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MIXING WITH OPEN IMPELLERS IN HIGHER VISCOSITY FLUIDS

Laser designed impeller brings high efficiency technology to high viscosity applications.

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ABSTRACT

Mixing technology is advancing rapidly. The advent of high flow efficiency impellers has drastically improved the processing capabilities of the chemical industry. The first high flow efficiency impellers were designed primarily for low viscosity blending and solids suspension. Now there is a whole family of high efficiency impellers; one for gas-liquid applications, another for the paper stock industry; and a third for draft tube circulators. In this paper, the term high efficiency impellers will mean the class of impellers that deliver high flow for lower power consumption. Research and development has been conducted for a high efficiency impeller for high viscosity applications. Results show that this impeller is more efficient than the pitched blade turbine, the current industry standard. This new high efficiency impeller has a blend time that is half that of a pitched blade turbine at equal power draw. When compared at equal blend time, the high efficiency impeller requires less than half the power of the pitched blade turbine.

INTRODUCTION

As the chemical industry progresses, an increasing number of processes involve higher viscosity materials. Usually, complete mixing of the higher viscosity materials is vital to most of these processes. But what does the term "high viscosity" really mean? High viscosity behavior is the operation of an impeller in a non--turbulent regime, either laminar or transitional. This article addresses the use of open impellers operating in the transitional regime. An open impeller is one that is not restricted by physical boundaries. The pitched blade turbine (PBT) and the propeller are examples of open impellers. Anchor and spiral impellers are examples of closed or close clearance impellers.

Not only is the term "high viscosity" ambiguous, but also it is misleading. Although viscosity does affect the fluid regime in which an impeller operates, there are other factors to consider such as the system geometry, impeller speed, and fluid density. It is actually the combination of these, the Reynolds number, that affects the fluid behavior. Figure 1 shows the effect of impeller diameter and viscosity on the Reynolds number and flow regime. As an example, a typical transitional regime for a 2000 gallon tank occurs between 8000 to 50,000 centipoise.

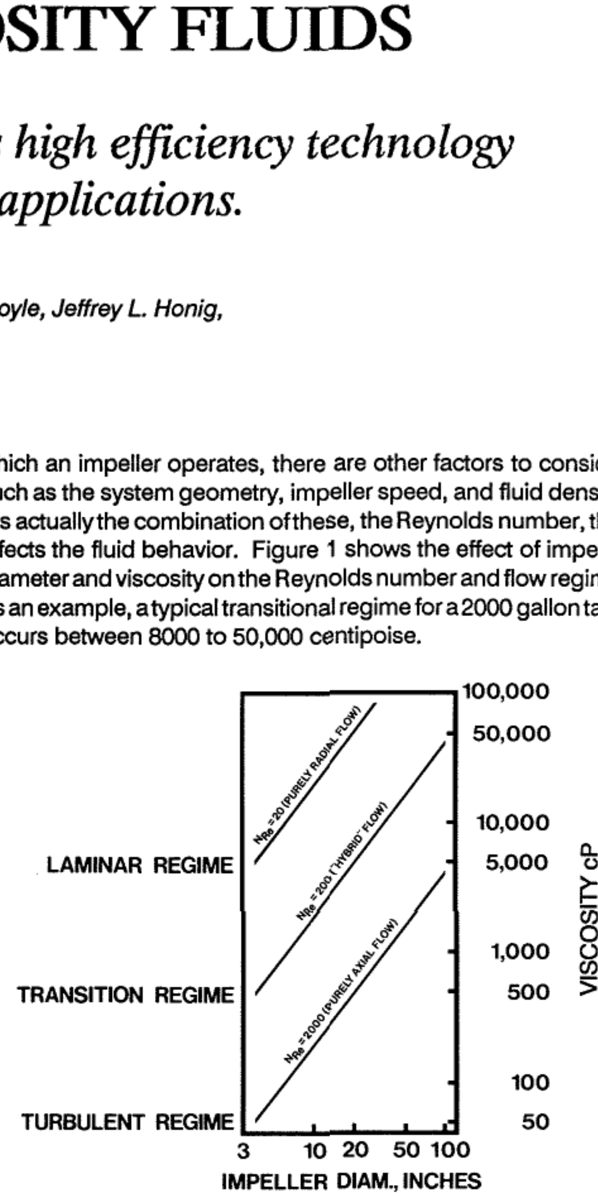

Figure 1

By far, the most common process requirement for high viscosity materials is uniform macro-scale blending of ingredients. Macro-scale blending means uniformity of particles greater than 1000 microns. Uniform blending results in an entire tank having a single property; that property could be color, pH, viscosity, temperature, etc.

