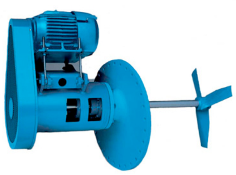
Hayward Gordon

MASTERING MIXING FUNDAMENTALS

A technical guide from the experts in the industry

2019

Technical Guide



Hayward Gordon has supplied impeller type fluid agitation equipment to the process industries for over 40 years acquiring considerable expertise in this field. Combining both experience and theory, this section covers the basics of fluid mechanics of mixing, the main criteria for mixer sizing and application limitations of fluid mixers.

Fluid Mixing

Technically, matter in the liquid or gas state is considered a fluid. For the purposes of “fluid mixers”, a fluid is defined as a liquid (or mixture of liquids), which may contain modest amounts of solid particles or gas bubbles. The presence of solids or gas must not alter the basic capacity of the fluid to “flow” and be pumped about in the mixing vessel by a mixing impeller.

A liquid must always be present, either “thin” with a water-like viscosity or “thick” with a relatively high viscosity. The thickest liquid that can be handled with a fluid mixer will typically have a viscosity less than 500,000 centipoise.

The simplest and most common fluid mixing application is simply to add liquid “A” to liquid “B”, where the liquids are soluble in one another, and blend them to uniformity. Application requirements can include the time available to mix the liquids and the degree of uniformity to which they must be mixed.

The second most common mixing application is the suspension of solid particles in a liquid. This can be for the purpose of dissolving the solids, leaching out valuable components in the solids, allowing the solids to participate in a chemical reaction with the liquid, or simply to keep the solids in suspension. The typical maximum concentration of solids which can be effectively mixed with a fluid mixer is 70-75% solids by weight.

Other functions of fluid mixers include dispersion of a gas into a liquid, dispersion of insoluble liquids into one another and heat transfer applications.

Mixing impellers are designed to “pump” fluid through the impeller and produce “turbulence” - both of these effects are essential to mixing. They produce “fluid velocity” and “fluid shear” respectively. Fluid velocity produces movement throughout the mixing vessel, intermixing material in one part of the tank with another, prevents solids from settling out and produces flow over heating or cooling coils when necessary. Fluid shear, in the form of turbulent eddies, is essential to micro-mixing within the large velocity streams breaking up gas bubbles or immiscible liquids into small droplets.

All mixing impellers produce both fluid velocity and fluid shear, but different types of impellers produce different degrees of flow and turbulence, either of which may be important, depending on the application.

Fluid Mechanics of Mixing

All impellers produce two results within the mixing chamber: circulation of fluid and fluid shear. The power "P" consumed by an impeller is related to the volumetric circulation rate "Q" (pumping capacity) and the velocity Head "Delta H" from the impeller by:

$$P = Q\rho\Delta\mathrm{H}$$

The pumping capacity of an impeller is defined as the volumetric flow rate normal to the impeller discharge area. The pumping capacity of an impeller is proportional to its diameter and speed:

$$\mathrm{Q}\,\alpha\,\mathrm{ND}^3$$

The head difference between the "suction" and "discharge" surfaces of an impeller blade results in fluid shear, which is also proportional to impeller diameter and speed:

$$\Delta\mathrm{H}\,\alpha\,\mathrm{N}^2 D^2$$

In general form:

$$\mathrm{P}\,\alpha\,\rho(ND^3)(N^2D^2)$$

$$\mathrm{P} = \kappa\rho(ND^3)(N^2D^2)$$

$$\mathrm{P} = \kappa\rho(N^3D^5)$$

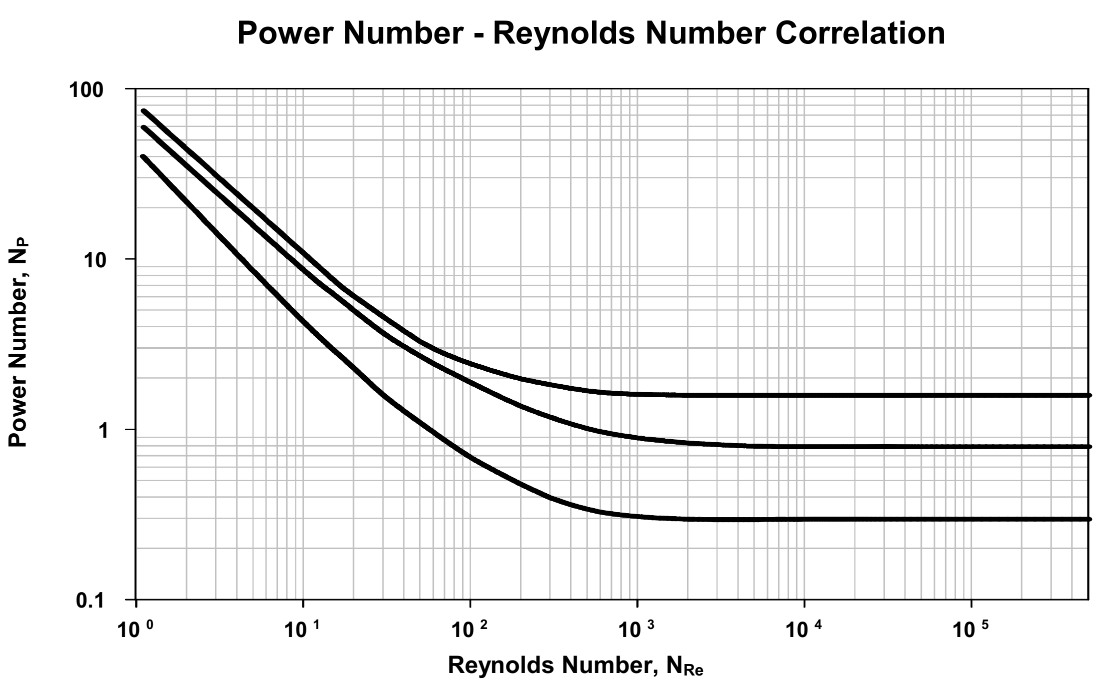
This development illustrates one of the basic principles of fluid mixing: for a constant horsepower, as impeller size increases, more power is expended on flow and less on shear. A large impeller running at a slow speed produces high pumping and low shear. Conversely, a small impeller running at high speed produces relatively low pumping capacity and high fluid shear.

Some process, such as flocculation, are shear sensitive and require high flow, low shear mixing. Other processes, such as gas dispersion, are at the other end of the scale and require high shear mixing. The selection of a mixer for a particular application depends on numerous process factors, some of which are:

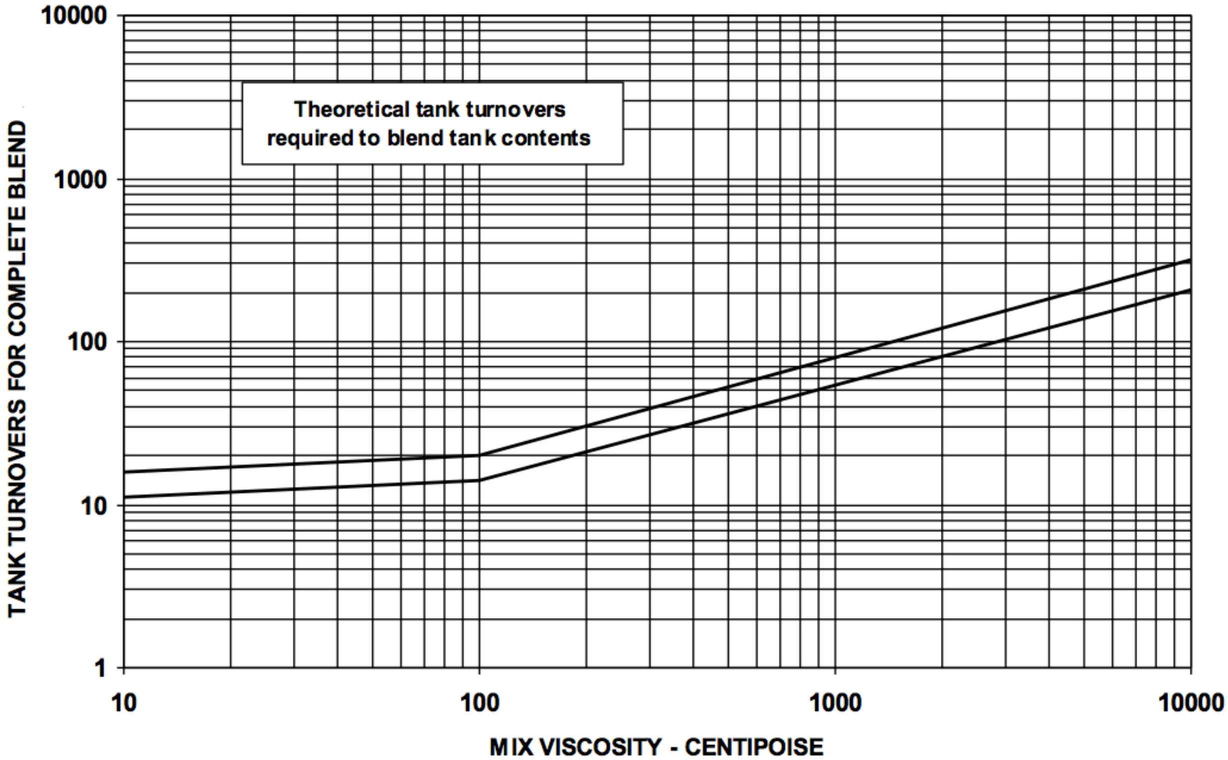
- Type of application (high flow or high shear requirements)
- Viscosity, % solids, amount of gas addition
- Tank Geometry
- Retention time and/or blend time

Viscosity Effect

The previous equations show the effect that a fluid's density has on the power draw of a mixing impeller. The next most common factor affecting power draw is viscosity. The graph below shows the relationship between viscosity and a mixing impellers power response - power draw increases with increasing viscosity. Every impeller has a Power Number vs. Reynolds Number curve similar to the one show below. The straight line portion at the left hand side is the laminar range which develops into the transition range and finally reaches a plateaus at a constant power number in the fully turbulent range. Power numbers of various impellers are normally compared in the fully turbulent range which typically starts at $N_{Re}=10^3$ to 10^4.



The viscosity of a fluid can have a significant impact on the overall mixer sizing for a particular application. The graph below shows the relative increase of theoretical tank turnovers for viscosities from 10 to 10,000 cps.



Basic Essentials of Mixer Sizing

The main sizing criteria for most applications are:

- Torque Invested into the Mix
- Impeller Style
- Impeller Diameter to Tank Diameter (D/T) Ratio
- Mixer Horsepower
- Pumping Capacity
- Impeller Tip Speed
- Superficial Velocity
- Torque/Equivalent Volume

Torque

In order for power (the rate at which work is done) to be meaningful there must be a standard of comparison. The most common unit to measure linear force is horsepower which is defined as the energy to move 100 pounds 330 feet in 1 minute or 33,000 Ft-Lbs/Min.

Mechanical transmission products, such as gearboxes, are evaluated on the basis of torque or rotational energy. Rotational power is defined as force times angular velocity. The angular velocity of a mixing impeller is normally measured in revolutions per minute (RPM).

The amount of torque applied to a fluid mix is one of the most important factors in determining mixing results. Using the most common units, torque is defined as:

$$Torque = \frac{HP \times 63025}{RPM} \quad [inch - lbs]$$

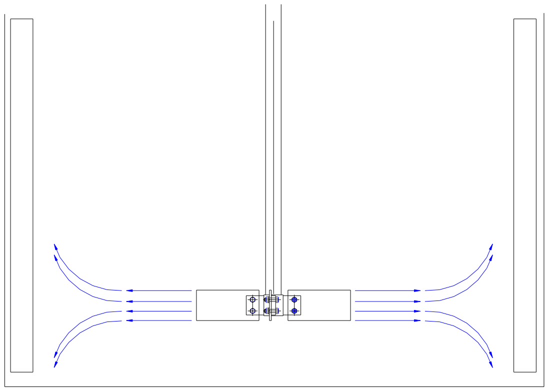
As can be seen from the equation, at a given horsepower, a relatively high mixer speed and small impeller diameter will result in lower torque (and therefore a lower mixing level) than a larger impeller turning at a lower speed.

Impeller Styles

Mixing impellers fall into one of two categories: Radial Flow or Axial Flow.

Radial flow impellers have multiple flat blades mounted parallel to the axis of the mixing shaft. The blades can be attached to a disc forming a “closed” impeller or on a simple hub making an “open” style impeller. Typical uses are gas/liquid dispersion, liquid/liquid dispersion, flash mixing and low level mixing applications.

Axial flow impellers have blades which make an angle of less than 900 with the mixing shaft axis. These impellers are further classified as A) constant angle of attack or B) variable angle of attack. The first group includes pitched blade turbines and the second group includes propellers and hydrofoils. Typical applications include simple blending, solids suspension and flocculation.



Radial Flow Turbines

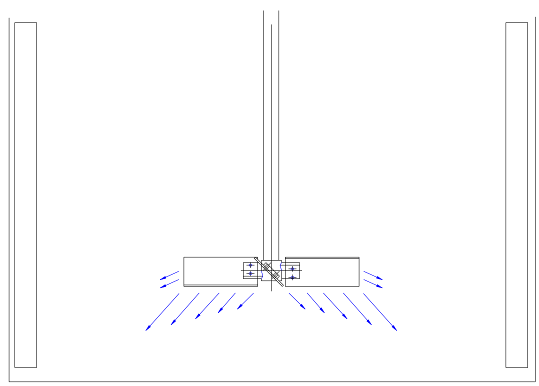
Power Number, N_P = 2.5 to 4.75
Pumping Number, N_Q = 0.95 to 1.23

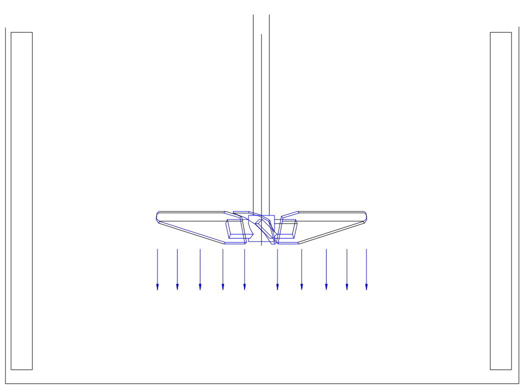
Applications:
- High Shear
- Gas\Liquid Dispersion
- Liquid Liquid Dispersion
- Low Level Mixing

Pitched Blade Turbines
(Constant Angle of Attack)

N_P = 0.9 to 1.62
N_Q = 0.68 to 0.86

Applications/Uses:
- Moderate Shear & Moderate Flow
- Moderate Viscosity Mixing
- High Intensity Mixing for Flow Dependent Applications
- Inexpensive "Axial Flow" Impeller





Low and Mid Solidity Hydrofoils
(Variable Angle of Attack)

N_P = 0.3 to 0.6
N_Q = 0.6 to 0.7

Applications/Uses:
- High Flow & Low Shear
- Low to Moderate Viscosities
- Limited Gas Dispersion for High Solidity Design
- Positioned Relatively High off Tank Bottom

Impeller Diameter/Tank Diameter (D/T) Ratio

The impeller diameter to tank diameter ratio typically falls in the range of 0.25 to 0.4. The low end of the range is used for waterlike viscosities and increases as the mixture viscosity increases. Refer to page 2.07 for optimum D/T ratios for various viscosities.

Horsepower

Although horsepower on its own is not enough to define the size of a mixer for most (flow sensitive) applications to ensure a certain process result, it is still an important consideration. Some applications, such as gas/liquid or liquid/liquid dispersions are quite sensitive to the HP invested.

The equation to determine the power draw of one impeller is:

$$BHP = \frac{N_P D^5 N^3 SG}{6.124 \times 10^7}$$

Where:
N_P = Impeller Power Number [Dimensionless]
D = Impeller Diameter [Feet]
N = Impeller Speed [RPM]
SG = Fluid Specific Gravity

And: N_P is adjusted for viscosity, proximity, blade width and number of blades.

Primary Pumping Capacity (Q)

The equation below calculates the Primary pumping capacity of one impeller and does NOT include entrained flow. Total flow (Primary + Entrained) is often considered to be 2.5 to 3 times greater.

$$Q = 7.48\, N_Q N D^3 \, [USGPM]$$

Where:
N_Q = Pumping Number [Dimensionless]
D = Impeller Diameter [Feet]
N = Impeller Speed [RPM]

Tip Speed (TS)

Impeller tip speeds are normally in the range of 400 to 1500 FPM. Tip speed is a more important criteria for some applications than others, ie. flocculation or dispersion.

$$TS = \pi D N \ [FPM]$$

Where: D = Impeller Diameter [Feet]
N = Impeller Speed [RPM]

Superficial Velocity (SV)

Normally used for solid suspension applications and compared to the settling rate of the solid in question. Superficial Velocity is calculated using the following equation:

$$SV = \frac{Q}{7.48\,A} \ [FPM]$$

Where: Q = Pumping Capacity [USGPM]
A = Tank Cross Sectional Area [Ft^2]

Torque per Equivalent Volume (TQ/Eq V)

This is an extremely useful ratio which is the basis for all Hayward Gordon mixer sizing and describes the level of mixing for any application.

$$\frac{T_Q}{Eq\,V} = \left(\frac{\frac{BHP \cdot 63025}{N}}{SG\,V} \right) [in - lbs / Eq.Vol]$$

Where: V = Working Volume of Tank [USG]
SG = Fluid Specific Gravity

Equation Summary

Impeller Diameter (ft)

$$D = \left(\frac{6.12E7 \cdot HP \cdot 0.85}{SG \cdot N_P \cdot N^3} \right)^{0.2}$$

Torque per Equivalent Volume (in-lbs/Eq. Vol)

$$\frac{T_Q}{Eq\,V} = \left(\frac{\frac{BHP \cdot 63025}{N}}{SG \cdot V} \right)$$

Impeller Power Draw (HP)

$$BHP = \frac{N_P D^5 N^3 SG}{6.124 \times 10^7}$$

Superficial Velocity (FPM)

$$SV = \frac{Q}{7.48\,A}$$

Pumping Capacity (usgpm)

Single Impeller

$$Q = 7.48\, N_Q N D^3$$

Dual Impellers

$$Q = 1.8 \cdot Single\,impeller$$

Equivalent Tank Diameter (ft)

Used to determine equivalent tank diameter of square or rectangular tanks

$$T_{Eq} = 1.13 \sqrt{L \cdot W}$$

Impeller Tip Speed (fpm)

$$TS = \pi D N \,[FPM]$$

Velocity Gradient (sec^{-1})

$$G = 444 \sqrt{\frac{BHP \cdot 1000}{V \cdot \mu}}$$

Where:

D is Impeller Dia in [Feet]
N is Impeller Speed [RPM]
Q is Pumping Capacity [USGPM]
HP is Nameplate Horsepower

T is Tank Dia in [Feet]
V is volume in [US Gal]
BHP is Brake Horsepower
T_Q is Torque [In-lbs]

POWER & PUMPING NUMBERS OF VARIOUS IMPELLERS

Axial & Radial Flow Impellers

Impeller Style	N_P	N_Q
4PBT45	1.62	0.86
4PBT32	1.0	0.71
4RBT90	3.60	1.10
4RSB90	2.52	0.95
6RD90	4.75	1.23
6RDC90	3.20	1.50

Hydrofoil Impellers

Impeller Style	N_P	N_Q
4HP45	CONTACT FACTORY	
3AL45		
3AL39		
3AM45		
3AH39		
4AH45		

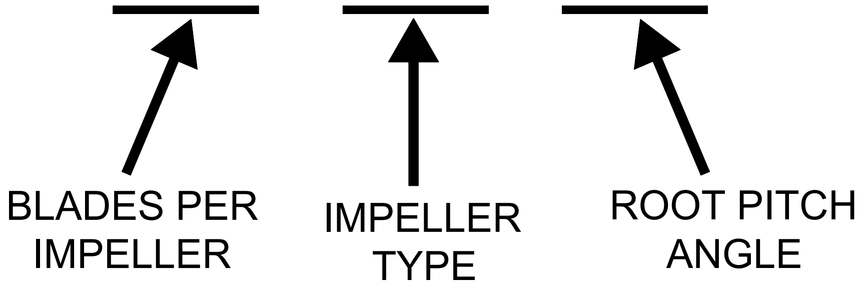
Notes

Power numbers assume fully baffled vessels with water-like fluid and proximity correction factors (off bottom and multiple impellers) of 1.0.

