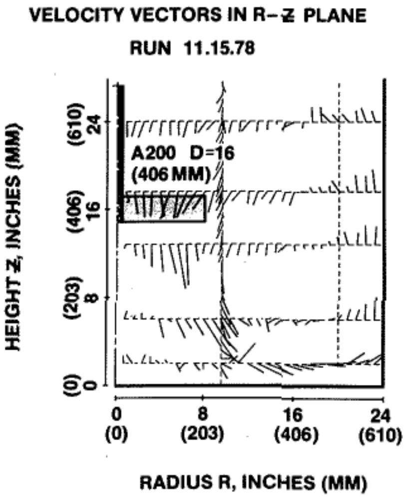

Figure 1. Axial flow turbine.

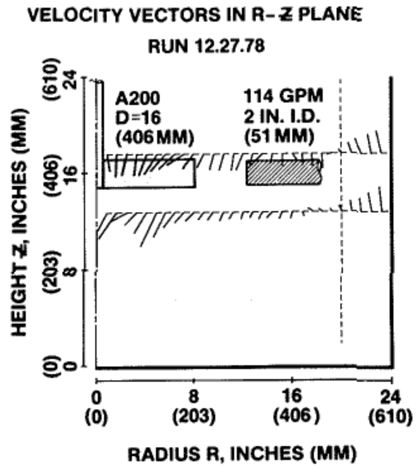

Figure 2. Axial flow impeller—side flow.

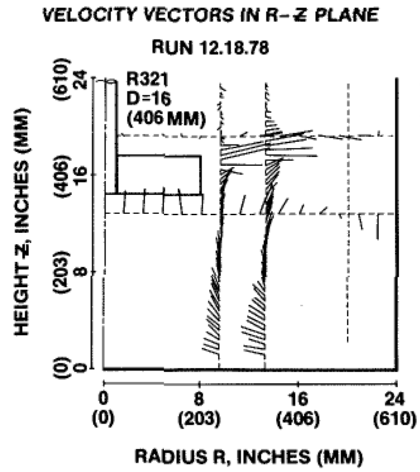

Figure 3. Lifter turbine.

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Impact of Side Flow on Mixing Impeller

Sophisticated instrumentation has made it possible to build improved empirical mixer models that can reduce the risk of failure and capital costs of full-size plants.

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The design of a mixer has two essential elements: process results and mechanical integrity. There are nearly as many variations in mixer/vessel designs as there are processes. This article discusses a process flow that is sparged directly into the impeller region to simulate a continuous stirred tank reactor.

The flow strength and the asymmetric introduction are of interest, because of resulting loads imposed on the agitator shaft and mounting structure. There are also several process questions related to scale-up such as bulk turnover rate, that are answered by the fluid dynamic study. The key element of the test is the simultaneous measurements of flow and fluid forces.

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Table 1. Effect of side flow.

Ratio with/without Side Flow	Axial	Radial
Power	1.02	0.85
Fluid Force	1.84	1.94
Primary Pumping	1.11	0.82
Total Pumping	1.16	0.68

Advanced mixing equipment

The mixing operation is fundamental to many chemical processes. Although natural mixing forces alone could perform many of these operations, it is usually profitable to install mechanical devices to speed up this process. In an operating plant, the mixers are a major user of electrical energy. To substantially improve plant efficiency, it is necessary to develop a detailed understanding of mixing fundamentals and their impact on process results so that operating costs vs. capitol investment analyses can be made.

