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Effect of the Size of Tank and Impeller to the Liquid-Liquid Dispersion on Mechanical Agitation[1,2]

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In this paper, it is purpose to study the effect of the size of tank and impeller to the liquid-liquid dispersion on mechanical agitation.

Tank diameters used in this experiment are 150, 200 and 250 mm respectively. Then, every particle size is measured by a microscopic photograph method, and each mean surface-volume diameter is calculated and still more energy efficiency of agitation is required. So, the following results are obtained.

(1) The values of agitation torque are almost same, though each size of tank diameter is different.

(2) Relationship of specific interfacial area to agitation power is shown as next experimental equation.

$$\log S_{\mathrm{A}}=0.399 \log P+3.376$$
$$\log S_{\mathrm{B}}=0.386 \log P+3.318$$
$$\log S_{\mathrm{C}}=0.385 \log P+3.262$$

S: specific interfacial area (cm²/g), P: agitation power (watt)

A: 150 mm of tank diameter, B: 200 mm of tank diameter

C: 250 mm of tank diameter

(3) The specific interfacial area becomes smaller as the size of tank diameter is increasing. When tank diameter is 200 mm, the value of $S_{\mathrm{B}}/S_{\mathrm{A}}$ is 0.876 at 1 watt and 0.825 at 100 watt. In the same way, when tank diameter is 250 mm, the value of $S_{\mathrm{C}}/S_{\mathrm{A}}$ is 0.770 at 1 watt and 0.720 at 100 watt.

We have investigated the liquid-liquid dispersion on mechanical agitation from two different points of view of surface chemistry and chemical engineering. So, we have mentioned a few results about the relation of particle size to agitation time and angle of impeller in our first report,[4] and the experimental equation concerned with particle size and impeller diameter have been discussed in our 7th report,[5] furthermore, the relationship between the agitation torque and particle size of emulsion have been expressed in our 11th report.[1]

On mechanical agitation, it seems that agitation torque is mainly put under the control of impeller diameter and revolution number. When particle about 100 μ is still more subdivided, it is considered that a greatly shear force is necessary for the dispersion. Thus, it is thought that the size of tank may be affected a little on the intense and wide of shear force.[6]

In this paper, it is purpose to study the effect of the size of tank and impeller to the liquid-liquid dispersion on mechanical agitation. And we discuss experimentally to pay attention to following four points of view.

(1) Relationship of agitation torque to the value of $\rho N^2 D^5$.

(2) Relationship of agitation power to specific interfacial area.

(3) Relationship of tank diameter to specific interfacial area.

(4) Relationship of particle size to energy efficiency of agitation.

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1) S. Tsukiyama and A. Takamura, *Chem. Pharm. Bull.* (Tokyo), 22, 2607 (1974).
2) Presents at the 95th Annual Meeting of Pharmaceutical Society of Japan, Osaka, April, 1975.
3) Location: *Yatocho, Tanashi-shi, Tokyo.*
4) S. Tsukiyama, H. Takahashi, I. Takashima and S. Hatano, *Yakugaku Zasshi*, **91**, 305 (1971).
5) S. Tsukiyama, A. Takamura and N. Nakura, *Yakugaku Zasshi*, **94**, 490 (1974).
6) J.H. Rushton, W.A. Rodger and V.G. Trice, *Chem. Eng. Progress*, 52, 515 (1956).

Experimental

Measurement Method of Agitation Torque——A sketch for the apparatus of agitation is shown in Fig. 1. The size of tank diameter used by this experiment are 150, 200 and 250 mm respectively. Rotary torque meter is Yamazaki SS-IR type[1] (Yamazaki Seiki Laboratories). The values of torque are measured at 90 points. Here, the each size of tank and impeller are given in Table I.

