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# Selection of Impellers

## For New Generation Process Plants

**Vineet Shroff**

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# Selection of Impellers

## for New Generation Process Plants

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SYNOPSIS

The agitator is the pulsating heart of the chemical plant. Unit processes in chemical engineering are very often dependent on the mass transfer and heat transfer characteristics that the agitator imparts to the operation. The impeller is the primary component of the agitation system which imparts the requisite mass and heat transfer.

This article talks about different type of impellers and their influence on mixing.

Mixing is often defined as the reduction in phase concentration or temperature heterogeneity to achieve a certain process result. When further extended, this translates into breaking down larger eddies to the smallest eddy to ensure diffusion of one phase into the other.

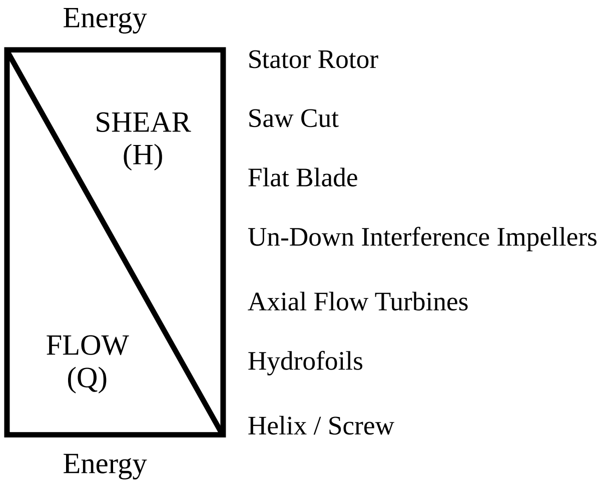
Selection of proper impeller system is therefore critical to ensure requisite process performance, be it mixing time, yield, particle size or by-product minimization.

### History

The earliest mixing systems were mechanical devices, manually operated, akin to that of paddles or oars used in rowing. With the industrial revolution and the steam engine, came the concept of propellers to achieve linear motion of ships. In a ship, the reaction force of the liquid push, propels it ahead. In the earliest mechanized mixing systems, the ship or marine propeller was mounted vertically and used to push liquid in an axial direction to achieve blending. This concept evolved into anchors and paddles for use in high viscosity and high solids concentration systems. Subsequently, in the 1960s, with a better understanding of mixing, the axial flow (pitched blade) and radial (Flat blade or Rushton) turbines were born. Later, the concept of energy efficient processes gave rise to hydrofoils and interference flow impellers. Today, requirements of stringent specifications, complex molecules and high quality, demand composite impeller systems.

### Impeller Energy Spectrum

The energy imparted for mixing gets divided into two components. Flow (Q) and Shear (H).



Flow in a mixing system = $K_Q \times N \times D^3$
Head in a mixing system = $V^2/2g$ a $N^2 D^2/2g$

The proportion of allocation depends on the type of the impeller. Stator rotors and Saw Cut impellers provide high shear, hydrofoils provide high flow. The requirement of shear or flow and combinations thereof depend on the process requirement. Tasks like blending and suspension require more flow and those like gas dispersion and emulsification require high shear. Heat transfer usually requires a combination.

### Power Consumption

Power consumption of an impeller is a function of Reynolds No. and Froude No.

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$$\begin{aligned}\text{Power} \quad &\alpha \quad Q \times H\\ &\alpha \quad (ND^3) \times (N^2D^2)\\ &\alpha \quad N^3D^5\end{aligned}$$

Based on this, co-relation has been established for power consumption of an impeller in the turbulent region as :

$\text{Power (HP)} = 6.25\text{E-}6 \times K_p \times N^3 \times D^5$

Where, $K_p$= Power no. of Impeller, N= Speed in RPM and D=Impeller Diameter in metres.

For conventional hydrofoils $K_p$=0.35, for Axial flow turbines, $K_p$= 1.2, for Flat blade disc trubines $K_p$ = 5.2, for Up-Down Interference Flow impellers, $K_p$ =0.65.

## Impeller Types

**Hydrofoils** : In aircraft wing section aerofoils, the concept of energy optimization involves maximization of Lift to Drag (L/D) ratio. In the case off hydrofoils, the focus is on maximization of the thrust to drag (T/D) ratio. Thrust imparted to a cylinder of fluid below the impeller has to be maximized and drag or fluid loss encountered by the rotating impellers has to be minimized.

Thrust maximization is done by ensuring that the entire energy is uniformly imparted to the fluid just below the impeller i.e. there is no dissipation or divergence of energy.