Pumping numbers allow calculation of the primary pumping capacity only, entrained flow is often considered to be 2.5 to 3 (or more) times greater. Pumping numbers assume Impeller Diameter to Tank Diameter ratio (D/T) is 0.33. The N_Q values given can be modified for different D/T ratios in the range of 0.2 to 0.45 by using the following equation:

$$N_{Q_R} = \left(\frac{D/T}{0.33} \right)^{-0.1} N_Q$$

Impeller Legend



AXIAL FLOW IMPELLERS

Designation	Key	Examples
AL	**A**xial Flow, **L**ow solidity	3AL39, 3AL45
AM	**A**xial Flow, **M**id solidity	3AM39, 4AM45
AH	**A**xial Flow, **H**igh solidity	3AH39, 3AH45
HP	**H**igh Efficiency **P**BT	4HP45, 3HP39
PBT	**P**itched **B**lade **T**urbine	4PBT45, 3PBT32

RADIAL FLOW IMPELLERS

Designation	Key	Examples
RBT	**R**adial **B**lade **T**urbine	4RBT90, 6RBT90
RD	**R**adial **D**isk	6RD90, 4RD90
RDC	**R**adial **D**isc **C**oncave Blade	6RDC90
RSB	**R**adial **S**wept **B**ack	6RSB90, 4RSB90

Glossary

Agglomeration - The combining of finely dispersed particles into larger particles, usually caused by a re-arrangement of surface forces resulting from a change of environment. (Opposite of Dispersion)

Axial Flow - Fluid flow directed axially along the mixer shaft, from top to bottom (down-pumping) or from bottom to top (up-pumping).

Baffles - Structure (normally flat plate) mounted vertically on the tank straight sides (can also be used in bottom heads and cones) to direct the flow vertically in the tank, preventing swirl and vortexing. [Section TG1-06]

Bending Moment - The product of force times distance. Fluid forces are exerted on a mixer shaft at each impeller. This force times the distance the impeller is located from the lower bearing of the drive creates bending moment. [Section TG1-08]

Bearing Life - Bearing life is most often reported as L-10 life, which is the number of hours of operation under a given set of load conditions during which a bearing has a 10% chance of failure. The L-10 life is about one-fifth of the average life.

Blending - Mixing two or more miscible liquid components to a specified level of uniformity. [Section TG1-02]

Consistency - The resistance of a fluid to deformation when subjected to shear stress; usually synonymous with Viscosity.

Coverage - The distance between the impeller and the liquid surface. Insufficient coverage can cause vortexing and air entrainment.

Critical Speed - A rotational speed equal to one of the natural frequencies of the shaft and impeller system. Operating at or near a critical speed will amplify vibrations possibly leading to shaft failure. [Section TG1-08]

Crystallization - Formation of a solid phase from a liquid solution (Opposite of Dissolving).

Density - The mass per unit volume of a substance. See Specific Gravity.

Dilatant Fluid - A material in which the apparent viscosity increases with increasing shear stress. (Opposite of Pseudoplastic).

Dispersion - A two-phase system in which one phase is broken into discrete particles which are completely surrounded by the second phase. Particles may be solid, liquid, or gas. For Mixing purposes the second phase is generally a liquid.

Dissolving - A change of phase from solid to liquid by combining with a liquid solvent. (Opposite of Crystallization).

Draft Tube - A hollow stationary cylinder mounted concentrically in the vessel with a mixing impeller mounted in, above or below it to promote increased vertical fluid flow during agitation.

Dry Well - A sleeve around the output shaft of a drive unit to prevent leakage of the gear lubricant down the shaft.

D/T - The ratio of impeller diameter (D) to tank diameter (T).

Emulsion - A colloidal dispersion of two or more liquids which are immiscible with each other. See Dispersion.

Entrainment - The result of the drawing force produced by a flowing fluid which drags additional fluid (entrained flow) or air (air entrainment) along with the pumped fluid.

Equivalent Volume - The product of vessel volume and the final liquid or slurry specified gravity.

Extraction - A process involving material transfer from one phase to another.

Flash Mixer - An agitator used to mix a small amount of additive into a continuous stream where the Residence Time is extremely short. It most often refers to addition of chemicals which cause or aid Flocculation in water or waste treatment operations. [Section TG2-02]

Flocculation - A mixing process whose object is to cause fine particles to collide and/or Agglomerate to larger sizes or to adhere to larger particles so they can more easily be separated from the liquid. [Section TG2-03]

Flooding - In gas-liquid mixing, an accumulation of gas which collects within the Impeller, reducing liquid circulation to a small fraction of normal, and thereby reducing mixing effectiveness. It can also occur when air is drawn into the liquid from the surface, either from Vortexing or accompanying solids which are being wetted.

Foot Bearing - See Steady Bearing

Freeboard - The distance from the liquid surface to the top of the tank.

Gear Types:

> **Spiral Bevel Gears** - Spiral bevel gears have teeth which are curved and oblique, used to transmit power in gearboxes with intersecting (right angle) shafts. Most efficient gearing for right angle drives with quiet and smooth operation.
>
> **Helical Gears** - A gear with teeth on an angle (typically 20-25°) to the axis of rotation, used to transmit power in gearboxes with parallel or non-intersecting shafts. The most efficient type of gearing commercially available for mixer drives.

Worm Gears - A gear used for obtaining large speed reduction between non-intersecting shafts whose axis are at a 90 degree angle from each other. A less expensive type of gearing than helical or spiral bevel but much less efficient.

Hindered Settling - Behavior of a Slurry having a high frequency of particle collisions, evidenced by reduced Settling Velocity. Generally, it becomes noticeable at solids concentrations above 35-40% by weight, but may occur at much lower concentrations if the particles are extremely fine or highly irregular in shape. [Section TG1-03]

Hold-up - In gas-liquid mixing, the increase in batch volume over the liquid volume, resulting from the gas which is Dispersed into the liquid.

Impeller - The portion of the agitator imparting force to the material being mixed. Propellers, Hydrofoils, Turbines, Gates, Anchors, and Paddles are all types of Impellers. [Section TG1-05]

Impeller Blade - One of the vanes on any type of Impeller, sometimes mis-used to indicate the entire Impeller.

Laminar Flow - Fluid flow characterized by long, smooth flow currents, mainly in the same direction as the bulk of the flow with little interaction between them. See Turbulent Flow.

Newtonian Fluid - A fluid whose rate of flow is proportional to the stress applied to it. The Viscosity is therefore constant and independent of shear stress.

Non-Newtonian Fluid - A fluid whose rate of flow is not proportional to the stress applied. The Viscosity is variable and may increase or decrease with stress, with time, or with a combination of both. See also Pseudoplastic, Thixotropic, Dilatant.

Pitch - The angle the blades make with a horizontal plane.

Power Number - A number which characterizes the power response of a particular impeller geometry. [Section TG1-01]

Propeller - A two, three or four bladed Axial Flow Impeller, having helically shaped blades.

Proximity Factor - A correction factor used in Impeller power calculations to allow for geometric variations, such as Impeller-to-tank bottom distance, Impeller-to-liquid surface distance, multiple Impeller spacing, etc.

Pumping Number - A number which characterizes the pumping capacity of a particular impeller geometry.

Pumping Capacity - The volumetric discharge rate of an Impeller operating at a given speed. Primary Pumping Capacity includes only the fluid that actually travels through the impeller, Total Pumping Capacity includes entrained flow. [Section TG1-01]

Radial Flow - Fluid flow from the tank center to the walls. Impellers that draw from above and below and discharge it towards the tank wall, perpendicular to the mixer shaft, are radial flow impellers. [Section TG1-05]

Rapid Mixer - See Flash Mixer.

Residence Time - The average time a process component remains in the mixing environment in a continuous process.

Reynolds Number - A dimensionless number used to characterize fluid flow data. The ratio of inertial to viscous forces.

Scrapers - Flexible or hinged members attached to the outer periphery of an Anchor Impeller to scrape the vessel wall, preventing buildup and improving heat transfer.

Service Factor (Gearbox) - The service factor of a gear drive is defined as the lowest AGMA mechanical power rating (strength or durability) of any pinion or gear in the drive divided by the nameplate power of the motor.

Settling Velocity - The velocity attained by a particle freely falling in a fluid due to gravity. See Terminal Settling velocity and Hindered Settling. [Section TG1-03]

Slinger - A device attached to a shaft above the liquid level to prevent the liquid from climbing or splashing up.

Slurry- A mixture of liquids and insoluble solids; ie. Solid Suspension.

Solid Suspension - A mixture of an insoluble solid material in a liquid. There are numerous degrees of suspension used in mixing such as: Just Suspended, Off Bottom, and Moderately Uniform

Solids Wetting - Dispersing solid particles so that a liquid film coats each particle.

Sparger - Pipe(s), pipe rings or cones for introducing a gas below the liquid surface in a tank; most often located below the Impeller.

Stabilizer - A device attached to an Impeller which directs the fluid flow pattern generated by rotation so as to dampen shaft deflection. The two most common forms of stabilizers are fins (flat plates attached to the individual impeller blades) and stabilizer rings (pipe section normally attached to the bottom of the impeller blades).

Steady Bearing - A radial shaft support bearing mounted in the vessel bottom used to reduce deflection in long shaft installations. Sometimes called a "foot bearing".

Superficial Velocity - An average velocity value used in computations of fluid flow due to the complexity of velocity distribution in the system. Usually encountered in gas-liquid systems, where it is the volumetric flow-rate divided by the cross sectional area of the tank. [Section TG1-01]

Swirl - the rotation of a liquid about an agitator shaft where little relative motion within the liquid is obtained.

Thixotropic - A material whose Viscosity drops gradually even at a constant shear stress, as opposed to materials whose viscosity changes instantaneously with changing shear stress. When shear stress is removed, viscosity of Thixotropic materials gradually increases again. These materials may also be Pseudoplastic or Dilatant.

Torque - The torsional moment exerted by a body (such as an Impeller) rotating at constant speed.

Turbine - A multi-bladed impeller (usually three to six blades).

Liquid Seal - Also referred to as a manometer seal. A liquid "trap" around a shaft to prevent vapor leakage from the vessel, used only in very low pressure systems.

Viscosity - The measure of resistance of a fluid to flow when a force is applied to it. Water at room temperature (20°C) has a viscosity of one centipoise.

Viscosity Factor - The correction factor applied to standard Impeller power draw to account for the difference caused by high liquid Viscosity.

Vortex - A depression occurring in a liquid surface when an agitator Swirls the liquid; a whirlpool.

Water Horsepower - The standard brake horsepower an Impeller will draw when operated in a waterlike liquid (viscosity =1 centipoise, Specific Gravity = 1.0) under standard conditions of Baffling and geometrical arrangement.

Nomenclature

Symbol	Definition	Typical Units
A	Tank Cross Sectional Area	ft^2
BHP	Brake Horsepower	HP
D	Impeller Diameter	inches
G	Velocity Gradient	ft/sec/ft or s^{-1}
HP	Motor Nameplate Horsepower	HP
L	Tank Length	feet or inches
μ	Viscosity at Design Temperature	cps
N	Impeller Speed	RPM
N_P	Impeller Power Number	Dimensionless
N_Q	Impeller Pumping Number	Dimensionless
N_{RE}	Reynolds Number	Dimensionless
Q	Impeller Primary Pumping Capacity	US GPM
ρ	Density	lbs/ft^3 or kg/m^3
SG	Specific Gravity	Dimensionless
SV	Superficial Velocity	ft/min
T	Tank Diameter	feet or inches
T_{EQ}	Equivalent Tank Diameter	feet or inches
T_r	Hydraulic retention time	minutes or seconds
T_Q	Torque	in-lbs
V	Tank Volume	US Gallons
W	Tank Width	feet or inches
Z	Liquid level in Tank	feet or inches

Blending

This section deals with blending of miscible fluids. If left for a long enough period of time, miscible liquids will dissolve in one another and form a homogeneous solution. The majority of liquid/liquid blending applications fall into this category. Applications involving immiscible (insoluble) fluids are classified as dispersion applications which involves very different mixer sizing methods.

The selection procedure is valid for blending operations in fully baffled, vertical cylindrical tanks with fluid viscosities up to 50,000 cps. Higher viscosity applications and other tank configurations may require different sizing techniques.

This procedure introduces the main criteria used for mixer sizing in blending applications. In addition, working through the following steps will allow the individual to better understand some of the calculations preformed by our Mixing Assist computer program.

Step 1

Complete the Application Data Form found on page 2.20; this will ensure that all pertinent information required for a mixer selection is available.

Step 2

Use the Mixer Sizing Work Sheet (Pg. 2.21) and the basic mixer equations found in Section TG1 to calculate the following:

- Calculate an equivalent volume, this is equal to the batch volume multiplied by the fluid specific gravity.
- Determine the Mixing Intensity Level required using the descriptions on Pages 2.03-2.05. Check to see if the application falls within the Portable Mixer range - Pg. 2.08. If so, select the mixer from this chart, otherwise proceed to the next step.
- Determine the number of impellers required and their optimum position by referring to the chart on Pg. 2.06.
- Using the guidelines on Pg 2.07, determine initial Impeller Diameter to Tank Diameter (D/T) ratio and from this, calculate the proposed Impeller Diameter.
- Select an impeller style using viscosity limits on Pg. 2.07 and descriptive literature. Record Impeller Factor from Pg. 2.05 on the Mixer Sizing Work Sheet.

- Refer to the appropriate Selection Chart, Pages 2.09 - 2.14, selecting the correct chart by using the final fluid viscosity. Record the Required Torque at a few different mixer speeds.

- Calculate Invested Torque which is equal to Required Torque x Impeller Factor.

Step 3

Calculate the BHP for the impeller diameter and RPM chosen (for the purpose of this example we will ignore viscosity and proximity corrections). At this point a number of iterations are normally required to fully utilize available hardware, i.e. a finite number of motor and gearbox sizes are available. This is accomplished by fine tuning the mixer speed and impeller diameter (and therefore the HP required). Finally check impeller tip speed, it should be in the range of 400 to 1500 FPM.

Step 4

We have now satisfied the process requirements of the application and the final step is to select/design suitable mechanical components. Based on the application requirements or experience, identify the appropriate gearbox service factor (1.25, 1.5 etc.) and the L-10 bearing life (30,000 hrs., 50,000 hrs., 100,000 hrs. etc.). Refer to Section TG8 for mechanical design fundamentals.

MIXING INTENSITY LEVELS

Review the mixing application and the process requirements and then use the following table to choose a mixing intensity level. The table on the following page can be used as a cross reference for some of the main mixer manufactures mixing intensity levels.

Mixing Intensity Level	Maximum Viscosity Ratio*	Maximum SG Difference	Description and Typical Applications
Mild	Ratio of Maximum Viscosity Component to Minimum Viscosity Component does not exceed 10:1.	Difference in SG of Components does not Exceed 0.2.	Storage or Holding Tanks Feed Tanks Non-Critical Blending Operations “Long” Blend Time Fluid Surface Barely in Motion
Moderate	Ratio of Maximum Viscosity Component to Minimum Viscosity Component does not exceed 50:1.	Difference in SG of Components does not Exceed 0.4.	Most Common Requirement Non-Critical Reaction Tanks Make-Up Tanks Blend Tanks Surface Rippling at Low Viscosities
Strong	Ratio of Maximum Viscosity Component to Minimum Viscosity Component does not exceed 200:1.	Difference in SG of Components does not Exceed 0.5.	Critical Make-Up Tanks Critical Blend Tanks Non-Critical Heat Transfer Shorter Blend Times Surface with Moderate Roll
Vigorous	Ratio of Maximum Viscosity Component to Minimum Viscosity Component does not exceed 500:1.	Difference in SG of Components does not Exceed 0.6.	Critical Mixing Applications Critical Reaction Tanks Most Heat Transfer Tanks with pH Feedback Surface in Rolling Boil
Intense	Ratio of Maximum Viscosity Component to Minimum Viscosity Component does not exceed 5,000:1.	Difference in SG of Components does not Exceed 0.8.	Critical Reaction Tanks Good Heat Transfer Rapid Blend Times Surging Surface, Some Vortexing
Violent	Ratio of Maximum Viscosity Component to Minimum Viscosity Component does not exceed 10,000:1.	Difference in SG of Components does not Exceed 1.0.	Special Critical Applications Critical Reaction Tanks Critical Heat Transfer High Shear Requirements Surface Splashing and Vortexing

*If fluid components are less than 100 cps, any Mixing Intensity Level can be used.

CROSS REFERENCE OF MIXING INTENSITY LEVELS

Hayward Gordon	Philadelphia	Chemineer	Lightnin
Mild	Mild	2	Mild
Moderate	Moderate	3	Moderate
Strong	Not Defined	4	Not Defined
Vigorous	Vigorous	5	Violent
Intense	Not Defined	7	Not Defined
Violent	Violent	9	Not Defined

BLEND TIMES

Blend time is a function not only of the degree of mixing, but also the density differences and viscosity differences between components. For ideal components with negligible density or viscosity differences, blend times can be estimated using the chart on the following table.

Blend times can be as much as ten times the values shown in the table for components with density or viscosity differences, or with unusual characteristics. Blending results are affected by the particular nature as well as the viscosity of the components. The relative concentrations of components and the method of adding them to the batch, as well as temperature and surface tension can significantly affect blend times. Blending never really reaches a distinct end point. A mixture just achieves greater uniformity. Different applications will have different criteria for determining adequate homogeneity. For example, it is important for a batch of paint to be as uniform as possible to avoid off-colour defects, but a blend of similar petroleum oils need not be perfectly uniform. Therefore blend time is not an absolute quantity and is normally not the primary selection criteria.

BLEND TIMES

Mixing Intensity	Viscosity (cps)	Blend Time (Min.)	Mixing Intensity	Viscosity (cps)	Blend Time (Min.)
MILD	Waterlike	5-10	VIGOROUS	Waterlike	1-2
	250	10-20		250	3-7
	1,000	20-30		1,000	5-9
	5,000	60-120		5,000	30
	10,000	120-240		10,000	50
MODERATE	Waterlike	3-5	INTENSE	Waterlike	1
	250	5-10		250	2-3
	1,000	10-15		1,000	5
	5,000	50		5,000	20
	10,000	90		10,000	40
STRONG	Waterlike	2-3	VIOLENT	Waterlike	<1
	250	4-8		250	1-2
	1,000	7-10		1,000	2-3
	5,000	40		5,000	5
	10,000	70		10,000	10

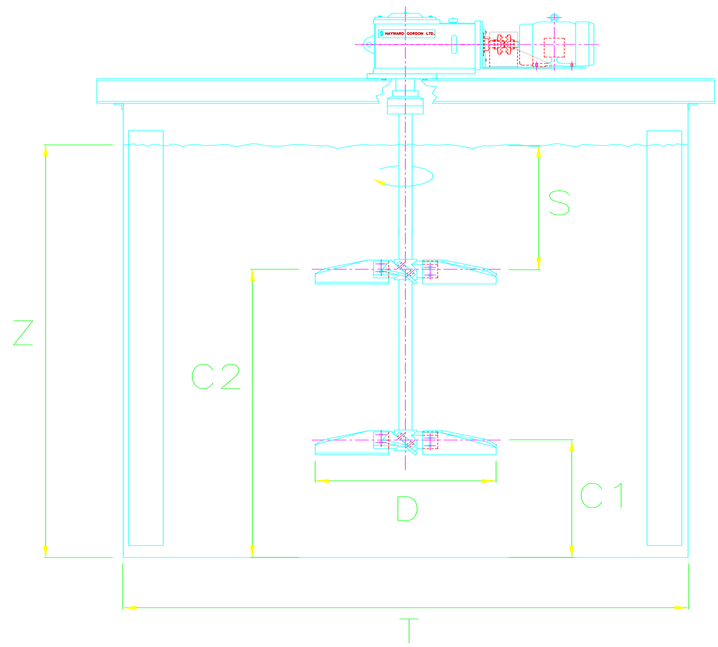
IMPELLER FACTORS

Once an impeller style has been chosen for the application, use the following table to pick the appropriate Impeller factor which then determines the final Invested Torque the application requires.

