

STUDY OF MICROMIXING IN A STIRRED TANK USING A RUSHTON TURBINE: COMPARISON OF FEED POSITIONS AND OTHER MIXING DEVICES

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The consecutive-competing iodide-iodate reaction scheme has been used to study micromixing phenomena in a baffled vessel of 0.29 m diameter agitated by a Rushton turbine. It has been confirmed that by using successive injections, this reaction scheme is very efficient for such a study. Four agitator speeds giving $\tilde{\alpha}_T$ from ~ 0.2 W/kg to ~ 1.2 W/kg have been used, with sub-surface feeding at one of four points. For a given speed, these points give four different local values of ϵ_T , ranging from less than $\tilde{\alpha}_T$ very close to the top of the liquid to much greater close to the impeller. The point closest to the impeller was chosen to be such that feeding was estimated to be at the point of maximum ϵ_T . For the maximum speed, the segregation index, as a measure of the amount of 'waste product', was $\sim 20\%$ with feed at the top of the liquid (as preferred industrially because of its convenience). This 'waste' was reduced to $\sim 5\%$ by feeding at the point of maximum ϵ_T close to the impeller. A comparison was also made with results reported in the literature using the same reaction for two new devices developed for improved micromixing. By feeding at the carefully chosen position close to the impeller, the results with the Rushton turbine were as good as or better than with the special devices even at the comparatively low $\tilde{\alpha}_T$ of ~ 1.2 W/kg. It was estimated that the maximum local specific energy dissipation rate was ~ 70 times the mean, in reasonable agreement with a very recent study where the same pair of reactions and LDV were both used.

Keywords: stirred vessel, segregation index, micromixing time, feed location, Rushton turbine

INTRODUCTION

Study of mixing at the molecular scale (micromixing) gives an indication of the best way to carry out important processes such as polymerization, crystallization and competing fast chemical reactions. Therefore, a lot of work in the last few years has been done on micromixing, developing experimental methods¹⁻³ to characterize it. In the case of semi-batch, parallel competing or consecutive reactions, many factors influence the product distribution¹. Figure 1 summarizes the general trend⁴ between the segregation index X_s (see below for the precise definition of X_s for this work) which relates to the product distribution, and the Damköhler number, Da , which is a measure of the reaction rate compared to the rate of micromixing. At low values of X_s , less unwanted material is produced and this is achieved by having low Da values. Da is itself reduced by a relatively low rate constant for the reaction leading to the undesired product, a low reactant concentration in the feed and a high local specific energy dissipation rate, ϵ_{δ} , as the latter enhances micromixing. In the past few years, experimental techniques like LDV and PIV have significantly improved giving more reliable values of local specific energy dissipation rate, ϵ_{δ} , from which, utilizing Kolmogorov's theory, the local micromixing time, t_m , can be calculated¹. Alongside these experimental studies, much modeling work has been undertaken especially by Baldyga and

Bourne^{1,4} and by Villermaux and co-workers⁵⁻⁹. Finally, very recently, chemical reactors of special geometry have been proposed specifically to give enhanced micromixing^{7,10}.

In the present work, micromixing has been studied under semi-batch conditions in a stirred tank equipped with a Rushton turbine using the iodide-iodate technique². Recently, Guichardon and Falk¹¹ suggested the use of successive injections with this technique which increases its flexibility. Firstly, the validity of the modified technique is tested here. Earlier work shows that if the feed rate into the semi-batch reactor is too high, the segregation index becomes a function of that rate. This phenomenon is known as mesomixing¹. Secondly, therefore, experiments were undertaken to ensure that mesomixing was not involved here and that micromixing is the controlling mechanism. Finally, a wide range of feed points have been used including the upper trailing vortex region of the Rushton impeller¹²⁻¹⁵ in order to utilize the highest local specific energy dissipation rate, ϵ_{δ} . The results have been compared to other literature results with Rushton turbines^{11,16,17} and with the new devices for micromixing^{7,10}. In order to make such comparisons, estimation of the mixing parameters used in the literature such as micromixing time, t_m , and its relationship to the local specific energy dissipation rate, ϵ_{δ} , have had to be considered.

