How to design agitators for desired process response

Effective agitation of fluids for blending and motion requires a detailed analysis of capacity, viscosity and dynamic response for the fluid system, in order to find power and shaft speed of the agitator and corresponding size of the turbine impeller.

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☐ Our purpose in this article will be to emphasize a design procedure for practical problems in the chemical process industries involving blending and motion.

The information presented here may be used for the design of turbine agitators in applications ranging from storage vessels requiring very little agitation to critical reactors needing a great deal of it.

To understand the need for an organized approach to design, we will follow the steps shown in the logic-flow diagram of Fig. 1 in deciding on an agitator for blending-and-motion problems. This illustration represents a portion of the overall logic-flow diagram originally presented in Part 1 of this series (*Chem. Eng.,* Dec. 8, 1975, p. 112). We will review the mechanical design of drives, shafts and seals, and economic evaluations, in future articles of this series. Here, we will limit our discussion to procedures for blending and motion up to and including design of the impeller system.

Classification of problem

The design procedure for blending and motion applies to agitation problems where fluids behave as a single phase and where a predictable level of fluid motion must occur. For example, a typical blending problem may require the mixing to uniformity of fluids having dissimilar viscosity, density or concentration. On the other hand, a fluid-motion problem may require improved convective heat-transfer coefficients to facilitate heat removal from a reacting fluid.

The agitator-design logic for blending and motion also applies to some two-phase systems that exhibit single-phase behavior. An example would be fluids containing a very small concentration of solids having very slow settling velocities.

It is equally important to state where the blending-and-motion logic is not applicable. The procedures in this article do not apply to problems such as immiscible liquid-liquid dispersion, or the blending of highly non-Newtonian fluids.

Following the design logic of Fig. 1, we will analyze each of the three components under the heading "magnitude of the agitation problem."

Size and difficulty

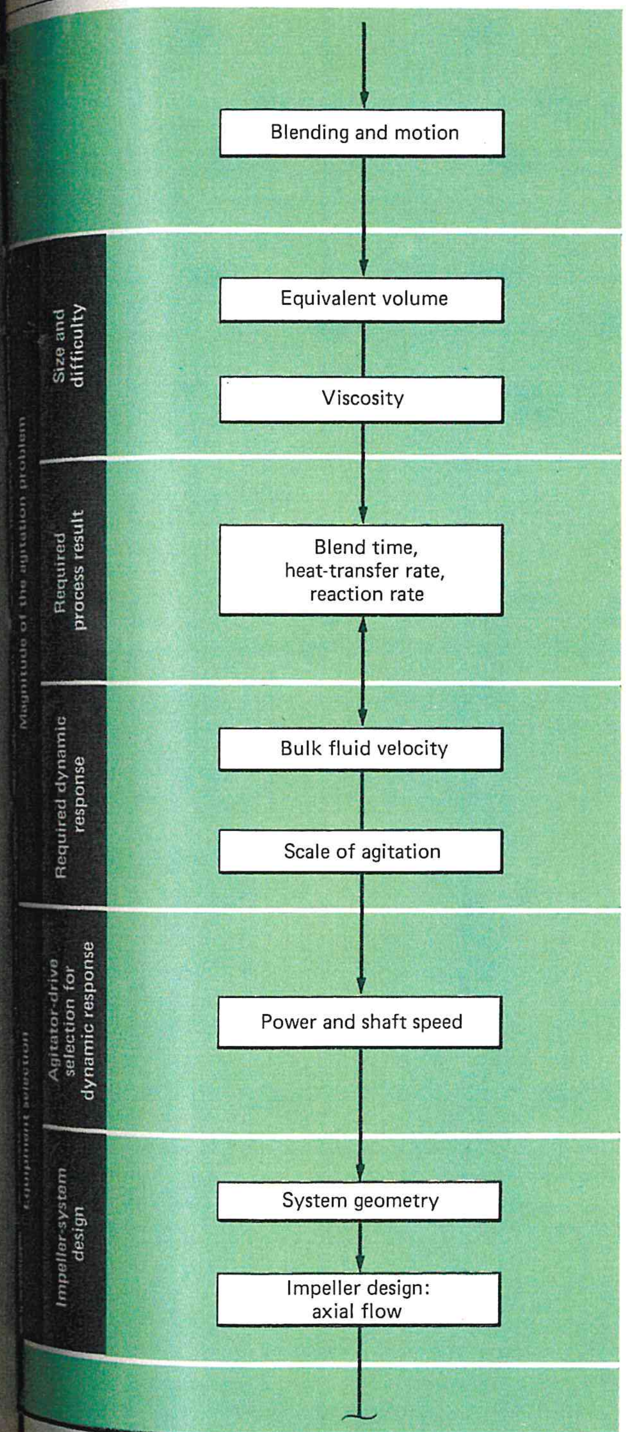
The size of a blending-and-motion problem is indicated by the maximum product of the specific gravity of the liquid, S_g, and the volume of the liquid, V, to be agitated. The product of these two quantities is termed the equivalent volume, V_{eq}, and is a measure of the total mass of the system:

$$V_{eq} = S_g V \quad (1)$$

The severity of a blending-and-motion problem is indicated by the maximum viscosity, μ, of the liquid phase to be agitated. Liquid viscosity is the primary variable in blending-and-motion problems involving the use of pitched-blade turbine agitators.

