IMPELLER DESIGN AND PERFORMANCE CONSIDERATIONS FOR INDUSTRIAL MIXING APPLICATIONS

- Mixing Impeller Design
- High Viscosity Mixing Impellers
- Mixing Impeller Flow Patterns
- Mixing Impeller Power
- Mixing Impeller Pumping Rate
- Glossary of Terms
The mixing impeller is a key component of industrial tank agitator design. A tank agitator uses selected mixing impellers rotated in a vessel to create the desired fluid dynamics for the mixing application. This selection is based on process goals and material properties of the mixed fluid.

This white paper reviews impeller considerations for a wide range of mixing applications.

- Part One: ProQuip High Performance Mixing Impellers
- Part Two: Types of Mixing Impellers
- Part Three: High Viscosity Mixing Impellers
- Part Four: Mixing Impeller Flow Patterns
- Part Five: Mixing Impeller Power
- Part Six: Should You Use Impeller Pumping Rate to Compare Industrial Mixers?
- Part Seven: Glossary of Terms Related to Industrial Mixing Impellers
## PART ONE

*ProQuip High Performance Mixing Impellers*

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PART TWO

Types of Mixing Impellers

Common Characteristics of Mixing Impeller Designs

The impeller is a key component of industrial tank agitator design. In technical terms, an industrial tank agitator describes the “application of mechanical motion in order to create fluid dynamic effects that achieve the desired process results.” More simply stated, a tank agitator uses a mixing impeller(s) rotated in a vessel to create the desired fluid dynamics.

There are five characteristics common to all mixing impellers:

- **Flow Pattern:** The flow pattern is a description of the movement of the fluids in a mixed vessel created by the rotation of the mixing impeller.
- **Impeller Power:** The power required to run a specific impeller with a given diameter at a given speed.
- **Fluid Pumping Rate:** The volumetric discharge rate of an Impeller operating at a given speed, measured at the impeller.
- **Fluid Velocity:** The vector quantity of the rate of change of position for the liquid.
- **Fluid Shear:** As applied to liquid mixing, it is that portion of the applied power which appears as turbulence, recycling drag on the blades, etc. It is the action which produces intimate mixing on a microscopic and molecular scale.

A general classification of mixing impellers is based on their characteristic of flow and shear. This relationship is used since all the power a mixer supplies to a fluid produces a combination of flow and shear as illustrated in the following graph.

*Flow and shear are inversely proportional. Knowing the flow and shear characteristics of your mixing process is critical in impeller selection.*
Open Impeller Design for Mixing Applications with Mid-Process Viscosity Changes

The right impeller design is especially important for mixing applications with mid-process viscosity changes (e.g., glue manufacturing). This section looks closer at these applications and how ProQuip tank agitators with Doubly-Pitched HiFlow impellers are ideally suited for them.

Three Primary Mixing Applications with Mid-Process Viscosity Changes for Doubly-Pitched HiFlow Impellers

In general, the Doubly-Pitched HiFlow impeller was developed for use in three primary mixing applications where a significant change in viscosity occurs during the mixing operation:

1. Wide viscosity reactions with materials going from water-like conditions to over 150,000 cps
2. Formation of high viscosity slurries by the addition of a high concentration of solids (i.e., 50%) to a water-like liquid
3. Shear sensitive solids incorporation

How Doubly-Pitched HiFlow Impellers Work

The Doubly-Pitched HiFlow impeller pumps in both directions and induces a vigorous top-to-bottom turnover of a vessel in a typical three impeller configuration without baffles (right). Water-like material circulates without excessive swirling. As viscosity increases, in applications like glue/adhesive manufacturing, top-to-bottom circulation is still maintained because the large diameter Doubly-Pitched HiFlow impeller creates a mixing zone essentially across the mixing tank diameter. This means viscous material cannot bypass the mixing zone because the entire diameter of the vessel is swept by the impeller. The Doubly-Pitched HiFlow impeller provides excellent agitation in the transition zone (Reynolds numbers in the range of 10³-10,000) without requiring tank baffles.

The proprietary design of the Doubly-Pitched HiFlow impeller results in a very low power demand. This makes it possible to use relatively large impellers without requiring excessive horsepower.