EXPERIMENTAL

EXPERIMENTAL RIG AND AGITATION CONDITIONS

Experiments were carried out at 20 °C in a temperature-controlled, cylindrical Perspex vessel (Figure 2), diameter $T = 0.29$ m with four baffles of width $B = T/10$. The tank was equipped with a standard Rushton turbine and the dimensions of both are given in Table 1. The experiments were carried out with an aspect ratio $H/T = 1.3$ in order to prevent surface aeration which could not be avoided at an aspect ratio of 1, even at the modest specific power input of ~ 1 W/kg. Four different rotational speeds have been investigated giving four mean specific energy dissipation rates, $\bar{\alpha}_T$, as determined by a torque/air bearing technique¹⁸.

Table 1 Dimensions of the tank

T (m)	V (m ³)	D (m)	H (m)	C (m)	x (m)
0.29	0.0249	0.0967	0.377	0.0725	0.0033

The tank was fitted with a lid that was used to hold the pH probe and a stainless steel pipe which secured the glass injection tube (internal diameter $d = 0.75$ mm). This lid and device were specially designed to minimize vibration and movement of the injection tube due to the forces arising from the rotating impeller. The feeding device itself can slide along a slot positioned midway between baffles along a radius to give a very accurate definition of the injection position inside the tank. The accuracy is necessary because the local energy dissipation rate is very sensitive to position very close to the impeller¹⁹. Altogether four injection positions were used as shown in Figure 2 and their exact coordinates in Table 2. Two were near the top of the vessel as favored by industry because of its convenience and one was close to the impeller near the wall as used by many others authors. For the fourth point, for the first time, injection into the trailing vortex was used.

Table 2 Coordinates of the injection positions

	Position <1>	Position <2>	Position <3>	Position <4>
$2r/D$	2.4	2.4	2.4	1.02
z/H	0.92	0.80	0.27	0.22

THE TEST REACTION

The iodide-iodate method² used in this work is based on a competitive parallel reaction and is described by the following scheme:



where the first reaction involves an instantaneous acid-base neutralization to give the desired product and the second one is the Dushman reaction giving the undesired product, here iodine. The kinetic of the second reaction has been determined recently²⁰ as

$$r = k(\text{H}^+)^2(\text{I}^-)^2(\text{IO}_3^-) \quad (3)$$

where the constant k depends on the ionic strength μ , so that

$$\text{for } \mu < 0.166 \text{ M } \log_{10}(k) = 9.28105 - 3.664\sqrt{\mu} \quad (4)$$

$$\text{for } \mu > 0.166 \text{ M } \log_{10}(k) = 8.383 - 1.5112\sqrt{\mu} + 0.23689\mu \quad (5)$$

The iodine formed further reacts with iodide to form triiodide according to the quasi-instantaneous equilibrium:



The test consists of adding a quantity of H_2SO_4 , at the chosen injection point, to a mixture of KI , KIO_3 and H_2BO_3^- . Under perfect micromixing conditions H_2SO_4 is instantaneously consumed by the first reaction which is faster than the second one. On the other hand, if rapid mixing of H_2SO_4 is not achieved down to the molecular scale, there will be formation of local aggregates of acid which can react with KI and KIO_3 giving I_2 and I_3^- . Therefore the analysis of I_3^- can be directly related to the segregation index (see below).

The concentration of I_3^- is determined from the optical density D_λ of the bulk measured at the end of the acid injection:

$$(\text{I}_3^-) = \frac{D_\lambda}{\epsilon_\lambda l} \quad (7)$$

where ϵ_λ is the extinction coefficient of the I_3^- at 353 nm and l is the optic distance of the cuvet equal to 1 cm.

As conducted here, successive injections have been used as developed recently¹¹. This approach allows the same batch to be used for a series of measurements. In the method, the first injection of acid is followed by analysis of I_3^- to obtain X_S (i.e. segregation index - see below) for those agitation conditions. A second injection of acid is then added to the bulk and the analysis for X_S is again carried out, up-dating the reactant concentration and so on.

