or two compartments installed in overloaded water treatment plants.

Key words | hydrodynamic evaluation, mechanical flocculation, model of series of stirred tanks, outlet configuration, short-circuit, water treatment

INTRODUCTION AND RELEVANCE
The mechanical flocculation units are designed as a plug flow reactor where each destabilized particle remains for the same theoretical detention time to contact each other, forming flocs and afterwards being removed by sedimentation, dissolved air flotation or even filtration. However, simultaneously, water entering and also being removed from the flocculator results in different detention times among destabilized particles. In this way, the short-circuit that comprises the reduction of the theoretical detention time can be detrimental in terms of floc characteristics and, in the final instance, also reduces the filter runs or even leads to deterioration of the final water quality.

The short-circuit effects are indirectly considered in recommendations of the Brazilian Technical Standards Association (ABNT 1992) for the design of mechanical flocculation facilities implanted in water treatment plants. For this kind of flocculation unit and without experimental tests, the theoretical detention time is established as between 30 and 40 minutes and the number of compartments is commonly three or four. For hydraulic flocculators, usually used in small plants, this design parameter can be reduced to between 20 and 30 minutes due to the number of compartments usually adopted being higher than eight. However, concerning the outlet configuration, there is just a vague mention to avoid a direct flow through the compartments of the mechanical flocculation unit. In a similar context, it is relatively usual in the operational routine of mechanical flocculators in Brazilian plants to invert the sense of rotation of the paddles in successive compartments (clockwise and anticlockwise).

According to Levenspiel (1999) and Lawler (2011), the fluid elements adopt different fluid paths running through the reactor and, consequently, remain for different times inside reactor. Thus, the distribution of these residence times for the fluid stream that leaves the reactor is named the exit age distribution (E) or residence time distribution (RTD). In fact,
the RTD translates into a description of how long different destabilized particles (or molecules of water) remain in the reactor. Tracers are typically used to obtain RTD curves, assuming that tracer behaviour is the same as that of coagulated water. It is suitable to convert the RTD curve into $E_\theta$ (exit age distribution), eliminating the effect of the mass of the tracer during the tests. These curves are shown in Figure 1.

For mechanical flocculation units, the RTD curve describes the distribution of times that destabilized particles (or the coagulated water) remain in the reactor and can be used to estimate the probability of contacts.

The simplest and most direct way to determine the $E$ curve is to analyze the use of a physical and non-reactive tracer in a reactor. To find the $E$ curve for a reactor with volume $V$, through which a fluid flows with flow rate $Q$, it is useful to apply in the influent $M$ units of a tracer and record the concentration that leaves the reactor. Thus, after obtaining the concentration–time curve, it may be possible to calculate the area ($A$) below the curve, as shown in Equation (1):

$$A = \int_0^\infty Cdt \approx \sum_i c_i \cdot \Delta t_i = \frac{M}{Q}$$

in which:

$c_i$: concentration of the tracer at time $i$;
$\Delta t_i$: time interval.

The average residence time ($t_m$) can be determined by means of Equation (2):

$$t_m = \frac{\int_0^\infty tCdtdt}{\int_0^\infty Cdt} = \frac{\sum_i t_i c_i \Delta t_i}{\sum_i c_i \Delta t_i} = \frac{V}{Q}$$

To find the $E$ curve from the concentration–time curve, it is necessary to change the concentration scale, so that the area under the curve is equal to unity. In this way, the concentration data will be divided by $M/Q$, as depicted in Equation (3):

$$E_i = \frac{c_i}{M/Q} \approx \frac{c_i}{\sum_j c_j \Delta t_j}$$

Another way of viewing the RTD curve comes from the mentioned conversion of the $E$ curve to the function $E_\theta$, that makes the time-scale dimensionless by applying the parameter $\theta$ (dimensionless residence time, $\theta = t/t_m$). This procedure brings the undoubted advantage of allowing comparison of the possibility of short-circuit occurrence between different reactors, without the need for theoretical residence time. In other words, the use of these parameters makes less relevant the knowledge of the reactor dimensions and the inflow rate. Thus, this function is obtained as shown in Equation (3) and is exemplified in Figure 1(b).