Measurement Method of Particle Size——Distilled water, in which Tween-20 is dissolved, is used as continuous phase. And a mixture of n-C_7H_{16} and CCl_4 of which density is adjusted to 1.000 (g/cm³), is used as dispersed phase. Emulsifying concentration is 0.1% (w/w) and dispersed phase concentration is 2% (w/w). Total capacity of liquid are 2000 ml (D_T=150 mm), 4900 ml (D_T=200 mm) and 9600 ml (D_T=250 mm) respectively. Experiment is carried out under the next three conditions.

(1) Tank diameters are 150, 200 and 250 mm.

(2) Impeller diameters are altered for 50.30, 65.20, 80.30, 90.10 and 99.20 mm under the revolution number to be constant.

(3) Revolution numbers are exchanged for 330, 400, 530, 660 and 812 rpm under the impeller diameter to be constant.

Then, every particle size is measured by a microscopic photograph method, and the values of mean surface diameter, mean volume diameter and particle size distribution are calculated by the SEIKO-S-301 computer. Now, experimental conditions are given in Table I.

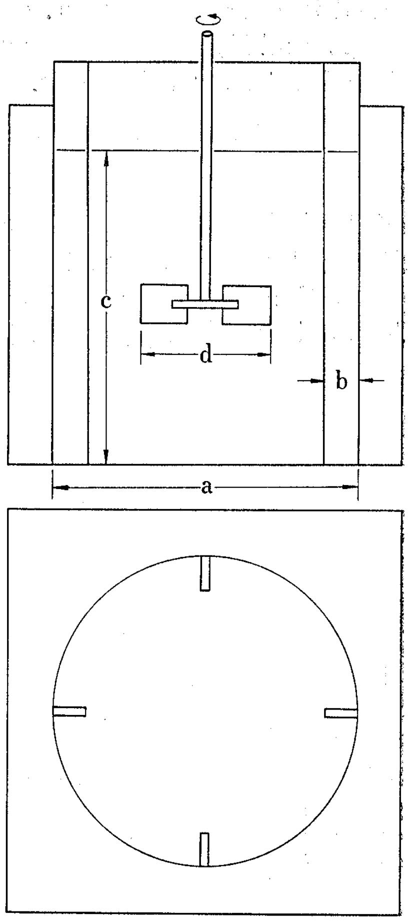

Fig. 1. Apparatus

unit: mm
a: tank diameter
b: baffle plate
c: depth
d: impeller diameter

Results

Relationship between Agitation Torque and the Values of ρN^2D^5

Agitation torque is proportional to the product of second power revolution number and fifth power of impeller diameter.[7] And it has been already

TABLE I. Each Size of Tank and Experimental Condition

Each size of tank (mm)		Impeller diameter (mm)		Revolution number (rpm)						Agitation time (min)	Emulsifying agent	Concentration (%)
	diameter (a)	I	50.30	203	335	404	539	666	812			
		II	65.20	203	335	401	539	661	816			
Tank A	buffle plate (b)	III	80.30	202	334	401	531	659	792	60	Tween-20	0.1
	depth (c)	IV	90.10	202	334	401	530	648	750			
		V	99.20	202	334	401	530	626				
	diameter	I	50.30	203	335	408	540	666	820			
		II	65.20	203	335	404	539	660	799			
Tank B	buffle plate	III	80.30	202	332	402	530	650	782	60	Tween-20	0.1
	depth	IV	90.10	202	332	400	530	636	745			
		V	99.20	200	330	398	516	614				
	diameter	I	50.30	203	334	408	540	660	800			
		II	65.20	202	334	400	530	657	798			
Tank C	buffle plate	III	80.30	202	332	400	528	649	782	60	Tween-20	0.1
	depth	IV	90.10	199	331	397	520	632	740			
		V	99.20	198	330	396	514	610				

7) J.H. Rushton, D.E. Mack and H.J. Everett, *Trans. Am. Inst. Chem. Engrs.*, **42**, 441 (1946).

studied in our recent report.[1] Relation of agitation torque to a value of ρN^2D^5 is appeared in Fig. 2 and Fig. 3. It shows a straight line on log-log coordinate, the experimental formula is found out from this result.

$$\log T_B = 1.041 \log(\rho N^2 D_I^5) - 6.325 \tag{1}$$

$$\log T_C = 1.025 \log(\rho N^2 D_I^5) - 6.198 \tag{2}$$

And, tank diameter to be 150 mm have been already shown in recent report. The values of agitation torque are almost same, though each size of tank diameter is different. Moreover, if revolution number and impeller diameter are required, a optical torque will be able to be calculated from Eq. (1) or Eq. (2).

