AIChE

EQUIPMENT TESTING PROCEDURE

MIXING EQUIPMENT (Impeller Type)

AIChE

ICAN INSTITUTE OF CHEMICAL ENGINEERS
ST 47 STREET • NEW YORK, NEW YORK 10017

AIChE Equipment Testing Procedure

MIXING EQUIPMENT

IMPELLER TYPE

A Guide to Performance Evaluation

Second Edition

Prepared by the
Equipment Testing Procedures Committee

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100.0 PURPOSE AND SCOPE

101.0 *Purpose*

This procedures offers methods of conducting and interpreting performance tests on impeller-type mixing equipment.

These tests may be conducted to determine process performance, mechanical reliability, or suitability of equipment for the intended use. Since the correct identification of the "real" problem can be the most difficult part of the tests conducted on mixing equipment, several of the procedures tend to follow trouble-shooting tactics.

Tests may be conducted to determine scale-up or scale-down criteria and to develop other equipment sizing.

The reasons for conducting performance tests can be varied, but the methods presented should be generally applicable to most situations. Care should be taken to set testing priorities and to select the most suitable methods for a given situation.

102.0 *Scope*

Rather than specific instructions, a collection of techniques is presented to guide the user. Emphasis is placed on practical methods which are likely to produce reliable results.

This procedure includes widely accepted nomenclature and definitions to assist in the collection and communication of results. General methods are provided for collecting and analyzing process results, but because of the enormous variety of possible applications for impeller-type mixing equipment, little detail is included.

Many of the useful indirect measures of process conditions involve mechanically related observations. Because mechanically sound equipment is necessary for successful process operation, many aspects of the testing are mechanical. Observations of mechanical operation are also essential for long equipment life and personnel safety.

103.0 *Liability*

AIChE and members of the various committees involved make no representation, warranties or guarantees, expressed or implied, as to the application or fitness of the testing procedures suggested herein for any specific purpose or use. Company affiliations are shown for information only and do not imply procedure approval by the companies listed. The user ultimately must make his own judgement as to which testing procedures to utilize for a specific application.

200.0 DEFINITION AND DESCRIPTION OF TERMS

201.0 *Introduction*

Impeller-type mixing equipment encompasses a wide variety of specific equipment used for fluid processing. No single description can provide complete information about all types of equipment. In general, impeller-type mixing equipment includes both the rotating mixing equipment and the tank in which it is used. The fluid in the tank is also an important consideration in any testing procedure.

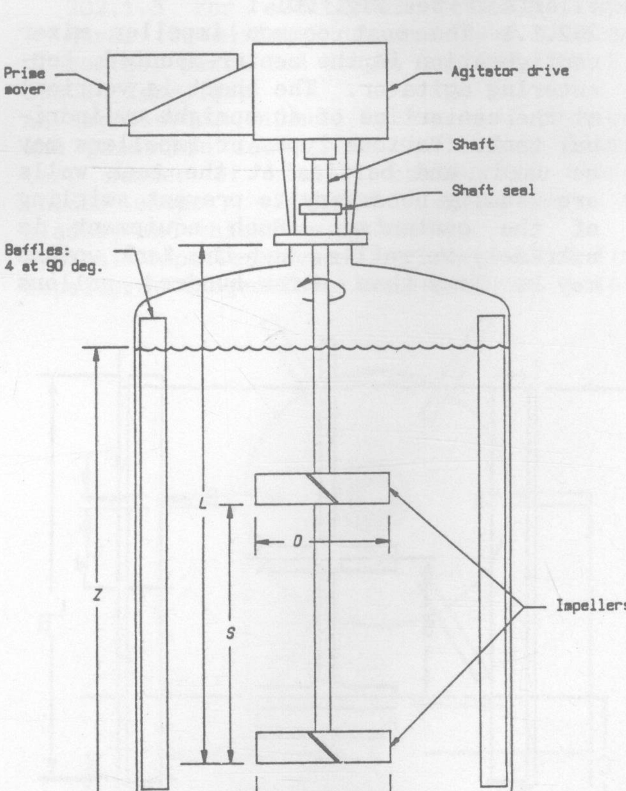


Fig. 201.1 Impeller Mixing Equipment

The terms mixing and agitation are used almost interchangeably. However, mixing may be used to refer more specifically to the blending of liquids, and agitation may be used to refer more generally to the motion of fluids for purposes other than blending, such as suspending solids in a slurry. Mixing equipment and agitation equipment are indistinguishable, unless their application has specific meaning.

202.0 *Mixing Equipment*

An impeller-type mixer or agitator can be defined as equipment for blending and agitation of liquids and liquids, liquids and solids, or liquids and gases or combinations, such that a liquid phase is continuous. A rotating impeller provides a thrusting or shearing action on the fluid in a vessel. The equipment takes many forms, but common to each is a device (impeller) attached to a rotating shaft.

202.1 *Equipment Configurations*

In general, the system includes the impeller-type mixer, the vessel, and all internal accessories, and sometimes auxiliary equipment. The impeller mixer usually consists of five (5) basic components: a prime mover (typically a motor), an agitator drive which reduces speed and increases torque (not always required), a shaft seal (used only with closed tanks), a shaft and impeller(s). See Fig. 201.1

202.1.1 The most common impeller mixer configuration is the center-mounted, top-entering agitator. The shaft is vertical at the centerline of an upright cylindrical tank. Various types of impellers may be used, and baffles at the tank walls are usually necessary to prevent swirling of the contents. Such equipment is extremely versatile, and the tank volume may be less than a few hundred gallons

