ICHE

QUIPMENT TESTING PROCEDURE

MIXING EQUIPMENT (Impeller Type)

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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 cffers 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.

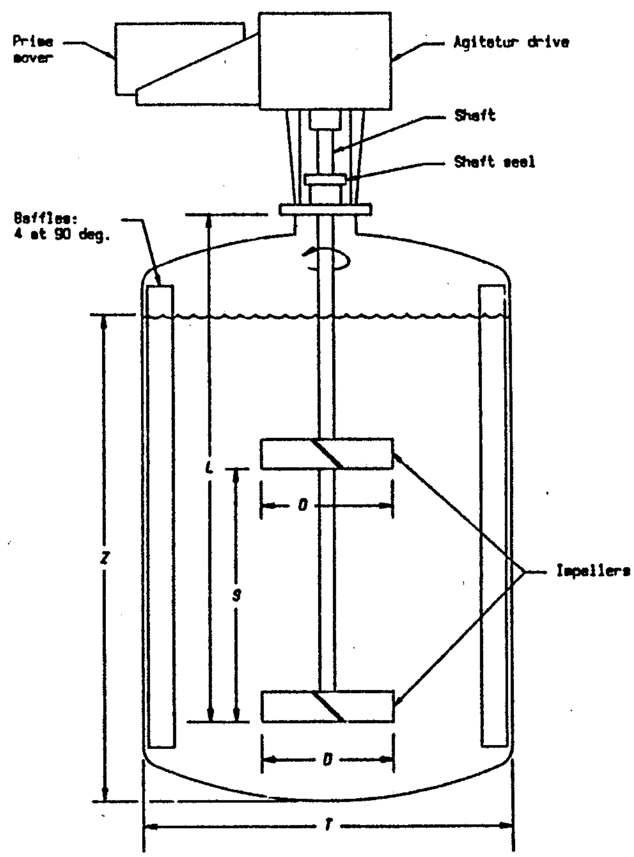


Fig. 201.1 Impeller Mixing Equipment

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 suspend- 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

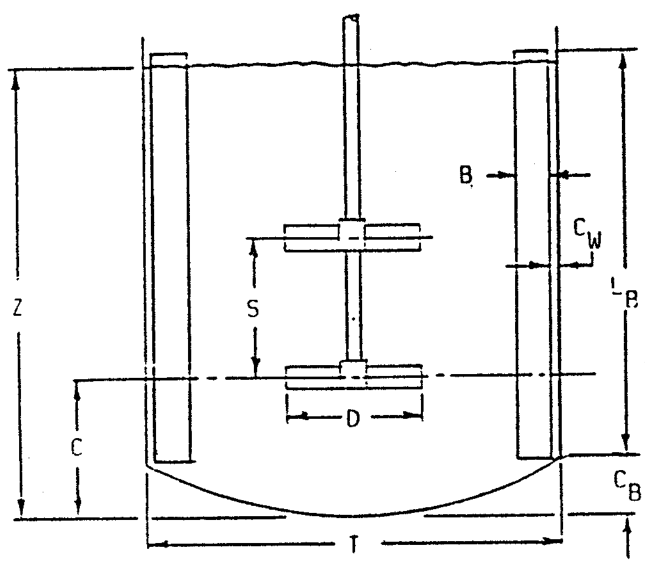


Fig. 202.1 Center Mount Impeller Mixer

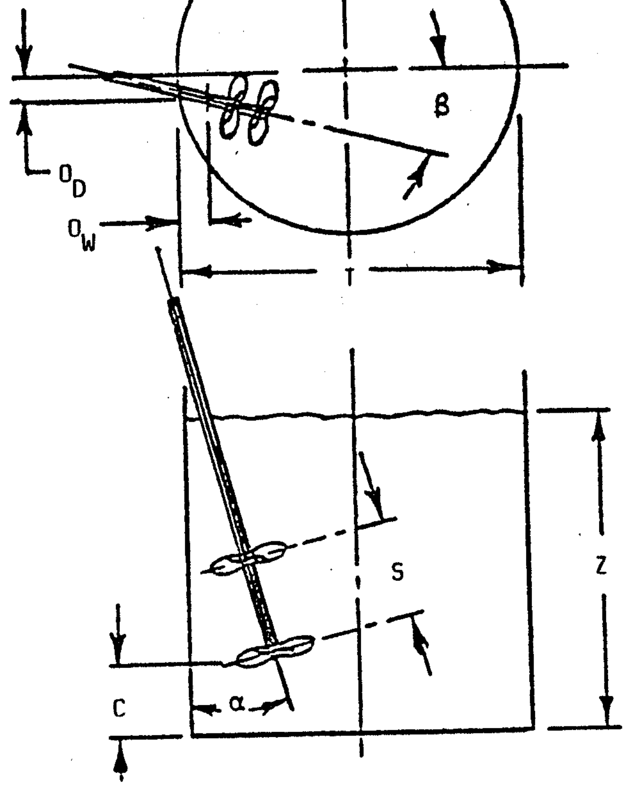


Fig. 202.2 Top-entering Propeller Mixer

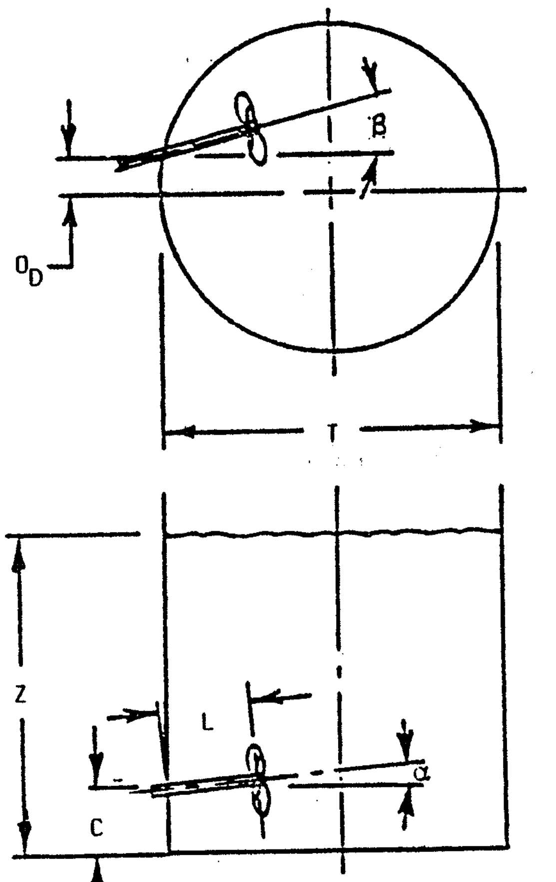


Fig. 202.3 Side-entering Propeller Mixer

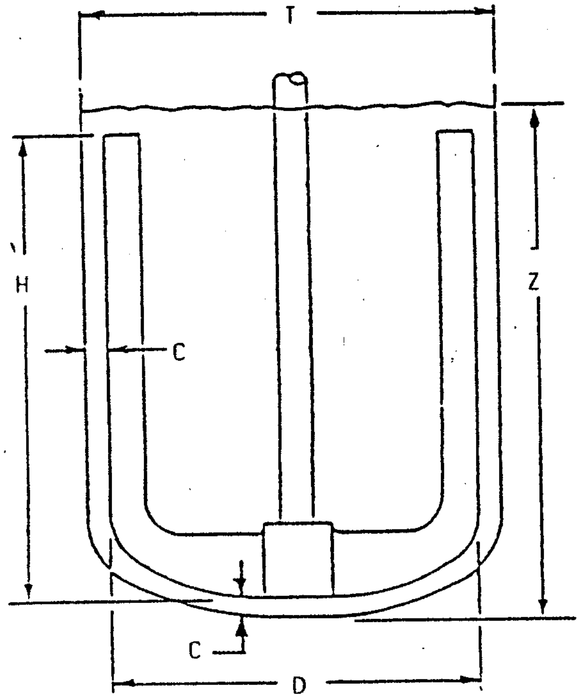


Fig. 202.4 Close Clearance Impeller Mixer

(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

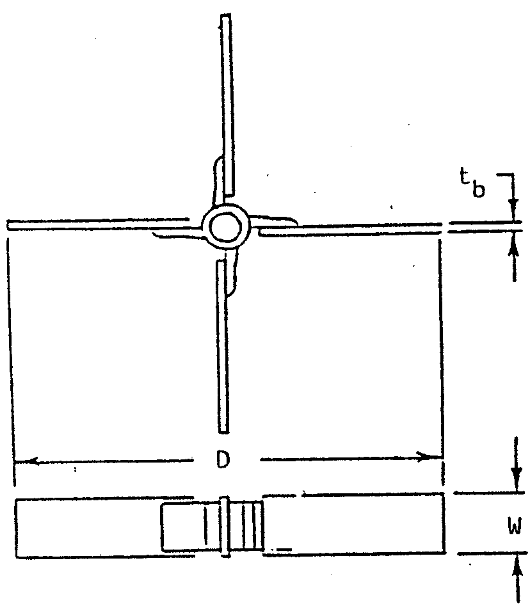


Fig. 202.5 Straight-blade Turbine

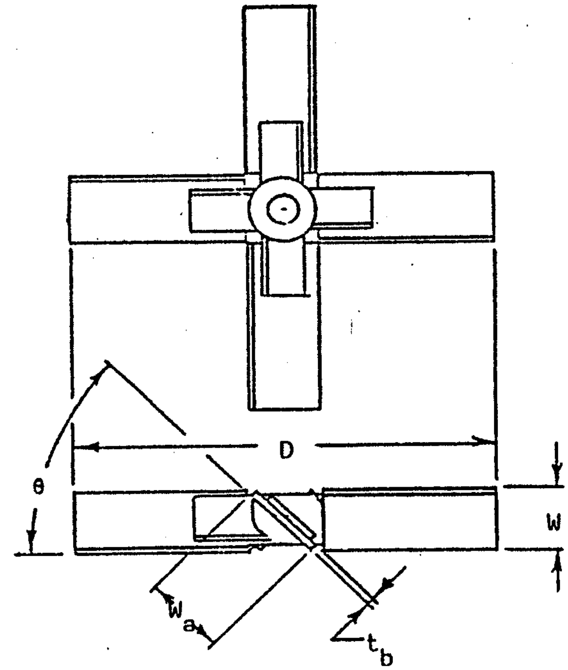


Fig. 202.6 Pitched-blade Turbine

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-

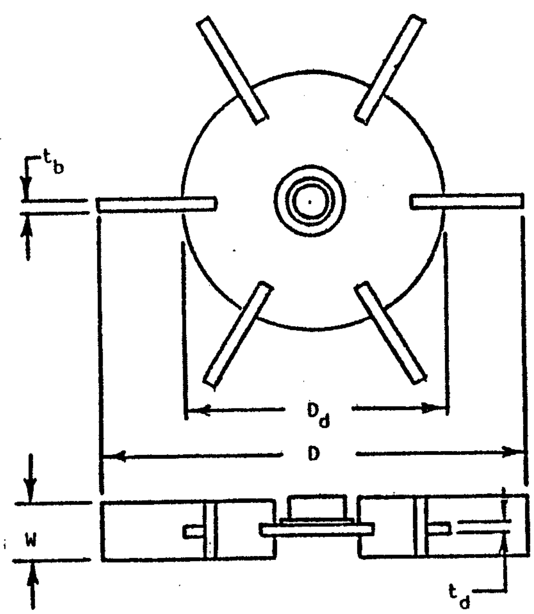
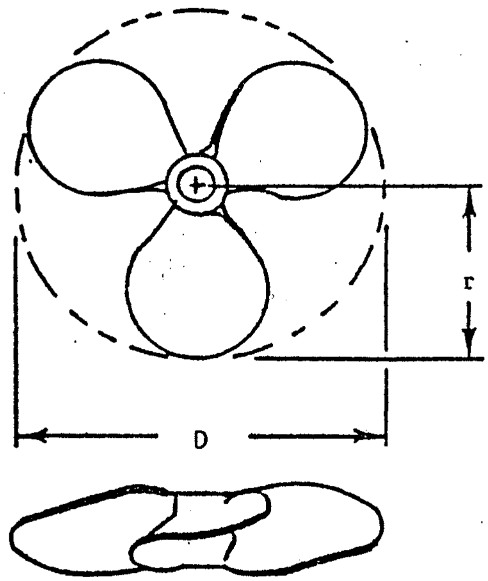


Fig. 202.7 Disc-style Turbine



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

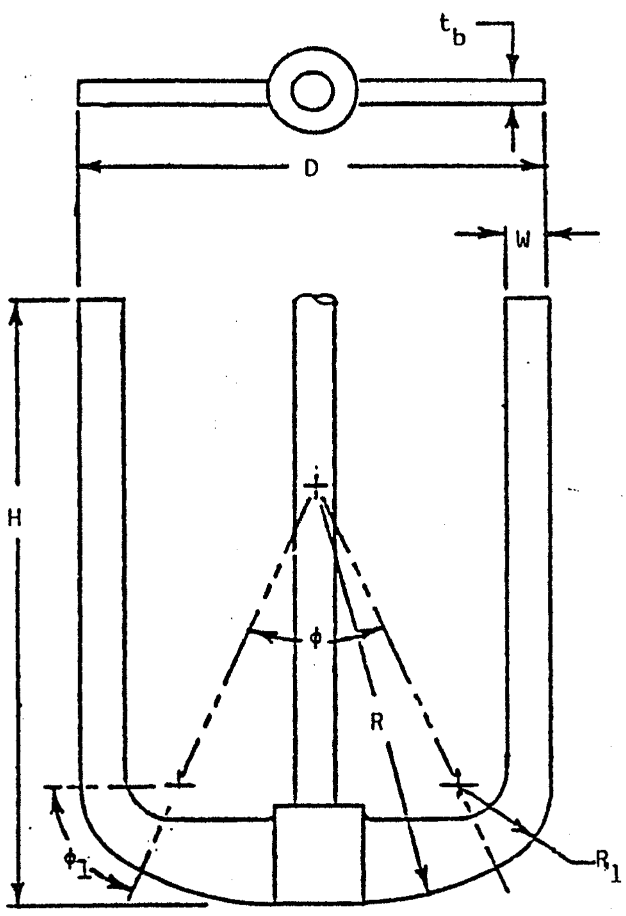


Fig. 202.9 Anchor Impeller

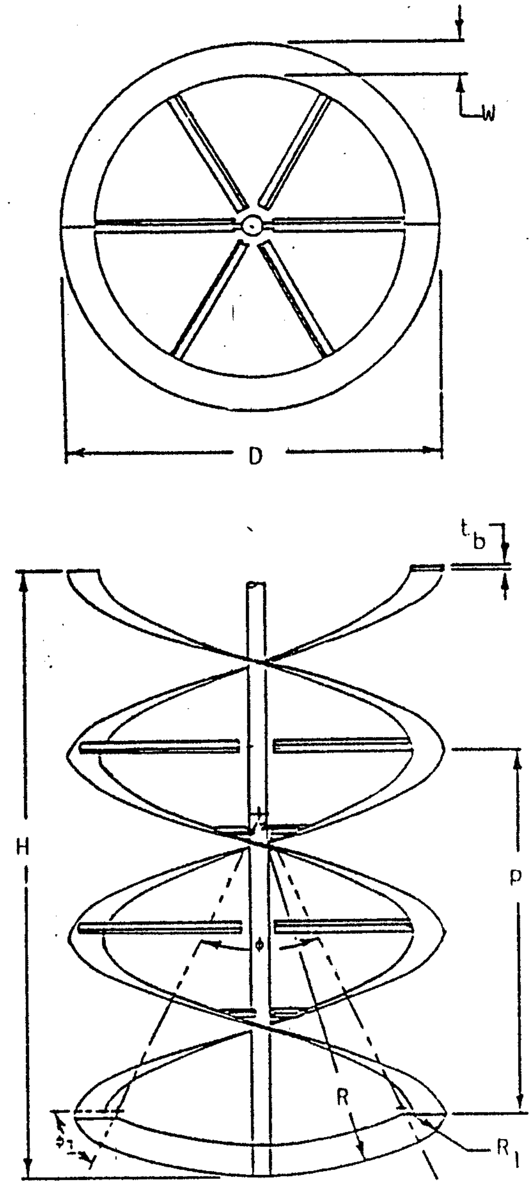


Fig. 202.10 Double Flight Helix

impellers are shown in Figs. 202.5 throu, 202.11.