The last major advance in mixing technology occurred during 1945–55. At that time, the design of mixing equipment advanced from an art to empirical technology. Newly available technology and the pressures of modern society give us the tools and the incentive to make another advance

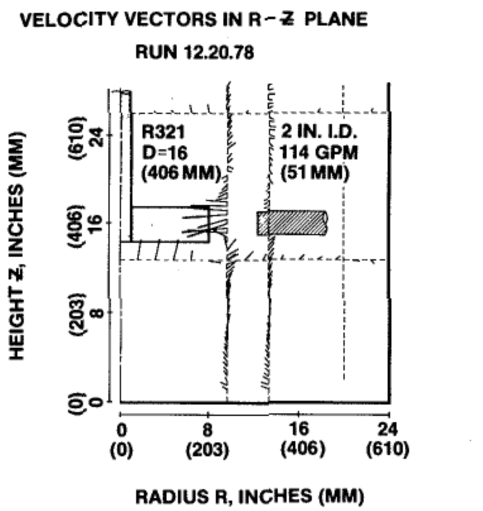


Figure 4. Lifter turbine side flow.

in mixing technology.

The fluid regime in a mixing vessel incorporates many types of complex fluid flows. For example, at the impeller outlet the flow has a strong pulsating action. It is possible for the flow to vary from negative to positive values during a single-blade passage. When the velocity is resolved into the mean and periodic components, measurements have shown that the periodic component can be larger than the mean value. At other points in the vessel strong vortices are evident. These vortices are shed from the impeller tip and at the baffles. In still other regions the mean flow is essentially zero. Superimposed on these large-scale flows are the macro- and micro-states of turbulence.

Recent advances in instrument technology now permit us to make flow measurement in the mixing vessel that could not be made with previous measurement techniques. The laser velocimeter is ideally suited to making these measurements because it does not disturb the flow, has fast time response, etc. As a result, we can develop improved empirical models essential to successfully scaling laboratory results to the design of full-size plants. The scale-up must include linking flow to process results and simultaneously determining the mechanical loads imposed upon the structures.

The absence of scale-up information does not prohibit the construction of full-size plants, but does increase both the risk and the capital costs. Those items that are not defined must be overdesigned or a risk of failure assumed. This applies to process and structural designs. The ability to link flow, process results and mechanical forces will improve design reliability and reduce operating expenses while minimizing capital.

Test data are presented for a research project studying the impact of a side flow on mixer design. The data includes simultaneous measurements of flow and mechanical forces. The test results are supplemented with a description of the LIGHTNIN test facility.

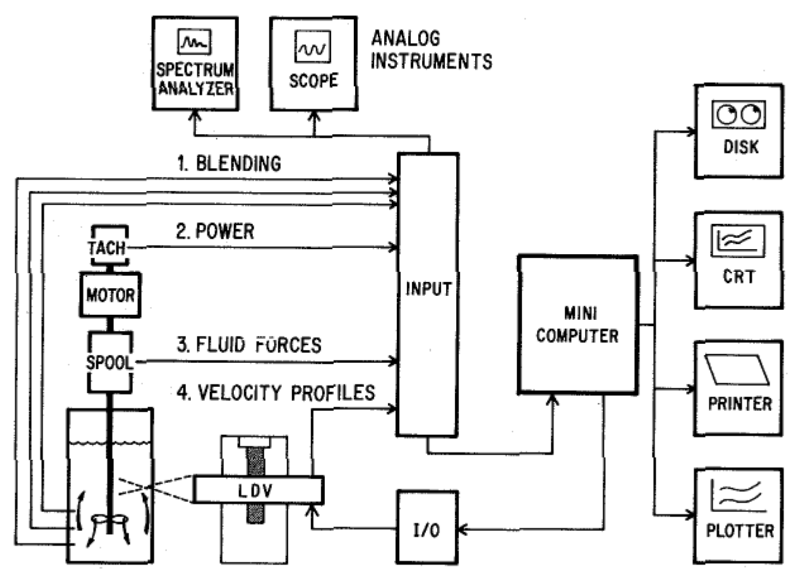
Test results

A recent study demonstrates the type of data required to scale a mixing process. The process requires a side flow (liquid jet) impinging radially into a mixing impeller. Because of the magnitude of this side flow, high bending loads are imposed on the mixer shaft. This study includes mixing measurements for both axial and radial impellers subjected to the same side flow.