Impeller Style	Impeller Factor, F_I	Impeller Style	Impeller Factor, F_I
3AL39	1.0	4HP45	1.1
4AL45	1.0	4PBT45	1.2
3AH39	1.0	4RBT90	1.3
3AM45	1.0	4RSB90	1.3

IMPELLER POSITIONING

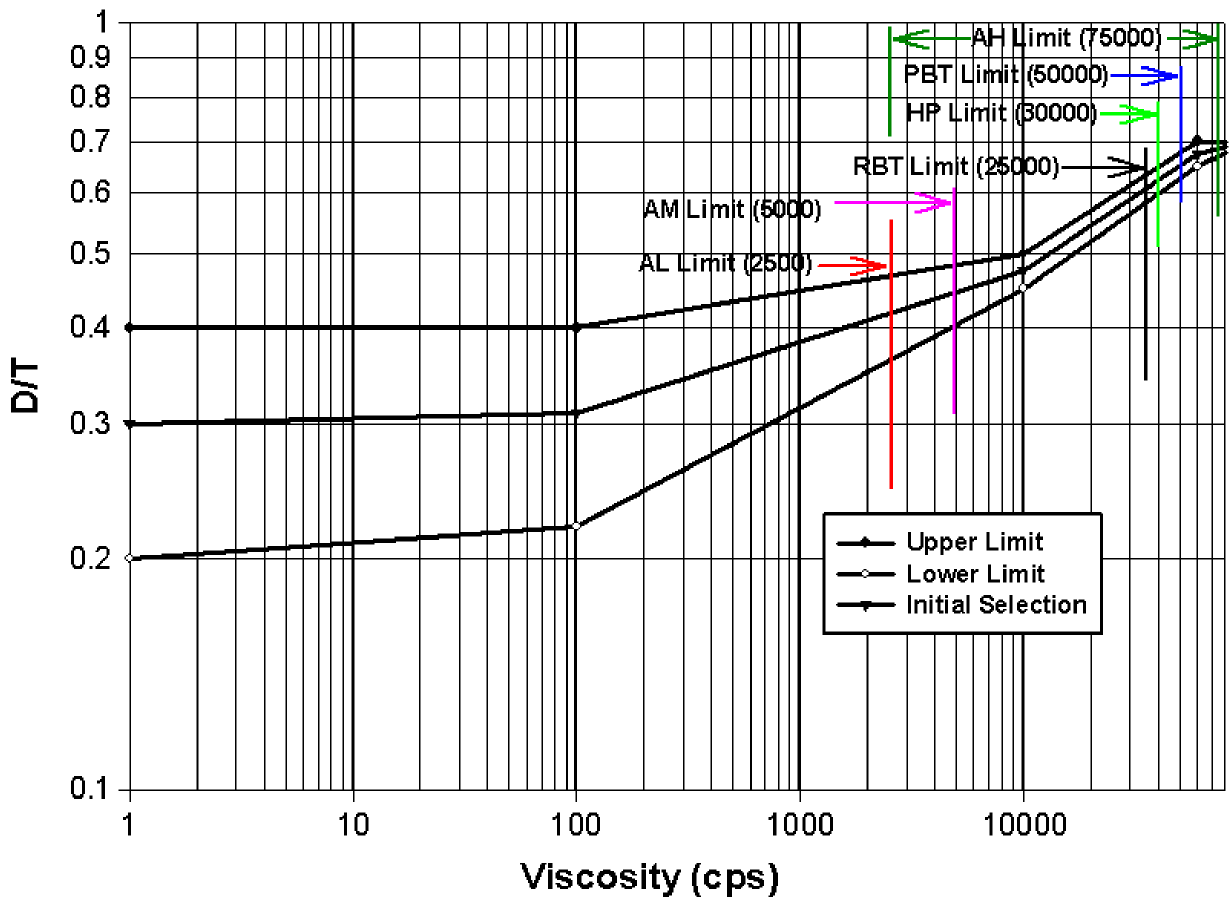
Recommendations given below are guidelines for use in the absence of previous application experience.



Impeller Style	Number of Impellers	Maximum Z/T	C_1 Optimum	C_1 Range	C_2	Minimum Submergence*
Radial	1	1.0	0.3D	0.16D - 0.5D	---	0.4D
	2	1.5			0.67Z	
PBT	1	1.2	0.67D	0.3D - 0.7D	---	0.6D
	2	1.9			0.67Z	
HP	1	1.25	0.9D	0.5D - 1D	---	0.75D
	2	2.0			0.67Z	
Hydrofoil	1	1.3	1.0D	.7D - 1.3D	---	0.9D
	2	2.1			0.67Z	

*For good mixing, minimal vortexing.

Optimum D/T Vs. Viscosity

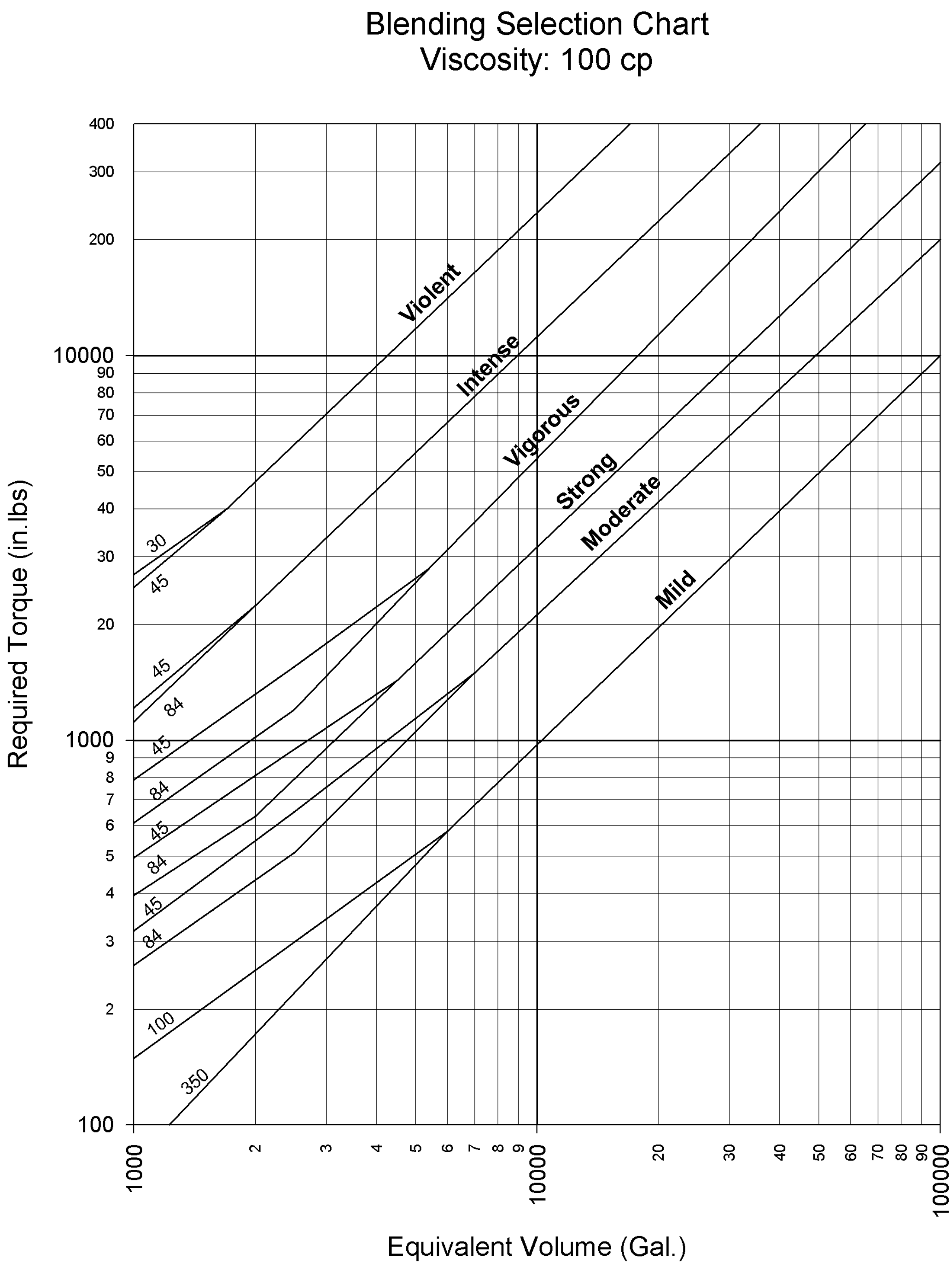


Portable Mixer Blending Selection Chart

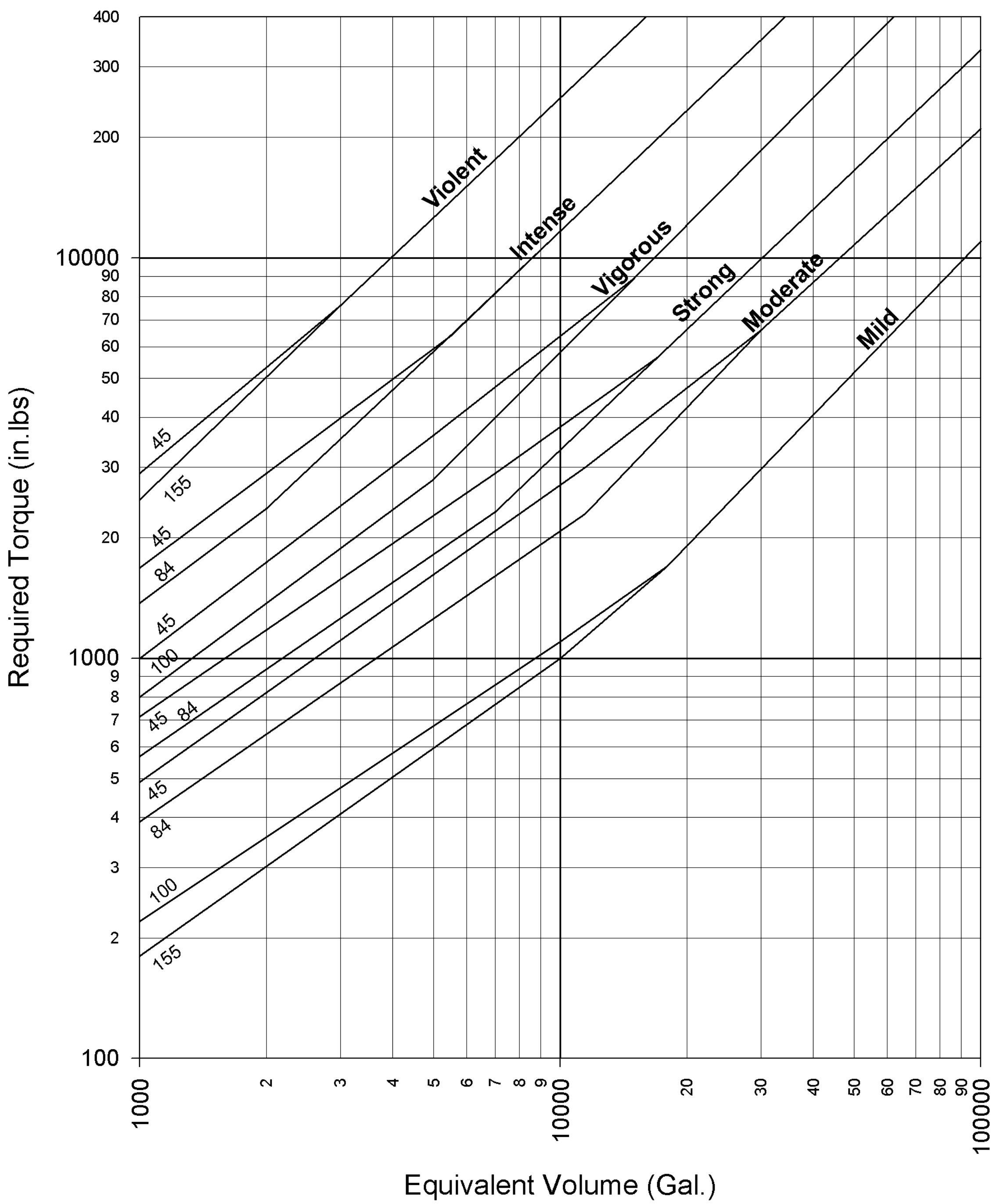
Viscosity (cps)		Tank Volume (US Gallons)									Mixing Action
		25	50	100	200	500	1000	2000	3000	5000	
(1) water (1) kerosene	1.0				DC-14 (1) 3.5" BT = 12	DC-13 (2) 3.25" BT = 20	GC-14 (1) 9.5" BT = 16	GC-14 (1) 9.5" BT = 30	GC-13 (2) 9.0" BT = 33	GC-34 (2) 10.5" BT = 35	MILD
(32) cream		DC-14 (1) 3.5" BT = 2	DC-14 (1) 3.5" BT = 3	DC-14 (1) 3.5" BT = 6	DC-12 (1) 4.0" BT = 8	GC-13 (2) 9.0" BT = 6	GC-12 (1) 10.5" BT = 12	GC-12 (1) 10.5" BT = 24	GC-34 (2) 10.5" BT = 21	GC-15 (2) 12.5" BT = 21	Vigorous
	100			DC-14 (1) 3.5" BT = 8	DC-13 (2) 3.25" BT = 12	GC-14 (1) 9.5" BT = 11	GC-14 (1) 9.5" BT = 21	GC-13 (1) 10.0" BT = 36	GC-34 (2) 10.5" BT = 26	GC-11 (2) 11.5" BT = 36	MILD
(100) SAE oil		DC-14 (1) 3.5" BT = 2	DC-14 (1) 3.5" BT = 4	DC-12 (1) 4.0" BT = 5	GC-13 (2) 9.0" BT = 3	GC-12 (1) 10.5" BT = 8	GC-12 (1) 10.5" BT = 16	GC-34 (1) 11.5" BT = 24	GC-15 (2) 12.5" BT = 17	GC-2 (2) 13.0" BT = 25	Vigorous
(240) mayonnaise, lard	250		DC-14 (1) 3.5" BT = 7	DC-13 (2) 3.25" BT = 10	GC-14 (1) 9.5" BT = 7	GC-14 (1) 9.5" BT = 16	GC-13 (1) 10.0" BT = 31	GC-34 (1) 11.5" BT = 42	GC-11 (2) 11.5" BT = 38	GC-15 (2) 12.5" BT = 49	MILD
		DC-14 (1) 3.25" BT = 4	DC-12 (1) 4.0" BT = 5	GC-13 (2) 9.0" BT = 3	GC-12 (1) 10.5" BT = 5	GC-12 (1) 10.5" BT = 14	GC-34 (1) 11.5" BT = 21	GC-15 (1) 13.0" BT = 30	GC-2 (2) 13.0" BT = 26	GC-3 (2) 14.25" BT = 34	Vigorous
	500		DC-13 (2) 3.25" BT = 8	GC-14 (2) 6.5" BT = 10	GC-14 (1) 9.0" BT = 13	GC-13 (1) 9.0" BT = 33	GC-34 (1) 10.5" BT = 42	GC-11 (2) 10.5" BT = 50	GC-15 (2) 11.5" BT = 57	GC-2 (2) 13.0" BT = 66	MILD
		DC-14 (1) 3.25" BT = 7	GC-13 (2) 7.75" BT = 3	GC-12 (2) 9.0" BT = 4	GC-12 (1) 10.5" BT = 9	GC-34 (1) 10.5" BT = 21	GC-15 (1) 13.0" BT = 22	GC-2 (2) 13.0" BT = 26	GC-3 (2) 13.0" BT = 39		Vigorous
(900) yogurt (900) castor oil (900) glycerin	1000	DC-13 (2) 2.75" BT = 10	GC-14 (2) 6.0" BT = 10	GC-14 (2) 6.0" BT = 19	GC-12 (1) 10.0" BT = 14	GC-34 (1) 10.5" BT = 35	GC-11 (1) 11.5" BT = 48	GC-15 (2) 11.5" BT = 57	GC-2 (2) 12.5" BT = 67	GC-3 (2) 13.0" BT = 99	MILD
		GC-13 (2) 7.75" BT = 3	GC-12 (2) 7.75" BT = 6	GC-12 (2) 7.75" BT = 9	GC-11 (1) 11.5" BT = 10	GC-15 (1) 12.5" BT = 19	GC-2 (1) 12.5" BT = 38	GC-3 (2) 13.0" BT = 40			Vigorous
	2500	GC-14 (2) 5.5" BT = 11	GC-14 (2) 5.5" BT = 22	GC-12 (2) 7.0" BT = 24	GC-34 (2) 9.0" BT = 22	GC-11 (2) 10.0" BT = 39	GC-15 (2) 10.5" BT = 70	GC-2 (2) 11.5" BT = 107	GC-3 (2) 13.0" BT = 112		MILD
(2500) honey		GC-12 (2) 7.75" BT = 5	GC-12 (2) 7.75" BT = 9	GC-11 (2) 10.0" BT = 8	GC-15 (2) 10.5" BT = 14	GC-2 (2) 11.5" BT = 27	GC-3 (2) 13.0" BT = 37				Vigorous
	5000	GC-14 (2) 5.5" BT=17	GC-12 (2) 7.0" BT = 18	GC-34 (2) 7.75" BT = 27	GC-11 (2) 9.0" BT = 34	GC-15 (2) 10.0" BT = 60	GC-2 (2) 11.5" BT = 82	GC-3 (2) 12.5" BT = 128			MILD
(3000) blackstrap molasses		GC-12 (2) 7.0" BT = 9	GC-11 (2) 9.0" BT = 9	GC-15 (2) 10.0" BT = 12	GC-2 (2) 11.5" BT = 17	GC-3 (2) 12.5" BT = 32					Vigorous
	10000	GC-13 (2) 6.0" BT = 20	GC-12 (2) 6.5" BT = 33	GC-34 (2) 7.0" BT = 53	GC-15 (2) 9.5" BT = 42	GC-2 (2) 10.0" BT = 89	GC-3 (2) 11.5" BT = 120				MILD
		GC-34 (2) 7.5" BT = 11	GC-11 (2) 9.0" BT = 13	GC-15 (2) 9.5" BT = 21	GC-3 (2) 11.5" BT = 25						Vigorous
(10000) corn syrup	15000	GC-12 (2) 6.0" BT = 24	GC-34 (2) 7.0" BT = 32	GC-11 (2) 7.75" BT = 46	GC-15 (2) 9.0" BT = 58	GC-3 (2) 11.5" BT = 72					MILD
(11200) mustard		GC-11 (2) 7.75" BT = 12	GC-15 (2) 9.0" BT = 15	GC-2 (2) 10.0" BT = 21	GC-3 (2) 11.5" BT = 29						Vigorous

Note:

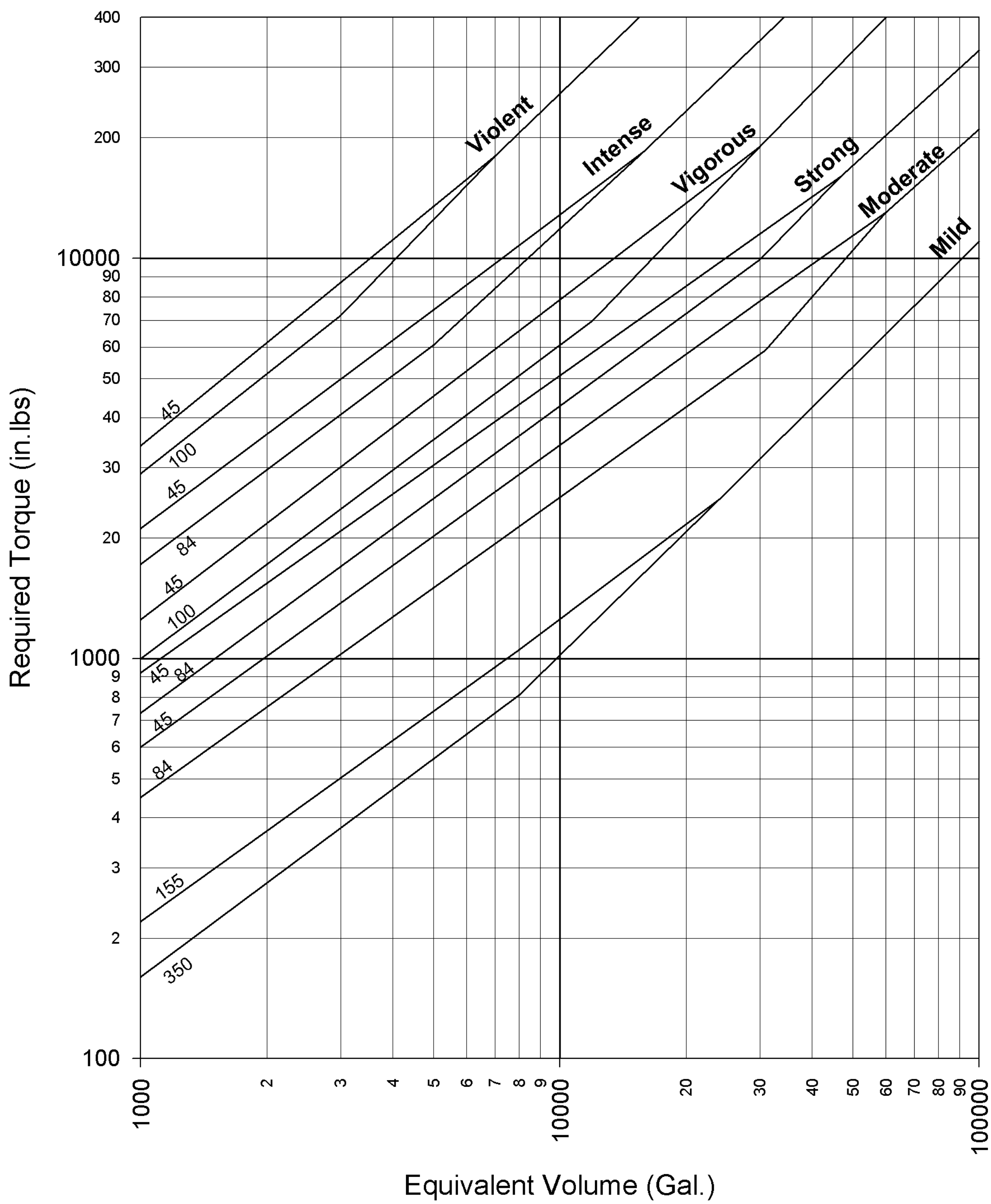
-Selections are based on a final fluid specific gravity of 1.10
-Blend Times (BT) indicated are in minutes and are approximate. They are based on blending pure fluids as opposed to blending two components with different viscosities.