According to Levenspiel (1999), mathematical models are useful for representing flows in reactors, making it possible to compare the experimental curves with the ideal flow model. In flocculation units, where short-circuits, dead zones or recycling of fluid take place, the RTD experimental curves usually present anticipated peaks in relation to the theoretical residence time, long tails and fluctuations in the curve.

For this paper, the model of the series of stirred tanks was chosen because it represents the flow through in the mechanical flocculation units. In this model, a number of tanks ($N$) of the same volume is established and the mixing degree is characterized by this number of tanks. Thus, a greater number of tanks relates to a lower mixing degree, and for an infinite number the plug flow will prevail.

Figure 1 | (a) RTD curve and (b) $E$ curve conversion to $E_\theta$ curve (Levenspiel 1999).
The ideal curve for this model is described by Equation (4):

$$E_\theta = N \left( \frac{N \theta^{N-1}}{(N-1)!} \right) e^{-N \theta}$$

Aiming at reactor performance optimization, advances in the area of computational numerical models have led to the growth of applications of computational fluid dynamics (CFD). The use of detailed flow modelling, coupled with Lagrangian description of particle trajectory, allows information to be used such as the distribution of residence times. This information can be used to describe the hydraulic reactor and to predict the efficiency of the chemical reactions that occur, for example, in disinfection reactors. Although the most common studies with CFD are still applied to reaction tanks (Zhang et al. 2007; Wols et al. 2008; Wols et al. 2010) and hydraulic flocculation units (Liu et al. 2004; Karches 2012), due to the simplicity of the flow modelling, there are already simulators with mechanical mixers (Bridgeman et al. 2010). Thus, any type of flocculation facility can currently be modelled with CFD tools.

Rauen et al. (2012) consider that the CFD models have become indispensable tools for studies on contact tank optimization with experimental practice persisting as a supply of data for calibration of the models. In this way, despite the undeniable progress that can be expected from the improvement of CFD modelling, the use of experimental models is still relevant for validating the results of the numerical code. Normally this validation is carried out by means of reproduction of the RTD curves obtained experimentally. As shown by Wols et al. (2010), among others, the reproduction of the RTD curves by the CFD model is a strong indication that other variables predicted by the numerical model are reliable.

Assuming that the tests with tracers are still the reference for the hydraulic characterization of reactors, this work proposes an experimental study of a mechanical flocculation unit. From a similar point of view, also supporting the methodological approach of this research, Heller (2011) considers that the physical models are still an important tool, although the scale effects that arise due to the force ratios are not identical between the model and the real prototype.

**OBJECTIVES**

According to these concepts, the main objective of this paper consists in carrying out a hydrodynamic evaluation at a pilot scale of a mechanical flocculation unit aiming to assess the short-circuit magnitude and to fit the experimental results to the model described by Equation (4). In the same context in terms of short-circuit magnitude, the paper also intends to evaluate the influence of:

(i) the outlet configurations between the compartments;
(ii) the value and variation of the velocity gradients;
(iii) the sense of paddle rotation (clockwise and anticlockwise).

**METHODS**

**Experimental apparatus**

For this proposal, a continuous flow mechanical flocculation unit was constructed at pilot scale using transparent acrylic (10 mm thickness) with four compartments of 144 L each, square bases of 0.6 m side, 0.4 m depth and square outlets of 0.1 m side. The vertical shafts with parallel paddles were constructed in aluminium with 0.35 m length and 25 mm width, each one connected to a motor as shown by Figure 2. The tests were performed with two, three and four compartments.

**Outlet configurations**

Between the compartments there were four different positions of outlets and it was possible to close three positions (with acrylic and silicone), keeping only one open. For better comprehension of the figures, small letters have been adopted for the lower outlets (left and right) and capital letters for the higher outlets (Left and Right on the flow direction as illustrated in Figure 3). This figure shows four out of the five outlet configurations for the mechanical flocculation unit with four compartments. The paddles have been omitted for better understanding of the drawings. For the fifth outlet configuration the tests were performed using a square baffle of 0.1 m side installed 0.1 m from the outlet (receiving the
code I/I/I/I for the four-compartment pilot unit). The objective of this baffle was to impel the flow upward in a similar way to some hydraulic flocculation facilities.

