Application guidelines for turbine agitators

A compilation by major process categories identifies the pertinent design data for the equipment components in which agitation occurs.

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☐ Turbine agitators have diverse applications throughout the chemical process industries (CPI). In these uses, turbine agitators primarily act as a device for creating liquid motion. Therefore, the selection of an appropriate agitator design for each application requires a conversion from performance requirements (such as liquid motion or dynamic response) to mechanical descriptions (such as horsepower, shaft speed and turbine diameter). The design procedure presented in this series (see box on p. 170) has emphasized the orderly transition from process requirements to mechanical equipment.

To relate selections of agitator equipment to dynamic response, we have described and used a scale of agitation. The one-to-ten range of this scale encompasses most practical levels of agitation. Although the dynamic response, associated with scale of agitation, provides considerable guidance, actual process experience gives an equally important indication of agitation requirements.

In this concluding article of the series, we list the scale of agitation required in numerous applications, as shown in Table I. These applications represent only a small portion of the total number found in the CPI. The information presented in Table I is intended only as a design guide because special process conditions may replace such generalities.

The organization of Table I follows the chapter headings in Shreve [1]. Because of the broad scope of the CPI, these headings are a convenient and orderly method of presenting diverse information. However, the applications appearing in this table do not necessarily represent equipment associated with the process flowsheets shown by Shreve.

No single criterion can be set for all agitator applications because both process requirements and economic factors influence a selection. Process requirements typically set a minimum scale of agitation for acceptable performance, and may set a maximum scale of agitation for feasible operation. Economic factors usually determine which end of the process-performance range should be selected. In many applications, the lowest scale of agitation that provides a satisfactory process result will represent the most economical equipment. However, in critical applications such as reactors, the increased equipment cost associated with a higher scale of agitation may be offset by increased productivity created by the additional agitation.

Design parameters for agitation

Table I summarizes process experience in terms of the agitator-design procedure. Throughout this series, a step-by-step design logic has been developed to identify equipment selections that satisfy process requirements. The relationships between such requirements and equipment selections are a combination of fundamental concepts and practical experience.

The first two columns in Table I identify the application by a typical operation name and a brief description of the process. Most of the descriptions apply only to operations characteristic of several specific processes. Within each application, actual design data regarding tank size, fluid properties and process considerations must be combined with process experience to design an agitator.

The column headed "design classification" indicates which one of the three major design categories, blending and motion, solids suspension, or gas dispersion should be used. Design procedures for these categories are described in Parts 4, 5 and 6 of the series, respectively. The design classifications are related primarily to the phases present in the process.

Associated with each category of agitation is a "primary design variable." This establishes the difficulty of the agitation problem. Usually, the value of the design variable is determined directly from the properties of the process fluids, although special cases require the selection of an empirical design value to satisfy process

Design guidelines for applications of turbine agitators in selected process industries **Table I**