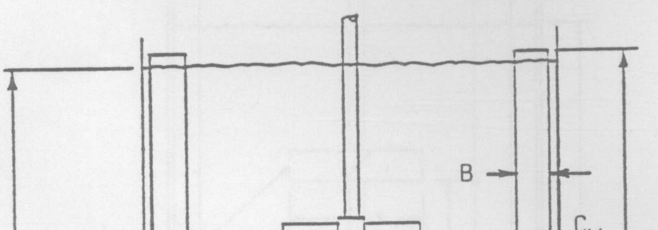


Fig. 202.1 Center Mount Impeller Mixer

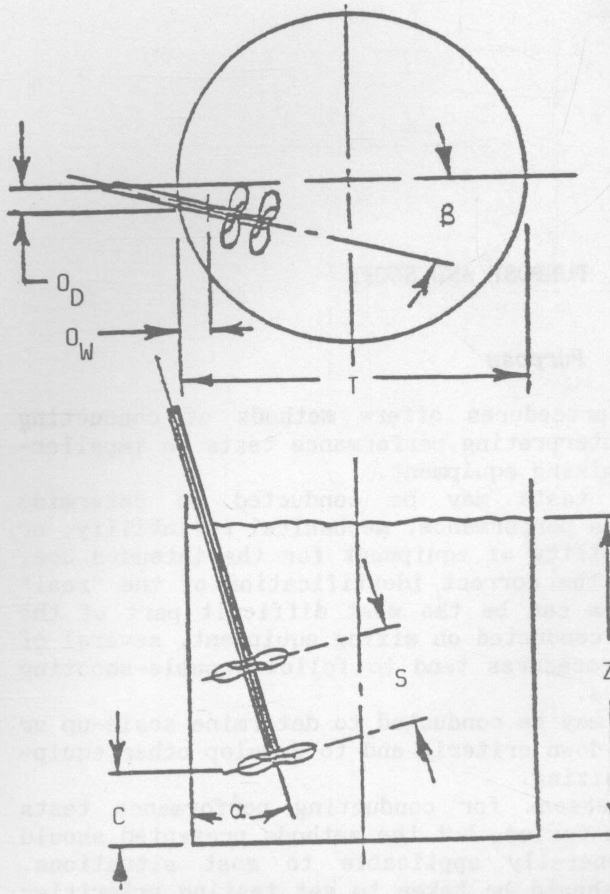


Fig. 202.2 Top-entering Propeller Mixer

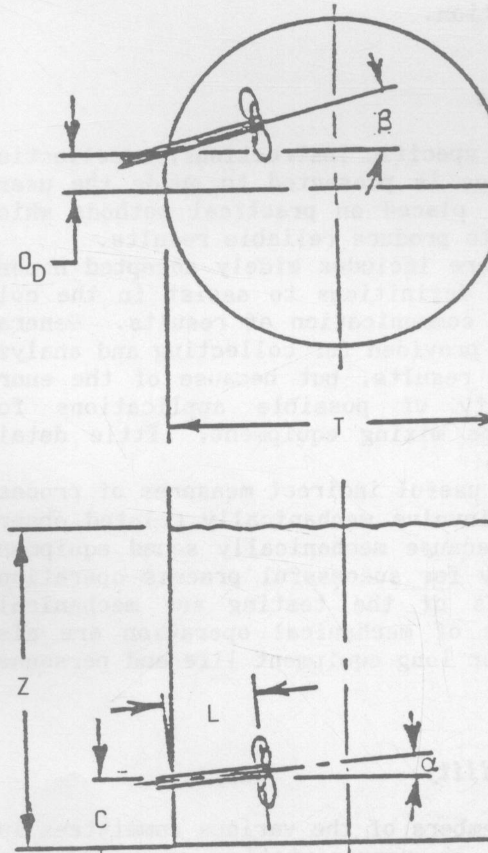


Fig. 202.3 Side-entering Propeller Mixer

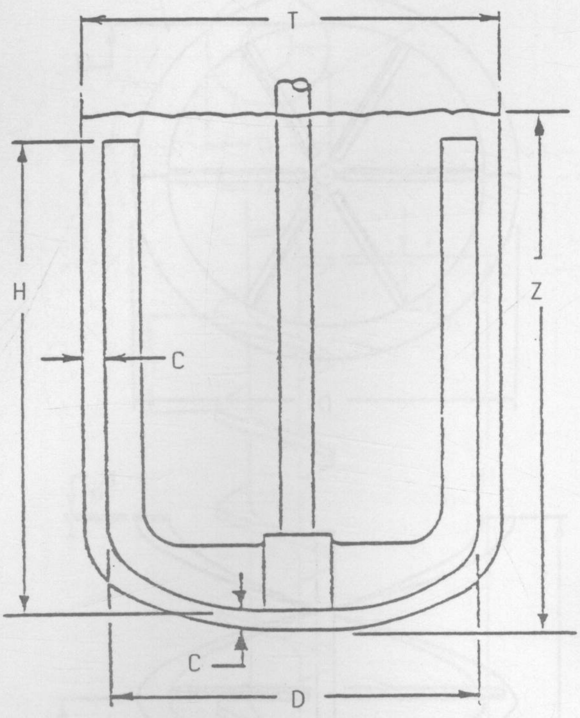


Fig. 202.4 Close Clearance Impeller Mixer

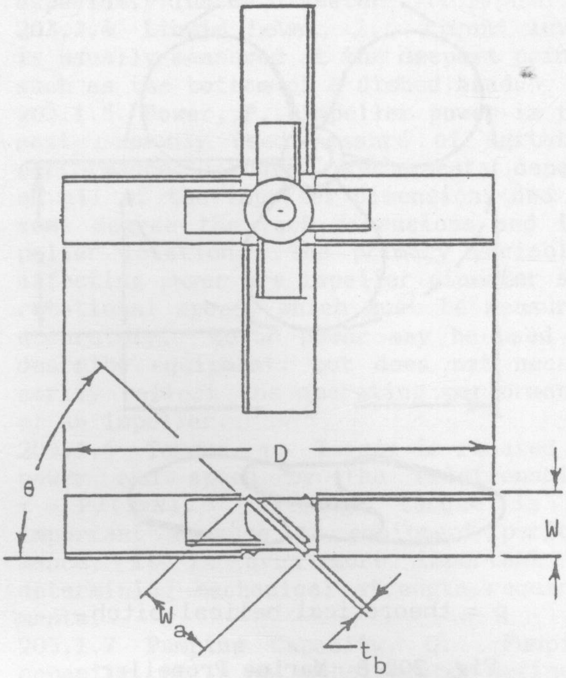


Fig. 202.6 Pitched-blade Turbine

(one cubic meter) to over a hundred thousand gallons (five hundred cubic meters).

202.1.2 Top-entering, angle-mounted mixers and side-entering mixers are some of the more common configurations using higher shaft speeds and propeller-style impellers.

202.1.3 Close clearance impeller systems are a special case of the center-mounted mixers, which are typically used in special applications with unusual fluids.

202.1.4 Additional impeller mixer configurations include bottom-entering mixers, and tanks with multiple top or side-entering mixers. Most of the test methods still apply, even to the more unusual mounting arrangements.

202.1.5 For additional testing procedures for mixing equipment used with dry solids, paste and dough, see Ref. 808.1.

202.2 *Impellers*

An impeller is defined by a set of physical and geometric factors which include diameter, number of blades, contour of blades (blade shape), width of blades, angle of blades, and thickness of blades.