In an Axial flow Turbine, as one moves from the center of the impeller to the tip, the velocity increases in direct proportion to the radius. V= w.r. With this increase in velocity there is a corresponding increase in flow momentum as one move from the centre of the impeller to it's tip. This means that momentum imparted to liquid below the centre of the impellers is less than that imparted to that below the tip of the impeller. Therefore, some fluid from below the tip will move towards the centre thus causing an inefficiency in the axial flow of the liquid mass as a whole.

In a hydrofoil, the increase in flow momentum due to increase in velocity, is compensated by a reduction in mass pushed by simply reducing the impeller cross sectional width. This effect is further enhanced by reining in the centrifugal forces, by an angle change with respect to the horizontal. This combined action ensures thrust maximization in a hydrofoil.

Drag reduction is achieved by a reduction in the angle of attack of the hydrofoil blade and by a curvature imparted that delays flow separation from the leading edge. This combined action of increased thrust and reduced drag, allows for an increased flow efficiency of hydrofoils.

The concept of flow momentum equalization can also be extended upstream of the impeller in designing impellers that have higher efficiency in suction from the top surface. This is often required in processes where acids that cause pH hotspots are added from the top or where there are solids with poor wettability and low bulk density that need to be suspended for the reaction.

Hydrofoils by design are conventionally low shear, high flow impellers. But very often there is a need for a combination of shear and flow. Say for example in dissolution of sparingly soluble components. Hydrofoils hybridized with axial flow turbines provide necessary combination of flow and shear.

The hydrofoil has thus emerged as the impeller of choice for the new generation of process plants, which by a judicious selection of type, diameter and speed can address a vast spectrum of process requirements.

**Fig. 1 below shows some of the hydrofoil systems in use.**

Hydrofoils are ideal for operation like blending, pH control, dilution, dissolution, mixing, solid suspension, crystallization, liquid-solid reaction, solvent extraction, washing etc.

Axial Flow Turbine requires approximately 70% higher energy than hydrofoils. And, at the same energy consumption, an axial flow turbine, will deliver approximately 60% of the hydrofoil's Pumping.

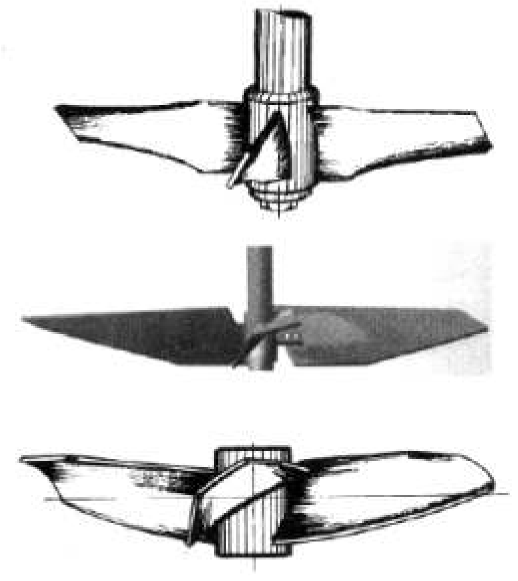
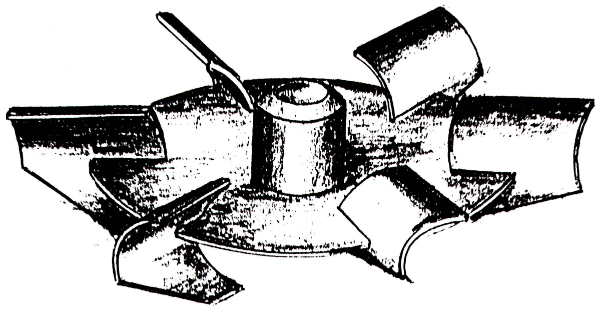


Fig. 1 hydrofoil systems

**Dispersers :** Concave blade disc turbines, Axial dispersers and Gas induction systems.

While hydrofoils are replacing axial flow turbines and propellers on the flow front, modern developments on the head front today see conventional Rushton turbines being replaced by concave blade disc turbines, high solidity ratio axial dispersers and gas induction impellers.



These impellers are finding increased usage in operations like, gas liquid dispersions for hydrogenation, fermentation, chlorination, ozonation and immiscible liquid applications like hydrolysis, extraction, suspension polymerization, washing with immiscible solvents, etc.

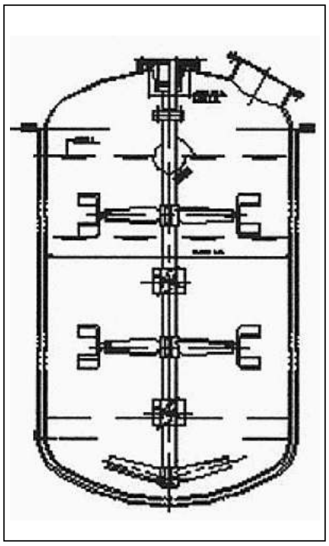
Three slightly different techniques have been used to increase the velocity head of the reacting components into each other, be it gas into liquid or immiscible liquid into another liquid.