These examples are far from all-inclusi\ but do reflect some of the commonly use impeller configurations. Many other impel lers are similar in construction and func tion, but different in detail. Other impe lers incorporate features from more than o of the types shown. For additional informa tion see Ref. 808.10 and 808.13.3.

202.3 *Vessels*

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

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

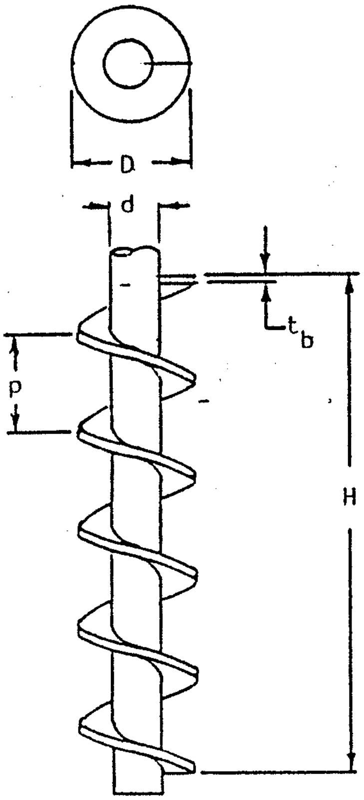


Fig. 202.11 Single Flight Auger or Screw

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 surfac tension forces.

203.3.2 **Nusselt Number,**

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

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

203.3.3 **Prandtl Number,**

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

Ratio of momentum transfer rate to hea transfer rate.

203.3.4 **Sherwood Number,**

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

Ratio of convective mass transfer rate t 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 referenc time.

203.3.6 **Peclet Number,**

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

Ratio of momentum transfer rate to hea conduction rate.

203.3.7 **Schmidt Number,**

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

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

204.0 *Operating Conditions*

Operation of mixing equipment include directl related conditions, such as: agitator spee and power requirements; and indirectly relate 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 mav 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 chara teristics of mixer performance, and indir measures of process performance. A knowle of these three variables is essential to te ing of any impeller mixing equipment. In ad tion, the design of other vessel accessor and support structures are directly related these variables.

Power data are also important for establishi operating costs, and in many cases, are dire ly related to the process result.

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

302.1 *Speed*
Impeller speed should be measured to ensu that the equipment operates at the speed f which it is designed. Accurate measuremen typically to the nearest revolution p minute (hundredth of a revolution per se ond), is necessary because of the stro influence of speed on power.

The measurement is also required in ord to relate power to torque. If the agitat is provided with variable speed capabilit other tests may be performed at maximu minimum, and intermediate speeds to test t full range of operation.

302.2 *Power*
Motor power draw may be measured to ensu that motor nameplate rating is not exceed and/or to determine if the impeller imparting the design or desired power to t fluid.

302.3 *Torque*
Torque may be measured to ensure that t torque rating of the gear drive or oth component is not exceeded, and/or to deter mine if the impeller is imparting the desi torque to the fluid.

303.0 *Plans for Mechanical Condition Tests*

303.1 *Equipment Verification*
As an important part of the planning a preparation process, a thorough inspecti and documentation of all aspects of t equipment should be performed. A comple review of drawings, instruction manual rating plates, and any other documentati may help identify or correct anticipat conditions.

303.2 *Alignment*
Alignment of flexible and rigid couplin or belt drives may be measured to ensu that they are within design specification The gear drive may have to be checked t assure that it is level. Special adjus ments, such as for a separate seal or stea 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 t measured with the following types of instru ments:

403.6.1 contact-type displacement trans ducers suitable for 0-10 mils (0-250 mic ron) peak-to-peak displacement wi 0.2 mil (5 micron) graduations and filter for 1-100 Hz.

403.6.2 contact-type velocity trans ducer suitable for 0-1 inches/secon (0-25 mm/s) peak velocity wit 0.02 inches/second (0.5 mm/s) gradua tions and a filter for 1-100 Hz.

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

403.7 ***Noise***

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

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

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

403.8 ***Temperature***

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

404.0 *Mechanical Operation Measurements*

404.1 ***Natural Frequency***

Shaft and structure natural frequencies a measured using vibration instrumentation Special low frequency resolution probabl will be required. It is not unusual fo large mixer shaft frequencies to be in t range of 0.3 to 2.0 Hz.

404.2 ***Shaft Strain***

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

Signals must be transmitted from the rota ting shaft to the stationary surroundings Slip rings or radio telemetry can be used Dynamic stress can be recorded on a stri chart recorder to get peak values. A spec tral analysis of this signal gives pertinent frequency information. Frequencies may hel 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.

)5.0 *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.

405.3 *Physical State*

405.3.1 *Gas-Liquid and Liquid-Liquid*

Hold-up is defined as the amount of dispersed phase maintained in a mixed system, and is usually expressed as a volume fraction or percent. The dispersed phase can be either a gas or liquid. Hold-up is frequently measured by collecting a sample of the material, allowing it to settle, and measuring the amount of material in each phase.

In a flow through system, hold-up does not necessarily equal the volume fraction of the added dispersed phase. If there are density differences, one phase may travel faster than the other.

Drop size of a dispersed phase depends on the component properties and the equipment design and operation. Drop sizes can be measured by such techniques as photography and light transmittance.

405.3.2 *Solid-Liquid*

Particle size distributions can be reported in many ways. For sieve analyses, the results are usually reported as the weight fraction that goes through one screen and is caught on the next, such as -48 +65, for particles which pass through 48 mesh and are caught on 65 mesh screens. Results are also reported as cumulative mass fractions of diameters larger or smaller than a given size.

Solids settling velocities are needed for proper design of agitators and thus may be needed to run an accurate agitator test. Higher settling velocities require higher fluid velocities for suspension. For relatively dilute (<10%), near-spherical particles, settling velocities can be measured by timing the fall of a sample of solids through a known distance in the test liquid.

405.4 *Chemical Composition*

In some instances it is necessary to know the chemical composition of the fluid. Direct determinations can be made, such as by chemical analyses and various spectroscopic means.

If it is necessary to determine composition or concentration during a operational test, it is more common to determine chemical composition by indirect means. Some physical or chemical property is selected that will vary with the change in composition. Appropriate calibrations are needed to determine the composition associated with the magnitude of the property. The property selected will depend on the fluid being evaluated. Tests to be used might include: density, refractive index, pH, light absorption, and even on-line chromatographic separations. Care must be taken to select a property that is not affected by other system changes and that varies enough so that experimental error does not significantly impact the results.

405.5 *Other Physical/Chemical Properties*

Many physical or chemical property measurements are possible. In some cases, any of the following parameters might be important: interfacial tension or surface tension, specific heat, thermal conductivity, boiling point, melting point, latent heat of vaporization or fusion, heat of reaction, heat of mixing, molecular weight, or mass diffusivity. Frequently, measurement is not required, because properties may be estimated from tabulated or empirical data. Even product quality may be a satisfactory measure of mixer performance or change in performance.

406.0 *System Operating Conditions*

406.1 *Temperature*

Process temperature can affect the process directly and could change what product is made. Temperature changes can also relate to the performance of mechanical components, such as in seals or gear box oil.

A variety of temperature measuring, recording and controlling devices are available. The choice will depend on the specific requirements. For specific suggestions and measurement techniques, see Ref. 808.3.

It is desirable to calibrate all temperature measuring devices before and after each test. Calibrated spares are often useful during a test.

The location of the measuring device is of the greatest importance. It should be installed to minimize the error introduced by radiation or convection and should be located in moving and mixed streams to obtain maximum sensitivity and to avoid errors due to stratification or stagnation.

406.2 *Pressure*

Equipment tests may be needed at elevated pressures such as to test for seal leaks. The volume of a gas present in a gas-liquid test will vary with pressure.

Many types of pressure measuring devices are available commercially. The choice will depend on specific requirements. See Reference 808.2 for specific suggestions and measurement techniques.

In some instances the process fluid needs to be isolated from the measurement element in the pressure gauge to prevent damaging, plugging, solidification, etc. Options include liquid seals or integral diaphragms to isolate the instrument from the process fluids.

406.3 *Fluid Level, Volume, and Flow*

406.3.1 *Fluid Level*

The type of instrument used to measure fluid level depends on the equipment size, the conditions of the test and the degree of accuracy needed.

Gas hold-up for gas-liquid processes can cause the liquid level to change significantly from gassed to ungassed conditions.

406.3.2 *Volume Measurement*

Differential volume and differential weight are commonly used to measure flow of fluids from tanks. When fluid flow measurement is made using volumetric or weigh tanks, several measurements should be made to ensure that steady state is obtained before the start of the test. Volumetric tanks should be calibrated prior to a test with weighed increments of liquid measured at a known temperature. Suitably designed volumetric tanks can be accurate within ±0.5% of total volume. Weigh tanks should be calibrated for volume over the entire range of weights at which they are to be used. Accuracies of ±0.2% of full tank weight can be obtained. Recommendations as to the proper design, construction, calibration, and operation of volumetric and weigh tanks are given in Ref. 808.4.

406.3.3 *Flow Measurement*

406.3.3.1 *Volumetric Meters*

The selection of meter type depends on the fluids being considered and the accuracy needed. However the meters listed here measure volume and not mass flow. Errors will be caused by any variations in actual specific gravity, such as those caused by temperature fluctuations, entrained gas, etc.

Rotameters of many types are commercially available and, when properly installed, calibrated and cleaned, are excellent devices for fluid-flow measurement. Accuracies of 0.5 to 10% of full scale are common, depending on size and calibration. For information concerning corrections for temperature and pressure, see Ref. 808.4.

The rate of flow of fluids is most often measured by differential pressure meters. Commonly used ones are orifice meters, venturi meters, flow nozzle meters, and pitot tube meters. Accuracies of 0.5 to 10% of full scale are common depending on the type of meter used. For additional information, see Ref. 808.4.

Magnetic flow meters are suitable for liquids that have slight electrical conductivity. This style meter is reported to be particularly useful for measuring flow of liquids containing suspended solids. Accuracies of about 0.5 to 2% of full scale are common.

406.3.3.2 *Mass Flow Meters*

This style of meter is designed to handle multiphase fluids or applications where the specific gravity is not constant. Different styles can handle dispersed gases or solid slurries. Accuracies of 0.4% of actual rate are possible with some models.

406.3.3.3 *Weirs*

Weirs may be used for fluid-flow measurement of large flows, such as flow through large basins. Accuracy of 2 to 5% of full scale may be obtained with a calibrated weir.

406.3.3.4 *Impeller Flow Measurement*

Flow produced by an agitator impeller can be a significant item. Various laboratory methods have been developed to measure flow including pitot tubes, hot wire or hot film anemometers, laser anemometers, rotary impeller flow meters, etc. For most of these methods it is necessary to measure the velocity at a point and then sum the values over an area. One has to be careful, however, to distinguish between the primary flow produced by an impeller and the total flow, which includes induced flow in the vessel. Impeller flow also has various vector components, which include axial (along the shaft), radial (out from the shaft), and tangential (in the direction of shaft rotation). Actual experimental measurements are difficult in large installed equipment. Visual observation may give some indication of surface motion, but little else. Impeller flow can be estimated using the data given in Sec. 804.2, although that this is only an estimate.

406.4 *Phase Ratios*

A determination is sometimes needed for the phase ratio of multiphase fluids. This can include liquid-solid, liquid-liquid, liquid-gas, and combinations.

Phase ratios are normally determined by obtaining a representative sample and then allowing the phases to separate, either naturally or with centrifugal force. The amount of each phase present must then be measured.

Phase ratios are generally expressed on a weight basis, although gas-liquid ratios can be expressed as a volume ratio at specific conditions. Some devices are available that may directly or indirectly measure the composition of the phases without needing separation.

It may be necessary to determine the composition of the various phases due to possible solubilities of different components in the phases.

406.5 *Blend Time*

Blend time can be defined as the time from the start of mixing at some unmixed condition until the vessel contents reach a predetermined value of uniformity. Frequently used criteria include the time to reach specified variations in temperature, density, component concentration, etc.

No universally accepted definition exists of what constitutes complete blending. Some processes may require as little as 95% uniformity, while others may require in excess of 99.9%. Methods of determining uniformity must be considered. The degree of uniformity must be established on the basis of process objectives or decided for each specific case. Since concentration is dependent on location, multiple samples as different locations are required to assure uniformity.

406.6 *Sampling*

Different types of sampling techniques can be used, depending on what is being measured.

Caution: grab-sample techniques should not be attempted while equipment is operating.

Some sampling methods include:

406.6.1 Grab scoops, bottles, buckets, etc., for surface samples.

406.6.2 Spigots and sample cocks for samples along walls.

406.6.3 Sample valves on discharge lines for exit condition samples.

406.6.4 Sampling pumps with movable sample lines for composite samples or sample from various locations.

406.6.5 A drop-bottle with a top that can be opened at the bottom or other known location may be used for multiple samples to estimate the average composition.

406.6.6 Samples should be taken from those points where the most useful data will be gathered rather than from those points where it is easiest to obtain. Depending on the reason for the test, one may need to sample the central region, quiet zones away from the agitator, the surface, the bottom, corners, etc.