Blending Selection Chart
Viscosity: 100 cp
Required Torque (in.lbs)
Equivalent Volume (Gal.)
Violent
Intense
Vigorous
Strong
Moderate
Mild
30
45
45
84
45
84
45
84
45
84
100
350
400
300
200
10000
90
80
70
60
50
40
30
20
1000
9
8
7
6
5
4
3
2
100
1000
2
3
4
5
6
7
8
9
10000
20
30
40
50
60
70
80
90
100000

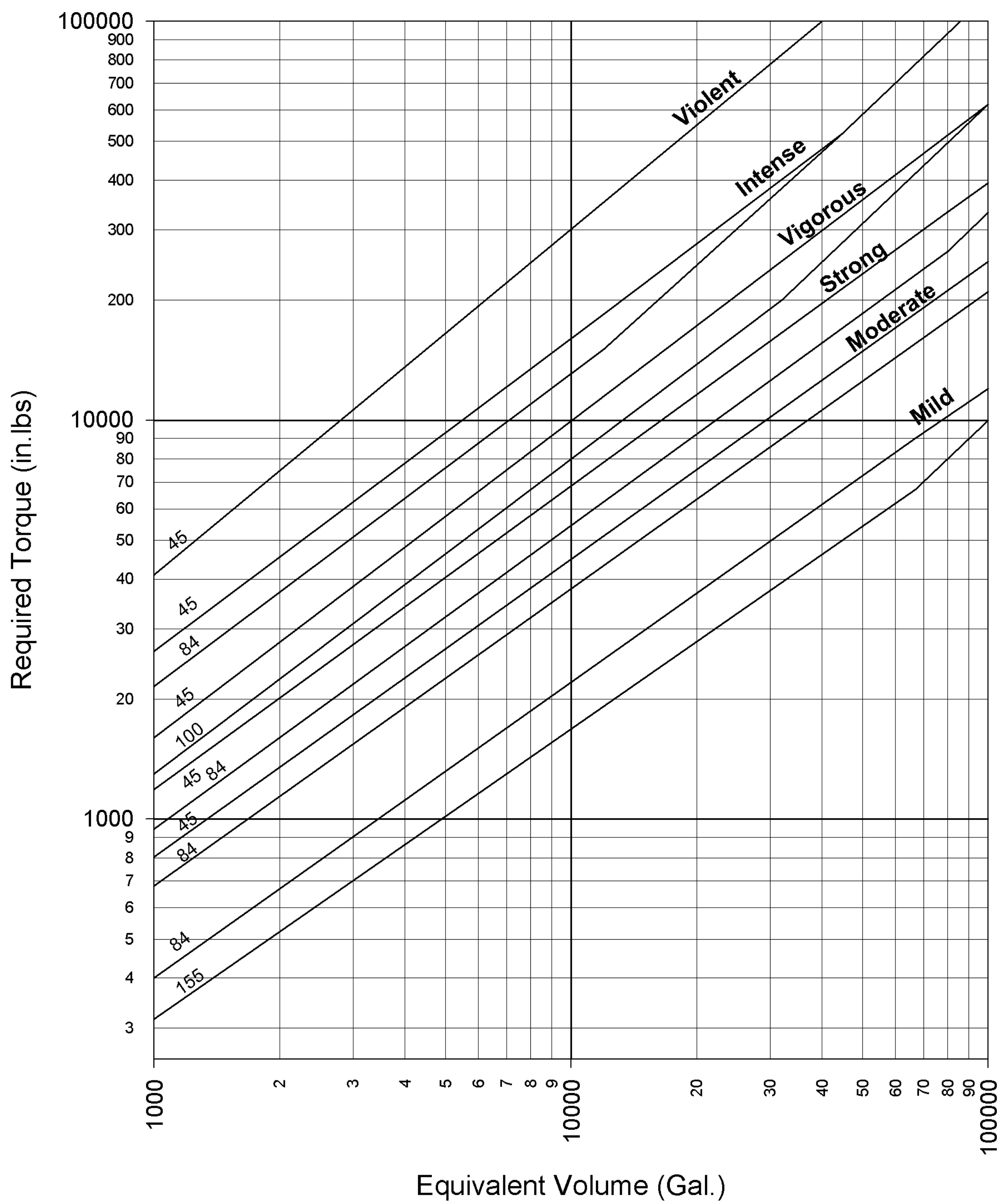
Blending Selection Chart
Viscosity: 250 cp



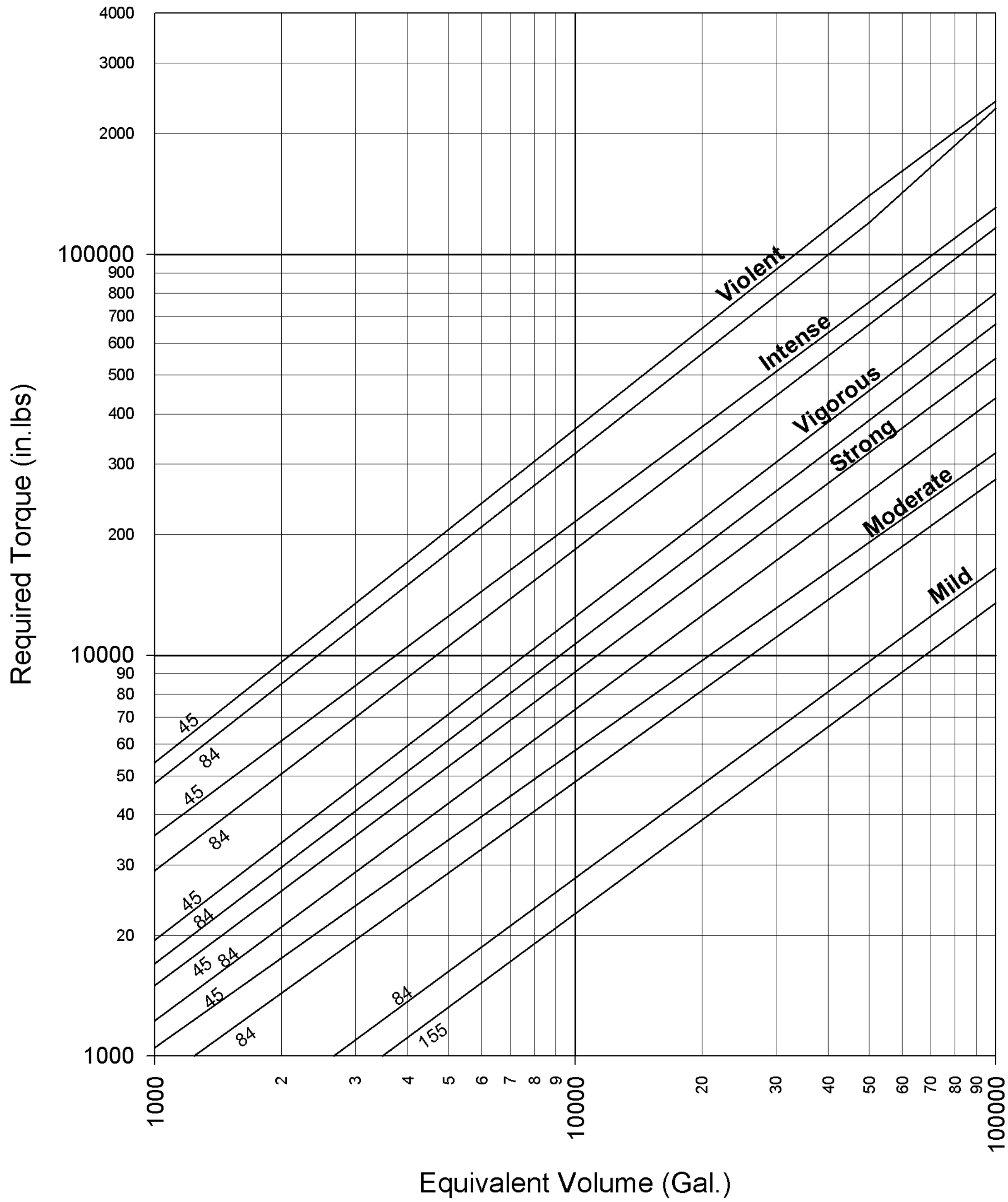
Blending Selection Chart
Viscosity: 500 cp



Blending Selection Chart
Viscosity: 1000 cp



Blending Selection Chart
Viscosity: 2500 cp



APPLICATION DATA FORM

CUSTOMER NAME: ______________________ CONTACT: ____________

ADDRESS: ______________________ PHONE: ____________

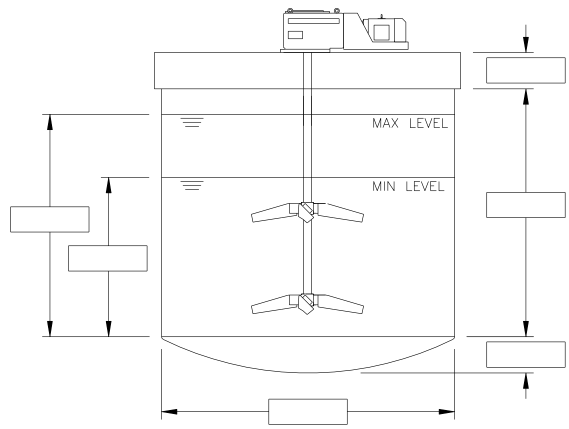
______________________ FAX: ____________

QUOTE #: ______________________ DATE: ____________

LIQUID A: NAME ____ %CONC ____ SG ____ VISCOSITY ____

LIQUID B: NAME ____ %CONC ____ SG ____ VISCOSITY ____

SOLIDS: NAME ____ %CONC ____ SG ____ SIZE ____



FINAL SOLUTION: NAME ____ SG ____ VISCOSITY ____

TEMPERATURE: ____ °C

BLEND TIME: ____ MIN

PRESSURE: ____ PSI

VOLUME: ____ GAL

GAS: NAME ____ RATE ____ SPARGE DEPTH ____

MIXING CLASS: ____ Blend, Dissolve, Disperse Gas, Solid Suspension, Heat Exchange, Emulsify, Maintain Condition

MIXING LEVEL: ____ Blending: Mild, Moderate, etc. Solid Suspn.: Off Btm., Uniform, etc.

MIXING CYCLE: ____ Batch, Continuous

FOAMING TENDENCY: ____ None, Mild, Badly

MIXER TYPE: ____ Portable, Side Entry, Top Entry

____ Ø ____ Hz ____ V ____ RPM ____ AC DC

IMPELLER TYPE: ____ Prop, PBT, FBT, Hydrofoil, CVBT, Etc.

ENCL.: ____ TEFC, ODP, XP

WETTED PARTS: ____ C/S, 304SS, 316SS, etc.

DRIVE DETAILS: ____ Direct, V–Belt, VFD, Gear

SEAL TYPE: ____ Open Tank, Stuffing Box, Mechanical Seal (Single/Dbl)

MOUNT: ____ Clamp, Baseplate, Flange

MIXER SIZING WORKSHEET

Use this sheet in conjunction with Application Data Form for Blending Applications

Process Requirements

Batch Volume	________	D/T Ratio	________
Equivalent Volume	________	Proposed Imp. Dia	________
Mixing Intensity	________	Impeller Style	________
Z/T Ratio	________	Impeller Factor F_I	________
No. of Impellers	________	Required Torque	______ @ ____rpm
		Required Torque	______ @ ____rpm

Invested Torque = Required Torque x Impeller Factor

= ________________________________

First Selection

Gearbox SF / L10 Life	________	Available Torque	________
Req'd Shaft Length	________	Actual Impeller Dia	________
Mixer Model	________	HP ______ @ _______ RPM	
Impeller(s)	________		
Shaft	________		

Second Selection

Gearbox SF / L10 Life	________	Available Torque	________
Req'd Shaft Length	________	Actual Impeller Dia	________
Mixer Model	________	HP ______ @ _______ RPM	
Impeller(s)	________		
Shaft	________		

Solid Suspension

This section deals with the suspension of "Free" settling solids; that is, there is a small enough concentration of the solids that the particles are not interfering with each other and therefore can reach their terminal settling velocity. Applications involving "Hindered" settling use a different selection procedure.

In addition, this selection procedure assumes operation in a fully baffled, vertical cylindrical tank.

This procedure introduces the main criteria used for free settling mixer sizing in solid suspension applications. Working through the following steps will allow the individual to better understand the calculations being done by the Mixing Assist computer program.

Step 1

Complete the Application Data Form found on page TG-1 pg 14; this will ensure that all pertinent information required for mixer selection is available.

Step 2

Use the Mixer Sizing Work Sheet (Page 14) and basic mixer equations found in section TG1 to calculate the following:

- Calculate an equivalent volume, this is equal to the batch volume multiplied by the slurry specific gravity. See Page 6 for equation to determine slurry SG, given solid SG and liquid SG.
- Using the chart on page 4 determine the type of settling (Free or Hindered). If Hindered settling is encountered. It is possible that a smaller mixer could be used than for a free settling application.
- Determine the Solid Settling Rate using the graph on page 5. Normally a sieve analysis is available giving particle size vs. Quantity, ie. 95% - 200 Mesh. A conservative procedure is to use the largest particle size given, but it is possible to develop a more finely tuned selection - see the Special Requirements Section on the following page.
- Check to see if the application falls within the Portable Mixer range - Pg. 6. If so, select the mixer from this chart, otherwise proceed to the next step.
- Determine the Suspension Requirement Factor (F_{SR}) using the chart on Pages 37 and knowing the degree of suspension required - barely suspended off the tank bottom or to a nearly uniform suspension throughout the tank. If a FSR of 0.5 or 1.0 is selected, see the Special Consideration section on the next page.

- Calculate the slurry height to tank diameter ratio (Z/T) and then determine the number of impellers required and their position in the tank by referring to the chart on Pg. 8.

- Calculate a Proposed Impeller Diameter using an Impeller Diameter to Tank Diameter (D/T) ratio of 0.3. The final D/T ratio should be kept in the range of 0.25 to 0.4.

- Determine the Tank Geometry Correction Factor (F_G) using the graph on page 9.

- Select an impeller style using the descriptions in section TG5. The most common impellers used for solid suspension applications are the HP, AM and AL series Hydrofoils. Determine the appropriate Impeller Factor (F_I) from page 7.

- Refer to the appropriate Selection Chart, Pages 10 - 13, selecting the correct chart by using the particle settling rate. Record the Required Torque at a few different speeds.

- Calculate Invested Torque which is equal to Required Torque x Impeller Factor (F_I) x Geometry Factor (F_G) x Suspension Requirement Factor (F_{SR}).

Step 3

- Based on the application requirements, record the gearbox Service Factor and the L-10 bearing life.

- Calculate the BHP for the impeller diameter and RPM chosen (for the purpose of this example we will ignore viscosity and proximity corrections). At this point a number of iterations are normally required to fully utilize available hardware, i.e. a finite number of motor and gearbox sizes are available. This is accomplished by fine tuning the mixer speed and impeller diameter (and therefore the HP required). Finally check impeller tip speed, it should be in the range of 400 to 1000 FPM for Pitched Blade Turbines and between 400 and 1200 FPM for Hydrofoil Impellers.

Step 4

- We have now satisfied the process requirements of the application and the final step is to select/design suitable mechanical components. Based on the application requirements or experience, identify the appropriate gearbox service factor (1.25, 1.5 etc.) and the L_{10} bearing life (30,000 hrs., 50,000 hrs., 100,000 hrs. etc.). Refer to Section TG8 for mechanical design fundamentals.

Special Considerations

Dry Solids Addition

Normally the solids are added to the tank in a pre-slurried form (already mixed with fluid). If however the solids are added to the surface in a dry form which may float, an upper impeller will be required to promote surface vortexing for better draw-down and wetting of the solids. In addition, the tank baffles can end short of the slurry surface which will also promote vortexing.

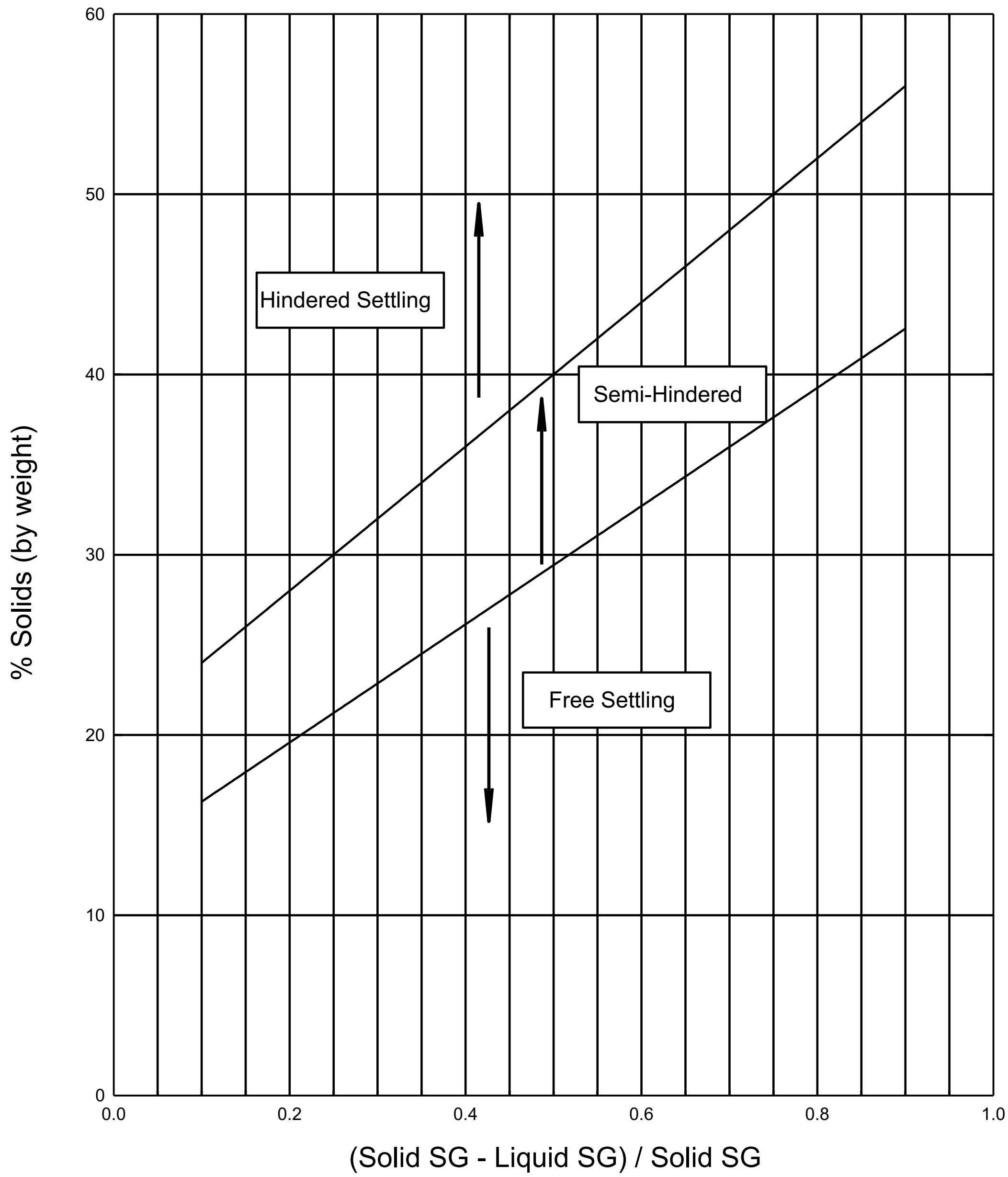
Off-Bottom Suspension Guidelines

For applications where only a minimal level of suspension is required (FSR=0.5-1.0), which may include bottom draw-off or dissolving situations, the full slurry height need not be used to calculate the working volume. Instead a slurry height of 0.33 times the tank diameter can be used to calculate this volume. Using a smaller volume allows selection of a smaller mixer remembering that the mixer is only influencing this portion of the tank.