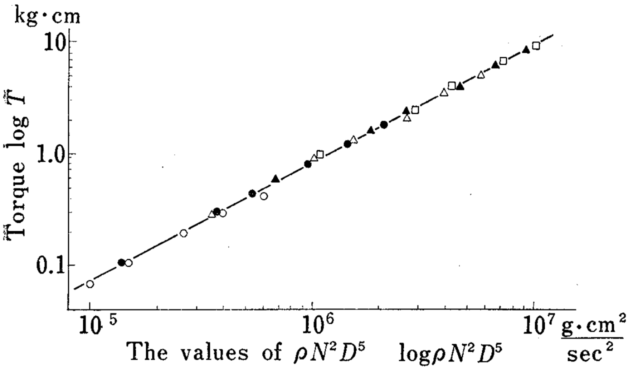

Fig. 2. Torque *v.s.* Values of ρN^2D^5

○: impeller I ▲: impeller IV tank diameter: 200 mm
●: impeller II □: impeller V
△: impeller III
emulsifying agent: Tween-20, concentration: 0.1%

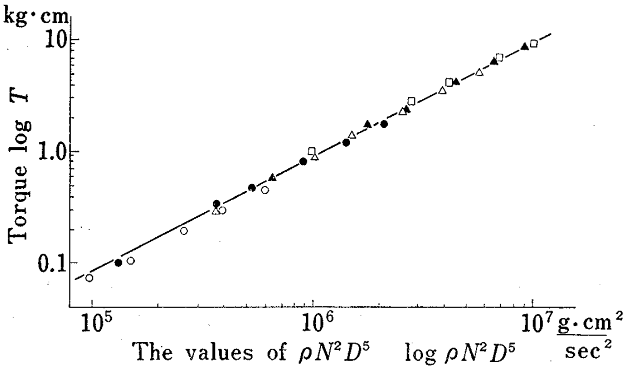

Fig. 3. Torque *v.s.* Values of ρN^2D^5

○: impeller I ▲: impeller IV tank diameter: 250 mm
●: impeller II □: impeller V
△: impeller III
emulsifying agent: Tween-20, concentration: 0.1%

Relationship between Specific Interfacial Area and Agitation Power

Specific interfacial area per 1 g is shown in Eq. (3).

$$S = \frac{6}{\rho_d \cdot d_{32}} \tag{3}$$

And, agitation power is written in Eq. (4).

$$P = \omega T = 2\pi \cdot N \cdot T \tag{4}$$

Relationship of specific interfacial area to agitation power is shown in Fig. 4. It shows a straight line on log-log coordinate, the next experimental formula is calculated by a least squares method.

$$\log S_A = 0.399 \log P + 3.376 \tag{5}$$

$$\log S_B = 0.386 \log P + 3.318 \tag{6}$$

$$\log S_C = 0.385 \log P + 3.262 \tag{7}$$

Nextly, we investigate how to effect the size of tank diameter on the increase of specific interfacial area. The value of S_A for tank diameter to be 150 mm is settled a standard, and the values of S_B/S_A and S_C/S_A are calculated and then it is shown in Fig. 5. It shows a straight line on log-log coordinate, Eq. (8) and Eq. (9) are obtained.

$$\log(S_B/S_A) = -0.0130 \log P - 0.0578 \tag{8}$$

$$\log(S_C/S_A) = -0.0145 \log P - 0.1135 \tag{9}$$

When tank diameter is 200 mm, the value of S_B/S_A is 0.876 at 1 watt and 0.825 at 100 watt from Eq. (8). In the same way, when tank diameter is 250 mm, the value of S_C/S_A is 0.770 at 1 watt and 0.720 at 100 watt from Eq. (9). Consequently, the specific interfacial area becomes smaller and the effect of agitation deteriorates as the size of tank diameter is increasing.