The majority of experimental work has been carried out with the following reactant concentrations which have been adopted from the work of Guichardon and Falk¹¹:

$$(\text{H}_3\text{BO}_3)_0 = 0.1818 \text{ M}$$

$$(\text{NaOH})_0 = 0.0909 \text{ M}$$

$$(\text{I}_2)_{\text{potential}} = 3(\text{IO}_3^-)_0 = \frac{3}{5}(\text{I}^-)_0 = 7 \cdot 10^{-3} \text{ M}$$

$$(\text{H}_2\text{SO}_4)_0 = 0.5 \text{ M and } 1.0 \text{ M}$$

Of the two acid concentrations used, only few of the results were obtained with an acid concentration of 1.0 M. Also, for the majority of the experiments, the volume of the acid added followed the literature¹¹ and varied from 50 ml for the case of successive injections to 100 ml when only a single injection was performed⁷.

INTERPRETATION OF THE RESULTS

THE SEGREGATION INDEX

The segregation index, X_S relates the actual yield of the undesired product, Y compared to the maximum yield, Y_{ST} i.e. $X_S = \frac{Y}{Y_{ST}}$ where

$$Y = \frac{2(n_{I_2} + n_{I_3^-})}{n_{H_3O^+}} = \frac{2V_{\text{tank}} [(I_2) + (I_3^-)]}{V_{\text{injection}} (H^+)_0} \quad (8)$$

$$Y_{ST} = \frac{6(IO_3^-)_0}{6(IO_3^-)_0 + (H_2BO_3^-)_0} \quad (9)$$

In other words, Y is based on the measured values of I_2 and can be considered to be the ratio of moles of acid consumed by the reaction to give I_2 over the total moles of acid injected. Y_{ST} is the yield of the reaction under total segregation condition where the quantity of iodine formed is only due to the stoichiometric ratio of the reactants. Further details regarding the calculation of the segregation index are reported in the literature^{2,7}.

The results obtained are, therefore, initially presented in terms of the segregation index, X_S . Conceptually, X_S can assume values between 0 and 1:

$$X_S=0 \quad \text{Perfect micromixing} \quad (10)$$

$$X_S=1 \quad \text{Total segregation} \quad (11)$$

$$0 < X_S < 1 \quad \text{Partial segregation} \quad (12)$$

For any particular pair of competing parallel reactions, the lower the value of X_S , the better the micromixing.

LITERATURE MODELS LINKING X_S TO THE MICROMIXEDNESS RATIO, THE MICROMIXING TIME AND SPECIFIC ENERGY DISSIPATION RATE

Another parameter used in literature² to represent the data is the micromixedness ratio, α . Guichardon and Falk¹¹, based on earlier ideas of Villermaux⁹, suggest that α represents the volume fraction of the vessel contents that are perfectly micromixed divided by the volume fraction that remains segregated and that α can be related to X_S by the relationship

$$a = \frac{1 - X_S}{X_S} \quad (13)$$

Much literature uses an "incorporation model" developed by Falk and Villermaux⁵ and Fournier et al.⁶. This model is based on the concept^{5,6} that the fresh acid injected is divided into aggregates that are surrounded and progressively invaded by the fluid containing iodate, iodide and borate ions. The reactions occur inside the growing acid aggregates and the characteristic time of incorporation is considered the micromixing time, t_m . Recently numerical solutions of the "incorporation model" have been used⁷ to determine the relationship between the micromixedness ratio, a , and the micromixing time, t_m . For the present set of reactant concentrations, the relationships are⁷:

$$2 < a < 5 \quad t_m = 0.73a^{-2.26} \quad (14)$$

$$5 < a < 7 \quad t_m = 0.82a^{-2.30} \quad (15)$$

$$7 < a < 20 \quad t_m = 0.158a^{-1.45} \quad (16)$$

It should be noted that α and t_m are essentially conceptual and model parameters though they are often considered in the literature^{7,8} as "experimental" values.