Typical impeller types include radial-flow impellers, tangential-flow impellers, axial-

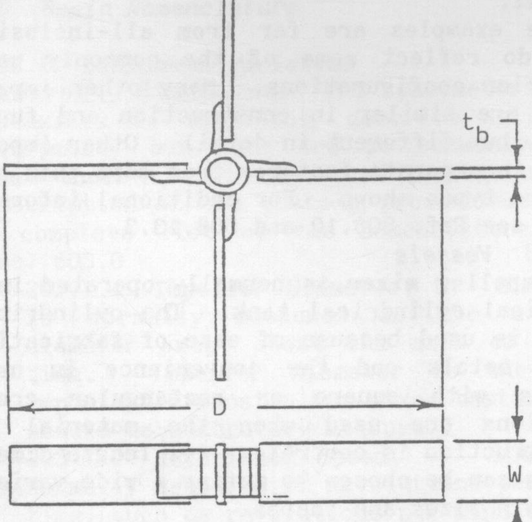


Fig. 202.5 Straight-blade Turbine

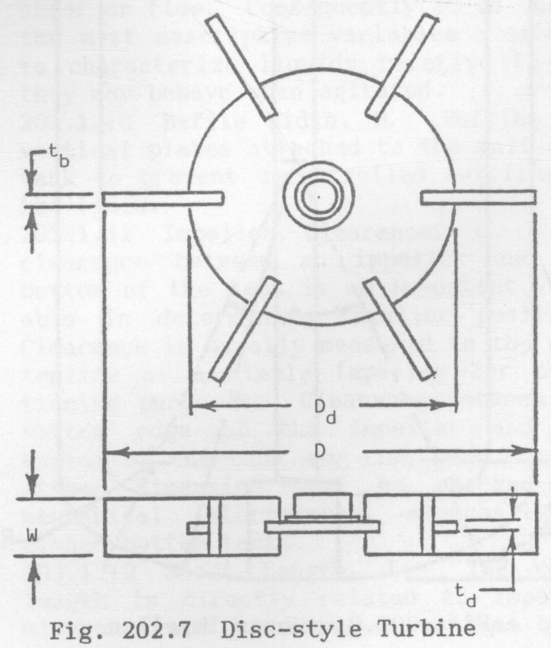
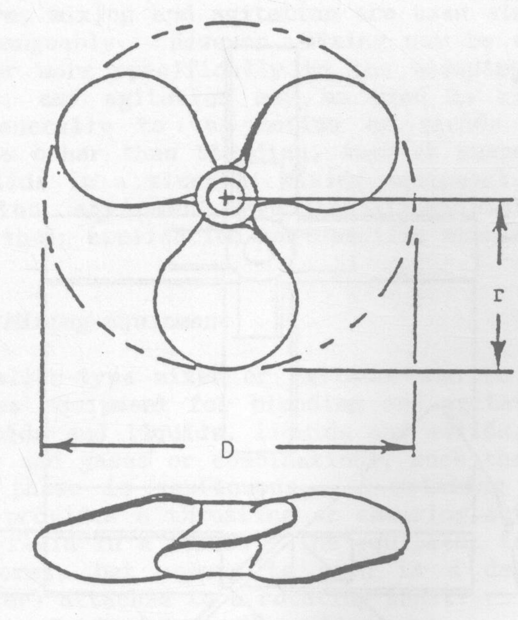


Fig. 202.7 Disc-style Turbine



p = theoretical helical pitch

Fig. 202.8 Marine Propeller

flow impellers, anchors, augers (screws), and helixes. The term "turbine" is frequently used when referring to impellers with flat plate-style blades. Examples of

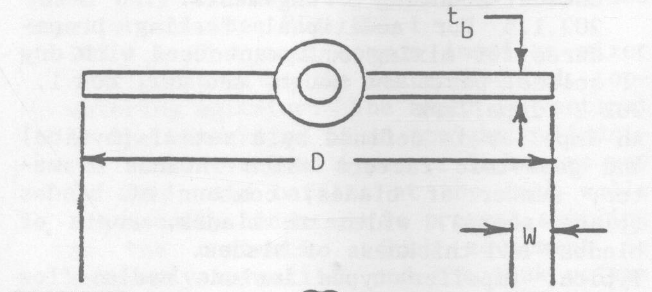


Fig. 202.9 Anchor Impeller

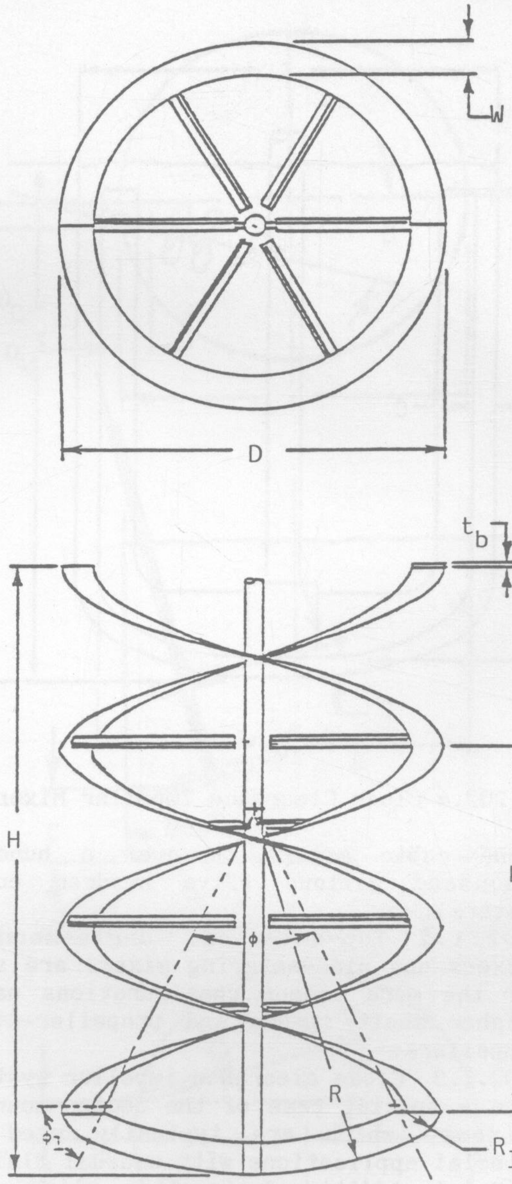


Fig. 202.10 Double Flight Helix

impellers are shown in Figs. 202.5 through 202.11.

These examples are far from all-inclusive but do reflect some of the commonly used impeller configurations. Many other impellers are similar in construction and function, but different in detail. Other impellers incorporate features from more than one of the types shown. For additional information see Ref. 808.10 and 808.13.3.

202.3 ***Vessels***

An impeller mixer is normally operated in a vertical cylindrical tank. The cylindrical tank is used because of ease of fabrication from metals and the convenience in use. Tanks with square or rectangular cross sections are used when the material of construction is concrete. All length dimensions can be chosen to define a wide variety of both sizes and shapes.