406.6.7 Multiple samples should be taken to determine statistical significance. Samples should be checked during the test to determine whether the sampling is sufficient as far as number, size, location, etc. Samples should be taken from more than one point depending on the degree of statistical certainty that is needed. Acceptable statistical methods should be used to determine means and deviations, and the reliability of each. This should be done to define size and number of samples and to check the sample variance, Ref. 808.1 provides additional information on sampling.

500.0 TEST PROCEDURES

501.0 *General Test Procedures*

Impeller-type mixing equipment includes a broad variety of specific types of equipment, which may be applied to an even greater variety o processes. To define a general procedure which would be applicable in all cases is impossible The best advice for testing any complicated combination of process and equipment variables is to first define the problems and then determine to most likely approaches to solving them The complexity of most processes relative to the performance of mixing equipment is such that only indirect measures of equipment performance are practical. As a result, many of the following procedures emphasize generall applicable measurement techniques which are often indicative of process performance or results.

502.0 *Preliminary Operation and Safety*

Prior to actual operating any mixing equipment a thorough safety check should be performed, including at least the following steps:

502.1 *Instruction Manuals*

Check manufacturer's instruction, operation and maintenance manuals for start up procedures. Check for recommended oil and grease quantities, levels and specifications.

502.2 *Check for Debris in Vessel*

The mixing vessel should be checked for debris, workmen's tools, ladders, and the like.

WARNING: Personnel should never be in a mixing vessel when the mixer is running, whether the vessel is empty or not.

502.3 *Check for Obstructions*

The mixing vessel should be checked for internal obstructions to the rotation of the impeller. Baffles or probes may have been installed inadvertently such that they would interfere with the impeller when rotated.

502.4 *Pre-Operational Check*

Measurements of significant dimensions and parameters should be made and compared with manufacturer drawings for mixer and vessel.

502.4.1 *Dimensional*

502.4.1.1 Impeller diameter, blade width and angle, and number of blades.

502.4.1.2 Shaft length and diameter, extra keyway.

502.4.1.3 Impeller location(s) on shaft.

502.4.1.4 Clearance between impeller and vessel bottom.

502.4.1.5 Baffle: number, width length, and spacing from the tank wall.

502.4.1.6 Shaft runout at bottom.

502.4.1.7 Vessel dimensions: diameter, height from inside bottom to mounting face, etc.

502.4.1.8 Liquid levels.

502.4.2 *Equipment*

502.4.2.1 Motor speed, power, electrical classification, etc. and any other useful information on name-plate.

502.4.2.2 Gear drive reduction ratio and power rating.

502.4.2.3 Equipment near impeller.

502.4.2.4 Equipment adjustment: bolts, belts, mounts, couplings, etc.

502.5 *Hand Turning*

Frequently the motor coupling can be turned by hand, or with a suitable manually operated lever, to produce slow motion of the impeller. This technique may be used to check: direction of rotation, agitator shaft runout, obstructions in the vessel, smooth feel indicating no mechanical defects in the drive equipment or seal, all prior to powered operation.

502.6 *Jog*

Prior to operational start up the mixer may be "jogged" or "bumped, meaning rapidly turned on and off. Direction of rotation can be observed along with smooth operation without unusual noise indicating the absence of obstructions or mechanical defects.

502.7 *Hydrostatic Pressure Tests*

Some mixers involve pressurized lubricant reservoirs and/or pressure in the mixing vessel. Seals and containers may be given a hydrostatic or all-liquid pressure test prior to pressurization with a vapor. If all vapor is purged from the system prior to pressurization, the danger of explosive failure will be reduced since the pressure will drop rapidly if the seal or container should fail.

502.8 *System Test in Air*

Prior to operation of the mixer with process fluid the system may be given a mechanical running test in air or water to verify mechanical soundness and freedom from vibration. The water test may also be used to verify proper motor loading. See next Section for water test.

Caution: not all mixers are designed to operate in air. Check with manufacturer before running a test in an empty vessel. Possible problems include:

502.8.1 Agitator shaft may be unstable in air.

502.8.2 Variable speed clutch may require a load in order to operate properly.

502.8.3 Submerged steady bearing may require fluid in vessel for lubrication.

502.8.4 Submerged mechanical seals may require fluid in vessel for lubrication. This is common for side-entry mixers with single mechanical seals.

502.8.5 All mixer system components should be operated, including:

502.8.5.1 Gearbox lubrication pumps.

502.8.5.2 Coolers.

502.8.5.3 Seal lubricator.

502.8.5.4 Steady bearing lubricator.

502.8.5.5 An air running test would normally be of short duration, 5 minutes to 30 minutes, to perform preliminary checks on: vibration, noise, runout, speed and direction.

502.9 *System Water Test*

Caution: not all mixers are designed to operate in water. Check with manufacturer before running a test in water.

502.9.1 Possible problems include:

502.9.1.1 Water may be an unsuitable lubricant for a submerged steady bearing or submerged mechanical seal.

502.9.1.2 The mixer may be designed to operate in a fluid that draws less power than water, and would overload the motor in water.

502.9.1.3 The materials of construction may not be corrosion-resistant to water.

502.9.1.4 Agitators designed to operate in high viscosity liquids may splash and vibrate excessively in water.

502.9.2 Typical water tests include:

502.9.2.1 All mixer system components should be operated as listed in Sec. 502.8.5.

502.9.2.2 A water batch test would usually be run for four or more hours, allowing equipment temperatures to stabilize and to perform tests on the following: motor power, agitator speed, direction of rotation, runout, gear tooth contact patterns, seal leakage, auxiliary equipment, vibration, noise, and temperature, as described in the next sections of this testing procedure.

503.0 *Operating Performance Tests*

The liquid surface location should be checked. Many mixers are not designed to operate with the surface near or just above the level of the impeller. Refer to the mixer instruction manual.

503.1 *Speed*

Measure within 1% accuracy and record. Check direction of rotation.

503.2 *Power*

503.2.1 *Start-Up*

Power draw during the start-up period is often greater than during steady-state operation. Extra power is required to accelerate the fluid to establish hydraulic equilibrium. In the case of solids suspension, it is conceivable that the impeller could be surrounded by compacted solids. In this case the start-up power could be several times greater than the steady-state operating power, and could cause shaft or gear failures under extreme circumstances.

503.2.2 *Steady State*

In long-term operations, the power draw of the mixing impeller has a mean and a variable component. The closed vessel and the unsteady nature of the flow reflected back into the impeller zone, causes a fluctuating component of impeller torque. For fast response instrumentation, the variable component of the power draw could range from 10% to 20% of the mean.

The actual magnitude would be a function of installation geometry and power intensity of the mixer. These variations might not be observed for the slow response of highly damped sensors or instruments.

503.2.3 *Free Surface*

During draw-off, or operation where the impeller is very near the free surface, the relative magnitude of the fluctuating to the mean components of power increases quite dramatically.

503.2.4 *Process Factors*

Mixer mean power or power variations can be affected by process related factors. Such factors might include: inlet and outlet flows, recirculation flows, equipment proximity, pressure, temperature, gas usage, liquid viscosity changes, etc.

503.2.5 *Variable Process Conditions*

Consider effects of changing liquid level, viscosity, speed, flow rates and other process conditions. Include power failures, coagulating batches, viscosities that change with time, phase changes, and other possible variable conditions.

503.3 *Torque*

All of the factors noted in the previous section on Power apply equally to torque. Additionally, torque variations may also result in speed fluctuations, so speed measurement should be an integral part of torque measurements if the results are to be converted to power results.

504.0 *Mechanical Condition Tests*

504.1 *Alignment and Adjustments*

The procedure of measuring alignments should be obtained from the mixer or component manufacturer.

504.2 *Runout*

Typical static shaft runout at unsupported locations along the shaft should be less than 0.030 inches runout/foot (2.5 mm/m) of shaft length from the primary support. Allowable runout at seals and steady bearings depends on the type of seal, size of shaft, and operational speed. Typically, such limitations reflect maximum deflections for the peripheral speeds between rotating and non-rotating parts.

504.2.1 Shaft runout may be measured while the agitator shaft is hand-turned.

504.2.2 A measurement may be made of shaft movement normal to its axis.

504.2.3 A measurement should be made at more than one radial location, such as every 90 degrees.

504.2.4 Runout can be measured at the seal and at the impeller.

504.3 *Gear Tooth Contact Patterns*

The gear drive manufacturer may provide instructions in the service manual to measure gear tooth contact patterns. The procedure may vary depending on gearing and gearbox design, but a typical procedure is as follows:

504.3.1 Drain gear box oil.

504.3.2 Remove gearbox inspection plate.

504.3.3 Wipe oil from several gear teeth.

504.3.4 Apply a thin layer of transfer dye to the gear teeth.

504.3.5 Replace inspection plate and oil.

504.3.6 Run the gear drive briefly either loaded or unloaded.

504.3.7 Drain oil, remove inspection plate, and record the pattern of dye removed, which is the gear tooth contact pattern.

504.4 *Seals*

A seal may be operated at design and/or normal pressure and temperature for a test. If seal leakage is measured over a long period of time, the tests may be performed during normal operation and use of the mixer.

Some seals are provided with an external leakage test or drain port, which may be isolated by a low pressure secondary seal, and this can be used to collect leakage out of a vessel.

Some seals are provided with an internal catchall and drain, and this can be used to collect leakage into the vessel.

A continuous log of seal lubricant replenishment may be kept during normal operation, which can be used to calculate seal leakage.

504.5 *Auxiliary Equipment*

504.5.1 *Steady Bearings*

Prior to installing a steady bearing, the agitator shaft should be turned by hand at the motor coupling. The shaft end will usually scribe a circle when rotated one full turn. The steady bearing housing should be installed concentric with the center of this circle.

504.5.2 *Variable Speed Clutch*

Manufacturer's instructions should be followed to operate a variable speed clutch. Run through specified speed range and measure agitator shaft speed. Sometimes a load is required in order to operate a variable speed device, and tests may have to be performed with water or process fluid in the mixing vessel.

504.5.3 *Lubrication and Cooling Systems*

Pressure measurements should be taken during operation in accordance with manufacturer's instructions.

Flow rate in forced pumping or thermosyphon systems can be difficult to measure directly.

Direction of flow and adequacy of flow can sometimes be deduced by measuring inlet and outlet temperatures of the system.

504.6 *Vibration*

If vibration measurements are being considered because of gear drive rocking, then the first step is to measure the magnitude of rocking or vibration. If the motion exceeds the manufacturers allowable limits, more detailed tests are required.

Vibration measurements should include basic information on magnitude and frequencies. The frequency ranges should be established to highlight shaft speed, blade passage, and other identifiable frequencies.

504.7 *Noise*

Noise is a result of mechanical actions similar to vibration being transmitted to the air in the form of pressure pulsations. Procedures for the use of noise measuring instruments may be obtained from their manufacturers.

504.8 *Temperature*

The temperature of gear drive oil and/or motor surface temperature should be measured after running at rated speed under load for four hours. Either water or process fluid should be in the mixing vessel.

If the gear drive is splash lubricated or internal pump lubricated, the sump oil temperature should be measured.

If the gear drive has an external pump and/or cooler, both drain and inlet oil temperatures should be measured.

Measure ambient air temperature at the same time equipment temperature is measured.

505.0 *Mechanical Operation Tests*

Before resorting to extensive testing, be sure that the equipment has been properly installed and that there has been no damage to the equipment. A complete dimensional check and static runout measurements should be made before proceeding. Discrepancies noted in these steps often lead to a solution to vibration problems.

505.1 *Natural Frequency*

Shaft natural frequencies are obtained with the mixer turned off.

CAUTION: for safety, the motor power supply should be locked out.

Some kind of disturbing force is required to displace the shaft and then let it oscillate at its natural frequency. Frequency measurement requires some sort of displacement transducer to detect motion and an analyzer, such as an oscilloscope to determine frequency.

Natural frequency measurement should be made of the mixer support structure and components in the vessel.

505.2 *Deflections of Structure*

These tests are performed with the mixer operating in process fluid. Do not operate the unit in air or water without checking with mixer designer/manufacturer.

505.2.1 *Mixer Support Structure*

Measure deflection, twist, etc.

505.2.2 *Mixer Housing*

Motion relative to support structure or other stationary equipment. Check for rocking at the mounting bolts.

505.2.3 *Mixer Shaft*

The mixer shaft measurements involve either strain or deflection. For deflection measurements runout must be measured and subtracted. If possible, spectral analysis of the shaft data should be obtained.

505.2.4 *Operating Modes of Vibration*

Operating system vibration magnitudes and frequencies should be measured on the tank structure and mixer housing.

506.0 *Process Condition Tests*

General test criteria and duration should be defined and frequency of data sampling established. All data should be identified as to source and recorded in sufficient detail. An immediate review of the data should be carried out and the results evaluated. Then the test should be continued until the original plan is completed.

506.1 *Blending*

Blending applies primarily to the combination miscible liquids to obtain uniform properties or uniform concentrations of ingredients. Measurements are usually applicable to batch operations, where properties become more uniform as mixing proceeds or continuous operations, where two or more streams are mixed and withdrawn at constant flow rates.

506.2 *Heat Transfer*

Heat transfer in an agitated tank is usually accomplished by exchange between the process fluid and some heat transfer fluid, contained in a jacket at the tank wall or pipe coils inside the tank. The exact methods of making heat transfer measurements depend on the test capabilities available with the installed equipment.

506.2.1 Heat rejection or addition can usually be measured by making a heat balance on the heat transfer medium. Accurate measurement of temperatures and flows into and out of the jacket or coils should provide an indication of heat transfer rate, plus any ambient losses.

506.2.2 If the rate of heat generation by the vessel contents can be determined, a further measure of the heat transfer rate can be made, and checked against the external measurements. Alternatively, a transient study can be performed to establish the rate of heat addition or removal from a known quantity of material in the tank.

506.2.3 Careful measurements of vessel contents temperatures and heat transfer fluid temperatures are necessary to convert heat transfer rates to an overall heat transfer coefficient. The coefficient may be a local or overall value depending on the temperatures or temperature averages used.

506.2.4 Heat transfer rates at actual operating conditions with real process fluids are usually the most significant and the most difficult to obtain. Heat transfer tests with water or other inert fluids are easier and may be useful depending on the exact nature of the desired results.

506.2.5 If the mixing equipment can be operated at different speeds, different heat transfer rates would be expected. The incremental change in heat transfer will depend on the limitation due to process-side heat transfer coefficient.

506.2.6 If the process fluids are viscous, or the agitation is intense, heat addition associated with the dissipation of input agitation horsepower cannot be neglected.

506.3 *Immiscible Liquids Dispersion*

Applications include processes where two immiscible liquids are contacted to promote mass transfer between phases or to create an emulsion. The purpose of an agitator is to make a liquid-liquid dispersion of a desired drop size range and at a desired production rate. Other things including process chemistry and upstream equipment have an effect on the apparent operation of the agitator. It is very important that the test differentiates between the effect of the agitator and the rest of the process.