In concave blade disc turbines, the quantum increase in performance has come about by an understanding of the trailing vortex phenomena. It was observed that when gas flow rates through the sparger were increased, the Rushton turbine would get flooded. A need was felt to increase the gas handling capacity of the disperser turbine and an innovation like making the flat blades into concave, angled or parabolic (elevational profiles) allowed this by ensuring that the gas being sparged, did not escape over the top of the blade, but was forced to see the zone of highest shear, viz. the tip of the impeller. This ensured breakdown into smallest bubble size and therefore highest mass transfer area.

High solidity axial dispersers evolved from extending the function of the disc in a Rushton turbine. The disc in the Rushton turbine prevents the gas from travelling up the zone of least shear (near the shaft). The gas sparged from below the disc, is blocked by it and the radial flow pattern carries it towards the impeller tip where it then sees the zone of highest shear and gets broken into smaller bubbles. Axial high efficiency dispersers, either have a disc or have overlapping blades that prevent the gas from rising up along the shaft. The D/T ratio of these impellers is often increased to entrap the gas going along the vessel walls as well as by bringing it back into circulation.

In gas induction systems, the tip of rotating impeller blades is used to induce gas from the vapour space above the liquid surface into the liquid surface and discharge it through the orifice on the rotating impeller blades. This ensures that the gas passes through the zone of high shear. It is also used to bring the unreacted gas that has escaped into the vapour space, back into the system. Normally, these designs are used for low H/D ratios as the impeller induced discharge pressure has to be higher than the pressure due to the liquid column plus the pressure in the vapour space above the liquid.

**Up-Down Interference flow impellers (UDIF):** Whatever goes up must come down, and if we may add, in mixing, whatever goes down, must come up. In axial flow impeller systems, conventionally, liquid is pumped down by the impeller. After it reaches the bottom, it has to turn 180 degrees often under the blocking influence baffles and move up along the vessel walls. An interesting school of thought visualized, that why not have the same impeller aid in both the down flow in the centre and the up flow along the vessel walls. This is one of the primary concepts in the UDIF type of impeller systems. The other concept in this impeller is that it uses hydrodynamic slip streams. The V-shaped flying formation of birds; the collective swimming of shoals of small fish are examples of the principle that less energy is required when the trailing entity moves in the turbulent slip stream created by the leading entity. This principle used in the UDIF almost doubles the performance with a marginal increase in energy consumption. In addition, to the above two winning concepts, the UDIF impeller systems have several other advantages. A large D/T ratio (Impeller diameter to Tank diameter) ensures that the impeller sweep is close to the vessel walls, thus proving useful in cases where a film formation tendency tends to reduce heat transfer along the vessel walls.



A large D/T ratio also inadvertently increases pumping. The UDIF impellers, being two bladed, can be easily fabricated in split hub construction. This allows any impeller to be placed anywhere along the shaft, thus allowing fine tuning of operations based on different batch sizes and different start up conditions. These impellers can also be used without baffles due to the flow turning characteristics of their construction. Additionally, at the point of throw change (inner and outer) portions, there is a zone of high shear, which can be used to advantage for inlet of reactants and gases to be dispersed. Another great flexibility provided by these impeller systems is in complicated multi-phase reaction systems, gas -liquid- solid. In such systems, the inner portion of the bottom impeller can be made up throwing. The inner portion of the topmost impeller can be made down throwing thus forcing a vortex that draws the unreacted gases back into the reaction zone.

These impellers have proved versatile in meeting a vast range of mixing needs and have been particularly useful in situations where both flow and shear are required in good measure. Proper design and selection are critical in making these systems work in tandem.

UDIF impeller systems have found use in crystallisers, polymerisation reactors, high solids content slurry preparation, high viscosity blending, reduced scaling/ deposits on vessel walls and better heat transfer, multi phase mixing (gas dispersion).

**High Shear :** High shear impellers come in two types open and closed.

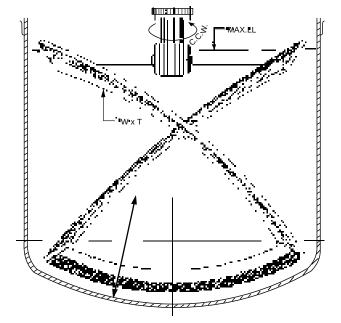
Open systems include Sawcut (Cowles disc) and closed systems comprise of Stator- Rotor assemblies.

Modern trends in the saw cut impellers have been towards larger diameters, with more teeth providing bigger zones of high shear mixing.