In addition to the vessel itself, baffles at the wall, impeller locations, and many other

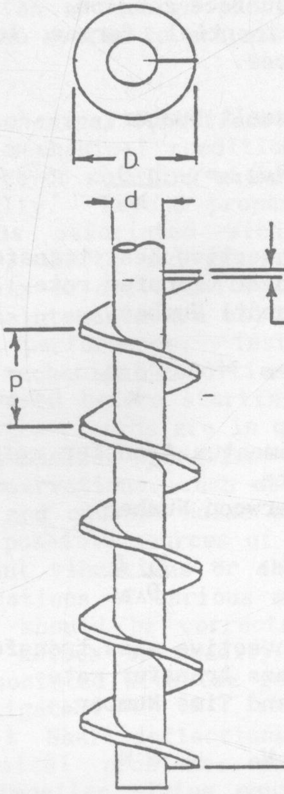


Fig. 202.11 Single Flight Auger or Screw

devices, such as: dip pipes, sparge rings, cooling coils, plate coils, feed points, draw-off points, and recirculation points are all part of the equipment.

202.4 Auxiliary equipment such as compressors for gas sparging, pumps for liquid recirculation, external heat exchangers, and similar devices associated with the agitated process must be considered. Such equipment may contribute substantially to the performance and/or behavior of the agitation equipment.

203.0 *Basic Nomenclature*

203.1 *Equipment Variables*

Numerous dimensions and parameters are necessary to completely describe agitation equipment, but some are so commonly used that their symbols are used throughout the description of the testing procedures. For a complete list of the nomenclature, see Sec. 803.0

203.1.1 **Impeller Diameter**, D. Diameter is normally measured as the maximum diameter swept about the axis of rotation. Impeller diameter is the most important dimension for mixer testing and should be accurately measured.

203.1.2 **Rotational Speed**, N. Speed is normally measured in revolutions per unit time, such as revolutions per minute.

203.1.3 **Tank Diameter**, T. Since most agitated tanks are cylindrical, diameter is an appropriate measure of tank size, especially inside diameter.

203.1.4 **Liquid Level**, Z. Liquid level is usually measured at the deepest point, such as the bottom of a dished head.

203.1.5 **Power**, P. Impeller power is the most commonly used measure of agitator performance. Power requirements depend on all of the impeller dimensions and to some degree the tank dimensions and impeller location. The primary variables affecting power are impeller diameter and rotational speed, which must be measured accurately. Motor power may be used to describe equipment, but does not necessarily reflect the operating performance of an impeller.

203.1.6 **Torque**, τ. Torque is related to power and speed by the relationship, $\tau = P/(2\pi N)$. Although torque is an important measure of equipment performance, it is even more important in determining mechanical strength requirements.

203.1.7 **Pumping Capacity**, Q. Pumping capacity, while not consistently defined, is often used to characterize the fluid motion resulting from impeller rotation. Primary pumping capacity normally describes the direct discharge from the impeller. Total pumping capacity may include some portion of the entrained flow, but definition must be provided.

203.1.8 **Fluid Density**, ρ. Density usually has a direct effect on impeller power, so while water-like liquids may have little effect, hydrocarbon liquids and heavy solutions or slurries must be appropriately characterized. Density is often handled as **specific gravity** (S.G.) relative to water.

203.1.9 **Viscosity**, μ. Viscosity is a measure of the resistance of a fluid to shear or flow. Consequently it is one of the most descriptive variables available to characterize liquids relative to how they may behave when agitated.

203.1.10 **Baffle Width**, B. Baffles are vertical plates attached to the wall of a tank to prevent uncontrolled swirling of the fluid.

203.1.11 **Impeller Clearance**, C. The clearance between an impeller and the bottom of the tank is an important variable in determining impeller position. Clearance is usually measured to the centerline of a simple impeller for positioning purposes. Clearance between the bottom edge of the impeller and the bottom of the tank may also be used, but either dimension must be checked for mechanical interference, especially in dished bottom tanks.

203.1.12 **Shaft Length**, L. The shaft length is directly related to impeller clearance and location, as well as being one of the most important mechanical design variables.

203.1.13 **Impeller Weight**, W_i. The weight of an impeller is important in shaft design relative to natural frequency.

203.1.14 **Blade Width**, W. The projected blade width is an important characteristic of the impeller blade, especially because numerous designs involve essentially rectangular blade shapes.

203.1.15 **Blade Thickness**, t_b. Another characteristic of an impeller blade, primarily related to the strength of the blade.

203.2 *Agitation Related Groups*

203.2.1 **Reynolds Number**,

$$N_{Re} = \frac{D^2 N \rho}{\mu}$$

Ratio of inertial forces to viscous forces.

203.2.2 **Power Number**,

$$N_P = \frac{P g_c}{\rho N^3 D^5}$$

where g_c is the gravitational force constant for consistent units.
Ratio of imposed forces to inertial forces.

203.2.3 **Pumping Number**,

$$N_Q = \frac{Q}{N D^3}$$

Ratio of actual flow rate to a reference flow rate.

203.2.4 **Froude Number**,

$$N_{Fr} = \frac{N^2 D}{g}$$

Ratio of inertial force to gravity force.

203.2.5 **Aeration Number**,

$$N_A = \frac{Q_g}{N D^3}$$

where Q_g is gas flow rate.
Ratio of gas flow rate to a reference liquid flow rate.

203.2.6 **Thrust Number**,

$$N_{Th} = \frac{F_{th} g_c}{\rho N^2 D^4}$$

where F_{th} is impeller thrust.
Ratio of imposed forces to inertial forces.

203.3 *Process Related Groups*

203.3.1 **Weber Number**,

$$N_{We} = \frac{N^2 D^3 \rho}{\sigma g_c}$$

where σ is surface tension.
Ratio of inertial forces to surface tension forces.

203.3.2 **Nusselt Number**,

$$N_{Nu} = \frac{h D}{k}$$

Ratio of convective heat transfer rate to conductive heat transfer rate.

203.3.3 **Prandtl Number**,

$$N_{Pr} = \frac{c_p \mu}{k}$$

Ratio of momentum transfer rate to heat transfer rate.

203.3.4 **Sherwood Number**,

$$N_{Sh} = \frac{k_L D}{D_{AB}}$$

Ratio of convective mass transfer rate to diffusive mass transfer rate.

203.3.5 **Blend Time Number**,

$$N_\theta = \theta N$$

where θ is the blend time.
Ratio of actual blend time to a reference time.

203.3.6 **Peclet Number**,

$$N_{Pe} = \frac{c_p D^2 N \rho}{k}$$

Ratio of momentum transfer rate to heat conduction rate.

203.3.7 **Schmidt Number**,

$$N_{Sc} = \frac{\mu}{\rho D_{AB}}$$

Ratio of viscous momentum transfer rate to diffusive mass transfer rate.

204.0 *Operating Conditions*

Operation of mixing equipment include directly related conditions, such as: agitator speed and power requirements; and indirectly related conditions, such as: feed rates, pressure, temperature, fluid properties, liquid levels, residence time, etc.