To achieve a uniform blend, there are many types of impellers from which to choose, including high efficiency impellers. Most high efficiency impellers have been designed for low viscosity blending. However, the high efficiency impeller spectrum has branched out to include specialty applications including gas-liquid dispersion, paper stock processing and draft tube circulation. Now research has been done to develop a high efficiency impeller for higher viscosity applications. This impeller has been designated the LIGHTNIN® A320 high efficiency impeller.

NON-NEWTONIAN FLUIDS

High viscosity fluids often have non-Newtonian behavior. A Newtonian fluid is one whose viscosity is independent of shear rate and time. Table 1 compares a Newtonian fluid with four types of non-Newtonian fluids. There are two types of non-Newtonian behavior associated with shear rate. A dilatant material is one in which viscosity increases as shear rate increases. High concentrations of starch slurry exhibit this property. When the viscosity decreases as shear rate increases, the material is pseudoplastic or shear thinning. This is the most common type of non-Newtonian fluid found in mixing applications. Most types of polymers and paints are in this category. Other kinds of non-Newtonian fluids are those which exhibit a change in viscosity with time at a constant shear rate. If the viscosity increases with time, the material is rheopectic. If the viscosity decreases with time, the material is thixotropic. A fifth type, a Bingham plastic requires a minimum shear stress before any flow will occur in the material - refer to Figure 2. Mayonnaise and high solids inks quite often exhibit this behavior. Pseudoplastic fluids are typically reflected in mixing systems by the following power law equation:

$$\text{Viscosity} = K \times (\text{shear rate})^{N-1}$$

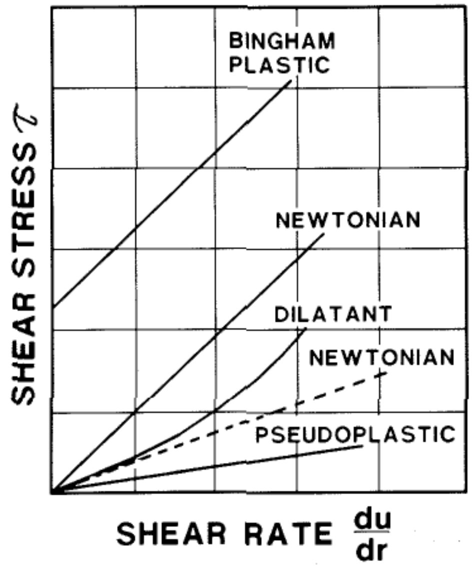

Figure 2

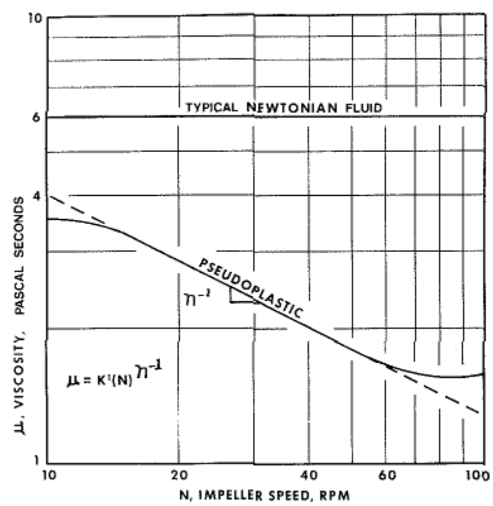

Figure 3

RHEOLOGY DEFINITIONS
EFFECT ON VISCOSITY, μ, OF

DEFINITION	TIME INCREASE	SHEAR RATE INCREASE
NEWTONIAN	NO EFFECT	NO EFFECT
NON-NEWTONIAN		
PSEUDOPLASTIC	NO EFFECT	DECREASE
DILATANT	NO EFFECT	INCREASE
THIXOTROPIC	DECREASE	NO EFFECT
RHEOPECTIC	INCREASE	NO EFFECT

Table 1

Figure 3 illustrates that the viscosity of a typical pseudoplastic fluid may have a complex correlation with shear rate. The power law can only approximate certain areas of the viscosity curve. Typically the power law is adequate as long as viscosity measurements are taken within the range of shear rates "seen" in the tank.