**Experimental tests**

The hydrodynamic evaluation was done by means of electric conductivity measurements. Three laboratory bench conductivity meters were used (Analion mod. C708, Digimed mod. DM3, Analyser mod. 650), with automatic compensation of temperature and precision better than 1.5% of the readings. One of the meters was connected to a computer and the readings of the other two were manually registered. Calibration curves of tracer concentration as a function of conductivity were made for each combination of meter and probe used in the tests. The calibration curves are practically linear in the range of experimental readings, with correlation coefficients better than 0.998. The calibration was checked before each tracer test with standard conductivity samples.

For each test the tracer solution, applied in a pulse input, was prepared with 25 g of sodium chloride, 84 mL of ethanol and distilled water. The use of ethanol was aimed at controlling the density of saline solution, and avoiding flow stratification and tracer accumulation in the bottom, according to recommendations in the technical literature (Hudson Jr 1975; Teefy 1996; Lawler 2011).

The discharge time of the pulse input tracer test was approximately 25 s for all tests. This time is less than 3% of the lowest theoretical detention times adopted for two compartments (14.8 minutes) basing on the constant inflow rate of 19.5 L.min⁻¹. In these circumstances, the highest velocity through the outlets was 3.3 cm.s⁻¹, resulting in velocity gradients less than 5 s⁻¹. In this context, there is a recommendation that the velocity gradient through the outlets must be lower than the velocity gradient inside the compartment, minimizing breakup or disaggregation of the formed flocs.

The readings were registered with one-minute time intervals. The conductivity probes were installed near the geometric centre of the outlets, with a horizontal spacing of approximately 15 mm downstream of the opening.

For each outlet configuration, the tests evaluated the influence of the sense of paddle rotation and the variability or constancy of velocity gradients. The adopted velocity gradient values are typical in design of water treatment plants worldwide. For example, the Brazilian Technical Standards Association (ABNT 1992) recommends flocculation velocity gradients from 10 s⁻¹ to 70 s⁻¹.

In such a way, five scenarios were established as follows:

(i) **Scenario 1** in which same anticlockwise rotation of the paddles and variable velocity gradients were adopted. In this way, for four compartments the

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**Figure 2** | Experimental apparatus used for hydrodynamic evaluation (dimensions in metres).
sequence was 70 s⁻¹, 50 s⁻¹, 35 s⁻¹ and 20 s⁻¹, for three compartments it was 50 s⁻¹, 35 s⁻¹ and 20 s⁻¹, and for two compartments the sequence was 35 s⁻¹ and 20 s⁻¹.

(ii) **Scenario 2** in which an alternating sense of paddle rotation (clockwise and anticlockwise successively) and variable velocity gradients were adopted (the same as **Scenario 1**).

(iii) **Scenario 3** in which the same sense of paddle rotation (anticlockwise) and constant velocity gradients (35 s⁻¹) were adopted. This value is very usual for constant velocity gradients in flocculation units at actual scale.

(iv) **Scenario 4** in which an alternating sense of paddle rotation (clockwise and anticlockwise) and constant velocity gradients (35 s⁻¹) were adopted.

(v) **Scenario 5** in which the agitators were turned off during the test.

One test was carried out for each scenario, for each outlet configuration and for four, three and two compartments. In this context, for estimating the RTD of a...
mechanical flocculation unit at pilot scale with four, three and two compartments, with five distinct scenarios described above and five outlet configurations, 25 tests were performed for each number of compartments (four, three and two), totalling 75 pulse input tracer tests.

STATISTICAL ANALYSES OF EXPERIMENTAL RESULTS

The data analysis was carried out based on the mentioned methodology proposed by Levenspiel (1999) and Lawler (2011). The experimental curves of tracer concentrations were normalized obtaining the exit age distribution curves using the dimensionless time parameter (θ), the ratio between sampling time and the theoretical detention time. These curves were adjusted to the theoretical model of the series of stirred tanks. The fitness criterion was the sum of the squared errors (SSE) between the model and the experimental curves.