Turbine-agitator application	Process description	Design classification	Primary design variable	Scale of agitation	Additional design information
Water industries					
Carbon make-down tank	Incorporate and suspend activated carbon in water	Solids suspension	Settling velocity of carbon particles	4 to 6	Dual turbines. One near the surface provides swirl to improve wetting and speed make-down.
Day tank	Hold carbon in contact with water	Solids suspension	Settling velocity of carbon particles	3	This scale of agitation is usually sufficient to resuspend carbon particles after periods with agitator off.
Flash mixer	Rapid mixing of water-treatment chemicals	Blending and motion	Viscosity	3 to 10	Scale of agitation depends on retention time and tank geometry; blend time should be considered.
Equalization basin	Blending to prevent concentration surges	Blending and motion	Viscosity	1, or less	Number and size of agitator depends on basin geometry. Sphere of influence for agitator is partially determined by liquid level.
Lime-slurry make-up	Suspend slaked lime [$Ca(OH)_2$] in water	Blending and motion	Viscosity (Design value based on percent solids)	4 to 5 (0 to 20% solids) 6 to 7 (20 to 38% solids)	Small particles give suspension an apparent viscosity. Typical lime-slurry properties:
Lime-slurry storage	Maintain slurry suspension	Blending and motion	Viscosity	2 to 3 (0 to 20% solids) 3 to 4 (20 to 38% solids)	Weight % / Sp. gr. / Viscosity: 10 / 1.1 / <100 cp.; 20 / 1.2 / 200 cp.; 30 / 1.3 / 1,000 cp.; 38 / 1.4 / 5,000 cp.; >38 / / Pseudoplastic
Lime-slaking tank	Convert CaO To $Ca(OH)_2$	Blending and motion	Viscosity	8 to 10	High scale of agitation required to keep balls of dry solids from forming. Upper turbine used to improve make-down.
Fuels and energy conversion					
Crude-oil storage	Suspend bottom sludge and water in crude	Blending and motion	Viscosity of crude	Less than 1	Side-entering agitators are usually used.
Fuel-additive blending	Blend miscible additives	Blending and motion	Viscosity	1	Location and number of agitators depends on tank configuration. Side-entering agitators are usually used.
Additive limestone-storage tank	Suspend limestone for power-plant SO_2 scrubber	Solids suspension	Settling velocity (design for 1 ft/min)	3	Multiple agitators usually required for small *Z/T* (*Z* = liquid depth, *T*=tank dia.) tank configuration. Usually rubber-covered pitched-blade turbines.
Absorber recycle tank	Maintain suspension of calcium sulfites and sulfates, and recycled lime or limestone from SO_2 scrubber	Solids suspension	Settling velocity (design for 1 ft/min)	3 to 6	Agitator location depends on tank configuration. Rubber-covered turbine.
Ceramics industries					
Blunger	Break up and suspend ball clay	Blending and motion	Viscosity (Non-Newtonian)	6 to 10	Wetting agents influence clay-slurry properties. Laboratory test usually required for verification.
Clay storage	Maintain clay suspension	Blending and motion	Apparent viscosity	2 to 5	Non-Newtonian viscosity depends on the specific clay and presence of wetting agents.
Ore refining					
Leach tank	Dissolve ore fraction as ammoniated complex in staged tanks (air sparge used to effect solubility)	Solids suspension	Solids-settling velocity	6 to 10	Stage in process determines scale level.
Reduction autoclave	Hydrogen used to reduce metallic complex to metal	Gas dispersion	Superficial gas velocity	8 to 10	Special turbines sometimes used.
Phosphorus industries					
Rock-slurry tank	Suspend crushed phosphate rock	Solids suspension	Settling velocity (typically 0.5 to 1 ft/min)	3 to 5	Turbine location and scale of agitation depend on location of outlet.

Design guidelines for applications of turbine agitators in selected process industries (continued) **Table I**