205.0 *Types of Tests*

205.1 *Operating Performance*
Mixer power, speed and torque are important indicators of operating performance, especially how close actual conditions are to those chosen by design. A quick check of these basic conditions could correct an

installation or design problem before committing the system to process operation.

205.2 *Mechanical Conditions*
Numerous mechanical conditions must be met for a piece or rotating machinery to operate successfully. Beyond proper installation, conditions associated with alignment of couplings, shafts and gears, adjustment of shaft seals or drive belts, lubrication and general maintenance are all associated with equipment performance. Tests and measurements of mechanical conditions should always be considered before starting equipment, or when service records are in question.

205.3 *Mechanical Operation*
Simple observations, such as: direction of rotation and unusual noise or vibration may identify possible sources of problems. Significant vibrations or shaft deflections are indications of serious mechanical problems and should be corrected immediately. Any loud noises or readily observed movements associated with the gear drive should be investigated.

205.3.1 Shaft deflections can be serious mechanical problems, especially since most impeller mixing equipment is built with long overhung shafts.

205.3.2 Large shaft deflections are defined as those where the amount of movement exceeds generally accepted engineering limits. Continued operation could result in premature bearing or seal failures or even catastrophic mixer shaft failure.

205.3.3 Large shaft deflections can result from simple mechanical causes or complex interactions between fluid forces and structural dynamics. The four most common causes are:

205.3.3.1 **Mechanical** - bent shaft, unbalanced impeller, shaft not vertical, loose bearings or couplings, etc.

205.3.3.2 **Fluid** - strong disturbances, such as side flows in the impeller region, can cause imbalanced loads.

205.3.3.3 **Dynamic** - excitation of structural harmonics, especially related to frequencies associated with rotational speed.

205.3.3.4 **Design** - structure or shaft inadequate for even normal fluid or mechanical forces.

205.4 *Process Conditions*
Various types of agitation tests can be considered and used to evaluate many types of process performance. Tests could be run as part of an equipment certification procedure or to re-evaluate an existing piece of equipment. Such tests might include, for example:

205.4.1 Miscible liquid blending - to evaluate mixing performance such as blend time or degree of homogeneity when processing miscible fluids.

205.4.2 Heat transfer - to evaluate agitator performance including local or overall heat transfer coefficients from heat transfer surfaces.

205.4.3 Immiscible liquid dispersion-to evaluate agitator performance such as maximum or minimum droplet size, droplet size distribution, emulsion stability and mass transfer when dispersing one fluid in another.

205.4.4 Solids suspension in liquid - to evaluate agitator performance such as level of suspension and segregation in suspended solids in a liquid.

205.4.5 Gas-liquid dispersion - to evaluate agitator performance such as gas hold-up, maximum bubble size and reaction rate.

205.4.6 Reaction rate - may be influenced by several aspects of mixing, including uniform blending, heat transfer, mass transfer; and rapid or complete mixing may be reflected in the quantity or quality or reaction products.

205.4.7 Variable conditions - to evaluate agitator performance when conditions change, such as: liquid levels, phase ratios, viscosity, solids content, temperature and pressure.

205.4.8 Other tests - because of the enormous variety of process applications which use mixing equipment, any other test may have significance to a user.

206.0 *Performance Criteria*

Performance criteria should be established according to process result or intended purpose of the equipment. The performance of an agitator is limited by its original design and may not be suitable to achieve performance for which it was not intended. For example, an agitator designed to handle liquids may be unsuitable for suspending solids, or a unit designed for heat transfer may not be able to handle a higher reaction rate.

300.0 TEST PLANNING

301.0 *Preliminary Considerations*

301.1 *Safety*
Any equipment testing must conform to the latest requirements of all applicable safety standards. These include, but are not limited to plant, industry, Local, State and Federal regulations. It is recommended that all testing be conducted under the supervision of personnel fully experienced in plant and equipment operating practices.

301.2 *Environmental*

The test procedures must conform to the latest requirements of all applicable environmental standards which include plant, industry, Local, State and Federal regulations. Environmental standards that apply to the equipment in normal operation should also apply during testing.

301.3 *Performance Criteria*

Performance of a mixer is more difficult to characterize than most types of process equipment, because a mixer usually performs several functions at once. Agitator performance is often judged on whether it makes the correct or acceptable product, and not whether it functions hydraulically as designed. A failure in any aspect of the mixer performance may cause unsatisfactory results.

Determination of the performance criteria must focus on the most important result. The tests required to determine level of performance may involve numerous indirect measures of performance in addition to the specific results.

Typical mixer functions may include:

Batch Environment	Physical Processes	Transport Processes
Liquid-Solid	Suspension	Dissolving
Liquid-Gas	Dispersion	Absorption
Immiscible Liquids	Emulsions	Extraction
Miscible Liquids	Blending	Reactions
Fluid Motion	Pumping	Heat Transfer

301.4 *Test Objectives*

The reasons for running a test must be clearly defined.

301.4.1 Tests may be run to ascertain that the agitator performs satisfactorily from a process and/or mechanical standpoint.

301.4.2 Process and mechanical requirements may be a contractual obligation with tests planned accordingly.

301.4.3 Tests may be conducted to identify a basis for scale-up or scale-down.

301.4.4 Tests may be run to identify possible causes of process or mechanical problems.

301.4.5 Tests may be part of an effort to improve process performance or productivity through equipment modifications.

301.5 *Multiple Applications*

Effects of changing liquid level, viscosity, speed, flow rates and other process conditions may be important in tests. Some equipment is used for different purposes at different times. The testing requirements, may be different for different situations.

302.0 *Plans for Operating Performance Tests*

Power, torque, and speed are important characteristics of mixer performance, and indirect measures of process performance. A knowledge of these three variables is essential to testing of any impeller mixing equipment. In addition, the design of other vessel accessories and support structures are directly related to these variables.

Power data are also important for establishing operating costs, and in many cases, are directly related to the process result.

To relate motor power to mixer power (energy applied to the batch), it is necessary to define the efficiency of each component of the drive system. These efficiencies are often a complex function of operating speed and applied power.

302.1 *Speed*

Impeller speed should be measured to ensure that the equipment operates at the speed for which it is designed. Accurate measurement, typically to the nearest revolution per minute (hundredth of a revolution per second), is necessary because of the strong influence of speed on power.

The measurement is also required in order to relate power to torque. If the agitator is provided with variable speed capability, other tests may be performed at maximum, minimum, and intermediate speeds to test the full range of operation.

302.2 *Power*

Motor power draw may be measured to ensure that motor nameplate rating is not exceeded and/or to determine if the impeller is imparting the design or desired power to the fluid.