It has also been suggested in the literature⁸ that the micromixing time t_m evaluated from micromixing studies is the same as that arising from the local specific energy dissipation rate, ε_T , in terms of Kolmogorov's turbulence theory, i.e. using the relationship¹:

$$t_m = 17.24 \sqrt{\frac{\nu}{\varepsilon_{\dot{o}}}} \quad (17)$$

where ν is the kinematic viscosity. Since ε_T is proportional to the mean specific energy dissipation rate, \tilde{a}_T , which is simple to determine from experiments as has been done here, ϕ , the ratio of ε_T to \tilde{a}_T , can be calculated.

$$\ddot{o} = \frac{\dot{a}_T}{\tilde{a}_T} \quad (18)$$

Alternatively, ε_T can be determined experimentally by LDA or PIV, though it is not a trivial task²¹ and requires certain significant assumptions and extensive data treatment, again leading to ϕ .

Thus, for the present reaction conditions, α can be calculated from X_S , (Equation (13)), t_m from Equations (14)-(16) depending on α , ε_T from Equation (17) and finally ϕ provided \tilde{a}_T is known from Equation (18). Recently, most workers^{7,8,10} have not expressed their results in terms of X_S but in these other parameters. Therefore, to compare the present work with these earlier studies, it is necessary to make use of the above relationships. Such comparisons are reported below. However, this aspect of the present paper is only as good as the conceptual models and the quality of the present and literature data.

RESULTS AND DISCUSSION

POWER AND \tilde{a}_T

The power number Po was found to be:

$$Po = \frac{P}{\rho N^3 D^5} = 4.33 \quad (19)$$

which is in good agreement with the value of 4.53 calculated from the expression proposed by Bujalski et al.²². The four speeds used gave the mean specific energy dissipation rates, \tilde{a}_T , reported in Table 3 where $\tilde{a}_T = P/\rho V$.

Table 3 Mean energy dissipation rates

N (rps)	\tilde{a}_T (W/kg)
5.0	0.18
7.0	0.50
8.7	0.97
9.2	1.14

METHOD OF SUCCESSIVE INJECTIONS

The results in Figure 3 for the position <2> show that for four successive injections of 10 ml of acid, the segregation index, X_S , is constant for the same rotational speed. This method has also been applied at the other positions investigated, as showed in Figure 4 for 1.0 M acid concentration. Again, X_S is constant. Thus, the results confirm the effectiveness of the successive injection technique¹¹.

MESOMIXING CONSIDERATIONS

If the feed time is too short in relation to the reaction time and the micromixing time, the value of X_S becomes a function of the feeding rate due to mesomixing^{1,2,23}. Figure 5 and Table 4 show X_S with different acid feed rates for the injection position <2> at the lowest rotational speed. X_S is constant in Figure 5 until the addition time is less than ~ 400 s and Table 4 shows the same data in terms of feed rate with X_S reaching an asymptotic value at < 9.6 ml/min. Thus, though the critical feed rate is a function of the local ϵ_T , provided a much longer time is used²³, mesomixing effects, i.e. variations in X_S with feed rate, can be neglected. Here, for all the other acid injection positions and rotational speeds, an acid flow rate of 1 or 2 ml/min has been used.

Table 4 Influence of acid addition rate on segregation index X_S at $N = 5.0$ rps; acid injection position <2>; $[\text{H}_2\text{SO}_4]=1.0$ M

Flow rate (ml/min)	X_S
1.0	0.264
2.0	0.274
3.1	0.274
3.9	0.279
5.8	0.273
9.6	0.289
19.8	0.315
26.4	0.326

EFFECT OF FEED CONCENTRATION

Figure 6 shows X_S values for the four stirrer speeds at the injection position <3> using two different acid concentrations. The higher the concentration of acid, the higher the value of X_S as expected¹ and as previously reported for this reaction scheme². This behavior is explained looking at the kinetics of the two reactions^{2,20}. With a decrease of the acid concentration, the rate of the neutralization reaction and of the Dushman reaction are slowed down but the rate of the second reaction is more sensitive because its order with respect to acid is higher and the difference between the two reaction rates is increased. Therefore, less iodine is produced and X_S decreases.

The results are also reported in Table 5 and Table 6 both as X_S and as the micromixedness ratio, α . The relative experimental errors, based on four experiments for each speed, calculated with a confidence of 95 % are also reported showing a maximum relative error of $\cong 8.5$ % and, therefore, good reproducibility as reported previously¹¹.