Required process result

The ultimate purpose of a turbine agitator is to achieve a desired process result. However, it is often difficult to state the process result with precision, or to relate that result to one specific agitator. Hence, the design logic begins with the selection of an appropriate



Design logic for blending-and-motion classification **Fig. 1**

Process requirements set degree of agitation for blending and motion **Table I**

Scale of agitation	Bulk fluid velocity, ft/min	Description
1	6	Agitation levels 1 and 2 are characteristic of applications requiring minimum fluid velocities to achieve the process result. Agitators capable of level 2 will: ■ Blend miscible fluids to uniformity if specific-gravity differences are less than 0.1. ■ Blend miscible fluids to uniformity if the viscosity of the most viscous is less than 100 times that of the other. ■ Establish complete fluid-batch control. ■ Produce a flat, but moving, fluid-batch surface.
2	12	
3	18	Agitation levels 3 to 6 are characteristic of fluid velocities in most chemical process industries agitated batches. Agitators capable of level 6 will: ■ Blend miscible fluids to uniformity if specific-gravity differences are less than 0.6. ■ Blend miscible fluids to uniformity if the viscosity of the most viscous is less than 10,000 times that of the other. ■ Suspend trace solids (<2%) with settling rates of 2 to 4 ft/min. ■ Produce surface rippling at lower viscosities.
4	24	
5	30	
6	36	
7	42	Agitation levels 7 to 10 are characteristic of applications requiring high fluid velocity for the process result, such as in critical reactors. Agitators capable of level 10 will: ■ Blend miscible fluids to uniformity if specific-gravity differences are less than 1.0. ■ Blend miscible fluids to uniformity if the viscosity of the most viscous is less than 100,000 times that of the other. ■ Suspend trace solids (<2%) with settling rates of 4 to 6 ft/min. ■ Provide surging surfaces at low viscosities.
8	48	
9	54	
10	60	

dynamic response, followed by the design of agitators that will give that response.

Required dynamic response

The design basis for blending-and-motion systems is the correlation shown in Fig. 2 for pitched-blade turbines. Here, the pumping number, N_Q, is shown as a function of Reynolds number for several ratios of D/T, i.e., impeller diameter to tank diameter.

From the correlation of Fig. 2, we can calculate the effective pumping capacity, Q, for a pitched-blade turbine. Dividing Q by the cross-sectional area of the tank having the geometry shown in Fig. 3 yields the bulk fluid velocity. This is the fundamental dynamic response for blending and motion. It is this velocity that is characteristic of all the velocities in the agitated fluid.

The fluid velocity at the impeller tip does not represent the velocities throughout the tank because it is