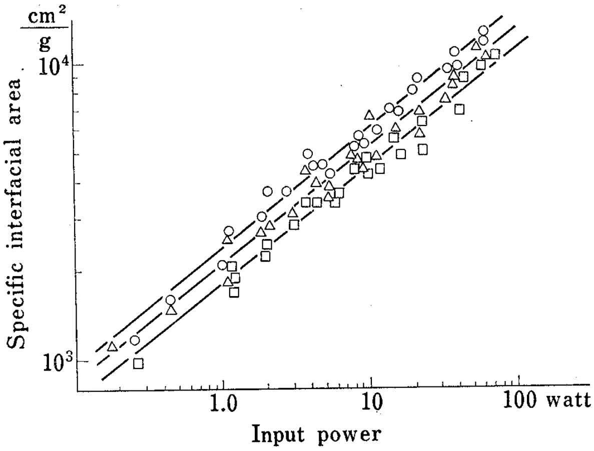

Fig. 4. Specific Interfacial Area *v.s.* Input Power

○: tank A △: tank B □: tank C
emulsifying agent: Tween-20, concentration: 0.1%

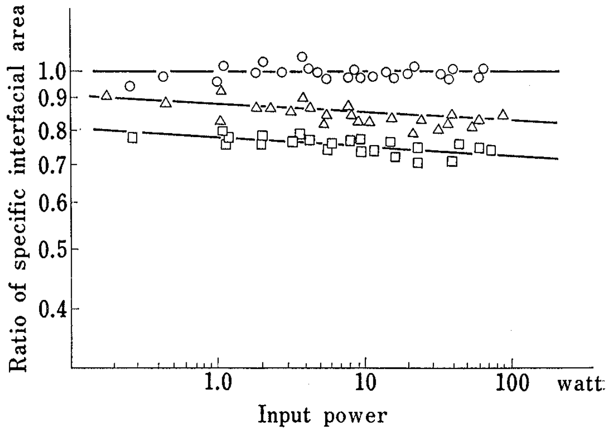

Fig. 5. Ratio of Specific Interfacial Area *v.s.* Input Power

○: tank A △: tank B □: tank C
emulsifying agent: Tween-20, concentration: 0.1%

Relationship between specific interfacial area and the ratio of impeller diameter to tank diameter is shown in Fig. 6. It shows a straight line on log-log coordinate. When D_I/D_T is constant, specific interfacial area has a large value as the size of tank diameter is increasing.

Energy Efficiency of Agitation

Subsequently, we deal with the effect of agitation on the increasing of liquid-liquid interfacial area. Where, energy efficiency is defined as Eq. (10).

$$\eta = E_S/E_A = \gamma \cdot S/P \cdot \theta \tag{10}$$

Relationship between energy efficiency per 1 g of dispersed phase and the ratio of impeller diameter to tank diameter is shown in Fig. 7. The relationship shows a straight line on log-log coordinate, too.

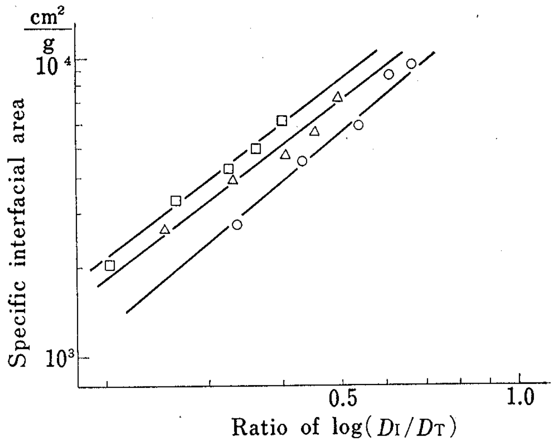

Fig. 6. Specific Interfacial Area *v.s.* Ratio of log (D_I/D_T)

○: tank A △: tank B □: tank C
emulsifying agent: Tween-20
concentration: 0.1%
revolution number: 530 rpm

Relationship of energy efficiency to mean surface-volume diameter is shown in Fig. 8. A value of energy efficiency becomes in the range of 10^{-6} and 10^{-8} at 1 hr's agitation time. As a value of average diameter decreases, energy efficiency becomes further small value.