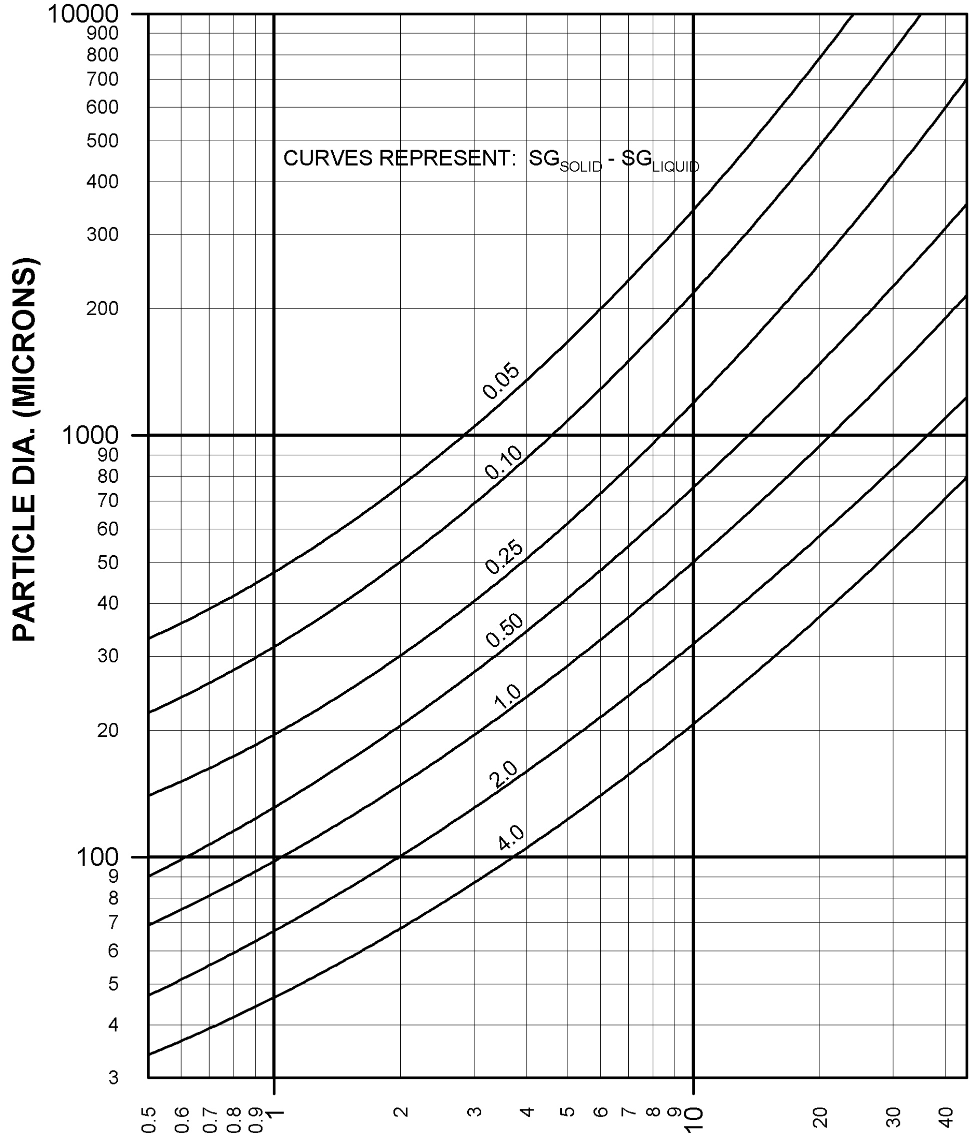
Solids Size Range

The size of solids will often vary over a range. To ensure that "over-sizing" the mixer does not occur, select different Suspension Requirement Factors (F_{SR}) for different solid sizes. For example, suppose solids are described as 100% - 200 microns and 95% - 100 microns and the application requires Moderately Uniform suspension for a bottom draw-off operation. Select F_{SR}=1.5 (Moderately Uniform) for the 100 micron solids and calculate the torque requirement. Then select F_{SR}=1.0 (Off Bottom) for the 200 micron particles and calculate this torque requirement. The result will be a more appropriately sized selection than using the largest particle size (200 micron) coupled with a F_{SR}=1.5.

Unrestricted or Hindered Settling



PARTICLE SETTLING VELOCITY



PORTABLE MIXER SELECTION CHART

Particle Settling Rate (FPM)	Equivalent Volume (Slurry SG x USG)								Suspension Requirement
	50	100	200	500	1000	2000	3000	5000	
1	DC-14	DC-13	DC-13	GC-13	GC-34	GC-11	GC-15	GC-3	Off-Bottom
	DC-12	DC-12	DC-34	GC-34	GC-11	GC-2	---	---	Uniform
5	DC-13	DC-12	GC-13	GC-11	GC-2	---	---	---	Off-Bottom
	DC-13	DC-11	GC-34	GC-2	---	---	---	---	Uniform
10	GC-13	GC-12	GC-11	---	---	---	---	---	Off-Bottom
	GC-34	GC-11	GC-2	---	---	---	---	---	Uniform
15	GC-12	GC-34	GC-15	---	---	---	---	---	Off-Bottom
	GC-11	GC-15	---	---	---	---	---	---	Uniform

Propeller spacing of (2) propeller diameters is recommended for GC mixers.
Propeller spacing of (4) propeller diameters is recommended for DC mixers.
Lower propeller off-bottom distance should be 1.5 propeller diameters.

SLURRY SPECIFIC GRAVITY

$$SG_{Slurry} = \frac{1}{\frac{X_1}{SG_{Solid}} + \frac{X_2}{SG_{Liquid}}}$$

Where: X_1 is weight fraction of solids and X_2 is weight fraction of liquid

SUSPENSION REQUIREMENT LEVELS

Review the mixing application and the process requirements and then use the following table to choose the appropriate Suspension Requirement Factor.

Description and Application Range	Suspension Requirement Factor F_{SR}
Solids Just Suspended Fastest settling particles barely rise clear of vessel bottom, others rise higher. Fillets will form in vessel corners. Use when only bottom pump-out is available or for dissolving solids applications when time is not critical	0.5
Off Bottom Suspension Adequate for the majority of storage applications. Solids are in moderate uniformity in the bottom quarter of vessel. Good for bottom draw-off applications. Continuous suspension. Some filleting.	1.0
Moderate Uniformity Strong turnover; uniformity of solids in bottom three-quarters of tank. Good for intermediate draw-off situations. No filleting.	1.5
Nearly Uniform Suspension Closest practical approach to uniform distribution of solids throughout mix. Suitable for most top draw-off and overflow applications.	2.0
Uniform Suspension Excellent contact between liquid and solids. Rapid mass transfer.	3.0

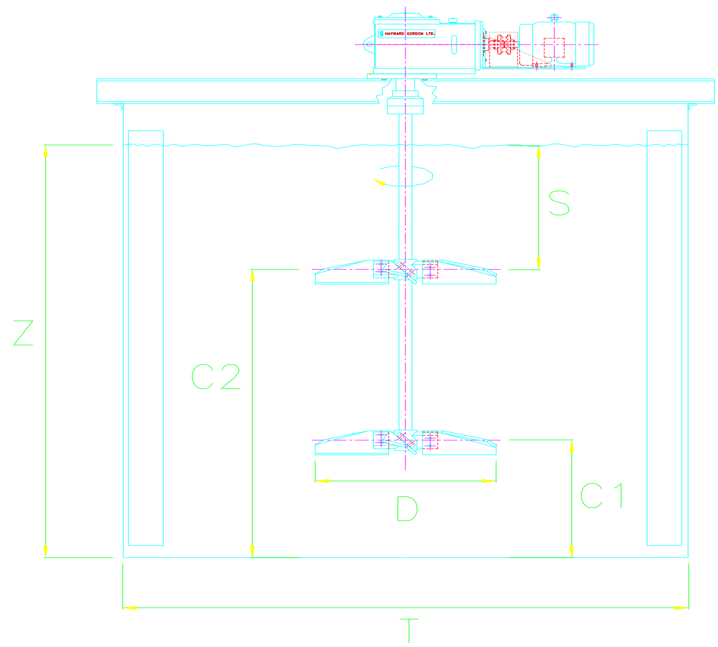
IMPELLER FACTORS

Once an impeller style has been chosen for the application, use the following table to pick the appropriate Impeller factor which then determines the final Invested Torque the application requires.

Impeller Style	Impeller Factor, F_I	Impeller Style	Impeller Factor, F_I
3AL39	0.50	4HP45	0.65
4AL45	0.55	4PBT45	0.75
3AH39	0.60	4PBT32	0.65
3AM45	0.51	4RBT90	1.25

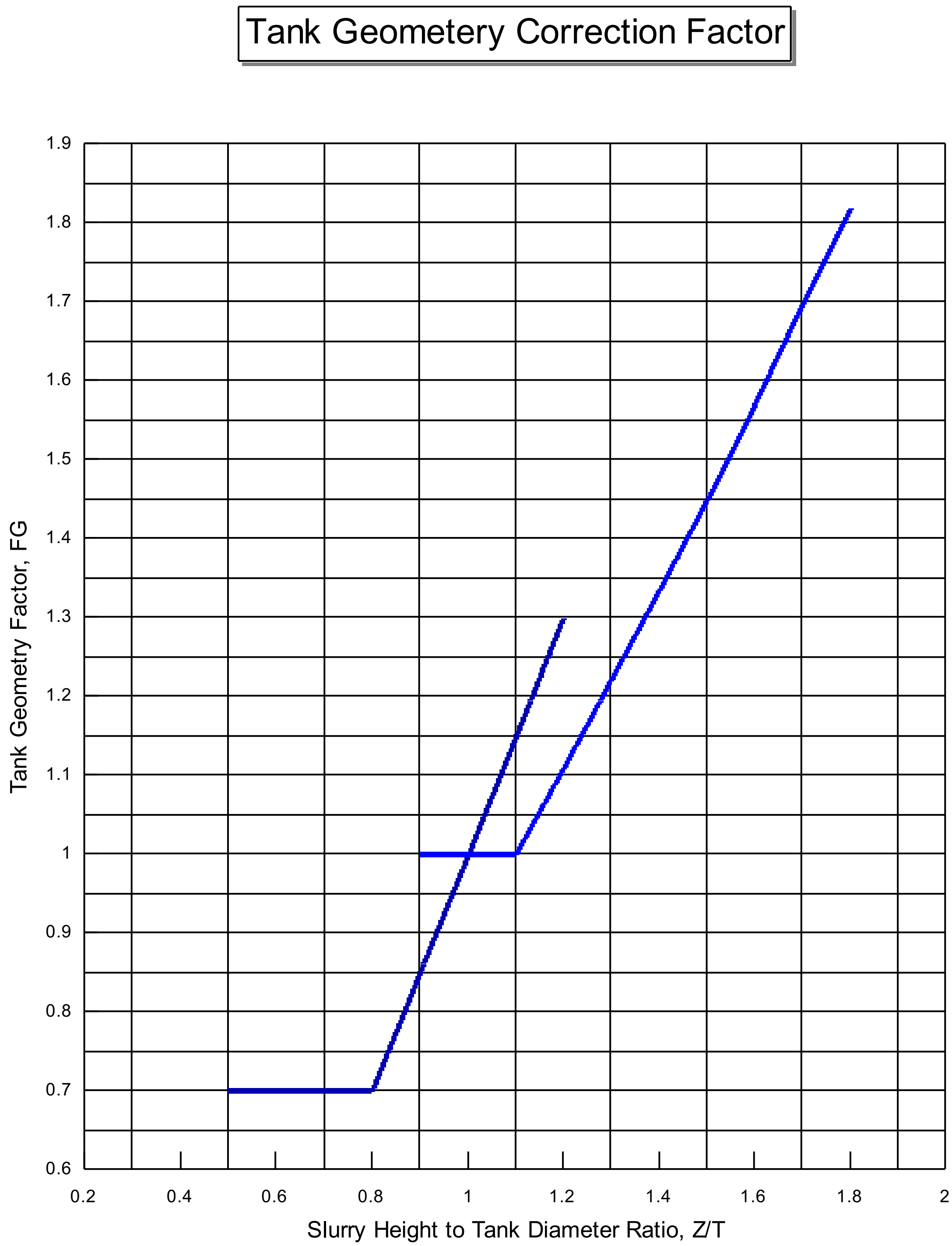
IMPELLER POSITIONING

Recommendations given below are guidelines for use in the absence of previous application experience.

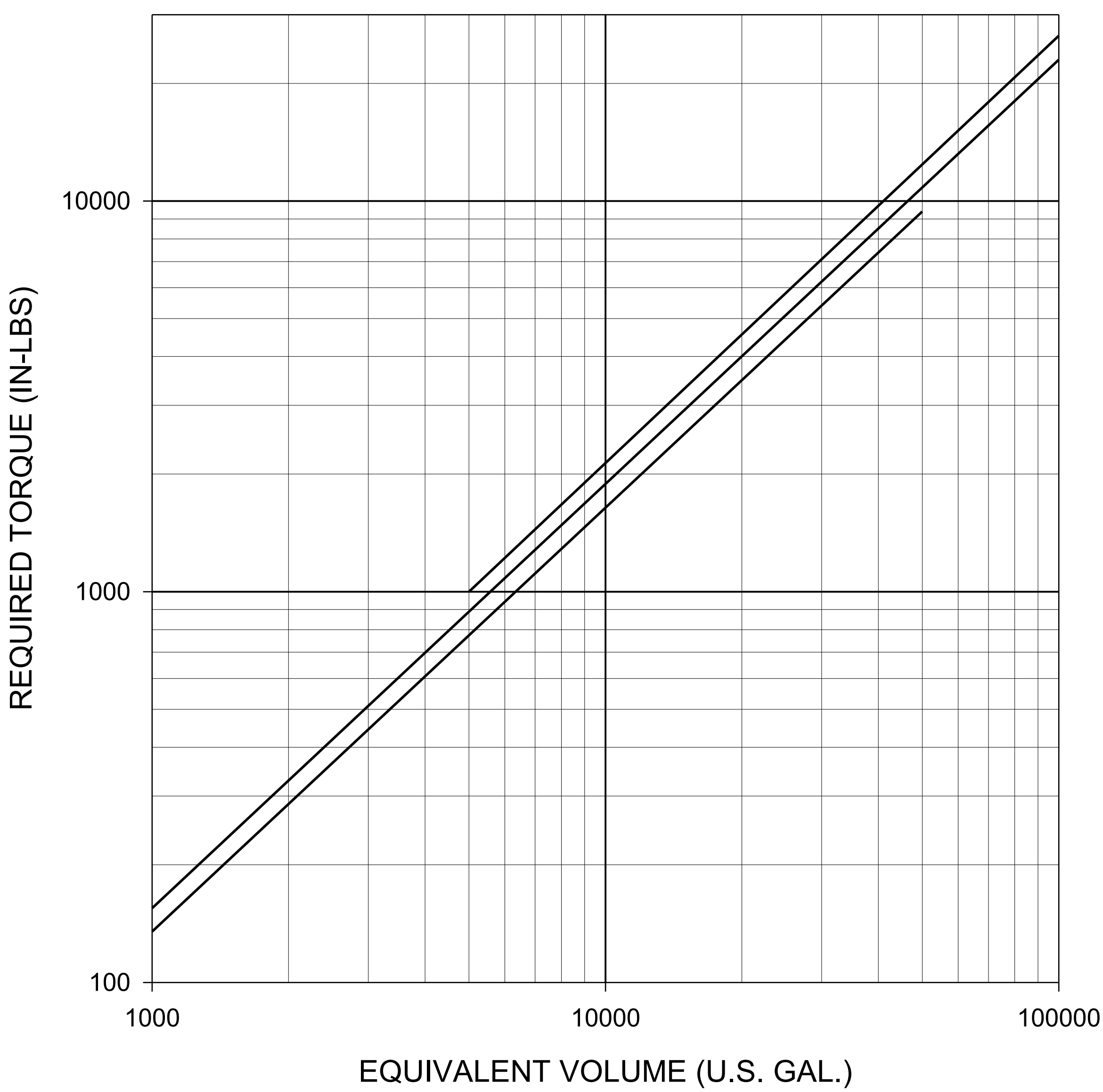


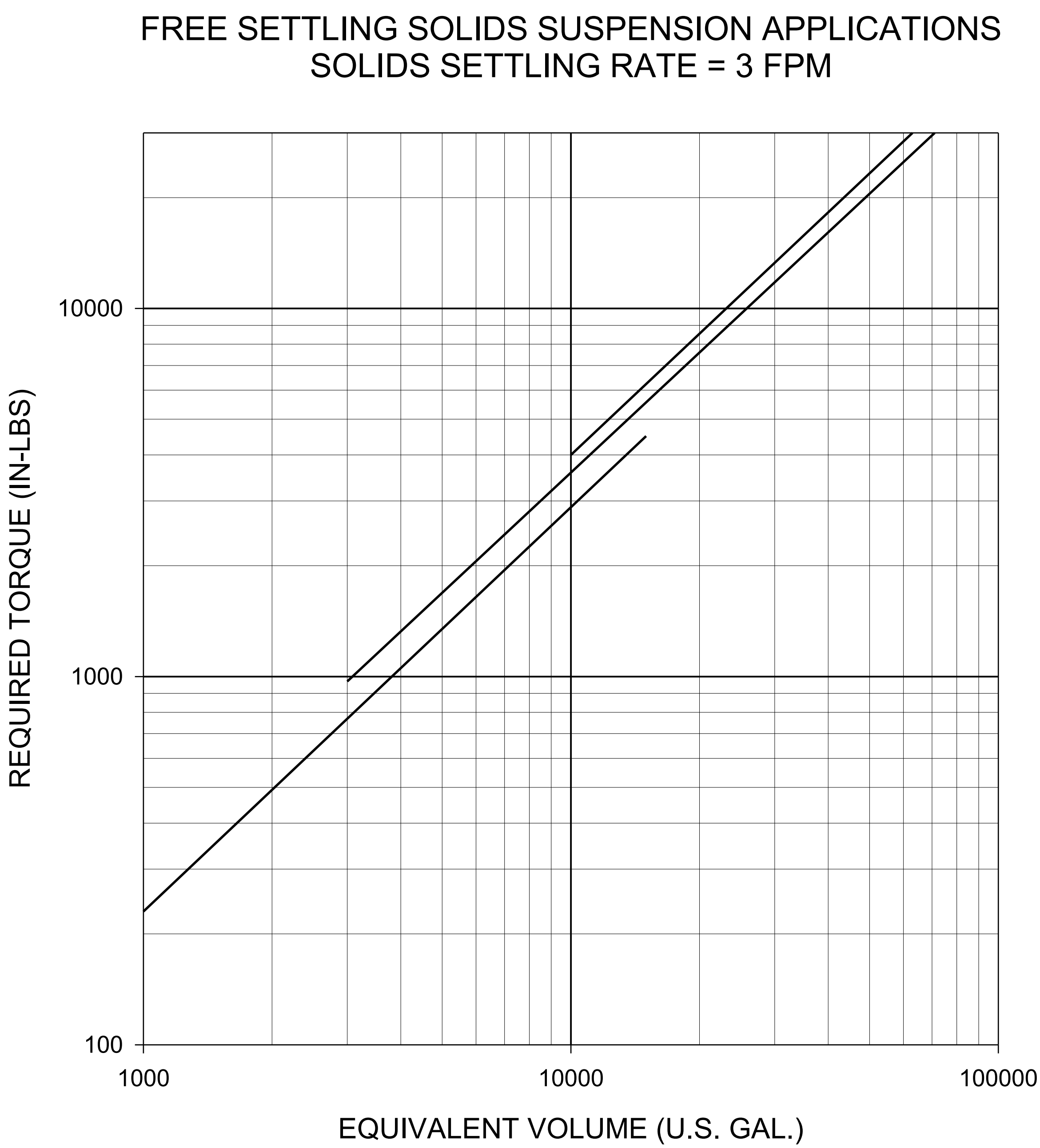
Impeller Style	Number of Impellers	Maximum Z/T	C_1 Optimum	C_1 Range	C_2	Minimum Submergence*
Radial	1	0.7	0.3D	0.16D - 0.5D	---	0.4D
	2	0.9			0.67Z	
PBT	1	1.1	0.67D	0.3D - 0.7D	---	0.6D
	2	1.7			0.67Z	
HP	1	1.15	0.9D	0.5D - 1D	---	0.75D
	2	1.8			0.67Z	
Hydrofoil	1	1.2	1.0D	.7D - 1.3D	---	0.9D
	2	1.9			0.67Z	

*For good mixing, minimal vortexing.