IMPELLER AND PROCESS VISCOSITIES

Since most materials exhibit pseudoplastic behavior, it is very important to define viscosity at a specific shear rate. When sizing mixers, we are concerned with viscosity at the impeller shear rate and the process shear rate. Impeller viscosity is the viscosity the impeller "sees" at the impeller shear rate. For any given impeller type, this shear rate is independent of impeller diameter. It is a function of rotational speed only. Therefore, a given impeller type operating at 100 RPM will see the same viscosity no matter what its size. Different impeller types will, however, have different shear rates at the same speed. Impeller viscosity is used in the calculation of mixer power draw.

Process viscosity is the viscosity the process sees. It is different from the viscosity the impeller sees. It is the viscosity at the average shear rate throughout the entire tank, otherwise known as the process shear rate. For a given impeller type, the process shear rate is a direct function of the impeller speed and turbine diameter to tank diameter ratio. Once again, different impeller types will have different shear rates. Process viscosity is used in the determination of process result calculations, including blend time.

REYNOLDS NUMBER

The impeller and process viscosities indirectly affect the impeller performance as a result of their relationship in the Reynolds number. The Reynolds number directly affects the performance of the impellers.

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

As the Reynolds number decreases, the power draw of an impeller increases, all else being equal. Figure 4 shows the effect of the Reynolds number on the impeller power number.

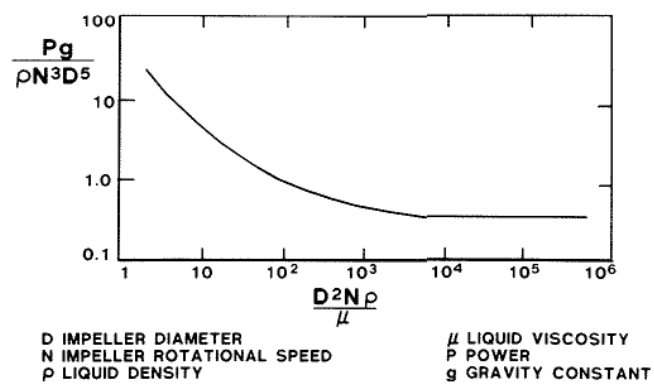

Figure 4

IMPELLER FLOW PATTERNS

There are two types of pure flow patterns. Figure 5 shows a radial flow pattern. Radial flow patterns are good for applications which require a significant amount of shear, but not as good for flow-controlled applications like blending. This is due to the fact that radial flow impellers inherently have a higher head (shear) to flow ratio than axial flow impellers. Figure 6 shows an axial flow pattern. Axial flow impellers give a shorter blend time than radial flow impellers at a fraction of the power input. Some impellers have a combination of both flow patterns. The PBT has a flow pattern that is half-way between axial and radial. Axial flow impellers have the added benefit of having a single flow pattern in a tank whereas radial flow impellers create separate stages. All high efficiency impellers to date have an axial flow pattern.

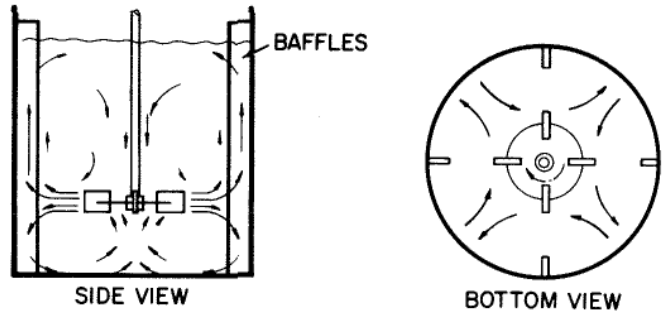

Figure 5

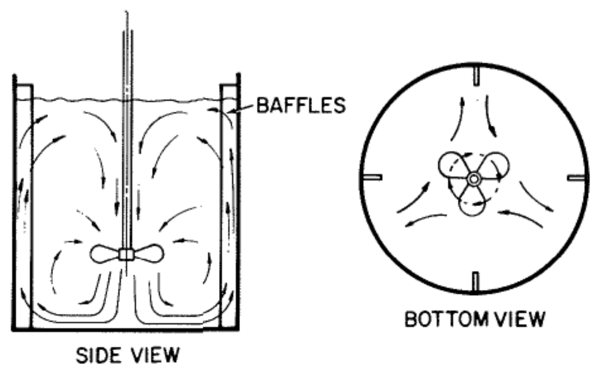

Figure 6

Going back to the Reynolds number equation, viscosity is defined as the resistance to shear stress. As viscosity increases, this resistance increases and the Reynolds number decreases. So, as the Reynolds number decreases, the resistance to flow increases, and the resulting flow pattern of an axial flow impeller becomes more radial. In a laminar regime, all open impellers exhibit a radial flow pattern. Consequently, the development work uses Reynolds numbers that are equivalent to those found in large production vessels (for the transitional regime); the viscosities need not coincide.