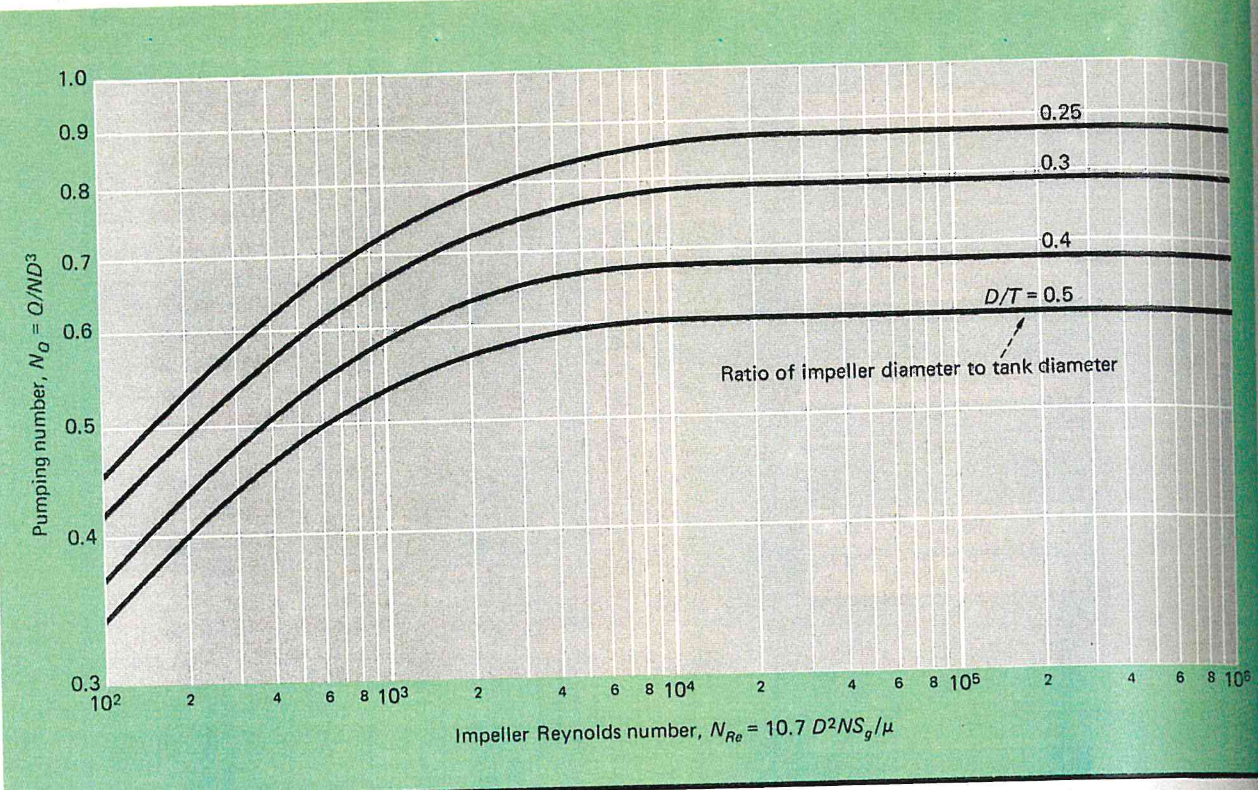


Fig. 2

Pumping number is the basis for design procedures involving blending and motion

primarily a function of impeller tip speed. Likewise, fluid velocities at the tank wall are very low and not characteristic of velocities throughout the tank.

A bulk fluid velocity ranging from 6 to 60 ft/min characterizes the majority of applications of turbine agitators for blending and motion. It is convenient to establish a 1 to 10 scale to cover this velocity range and to establish turbine performance criteria within this scale of agitation.* Table I is the result of such an analysis and defines problems involving blending and motion. Note that performance criteria are enumerated in terms of miscible-fluid blending, low-viscosity surface activity, batch control, and other process results. These scale levels are not intended to serve as design points; rather, they indicate capabilities of the various agitation intensities. While adjacent scale levels are distinctly different in dynamic response (bulk velocity differences of 6 ft/min), it may or may not be possible to distinguish the process results that adjacent scale levels yield.

Nomenclature

C_f	Correction factor for diameter of pitched-blade turbines (see Table V)
D	Impeller diameter, in
D_T	Impeller diameter for turbulent regime, in
H_p	Prime-mover power, hp
L	Shaft length, in
N	Shaft speed, rpm.
N_Q	Pumping number
N_{Re}	Impeller Reynolds number
n	Number of impellers
Q	Effective pumping capacity, ft³/min
S	Impeller spacing, in
S_g	Specific gravity
T	Vessel diameter, in
V	Volume, gal
V_{eq}	Equivalent volume [Eq. (1)], gal
v_b	Bulk fluid velocity, ft/min
Z	Fluid batch depth, in
μ	Viscosity, cp

Selection of the agitator drive

Since prime-mover power and shaft speed are the most practical means for specifying turbine agitators, it is more convenient to compute these relations for various equivalent volumes and viscosities for the 10 scales of agitation in tabular form. Condensed examples of the agitator selection tables are shown as Tables II and III. Table II comprises selections for fluids having viscosities of 5,000 cp; and Table III, viscosities of 25,000 cp. Calculations done by the computer using a logic program generate Tables II and III. For an analysis of the power/speed relations for turbine agitators, see the material in the accompanying box on the opposite page.

We can use Tables II and III to make a first approximation of power and speed of a turbine agitator for fluids having viscosities other than 5,000 or 25,000 cp. Interpolation between these tables is possible.

The horsepowers and shaft speeds shown reflect in-

*Chemineer calls this scale of agitation: ChemScale.

Analysis of power/speed relationship for turbine agitators

A 5,000-gal reactor will be used to agitate a fluid that has a specific gravity of 1.0 and a viscosity of 5,000 cp. What is the size of the agitator that will give a dynamic response corresponding to a bulk fluid velocity of 36 ft/min? What will be the required power and speed for such an agitator?

Let us start by assuming that the batch in the reactor occupies a depth that is equal to the diameter of the reactor. (This procedure is equally applicable to other batch shapes. We have chosen a batch whose liquid depth is the same at the diameter of the tank because this is the basis of Tables II and III.)

We calculate the tank (i.e., reactor) diameter, T, and liquid depth, Z, from the volume relation:

$$V = \pi(T/2)^2 Z$$

Since V is given as gal, we multiply the righthand side of the equation by 7.50 gal/ft^3. Since T must equal Z, we find:

$$5{,}000 = \pi(T/2)^2 T(7.50)$$
$$T = 9.47 \text{ ft}$$

Next, we calculate the horizontal cross-sectional area of the tank from $\pi(T/2)^2$ and find it to be 70.4 ft^2.

To calculate the effective pumping capacity, Q, of the impeller so as to generate a bulk fluid velocity of 36 ft/min in the vessel, we substitute in:

$$Q = v_b A$$
$$Q = 36 \times 70.4 = 2{,}534 \text{ ft}^3/\text{min}$$

This value of Q will stay fixed throughout the calculation.

It is now necessary to pick a D/T ratio (i.e., turbine diameter to tank diameter). Typical values for this ratio range between 0.2 to 0.6. For this example, we pick a midrange value of 0.3. Hence, the impeller diameter becomes:

$$D = 9.47(0.3)(12) = 34.09 \text{ in}$$

From Fig. 2, we must establish a pumping number, N_Q, for this geometry. Since we do not yet know the impeller's rotative speed, we cannot calculate its Reynolds number. Therefore, we make another assumption that agitation occurs under fully turbulent conditions. From Fig. 2, we find $N_Q = 0.8$ for $D/T = 0.3$.