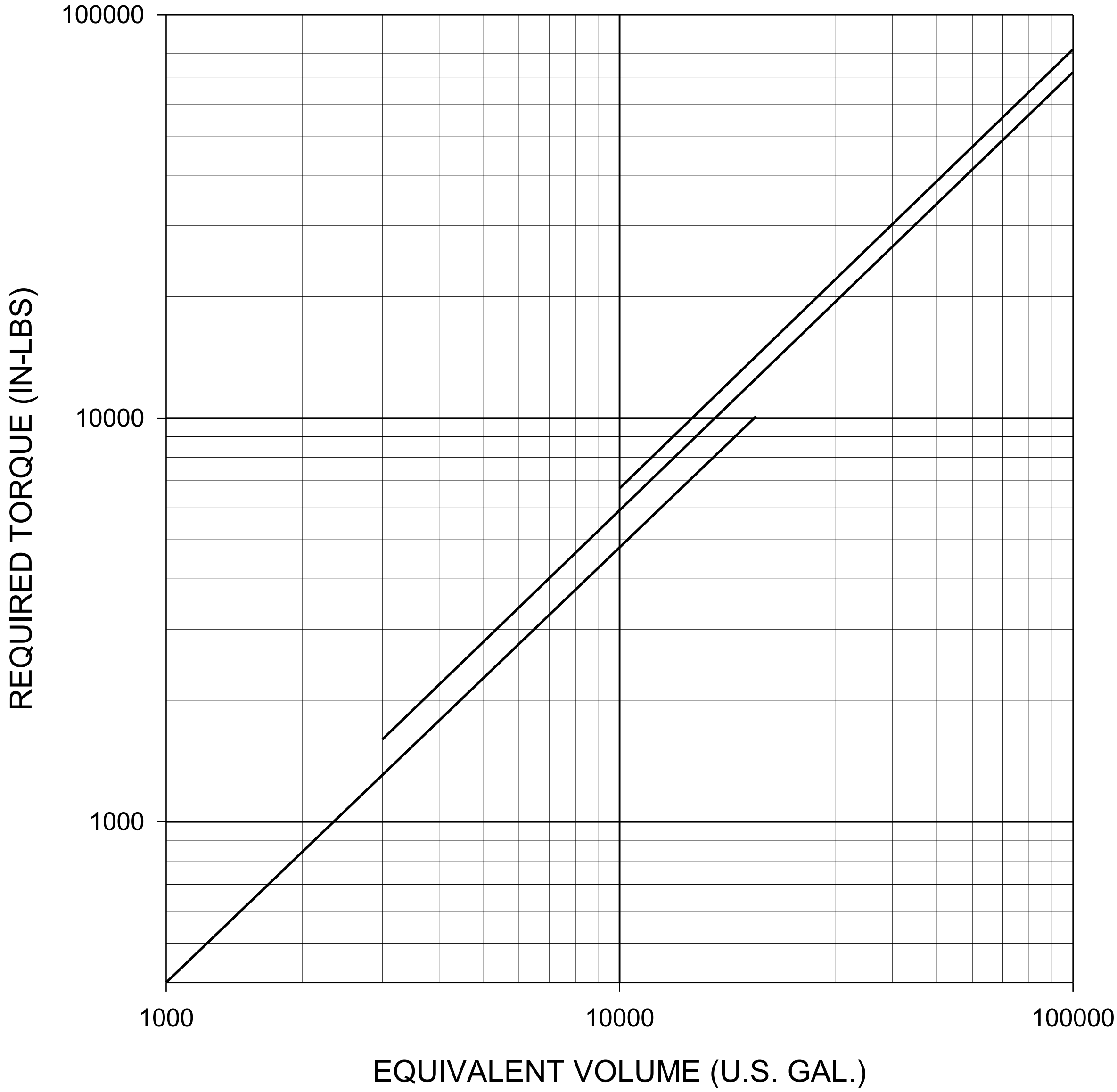

Tank Geometery Correction Factor
Tank Geometry Factor, FG
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Slurry Height to Tank Diameter Ratio, Z/T

FREE SETTLING SOLIDS SUSPENSION APPLICATIONS
SOLIDS SETTLING RATE = 1 FPM

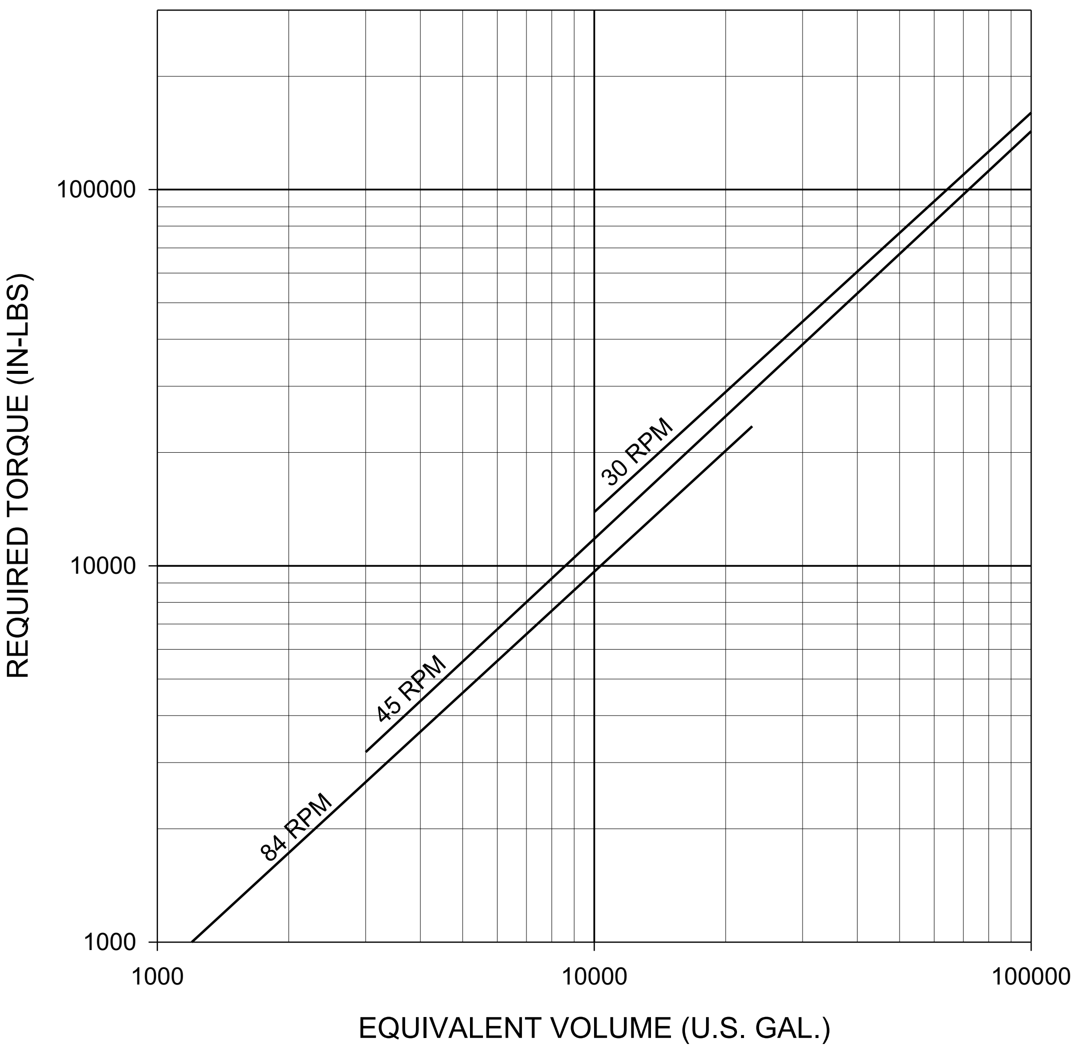



FREE SETTLING SOLIDS SUSPENSION APPLICATIONS
SOLIDS SETTLING RATE = 3 FPM
REQUIRED TORQUE (IN-LBS)
10000
1000
100
1000
10000
100000
EQUIVALENT VOLUME (U.S. GAL.)

FREE SETTLING SOLIDS SUSPENSION APPLICATIONS
SOLIDS SETTLING RATE = 5 FPM



FREE SETTLING SOLIDS SUSPENSION APPLICATIONS
SOLIDS SETTLING RATE = 10 FPM



MIXER SIZING WORKSHEET

Use this sheet in conjunction with Application Data Form for Solid Suspension Applications

Process Requirements

Batch Volume	______________	D/T Ratio	______________
Equivalent Volume	______________	Proposed Imp. Dia	______________
Hindered or Free Settling	______________	Geometry Factor	______________
Settling Rate	______________	Impeller Style	______________
Suspension Requirement, F_{SR}	______________	Impeller Factor F_I	______________
Z/T Ratio	______________	Required Torque	_____ @ ____rpm
No. of Impellers	______________	Required Torque	_____ @ ____rpm

Invested Torque = Required Torque x F_{SR} x F_G x F_I

= ______________________________

First Selection

Gearbox SF / L10 Life	______________	Available Torque	______________
Req'd Shaft Length	______________	Actual Impeller Dia	______________
Mixer Model	______________	HP ______ @ _______ RPM	
Impeller(s)	______________________________		
Shaft	______________________________		

Second Selection

Gearbox SF / L10 Life	______________	Available Torque	______________
Req'd Shaft Length	______________	Actual Impeller Dia	______________
Mixer Model	______________	HP ______ @ _______ RPM	
Impeller(s)	______________________________		
Shaft	______________________________		

GAS DISPERSION

The third most common mixer application is the dispersion of a gas into a liquid. The role of the mixer is to decrease the gas bubble size, increasing the total gas surface area, which increases the mass transfer between the gas and liquid phase. The mixer accomplishes this by creating large velocity gradients, or shear rates, to break the gas into smaller bubbles. In addition, the mixer should be sized to ensure it controls the flow pattern throughout the vessel as the mixer and the gas compete to control the overall flow pattern.

The introduction of a gas into a fluid is to promote either a stripping or addition to the product. The most common application is air dispersion, where the O_2 component of the air is absorbed into the liquid and used in a chemical reaction. The transfer of oxygen from the air bubble to the liquid is an example of “mass transfer”.

An example of gas dispersion used to remove a component from a liquid is “nitrogen stripping”. An inert gas, commonly nitrogen, is bubbled through a liquid to absorb various gases in the liquid. These various gases will permeate the nitrogen bubbles and leave the system as the bubbles exit the liquid at the surface level.

Industrial Processes Using Gas Dispersion include:

- Hydrogenation – the production of food batters and creams, nickel reduction
- Carbonations – CO_2 gas conversions of hydroxides to bicarbonates
- Air Dispersion – for O_2 absorption, e.g. fermentation, oxidation autoclaves

Gas is normally introduced into the fluid by means of a blower or compressor feeding a gas sparging system located in the bottom of the vessel. In this case, the mixer is required to disperse the gas, to some degree, and also to provide a strong “mixer controlled” flow pattern throughout the vessel. Occasionally, the mixer is required to induce gas from the surface into the mixed fluid while also providing dispersion of the gas throughout the fluid and ensuring a strong “mixer controlled” flow pattern throughout the vessel.

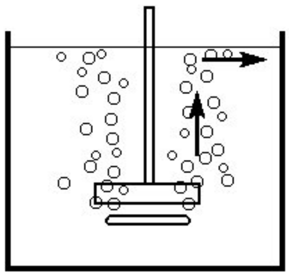
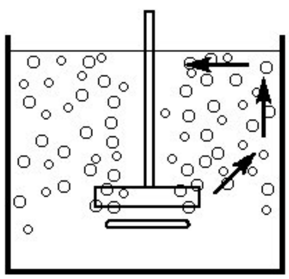
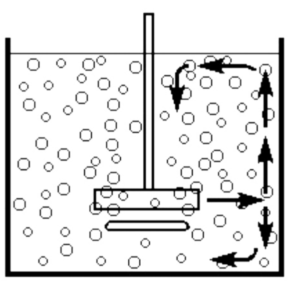
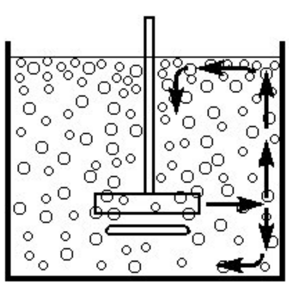
A mixer can improve mass transfer efficiency by:

- Decreasing the gas bubble size, thereby increasing the total interfacial area of the gas
- Increasing the gas-liquid interface turbulence, thus reducing the liquid film resistance
- Giving a uniform gas concentration throughout the tank contents.
- Increasing the time each bubble spends in the liquid

Gas dispersion applications are broken into two main categories:

- Reaction Rate System (Physical Dispersion of the Gas)
- Mass Transfer Controlled Systems

Further descriptions of these two processes are described below.

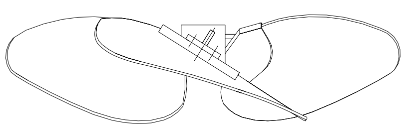
Gas Dispersion Levels	Gas Dispersion Level	Application
	**Flooding – Gas controlled fluid flow pattern** The flow regime where the impeller has little effect in re-directing the flow pattern established by the gas. Gas rises directly to the surface.	Not used
	**Minimal Gas Dispersion – Mixer just controls the fluid flow pattern.** At higher speed and/or lower gas addition rate, the bubbles are pushed out to fill most of the vessel volume, but not uniformly, especially at the bottom. Bubbles are seen to break in moderately uniform pattern across the liquid surface.	Reaction rate system (physical dispersion): The rate of reaction in this type of system is controlled by the rapidity of the chemical reaction of the system. The addition of more gas or mixer horsepower beyond the optimum will not speed up the reaction. Factors other than the rate of mass transfer across the bubble-liquid interface limit the process.
	**Moderate Gas Dispersion – Mixer strongly controls the fluid flow pattern.** Bubbles are driven outward to the wall of the vessel. Only moderate dispersion of bubbles at the bottom.	Moderate mass transfer: Limited mass transfer applications. Used in semi-critical reactors.
	**Uniform Gas Dispersion – Mixer very strongly controls the fluid flow pattern.** The bubbles are reduced further in size and distributed uniformly throughout the vessel with many bubbles recycling through the impeller several times. Surface is seen as a fine uniform froth of bubbles.	Mass transfer controlled: Increasing the gas rate or mixer horsepower will give a corresponding increase in the rate of reaction. Relatively fast chemical reactions and/or relatively high gas addition rates usually characterize this type of process. The rate of mass transfer to or from the gas bubbles directly affects the process result. Typical of fermentors.

Impellers

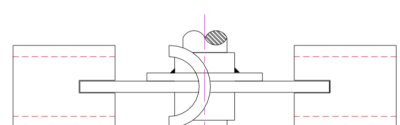
Radial disk turbines are often used for gas dispersion with their D/T ratio in the range of 0.23 to 0.35 to ensure good dispersion. With a “square batch”, a single radial disk turbine mounted 0.5 – 0.75 of the impeller diameter off-bottom is often used. When liquid depth approaches 1.5 times the tank diameter, two impellers should be used with the top impeller having a liquid cover of at least one diameter.

A radial disk turbine is often termed a Rushton Turbine. A modification, using half pipes instead of flat blades, also know as a Smith Turbine, was introduced in the late 1980’s. The Smith Turbine has a lower power number (about 25% less) than the Rushton impeller, and is suitable for Reaction Rate Controlled applications at about 25% less HP/ 1000 gallons, since it will handle more gas without flooding. However, the two styles produce about the same mass transfer results at elevated power levels.

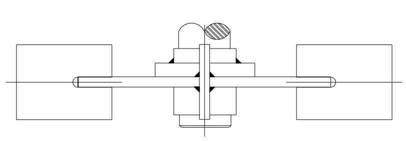
Most axial flow impellers are not suitable for gas dispersion because rising bubbles easily disrupt the opposing downflow from the impeller. An exception is the wide blade hydrofoil. The AH hydrofoil will handle much more gas than a Rushton at equal power, but as with the Smith Turbine, there is no advantage in mass transfer rate at the elevated power levels. The AH hydrofoil is suitable for Reaction Rate Controlled applications at about 35% less HP / 1000 gallon than a Rushton. The AH hydrofoil is also employed on multi-phase applications where good blending and/or solids suspension is also a critical process requirement. At very low gassing rates, e.g. gold leach tanks, the mid solidity (AM) hydrofoil is used as it can effectively disperse a small amount of gas while ensuring suspension of the solids and good tank turn-over.



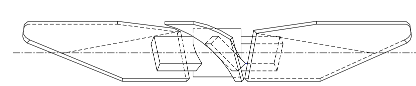
AH HYDROFOIL



RDC IMPELLER



RD IMPELLER



AM HYDROFOIL

Sizing Procedure

- Obtain the actual gas flow rate, Q_G, in cubic feet per minute for the pressure and temperature inside the tank. Often, the customer will provide the flow rate going into the tank at a different temperature and pressure than exists in the tank e.g. SCFM – flow rate at standard conditions (20°C, 1.0 atm). This has to be converted to ACFM for the tank conditions.

- Calculate the superficial gas velocity from the gas flow rate (ACFM).

- Calculate the required horsepower for the desired level of gas dispersion from the table below – dispersion degree assumes water-like viscosity.

Gas Velocity (fpm)	Power Required (BHP) at Gassed Impeller		
	Reaction Rate System (Minimal Dispersion)	Moderate Mass Transfer **(Moderate Dispersion)**	Mass Transfer Controlled **(Uniform Dispersion)**
0.1	0.03 BHP / 1000 USG	0.08 BHP / 1000 USG	0.2 BHP / 1000 USG
0.2	0.06 BHP / 1000 USG	0.13 BHP / 1000 USG	0.3 BHP / 1000 USG
0.5	0.2 BHP / 1000 USG	0.4 BHP / 1000 USG	0.9 BHP / 1000 USG
1.0	0.3 BHP / 1000 USG	0.6 BHP / 1000 USG	1.3 BHP / 1000 USG
2.0	0.6 BHP / 1000 USG	1.2 BHP / 1000 USG	2.5 BHP / 1000 USG
5.0	1.2 BHP / 1000 USG	2.4 BHP / 1000 USG	4.8 BHP / 1000 USG
10	2.2 BHP / 1000 USG	4.3 BHP / 1000 USG	8.4 BHP / 1000 USG
20	4.1 BHP / 1000 USG	7.8 BHP / 1000 USG	15.0 BHP / 1000 USG

NOTES

- Table values based on a Rushton (6RD90) turbine at a D/T ratio of 0.3.
- To achieve Minimal Dispersion at a D/T ratio of 0.25, 25% MORE HP is required
- To achieve Minimal Dispersion at a D/T ratio of 0.35, 25% LESS HP is required
- Smith turbine requires 25% less power than shown to achieve Minimal Dispersion
- AH hydrofoils requires 35% less power than shown to achieve Minimal Dispersion

- For the selected impeller style, determine impeller diameter based on the D/T range detailed in the table below.

Impeller Style	Typical D/T Range
RD	0.22 – 0.35
RDC	0.22 – 0.35
RBT	0.25 – 0.33
AH	0.30 – 0.40

- Select an initial impeller rotational speed. Note that the diameter and operating speed are adjusted to meet the required horsepower while maintaining a proper D/T ratio.

- Calculate the Aeration number, N_{Ae}

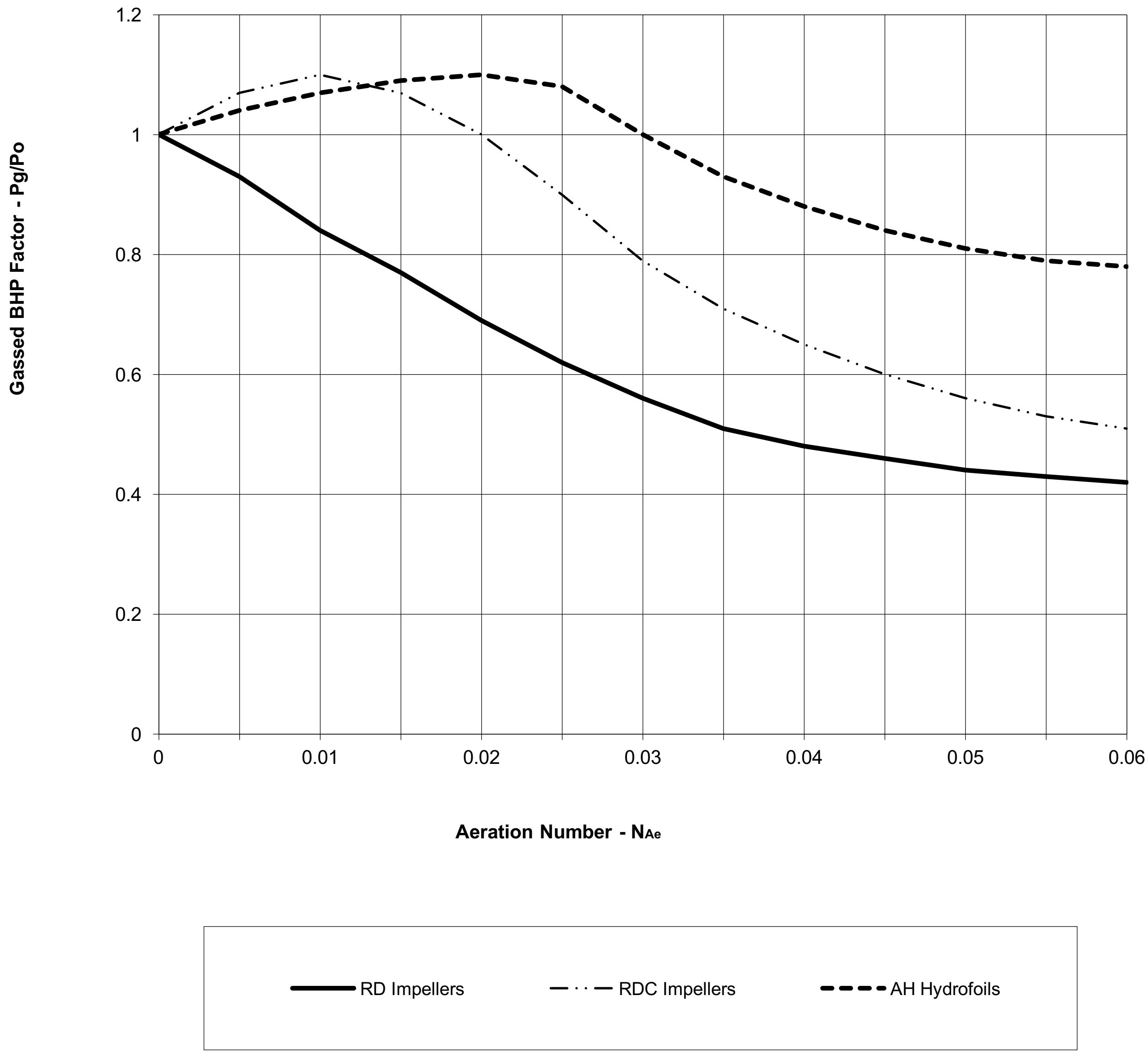
- Refer to the chart P_g/P_o vs. N_{Ae} (on Page 4.06) to obtain Gassed Power vs. Ungassed Power for the chosen impeller style.