Table 5 Experimental X_S and α values; feed position <3>; $[\text{H}_2\text{SO}_4]=0.5$ M

N (rps)	X_S	Relative error %	α	Relative error %
5.0	0.163	4.11	5.207	5.50
7.0	0.120	3.43	7.330	3.86
8.7	0.110	7.55	8.122	8.48
9.2	0.107	1.93	8.476	2.16

Table 6 Experimental X_S and α values; feed position <3>; $[H_2SO_4]=1.0$ M

N (rps)	X_S	Relative error %	α	Relative error %
5.0	0.179	4.08	4.632	3.69
7.0	0.153	2.11	5.540	2.52
8.7	0.136	1.13	6.340	1.32
9.2	0.133	0.48	6.520	0.55

EFFECT OF AGITATOR SPEED AND FEED POSITION

In both Figure 3 and Figure 4, the segregation index X_S decreases with increasing rotational speed and, therefore, with increasing mean energy dissipation rate as expected^{1,2}. Figure 7 compares X_S for the four speeds and the four feed positions investigated with the experimental error bars obtained from repeating the experiments on average four times for each conditions investigated. Thus, for each speed, X_S decreases in going from position <1> to the position <4>, i.e. from positions of low to high local energy dissipation rates as indicated by LDV studies¹⁹. Though other work has looked at the impact of feed position, when this work started, none had tried to inject at a point in the trailing vortex, i.e., position <4>, which is also in the same region as that shown²¹ to have the highest ϵ_0 value. This feed position has led to very good micromixing. Position <4> was chosen after a careful literature review¹²⁻¹⁴ and, although there is some disagreement regarding the position of the trailing vortices, a location of 2 mm from the blade in the r direction and at the distance of the upper blade edge in the z direction was utilized.

Figure 7 shows that there is a very small difference in X_S when different positions far above the impeller (position <1> and <2>) are utilized and where micromixing is very poor. In this region, experimental ϕ values from LDA are <1 and do not change much spatially. On the other hand, there is a big difference between these positions and positions <3> and <4> and between the latter two themselves. The sensitivity is because, in this region, experimental ϕ values change a great deal spatially giving values $\gg 1$ very near the impeller.

COMPARISON WITH THE LITERATURE BASED ON α , t_m , ϵ_T AND ϕ

In Figure 8, α data are presented from studies in the literature. Guichardon and Falk¹¹ and Camps Rota¹⁶ both used a Rushton turbine for agitation and the same reactant concentrations as those employed here. For Guichardon and Falk¹¹, α values were given and ϵ_T was estimated here from \hat{a}_T in their paper, using $\phi = 4$ which they assumed for the feed position for this set of data. For Camps Rota¹⁶, a similar approach was adopted but different ϕ values, as suggested in the original work¹⁶, were used to account for the four feed positions employed. Also in the plot are the results of Rousseaux et al.^{7,10}. They used the same reactant concentrations but very different mixing devices (the Sliding-Surface Mixing Device, SSMD and the Special Rushton Turbine Reactor, SRTR), each with the intention of giving enhanced micromixing and the data are reported^{7,10} in the form of t_m . Here, α for their study has been calculated via Equation (14)-(16) and the local ϵ_T from Equation (17). Schaer et al.⁸ used the same approach for estimating ϵ_T in an impinging jet mixer. The present data have been added starting from X_S to obtain α (Equation (13)) and with t_m being obtained from Equation (14)-(16) and local ϵ_T from Equation (17). As can be seen, all of the data are in very good agreement. A careful inspection of Figure 8 leads to an interesting and surprising observation. The highest values of ϵ_T have been obtained using the Rushton turbine when feeding into the trailing vortex (points with $\epsilon_0 < 10$ W/kg in this work), even higher than the values produced by the two recently developed special devices designed to enhance

micromixing. Yet, the mean specific energy dissipation rate is only ~ 1.2 W/kg, considered a moderate value for agitated vessels²⁴. It would appear that, by injecting into the trailing vortex, very good micromixing can be obtained at rather modest power inputs without going to different mixing devices. The actual micromixing time estimated from Equation (14)-(16) for the highest ε_T is ~ 2.2 ms compared to values ranging between 10 to 165 ms for the new devices.