506.3.1 Dispersion tests measure the capability of the agitator to make drops of the correct size. The result of such a test could be a mass transfer coefficient or a number of theoretical mass transfer stages.

506.3.2 Hydraulic capacity tests measure the volumes of the phases which can be processed. The result would be the operating limits before entrainment becomes significant.

506.3.3 Emulsion tests would measure the stability of the emulsion as well as the droplet size distribution.

506.3.4 Other factors including process chemistry and upstream equipment have an effect on the apparent operation of the agitator.

506.4 *Liquid-Solid Contacting*

Applications include all processes where an impeller is used to disperse a solid into a liquid, maintain suspension, or promote mass transfer between the phases.

Caution: some mixers are not designed to start in settled solids or operate through draw-off.

In these cases, test operations beyond the design limits could overload the motor or break mixer components.

506.4.1 In order to interpret results, it usually is necessary to characterize the solids as well as the slurry. Measurements of particle size distribution, material density, and settling rates should be considered. The bulk slurry density is another important measurement. Slurry properties are important for mixer power evaluation since power draw increases in proportion to slurry density.

506.4.2 For continuous flow processes, the tests must monitor slurry densities of the incoming and exiting process streams. Solids accumulation or depletion could grossly change the slurry density in the vessel being tested. Such a change in density would affect mixer power and other process results.

506.4.3 Process tests could include solids suspension capability, mass transfer, material wetting characteristics, and changes in particle size.

506.5 *Liquid-Gas Contacting*

Applications include all processes where the mixer promotes contact between a liquid and gas. These processes may include the presence of solids also. In the latter case, the section on liquid-solid contacting should also be reviewed for applicability.

Some mixers are designed with gas rate limitations. Operation at reduced gas rate could overload the unit. For other units, operation above a prescribed gas rate could cause large fluid forces with the attendant increases in shaft deflections. The operating limit must be determined and observed.

506.5.1 The term "flooding" is often used to identify a condition where too much gas is supplied. No single definition of "flooding" exists. The definition depends on the type of impeller and the application. If a process criteria uses this word, further description is required to be sure that all parties understand what is meant.

506.5.2 In order to interpret results it is often necessary to measure gas rate, gas hold-up, interfacial tension, and other liquid phase and gas phase properties including density, viscosity, temperatures, pressures, etc. In some processes gas evolution is used for batch temperature control. Independent procedures might be required to calculate or measure the rate of evolution.

506.5.3 Gas rate can have a significant impact on mixer power. It is sometimes desirable to measure ungassed and gassed power. This ratio is often referred to as the gassed power factor.

506.5.4 Process tests could include gas dispersion capabilities, flooding, gas hold-up, mass transfer, etc. Mass transfer testing techniques have been developed for steady state and unsteady state processes. If processes cannot be run under process conditions, air-water tests might be applicable.

506.6 *Liquid-Gas-Solid Tests*

Solids in the form of low viscosity suspensions or slurries should have a minimal effect on gas dispersion. Therefore, typical gas dispersion tests for flooding and bubble size should be possible even with solids present.

The presence of gas will almost always adversely affect the ability of an agitator to suspend solids. A suspension level test should be conducted at maximum gas rate.

Although multiphase tests are extremely complicated, and no general procedures specific to this situation are offered. Most tests for simpler systems may be applicable, and some combination of these tests may be appropriate for a given condition.

506.7 *Other Tests*

If tests in the full scale process equipment are impractical, or do not reveal the cause of problems or possible methods for solution, small scale modeling tests may be the next best approach. Although small scale modeling, scale-up, and scale-down are beyond the scope of this procedure, the methods must be considered as an alternative.

In many cases, pilot or laboratory scale mixing equipment may be available. Tests performed in transparent tanks with variable speed agitators can provide enormous insight into many mixing and agitation problems with relatively simple equipment.

Many of the same tests described in this procedure can be applied to pilot plant equipment with greater ease, less cost, and better control. Changes to the equipment can be tried in less time and at less cost than with larger equipment.

Properly interpreted and scaled-up, the results of small scale testing can be of enormous benefit. Any test program for impeller mixing equipment should consider small scale testing as a possible alternative to large process tests.

600.0 COMPUTATIONS OF RESULTS

601.0 *Data Requirements*

All relevant dimensions, operating conditions and results should be recorded, indicating the appropriate units of measure. If the accuracy or measurement technique associated with a result might be questioned later, a notation should be made. Readings which fluctuate during a test may be recorded as an average, possibly along with a minimum and maximum. If the variation is significant or an accurate average is required, some sort of monitoring and averaging techniques may be considered.

601.1. *Dimensional Measurements*

All dimensional measurements (Section 502.3) should be verified and recorded. Simple differences between actual and design impeller diameter can account for major process and mechanical failures.

601.2. *Operating Conditions*

Pressure temperature, liquid level(s), feed and discharge rates, and output shaft speed should be recorded, along with any special variable measurements.

601.3. *Process Properties*

Fluid properties, such as density and viscosity should always be determined and recorded. Other properties such as solids size and density, gas flow rates, and thermal properties may also be determined depending on the type of test being performed.

602.0 *Fundamental Calculations*

Certain fundamental calculations are recommended to help evaluate operational performance for most mixing systems. The following list of relationships is not comprehensive, but should suffice for many situations. Other relationships with more specific meaning are presented where appropriate.

602.1. *Reynolds Number*

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

D = impeller diameter
N = rotational speed
ρ = fluid density
μ = viscosity

602.1.1. English units

$$N_{Re} = \frac{10.7\ D^2\ N\ (S.G.)}{\mu}$$

D [inches]
N [rev/min]
S.G. = specific gravity
μ [centipoise]

602.1.2. SI metric units

$$N_{Re} = \frac{0.159\ D^2\ N\ \rho}{\mu}$$

D [m]
N [radians/s]
ρ [kg/m^3]
μ [Pa s]

602.1.3. typical values:

Turbulent Mixing: $N_{Re} > 20{,}000$
Transition: $5 < N_{Re} < 20{,}000$
Laminar Mixing: $N_{Re} < 5$

602.2. *Power Number*

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

P = impeller power
ρ = density
N = rotational speed
D = impeller diameter

602.2.1. English units

$$N_P = \frac{1.52\text{x}10^{13}\, P}{S.G.\; N^3\, D^5}$$

P [horsepower]
S.G. = specific gravity
N [rev/min]
D [inches]

602.2.2. SI metric units

$$N_P = \frac{2.48\text{x}10^5\, P}{\rho\, N^3\, D^5}$$

P [kW]
ρ [kg/m^3]
N [rad/s]
D [m]

602.2.3. typical values (depend on impeller type):

Low: $0.1 < N_P < 0.5$
for axial flow impellers: propellers, high efficiency impellers, etc.

Middle: $0.5 < N_P < 3.0$
for mixed flow impellers: pitched-blade turbines, simple paddles, etc.

High: $3.0 < N_P < 7.0$
for radial flow impellers: straight-blade turbines, disk-style turbines, etc.

602.3. *Torque*

$$\tau = P / (2\, \pi\, N)$$

τ = torque
P = power
N = rotational speed

602.3.1. English units

$$\tau = 63{,}025\ P / N$$

τ [inch-pounds]
P [horsepower]
N [rev/min]

602.3.2. SI metric units

$$\tau = 1{,}000\ P / N$$

τ [N·m]
P [kW]
N [rad/s]

602.4. *Agitator Speed*

$$N = \frac{N_R}{t}$$

N_R = number of shaft revolutions
t = time interval in which shaft revolutions are counted

602.4.1. English units

$$N = \frac{N_R}{t}$$

N [revolutions/minute]
N_R [dimensionless]
t [minutes]

602.4.2. SI metric units

$$N = \frac{2\, \pi\, N_R}{t}$$

N [rad/s]
N_R [dimensionless]
t [seconds]

603.0 *Operating Performance Calculations*

Perhaps the simplest performance evaluation is motor loading. Electrical measurements can be compared directly with the manufacturer's performance curves. A typical motor performance curve is shown in Fig. 805.4, and a sample calculation performed in Sec. 805.1.5. Similarly, actual performance data can be obtained with a watt meter and interpreted.

603.1. *Power*

Simple calculations convert voltage and amperage to input electrical power. This information, in combination with motor performance curves or experimentally measured power factors can determine a motor loading, or the fraction of available motor power being delivered to the mechanical equipment.

Mixer power can be related to power and/or torque plus speed measurements by factoring the efficiencies of all the interceding components. Typical components include: electric motor, gear drive, couplings, belts and pulleys, torque limiters/clutches, shaft seals, bearings and shaft supporting devices, and etc.

Since power is a magnitude parameter, strongly related to the size of the equipment involved, power relative to the amount of process fluid is more relevant on a general basis.

603.1.1. *Power per Unit Volume*

$$\frac{P}{V} = \frac{P_m L_f E_m}{V}$$

P_m = motor power rating
L_f = motor loading, fraction
E_m = mechanical efficiency of couplings, gearbox and seal, fraction
V = fluid volume

603.1.1.1. English units

$$\frac{P}{V} = \frac{1{,}000\ P_m L_f E_m}{V}$$

P/V [horsepower/1,000 gallons]
P_m [horsepower]
L_f [fraction]
E_m [fraction]
V [gallons]

603.1.1.2. SI metric units

$$\frac{P}{V} = \frac{P_m L_f E_m}{V}$$

P/V [kW/m^3]
P_m [kW]
L_f [fraction]
E_m [fraction]
V [m^3]

603.1.1.3. typical magnitudes (English units - hp/1,000 gal) for process applications in low viscosity liquids. Higher values in high viscosity liquids, lower values in large storage tanks and basins.

Low:	$0.1 < P/V < 0.5$
Middle:	$0.5 < P/V < 3.0$
High:	$3.0 < P/V < 15.0$

The mixer speed can be measured directly or calculated based on motor speed and drive reduction, provided the exact gear ratio is known or measured. Standard motor curves give slip versus motor load, to predict actual motor speed. The standard gear drive speed ratio values based on the AGMA rating procedure will be within 2-4% of the true ratio. Some mixer manufacturers use exact ratios, or the ratio may be determined by counting input and output shaft revolutions, or knowing numbers of gear teeth.

A complete analysis of mixer power draw is more complex. The equipment designer should have historic data to predict the impeller power draw for standard conditions. There are also many references (including Ref. 808.9.2, 808.10, 808.11 and 808.13.3) in the literature with power draw data for mixing impellers. Non-standard process factors and non-standard installation geometry factors must also be considered.

Typical geometry factors likely to influence power requirements include: impeller proximity to surface, bottom, side walls or any nearby obstruction, unusual tank shape or baffle arrangement and etc. In all cases, geometric variables should be accurately measured for future evaluation.

603.2. *Torque*

From agitator speed and impeller power the torque applied to the process can be determined. For most blending applications, torque per volume is considered to be a better indication of agitation intensity than the corresponding power per volume information.

603.2.1. *Torque per Unit Volume*

$$\frac{\tau}{V} = \frac{P_m L_f E_m}{N\ V}$$

P_m motor power rating
L_f motor loading [fraction]
E_m mechanical efficiency of couplings, gearbox and seal, [fraction]
N rotational speed
V fluid volume

603.2.1.1. English units

$$\frac{\tau}{V} = \frac{63{,}205\ P_m L_f E_m}{N\ V}$$

τ/V [inch-pounds/gallon]
P_m [horsepower]
L_f [fraction]
E_m [fraction]
N [rev/min]
V [gallons]

603.2.1.2. SI metric units

$$\frac{\tau}{V} = \frac{1{,}000\ P_m L_f E_m}{N\ V}$$

τ/V [N m/m^3]
P_m [kW]
L_f [fraction]
E_m [fraction]
N [rad/s]
V [m^3]

603.2.1.3. typical magnitudes (English units - inch-pounds/gallon) for low viscosity fluids, higher values for high viscosity.

Low:	$0.05 < \tau/V < 0.2$
Middle:	$0.2 < \tau/V < 1.5$
High:	$1.5 < \tau/V < 10$

603.2.2. *Torque per Specific Volume*

$$(\tau/V^*) = \frac{(\tau/V)}{S.G.}$$

V^* = specific volume
S.G. = specific gravity

604.0 *Mechanical Condition Calculations*

Most alignment, adjustment and vibration measurements are basically comparative. Specific calculations may be required to interpret certain results, but general calculation procedures do not exist.

605.0 *Mechanical Operation Calculations*

605.1. ***Natural Frequency***
The natural frequency of an impeller shaft depends on shaft length, impeller weight, bearing spacing and material properties.

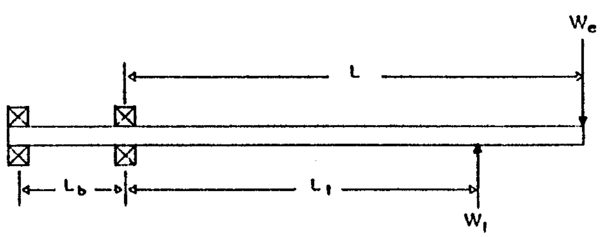


Fig. 605.1 Shaft for Natural Frequency

The equation for natural frequency (critical speed) of a constant diameter cantilevered beam can be written as follows for English units:

Natural Frequency

$$N_c = 37.8 \frac{d^2 \sqrt{(E_Y/\rho_m)}}{L \sqrt{W_e} \sqrt{(L + L_b)}}$$

d = shaft diameter, [inches]
E_Y = modulus of elasticity, [psi]
ρ_m = metal density, [lb_m/in^3]
L = shaft length, [inches]
L_b = bearing spacing, [inches]
W_e = equivalent weight (at end of shaft of length, L), [lb_m]

$$W_e = W_i (L_i/L)^3 + w_s L/4$$

L_i = impeller location (down shaft), [inches]
W_i = impeller weight, [lb_m]
w_s = shaft unit weight, [lb_m/in]

Conventional calculations reflect only static analysis of the shaft. Such calculations are adequate for most mixing equipment. Equipment with large, high speed shafts may require dynamic analysis.

For more complex shafts or ones with additional bearing supports, contact the mixer designer/manufacturer.

605.2. *Deflection*
There are two principal forces which contribute to shaft deflection. Fluid forces are the result of unsteady hydraulic flow in the region of the impeller. The second is centrifugal forces due to the combined effect of shaft runout and mechanical imbalance.
Fluid force data are not readily available. Each impeller has a characteristic force number (in similar fashion to power and flow numbers). The mixer designer/manufacturer should be contacted for standard fluid force numbers. Process (503.2.4) and geometry (603.0) factors act as multipliers to increase these forces for non-standard installations.
The centrifugal forces can be readily calculated by measuring runout and estimating mechanical imbalance.
A simple beam analysis will give shaft deflection versus forces applied at the impellers(s).