The statistical analysis of the deviations of experimental data relating to the ideal curve of the model of series of stirred tanks was done using a comparison among the means of SSE by significance tests of difference of means. The confidence interval used for rejection of the null hypothesis was 95%. However, for small samples, the sample standard deviation is not a good estimation of the population standard deviation. Thus, the t-distribution (Student) was applied because in this case it is not possible to remove a large number of samples to determine the confidence interval of the sample means. For the hypothesis test focusing on difference of means, these have been grouped two by two, and tested according to the usual procedure of the t-test for differences between two means with different sample numbers. The F-test (Fisher) was also used as additional information. Tests were carried out with all the experimental data without the elimination of extreme values.

RESULTS AND DISCUSSION

Absence of rotation (Scenario 5)

First of all, it is important to emphasize the high recovery ratios of tracer obtained for all tests whose range was from 85% to 95%. These results are considered good or excellent according to Teefy (1996). The curves were normalized in terms of M/Q as mentioned in Equation (3).

The first evaluation comprised comparison among the five configurations when the agitators were turned off during the test (Scenario 5), an atypical situation mainly due to the maintenance of the equipment. Some experimental results are shown in Figure 4. In this circumstance, these results were presented only for four and three compartments, in which was possible to note the difference among tracer detention times of the five outlet configurations.

The RTD curves illustrated in Figure 4 showed the superiority of the fifth outlet configuration (I/I/I/I/I) and these results suggest the possibility of minimizing short-circuit effects in mechanical flocculation facilities at actual scale whose agitators are out of service. On the other
hand, these results pointed out the inadequacy of the fourth configuration whose outlets are in the same position in the bottom of the unit (llll), with the peak of tracer concentration appearing in less than 10% of θ. The experimental tests with two compartments presented similar results.

Velocity gradient and sense of rotation

As mentioned in the methodology, the next step in the experimental tests was to evaluate the influence of the velocity gradient (constant or variable) and the sense of rotation of the agitators on short-circuit effects. In order to be brief, the results for two of the five outlet configurations are shown in Figure 5 for four compartments and four scenarios.

Similarly to the RTD curves shown in Figure 5, the other three configurations demonstrated the irrelevance of these parameters on the magnitude of short-circuits when the flocculation facility has four (or more) compartments. The RTD curves for three and two compartments showed more dispersion than observed with four compartments, pointing out the increasing influence of the agitators’ operational parameters (velocity gradient and sense of rotation) with the diminution of the number of compartments. Although the influence of the agitation scenario is apparent to some extent in the observed dispersions of the RTD curves for three and two compartments, it is not easy to visually identify the best combination of scenarios of agitation and configuration of the outlets.

In the general way, the RTD curves for four, three and two compartments and for five outlet configurations showed that the sense of rotation and the velocity gradient become more relevant whereas the number of compartments decreases.

Fitness analysis of the experimental results to the model of the series of stirred tanks

The SSE of the RTD curves for four compartments (T = 29.5 minutes) and for five outlet configurations in comparison with the curve obtained from the model of four stirred tanks in series are presented in Table 1.

The analysis of the SSE indicates that the reduction of this value increases the fitness of the experimental curve to the model curve for the series of stirred tanks. In this context, once more, the fifth configuration with square baffles presented the best adherence to the model as shown by Table 1. The results obtained for three and two compartments presented the same tendency. The descriptive statistics shown in Table 2 aimed to corroborate these SSE values.

The results stated in Table 2 make a forceful statement difficult due to the high coefficients of variation. Thus, t- and F-tests of hypothesis were performed to determine whether the differences between the means of SSE are in fact significant. In the significance test the square root of the SSE was considered, in order to minimize errors, and also the results with agitators turned off. In this way, 15 tests for each configuration (five scenarios and flocculation units with four, three and two compartments) were carried out.