The flow pattern for a 406 mm (16 in.) diameter axial flow impeller operating in the baffled circular cylindrical vessel is shown in Figure 1. This graphically represents velocity measurements made using a laser velocimeter. The laser scan output plot is comparable to streak photographs used for many years. The five horizontal dotted lines include the points where velocity measurements are made in the R–Z plane. Initiating from these dotted lines are the velocity vectors (axial and radial components) in the plane of the data. The left axis of the figure is the tank center line. The rectangle drawn at 406 mm (16 in.) from the tank bottom represents the impeller. The dotted line on the right indicates the baffle dimension. For this test, the baffles are located at 45° to the plane of the scan. The solid line on the far right is the tank wall.

The tests consisted of a side flow from the right directed into the impeller. Laser scans were made in the plane of the jet and at 180° to observe the total flow. Figure 2 shows the vessel half with the inlet flow. Pumping capacity data are based on scans in both halves of the vessel. For this specific application, Table 1 indicates that the power is increased only 2% while pumping increases by 11%. The critical

Figure 5. Integrated laboratory.



design problem is that the forces exerted on the shaft are increased by 84% from the case of a tank without side flow. The primary pumping shown in Table 1 is defined as the flow discharging from the impeller outlet. The total flow is defined as the sum of the primary flow and the flow induced by the primary flow.

A parallel study with a radial (lifter turbine) is shown in Figures 3 and 4. This particular turbine has a series of back-swept vertical blades attached to the underside of a solid disc. This impeller induces flow underneath and pumps radially, Figure 3. The turbine outlet flow is a radial plume with a distinct rising vertical component. The data obtained with this class of impeller demonstrates that the side flow has a substantial impact on power, flow and shaft forces. The results are given in Table 1.

Power draw is reduced by 15% while the fluid forces are nearly doubled versus a tank without side flow. The side flow also has an impact on the impeller pumping. The primary flow from the impeller is reduced by 18%. Hydraulic power is proportional to flow times resisting head; hence, the pumping data are consistent with the change observed in power draw. The side flow introduces asymmetries which make it difficult to characterize the total vessel turnover. The results obtained for measurements in the plane opposite the jet indicate a 32% decrease in vessel turnover. Table 1 also provides data for several runs and not exclusively those illustrated by Figures 1 to 4. In each case, the number represents a ratio of the performance with the side flow divided by the performance without side flow.

The normal flow pattern for the axial flow turbine, Figure 1, includes radial flow into the impeller region. Therefore, the side flow acts to increase the impeller pumping. A similar increase is noted for the total tank turnover. In the case of the radial (lifter turbine) flow device, the side flow acts in opposition to the pumped liquid. The total pumping is, therefore, decreased by the action of this directed jet. The power draw decreases in a similar fashion; therefore, maintaining a constant hydraulic efficiency. Table 1 also shows that tank turnover (total pumping) is also substantially reduced due to the action of this side flow. Therefore, if a process were strongly dependent on either tank turnover or dissipative micromixing, the consequences of the side flow would have to be considered for its impact on process results.

Table 1 clearly illustrates the data required for linking process and mechanical design considerations. In applications requiring sparging materials into the impeller, asymmetric placement of the impeller, or other nonstandard design factors, the impact of process requirements on mechanical design loads must be considered.