Doubly-Pitched HiFlow Impellers Incorporate High Solids Faster

Using the Doubly-Pitched HiFlow impeller, surface movement and overall circulation in the vessel is much greater than could be obtained by another design at the same power level. This allows dry product to be added to the batch at a faster rate. The very large diameter of the Doubly-Pitched HiFlow impeller means that the surface available for pulling down solids is much greater. For example, the addition of dry starch for adhesive manufacturing.
Doubly-Pitched HiFlow Impellers Smoothly Incorporate Delicate and Shear-Sensitive Components

The smooth geometry of Doubly-Pitched HiFlow impellers produces the same low level of shear as our patented HiFlow™ impeller. Combining this low shear and the low power demand for the Doubly-Pitched HiFlow impeller results in an ideal impeller for processes incorporating delicate or shear-sensitive components such as storage floor packaging of personal care products.
PART THREE

**High Viscosity Mixing Impellers**

High viscosity mixing impellers (i.e., laminar flow impellers) include the double helix impeller and ProQuip Doubly-Pitched HiFlow impeller.

**Laminar Flow Impellers**

Blending high viscosity fluids generally requires a mixing impeller that operates effectively in a high viscosity/laminar flow regime. Laminar flow is a fluid flow characterized by long, smooth flow currents, mainly in the same direction as the bulk of the flow with little interaction between them. In a mixing system, these fluids have a calculated Reynolds number less than 2000 (Reference: Industrial Mixing Basics: What is Reynolds Number?). Typical laminar flow impellers include anchor impellers, gate impellers and double-helix impellers.

**Double-Helix Impellers**

A double-helix impeller is commonly used to blend high viscosity fluids operating in a laminar flow regime. The helical ribbons in this impeller are designed for close wall clearance. They operate at relatively slow speeds rotating in a direction to create fluid movement up along the wall. The fluid returns down the center of the tank providing overall blending in the tank. There are many high viscosity polymer applications mixed with helix impellers with viscosities exceeding 500,000 cps.

View this video for a demonstration of the action of a high viscosity fluid with a double helix impeller. A 13.25” diameter vessel with a 12.5” diameter double helix impeller is used in the video. The fluid viscosity is 10,000 cps. The helix is operating in a laminar flow regime. A colored dye is added to allow visualization of the blending with fluid flow up along the walls and down the center. The blend time for this high viscosity fluid is relatively short.

**ProQuip Doubly-Pitched HiFlow Impellers – Open Impeller Design for High Viscosity Mixing Applications**

The ProQuip Doubly-Pitched HiFlow impeller can be used in select high viscosity applications as an alternative to a double-helix impeller design.

The ProQuip Doubly-Pitched HiFlow impeller pumps in both directions and induces a vigorous top-to-bottom turnover of a vessel in a typical three impeller configuration without baffles. Water-like material circulates without excessive swirling. As viscosity increases, in applications like glue/adhesive
manufacturing, top-to-bottom circulation is still maintained because the large diameter Double-Pitched HiFlow impeller creates a mixing zone essentially across the mixing tank diameter. This means viscous material cannot bypass the mixing zone because the entire diameter of the vessel is swept by the impeller. The Doubly-Pitched HiFlow impeller provides excellent agitation in the transition zone (Reynolds numbers in the range of 10-10,000) without requiring tank baffles.

The proprietary design of the ProQuip Doubly-Pitched HiFlow impeller results in a very low power demand. This makes it possible to use relatively large impellers without requiring excessive horsepower.

View this video for a demonstration of the mixing of the same high viscosity fluid used in the double-helix impeller video. The lab scale vessel is 13.25” diameter with three 12” diameter ProQuip Doubly-Pitched HiFlow impellers. The fluid viscosity is 10,000 cps.

The impellers are operating in a laminar flow regime. A colored dye is added to demonstrate the flow patterns and mixing of this high viscosity fluid. The impellers pump down in the center of the mixing vessel and up along its walls. The blend time for this high viscosity fluid using the Doubly-Pitched HiFlow impeller is also relatively short.
PART FOUR

Mixing Impeller Flow Patterns

A primary classification of industrial mixer impellers is their liquid flow pattern in a mixed vessel. This characteristic is used to provide the type of mixing that is desired for a particular application.

Axial Flow Pattern

Axial flow impellers are designed to provide primarily an up and down flow pattern. This flow pattern develops using a center mounted axial flow impeller in a “fully baffled” tank. A center mounted, axial flow impeller in a non-baffled tank will result in rotation of the fluid with little top to bottom motion.

Applications of axial flow impellers include flow controlled liquid blending and solid suspension of particles.