To make the first trial calculation of the impeller speed, we substitute in the expression for the pumping number:

$$N_Q = Q/ND^3$$

where Q is effective pumping capacity, ft^3/min; N is impeller speed, rpm; D is impeller diameter, ft. Substituting the appropriate values and rearranging, we find the impeller speed as:

$$N = 2{,}534/(0.8)(34.09/12)^3 = 138.2 \text{ rpm}$$

We substitute into Eq. (3) in order to check the agreement between the impeller's Reynolds number and the pumping number:

$$N_{Re} = \frac{10.7(1.0)(138.2)(34.09)^2}{5{,}000} = 344$$

From Fig. 2, we find that an N_{Re} of 344 does not match an $N_Q = 0.8$ for a D/T ratio of 0.3. We must now make a second trial calculation using revised assumptions.

Based on the previously calculated $N_{Re} = 344$, we pick an $N_Q = 0.55$ for $D/T = 0.3$. The second trial calculation of impeller speed yields:

$$N = 2{,}534/(0.55)(34.09/12)^3 = 201 \text{ rpm}$$

For a speed of 201 rpm, the impeller's Reynolds number becomes:

$$N_{Re} = \frac{10.7(1.0)(201)(34.09)^2}{5{,}000} = 500$$

Agreement between an $N_Q = 0.55$ and an $N_{Re} = 500$ for a $D/T = 0.3$ on Fig. 2 is reasonable. Can it be improved with a third trial?

Using an $N_{Re} = 500$ from the second trial, we now pick an $N_Q = 0.60$ from Fig. 2 for a $D/T = 0.3$. The third trial calculation of impeller speed yields:

$$N = 2{,}534/(0.6)(34.09/12)^3 = 184.2 \text{ rpm}$$

For a speed of 184.2 rpm, the impeller's Reynolds number becomes:

$$N_{Re} = \frac{10.7(1.0)(184.2)(34.09)^2}{5{,}000} = 458$$

For a Reynolds number of 458 and $D/T = 0.3$, we find $N_Q = 0.60$ from Fig. 2. Agreement is good. Trial-and-error iterations can stop.

Since we have now established the speed at which a pitched-blade turbine must operate for this example, we must next determine the power necessary to rotate it. By using Eq. (2) and the data from Table V, we can compute the required horsepower. From Table V, we obtain the viscosity correction factor, C_F, for an impeller $N_{Re} = 458$ as 0.985. Hence, the corrected turbine diameter, D_T, is computed from Eq. (4) as:

$$D_T = 34.09/0.985 = 34.61 \text{ in}$$

By substituting into Eq. (2) and rearranging, we calculate impeller power, H_p, as:

$$H_p = (34.61/394)^5(1)(1)(184.2)^3 = 32.7 \text{ hp}$$

Thus, in this application where a bulk fluid velocity of 36 ft/min is specified, we need an agitator drive of 32.7 hp rotating the impeller shaft at 184.2 rpm for an initial assumed value of $D/T = 0.3$.

Calculations at other D/T ratios will yield other agitator speeds and the prime-mover power associated with these speeds. The speeds that result from these assumptions of D/T may or may not be AGMA* speeds (230,190, 155, 125, 100, 84, 68, 56, 45, 37 rpm, etc.). The corresponding horsepowers also may be or not be available as standards (10, 15, 20, 25, 30, 40 hp). It is normal engineering practice to select speeds and horsepowers closest to standard sizes. Thus, it is far more practical to begin with commercially available prime-mover powers and speeds, and to calculate the bulk fluid velocity that will be produced in various volumes and viscosities. These agitator selections can then be put into a volume, viscosity, bulk-fluid-velocity matrix (Tables II and III) for ease of application.

*American Gear Manufacturers Assn.

Prime-mover power and shaft speed (hp/rpm) for blending and motion (viscosity = 5,000 cp) — Table II