Turbine-agitator application	Process description	Design classification	Primary design variable	Scale of agitation	Additional design information
Phosphorus industries (cont'd)					
Attack tank	Contacting phosphate rock with sulfuric acid (often in multiple stages or compartments)	Solids suspension	Settling velocity (design for 10 ft/min)	6 to 8	Scale of agitation and compartment geometry influenced by previous experience.
				4 to 6	With multiple compartments, lower scale of agitation used in downstream compartments. Tip speed determines size of gypsum crystals.
Aging tank	Surge capacity with some gypsum crystal growth	Solids suspension	Settling velocity of gypsum crystals	2	Typically 2 to 7% gypsum solids produced as acid cools.
Paint and varnish industry					
Thin and tint	Blending of base, vehicle, and pigments	Blending and motion	Viscosity (use maximum apparent viscosity)	6 to 10	Trade-sales paints typically have viscosities from 1,000 to 50,000 cp. Industrial paints typically have viscosities from 100 to 1,000 cp [2].
Feed and hold	Maintain product uniformity during temporary holding	Blending and motion	Viscosity (use maximum apparent viscosity)	3	
Titanium dioxide	Maintain suspension of 60 to 75% TiO_2	Blending and motion	Viscosity	2 to 3	Solids, % / Design Viscosity, cp: <60 – 100; 70 – 500; 72 – 1,000; 75 – 2,500. Low agitator speeds (less than 45 rpm) required because of dilatant viscosities.
Resin reactors	(See polymerization reactors)				
Adhesives					
Blend tank	Blend ingredients	Blending and motion	Viscosity (usually high)	3 to 8	Design for large *D/T* (impeller dia. to tank dia.). Variable-speed drive may be necessary to handle different formulations. Double-motion or other high-viscosity agitator may be used.
Rubber-cement tank	Cutting and dissolving rubber in solvent	Blending and motion	Maximum viscosity	6 to 10	Special turbine may be required.
Oils, fats and waxes					
Hydrogenation	Flow-through type (hydrogen is recirculated)	Gas dispersion	Superficial gas velocity of recirculated gas	4 to 6	Radial-flow turbines used.
	Dead-end type (hydrogen fed as needed)	Gas dispersion	Superficial gas velocity (design for 0.01 ft/sec)	4 to 6	Upper turbine is pitched-blade located near liquid surface to reincorporate gas from head-space of tank.
Sugar and starch industries					
Sugar-dissolving tank	Dissolve dry sugar to form syrup	Blending and motion	Viscosity of final batch	3	Design for the larger agitator as determined by blending-and-motion or solids-suspension procedures.
		Solids suspension	Settling velocity of initial particles	3	
Wet milling of corn					
Grind tank	Suspend corn following initial grind	Solids suspension	Settling velocity (design for 2 ft/min)	3	
Starch storage	Holding tank for suspended starch	Blending and motion	Apparent viscosity	3 to 4	Design for minimum liquid level or changing liquid level with multiple turbines.
Starch converter	Acid conversion in staged column	Blending and motion	Maximum viscosity in column	10, or more	Most of the power is invested in lower stages by using larger turbines
	Enzyme conversion	Blending and motion	Viscosity (usually low)	2 to 4	
Syrup storage	Holding tank	Blending and motion	Viscosity of syrup	2	

Design guidelines for applications of turbine agitators in selected process industries (continued) — Table I