Relationship between energy efficiency and average diameter for each size of tank diameter is obtained by a least sequares method as follows.

$$\log \eta_A = 1.444 \log d_{32} - 1.308 \tag{11}$$

$$\log \eta_B = 1.499 \log d_{32} - 1.529 \tag{12}$$

$$\log \eta_C = 1.489 \log d_{32} - 1.671 \tag{13}$$

Moreover, each value of mean surface-volume diameter, specific interfacial area, interfacial energy and agitation energy is given in Table II and Table III.

When the ratio of impeller diameter to tank diameter is same, energy efficiency is better as the size of tank diameter has a small value.

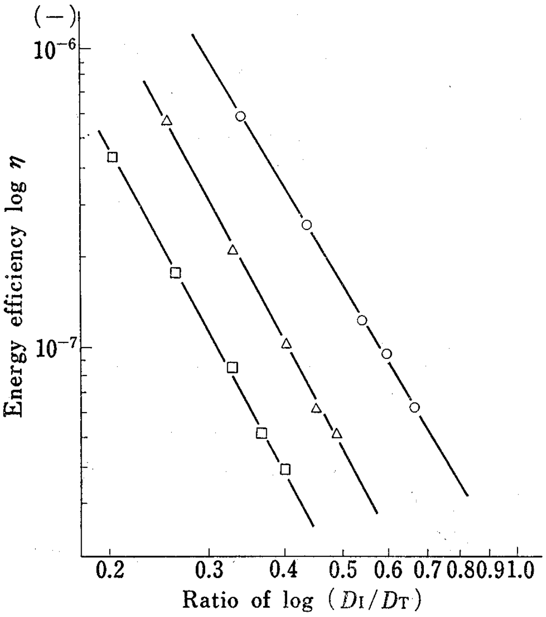

Fig. 7. Energy Efficiency *v.s.* Ratio of D_I/D_T

○: tank A D_I: impeller diameter
△: tank B D_T: tank diameter
□: tank C
emulsifying agent: Tween-20
concentration: 0.1%
revolution number: 530 rpm