Scale of agitation	Equivalent volume, gal.							
	500	1,000	2,000	5,000	10,000	30,000	100,000	300,000
1	1/280	2/280 1/190	2/190 1/100	2/100	3/84	7.5/84 5/56 3/37	20/100 15/68 10/45 7.5/37	75/125 50/84 30/45 20/37
2	2/280 1/190	2/190 1/100	2/125 2/84 1.5/84	5/125 3/84 3/68 2/45	5/125 5/84 3/68 2/45	15/155 10/84 7.5/68 5/45	25/84 20/68 15/45 10/37	60/84 50/68 40/56 30/37
3	2/190 1/100	2/125 1.5/84	3/84 1.5/56	7.5/125 5/100 5/84 3/56	15/155 10/84 7.5/68 5/45	25/84 20/68 15/45 10/37	60/84 50/68 40/56 30/37	125/68 100/56 75/45 75/37
4	2/125 1.5/84	2/84 1.5/56	5/125 3/68 3/56 2/45	10/84 7.5/68 5/45 3/37	25/125 20/100 10/45 7.5/37	40/84 30/68 25/56 20/37	75/68 60/56 50/45 40/37	250/84 200/68 150/45 125/37
5	3/125 2/84	5/125 3/84	7.5/125 5/84	15/100 10/68 7.5/45	20/68 15/68 15/56 10/37	60/84 50/68 40/56 30/45	125/68 100/56 75/45 75/37	300/68 250/56 200/45 150/30
6	2/68 1.5/56	5/100 3/68 3/56 2/45	15/155 10/100 7.5/84 3/37	25/125 20/100 10/56 7.5/37	30/100 25/84 15/45	75/84 50/56 30/37 25/30	250/84 200/68 150/56 125/45	400/56 350/45 250/37 200/30
7	3/84	7.5/125 5/84	10/84 7.5/68 5/45	15/68 15/56 10/45 10/37	40/84 30/68 25/56 20/45	75/68 60/56 50/45 40/37	300/100 150/45 125/37 100/30	
8	5/125	10/125 7.5/100	10/68 7.5/56	30/100 25/84 20/68 15/45	50/100 20/37	150/100 100/68	300/68 250/56 200/45 150/37	
9	7.5/155 5/100 5/84	15/155 10/100 7.5/84	15/84 10/56 7.5/45	60/155 40/100	60/84 50/84 40/56 30/45	150/84 125/68 100/56 75/45	150/30 125/25 100/20	
10	10/155 7.5/125	10/84 7.5/68	30/155 25/125 20/100 15/68	50/100 40/84 30/68 25/56	75/100 50/68 30/37 25/30	200/68 75/37 60/30 50/25	400/56 350/45 250/37 200/30	

dustrially available turbine agitators. For example, the selection 10/84 indicates a 10-hp agitator at a shaft speed of 84 rpm. The horsepowers are those for the standard prime-mover sizes. Shaft speeds are those for the commonly available prime-mover speeds (1,750 rpm, 1,150 rpm, etc.) in combination with standard American Gear Manufacturers Assn. (AGMA) gear ratios.

We will use Tables II and III to demonstrate the design concept through sample-problem analysis.

Impeller-system design

To correctly apply the selections of turbine agitators from Tables II and III, we must properly design the impeller system. This design includes the turbine type, number of turbines, location in the batch, and diameter of the impeller. Correct baffling of the system is also necessary.

For blending and motion, the impeller type is a pitched-blade turbine.

Table IV lists the recommended number of impellers and their location in the batch for blending and motion. For example, if the given liquid has a viscosity of less than 25,000 cp and a ratio of liquid depth to tank diameter (Z/T) of 1.3, one turbine located at a bottom clearance of $Z/3$ would be adequate.

The parameters affecting turbine power were discussed in Part 2 of this series (*Chem. Eng.*, Jan. 5, 1976, pp. 140–143). In the turbulent-flow regime, the power number becomes constant at high Reynolds numbers.

Based upon Eq. (19) in Part 2, we obtain an expression for the first estimation of turbine diameter, D_T, as:

$$D_T = 394\left(\frac{H_p}{nS_gN^3}\right)^{1/5} \quad (2)$$

where H_p is prime-mover power, hp; n is number of

Prime-mover power and shaft speed (hp/rpm) for blending and motion (viscosity = 25,000 cp) **Table III**

Scale of agitation	Equivalent volume, gal: 500	1,000	2,000	5,000	10,000	30,000	100,000	300,000
1	1.5/125 1/100	2/125 1.5/84	2/84 1.5/56	7.5/125 5/100 5/84 3/56	15/155 10/100 7.5/68 5/45	25/125 20/100 15/68 10/45	75/125 50/84 30/45 20/37	150/100 100/68
2	2/190 2/125 1.5/84	3/84 2/84 1.5/56	5/125 3/84 3/68 2/45	10/84 7.5/68 5/45 3/37	20/100 15/68 10/84 10/45	30/100 25/84 20/68 15/45	60/84 50/68 40/56 30/37	125/68 100/56 75/45 75/37
3	3/84 2/84 1.5/56	5/125 5/84 3/68 2/45	15/155 7.5/68 5/45 3/37	20/100 15/68 10/45 7.5/37	25/84 20/68 15/45 10/37	60/84 50/68 40/56 30/37	125/68 100/56 75/45 75/37	200/45 150/45 150/30 125/37
4	5/125 5/100 3/68 3/56	7.5/84 5/56	10/84 7.5/45	30/100 25/84 20/68 10/37	40/84 30/68 25/56 20/37	75/68 60/56 50/45 40/37	250/84 200/68 150/56 125/45	400/56 300/45 250/37 200/30
5	7.5/125 5/84	15/155 10/100 10/84 7.5/68	25/125 20/100 15/84 10/56	75/190 60/155 40/100 15/45	60/84 50/84 40/56 30/45	200/125 150/100 100/68 75/45	150/45 150/37 125/37 100/30	350/45
6	10/125 7.5/84	20/155 15/125	25/100 15/68 15/56 10/45	40/84 30/68 25/56 20/37	75/100 50/68 30/37 25/30	150/84 125/68 100/56 75/37	300/68 250/56 200/45 150/30	
7	15/155 10/100	25/155 15/84	40/155 30/100 25/84 20/68	75/125 50/84 30/45	75/68 60/56 50/45 40/37	150/68 75/30	150/45	
8	20/155 15/125	30/155 25/125 20/100	50/155 40/125	75/100 60/84 50/68 40/56	100/84 75/56	250/84 200/68 150/56 125/45	400/56 350/45 250/37 200/30	
9	25/155 20/125	40/155 30/125 25/100	75/190 60/155 40/100 30/68	75/84 60/68 50/56	150/100 100/68	300/100 150/45 125/37 100/30		
10	30/155 20/84	40/125 30/100	60/125 50/100 50/84 40/84	125/125 100/100 75/68 60/56	150/84 125/68 100/56 75/45	250/56 200/45 150/37 150/30		

turbines; S_g is fluid specific gravity; and N is shaft speed, rpm.