Table 7 shows the values of ϕ , based on \hat{a}_T given in Table 3 and local ε_T from Figure 8. Generally, the values are of the order expected, being significantly less than 1 at positions <1> and <2> and well above 1 at position <3>. All these values are in reasonable accord with the trends reported from LDA measurement, e.g., from Geisler et al¹⁹. Also, in accordance with theory, ϕ is essentially constant for a range of impeller speeds at each position except position <4> which was very close to the impeller. Here, the value of ϕ decreases with increasing speed from around 120 to 50. These values are rather high compared to the literature values based on LDA or PIV^{17,19,21}. The fall in ϕ with increasing speed may be due to the greater rate at which the reactants are swept away from the highest ε_T region very close to the impeller to lower values as the speed increases. Baldyga and Bourne¹ indicate that the "apparent" ϕ estimated from such experiments should change with agitator speed close to the impeller. However, for the present feed position, they suggest that ϕ should increase with increasing speed, i.e. the opposite of what is reported here.

Table 7 Values of ϕ ($= \varepsilon_T/\hat{a}_T$)

N (rps)	ϕ (-)			
	Position <1>	Position <2>	Position <3>	Position <4>
5.0	0.23	0.43	5.02	118.29
7.0	0.30	0.34	8.30	93.62
8.7	0.28	0.45	5.84	55.16
9.2	-	-	5.58	51.24

Since this work commenced, Schäfer¹⁷ has used the same reaction scheme as the one used here to measure micromixing whilst at the same time feeding into the region of highest ε_T as measured by him using LDA. The position is close to the one used here. These measurements gave a maximum ϕ value of 52 which, given the difficulty of making the experiments²¹ and the sensitivity to position, is reasonably in agreement with the present values. Unfortunately, the reactant concentrations were a little different from those used here but exactly the same as those used by Villermaux et al.² except that the acid concentration was lower. Surprisingly, the α values reported by Schäfer¹⁷ are lower than any of those reported by Villermaux et al.² even though from the basic theory, one might have expected a lower X_S with the lower acid concentration and, therefore, a higher α . No explanation for this discrepancy can be given.

CONCLUSIONS

It has been confirmed that the iodide-iodate reaction scheme operating in the successive injection mode¹¹ gives reproducible results and is an efficient way of studying micromixing. Using feed rates that ensure mesomixing effects are eliminated, micromixing has been studied using a Rushton turbine at four mean energy dissipation rates from ~ 0.2 W/kg to ~ 1.2 W/kg. By also using four feed positions, fourteen local energy dissipation rates have been employed. For feed positions near the top surface and at the lowest speed, the segregation index X_S was ~ 0.3 . However, at the feed points carefully positioned in the trailing vortex of the Rushton turbine a position for which results had not been reported when this work started, the value of

X_S was much lower at the lowest speed (~ 0.07) falling to ~ 0.05 at the highest. These results clearly show the advantage of feeding into the trailing vortex of the impeller. A comparison with other works in the literature using exactly the same reaction suggests that even at the modest mean energy dissipation rate of 1.2 W/kg, better micromixing was achieved than with two recently developed micromixers^{7,10} (SSMD and SRTR). Finally, it was estimated that the maximum local energy dissipation rate at the feed point in the trailing vortex was about 70 times $\bar{\epsilon}_T$, though the value decreased with increasing speed. It is hypothesized that this fall is due to the reactant being swept away from the region of highest ϵ_T when the agitation speed is high. The value of 70 is in reasonable agreement with that of 52 in a very recently reported study combining LDA and micromixing¹⁷.

ACKNOWLEDGEMENTS

One of us (MA) acknowledges financial support for this project by Huntsman Polyurethanes and the School of Chemical Engineering in Birmingham. The authors also thank Bob Sharpe and the people of the workshop for their technical assistance.