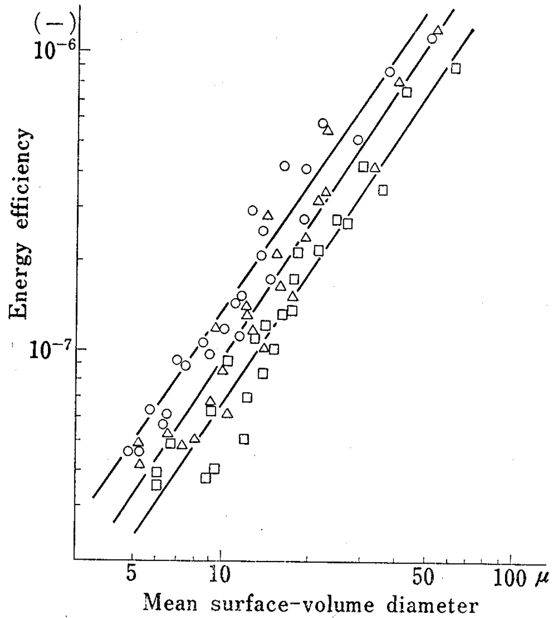

Fig. 8. Energy Efficiency *v.s.* Mean Surface-Volume Diameter

○: tank A △: tank B □: tank C
emulsifying agent: Tween-20
concentration: 0.1%

TABLE II. Experimental Calculated Values

		Mean surface-volume diameter (μ)	Specific interfacial area (cm²/g)	Interfacial energy (joul)	Agitation energy (joul)
I	330	53.26	1126	9.526×10^{-4}	0.826×10^{3}
	400	40.00	1500	12.690	1.584
	530	22.24	2698	22.825	3.989
	660	21.26	2823	23.883	7.502
	812	13.97	4295	36.336	12.722
II	330	33.17	1809	15.304	3.722
	400	22.61	2654	22.453	6.566
	530	15.19	3951	33.425	15.926
	660	12.50	4800	40.608	30.229
	812	9.27	6476	54.787	53.712
III	330	19.01	3155	26.691	11.002
	400	17.38	3454	29.221	19.303
	530	12.62	4754	40.219	39.542
	660	9.11	6590	55.751	81.630
	812	6.52	9202	77.849	144.421
IV	330	15.73	3816	32.283	19.620
	400	13.88	4324	36.581	33.980
	530	10.45	5741	48.569	78.304
	660	7.32	8197	69.347	143.608
	812	5.25	11431	96.706	228.395
V	330	12.00	5000	42.300	30.474
	400	10.21	5879	49.736	57.334
	530	8.05	7454	63.060	123.883
	660	5.13	11705	99.024	204.109

tank diameter: 200 mm

TABLE III. Experimental Calculated Values

		Mean surface-volume diameter (μ)	Specific interfacial area (cm²/g)	Interfacial energy (joul)	Agitation energy (joul)
I	330	61.50	976	8.257×10^{-4}	0.925×10^{3}
	400	42.30	1418	11.996	1.584
	530	29.95	2003	16.945	3.989
	660	24.94	2406	20.355	7.312
	812	18.07	3321	28.096	13.298
II	330	35.29	1700	14.382	4.133
	400	26.67	2250	19.035	7.016
	530	17.90	3354	28.375	16.052
	660	13.96	4298	36.361	29.606
	812	10.48	5728	48.459	53.064
III	330	21.14	2839	24.018	10.969
	400	17.53	3422	28.950	20.686
	530	13.94	4303	36.403	42.905
	660	9.31	6445	54.525	83.902
	812	6.64	9029	76.385	147.308
IV	330	17.15	3499	29.602	21.582
	400	15.01	3997	33.815	33.725
	530	12.00	5000	42.300	84.179
	660	8.87	6765	52.232	151.733
	812	5.96	10064	85.141	237.794
V	330	12.97	4626	39.136	33.714
	400	12.46	4817	40.752	58.507
	530	9.62	6235	52.748	132.894
	660	6.05	9919	83.915	214.045

tank diameter: 250 mm

Discussion

The Effect of Tank Diameter to Liquid-Liquid Dispersion on Mechanical Agitation

Agitation torque, which is continuously suplied with the rotation of impeller into the agitation tank, is scarcely effected by the size of tank diameter but is almost dependent on both revolution number and impeller diameter. So, this fact is evident from Fig. 2 and Fig. 3. Furthermore, when a impeller revolves in the tank, it may be considered that an agitation energy is almost consumed in and near impeller. These phenomena have been already explained in the studies of Takashima,[8] Nagata[9] and so on.[10]

We find that the specific interfacial area is a larger value according as a tank diameter becomes smaller. The factor affecting it can be as follows: that is, liquid-liquid is more sufficiently agitated as tank diameter is smaller, consequently, the probability for emulsion particles to pass through the powerful shear flow becomes higher. Comparing from tank diameter to be 150 mm, the value of specific interfacial area is the range of 0.876 and 0.825 at 200 mm, and 0.770—0.720 at 250 mm.