302.3 *Torque*

Torque may be measured to ensure that the torque rating of the gear drive or other component is not exceeded, and/or to determine if the impeller is imparting the design torque to the fluid.

303.0 *Plans for Mechanical Condition Tests*

303.1 *Equipment Verification*

As an important part of the planning and preparation process, a thorough inspection and documentation of all aspects of the equipment should be performed. A complete review of drawings, instruction manuals, rating plates, and any other documentation may help identify or correct anticipated conditions.

303.2 *Alignment*

Alignment of flexible and rigid couplings or belt drives may be measured to ensure that they are within design specifications. The gear drive may have to be checked to assure that it is level. Special adjustments, such as for a separate seal or steady bearing, may be required.

303.3 *Runout*
Runout (lack of centering) of the impeller shaft and other shafts may be measured to ensure that they are within design specifications. Shaft runout is of particular importance at a shaft seal or at the end of the overhung shaft.
303.4 *Gear Tooth Contact*
Gear tooth contact pattern may be measured to ensure compliance with design specifications. A poor contact pattern can be an indication of mechanical defects.
303.5 *Seals*
Most agitator shaft seals are designed to leak at a small finite rate for lubrication and cooling. Vessel contents (liquid or vapor) may leak out of the vessel, or there may be leakage of the seal fluid into the vessel. The leakage rate may be measured, or the leakage analyzed for content, to determine if the seal is operating as designed.
303.6 *Auxiliary Equipment*
Tests may be required to ensure auxiliary equipment is operating within design specifications. Auxiliary equipment can include: steady bearings, variable speed clutch, lubrication system, cooling system, and similar devices.
303.7 *Vibration*
Vibration may be measured on the motor and/or the gear drive to ensure it does not exceed design standards and to ensure that there is no adverse vessel/support/agitation equipment interaction causing excessive vibration.
303.8 *Noise*
Noise may be measured to ensure compliance with design and/or environmental standards. Excessive noise may be an indication of a mechanical defect or adverse interaction with the vessel support system.

304.0 *Plans for Mechanical Operation Tests*

Most mixers have cantilevered (overhung) shafts. Lateral forces due to flow instabilities act at the impeller to bend (deflect) the shaft. If the deflections are too large, seal or accessory life problems might be encountered. Ultimately complete failure of the shaft could also occur.

Before proceeding further in planning a test, review the installation. The most common causes of shaft deflection problems are errors in mechanical installation or damaged equipment. A complete dimensional check should be performed first. Bent shafts, unbalanced impeller, out of plumb shaft, loose equipment, etc. are typical factors.

If there is a question about shaft deflections, the mixer designer/manufacturer should be contacted for specific information about acceptable limits. Dynamic tests should be considered only after problems have been documented. The testing procedure should be a sequential program to eliminate possible causes of large deflections.

304.1 Measure and quantify deflections. Identify runout and point of measurement.

304.2 In general, any process factor which effects power input or liquid motion will probably affect fluid forces. Typical factors include: gas sparging, liquid feed, baffles, accessories near impeller, system asymmetries, etc. Because of this relationship a review of power data could be helpful.

304.3 Measure natural frequency of shaft and mounting structures.

304.4 Measure shaft strain or deflection under operation. If possible, vary speed and measure changes in shaft strain or deflections.

305.0 *Plans for Process Condition Tests*

If multiple process variables are an essential part of a testing program a systematic approach to experimental design is recommended. Only through experimental design can process effects be adequately decoupled for analysis and interpretation.

305.1 *Miscible Liquid Blending*. Measure time required (blend time) to achieve a specified degree of uniformity. Sample volume and location must be specified in addition to uniformity criteria to achieve consistent results. See Ref. 808.11, 808.13.2, 808.13.4, 808.13.7 and 808.13.8 for additional information about mixing.

305.2 *Heat Transfer*. Overall heat transfer coefficients may be determined and an estimated process side heat transfer coefficient computed. See Ref. 808.10, 808.11, and 808.13.5 for additional information about heat transfer.

305.3 *Immiscible Liquid Dispersion*. Dispersion may be tested by physical criteria such as droplet size distribution or mean droplet size or by mass transfer criteria, i.e., mass transfer coefficient.

305.4 *Solids Suspension in Liquid*. Usually percent solids and size distribution as a function of position in a vessel is measured. For incomplete suspensions, fillet size and contour may be measured. See Ref. 808.11, 808.12, 808.13.9 and 808.13.12 for additional information about solids suspension.

305.5 *Gas-Liquid Dispersion*. The usual criteria in gas dispersion is related to mass transfer, e.g., k_LA measured according to certain assumptions by standard or special methods.

305.6 *Variable Conditions*. Changes in physical properties such as viscosity, or other operating conditions may impact test results for any of the aforementioned process tests and should be taken into account.

305.7 *Other Measurable Results.* Tests could be run to evaluate many other process parameters. Tests must be appropriately planned so that the needed evaluations can be made.

306.0 *Performance Criteria*

A precise numerical definition should be established, if possible, on each test to determine what is successful, or at least if improved performance has been achieved.

400.0 MEASUREMENT METHODS & INSTRUMENTS

401.0 *Introduction*

A variety of equipment is available for measuring the characteristics of the mixer and the process. The following sections describe some of the more important equipment and tests that can provide information necessary for performance tests.

In developing technical information it is important that the degree of accuracy and the rigor of the development of the information match the required application.

The results need not be any more precise or accurate than required for the intended application. In some cases a preliminary measurement using simple methods will establish whether or not the result is important and whether more accuracy is required. The calibration accuracy and data reproducibility (precision) must be defined for each measurement.

402.0 *Operating Performance Measurements*

402.1 *Speed*

The speed of the mixer shaft can be measured by using a tachometer, a stroboscope, or by counting the low speed shaft rotations. Any device should have an accuracy of plus or minus one percent of this important measurement. Uncertainty in power will be less than plus or minus three percent with this accuracy.

The use of nameplate motor speed and nominal gear ratio is not sufficiently accurate for speed determination. Motor slip and variance within nominal speed ratios, accepted by AGMA Standards, can contribute to significant errors relative to actual speed. Motor speed can be used only if it is accurately measured and the exact gear ratio is known or determined.

402.2 *Power*

The measurement of power is an important characteristic of the mixer performance. Aside from mixer design, vessel hardware and support structure are directly related to power requirements. Power data are also important for establishing operating costs and in most cases are related to process results.

402.2.1 *Electrical Power Measurements*

Direct measurement of electric power (kilowatts) is accomplished by the use of a wattmeter. This method is preferred for determining the power drawn from alternating current, induction motors. A good wattmeter contains the circuitry necessary to measure volts, amps and phase angle (power factor or voltage-amperage reactance), and thus to accurately reflect true power.