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NOTATION

D	Impeller diameter, m
Da	Damköhler number
D_λ	Light absorption
H	Liquid height, m
K	Kinetic constant, $(\text{mol}^{-1})^4 \text{s}^{-1}$
L	Optic length, cm
N	Stirring speed, s^{-1}
Po	Power number
R	Radial distance, m
T	Temperature, K; tank diameter, m
t_m	Micromixing time \equiv incorporation time, s
V	Liquid volume, l
X	Disk and blades thickness, m
X_S	Segregation index
Y	Actual yield of undesired product
Y_{ST}	Maximum yield of undesired product
Z	Axial coordinate, m
Greek letters	
α	Micromixedness ratio
ν	Kinematic viscosity, $\text{m}^2 \text{mol}^{-1}$
ϵ_T	Local rate of energy dissipation, W/kg
$\bar{\epsilon}_T$	Mean rate of energy dissipation, W/kg
ϵ_λ	Molar extinction coefficient, $\text{m}^2 \text{mol}^{-1}$
ϕ	Relative power dissipation rate
μ	Ionic strength, M^{-1}
λ	Wavelength, nm

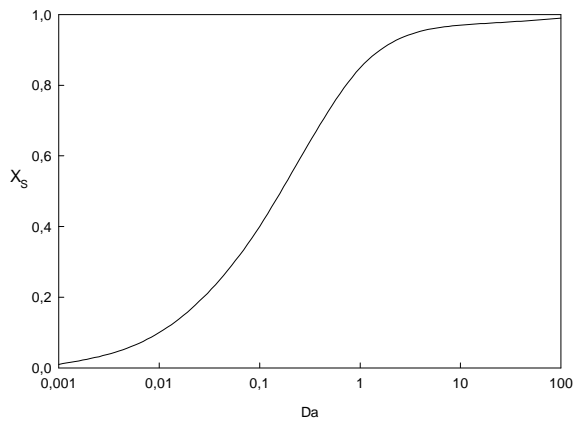


Figure 1 Generic trend of segregation index vs Damköhler number (modified from Baldyga and Bourne⁴)

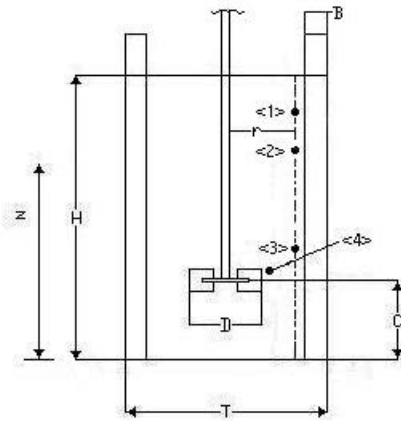


Figure 2 Details of the tank and addition points

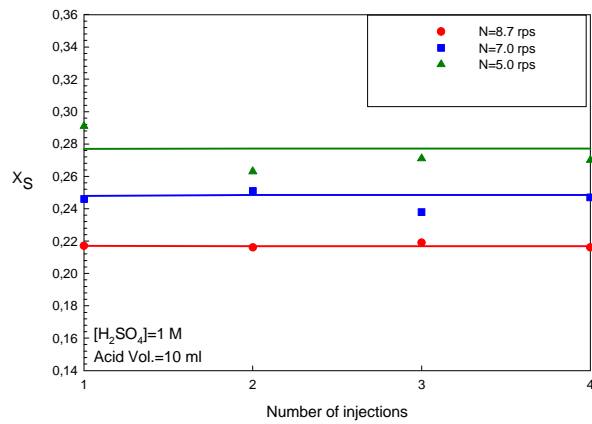


Figure 3 X_S for successive injections for position <2> and three impeller speeds; [H₂SO₄]=1.0 M

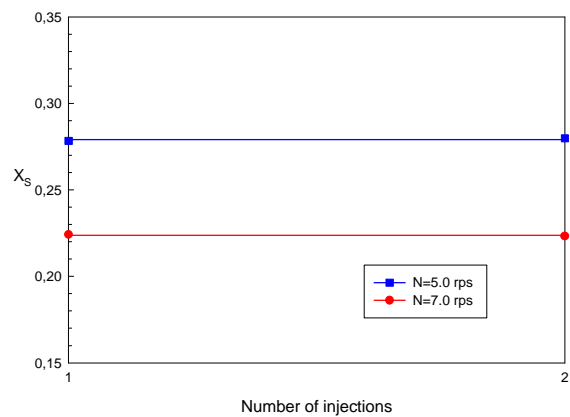


Figure 4 X_S for successive injections for position <1> and two impeller speeds; [H₂SO₄]=0.5 M