606.0 *Process Condition Calculations*

606.1. ***Blending***
A first step in determining blending results is complete documentation of the test conditions, the measurement locations, and the sensing or sampling equipment used. Observation of blend time may be highly dependant on minor factors, especially those related to the measurement location or method of initiating the blend test. Times may be unnecessarily extended by poorly agitated locations on the liquid surface or in exit nozzles.
True uniformity is difficult to measure since it is dependent on both time and location. However, use of a pH or ion electrode may work to detect the final concentration resulting from a pulse addition. Other sampling techniques may work in large vessels, where blend times are relatively long.
Typical blend time results might be obtained by measuring the time required for uniformity in five to ten repeated tests. Variability between runs is typically at least ten percent because of the random nature of mixing. An average time may be combined with the impeller rotational speed to establish a dimensionless number, especially if scale-up is involved.

606.1.1. *Dimensionless Blend Time*

$$N_\theta = \theta_b N$$

θ_b = blend time
N = rotational speed

Caution must be exercised in the use of a dimensionless quantity obtained by this means, since it assumes that at least geometric similarity is retained in any other situation. Important factors, such as impeller to tank diameter ratio, must be the the same for other conditions.

606.2. *Heat Transfer*

Specify all properties, geometry, and operating conditions and use the results in computations as needed. The most essential properties are specific heat, specific gravity, thermal conductivity and viscosity at specified temperatures and compositions. Additional test may be needed if actual conditions differed from design conditions.

606.3. *Immiscible Liquid Dispersion*

Liquid dispersion mechanisms are complex since two liquids are involved, and both agitation intensity and relatively fluid properties influence results. Fluid properties which influence process results include density, viscosity, and surface tension. The dispersion of two liquids is also influenced by which phase is continuous and which is dispersed.

In spite of the fluid complexities, the tip speed of a given impeller seems to have a pronounced effect on the final drop size. Although no simple rules exist for drop size, determination of impeller tip speed is probably a good operational variable to record in conjunction with dispersion.

606.3.1. *Impeller Tip Speed*

$$v_{ts} = \pi N D$$

N = rotational speed
D = impeller diameter

606.3.1.1. English units

$$v_{ts} = 0.2618 N D$$

v_{ts} [ft/min]
N [rev/min]
D [inches]

606.3.1.2. SI metric units

$$v_{ts} = 0.5 N D$$

v_{ts} [m/s]
N [rad/s]
D [m]

606.3.1.3. typical magnitudes (English units - ft/min)

Low:	$200 < v_{ts} < 500$
Middle:	$500 < v_{ts} < 900$
High:	$900 < v_{ts} < 2000$

Material balances are also important in liquid dispersion. To determine the equipment performance and the adequacy of procedures, select data from known periods of steady operation. Steady state can be determined from charts of flow rates, valve positions, and decanter levels. The balances should be calculated on as many of the stream species as possible. The balances can be checked by comparing predicted readings with the actual measurements.

Entrainment of one phase into the other is a common cause and/or result of poor hydraulic performance. The important data include the flow rates and the measurement of one phase contained in the discharge stream of the other phase.

606.4. *Liquid-Solid Contacting*

Material balances are important to determine the equipment performance. The balances can be used to determine the approach to steady state to see if significant particle classification is occurring. Select the data from known periods of steady inflow and outflow. These periods can be determined from flowmeter readings, level readings, and valve positions. The balances should be calculated on both the overall quantity of material and on the individual particle size ranges.

Mixer capacity should be measured by means of material balances. The data should be selected from periods of steady operation. This means not only steady in-flows and outflows but also no accumulation. The capacity can be affected by upstream process conditions. The process materials should be that used for the actual operations.

606.5. *Liquid-Gas Contacting*

The gas hold-up should be measured during steady state operation. Select data from steady periods of operation. The hold-up is calculated by the difference in apparent liquid volume between ungassed and gassed periods of operation. Mass transfer measurements can be made during steady operation or by a transient technique. For the steady state operation tests, select data from periods of well-established steady operation. For transient tests, duplicate runs should be selected as a check for the reproducibility of the data.

606.6. *Other Tests*

Other calculations may be required for other tests, such as interpretation of concentration results as rates of reaction.

700.0 INTERPRETATION OF RESULTS

701.0 *Introduction*

The test results should be interpreted and evaluated for the specific objective of the test as well as the degree of accuracy required.

702.0 *Interpretation of Operating Performance*

702.1 *Speed*
The measured speed should be compared with the predicted value. The difference should be within the error of measurement. Impeller power is strongly dependent upon speed. The table below shows how the errors in predicting speed affects the prediction for power.

	Power Error	
Speed Error	Laminar (NRe < 20)	Turbulent (NRe > 10,000)
5%	10%	16%
10%	21%	33%

702.2 *Power*
The measured power should be within approximately 8% of the calculated value for normal conditions.
Greater variations are usually the result of complicating process factors or installation geometry factors. In some cases a process upset results in significantly higher mixer loads. The unit design is generally based on the worst case condition. Under normal conditions the mixer power draw may be much lower than the capability of the motor and drive.
702.3 *Torque*
The product of torque and speed (See Sec. 602.3) should be within 10% of the predicted power. Greater variations are usually the result of complicating process factors or installation geometry factors.
In some cases a process upset results in significantly higher mixer loads. The unit design is generally based on the worst case condition. Under normal conditions the mixer power draw may be much lower than the capability of the motor and drive.

703.0 *Interpretation of Mechanical Conditions*

703.1 *Alignment and Adjustments*
Adjustments should be made until all mechanical equipment is mounted and aligned to within specifications of the manufacturer. Any deviations which cannot be corrected should be brought to the attention of the manufacturer and resolved.
703.2 *Runout*
Runout measurements should be compared to manufacturer or purchase specifications. Any deviations which cannot be corrected should be brought to the attention of the manufacturer and resolved.
703.2.1 Total indicated runout at a seal is commonly limited to 5 to 30 mils (125 to 750 microns), depending on seal type and operating speed.
703.2.2 Total indicated runout at the end of a shaft is commonly limited to 30 mils per foot of shaft (2.5 mm per meter of shaft length).
703.3 *Gear Tooth Contact Patterns*
The gear tooth contact pattern may be compared with the gear drive standards of the manufacturer. If percent contact is excessively low the gear drive may require adjustment or replacement of parts as needed.
703.3.1 The percent contact rarely exceeds 80-90% under the best conditions. A gear drive may be designed to operate at lower than 80% contact.
703.3.2 For an interpretation of gear tooth contact pattern see: AGMA 390.03, Section 9, pages 96-99.
703.4 *Seals*
703.4.1 *Separately Mounted Seals*
Compare concentricity and squareness of seal to manufacturer's standards.
703.4.2 *Packing Seals*
Compare leakage rates to specifications.
703.4.3 *Mechanical Seals*
Compare leakage rates and temperature to specifications.
Seal designs differ, but leakage rate of lubricant can be expected to be about one drop per minute per inch of shaft diameter per 100 psi pressure differential (41 mL per day per 100 mm of shaft diameter per 100 kPa pressure differential).
703.5 *Auxiliary Equipment*
Measurements should be compared with specifications.
703.6 *Vibration*
703.6.1 Displacement measurements may be compared to AGMA 300.01, Figure 1, type A.
703.6.2 Velocity measurements may be compared to AGMA 300.01, Figure 2, type A.
703.6.3 Acceleration measurements may be compared to AGMA 300.01, Figure 3, type A.
703.7 *Noise*
703.7.1 Sound pressure level measurements can be compared to motor and gearbox manufacturer's specifications.
703.7.2 A typical maximum sound level is shown for enclosed gear drives in AGMA 297.02, Figure 2.
703.7.3 Measurements can be compared to the O.S.H.A. and Walsh-Healey Public Contracts Act, 50-204.10. Sound level is currently limited to 90 dBA for 8 hours exposure per day without protection.
703.7.4 Octave band measurements of excessive or unusual noise can be interpreted in terms of possible causes. Noise can be reduced either by dealing directly with the causes or by shielding the mixer drive.
703.8 *Temperature*
703.8.1 Gear drive oil temperature and motor surface temperature should be

compared to specifications of the manufacturer.

703.8.2 Gear drive thermal ratings are based on a maximum sump temperature rise of 100°F (55°C) above ambient, and sump temperature not to exceed 200°F (93°C) per AGMA 420.04, Section 6.2.

703.9 *Water Power and Corrections*

Power measurements taken with water in the vessel can be translated to expected process power draw by making a correction for process fluid specific gravity provided the impeller Reynolds number (See Sec. 602.1) indicate turbulent conditions. For viscosities resulting in transitional or laminar conditions, a complete power number curve is necessary to estimate actual power requirements.

704.0 *Interpretation of Mechanical Operation*

The support structure should be relatively rigid. Significant motion of this structure could be due to insufficient design rigidity for the mixer loads or dynamic interaction due to the frequency of the loads. If there is significant motion, the structure must be reinforced and the mixer rechecked for shaft deflection.

Relative motion between the mixer and support structure could be the result of insufficient bolt down forces.

Assuming that the support structure is rigid and there is no relative motion between the drive structure and support, measure the shaft deflections. Compare these measurements with the manufacturers design values. If shaft deflections exceed the values, there are several possible causes:

704.1 *Natural Frequency Vibrations*

The calculated value for shaft natural frequency should be within 5-10% of the measured value. A discrepancy greater than this will require a determination of the cause.

The measured natural frequency should be a sharp peaked response on the signal versus frequency plot. A broad band frequency response indicates improper mounting hardware tension or flexible support structure.

A direct comparison of measured system natural frequency to operating speeds is the most direct way of determining structural resonance problems. If the ratio of operating vibration frequency to system natural frequency (harmonic ratio) is in the range of 0.8 to 1.20, then structural resonance problems are likely. Good design practice dictates this ratio should be, at least, less than 0.8. Lower operating speeds may be advisable in cases where additional loads, such as those caused by impeller operation at the liquid level, are likely to be encountered.

For large equipment, over-critical operations (ratio greater than 1.0) can create unstable speed ranges and should be used only after detailed analysis and testing. Many small or portable mixers operate above first critical.

Blade passage frequency can be a factor for geometries involving asymmetries in the flow field.

No. of Blades	Harmonic Ratio
2	0.50
3	0.33
4	0.25

The principle operating harmonics are shaft speed and blade passage frequency. Other harmonics could be generated by baffle interactions, sparge flows, gas, etc. The solution scheme will depend on the magnitude of the harmonic ratio. For harmonic ratios between 0.8 and 1.0 the solution would likely include stiffening the structure or lowering the operating speed. For harmonic ratios between 1.0 and 1.2, the solution above could make the problem worse. It is essential that the changes reduce the harmonic ratio to a value less than 0.8.

704.2 *Deflection*

Compare the calculated shaft deflection with the measured values. If the sum of fluid forces and centrifugal forces (runout/-imbalance) give a calculated deflection within 30% of the observed value, then these forces are the likely primary cause. If large forces are the cause, then the solution is either to stiffen the shaft or reduce the forces.

Fluid forces are proportional to shaft speed squared and diameter to the fourth power. Changing either would significantly alter the magnitude of fluid forces.

Additionally, if geometry or process factors are causing abnormally large forces, these factors may be changed to reduce the forces.

705.0 *Interpretation of Process Conditions*

705.1 *Blending*

For batch mixing, a summary of properties versus mixing time can be used to see when all points lie within the range of desired uniformity. For continuous mixing, a summary of properties for each sample taken can be used to see if all points are within a desired range. Both average values and standard deviations of values can be used to evaluate batch and continuous blending test results, and may be used to estimate the frequency of data required for the remainder of a test. Interpretation of results should begin at the start of a test and continue throughout the test.

Although blend time results indicate that the time required for uniformity is inversely proportional to rotational speed for a given tank, a speed change is rarely a practical solution for improved blending. Typical increments in speed for fixed ratio gear reducers are about twenty percent. A twenty percent increase in speed results in more than a seventy percent increase in required power. Adjusting the process to the available blend time is often the only practical approach, although batch size and method of ingredient addition may help control the effects of blending.

705.2 ***Heat Transfer***

Log-mean temperature differences, actual heat transfer area and total heat transferred are essential to calculate an over-all coefficient for coils and jackets. Compare the calculated over-all coefficient with the design or operating coefficient. Fouling may cloud results and efforts should be made to avoid fouling by proper cleaning. Corrections for different operating conditions, heat losses and heat gains should be made. Correlations related to the Nusselt number are usually available in references on agitation.

705.3 ***Immiscible-Liquid Contacting***

The capacity of a system is the combination of the hydraulic capacity and the mass transfer rates.

705.3.1 The hydraulic capacity is usually determined by either entrainment or flooding.

705.3.2 The mass transfer capacity is determined by the residence time, interfacial area, and interfacial chemistry. The mixer design primarily affects the residence time and interfacial area.

705.3.3 Corrections to other conditions must be done with caution since the new conditions may change the interfacial chemistry. If the chemistry will not be affected, the adjustments based on volume handling capabilities, power input, and number of theoretical stages are adequate.

705.3.4 The sources of error for both types of testing include flowmeter readings, sampling error, and chemical analysis error. All these will give material balance errors.

705.3.5 The results of these tests are only valid for the range of the operating conditions studied. If changes in performance occur, then both the current operating conditions and the system chemistry must be examined in order to find the cause.

705.3.6 Liquid-liquid contacting results are very hard to generalize. Any test of process equipment should include consultation with the equipment vendor, the contractor designer, and process chemistry experts.

705.3.7 Frequent causes of poor performance include poor dispersion, poor mass transfer rates, and poor phase separation.

705.3.7.1 Poor dispersion is related to inadequate hydraulic performance. Contactor flooding and low power draw are indicators of this problem.

705.3.7.2 Poor mass transfer and poor separation indicate a change in the interfacial chemistry of the system. Changes in feed stream impurity concentration indicate potential problems in this area.

705.4 ***Liquid-Solid Contacting***

The capacity of a system is determined by the ability of the mixer to achieve the desired degree of solids uniformity. Once this is achieved, system chemistry becomes the limiting factor.

705.4.1 The solid suspension results can usually be extrapolated to other conditions using equations, correlations or scale-up.

705.4.2 The mass transfer results can usually be extrapolated to other conditions provided the state of the suspension will remain constant.

705.4.3 A conservative estimate of the preferred new operating conditions can be made on the basis of equal power per unit volume.

705.4.4 The sources of error for both solid suspension and mass transfer are related to material balance error. A likely source of error is the sampling method.

705.4.5 Liquid-solid results are hard to generalize and extrapolate from one chemical system to another. Any attempt to extrapolate the results of these tests should involve consultation with the equipment vendor, designer, and recognized experts in the field.