Computational Fluid Dynamics (CFD) can be used to show liquid flow patterns created by an axial flow impeller. The velocity contour plot below shows high velocity below the impeller. The direction and magnitude of flow is shown by a Velocity Vector plot.
The above CFD plots were scaled to match a lab tank video demonstrating axial flow pattern. The video shows a ProQuip HiFlow™ Impeller (axial flow hydrofoil impeller), center mounted in a lab scale baffled tank. The liquid is water. Colored beads are added to aid visualization of the top to bottom flow pattern.

Other axial flow impellers include pitched blade turbines. These impellers also create top to bottom flow patterns but with higher fluid shear rate and power draw compared to High-Efficiency hydrofoils.

**Radial Flow Pattern**

A radial flow impeller provides primarily a side to side flow pattern in a baffled tank. This impeller design provides higher shear to flow compared to axial flow turbines. Typical applications include placement of the impeller close to the bottom of a tank for sweeping vessel floor. Other configurations include high shear applications for solid or gas dispersions.

The CFD plots below are for a radial turbine impeller. The velocity contour plot shows high velocity between the impeller and the tank wall. The direction and magnitude of flow is shown by a Velocity Vector plot.
The above CFD plots were scaled to match a lab tank video demonstration for a radial turbine. This video demonstrates the flow pattern for a 90°, 4-blade radial flow impeller. The impeller is center mounted in a lab scale baffled tank. The liquid is water. Colored beads are added to aid visualization of the flow pattern.
PART FIVE

Mixing Impeller Power

To determine the right mixing impeller design for an application, it is important to understand the mechanical power associated with a mixing impeller in a stirred tank.

The power associated with an impeller is related to four primary factors:

1. Impeller geometry
2. Impeller diameter
3. Impeller rotational speed
4. Fluid properties of the material being mixed

The relationship of these components can be expressed in the following equation:

\[
\text{Power} = N_p \times n^3 \times d^5 \times sg \times K
\]

Np: impeller power number (geometry factor)

n: impeller rotational speed

d: impeller diameter

sg: specific gravity of fluid

K: Reynolds Number (viscosity) correction factor

The value of the dimensionless power number (Np) depends on several factors including impeller design, number of impellers and location within a tank, tank baffling and fluid viscosity. Typically, the power number is shown for mixing in fully turbulent flow. A correction factor can then be applied to take all these factors into account as illustrated above.
The value of the dimensionless power number \( (N_p) \) depends on the impeller design as well as several other factors including the number of impellers, their location within a tank, tank baffling and fluid viscosity.

Changes in both rotational speed and impeller diameter have an exponential effect on impeller power. Accordingly, small changes in impeller speed and diameter can have a significant effect on mechanical power as illustrated below. The graph below plots mechanical power (as an index) verses rotational speed.
Small changes in impeller speed and diameter can have a significant effect on mechanical power.

Although understanding the factors that determine impeller mechanical power is certainly important, this is one of many factors to consider in agitator design.

It is also worth noting that agitator HP by itself is not always a good measure for comparing industrial mixers. The overall design is more dependent on torque. The following example compares two mixers that both use a 5HP motor.

<table>
<thead>
<tr>
<th>Agitator</th>
<th>HP</th>
<th>Operating Speed</th>
<th>Agitator Shaft Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable</td>
<td>5</td>
<td>1750 RPM</td>
<td>180 in-lbs</td>
</tr>
<tr>
<td>Fixed Mount</td>
<td>5</td>
<td>350 RPM</td>
<td>900 in-lbs</td>
</tr>
</tbody>
</table>
The fixed mount agitator above produces five times the torque of the portable. Accordingly, this agitator has much larger components such as gearbox and shafting and will provide a greater degree of agitation.
PART SIX

Should You Use Impeller Pumping Rate to Compare Industrial Mixers?

No industrial mixer topic is subject to more misunderstanding, misinformation, and misapplication than impeller pumping capacity. This may surprise some, since it appears to be THE simple quantitative way to compare different mixers designed for the same application.

The good news is impeller pumping capacity can be a quantitative means to compare industrial mixers. However, there are caveats, and it should not be the ONLY comparative measure you use for the following reasons:

1. It is subject to interpretation

The impeller pumping capacity is subject to interpretation, and it is practically impossible to verify without specialized equipment. With a mixer or pump, you can easily verify actual power by putting an amp meter on the motor. With the pump you can also verify flow performance by putting a flow meter in the line or running a timed transfer between two vessels. But how can you check mixer flow? You can’t.