Still more, we try to calculate as following in order to study minutely the effect of the tank diameter to an emulsification. That is, when an emulsion having an optional interfacial area wants to be made, the mechanical optimum conditions such as tank diameter, impeller diameter and revolution number are investigated from the calculation of these results. And the relationship impeller diameter to revolution number is shown in Fig. 9. The conditions for

8) I. Takashima and M. Mochizuki, *Chem. Eng. Japan*, **4**, 66 (1971).
9) S. Nagata, "*Kakuhanki no Shoyōdōryoku*," Nikkan Kōgyō (1961).
10) K. Takeda and T. Hoshino, *Kagaku Kōgaku*, **30**, 554 (1966).

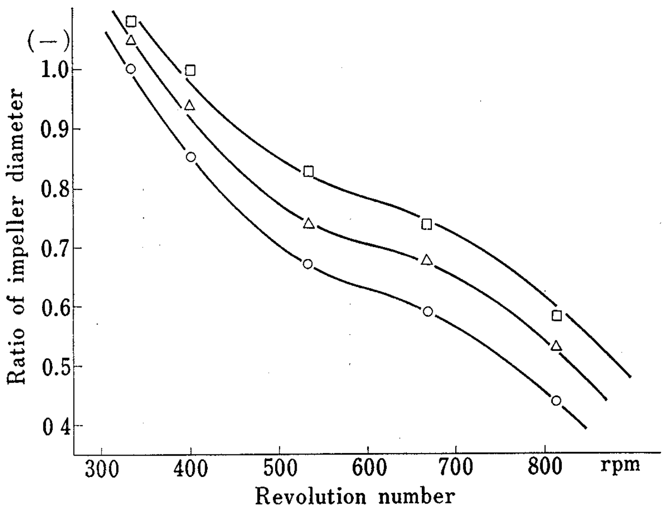

Fig. 9. Ratio of Impeller Diameter *v.s.* Revolution Number

○: tank A △: tank B □: tank C
emulsifying agent :Tween-20, concentration: 0.1%

150 mm of tank diameter and 330 rpm of revolution number are chosen to the standard state. For example, if the specific interfacial area is same and the impeller diameter at 330 rpm is unity, the size of impeller diameter at 400, 530 and 812 rpm are 0.85, 0.70 and 0.45 respectively. And if impeller diameter is same, the revolution number are 360 rpm at 200 mm of tank diameter and 390 rpm at 250 mm of tank diameter. In any case, when an emulsion having an optional interfacial area is desired, and if tank diameter is decided, the rough values of revolution number and impeller diameter are able to read and calculate from the line at Fig. 9. Therefore, it will be a valuable guide for the research of the physical and mechanical optimum condition in order to make a good emulsion.

Conclusion

In view of the results of this investigation, the following conculusions are obtained.

(1) The values of agitation torque are almost same, though each size of tank diameter is different.

(2) Relationship of specific interfacial area to agitation power is shown as next experimental equation.

$$\log S_A = 0.399 \log P + 3.376$$

$$\log S_B = 0.386 \log P + 3.318$$

$$\log S_C = 0.385 \log P + 3.262$$

(3) The specific interfacial area becomes smaller as the size of tank diameter is increasing. When tank diameter is 200 mm, the value of S_B/S_A is 0.876 at 1 watt and 0.825 at 100 watt. In the same way, when tank diameter is 250 mm, the value of S_A/S_B is 0.77 at 1 watt and 0.720 at 100 watt.

(4) As a value of average diameter decreases, energy efficiency becomes further small value.

Nomenclature

D_I : impeller diameter (mm)
D_T : tank diameter (mm)
d : mean surface-volume diameter (μ)
E_A : agitation energy (erg/g)
E_S : specific interfacial energy (erg/g)
N : revolution number (rps)
P : agitation power (watt)
S : specific interfacial area (cm²/g)
T : agitation torque (kg-cm)
γ : interfacial tension (dyn/cm)
η : energy efficiency of agitation (−)
θ : agitation time (min)
ω : angular velocity (angle/sec)
ρ_d : specific gravity of dispersed phase (g/cm³)

Subscripts

A : 150 mm of tank diameter
B : 200 mm of tank diameter
C : 250 mm of tank diameter

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