705.4.6 A frequent cause of poor performance is poor off-bottom suspension of solids.

705.4.6.1 Possible methods to correct off-bottom suspension problems include higher shaft speed, larger impeller blade, reduced solid concentration, and smaller particle size.

705.4.6.2 Once the performance is adequate, further changes in any of the variables listed above will usually give a minor improvement to the performance.

705.4.7 Another common source of problems with particulate solids, is the wetting of dry materials.

705.4.7.1 Dry materials dumped on the surface of the liquid in an agitated tank my not wet well enough to be drawn into the batch.

705.4.7.2 Changes in methods of adding materials may correct the problem.

705.4.7.3 Partial removal of baffles (at the top of the tank) or increased agitation intensity may me necessary.

705.5 *Liquid-Gas Contacting*

The power results are usually reported as the ratio of the gassed to the ungassed power. The gas hold-up is reported as a function of the shaft power and the physical properties of the system. The mass transfer coefficient usually is reported as the combined coefficient-area term. The coefficient-area term is a function of the power and the physical properties of the system. Results should be extrapolated to other conditions with caution.

705.5.1 The common sources of error are in the power measurements, in the samples for mass transfer measurements, and in knowing exactly what the level instrument reading means.

705.5.2 A common reason for poor operation is poor gas dispersion. This is normally corrected by increasing the power input to the system by means of either higher shaft speed or a larger impeller.

705.6 *Other Tests*

Interpretation of other tests must be based on the purpose of the test. It is important to review such results with appropriate experts in the field.

)6.0 *Sources of Error*

: most common sources of errors in mixer ;sts are in the differences between the actual ıd the desired measurements. For instance, in ·ocess tests it is important to know how much ›wer is being input into the fluid. Almost ıl methods for power measurement require some ;timates for losses between the point of ;asurement and the process fluid. Similarly, knowledge about the uniformity of batch ›mposition is desired, most available measure-·nt techniques are indirect, such as monitor-ıg exit composition.

lditional problems arise when calculations ;st be performed after the test data are llected or samples must be analyzed in the boratory. A torque measurement, which will most certainly fluctuate, must be computa-onally combined with the operating speed to termine pcwer. Selection of the appropriate ·rage torque reading to go with the correct eed may not be a simple problem. Similarly, boratory measurements of viscosity may be gnificantly in error relative to process nditions for several reasons, including ınges with time, temperature and shear rate.

l of the other common sources of experimental ·or can pose problems. Instrument errors, libration problems, recording errors, ·orrect calculations or units conversion, and) forth.

800.0 APPENDIX

801.0 *Trouble Shooting Checklist*

Problems and Possible Causes

1. Unit doesn't turn
   - Not wired correctly
   - Mechanical blockage

2. Motor overloads
   - Mechanical blockage
   - Alignment problems
   - Motor is faulty
   - Motor under-sized
   - Impeller diameter or speed wrong
   - Bearing problems
   - Viscosity and/or density too high
   - Impeller imbedded in settled solids

3. Agitator turns, but
   a. No apparent motion in tank
      - Shaft or impeller not attached
      - Very low agitation intensity
      - Agitator incorrect for process
   b. Wrong flow pattern in tank
      - Motor turning in wrong direction
      - Baffles incorrect or missing
      - Impellers in wrong location
      - Incorrect impellers installed
      - Agitator installed incorrectly
   c. Agitator overheats
      - Improper lubrication
      - Under-sized gearbox
      - Drive belts slipping
      - Bad bearings
      - Seal problems
   d. Excessive noise in gearbox
      - Poor lubrication
      - Bad bearings
      - Loose component in gearbox
      - Gear defective or worn

4. Noise in tank
   - Loose components
   - Debris in tank
   - Intense turbulence
   - Cavitation

5. Excessive vibration
   - Improper support or wall thickness
   - Misalignment
   - Improper mechanical design
   - Impeller cavitation
   - Imbalance (e.g., lost impeller blade, poor construction)

802.0 *Glossary*

For definitions of the basic equipment variables, see Sec. 203.1. Agitation related groups are shown in Sec. 203.2.

802.1 *accuracy* - The amount by which a measurement differs from the true value.

802.2 ***agitation*** - The random and fluctuating fluid motion resulting from the operation of an impeller-type mixer. The purpose of agitation can be liquid blending, heat transfer, solids suspension, gas dispersion, or numerous batch or continuous fluid operations.
802.3 ***agitator drive*** - Usually a specially designed gear reducer or other drive arrangement to reduce speed and increase torque, with heavy duty bearings on the output shaft to handle large overhung loads.
802.4 ***baffles*** - Vertical plates attached to tank walls to prevent uncontrolled swirling of liquid contents.
802.5 ***bearings*** - A low friction contact point for supporting a rotating in a stationary housing. Most commonly used in agitation equipment are tapered roller bearings, ball bearings or thrust bearings.
802.6 ***blending*** - The action of combining two materials, usually fluids in impeller-type mixing equipment, to make one uniform mixture. The time required to accomplish this action may be called ***blend time***.
802.7 ***coupling*** - A connecting device used to join two rotating shafts in a mechanical system. The purpose of a coupling is usually to provide some flexibility in alignment, but may also cushion vibration or reduce start-up torque.
802.8 ***critical speed*** - Rotational speed corresponding to first lateral natural frequency of mixer shaft and impellers.
802.9 ***deflection*** - The temporary bending, below the elastic limit, of a shaft, for instance.
802.10 ***dimensionless group*** - A combination of process variables, normally in the form of a ratio, in which the units of measure cancel one another. The resulting value is independent of the units used, and may have some physical significance independent of the absolute size of the equipment.
802.11 ***dispersion*** - The action or result of combining two immiscible fluids. In impeller mixing and agitation, dispersions may be formed with two liquids or a liquid and a gas (liquid phase continuous).
802.12 ***efficiency*** - Effectiveness of a component in transmitting or converting energy. For most mechanical drives, efficiency varies with both load and speed.
802.13 ***flooding*** - A condition where natural forces, typically gravity, dominate over imposed forces, such as mechanical agitation. Flooding is normally associate with gas dispersion, where too much gas may exceed the ability of the agitator to disperse the gas into the liquid.
802.14 ***fluid force*** - Lateral or axial force applied to the mixer impeller as a result of flow patterns or turbulence.
802.15 ***harmonic ratio*** - Ratio of operating speed, or any driving frequency to a natural frequency.
802.16 ***immiscible*** - A condition in which two liquids fail to blend, and instead form two separate liquid phases with different properties and compositions. Interfacial tension exists along the surface separating the two phases. In typical liquid dispersions, one or the other phase is continuous and the other dispersed at given conditions.
802.17 ***impeller*** - The general term used to describe the device attached to the rotating shaft, which causes fluid motions. Impellers may be called by more specific terms, such as: propellers, turbines, etc.
802.18 ***impeller power*** Actual power delivered to the process fluid by the impeller system.
802.19 ***natural frequency*** - First lateral vibrational frequency associated with an overhung shaft. Primary factors include impeller weight, shaft length and diameter. Other components, including the supports, also have natural frequencies and other modes of vibration are possible and may be important in special cases.
802.20 ***precision*** - The ability to discriminate or resolve differences in measurements. Related to repeatability or the ability to reproduce a measurement within a defined tolerance.
802.21 ***prime mover*** - A device to convert primary energy to mechanical energy. Usually an electric motor in impeller mixer applications. Alternate prime movers include:

a. steam turbine
b. hydraulic motor
c. internal combustion engine
d. gas turbine

802.22 ***pumping capacity*** - A defined quantity used to characterize the amount of liquid motion provided by the operation of a mixing impeller. Because typical impeller mixer operation involves only recirculating flows within a vessel, no readily available point-to-point measurement techniques apply.
802.23 ***runout*** - The variation in position caused by a rotating shaft which is not centered on the axis of rotation. The magnitude is usually measured as a peak-to-peak value.
802.24 ***shaft*** - The rotating extension on which impellers are mounted for mixing equipment. The shaft is typically of a cylindrical metal construction.
802.25 ***shaft seal*** - A device designed to retain pressure or restrict flow around a rotating shaft. Typical seal types include: ***lip seals*** - simple elastomeric rings, ***stuffing box seals*** - compression packing materials around the shaft, ***mechanical seals***-machined rings held against other machined surfaces, and a few other types.
802.26 ***scale-up*** - Techniques by which laboratory or pilot plant results are interpreted for use in large scale equipment. Similarity techniques are most often used.

In addition to geometric similarity, kinematic and dynamic similarity may be involved. The opposite process of *scale-down* may be performed to perform laboratory tests intended to duplicate large scale conditions.

802.27 *steady bearing* - A device which serves as a rotating bearing at the lower end or an overhung mixer shaft.

802.28 *structural resonance* - A condition which can occur when the operating vibration frequency is too close to the system natural frequency.

802.29 *suspension* - The action or result of combining a particulate solid and a liquid, and providing sufficient motion to retain fluid characteristics.

802.30 *tank* - Most often, a vertical cylindrical container. Typically fabricated of metal, perhaps closed at the ends by shaped heads. Design for use with an impeller-type mixer is usually stronger than for simple storage purposes.

802.31 *top-entering* - The most common mounting configuration for impeller-type mixing equipment. Center mounted is most common for large mixers, angle mounted, for small mixers. Other mounting arrangements include: *side-entering* and *bottom-entering*.

802.32 *vibration* - The cyclical or oscillatory motion of a piece of equipment. Depending on frequency, vibrations in mixing equipment may appear as noise, shaking or rocking motions. Causes are numerous, and may be indicative of mechanical problems.

803.0 *Notation*

Generalized dimensions are given for the notation because both English and SI Metric are used in the examples. Generalized dimensions include: force [F], length [L], mass [M], temperature [T], and time [t].

a = specific area, [L²/L³]
B = baffle width, [L]
C = impeller clearance, [L]
C_B = baffle clearance to tank bottom, [L]
C_W = baffle clearance to tank wall, [L]
c_p = heat capacity, [FL/(MT)]
D = impeller diameter, [L]
D_{AB} = molecular diffusivity, [L²/t]
D_d = disk diameter, [L]
d = shaft diameter, [L]
d_p = particle diameter, [L]
E_V = electrical voltage, [V]
E_Y = modulus of elasticity, [F/L²]
E_m = mechanical efficiency
e = runout, [L]
F = force, [F]
F_c = centrifugal force, [F]
F_f = lateral fluid force on impeller, [F]
F_t = fluid force plus centrifugal, [F]
F_{th} = axial-flow impeller thrust, [F]
g = acceleration of gravity, [L/t²]
g_c = gravitational constant, [ML/(Ft²)]

Force	Mass	g_c
N	kg	1 (kg/N)(m/s²)
lb_f	lb_m	32.17 (lb_m/lb_f)(ft/s²)
kg_f	kg	9.81 (kg/kg_f)(m/s²)
dyne	gram	1 (gm/dyne)(cm/s²)
lb_f	slug	1 ($slug/lb_f$)(ft/s²)

H = impeller height, [L]
h = heat transfer coefficient, [F/(LtT)]
I = moment of inertia, [L⁴]
I_A = electrical current, [A]
k = thermal conductivity, [F/(tT)]
k_L = mass transfer coefficient, [L/t]
k_La = specific mass transfer coef., [1/t]
L = shaft length (below bearing), [L]
L_B = baffle length, [L]
L_b = bearing spacing, [L]
L_f = motor loading fraction
L_i = shaft length to impeller, [L]
L_t = total shaft length, [L]
M_B = bending moment, [FL]
N = rotational speed, [rev/t]
N_c = critical speed (nat. freq.), [rev/t]
N_R = revolutions
n = scale-up exponent
O_D = shaft offset from diameter, [L]
O_W = shaft offset from wall, [L]
P = power, [FL/t]
P_f = electrical power factor
P_{In} = motor input power, [FL/t]
P_m = motor power, [FL/t]
P_p = impeller power (process), [FL/t]
P_w = impeller power in water, [FL/t]
p = propeller or helix pitch, [L]
Q = impeller pumping rate, [L³/t]
Q_g = gas volumetric flow rate, [L³/t]
R = radius, [L]
S = impeller spacing, [L]
S.G. = specific gravity
T = tank diameter, [L]
t = time, [t]
t_b = impeller blade thickness, [L]
t_d = disk thickness, [L]
TIR = total indicated runout, [L]
V = fluid volume, [L³]
v_t = terminal settling velocity, [L/t]
v_{ts} = impeller tip speed, [L/t]
W = impeller blade width (projected), [L]
W_a = impeller blade width (actual), [L]
W_i = impeller weight, [M]
w_s = shaft weight per unit length, [M/L]
X = mass fraction
Z = liquid depth, [L]

803.1 *Greek Letters*

α = blade angle, [deg]
α,β = propeller shaft angles, [deg]
δ = deflection of shaft at impeller, [L]
θ_b = blending time, [t]
μ = fluid viscosity, [M/(Lt)]
ρ = fluid density, [M/L³]
ρ_m = metal density, [M/L³]
ρ_p = process fluid density, [M/L³]

ρ_s = solid particle density, $[M/L^3]$
ρ_w = water density, $[M/L^3]$
σ = surface tension, $[F/L^2]$
τ = torque, $[FL]$

803.2 *Dimensionless Groups*

N_A	=	aeration number	=	$Q_g/(ND^3)$
N_{th}	=	axial thrust number	=	$F_{th}g_c/(\rho N^2D^4)$
N_f	=	fluid force number	=	$F_f g_c/(\rho N^2D^4)$
N_{Fr}	=	Froude number	=	N^2D/g
N_{Nu}	=	Nusselt number	=	hD/k
N_{Pe}	=	Peclet number	=	$c_p\rho ND^2/k$
N_P	=	power number	=	$Pg_c/(\rho N^3D^5)$
N_{Pr}	=	Prandtl number	=	$c_p\mu/k$
N_Q	=	pumping number	=	$Q/(ND^3)$
N_{Re}	=	Reynolds number	=	$D^2N\rho/\mu$
N_{Sc}	=	Schmidt number	=	$\mu/(\rho D_{AB})$
N_{Sh}	=	Sherwood number	=	k_LD/D_{AB}
N_{th}	=	thrust number	=	$F_{th}g_c/(\rho N^2D^4)$
N_{We}	=	Weber number	=	$\rho N^2D^3/(\sigma g_c)$
N_θ	=	blend time number	=	θ_bN

804.0 *Equations and Related Groups*

804.1 *Impeller Flow*
Discharge flow produced by an impeller can be estimated from empirical data for pumping numbers, see next section for some typical values:

$$Q = N_Q\, N\, D^3$$

Q = impeller pumping rate
N_Q = impeller pumping number
N = rotational speed
D = impeller diameter

804.1.1 English units

$$Q = 4.33\text{x}10^{-3}\, N_Q\, N\, D^3$$

Q [gal/min]
N_Q [dimensionless]
N [rev/min]
D [inches]

804.1.2 SI metric units

$$Q = 0.159\, N_Q\, N\, D^3$$

Q [m^3/s]
N_Q [dimensionless]
N [rad/s]
D [m]

804.2 *Power and Flow Numbers*
Some typical values of N_P and N_Q* for various impellers are provided for basic guidance. Because of design and application details a range of values may exist for each category. Interpretation of pumping number varies, and pumping capacities are a function of impeller to tank size.