PRIMARY AND ENTRAINED FLOW

Blending relies on flow for the process result. There are two mechanisms of flow in a tank. First, there is the primary flow or pumping capacity of an impeller. This is the amount of fluid displaced directly through an impeller. The second is the entrained or secondary flow created by the primary pumping. At water-like viscosities, this can be three times as much as the primary pumping. As shown in Figure 7, as the viscosity increases, the entrained flow decreases. The amount of entrained flow an impeller provides is very sensitive to viscosity. As the viscosity rises the blend time will increase much faster than the power draw.

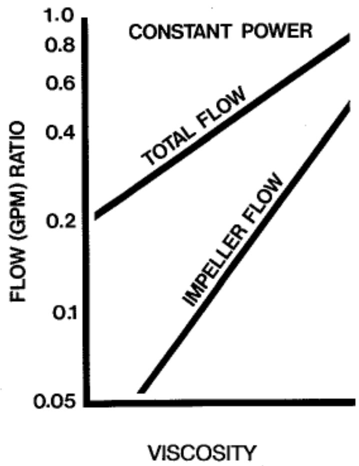

Figure 7

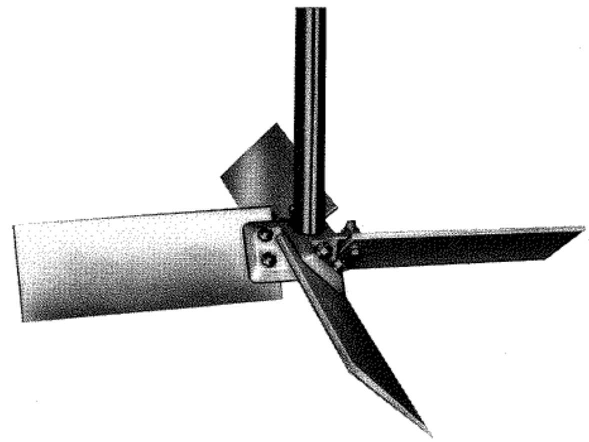

Figure 9

RESEARCH OF HIGH EFFICIENCY, HIGH VISCOSITY IMPELLER

The standard impeller of the chemical industry to mix high viscosity fluids in the transitional regime is the pitched blade turbine. All development work uses the pitched blade turbine as a base line for comparing process results and power draw.

EXPERIMENTAL PROCEDURE

Figure 8 shows the laboratory configuration. A 444 mm (17-1/2") diameter acrylic tank was used. The liquid level was held constant at 343 mm (13-1/2"). The fluids used for the experiment were a corn syrup/water mixture and a glycerin/water mixture. Water content was altered to change the viscosity in each case. A visual blend time was measured by inspection of the color change from the use of a phenolphthalein indicator and acid-base titration. A 178 mm (7") pitched blade turbine and a 203 mm (8") high efficiency impeller were used. These are shown in Figures 9 and 10 respectively. The impeller diameters were chosen to keep both the Reynolds number and power draw as close as possible. The impellers were driven by a 5 hp DC drive. A LeBow torque transducer and tachometer were used to measure the torque and speed respectively.