Several power-draw correction factors such as proximity and impeller spacing are neglected in this estimate because they are minor. However, it is necessary to correct for viscosity effects. To do so, we calculate the impeller Reynolds number from:

$$N_{Re} = 10.7 S_g N D^2/\mu \qquad (3)$$

where S_g is fluid specific gravity, D is impeller diameter, in; and μ is viscosity, cp.

The correction factor, C_F, for the calculated Reynolds number is obtained from Table V, and the corrected turbine diameter becomes:

$$D = D_T C_F \qquad (4)$$

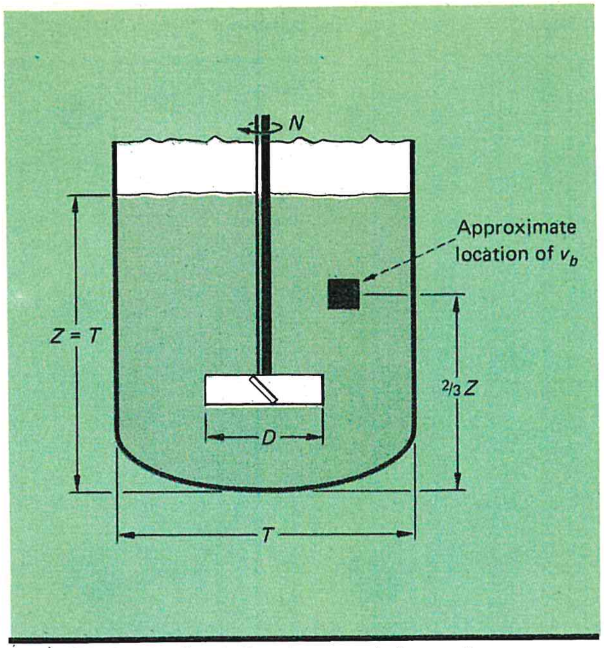
Baffle recommendations for systems requiring blending and motion are listed in Table VI.

Examples illustrate design analysis

The design logic to solve problems involving blending and motion has now been described in accordance with the sequence of Fig. 1. By solving some practical agitation problems, we can analyze the steps necessary to arrive at a basic agitator selection.

Example 1—A 10,000-gal storage tank, as sketched in Fig. 4a, receives product from a series of batch reactors. The product has a specific gravity of 1.05, with a maximum variation of 0.05. Viscosity of product is 4,900 cp, and there is no significant viscosity variation between batches. The product is held in the storage tank for at least two days. Tank diameter is 11 ft 6 in, with a 12-ft straight side. The top head is flat, and the bottom head is ASME dished. The agitator will be mounted on 12-in channels. Select the agitator system for blending batches of miscible product delivered to the storage tank.

(text continues on p. 110)



Bulk fluid velocity is fundamental dynamic response for blending and motion — Fig. 3

Number of impellers for blending and motion — Table IV

Viscosity, cp	Impellers, no.	Impeller clearance* Bottom	Impeller clearance* Upper	Maximum ratio, Z/T
Up to 25,000	1	Z/3	–	1.4
Up to 25,000	2	T/3	(2/3)Z	2.1
> 25,000	1	Z/3	–	0.8
> 25,000	2	T/3	(2/3)Z	1.6

* Z = liquid depth; T = vessel diameter.