2. The pumping capacity value has no direct relationship to any specific process requirement in mixing engineering

Impeller pumping capacity is hard to compare on a one to one basis and is subject to “inflation”. The impeller pumped flow has no direct relationship to any specific process requirement in the realm of mixing engineering. You need to evaluate mixer performance, and while some analogies do apply, a mixer is not a pump (as discussed in this white paper).

Continue reading for more information on how ProQuip addresses these problems to effectively use impeller pumping capacity as one of the means to compare industrial mixers.

Defining Mixer Pumping Capacity

Mixing impeller pumping capacity is often equated to centrifugal pump capacity and used to evaluate/compare performance of various agitators. A mixing impeller does have a reportable flow capacity, but it is not directly related to the performance of the mixer in practical applications. To understand this, we first need to look at what mixer pumping capacity is and how it is determined.
At first glance, determining mixer pumping capacity looks pretty simple – at least for turbulent flow. The pumping capacity of a given impeller geometry equals Flow Number (NQ) times impeller speed (N) times impeller diameter cubed (D³) or

\[ Q = NQND^3 \]

This is a dimensionally consistent expression where NQ is a dimensionless constant. If, for example, you take N in RPM and D in feet, you get flow Q in cubic feet per minute. Any other set of dimensions can be used consistently (e.g., RPS and meters for cubic meters per second, etc.). How do we get a value for NQ? It has to be measured, and there are a number of ways to do so. Since NQ depends on impeller geometry, experiment with a sample impeller on a test stand to determine flow capacity.

Measuring Pumping Capacity

There is no practical way to measure impeller flow directly. The standard procedure for an axially pumping impeller is to measure a velocity profile across the face of the impeller and integrate for the resulting flow. Then divide the flow by the test impeller’s ND³ to get NQ.

You might also use laser-doppler anemometry, particle tracking or a number of other techniques that are described in the mixing literature to determine velocity profile. The classical method uses a small propeller velocimeter (which is preferred by ProQuip), but this requires the use of a full-scale test impeller to get good results. We typically make numerous runs at different speeds and with different impeller diameters to ensure consistent results.

Regardless of how you measure pumping capacity, there are problems in interpreting the data:

- The flow readings are unstable. In turbulent flow, you must take data at each test point long enough to get a valid average.
- Vortices are being shed off the blade tips. At about 80% of the impeller radius, the flow direction can totally reverse for a few seconds and then go back to “normal.”
- There is a downward flow beyond the blade tips. This is liquid entrained into the direct flow of the impeller.

You must decide on a method to average your velocity data and an outer bound for your integral. Most of the flow developed by the impeller is generated around the outer portion of the blade. This part of the impeller both moves the fastest and sweeps out the largest area. But this is also the region where the data shows the most scatter and is hardest to interpret.

ProQuip addresses the problem of data scatter and flow boundary by measuring axial thrust and velocity at the same time. Since the density of water is known, we can integrate the velocity profile to get the thrust. If the profile fit to the data is reasonable, then the calculated thrust will agree with the measurements.
Locating the Measurement Reference Plane

Another problem is the measurement reference plane. It is supposed to be at the plane of the impeller, but it is not practical to get measurements there. You cannot stick an instrument into a rotating impeller, and it is hard to measure velocity between the blades even indirectly. You must pick a measurement plane at some distance below the impeller. However, the measured velocity profile varies with distance from the impeller. Because of momentum transfer, the velocity goes down, but the profile widens as you move away from the impeller. This results in an increase in measured flow. So, if you want an impeller to show a higher or lower flow number, relocate the measurement plane.

ProQuip takes measurements at several planes and extrapolates back to the face of the impeller to get reference velocities. We typically find the flow numbers of industrial mixers from other vendors (yes, we test their impellers, too), as well as many commodity-design impeller flow numbers reported in the literature, are anywhere from 10 to 50 percent too high. These are also “consistently inconsistent” with their measured axial thrust.

The increase in flow at different reference planes is real and often reported as “entrained flow” as opposed to “direct flow.” When reporting flow, some mixer vendors will start with direct flow and then multiply by an entrainment factor anywhere for 1.5 to 2.5. A reported flow should state if the basis is “direct” or “entrained.” You should be cautious when using entrainment factors.

What if I Have Multiple Impellers?