	N_P	N_Q
Axial flow:		
Propeller 1 :1 pitch	0.3	0.4
1.5:1 pitch	0.8	0.6
45° pitched-blade turbine **		
4 blade (W/D = 0.15)	1.3	0.6
4 blade (W/D = 0.2)	1.7	0.8
Radial flow:		
Straight-blade turbine		
4 blade (W/D = 0.15)	3.2	1.1
4 blade (W/D = 0.2)	4.3	1.3
Disc turbine		
4 blade (W/D = 0.2)	5.4	1.4
6 blade (W/D = 0.25)	6.6	1.3

* Data assume turbulent flow with no significant wall interference effect. N_P is based on impeller power. N_Q is based on primary flow, rather than total induced flow.

** Width/diameter ratio is projected width divided by actual diameter.

High efficiency axial flow impellers are a major new class of impellers, however geometries vary significantly between suppliers. Power numbers between 0.1 and 1.0 and pumping numbers between 0.3 and 0.7 are possible.

805.0 *Calculation Examples*

805.1 *Power*
805.1.1 Wattmeter
A wattmeter is attached to a 100 HP electric motor driven mixer.

P_{In} = 90 kW Start-Up
P_{In} = 73 kW Steady State

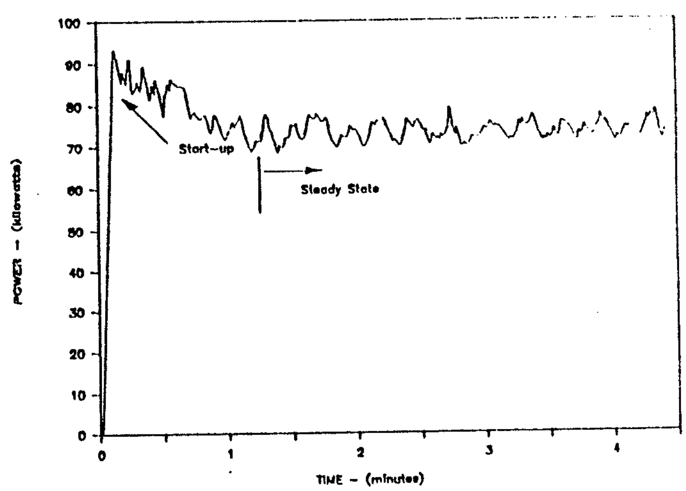


Fig. 805.1 Watt Meter Reading

805.1.2 Amp Probe and Volt Meter
Steady Operating Condition

I_A = 105 amps
E_V = 460 volts
P_f = 0.86
Three Phase Power

$P_{In} = 105 \times 460 \times 0.86 \times \sqrt{3}$
$= 71.9$ kW

805.1.3 Torque - Rotating Torque Cell
A 10,000 inch-pound capacity torque cell is mounted between the gear drive input and electric motor output shaft. Shaft speed was determined using a stroboscope and a mark on the motor output shaft.

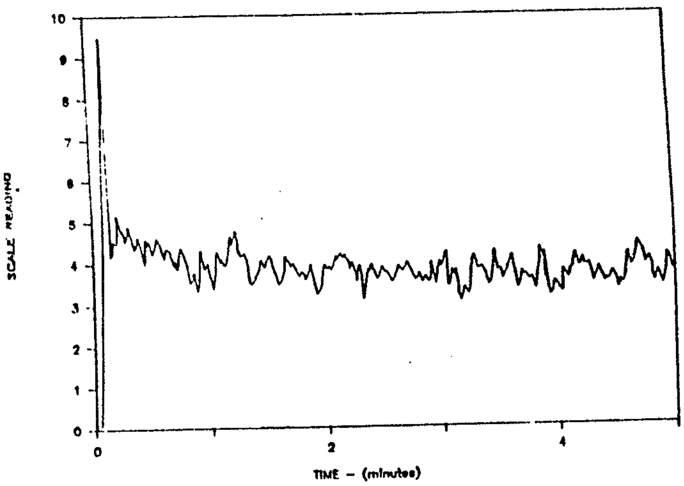


Fig. 805.2 Torque Cell Reading

NOTE: Unit is calibrated by inserting resister into bridge. Torque equivalent of reading as given by manufacturer: 6 units equivalent to 5000 in-lb_f

Start-Up: Reading = 4.9
Speed = 1743 rpm
τ = (4.9/6) x 5000 = 4083 in-lb_f
$P_m = 1.59 \times 10^{-5} \times 1743 \times 4083$
= 113 hp

Steady-State: Reading = 3.9
Speed = 1750 rpm
τ = (3.9/6)x5000 = 3250 in-lb_f
$P_m = 1.59 \times 10^{-5} \times 1750 \times 3250$
= 904 hp

805.1.4 Reaction Torque - Bearing Mounted
A small laboratory mixer is mounted on a low friction bearing. Restraining the rotation of the mixer is a lever arm attached to a force gauge. A 6 inch diameter turbine impeller is run at several different speeds in water. The speeds and force readings are to be used to calculate power and power number.

Lever Arm = 3.10 inches
Rotational Speed = N rpm
Scale Reading = F lb_f

Torque
$\tau = 3.10 \times F$ inch-pounds

Power (from Sec. 602.3.1)
$P = \tau N / 63025$
$= 3.10 \times F \times N / 63025$
$= 4.92 \times 10^{-5} N F$ (hp)

Power Number (from Sec 602.2.1)

$$N_P = \frac{1.52\times10^{13}\ P}{S.G.\ N^3\ D^5}$$
$$= 1.52\times10^{13}\ P / (1.0\ N^3\ 6^5)$$
$$= 1.95\times10^{9}\ P / N^3$$

N(rpm)	F(lb_f)	P(hp)	N_P
310	5.3	0.081	5.3
495	14.3	0.35	5.6
690	28.0	0.95	5.6

805.1.5 Steady State Power
Calculate the steady state mixer power based on the watt meter reading in Fig. 805.1 and the equipment shown in Fig. 805.3. The mixer consists of an electric motor, represented by the motor curve in Fig. 805.4, and a gear drive, represented in Fig. 805.5.

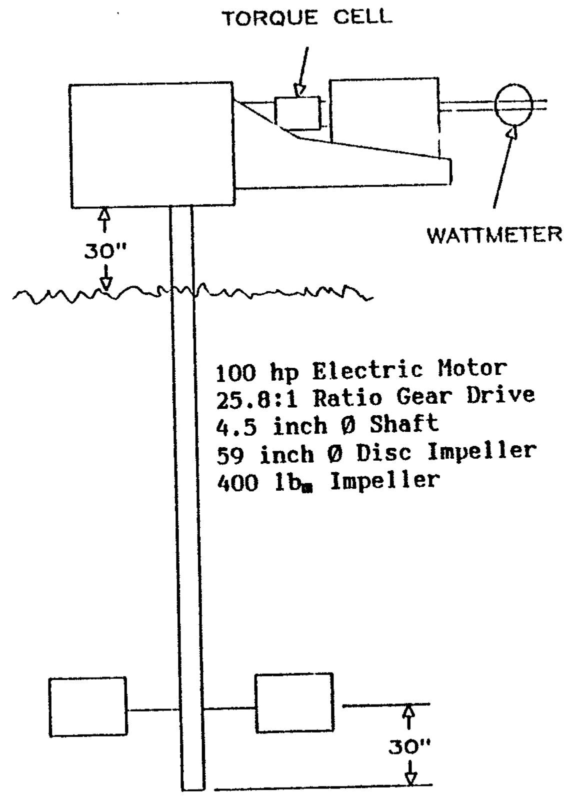
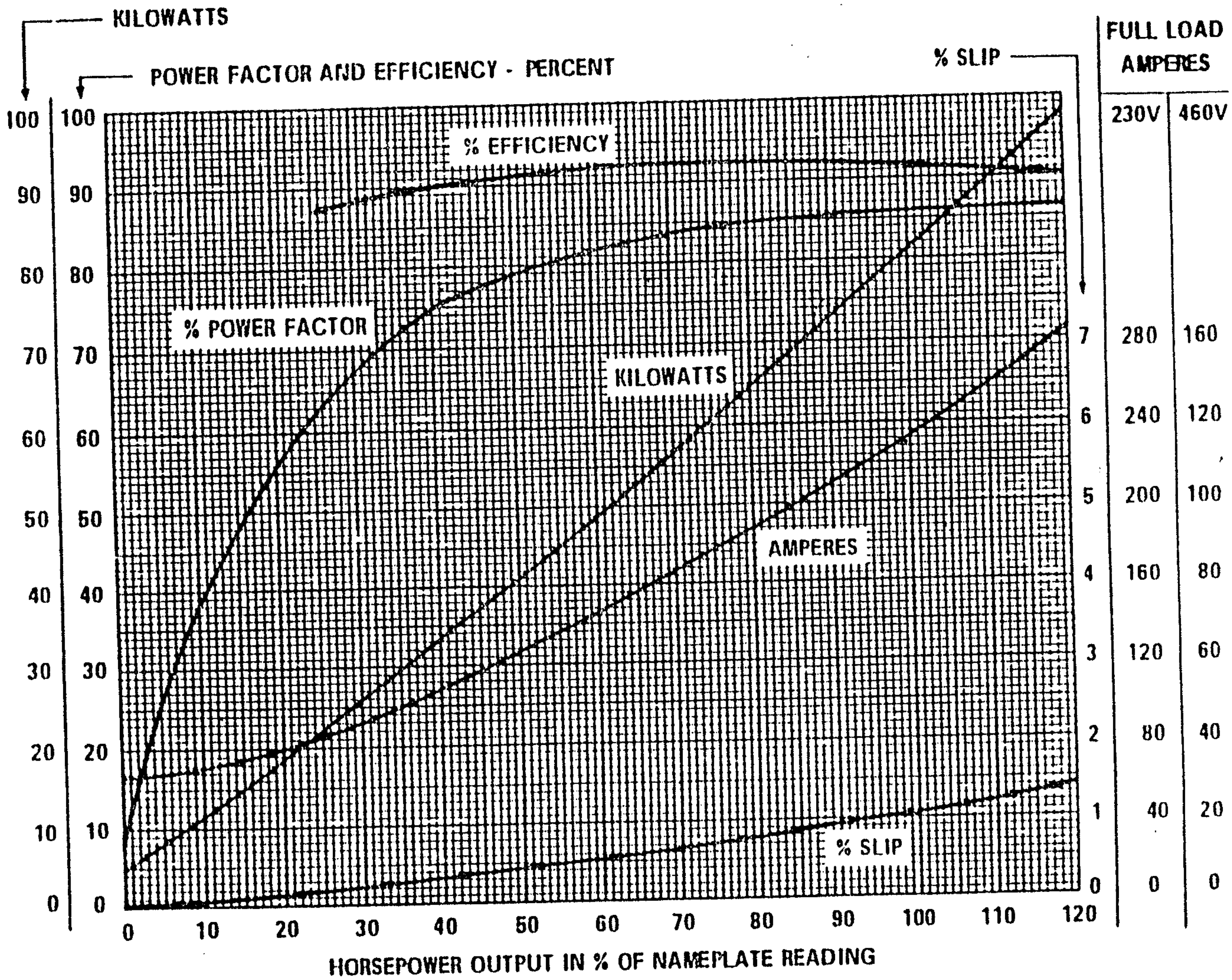


Fig. 805.3 Mixer for Sample Problems



COURTESY OF LOUIS ALLIS COMPANY

Fig. 805.4 Typical Motor Performance Curve
Horsepower 100 , Frame 405T , R.P.M. 1780 ,
Cycle 60 , Phase 3 , Volts 230/460 , Full Load Amps 234/117

P_{In} = 73 kW (Sec. 805.1.1)
P_m = 90 hp (Fig. 805.4)

Gear drive efficiency

$$E_m = \frac{90 - 6.5}{90} \quad \text{(Fig. 805.5)}$$
$$= 0.93$$

Mixer Power

$$P = 0.93 \times 90 \text{ hp}$$
$$= 83.5 \text{ hp}$$

805.1.6 Speed
While a tachometer or stroboscope is necessary to measure motor shaft speed, the output shaft speed on many mixers is low enough to count and time several revolutions. The following data shows a simple determination of rotational speed:

Rev	Time	rpm	(cps)
50	0:44.3	67.7	(1.13)
80	1:11.6	67.0	(1.12)
60	0:52.7	68.3	(1.14)

N = 67.6 ± 0.70

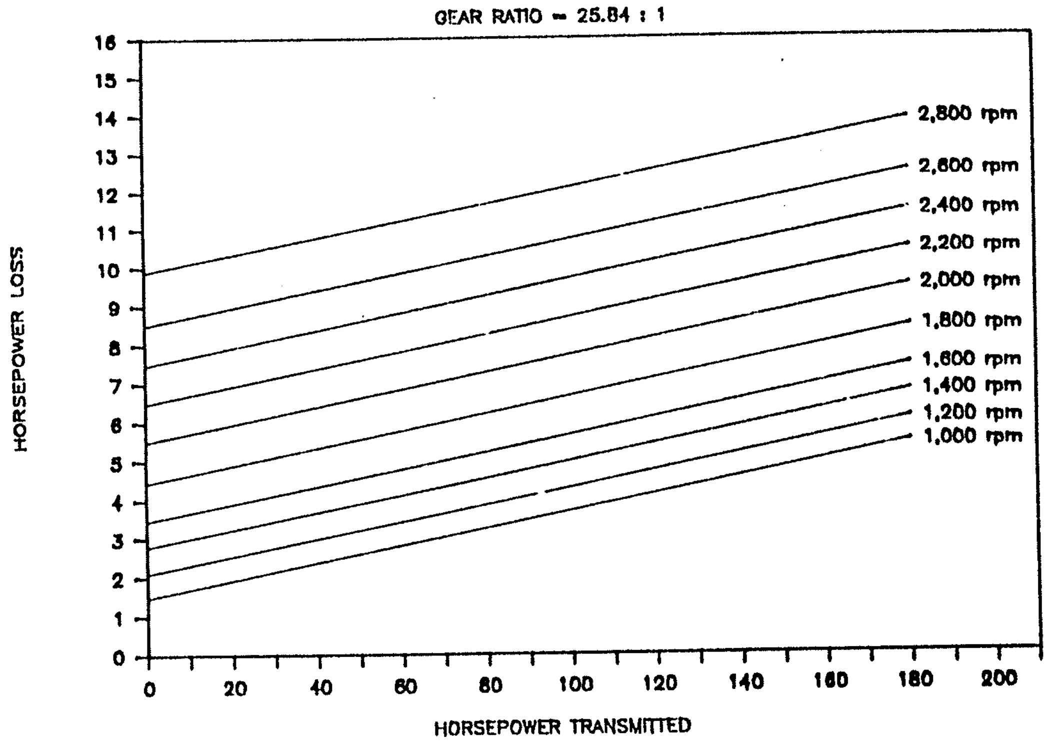


Fig. 805.5 Typical Power Loss for Agitator Drive

805.1.7 Theoretical Mixer Power
The mixing impeller is a 60 inch diameter, disk-style turbine operating at 67.6 rpm.

Reynolds Number (Sec. 602.1.1):

D = 60 inches
N = 67.6 rpm
S.G. = 1.0
μ = 1.0 cp

$$N_{Re} = \frac{10.7\ D^2\ N\ (S.G.)}{\mu}$$

$$= 2.6 \times 10^6$$

Thus the impeller is operating in the turbulent region. Reported power numbers range from 5.0 to 5.7. Rearranging the power number from Sec. 602.2.1:

$$P = 6.55 \times 10^{-14}\ N_P\ S.G.\ N^3\ D^5$$

Thus we would expect:

$$78.7 < P < 89.7$$

In Sec. 805.1.5 we calculated 83.5 hp to the mixer based on measured power and correcting for component efficiencies. The two values for impeller show excellent consistency.