Modern trends in stator rotor assemblies have been towards multiple rows of stators and rotors leading to multiple zones of sequential shearing to break down particle size. Micro mixing with in line stator-rotor assemblies is another area of increasing interest.

**High Viscosity Mixers :** The mainstays of high viscosity mixing systems have been Anchors and Helices. These continue to rule the roost, albeit with some interesting hybridization.

The fundamental flaw in the anchor has been its inability to deliver a structured axial flow pattern in the reaction mass. This leads to hetrogeneity in temperature when heat transfer is carried out, with large gradients between the vessel wall and centre. This also a leads to large hetrogeneity in solid concentration when solids are present either as reactants or as products.

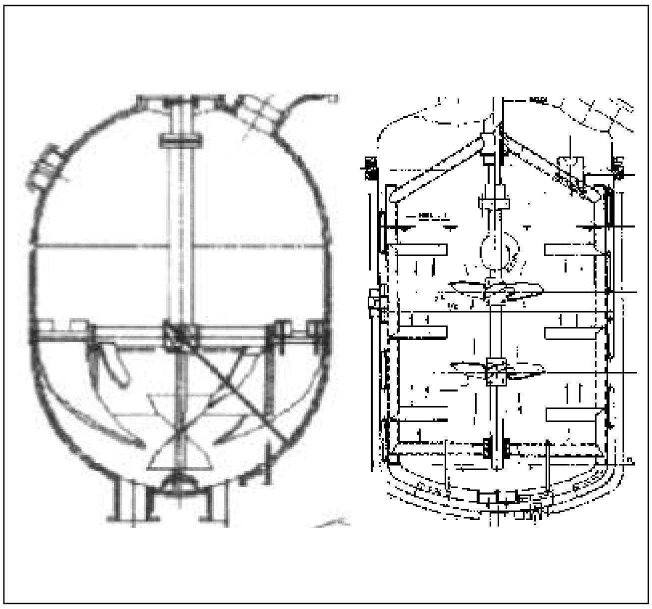


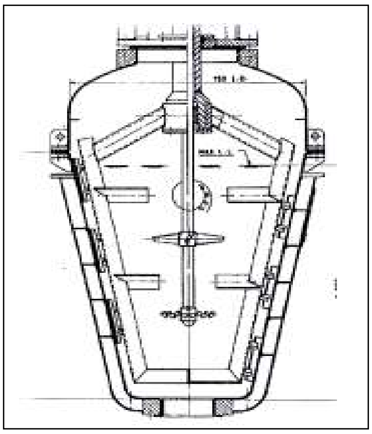
The biggest deterrent to prolific use of helices has been the large cost of construction. Even single helix flights have ended up being uneconomical from capital cost considerations.

The new solution to both these issues has been the hybridization of the anchor and helix into an impeller system the Helixan. This has the advantage of an helix. Various combinations of stiffeners and cross arms allow for good flexibility in fine tuning to the precise needs of different processes including wall scrapers.

For certain extremely high viscosity applications like polymerization, this same concept is used in conjunction with hemispherical vessel construction to good effect.

**Co-Axial Systems :** Modern processing needs extend to complicated combinations within the same process and simultaneously in the same reactor. There is often a need to react or blend high viscosity components. High viscosity mixing can be done only with good shearing. This is achieved with counter rotating, mixing systems, with two co-axial shafts moving opposite each other. Hydraulically loaded wall scrapers, ensure good heat transfer and temperature homogeneity, while axial





cross arms, provide intense intermixing. Independent drives provide opportunity to have different speed combinations for the inner and outer mixing systems. One example of such requirements is in the manufacture of grease.

Another example off fundamentally deviant mixing needs is when dispersions (solid or liquid) need to be carried out into high visosity, non-newtonian systems, such as polymers, epoxy resins, rubbers, oils, high solid slurries. Here the mixing system needs to have a good axial flow characteristic for the bulk viscous mass as well as high shear capability to intimately disperse the added phase into the bulk phase, breaking any agglomerates that tend to build up.

These systems essentially comprise of high viscosity closed impeller system such as a helixan and a co-axial high speed , high shear impeller.

**Conclusion**

Desired process results can be easily achieved at the laboratory scale, often by brute force (higher energy levels ) and because of ease of homogeneity in small vessels. At the industrial scale, increase in complexity due to size and performance requirements, as well as energy and capital cost constraints, the optimal selection of the impeller system remains an art based on experience, innovation and capabilities coupled with perseverance.

Power saving is driving the use hydrofoils where formerly axial flow turbines and propellers were used.

Rapid transition from batch to continuous processes and from thin fluids to high viscosity, multi phase systems, is driving the need for composite mixing systems.

* * *