Through the results of t- and F-tests of hypothesis at the 95% significance level, it was possible to evaluate the

![Figure 5](https://iwaponline.com/ws/article-pdf/16/1/17/413008/ws016010017.pdf)
significance of the differences between the means of outlet configurations based on ten comparisons (N), as shown in Table 3. For each test ($t$ and $F$), the term $H_0$ represents the hypothesis that the means are equal.

As shown in Table 3, the differences between the means were not significant at 95% significance level for almost all comparisons, probably due to the high values of the standard deviations. For example, in practice, although the configuration $IRIRI$ (0.55) was better fitted to the model of the series of stirred tanks than the configuration $ILILI$ (0.85), the tests indicated that this difference can be attributed to chance, that is, the repetition of the tests will probably not lead to the same results.

Based on Table 3, it is possible to affirm that the configurations $IRIRI$ (0.55) and $I/1/I/1/I$ (0.37) fit better than configuration $ILILI$ (0.85) to the model of the series of stirred tanks. This statement indicates that for a flocculation facility with four, three or two compartments and with the studied outlet configurations the short-circuit effects and formation of dead zones will be less significant.

Finally, it should be pointed out that possible scale-up effects were not considered in the preceding analysis. However, considering that in the four scenarios with agitators turned on there is a good fit to the complete mixing model, it can be stated that relevant scale-up effects were not expected. This conclusion is supported by results presented by Teixeira & Rauen (2014), showing no significant scale effect in tanks with a flow pattern approaching complete mixing. On the other hand, with agitators turned off (Scenario 5), the flow pattern in the tanks indicated by Figure 4 is between plug flow and complete mixing. In this case, following Teixeira & Rauen (2014),

Table 1 | Sum of square errors of the RTD curves for four compartments (highlighting in bold the lowest values for each scenario)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>ILILI</th>
<th>IRIRI</th>
<th>lrlrl</th>
<th>lllll</th>
<th>l/l/l/l/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2888</td>
<td>0.1086</td>
<td>0.0512</td>
<td>0.1574</td>
<td>0.0905</td>
</tr>
<tr>
<td>2</td>
<td>0.3217</td>
<td>0.1353</td>
<td>0.1317</td>
<td>0.0772</td>
<td>0.0692</td>
</tr>
<tr>
<td>3</td>
<td>0.3211</td>
<td>0.1676</td>
<td>0.1504</td>
<td>0.0850</td>
<td>0.0732</td>
</tr>
<tr>
<td>4</td>
<td>0.1929</td>
<td>0.2026</td>
<td>0.0742</td>
<td>0.0935</td>
<td>0.0788</td>
</tr>
</tbody>
</table>

Table 2 | Descriptive statistics of the sum of square errors for all outlet configurations

<table>
<thead>
<tr>
<th>Statistical parameter</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.85</td>
<td>0.55</td>
<td>0.44</td>
<td>1.06</td>
<td>0.36</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.57</td>
<td>0.27</td>
<td>0.39</td>
<td>1.61</td>
<td>0.36</td>
</tr>
<tr>
<td>Coefficient of variation (%)</td>
<td>67</td>
<td>50</td>
<td>87</td>
<td>152</td>
<td>67</td>
</tr>
</tbody>
</table>

Configuration A – Represents the outlet configurations ILILI, ILIL and ILI.
Configuration B – Represents the outlet configurations IRIRI, IRIR and IR.
Configuration C – Represents the outlet configurations lrlrl, lrlr and lrl.
Configuration D – Represents the outlet configurations lllll, llll and lll.
Configuration E – Represents the outlet configurations l/l/l/l/l, l/l/l/l and l/l/l.