- Calculate the Froude number, N_{Fr}

- Calculate the Gas Expansion power, P_{ge}

- Calculate the Flood Factor to determine the degree of gas dispersion beyond flooded and therefore the degree of additional power remaining to accomplish other mixing jobs, i.e. blending and/or solids suspension.

Gassed / Un-Gassed Impeller BHP Factor
vs.
Aeration Number



EQUATIONS

Superficial Gas Velocity (V_G) – Average upward velocity of gas sparged into the tank.

$$V_G = \frac{Q_G}{A_{Tank}}$$

where : Q_G = actual gas flow rate (ACFM)
A_{tank} = cross-sectional area of tank (ft^2)

Aeration number (N_{Ae}) – Dimensionless number used in determining P_g/P_o ratio and flood factor. The Aeration number includes the effects of gassing rate, impeller rotational speed, and impeller diameter.

$$N_{Ae} = \frac{Q_G}{ND^3}$$

where : Q_G = actual gas flow rate (ACFM)
N = impeller rotational speed (rpm)
D = impeller diameter (ft)

Gassed Power (P_g) – Power drawn by agitator when gas is introduced into the vessel. The gas-liquid mixture surrounding the impeller has a lower specific gravity than the fluid alone, and therefore the mixer draws less power.

Ungassed Power (P_o) – power drawn by agitator when no gas is introduced into the vessel (blending of fluid/slurry only).

$$P_o = \frac{SG \times N_P \times D^5 \times N^3}{6.12 \times 10^7}$$

where : SG = specific gravity of the liquid
N_P = impeller power number
D = impeller diameter (feet)
N = rotational speed (rpm)

Gas Factor (P_g/P_o) – Ratio of power draw in the gassed condition to power draw ungassed

Froude number (N_{Fr}) – Dimensionless number used in determining the flood factor. The Froude number is the ratio of inertial forces to gravitational forces (for the impeller).

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

where : N = impeller rotational speed (rpm)
D = impeller diameter (ft)
g = gravitational constant (ft/sec²)

Gas Expansion Horsepower (P_{ge}) – The power of the gas sparged into the vessel.

$$P_{ge} = V_G \times \frac{V}{4000}$$

where : V_G = gas velocity (fpm)
V = equivalent batch volume (US gallons)

Flooding Factor – A value helping to quantify the level of gas dispersion in the vessel. In theory, a flood factor of 1.0 represents the transition point where the system transforms from Flooded to Minimal Dispersion. If the application also requires blending of the fluid and/or suspension of solids there must be enough extra mixing energy to meet these requirements. This normally means that a flooding factor > 2.0 is often required on these multi-phase applications.

$$Flooding\ Factor = \sqrt{\frac{P_g}{P_{ge}}} \times \sqrt{\frac{N_{Fr}}{N_{Ae}}}$$

where : P_g = gassed power (hp)
P_{ge} = gas expansion horsepower (hp)
N_{Fr} = Froude number
N_{Ae} = Aeration number

Hold-Up – Hold-up of the gas in the liquid is defined as:

$$h = \frac{V_g}{V} = \frac{\Delta Z}{Z}$$

where : V_g = volume of gas in liquid (US gallons)
V = batch liquid volume (US gallons)
Z = ungassed liquid depth
ΔZ = increase in liquid level with gassing

For estimating holdup in an air-water system the following equation can be used:

$$h = 3.21(BHP/V)^{0.47}(V_g)^{0.65}$$

where : BHP = impeller brake horsepower (hp)
V = batch liquid volume (US gallons)
V_g = superficial gas velocity (ft/sec)

Gas Sparging Devices

Numerous devices are used to inject gas into a vessel including, single or multiple pipes, sparge rings, plates and inverted cones. The sparging device affects the initial dispersion of the gas, influencing the mass transfer rate i.e. a sparge ring with numerous small outlet holes provides better initial dispersion than three open pipes delivering the same amount of gas. In addition, the sparging device also affects the shaft and impeller loading of the mixer; the better the initial dispersion, the less shock loading on the mixer.

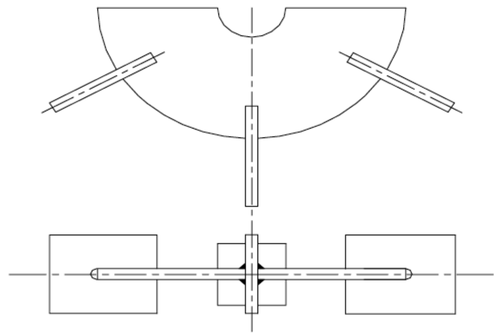
Independent of the sparge type, it is normally preferable to introduce the gas below the impeller at a circumference of 0.8 to 1.2 of the impeller diameter. When a central sparge pipe is used, a disk type impeller (RD or RDC) is mandatory to ensure the gas is forced into the high shear/high flow areas of the impeller for good dispersion.

Impeller Design

The following pages describe the most commonly available mixing impellers, the function of each design and where the individual styles are most appropriately applied. The order of presentation is generally from the highest power number (generally the highest shear) to the lowest power number (generally the highest flow).

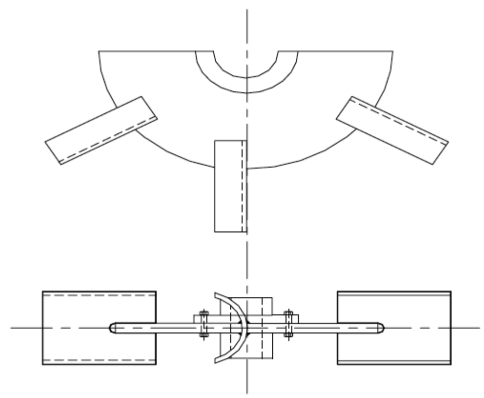
RD

This vertical flat blade, radial flow, disc-type turbine is available as both a 4 and 6 blade design, with the 6 bladed version being the most common. The style is commonly referred to as the Rushton impeller. This high shear device is normally employed on gas dispersion applications.



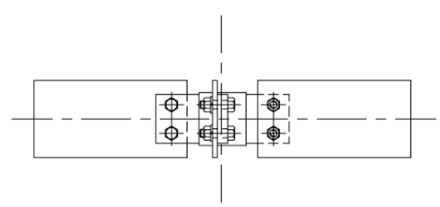
RDC

This impeller is similar to the Rushton turbine except curved blades are substituted for the vertical flat blades resulting in a lower power number. Although it is more expensive than the Rushton it is able to handle more gas before flooding and does not experience as great a power drop-off due to gas loading. However at elevated power levels it produces similar mass transfer as the Rushton design.



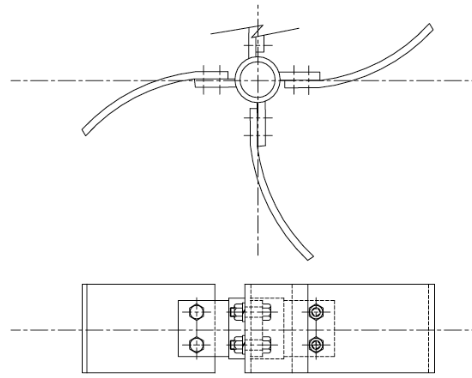
RBT

The Vertical Blade Turbine can be the impeller of choice when very high torque is required for blending applications at the expense of flow efficiency. Other uses for this impeller include high shear applications other than gas dispersion, ie. Liquid-liquid emulsions, solids scrubbing or where low level mixing requirements need an impeller located close to the tank bottom.



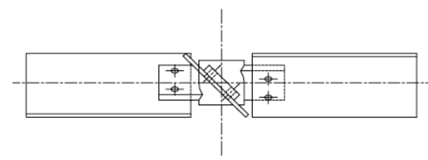
RSB

The Swept Back or Retreat Curve Turbine is the most flow efficient radial flow impeller. It is used in flow sensitive (maximum pumping desired) applications when pumping in the radial direction is required. Typical applications include plug flow break-up, heat transfer, low level blending and low level solid suspension.



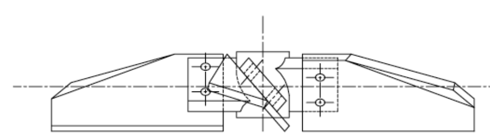
PBT

The Pitched Blade Turbine is more flow efficient than the radial style impellers and produces more fluid shear than the hydrofoil impellers. It is the impeller of choice when both flow velocity and fluid shear is required and/or when very high mixing intensity is required when the use of a hydrofoil would result in too high a tip speed or operating speed. The most common configuration is 4 blades pitched at 45º with the next most common types being either 3 or 4 blades pitched at 32º. The 32º variety can handle slightly higher viscosity and is useful in low level mixing operations. This style of impeller is the least expensive axial flow impeller.



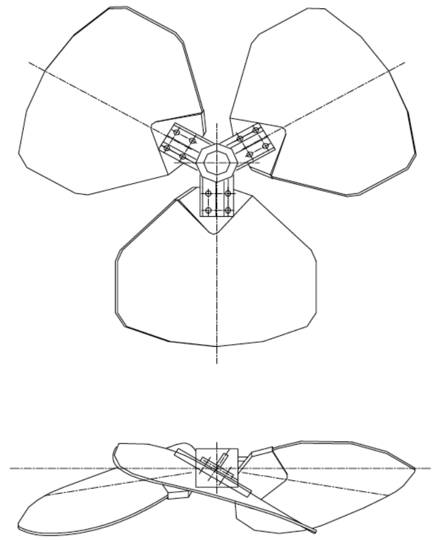
HP

The HP impeller is more flow efficient than a Pitched Blade Turbine and therefore imparts less shear into the fluid. The 4HP45 power number of 1.0 lies exactly in the middle between the 4PBT45 and the 3AL39 which is indicative of its flow and shear characteristics. It is normally used on small to medium size mixers as a cost effective hydrofoil and where applicable should be looked at first. In addition, the HP should be considered on taller tank applications because the HP can invest the same or greater torque into a fluid at lower speeds than a AL impeller normally allowing longer shaft lengths.



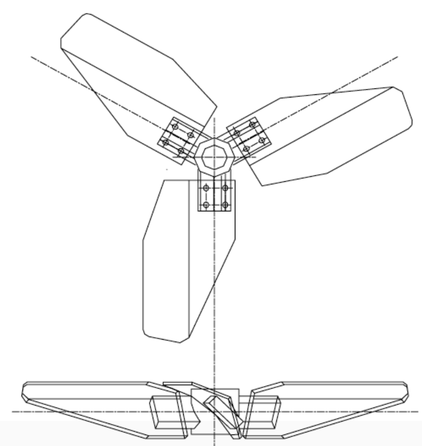
AH Hydrofoil

The AH design is characterized by a very wide blade and is the most flow efficient impeller available for higher viscosity mixing (2500 to 75,000 cps). The AH is the impeller of choice for coarse gas dispersion applications when bottom flow velocities are also required, ie. gas dispersion with solid suspension. The two most common configurations are 3 blades mounted on a 39º hub and 4 blades mounted on a 45º hub. The 3 blade version is used for high viscosity blending while the 4 blade design is for gas dispersion. This style of hydrofoil is sometimes referred to as a “high solidity” design.

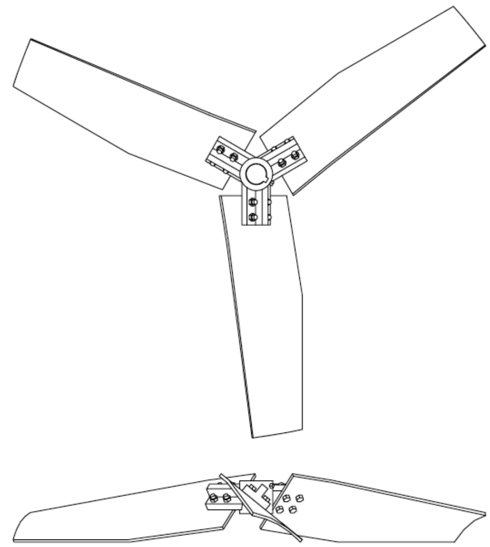


AM Hydrofoil

The AM impeller (N_p=0.35-0.40) with its slightly wider blade than the AL design is useful on applications where viscosities of 2000-5000 cps. are encountered or when a small amount of gas handling capability is required. They are commonly applied to solid suspension applications which have a relatively high percent solids (35-55) particularly when solid size is small which sets up an apparent viscosity in the slurry. This style of hydrofoil is sometimes referred to as a “mid solidity” design.



AL Hydrofoil

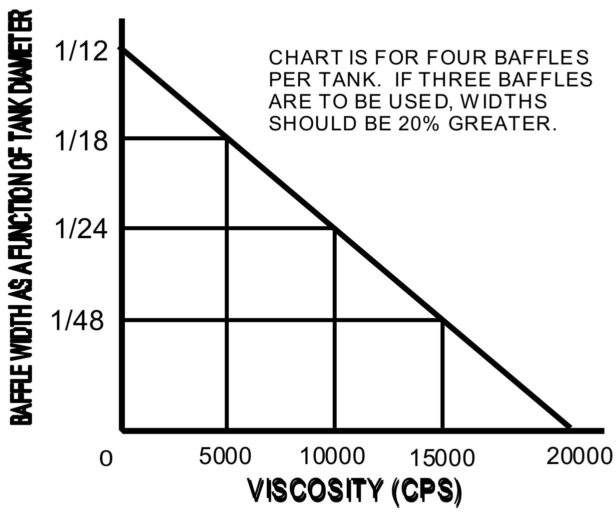


This style of hydrofoil is the most flow efficient impeller for low viscosity (up to 2500 cps) blending applications. It is also used on solid suspension mixing problems where a relatively low percent solids will be encountered (free settling applications). The two most common configurations are 3 blades mounted on either a 45° hub or a 39° hub. This design has the narrowest blades and therefore sometimes referred to as a "low solidity" hydrofoil.

Baffle Sizing

Baffles are required in almost all mixing operations. The following chart shows the relationship of baffle width to fluid viscosity and should be used as a guide for proper baffle selection in round tanks with any combination of mixing impellers. The normal recommendation is for 4 baffles located at 90^o - more than 4 baffles gives relatively little increase in HP draw and virtually no change in the desired flow pattern in the tank. Three baffles located at 120^o, while not our normal recommendation, have been used successfully provided the baffles are wider than normal - see chart below.

Without baffles, it is impossible to load the impellers properly in low viscosity mixtures because of swirling and insufficient top to bottom movement which results in very poor mixing.



The reason for a decreasing need for baffles, as the viscosity increases, is that high viscosity liquids offer fluid flow resistance which produces less swirl and more vertical flow for the same power input as equal amounts of low viscosity liquids.

Off-Wall Location

Ideally, baffles are to be mounted off the tank wall a distance equal to 1/6 of the baffle width. This is necessary to minimize stagnant areas on the back side of the baffle, ensuring complete mixing in the shortest possible time. It is possible to mount the baffles directly against the tank wall on low viscosity (1-500 cps) applications and still have acceptable results. However, on heat transfer applications the baffles should always be mounted off the tank wall.

In the higher viscosity ranges, it is apparent that the off-wall clearance of 1/6 baffle width can be quite small. Therefore in cases where the fluid viscosity is 10,000 cps or greater the baffles should be mounted 1 to 1.5" off the wall.

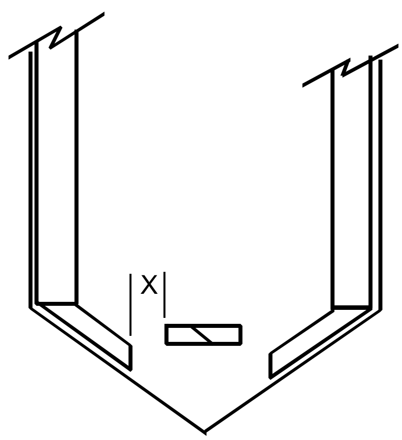
Baffle Height

Normally, baffles run the full straight side of the tank. For surface draw-down of light solids or gas induction from the surface, the baffles should end 10-12" below the fluid surface. When baffles end below the surface, an extended keyway should be provided for the upper impeller to allow for adjustment that may be required to optimize surface vortexing.

Solid suspension applications which require low level mixing (impeller located relatively close to the tank bottom) should have baffles terminate at a point level with the top of the impeller. This is to induce a slight swirl to ensure the particles are in constant motion in the tank bottom.

Tanks with ASME or Semi-Ellipsoidal dished bottoms should have the baffles extend to the lower tangent line of the tank.

Tanks with deep cone bottoms (cone angle over 20º) should have baffles extend into the cone as shown in the sketch below. The baffle width should be 2/3 the width of the main baffles on the tank straight sides. The distance “x” is ½ the impeller diameter.



Deep dished (spherical) tanks should have baffles extend into the bottom head to ensure good mixing results in this region. In addition, if low level mixing is required in a semi-elliptical head these tanks should also have the baffles extend into the lower head. Ideally, the baffle shape should conform to head profile, however, straight baffles have been used with acceptable results. The baffle in this portion of the tank should have the same geometry as for a cone bottom tank.

Baffles in Tanks Equipped with Coils

Helical coils installed in a tank for heat exchange purposes normally offer a very limited baffling effect and therefore it is necessary to install baffles. The normal practice is to install coils with 1.5 to 2 tube diameter spacing between each coil. With this spacing, baffles with standard geometry should be mounted between the tank wall and the coils - the baffle is often used for coil support.

When two rows of coils are installed in a tank, standard baffles should be used as described above and no baffle between the coil rows. Support for the inside row of coils can be arms extending from the baffles but their area should be kept to a minimum.

Vertical tube bundles are sometimes used in tanks and in these cases, the tube bundle side area should be considered as baffles. In most cases with vertical tube bundles, no further baffling is required.

Tanks without Baffles

Occasionally an application will be encountered where baffles cannot be tolerated. In these cases it is possible to achieve acceptable results by mounting the mixer off the tank centre to load the impeller(s) and reduce swirl.

On tanks up to five feet in diameter, mounting the mixer 1/6 of the tank diameter off-centre will normally give reasonable mixing. On larger tanks, 1/4 the tank diameter offset should be used.

Off-centre mounting causes larger than normal fluid forces on the mixer shaft and your selection should be checked by the factory for proper shaft selection.

Baffles in Square or Rectangular Tanks

Baffles are normally NOT required in these tanks provided the application falls into one of the following categories:

- Blending application with a mixing intensity level requirement of Mild or Moderate.
- Two or more mixers mounted in the same tank.
- Blending application with a viscosity of 250 cps or greater.

All other applications should have a minimum of 2 baffles @ 1800 - mounted on the short walls for rectangular tanks.

Fluid Forces Acting on the Baffles

To determine the baffle thickness, a conservative method is to design the baffles assuming the full torque developed is concentrated at a point directly opposite the impeller. The actual forces are distributed over the entire length of the baffle with the highest concentration in the impeller region, however, satisfactory data has never been developed to show the exact force distribution.

The following formula can be used to calculate maximum baffle point loading per baffle in a tank equipped with 4 baffles:

$$F_B = \frac{56{,}800 \cdot HP}{2N(T - B - 2B_C)} \; [lbs]$$

Where: HP = Motor Nameplate Horsepower
N = Impeller Speed
T = Tank Diameter (in.)
B = Baffle Width (in.)
B_c = Baffle Wall Clearance (in.)