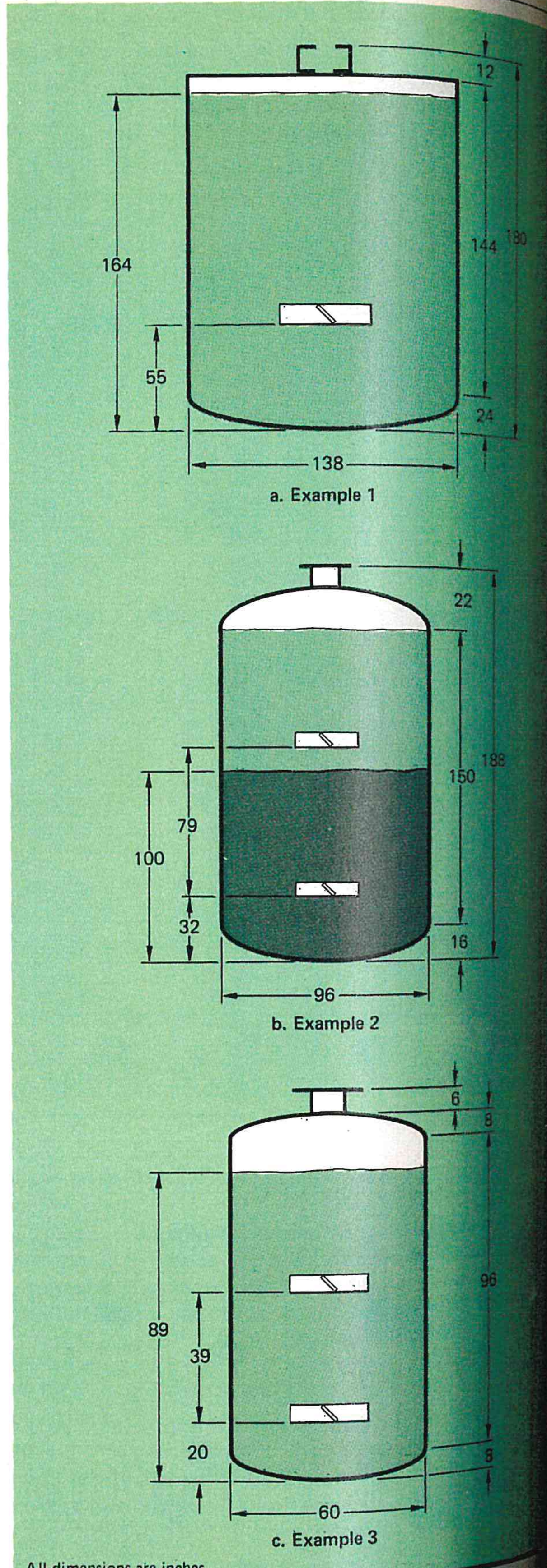
Viscosity correction factor for diameter of pitched-blade turbine — Table V

Reynolds number, N_{Re}	Factor, C_F	Reynolds number, N_{Re}	Factor, C_F
700	1.00	150	0.93
500	0.99	100	0.91
400	0.98	80	0.90
300	0.97	70	0.89
200	0.95	60	0.88
		50	0.87

Recommended baffling for blending and motion — Table VI

Volume, gal	Viscosity, cp	Baffles*
< 1,000	< 2,500	4 at 90°, T/12 width, T/72 offset
< 1,000	> 2,500	None
> 1,000	< 5,000	4 at 90°, T/12 width, T/72 offset
> 1,000	> 5,000	None

* T = vessel diameter.



Sizes of process vessels, liquid depths, and related geometric dimensions for sample problems — Fig. 4

Summary of process requirements and selection procedures for typical examples of blending and motion **Table VII**

	Example 1	Example 2	Example 3
System			
Vessel	Fig. 4a	Fig. 4b	Fig. 4c
Nozzle or mounting height, in	12	6	6
Top head: Type	Flat	ASME	Dished
Top head: Depth, in	0	16	8
Diameter, *T*, in	138	96	60
Straight side, in	144	150	96
Bottom head: Type	ASME	ASME	Dished
Bottom head: Depth, in	24	16	8
Overall height, in	180	188	118
Fluid batch			
Bottom head,			
Capacity, gal	926 max.	314 max. 314 min.	52 max.
Depth, in	24 max.	16 max. 16 min.	8 max.
Straight side,			
Capacity, gal	9,074 max.	4,686 max. 2,632 min.	990 max.
Depth, in	140 max.	150 max. 84 min.	81 max.
Total,			
Capacity, *V*, gal	10,000 max.	5,000 max. 2,946 min.	1,042 max.
Depth, *Z*, in	164 max.	176 max. 100 min.	89 max.
Ratio, *Z/T*	1.19 max.	1.83 max. 1.04 min.	1.48 max.
Specific gravity, S_g	1.05	1.3	0.95
Viscosity, μ, cp	4,900	5,000	25,000
Equivalent volume, V_{eq}, gal	10,500	6,500	990
Scale of agitation			
Initial	1	3	10
Alternate	–	–	7
Power and shaft speed			
Initial selections, hp/rpm			
1.	3/84	7.5/125	40/125
2.	–	5/100	30/100
3.	–	5/84	–
4.	–	3/56	–
Alternate selections, hp/rpm			
1.	–	–	25/155
2.	–	–	15/84
3.	–	–	–
4.	–	–	–
Equipment selection			
Number of turbines	1	2	2
Turbine, blade type	Pitched	Pitched	Pitched
Bottom clearance,			
Lower turbine, in	(1/3)*Z* = 55	*T*/3 = 32	*T*/3 = 20
Upper turbine, in	–	(2/3)*Z* = 111	(2/3)*Z* = 59
Shaft length, *L*, in	125	156	98
Turbine spacing, *S*, in	–	79	39
Turbine diameter, *D*, in			
Initial selections			
1.	32	26	36
2.	–	27	38
3.	–	30	–
4.	–	34	–
Alternate selections			
1.	–	–	28
2.	–	–	37
3.	–	–	–
4.	–	–	–
Baffles			
Number	4	4	None
Location, °	90	90	–
Width, in	11.5	8	–
Length, in	144	150	–

This problem requires a low level of dynamic response because it involves the blending of miscible fluids with small differences in specific gravity and no significant variations of viscosity. Table I indicates that a scale level of 1 to 2 is appropriate. Since no specific degree of uniformity has been stated and the residence time is long, we choose the minimum scale level of 1.