Turbine-agitator application	Process description	Design classification	Primary design variable	Scale of agitation	Additional design information
Fermentation industries					
Brew kettles (Anaerobic)	Beer fermentation	Blending and motion	Viscosity	1 to 2	Only small amount of liquid motion required.
Aerobic fermenters	Chemicals: acetic acid citric acid, etc.	Gas dispersion	Superficial gas velocity	8 to 10	Scale-up from previous experience strongly influences design. Fluids often non-Newtonian because of suspended cells.
	Pharmaceuticals: penicillin, tetracycline, steroids, vitamins, etc.	Gas dispersion	Superficial gas velocity	9 to 10	
	Single-cell protein from hydrocarbon feedstock	Gas dispersion	Superficial gas velocity	10, or more	Design depends on substrate—hydrocarbon substrate requires high intensity agitation because of low oxygen solubility.
Seed, bump or inoculum tank	Fermentation to develop cell growth	Gas dispersion	Superficial gas velocity	8 to 10	Conditions usually similar to primary fermenter.
Pulp and paper industries					
Stock chest	Stock uniformity maintained for further processing	Blending and motion	Percent pulp consistency	Not designed from scale of agitation	Geometry of stock chest influences design. Large, side-entering, propeller agitators used more often than turbine agitators.
Starch cooking	Starch preparation for coatings and fillers	Blending and motion	Maximum viscosity	6 to 8	Viscosity goes through a maximum during cooking, typically about 10,000 cp.
Starch storage	Holding tank for starch	Blending and motion	Viscosity	3 to 4	Viscosity usually less than for cooking.
Clay storage	Clay for coatings	Blending and motion	Apparent viscosity	3 to 4	Clay suspension behaves like pseudoplastic fluid, and contains up to 70% solids.
Polymer industries					
Polymerization reactors [3] for:					
Bulk polymerization [4]	Polymer is molten or soluble in monomer (examples: polystyrene, polyester)	Blending and motion	Maximum viscosity	8 to 10	Viscosity increases as polymerization procedes. Turbine agitators may be used with viscosities up to 75,000 cp. Above 75,000 cp, helix or anchor agitators are usually used. Volume of reactor limited by heat transfer.
	Polymer is insoluble in monomer (example: polyvinyl chloride)	Solids suspension	Settling velocity (design for 25 ft/min)	10	Tip speed determines particle size of polymer [5]
Solution polymerization [6]	Monomer and polymer are soluble in solvent (examples: polypropylene and polyethylene)	Blending and motion	Maximum viscosity	8 to 10	Turbine agitators are usually suitable although helix and anchor agitators are also used. Variable-speed agitators may be used.
	Monomer soluble but polymer insoluble (examples: polypropylene and polystyrene)	Solids suspension	Settling velocity	9 to 10	Shear rate and solvent influence particle size. Design strongly influenced by previous experience.
Suspension polymerization [7]	Liquid monomer droplets polymerize to solid polymer particles (examples: polyvinyl chloride, polystyrene, polyethylene, polymethylmethacrylate)	Solids suspension	Settling velocity (design for 25 ft/min)	8 to 10	Tip speed influences droplet size and therefore polymer particle size [5].
Emulsion polymerization [8]	Monomer emulsion usually in water stabilized with surfactants (examples: acrylic polymers, polyvinyl acetate, butadiene-styrene copolymers, polyvinyl chloride)	Blending and motion (two phases behave as single phase)	Viscosity (design for 1,000 cp)	6 to 10	Surfactant is primarily responsible for particle size, low shear rate (tip speed 800 ft/min) necessary to avoid coagulation.
Other applications					
Stripper	Steam stripping of monomer from polymer	Solids suspension	Settling velocity depends on particle size	6 to 9	Scale-up may be based on equal free-liquid-surface area/volume. Surface motion important.

Design guidelines for applications of turbine agitators in selected process industries (continued)					Table I
Turbine-agitator application	**Process description**	**Design classification**	**Primary design variable**	**Scale of agitation**	**Additional design information**
Other applications (cont'd)					
Blend tank, wash tank or centrifuge feed	Agitated holding of suspended polymer	Solids suspension	Settling velocity	2 to 6	Level of suspension determined by required uniformity of suspension.
Product storage	Polymer suspension	Solids suspension	Settling velocity	2 to 3	Higher level of agitation may be required if polymer particles are sticky.
	Emulsions	Blending and motion	Viscosity	2 to 3	
Slurry tank	Carbon-black slurry suspension and storage for elastomers	Solids suspension	Settling velocity (usually < 0.5 ft/min)	2 to 3 (5 wt% carbon) 3 to 4 (10 wt% carbon)	
Coagulator	Chemical or steam coagulation of rubber crumb	Solids suspension	Settling velocity (design for 25 ft/min)	9 to 10	High scale of agitation keeps coagulated rubber in crumb form.
Crumb tank	Washing and suspension of rubber crumb	Solids suspension	Settling velocity (design for 25 ft/min)	6 to 8	Crumb floats. Upper turbine used to create surface swirl. Cut-off baffles may be used.

requirements. The size (represented by equivalent volume) and difficulty of agitation are the principal elements of problem magnitude for agitator design.

The scale of agitation* is the communication tool developed for the agitator-design procedure. The value of the scale directly indicates the dynamic response produced by a given piece of agitation equipment for a given problem magnitude. Dynamic response can be related to process results through an understanding of the liquid motion provided by the turbine agitator. Although the application table frequently indicates a range of values for the scale of agitation, specific process conditions or economic factors will narrow this range and indicate the proper choice of equipment.