With flat baffles and assuming that the force is applied midway between 2 baffle supports, the required baffle thickness can be calculated as follows:

$$B_T = \sqrt{\frac{3F_B L}{2 \cdot B \cdot S}}$$

Where : B_T = Baffle Thickness (in.)
F_B = Force on One Baffle - From Equation 1 (lbs.)
L = Spacing Between Baffle Supports (in.)
B = Baffle Width (in.)
S = Allowable Bending Stress for Steel = 5000 psi.

Scale-Up

One of the most common uses of scale-up technology is to accurately predict mixer requirements in the plant size vessel based on lab or pilot testing. In addition, smaller scale existing applications can be used as a basis for mixer sizing in larger volumes. There are two ways to use scale-up to determine the mixer size required for the new volume, these are:

1. Knowing the type of mixing duty (simple blending, dilute solid suspension, etc.) and details of the process, the appropriate scale-up exponent is picked from the following table and then applied to the scale-up equation.

2. Lab and bench mixing tests are completed and the scale-up exponent is calculated from the test results. This exponent is then applied to the standard scale-up equation.

Common processes with established scale-up exponents are as follows:

Equal Blend Time

This is an unusual requirement and tends to predict the need for extremely large mixers in larger vessels. Some fast chemical reactions with slower undesirable side reactions do require rapid blend times which will limit the maximum volume for these applications which a reasonable sized mixer can handle.

Vortex Action

This type of scale-up is called for when the critical mixing action is the formation of a surface vortex for gas or dry solids induction. This also predicts very large mixers for larger volumes, in other words, it is relatively easy to create a vortex in a small vessel and becomes significantly harder as the working volume increases.

Dispersion

This is a common requirement for shear dependent applications. Gas-liquid dispersions and liquid-liquid dispersions are common examples. Some heat transfer and chemical reactions also fall into this category. These processes typically scale-up as equal power per unit volume.

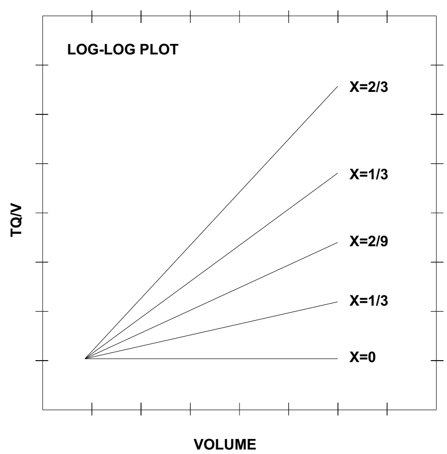
Free Settling Solids

This scale-up rule applies provided the solids being suspended in the fluid have an unrestricted settling rate - refer to TG3, Page 3.04 for details on Hindered vs. Free Settling applications. Free settling generally occurs when the concentration of solids by weight is less than 25-30%. Larger vessels require slightly more torque per unit volume and slightly less power per unit volume than smaller vessels.

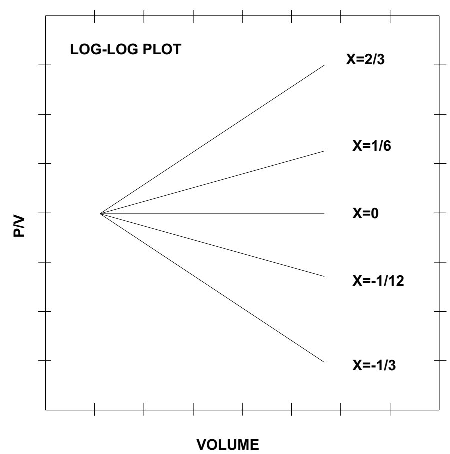
Equal Flow Velocity

This is a common requirement for processes where fluid velocities in a large tank are desired to be the same as in the smaller tank. Most viscous blending applications can be scaled up this way, keeping in mind that the blend time will increase approximately in proportion to the tank diameters. Most hindered settling (>35% solids) applications also scale-up by this rule. Larger vessels require the same torque per unit volume as smaller vessels.

TORQUE/VOLUME SCALE-UP



POWER/VOLUME SCALE-UP



Typical Scale-Up Exponents

Torque/Volume

Application	Exponent, x
Equal Blend Time	2/3
Vortex Action	1/3
Dispersion	2/9
Free Settling Solids	1/6
Equal Flow Velocity	0

Power/Volume

Application	Exponent, x
Equal Blend Time	2/3
Vortex Action	1/6
Dispersion	0
Free Settling Solids	-1/12
Equal Flow Velocity	-1/3

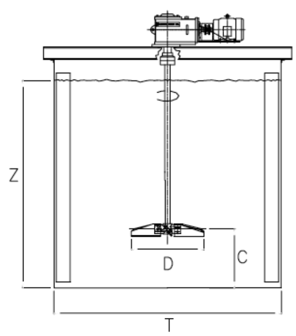
Scale-Up Exponents

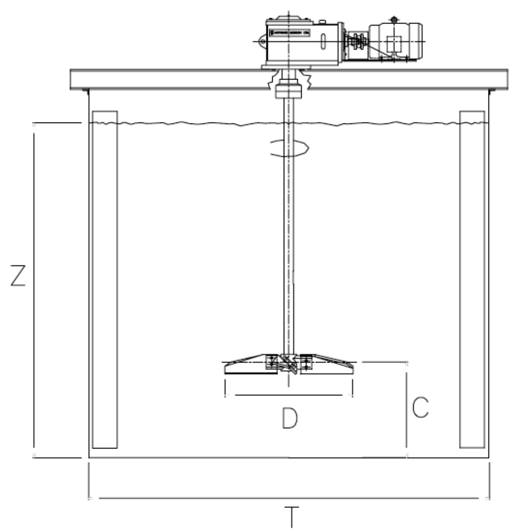
$$\left(\frac{T_Q}{V}\right)_2 = \left(\frac{T_Q}{V}\right)_1 \left(\frac{V_2}{V_1}\right)^x \qquad \left(\frac{P}{V}\right)_2 = \left(\frac{P}{V}\right)_1 \left(\frac{V_2}{V_1}\right)^x$$

Both Torque per unit Volume and Power per unit Volume have been successfully used as scale-up techniques. Torque per unit Volume tends to be constant for scale-up of Equal Flow Velocity applications, common to many blending and hindered settling solid suspension mixing problems. Power per unit Volume tends to be constant when the process requirement is dispersion, typically gas dispersion. Torque per unit Volume is normally the preferred method as it is less sensitive to geometric similarity and it predicts gearbox size directly.

Although the Torque per unit Volume method is less sensitive to geometric changes, it is very desirable to hold geometric ratios as constant as possible. In particular these ratios are:

- D/T - Impeller Diameter / Tank Diameter
- Z/T - Liquid Height / Tank Diameter
- C/T - Impeller Diameter Bottom Clearance / Tank Diameter





In addition to maintaining geometric similarity, the same impeller style should be used throughout the scale-up process.

Shaft Design

The process requirements determine the overall mixer size and configuration, ie. HP, RPM, number and style of impeller(s) etc.; the next step is to design an appropriately sized shaft system. The absorbed Horsepower of the impeller(s) creates torsional and bending stresses on the mixing shaft. The torsional stress is due to the transmitted torque (BHP at the speed of rotation) and the bending stress is due to the fluid hydraulic forces acting on the impeller(s).

Pure Torsional Stress

If a mixer shaft and impeller assembly had no fluid hydraulic forces acting at the impeller we would only be concerned with torsional stress which is the torque transmitted by the shaft divided by its Polar Section Modulus. The formula for Pure Torsional Stress is:

$$\tau = \frac{T_Q}{Z'} = \frac{\frac{HP \cdot 63025}{RPM}}{\frac{\pi d^3}{16}} \quad \left[\frac{lbs}{in^2}\right]$$

Where: HP is motor HP
RPM is impeller speed
d is shaft diameter [in.]

Pure Bending Stress

If we were interested in determining the stress in the shaft due only to the unbalanced hydraulic forces acting on the mixing impellers (ignoring torsional stress) it would be a matter of determining the magnitude of these hydraulic forces and where along the shaft they were acting (impeller location).

The hydraulic forces, created by the action between the fluid and the impeller, produce side loads on the shaft causing this tensile or bending stress. The fluid hydraulic force acting at an impeller is random in both direction and magnitude, we therefore must calculate the maximum possible hydraulic load to determine the shaft stress. The equation for hydraulic loading at an impeller is:

$$F_H = \frac{24000(HP)(CF)}{RPM(D)} \; [lbs.]$$

Where: HP is Impeller Power
CF is a Condition Factor based on impeller style and application (Typ. 1 to 3)
RPM is impeller speed
D is impeller diameter [in.]

After the hydraulic force is found at the impeller(s), the total Bending Moment can be calculated by using the following:

$$M = \{F_{H_1}(L_1)\} + \{F_{H_2}(L_2)\} + \ldots.. \{F_{H_N}(L_N)\} \quad [in - lbs]$$

Where: F_{H1}, F_{H2} ... F_{Hn} are Fluid Hydraulic Forces at each Impeller [lbs.]
L_1, L_2 ... L_n are the distances from the lower gearbox bearing to the impeller [in.]

Finally the Pure Bending Stress can be calculated by dividing the total bending moment (M) by the shaft rectangular section modulus.

$$\sigma = \frac{M}{Z} = \frac{M}{\frac{\pi d^3}{32}} \quad \left[\frac{lbs}{in^2}\right]$$

Where: M is the Bending Moment calculated above [in.lbs.]
d is shaft diameter [in.]

Combined Stresses

When a mixer is operating the shaft is experiencing both bending and torsional stresses, therefore the final step in shaft design is to calculate the combined stresses in the shaft. The combined torsional stress can be found by using the following equation:

$$\tau_{\max} = \sqrt{\left(\left(\frac{\sigma}{2}\right)^2 + (\tau)^2\right)} \left[\frac{lbs}{in^2}\right]$$

And the combined bending stress can be found by using:

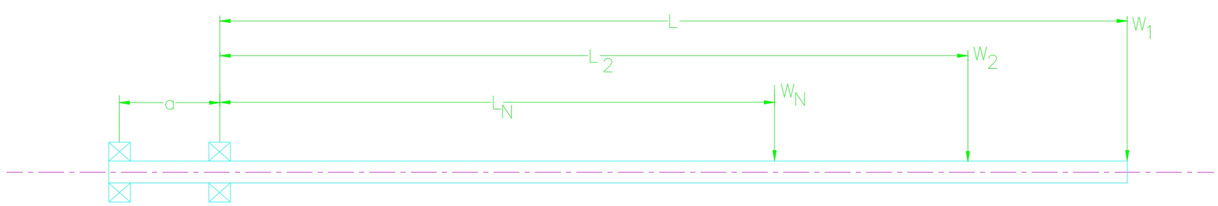
$$\sigma_{\max} = \left(\frac{\sigma}{2}\right) + \sqrt{\left(\left(\frac{\sigma}{2}\right)^2 + (\tau)^2\right)} \left[\frac{lbs}{in^2}\right]$$

Critical Speed

If a shaft and impeller assembly were struck with a hammer, the assembly would begin to vibrate. The vibratory mode with the lowest frequency is defined as the first natural frequency of the system, the next highest is the second natural frequency and so on. Critical Speed is defined as the mixer rotational speed (RPM) which coincides with its first natural frequency (Hz).

Rotating a mixer assembly at a rate equal to its natural frequency is like hitting it with a hammer. However, unlike a hammer which provides a momentary influx of energy, the mixer motor continues to pump energy into the vibrating assembly causing it to oscillate at higher and higher amplitudes until failure occurs. We therefore must calculate the first natural frequency of each mixer assembly to ensure we are not operating near this critical point.

The following equation can be used to determine the first natural frequency (N_C) of a mixer with a uniform solid shaft.



$$N_C = 146.4\left(\frac{d^2}{L^2}\right)\sqrt{\frac{E}{\left(\frac{L+a}{L}\right)\cdot\left(W_B + \frac{4.13W_e}{L}\right)}}$$

Where:

$$W_e = W_1 + W_2\left(\frac{L_2}{L}\right)^3 + \ldots + W_N\left(\frac{L_N}{L}\right)^3$$

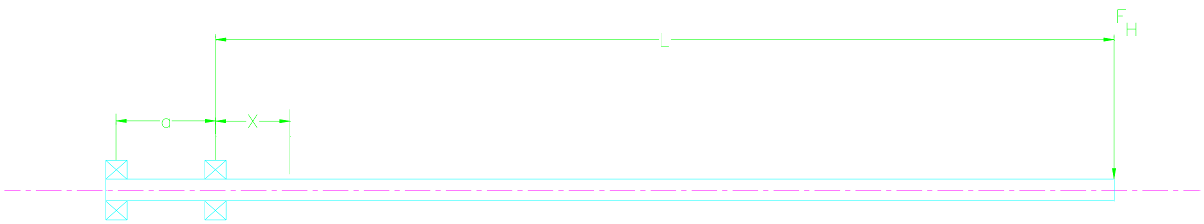
And: d is the shaft diameter (in)
L shaft length from lower gearbox bearing (in)
L_2 ,... L_N is the distance from the lower gearbox bearing to the impeller (in)
a is the gearbox bearing span (in)
W_1, W_2, ... W_N are impeller weights (lbs)
W_B is the shaft weight (lbs/in^3)
E is the Modulus of Elasticity (lbs/in2), ie. E=30,000,000 psi for steel.

Note: All calculations for critical speed assume that the mixer is rigidly supported.

Deflection

When a mixer is supplied with a shaft seal for closed tank applications or when tank internals (heating coils, draft tube, limit ring, etc.) are in relatively close proximity of the mixer wet end, it is necessary to check the shaft deflection due to hydraulic forces at the impeller(s).

The following equations can be used to check shaft deflection in the seal area or at the bottom of a uniform solid shaft:



Deflection at seal:

$$\Delta y = \left(\frac{F_H L^2}{6EI}\right) \cdot \left(2La + 3LX - X^2\right)$$

Deflection at end of shaft (X=L)

$$\Delta y = \left(\frac{F_H L^2}{3EI}\right) \cdot (a + L) \quad where, \quad I = \frac{\pi d^4}{64}$$

And: L shaft length from lower gearbox bearing (in)
a is the gearbox bearing span (in)
F_H is the hydraulic force acting on the impeller (lbs)
E is the Modulus of Elasticity (lbs/in^2), ie. E=30,000,000 psi for steel
d is the shaft diameter (in)
$\in$y is shaft deflection at point of interest (TIR is two times $\in$y)

Mixer Support Design Loads

The mixer support structure is to be designed so that dynamic angular deflection of drive is limited to 0.25 degrees in any direction.

$$Static\ Weight = Sum\ of\ Component\ Weights\ [lbs]$$

$$Dynamic\ Torque = \frac{HP \cdot 63025 \cdot 2}{N}\ [In - lbs]$$

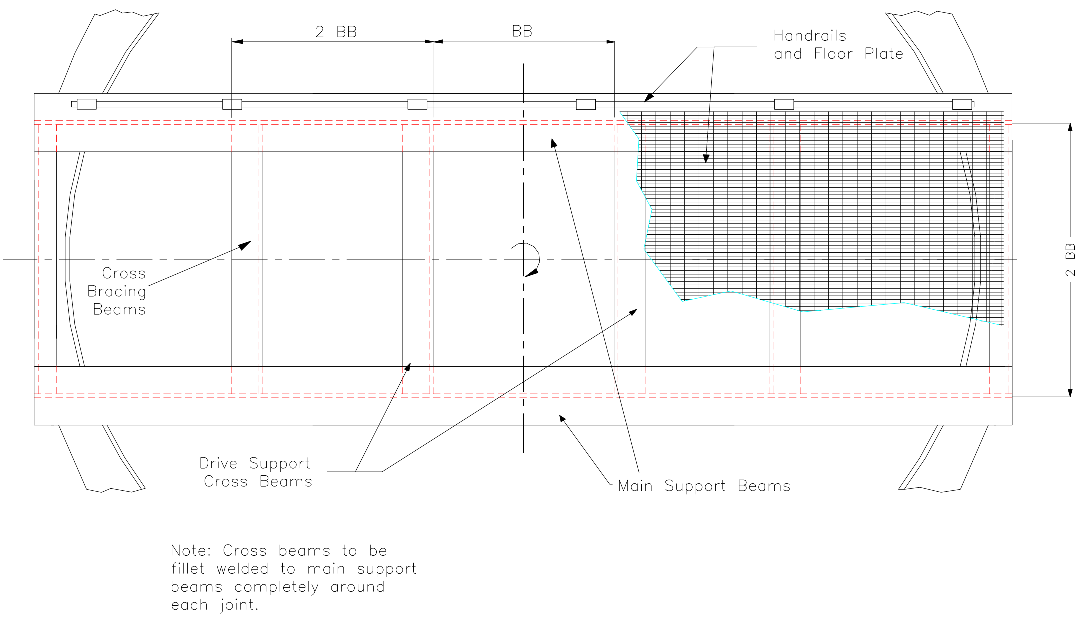
$$Bending\ Moment = \sum_{x=1}^{NI} \left(FH_x \cdot L_x \cdot 2\right)\ [In - lbs]$$

Where:
D is Impeller Dia. in [In.]
N is Impeller Speed [RPM]
NI is the Number of Impellers
HP is Nameplate Horse Power
L_X is distance from impeller to mounting surface [In.]
FH_X is the fluid hydraulic force at each impeller (see Pg. 8.01) [lbs.]

Open Tank Mixer Support Structures

For purposes of use during preliminary investigations, information on practical support construction for mixers mounted above open tanks is outlined here. Suggested beam sizes are rather conservative, and apply for use with the highest output torque capacity of each drive – and at the longest agitator shaft overhangs practical for each size. For maximum economy in a specific installation, it is recommended that the Processor or Engineering Contractor apply his own beam support design standards to the specific mixer that will be utilized.

Some degree of cross bracing between main beams always represents a sound engineering approach. The user is encouraged to apply more sophisticated designs of cross bracing – particularly with the larger tanks where cost of supports can become substantial. It is normal to apply floor plate or grating between the main support beams which provides walkway access while providing additional rigidity in the support structure. This information is intended as a guideline and does not relieve the user of completely analysing the entire mounting system for each mixing application.



"BB" Dimension (inches)

Drive Size												
HRF's	**ST-10**	**ST-11**	**ST-12**	**MB-53**	**MB-54**	**MB-55**	**MB-56**	**MB-57**	**MB-58**	**MB-59**	**LH-9**	**LH-10**
11	10	12	14	12	13	15	17	21	23	23	19	19

Drive Size	Beam Function	Tank Diameter (inches)				
		120	180	240	300	360
HRF's	Main Support	6C10.5	8WF24	10WF33	12WF45	12WF79
	Drive Support	4C7.25	5C9.0	7C9.8	8C11.5	8C11.5
	Cross Bracing	4C7.25	5C9.0	7C9.8	8C11.5	8C11.5
ST-10	Main Support	6WF20	10WF25	10WF60	12WF72	12WF120
	Drive Support	4C7.25	7C9.8	7C9.8	8C11.5	8C11.5
	Cross Bracing	4C7.25	7C9.8	7C9.8	8C11.5	8C11.5
ST-11 ST-12 MB-53	Main Support	6WF25	10WF29	10WF60	12WF79	12WF133
	Drive Support	4C7.25	7C9.8	7C9.8	8C11.5	8C11.5
	Cross Bracing	4C7.25	7C9.8	7C9.8	8C11.5	8C11.5
MB-54	Main Support	8WF20	10WF33	12WF53	12WF92	14WF119
	Drive Support	5WF16	8C11.5	8C11.5	8C11.5	9C13.4
	Cross Bracing	5C6.7	8C11.5	8C11.5	8C11.5	9C13.4
MB-55 MB-56	Main Support	8WF31	10WF45	12WF58	14WF87	14WF142
	Drive Support	5WF16	8C11.5	8C11.5	9C13.4	9C13.4
	Cross Bracing	5C9.0	8C11.5	8C11.5	9C13.4	9C13.4
MB-57	Main Support	8WF35	10WF49	12WF72	14WF103	14WF167
	Drive Support	6WF15.5	6WF15.5	8WF31	10WF33	10WF33
	Cross Bracing	6C13	6C13	8C11.5	10C15.3	10C15.3
MB-58 MB-59	Main Support	8WF40	10WF60	14WF68	14WF127	14WF202
	Drive Support	6WF15.5	6WF15.5	10WF33	10WF33	10WF33
	Cross Bracing	6C13	6C13	10C15.3	10C15.3	10C15.3
LH-9	Main Support	10WF45	12WF58	14WF95	14WF167	14WF264
	Drive Support	8WF31	8WF31	10WF33	10WF33	10WF33
	Cross Bracing	8C11.5	8C18.75	10C15.3	10C15.3	10C15.3
LH-10	Main Support	10WF45	12WF58	14WF95	14WF167	14WF264
	Drive Support	8WF31	8WF31	10WF33	10WF33	10WF33
	Cross Bracing	8C11.5	8C18.75	10C15.3	10C15.3	10C15.3