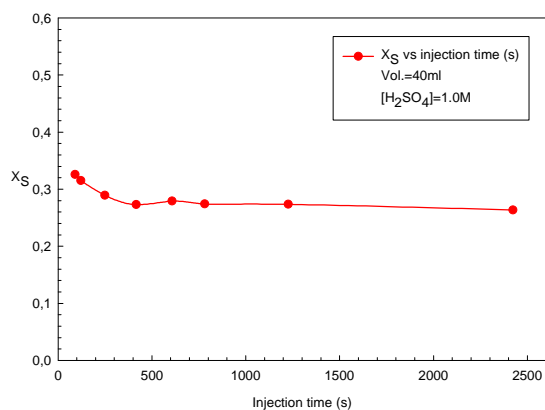


Figure 5 Influence of the acid feed rate on X_S at position <2> at $N = 5.0$ rps

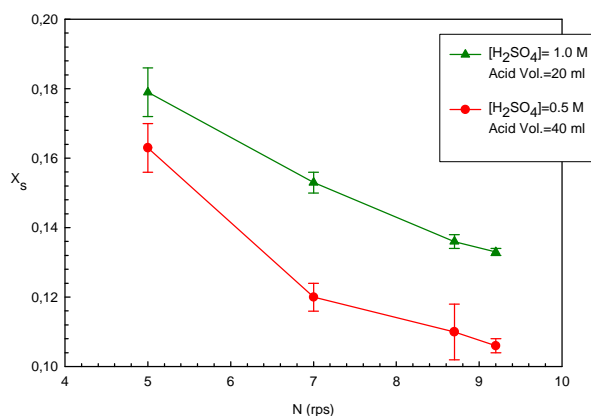


Figure 6 Influence of the acid concentration on X_S at position <3>

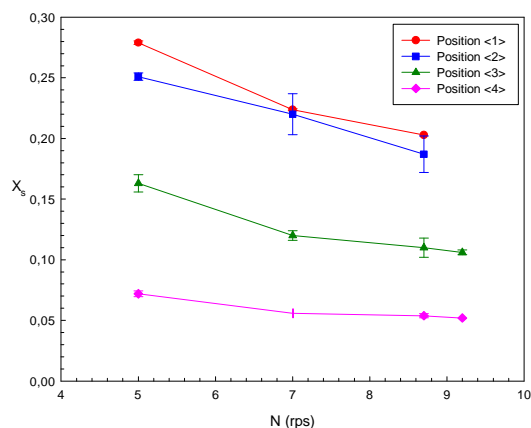


Figure 7 Influence of the feed position on segregation index, X_S ; $[H_2SO_4]=0.5$ M

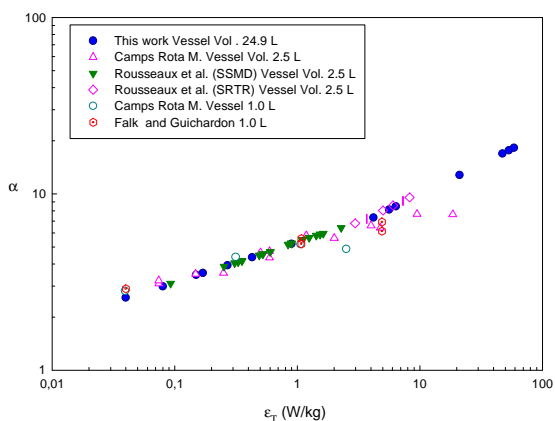


Figure 8 A comparison of various literature results with the present work in which in each case the same chemical compositions were used; $[I_2]_{\text{potential}} = 7 \cdot 10^{-3}$ M; $[H_2SO_4]=0.5$ M; (SSMD - Sliding-Surface Mixing Device); (SRTR - Special Rushton Turbine Reactor)

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