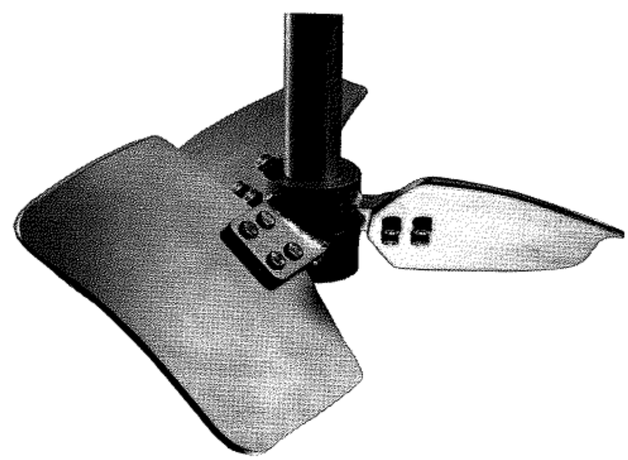

Figure 10

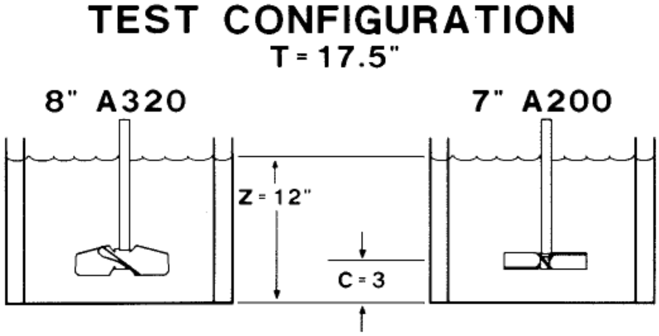

Figure 8

BLEND TIME COMPARISON

Figure 11 plots NΘ (product of mixer speed and blend time) versus Reynolds number. NΘ is often used as a dimensionless measure of blend time. This comparison of dimensionless terms is commonly used to define blend time irrespective of scale. In the turbulent regime, NΘ is a horizontal line for all impellers. As Figure 11 shows, NΘ is not constant over the Reynolds number range examined. The slopes of the two lines are between -1.5 and -2.0. The graph shows that the A320 high efficiency impeller has a lower dimensionless blend time than the pitched blade turbine at the same Reynolds number. By using a typical data point for each impeller, the power draw can be compared to the blend time.

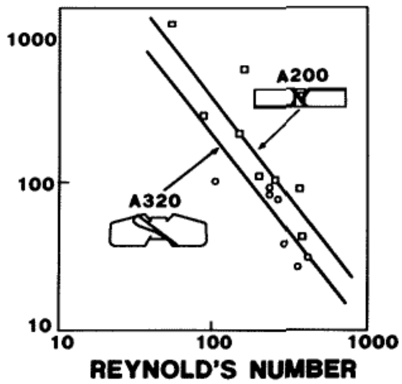

Figure 11

Blend time versus power draw is plotted at a constant viscosity on Figure 12. All measurements were between Reynolds numbers of 50 and 400 which is considered the transitional regime. The A320 high efficiency impeller gave an equal blend time at a fraction of the power draw. Using the mid-point of the data at a Reynolds number of 240, a blend time of 38 seconds was achieved at 45% of the power requirement of the pitched blade turbine. Using the same data, the A320 high efficiency impeller required 59% of the torque of the pitched blade turbine. Torque is an indicator of the size of the mixer drive. A 41% savings on torque will undoubtedly reduce the cost of a mixer drive.

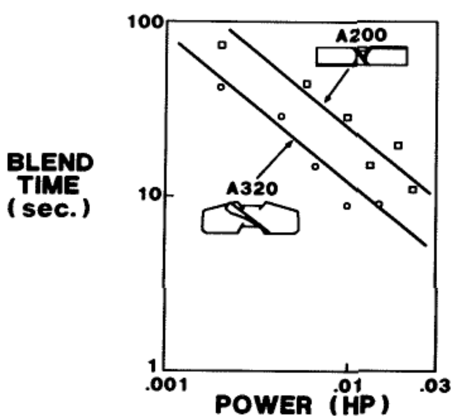

Figure 12

CONCLUSIONS

1. The LIGHTNIN® A320 high efficiency impeller has demonstrated a 50% power savings over the pitch blade turbine at equivalent blend time.

2. The LIGHTNIN A320 high efficiency impeller provides a 41% torque savings over the pitch blade turbine at equivalent blend time.

3. At the same power level, the LIGHTNIN A320 high efficiency impeller has a blend time that is 45% that of the pitch blade turbine.

NOMENCLATURE

D	Impeller Diameter
K	Constant
N	Impeller Speed
n	Constant
N_P	Power Number (Dimensionless), $N_P = P/N^3D^5 \rho$
N_{Re}	Reynolds Number (Dimensionless), $N_{Re} = ND^2 \rho/\mu$
P	Impeller Horsepower
μ	Viscosity
ρ	Specific Gravity
θ	Blend Time

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