Table 3 | Results of significance test for difference between the means of sum of square errors

<table>
<thead>
<tr>
<th>$N$</th>
<th>Config. 1</th>
<th>Mean</th>
<th>SD</th>
<th>Config. 2</th>
<th>Mean</th>
<th>SD</th>
<th>$t$</th>
<th>$t_{max}$</th>
<th>Reject $H_0$</th>
<th>$F$</th>
<th>Fmax</th>
<th>Reject $H_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ILILI</td>
<td>0.85</td>
<td>0.57</td>
<td>IRIRI</td>
<td>0.55</td>
<td>0.28</td>
<td>1.86</td>
<td>2.05</td>
<td>N</td>
<td>3.45</td>
<td>4.20</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>ILILI</td>
<td>0.85</td>
<td>0.57</td>
<td>lrlrl</td>
<td>0.45</td>
<td>0.39</td>
<td>2.25</td>
<td>2.05</td>
<td>Y</td>
<td>5.07</td>
<td>4.20</td>
<td>Y</td>
</tr>
<tr>
<td>3</td>
<td>ILILI</td>
<td>0.85</td>
<td>0.57</td>
<td>lllll</td>
<td>1.06</td>
<td>1.62</td>
<td>0.47</td>
<td>2.05</td>
<td>N</td>
<td>0.22</td>
<td>4.20</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>ILILI</td>
<td>0.85</td>
<td>0.57</td>
<td>l/l/l/l/l</td>
<td>0.37</td>
<td>0.25</td>
<td>3.01</td>
<td>2.05</td>
<td>Y</td>
<td>9.06</td>
<td>4.20</td>
<td>Y</td>
</tr>
<tr>
<td>5</td>
<td>IRIRI</td>
<td>0.55</td>
<td>0.28</td>
<td>lrlrl</td>
<td>0.45</td>
<td>0.39</td>
<td>0.85</td>
<td>2.05</td>
<td>N</td>
<td>0.72</td>
<td>4.20</td>
<td>N</td>
</tr>
<tr>
<td>6</td>
<td>IRIRI</td>
<td>0.55</td>
<td>0.28</td>
<td>lllll</td>
<td>1.06</td>
<td>1.62</td>
<td>1.21</td>
<td>2.05</td>
<td>N</td>
<td>1.46</td>
<td>4.20</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>IRIRI</td>
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<td>0.28</td>
<td>l/l/l/l/l</td>
<td>0.37</td>
<td>0.25</td>
<td>2.01</td>
<td>2.05</td>
<td>N</td>
<td>4.03</td>
<td>4.20</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>lrlrl</td>
<td>0.45</td>
<td>0.39</td>
<td>lllll</td>
<td>1.06</td>
<td>1.62</td>
<td>1.43</td>
<td>2.05</td>
<td>N</td>
<td>2.04</td>
<td>4.20</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>lrlrl</td>
<td>0.45</td>
<td>0.39</td>
<td>l/l/l/l/l</td>
<td>0.37</td>
<td>0.25</td>
<td>0.69</td>
<td>2.05</td>
<td>N</td>
<td>0.47</td>
<td>4.20</td>
<td>N</td>
</tr>
<tr>
<td>10</td>
<td>lllll</td>
<td>1.06</td>
<td>1.62</td>
<td>l/l/l/l/l</td>
<td>0.37</td>
<td>0.25</td>
<td>1.65</td>
<td>2.05</td>
<td>N</td>
<td>2.71</td>
<td>4.20</td>
<td>N</td>
</tr>
</tbody>
</table>
some scale effects can be expected since flow was in non-turbulent conditions.

CONCLUSIONS

It is possible to draw the following conclusions, anchored in the evaluated mathematical models, the experimental results and the statistical analyses:

- The influence of the sense of paddle rotation, the constancy or variability of velocity gradients and, mainly, the outlet configurations over the RTD curves increased with the reduction of the number of compartments. For a mechanical flocculator with four compartments this influence appeared almost not to be expressed, increasing the relevance of the other features for flocculation efficiency.

- When the agitators were turned off, the outlet configuration showed its high relevance, suggesting the installation of baffles after the outlets as a suitable solution to minimize the short-circuit effects at actual scale. With the baffles, this outlet configuration presented hydrodynamic performance practically identical with the other configurations usually adopted by water treatment plant designers.

- At the 95% level of significance, the \( L_H/N \) and \( I/I/I/I/I \) configurations presented a better fit to the model of the series of stirred tanks than the \( I/I/I/I/I \) configuration for a flocculation unit with four, three or two compartments. This fact indicates that short-circuit effects and formation of dead zones will be less pronounced.

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