The column headed "additional design information" provides special guidance to equipment selection or identification of design variables. Many of the applications summarized in Table I are sufficiently unusual as to require some special considerations. Occasionally, the only method for accurate design estimation involves scale-up of a laboratory or pilot-scale test. Such procedures were discussed in Part 10 of the series, and demonstrated by an example in Part 11.

How to use Table I

The terminology in different industries of the CPI is sufficiently ambiguous so that accurate identification of a process from the application name is difficult. Therefore, the process descriptions both identify a process and indicate examples for the application.

Agitator applications are also difficult to categorize, because similar applications are found in different industries. For instance, lime slurries are used in both water industries and in fuel-and-energy conversions for SO_2 removal. Similar design considerations exist for both applications even though some differences in materials and process requirements may apply.

Most of the design classifications are determined directly from the phases present. The blending-and-motion category is used whenever the agitated fluid involves a liquid phase or multiple liquid phases. Solids-suspension and gas-dispersion classifications apply when either a settling solid or sparged gas is present, respectively. In some cases, a finely divided solid can be suspended in a liquid such that the behavior is primarily that of a single-phase liquid. For example, the blunger in the ceramics industries has finely-divided clay particles present in water, yet the design analysis is performed on the basis of liquid motion.

In more-complicated applications such as those in the fermentation industries, both suspended solids and sparged gas are present. The suspended solids create an apparent viscosity in the liquid phase. Certain justification exists for treating fermentation problems as either solids suspension or blending and motion. However, gas dispersion is almost always the critical parameter.

Normally, the value of the primary design variable is directly set by the fluid properties. Viscosity, settling velocity and superficial gas velocity can be measured and calculated. Sometimes, experience dictates that the calculated values are unsuitable for process design, and an empirical value must be selected. In the phosphoric-acid attack tank, a design settling velocity of 10 ft/min is used—even though the actual settling velocity of the rock particles may be considerably less. The design variable is modified to provide equipment selections typical of previous experience and process requirements. Several entries in the design variable column indicate values that reflect actual experience better than the calculated parameters.

Scale of agitation is the key element for entry into the design tables. The scale value is a direct indication of the dynamic response for the agitated fluids. In some cases, the table shows a single value because process conditions are well defined. In other cases, a range of values has been indicated because no single level of agitation applies universally.

Process and economic factors must be considered to more accurately identify the scale value desired. The values presented in Table I are intended to be a guide for making reasonable estimates and are not absolute

* Chemineer calls scale of agitation, ChemScale.

design inputs. Sometimes, as in the case of stock chests in the pulp-and-paper industries, the design procedure is not suitable as a method of agitator selection.

Additional factors that enter into the design of an agitator include: special fluid properties, unusual tank requirements. The column headed "additional design information" in Table I is intended to provide some guidance in these areas. For actual design problems, more-extensive information can be developed from specific process requirements. Economic factors can always be of equal importance to these requirements, and further affect design.

Summary of agitator design

In this series, we have presented a unified approach to turbine-agitator design. The basic logic of the design procedure was presented in Part 1. The development of individual design concepts was based on some of the fundamentals of Parts 2 and 3. Step-by-step methods of agitator design for blending and motion, solids suspension, and gas dispersion were given in Parts 4, 5 and 6. Key elements in the mechanical design of a turbine agitator were discussed in Parts 7 and 8. Economic evaluation along with cost estimating information was presented in Part 9. Part 10 summarized scaleup procedures. Use of the design procedure has been presented in Parts 11 and 12.

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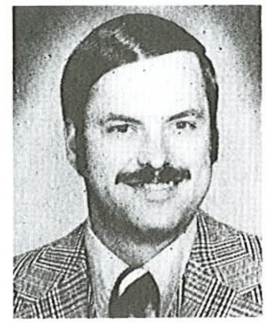

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