If you have two impellers in the vessel, should you add their flows to get a total flow for the mixer? The answer: maybe. An axial flow impeller in a vessel is somewhat analogous to an axial flow pump without a casing.

The question then becomes, “Do I have two pumps in series or in parallel?” If the impellers are in parallel, you can add the flows. If the impellers are in series, the flow is not at all additive and is a strong function of the particular installation.

The real case for your mixer can only be determined from the actual layout of the impellers in the vessel. The impellers-in-series model is closer to reality. The addition of a second impeller has a moderate effect on total flow (but can have a profound effect on the overall flow field in the vessel – discussed in the next post in this series). However, it is common practice to add impeller flows if a pumped flow rate is requested.
PART SEVEN

Glossary of Terms Related to Industrial Mixing Impellers

**Anchor Impeller**
An impeller with vertical blades whose contour closely conforms to the vessel bottom and walls.

**Axial Flow**
The circulation of a fluid from top to the bottom of the tank.

**Axial Turbine**
A turbine with pitched blades (usually 45°) whose discharge is a mixture of Axial and Radial Flows.

**Blade**
One of the vanes on any type of Impeller, sometimes misused to indicate the whole impeller.

**Cleanup Impeller**
See Slinger

**Computational Fluid Dynamics**
A branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows.

**Flooding**
In gas-liquid mixing, an excessive accumulation of gas around 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.

**Gate Impeller**
An Anchor type impeller having additional horizontal and vertical blades.

**Helix**
A type of impeller consisting of one or more narrow ribbons which spiral around the shaft, affixed to arms mounted on the shaft, and having a diameter near that of the vessel: It is used for high viscosity liquids or solids.

**Impeller**
The portion of the agitator imparting force to the material being mixed. Propellers, Turbines, Gates, Anchors and Paddles are all types of Impellers.
**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.

**Paddle**
A two-bladed impeller whose diameter is usually greater than 60% of the tank diameter.

**Paste Mixer**
A mixer with a modified Anchor Impeller, having several vertical bars or fingers which intermesh with stationary baffles extending down from the tank top. Used to make low to medium Viscosity pastes such as caulking compound.

**Pitch**
For a turbine, the angle the blades make with a horizontal plane.

**Power Number**
A dimensionless ratio used in calculating Impeller power loadings. Impellers of similar design but different sizes will have equal power numbers under dynamically equal conditions.

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

**Pumping Rate**
The volumetric discharge rate of an Impeller operating at a given speed, measured at the impeller.

**Radial Flow**
The movement of a fluid generally from the center of the tank to the wall.

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

**Radial Turbine**
A turbine whose blades are vertical and whose discharge creates radial flow.

**Scrapers**
Flexible or hinged members attached to the outer periphery of an Anchor Impeller to scrape the tank wall, preventing buildup and improving heat transfer.
Shear
As applied to liquid mixing, it is that portion of the applied power which appears as turbulence, recycling drag on the blades, etc. It is the action which produces intimate mixing on a microscopic and molecular scale.

Slinger
(1) A device attached to a shaft above the liquid level to prevent the liquid from climbing or splashing up on the shaft.
(2) A small Impeller placed as low as possible in a tank to agitator the "heel" when the tank is nearly empty. Sometimes called a Cleanup Impeller or heel agitator.

Stabilizer
A device attached to an impeller which directs the fluid flow pattern generated by rotation so as to resist shaft deflection. Useful when the mixer is mounted with the shaft at an angle off vertical.

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

Turbine
A multi-bladed (usually four or more), relatively short armed Impeller. The impeller diameter to tank diameter ratio usually varies from 0.2 to 0.5 for turbines. Curved Blade Turbine - A Radial Turbine whose blades form arcs. Single Inlet Turbine - A Radial Turbine with one face shrouded for the purpose of controlling the direction of fluid flow. See Lifter Turbine. Lifter Turbine - A Single Inlet Turbine which is open at the bottom of the blades.

Viscosity
The measure of resistance of a fluid to flow when a force is applied to it. See Apparent Viscosity. Absolute Viscosity is usually measured in centipoises (cp). Water at room temperature has a viscosity of one cp. Kinematic Viscosity is reported in many different forms depending on the measuring instrument. It is convertible into centistokes. Centipoises equal centistokes multiplied by Specific Gravity of the fluid.

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

For additional information on impeller design and performance considerations for industrial mixing applications, go to the ProQuip Applications Data Sheet or contact us at 330-468-1850 or applications@proquipinc.com.