We now enter Table II and find that for a scale level of 1 and an equivalent volume of 10,000 gal the appropriate agitator unit is 3/84 (i.e., 3 hp at 84 rpm). A single agitator selection does not indicate that there is only one power/speed combination that is appropriate but rather that the choice of equivalent turbine agitators is reduced for the smaller machine sizes.

We complete the design for the impeller and baffling in accordance with the previous discussion. The results of this design are summarized in Table VII.

Example 2—The waste product from a reaction has a specific gravity of 1.3 and a viscosity of 5,000 cp, and collects in a 5,000-gal vessel to a total depth of 100 in. An acid stream having a specific gravity of 1.05 and a viscosity of 1 cp is then added to neutralize the waste. A total of 2,054 gal of acid is added to the waste. This raises the liquid level to the upper tangent line of the vessel. The tank is 96 in dia., and has a straight side of 150 in (see sketch in Fig. 4b). The top and bottom heads are ASME dished. Select the agitator for this system.

Several points are to be made by this example. First, the equivalent volume is 6,500 gal (i.e., 5,000 × 1.3). Since the selection tables go from 5,000 to 10,000 gal, interpolation is required when using Table II. From Table I, we find that a scale of agitation of 3 should be adequate. However, a scale of 4 might be a logical alternative because the selections will be made for an equivalent volume of 5,000 gal rather than for 6,500 gal. Hence, a degree of conservatism is realized because the acid phase will dilute the waste to a viscosity less than 5,000 cp.

Since the ratio of $Z/T = 1.83$, we find from Table IV that the system geometry will require the use of two pitched-blade turbines. We now enter Table II at a scale level of 3 for an equivalent volume of 5,000 gal to select the four power/speed combinations, as listed in Table VII. The estimated turbine diameters (Table VII) for each of the four selections are for a two-impeller system. While the requirement for baffles (see Table VI) is on the borderline, it has been assumed that the low-viscosity acid phase would thin the waste and make baffles advisable.

In this example, four combinations of power and shaft speed are obtained. In a later article of this series, dealing with mechanical analysis, we will show that two of the four combinations will not be consistent with the shaft-extension requirements.

Example 3—Let us make a preliminary analysis of the agitation requirements for a 1,000-gal bulk-polymerization reactor. The reactor is 5 ft dia. by 8 ft straight side, with 8-in-deep vessel heads, and a 6-in-high nozzle on the top head (Fig. 4c). The vessel is equipped with a full straight-side and bottom-head cooling-water jacket. The monomers to be polymerized have a maximum specific gravity of 0.95 and an initial viscosity of 10 cp. The monomers are charged to the reactor to a level of 89 in. Simultaneously charged with the monomers are 50 lb of a finely divided catalyst. The exothermic polymerization is initiated and reacts isothermally until batch viscosity reaches 25,000 cp. The reaction is then stopped, and polymer solution removed from reactor.

The data for the system geometry of this example are summarized in Table VII along with the variables that affect the fluid batch. Before attempting to select the agitator drive, an analysis of the batch characteristics and the resulting polymerization is necessary.

First, the presence of trace solids can be ignored because the 50 lb of catalyst represent less than 2% by weight of the charge. And this catalyst will settle slowly—particularly as the batch viscosity increases with polymerization.

Second, the primary variable to be used for design is the maximum viscosity to be reached of 25,000 cp.

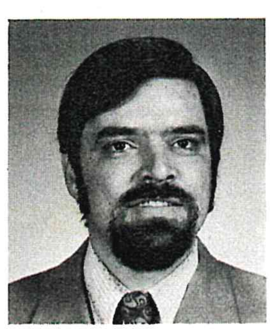
Third, at startup of polymerization, the viscosity will be low and the monomer will swirl rapidly without baffles. As the reaction proceeds, the viscosity builds up and the swirl diminishes. The impellers will then establish the desired flow pattern and batch control. Because the critical part of the reaction occurs during the high-viscosity finishing step, no baffles are recommended.

Scale levels of 10 and 7 for agitation were selected for investigation because they bracket the range commonly associated with reactors of this type (Table I). The power/speed combinations appropriate to these scale levels are obtained from Table III, and listed in Table VII. A mechanical and economic analysis is necessary to select the optimum agitator for each scale level. A heat-transfer analysis of the resultant systems must then be made to assure that the exothermic polymerization can proceed isothermally in the reactor.

The examples in this article have been chosen to show the interaction between the magnitude of the agitation problem and equipment selection. The examples started with a 10,000-gal storage tank requiring a small dynamic response and ended with a 1,000-gal polymerizer requiring a large response. Consequently, turbine agitators that satisfy the process requirements for each example became physically larger even though the required volumes of the vessels became successively smaller.

We have emphasized the rational selection of the scale of agitation in these examples. In a future article, we will explore more-sophisticated analyses of blending-and-motion problems by using criteria for heat transfer and blend time.

The authors



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Richard W. Hicks—For biography, see *Chem. Eng.*, Feb. 2, 1976, p. 100.

John G. Fenic—For biography, see *Chem. Eng.*, Dec. 8, 1975, p. 114.