For more information on power and power numbers, most complete references on mixing provide both standard and special values.

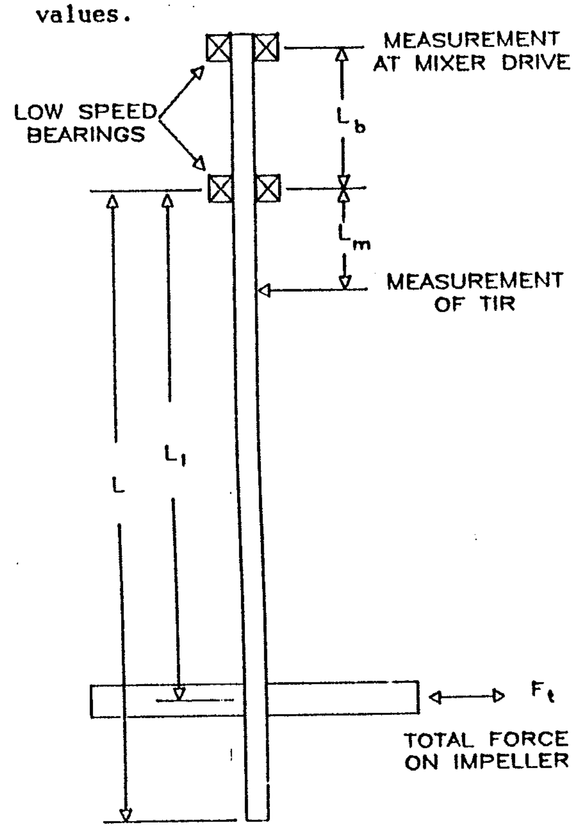


Fig. 805.6 Mixer Shaft for Sample Problems

805.2 *Mechanical*

805.2.1 *Dynamic Shaft Deflection*

A mixer vibration problem has been observed during commissioning. The important shaft dimensions are shown in Fig. 805.6.

Bearing Spacing, L_b = 24 inches
Overhung Length, L = 240 inches
Length to Impeller, L_i = 210 inches
Shaft Diameter, d = 4.5 inches
Impeller Weight, W_i = 400 lbs.

The vessel was filled with water for these tests. Dial gauge measurements were made for motion or runout (TIR) as follows:

1. Support structure - no flexure measurable.
2. Top of mixer - TIR = 0.010 inches. Mounting fasteners checked and retightened. No change in motion.
3. Mixer shaft: 15 inches below drive
   Static runout: TIR = 0.008 in.
   Dynamic runout: TIR = 0.160 in.

Rough estimate of deflection due to shaft dynamics is half the difference between dynamic and static runout:

$$(0.160 - 0.008)/2 = 0.076 \text{ inches}$$

805.2.2 Calculate the expected deflection caused by a 350 pound fluid force (F_f) and 1 inch runout. From Fig. 805.6, the equation for shaft deflection versus F_t at the impeller location is obtained. The point of measurement (L_m) is 15 inches below the lower bearing.

$$\delta = \frac{F_t L_m}{6\, E_Y I} (2\, L_i\, L_b + 3\, L_i\, L_m - L_m^2)$$

Modulus of Elasticity
$$E_Y = 28.5 \times 10^6$$

Moment of Inertia
$$I = \frac{\pi}{64} \times 4.5^4 = 20.13$$

Calculating for Lengths
$$\delta = 8.41 \times 10^{-5}\, F_t$$

Forces
Centrifugal force

$$F_c = (2\pi\, N/60)\, 2\, W\, \delta\, /\, g_c$$

Runout, δ = 1 inch
Impeller Weight, W = 400 lb_m
Speed, N = 67.6 rpm

$$F_c = 52 \text{ lb}_f$$

Centrifugal force due to runout at the impeller is a small factor compared with fluid forces.

The total force is at the impeller.

$$F_t = F_f + F_c = 350 + 52 = 402 \text{ lb}_f$$

Thus:

$$\delta = 8.41 \times 10^{-5}\, F_t = 8.41 \times 10^{-5} \times 402 = 0.034 \text{ inches}$$

Total indicated runout (TIR) is the sum of the runout at the measurement point plus twice the deflection. This multiplier of two accounts for deflections toward and away from the gauge.

$$TIR = 0.008 + 2 \times 0.033 = 0.074 \text{ inches}$$

The measured deflection (Sec. 805.2.1) is twice this value. Either fluid forces are far larger than predicted or there is a dynamic interaction between the shaft operating speed and the natural frequency.

805.2.3 A detailed physical inspection of the mixer of in this example revealed only one discrepancy with the drawing, Fig. 805.6. The impeller was located at the bottom of the shaft. The drawing called for a placement 30 inches from the bottom of the shaft. Runout was subsequently measured to be 1 inch at the impeller.

805.2.4 Calculate natural frequency for the impeller located at the bottom of the shaft and 30 inches from the bottom. For a constant diameter shaft, Fig. 805.6.

Natural Frequency

$$N_c = 37.8\, \frac{d2}{L} \frac{\sqrt{(E_Y/\rho_m)}}{\sqrt{W_e}\ \sqrt{(L + L_b)}}$$

where:

Shaft Diameter, d = 4.5 inches
Modulus of Elasticity, E_Y = 28.5x10⁶ psi
Metal Density, ρ_m = 0.284 lb_m/in^3
Shaft Length, L = 240 inches
Bearing Spacing, L_b = 24 inches

Equivalent Weight at End of Shaft (L)
$$W_e = W_i\, (L_i/L)^3 + w_s\, L/4$$

Impeller Weight, W_i = 400 lb_m
Shaft Unit Weight, w_s = 4.45 lb_m/in

Calculation for Impeller at Bottom of Shaft:

$$W_e = 400\ (240/240)^3 + 4.45\ (240/4)$$
$$= 400 + 267$$
$$= 667$$

$$N_c = 37.8 \quad \frac{4.5^2 \sqrt{(28.5x10^6/0.284)}}{240 \sqrt{667} \sqrt{(240+24)}}$$
$$= 76.1 \text{ rpm}$$

Operating Speed, $N = 67.7$ rpm

$$N/N_c = 67.6 / 76.1$$
$$= 0.89$$

With the shaft operating at 89% of critical, serious problems exist, and the high deflections are probably caused by this condition.

Calculation for Impeller 30 inches from the Bottom of Shaft:

$$W_e = 400\ (210/240)^3 + 4.45\ (240/4)$$
$$= 400\ (0.67) + 267$$
$$= 535$$

$$N_c = 37.8 \quad \frac{4.5^2 \sqrt{(28.5x10^6/0.284)}}{240 \sqrt{535} \sqrt{(240+24)}}$$
$$= 85.0 \text{ rpm}$$

Operating Speed, $N = 67.7$ rpm

$$N/N_c = 67.6 / 85.0$$
$$= 0.80$$

With the shaft operating at 80% of critical, a reasonable design condition exists.

The mixer was re-tested with the impeller properly located 30 inches from the bottom of the shaft, deflections measures 15 inches below the drive were as follows:

Static runout, TIR = 0.008 inches
Dynamic runout, TIR = 0.050 inches

Problems solved.

805.3 ***Liquid-Solid***

805.3.1 Nearly spherical particles of 120 micron (micrometer) diameter are to be suspended in a fluid of 0.008 Pa·s (8 cp) viscosity and 0.95 specific gravity. The absolute particle specific gravity is 3.2 (density of 3200 kg/m³). Estimate the terminal settling velocity of the particles from Stokes Law.

From Stokes Law, the terminal settling velocity (v_t) is calculated:

$$v_t = (\rho_s - \rho)\ d_p^2\ g\ /\ (18\ \mu)$$
$$= 0.0022 \text{ m/s} = 0.43 \text{ ft/min}$$

The Stokes Law correlation is accurate at particle Reynolds numbers below 0.1 and reasonably accurate between 0.1 and 1, which is based on the fluid viscosity and density and the particle diameter. For this example, the particle Reynolds number (N_{Rep}) is

$$N_{Rep} = d_p\ \rho\ v_t\ /\ \mu$$
$$= \frac{(0.00012\ m)(950\ kg/m^2)(0.0022 m/s)}{0.001\ Pa \cdot s}$$
$$= 0.031$$

Since this is less than 0.1, the Stokes Law correlation is valid.

806.0 *Sample Log Sheet*

The purpose of this log sheets is to provide a guide for recording of data required to conduct and analyze a performance test for specific mixing situations.

806.1 ***System Test Log***

A complete record of all conditions and operations performed during testing is essential. The results of some tests may have to be analyzed later.

806.2 ***Physical Description Sketch***

A complete sketch of the system, including variations in liquid levels, will frequently help identify potential problems.

807.0 *Scale-Up/Scale-Down*

The purpose of many mixing tests is to provide assistance with scale-up or scale-down of a process. Scale-up is the more common concern to produce production scale equipment. Scale-down, however, can be as large a concern. You need to do scale-down when you must design mixing tests prior to scale-up as you want to use pilot scale equipment that closely simulates production scale performance.

Different classes of mixing problems are controlled by different hydrodynamic regimes, and different types of correlations have been developed. No universally accepted procedures or correlations exist for handling scale-up tests. Below are some guidelines that have frequently been used. In addition it is highly recommended to contact personnel experienced in mixing processes and mixing scale-up for assistance.

807.1 ***Geometric Similarity***

During scale tests, it is often useful to maintain geometric similarity for all mechanical components between mixing systems, including:

807.1.1 Impeller style and number
807.1.2 Number and style of baffles
807.1.3 Geometry ratios such as impeller to tank diameter, fluid height to diameter, etc.

AGITATION TEST--GENERAL PROCESS LOG SHEET

Test Name ______________________________ Ident. No. ______________

Location ______________________________ Date ______________

Test Operator ______________________________

AMBIENT CONDITIONS Temp. __________ Bar. Pres. __________ Humidity ______

FLUIDS--MATERIALS

Material	Quantity	Sp. Gr.	Viscosity[1]	Other
Mixture				

1 If non-Newtonian, identify type and how viscosity was measured under Notes.
Solids--attach size distribution, sieve analysis, general description, lot number, et

VESSEL (Sketch total system to scale and show all relevant dimensions)

Diameter __________ Vessel height __________ Top/bottom heads ______________

Baffles number/size/location ______________________________

Inlets/outlets/coils/obstructions ______________________________

AGITATOR

Type/Model ____________________ Power __________ Output speed __________

Impellers number/type/size ______________________________

Impeller location ______________________________

OPERATING CONDITIONS

Temperature ______________ Pressure ______________ Flow ______________

Liquid Levels: Min. ____________ Normal ____________ Max. ____________

Liquid Volumes: Min. ____________ Normal ____________ Max. ____________

Describe mixing cycle on back.

TEST LOG

Time	Sample No.	Flow 1	Flow 2	Flow 3	Temp.	Agit. Speed	Power Drawn	Measured Results	Comments

807.3 *Scale Parameter*

A scale parameter should be selected, such as:

807.3.1 A linear dimension, such as vessel diameter for a circular cross-section vessel.

807.3.2 Vessel volume

807.4 *Correlating Process Parameters*

A process parameter must be selected to use in scale-up. Measurements of it can be made and correlations produced. These parameters will be appropriately modified and not necessarily kept constant on scale-up. With proper mathematical manipulations, correlations can frequently be changed from one process parameter to another.

It should be noted that in scale-up or scale-down, it is impossible to keep all parameters constant so you must determine which parameters is most important to you. Assistance from an experienced mixing expert is helpful in selecting which parameter to use.

Frequently used correlating parameters include:

807.4.1 Power per volume - P/V

807.4.2 Torque per volume - τ/V

807.4.3 Impeller tip speed - ND

807.4.4 Bulk fluid velocity or velocity at a point

807.4.5 Arbitrary combinations of basic variables, such as:

$$N^{x_1} D^{x_2} T^{x_3}$$

807.5 *Correlating Conditions*

When a scale test is being run, you have to define what conditions are to be compared (remain constant) to determine when equal performance is reached. Many such conditions exist, depending on the process needs. Examples of potential correlating conditions are:

807.5.1 A visual or measured degree of uniformity.

807.5.2 A visual or measured degree of solids suspension.

807.5.3 A gas dispersion rate or superficial gas velocity.

807.5.4 A desired blend time.

807.5.5 A fluid velocity measured at a significant point in the vessel.

807.5.6 The type of surface motion.

807.5.7 A reaction rate or rate coefficient.

807.5.8 A standard fluid against which other produced fluids may be compared in quality.

807.6 *Mixing Correlation*

Usually the end result of the scale test is a scale equation. The testing necessitates evaluating the form of the correlation and determining the value of appropriate scale factors (x_1, x_2, x_3). Scale equations can take various forms including:

$$(P/V)_2 = (P/V)_1 (T_2/T_1)^{x_1}$$

$$N_2^{x_1} D_2^{x_2} T_2^{x_3} = N_1^{x_1} D_1^{x_2} T_1^{x_3}$$

$$(\tau/V)_2 = (\tau/V)_1 (V_2/V_1)^{x_1}$$

$$N_2 = N_1 (D_1/D_2)^n$$

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808.13.15 Scale-Up of Equipment for Agitating Liquids
808.13.16 Mixing of Particulate Solids

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