402.2.2 *Other Electrical Measurements*

Power may be calculated quite accurately if amperage, voltage and power factor are measured. Accuracy decreases if power factor and/or voltage are not actually measured, possible errors are in excess of twenty percent.

402.2.2.1 *Current*

An ammeter is used to measure the electric current. Clamp-on induction coil meters are commonly used. For multi-phase motors, the current needs to be measured for each active leg.

402.2.2.2 *Potential*

A voltmeter is used to measure electric potential. For multi-phase circuits the voltage should be measured between active legs, and readings matched with current readings.

402.2.2.3 *Power Factor*

Although the power factor is frequently thought to be a characteristic of an individual circuit element, it can be strongly dependent on other equipment installed on the line. For the highest degree of accuracy, the power factor should be measured for each application. Low power factor may even be a contributing factor in motor overloads.

402.2.3 *Component Losses/Efficiency*

A complete mixer analysis includes the performance of several drive components: motor, couplings, variable speed drives, gear reducers, etc. Power is often not identified by the point of measurement.

The difference between input power (usually kilowatts) to the prime mover (electric motor) and the power applied to the fluid (shaft power) may exceed fifteen percent. Converting a measurement of power from one point to another requires a detailed knowledge of the power losses for each component. The loss (or efficiency) for several components depends on both operating speed and transmitted power.

402.2.4 *No-load Power*

The full-load drive losses cannot be accurately measured by operating the mixer in air, a "no-load" condition.

Aside from measurement accuracy, component losses at no-load conditions are often substantially different from losses at full-load conditions. Measurement of no-load losses may in some cases give some indication of the magnitude of actual losses or to identify other problems.

402.2.5 *Other Power Measurements*

Since power sources other than electricity can be used to drive a mixer, other measurements may be appropriate for a given application. For example, power can be determined for air motors and hydraulic drives from measurements of pressure drop across the motor and the operating speed (flow rate).

402.3 *Torque*

Direct measurement of torque is most often used as an alternative method of determining power requirements. The product of torque and speed for a rotating shaft is a direct representation of transmitted power. The accuracy of power measured by these techniques depends on cumulative errors in the individual measurements. The careful application of torque measurement techniques can yield an accurate and direct measure of impeller power.

402.3.1 *Rotating Shaft*

Instrumentation is available to measure the torsional loading on a rotating shaft. These devices are generally based on a flexural member with a strain gauge bridge attached. Associated circuitry powers the bridge and measures the resistance imbalance due to torsional loading. These devices may be subject to error induced when the strain gauge region is subjected to excessive bending loads. Errors can also be introduced during the transmission of the signal from the rotating shaft to the observational environment.

402.3.2 *Reaction Load*

On small scale tests, the vessel or drive system can be mounted on a low friction bearing. The torque required to prevent rotation of either the vessel or drive is measured. This technique has limited applicability in large scale equipment.

402.3.3 *Reaction Strain*

Torque might also be measured by the deflection of motor mounts or other support structures. Materials loaded in the elastic range will undergo deflections directly proportional to the associated load. A suitably precise measurement using strain gauge techniques to measure these deflections can be used to measure torque.

402.3.4 *Calibration*

For any custom measuring technique, a detailed calibration must be performed. Tests must be devised to quantify the precision and the accuracy of the measurements. The most convenient method of calibration involves applying known static loads. The dynamic agitator loads can be compared to the static calibration. The calibration must include any effects of installation geometry which might affect the measurements.

403.0 *Mechanical Condition Measurements*

If possible, measure all dimensions of the installed equipment and keep dated records. Photographs of the equipment and tank internals also provide an excellent permanent record for subsequent comparison with future conditions.

403.1 *Alignment and Adjustment*

403.1.1 *Couplings and Belt Drives*

Alignment of flexible couplings, rigid couplings and belt drives is normally accomplished with a scale and a clamp-on or magnetic-base adjustable-arm dial indicating micrometer or other instruments as specified by the manufacturer. Electronic indicators are also available.

403.1.2 *Gear Drive Base*

A level and feeler gauge can be used to ensure the gear drive is level to within the specifications of the manufacturer.

403.1.3 *Vertical Alignment*

Proper leveling and locating of the gear drive normally satisfies vertical alignment, however, the vertical alignment should be checked, and may be used to check drive leveling.

403.1.4 *Special Requirements*

Manufacturers may indicate special adjustments are required. Refer to the following sections for separately mounted seals and steady bearings.

403.2 *Runout*

Shaft runout may be measured with a magnetic-base dial indicating micrometer, displacement proximity probe, or other suitable device. A measurement range of 0-50 mils (0-1000 micron) peak-to-peak displacement with 0.5 mil (10 micron) graduations would normally be sufficient for measurement at the drive base or seal.

403.3 *Gear Tooth Contact Pattern*

Gear tooth contact pattern may be measured with marking compound, commonly termed transfer dye or bluing dye. A spray coating of molybdenum disulfide may also be used to mark the gearing. Depending on the type of gearing, the exact pattern may be different, but in general it should show consistent and uniform contact on all the teeth.

403.4 *Seals*

403.4.1 *Packing Seals*

A packing seal is usually characterized by a pliable compound or rope which is held tightly around the shaft. Although this method of sealing can retain a considerable pressure, a certain amount of liquid or lubricant leakage is normally necessary to reduce friction and remove heat generated by friction. The rate of leakage may be important. Some packing compounds, especially those with a graphite or graphite and PTFE base, may not require grease lubrication.

403.4.1.1 Liquid leakage out of a submerged packing seal (stuffing box seal) may be detected visually. Liquid may be collected over a period of time and volumetric leakage rate determined.

403.4.1.2 Grease consumption may be the only leakage in or out of a packed seal located above the liquid level. Grease requirements over a period of time, up to weeks or more, may be logged and reported as a volumetric consumption rate.

403.4.1.3 Vapor leakage out of a packed seal may be detected with soapy water. Leakage rate may be recorded as bubbles per minute. The vapor may be collected if a backup seal is provided and analyzed for content and rate.

403.4.2 *Mechanical Seals*

A mechanical seal with a liquid barrier lubricant is the seal type least likely to show visible leakage, although lubricant may leak in to or out of the vessel. Lubricant leaking out of the seal may vaporize and not be visible. The volume of lubricant in the barrier liquid reservoir may be measured periodically and additions logged for weeks or months to be reported as a volumetric consumption rate. The temperature of the barrier lubricant may be measured at operating conditions using a suitable thermometer.

403.4.3 *Separately Mounted Seals*

Most seals will be mounted in a rigid frame attached to the gear drive, which ensures alignment with the agitator shaft. However, some types of seals, typically called "separately mounted seals", must be aligned after installation. Concentricity and squareness of the seal to the shaft may be measured with a clamp-on or magnetic-base dial indicating micrometer.

403.5 *Auxiliary Equipment*

403.5.1 *Steady Bearings*

If needed, a steady bearing is usually installed after the gear drive and shaft have been fixed in place. The steady bearing housing can be set in place to suit the shaft using a rule and scribe.

403.5.2 *Lubrication and Cooling Systems*

Pressure measurements may be made at various locations with a pressure gauge. Pressure gauges may be installed permanently.

Flow rate for proper operation may be verified directly by flow measurement or indirectly by temperature measurement.

403.6 *Vibration*

Vibration of equipment components may be measured with the following types of instruments:

403.6.1 contact-type displacement transducers suitable for 0-10 mils (0-250 micron) peak-to-peak displacement with 0.2 mil (5 micron) graduations and a filter for 1-100 Hz.

403.6.2 contact-type velocity transducer suitable for 0-1 inches/second (0-25 mm/s) peak velocity with 0.02 inches/second (0.5 mm/s) graduations and a filter for 1-100 Hz.

403.6.3 contact-type accelerometer suitable for 0-5 g's (0-50 m/s^2) peak acceleration with 0.1 g's (1 m/s^2) graduations and a filter for 1-100 Hz.

403.7 *Noise*

Field noise measurements would normally be for sound pressure level in decibels (dB). The following types of instruments may be used:

403.7.1 Sound level meter with an A-weighted filter network suitable for 50-120 dBA with 1 dBA graduations.

403.7.2 Octave band analyzer suitable for 50-120 dB with 1 dB graduations with standard set of contiguous octave bands in the range 60-8000 Hz.

403.8 *Temperature*

The temperature of the oil in a gear drive or motor surface temperature may be measured with an indicating device suitable for 0-150°C with 1°C graduations.

404.0 *Mechanical Operation Measurements*

404.1 *Natural Frequency*

Shaft and structure natural frequencies are measured using vibration instrumentation. Special low frequency resolution probably will be required. It is not unusual for large mixer shaft frequencies to be in the range of 0.3 to 2.0 Hz.

404.2 *Shaft Strain*

Stress is directly proportional to the strain as measured by foil gauges. A strain gauge bridge may be mounted on the shaft or a separate spool piece inserted between the mixer and drive. Signal amplitude increases as the location point is moved closer to the bearing adjacent to the overhung portion of the shaft.

Signals must be transmitted from the rotating shaft to the stationary surroundings. Slip rings or radio telemetry can be used. Dynamic stress can be recorded on a strip chart recorder to get peak values. A spectral analysis of this signal gives pertinent frequency information. Frequencies may help identify the source of problems.

The output from these gauges can be used for natural frequency measurements in place of the acceleration probe.

404.3 *Deflection*

Shaft deflection is a primary indicator of shaft dynamics. Dial indicators, magnetic proximity probe, and strain gauge deflection arms (i.e., "flipper gauges") have been used to measure deflections. In general, these devices are mounted above the liquid level.

Deflection magnitude increases as the distance from the bearing increases. Greatest resolution would be obtained by having a sensor near the impeller on a cantilevered shaft.

A limitation for any of the direct shaft deflection measurements is that the static runout must be subtracted from it. It is conceivable that at the point of measurement, equipment runout (though within acceptable tolerances) is a significant part of the total deflection.

With suitable placement and signal processing, a displacement sensor could be used for natural frequency measurements in place of an acceleration probe.

404.4 *Spectral Analysis*

Shaft strain or deflection under operating conditions gives magnitude and frequency data. The ability to perform a spectral analysis of these signals is a powerful aid in tracking down the source or cause of mechanical vibrations. In addition to natural frequencies of shafts and structural components, gear mesh and bearing contact frequencies can be measured.

405.0 *Process Condition Measurements*

405.1 *Density or Specific Gravity*

Agitation tests will almost always involve the measurement of fluid density, since power consumption is directly proportional to density except at low Reynolds numbers. Other fluid forces on the agitator are also proportional to density. Fluid blending applications frequently involve the blending of fluids of different densities. Apparent fluid density can be affected by entrained gases and suspended solids.

Density can be readily measured for homogeneous fluids. Hydrometers may be used, when available. An accuracy of ±0.01 can usually be obtained with such measurement techniques. A known volume can be weighed in a graduated cylinder, usually with a little less accuracy, but with satisfactory results.

For non-homogeneous fluids, a variety of methods are available, including those just mentioned, to obtain a pseudo-homogeneous value.

Average densities of liquid-gas systems are usually estimated by determining gas hold-up. Hold-up can be determined by the volume change on settling or by other methods, such as pulse testing. Measurement of the liquid surface may be difficult because of foam.

Densities of liquid-liquid and liquid-solid mixtures may be determined by calculating densities of the various phases and determining the volume fraction by settling or other separation techniques.

The average density (ρ) of a mixture can usually be estimated by

$$\rho = \left| \frac{x_1}{\rho_1} + \frac{x_2}{\rho_2} + \ldots \right|^{-1}$$

where x_i and ρ_i are the mass fraction and density respectively of each component. Average densities should not be calculated in this manner if a significant volume change on mixing occurs.

405.2 *Viscosity*

Viscosity is an important physical parameter in many mixing tests. At viscosities less than 100 cp (0.1 Pa·s), viscous effects are typically small. At higher viscosities, the viscosity basically determines how difficult the movement or flow of the fluid will be. At viscosities greater then 10,000 cp (10 Pa·s), the effects may dominate the problem.

Process effects are usually correlated by a Reynolds number, and as such, related to many other parameters, such as power number, impeller pumping number, and heat transfer coefficient. In the laminar region of impeller Reynolds number, power consumption is proportional to viscosity, rather than density.

As much as possible, viscosity should be measured at the operating conditions of the mixer, including temperature, pressure, and shear rate. Newtonian fluids, for which viscosity does not change with shear rate, several types of viscometers can be used, including: open spindle, falling ball, cup and orifice, close clearance cup and bob, or cone and plate.

Shear stress may significantly change the apparent viscosity of some fluids, which may greatly affect agitator performance. The degree of non-Newtonian behavior of fluids can be estimated by operating a viscometer at varying shear rates. Such tests could include running an open spindle viscometer at several speeds. A discussion of non-Newtonian fluids can be found in Ref. 808.10, 808.11, and 808.13.8.

There are also viscometers available which measure viscosity using a spindle shaped much like an agitator paddle. Laboratory agitators with torque measurement capabilities may also be used. Again, operation at several speeds can be used to determine viscosity at different shear rates.

The viscosity of some fluids change with time. The tests must measure viscosity of the fluid sheared at a known shear rate for a period of time. Other fluids have different types of shear dependent behavior, including viscoelasticity.