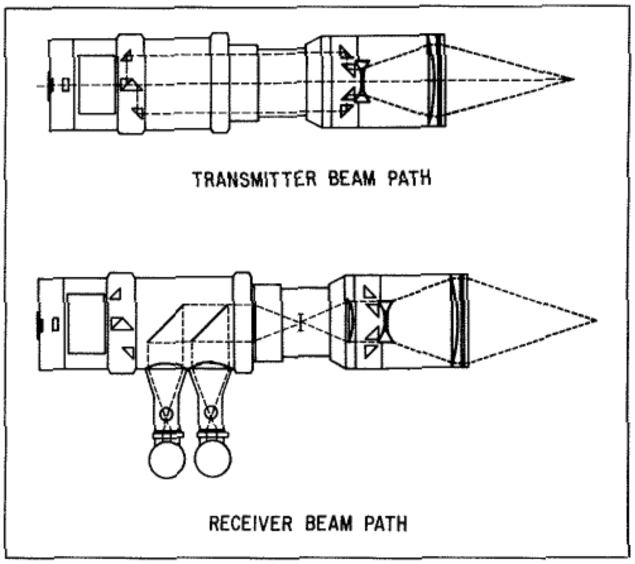


Figure 7. Optical paths.

Data validation

The accuracy of the laser velocimeter is dependent on two key items: the optical path and the electronic processing. Alignment of the optics is critical in obtaining the precise crossing point and fringe spacing. The beam crossing angle plus the frequency of the laser light determines the spacing of the interference fringes. Misalignment of the velocimeter lens system would result in a systematic error in velocity measurements. The value of this error would not exceed 1% for the alignment techniques currently used. The second step in checking the accuracy of the anemometer is an electronic check of the signal processor. Therefore, the value of the velocity is known with a high degree of certainty.

In a previous test, several replicate runs had been made to define the expected variations of flow and force measurements. For that series the observed standard deviation for flow was 5.6% of the mean value. This by no means

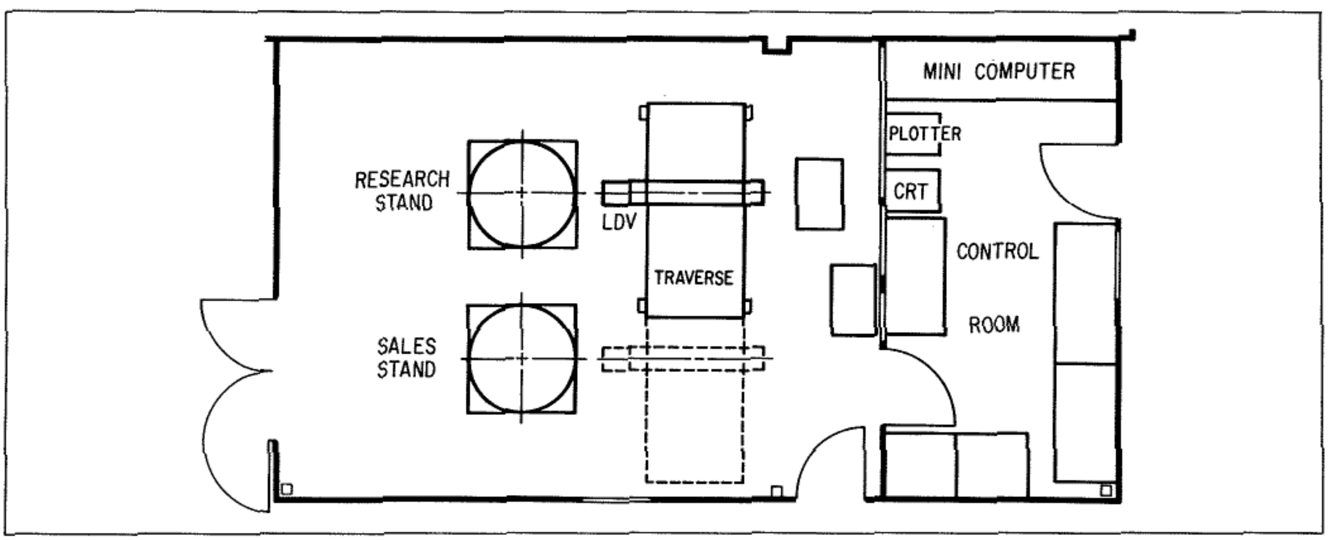


Figure 6. Integrated laboratory facility.

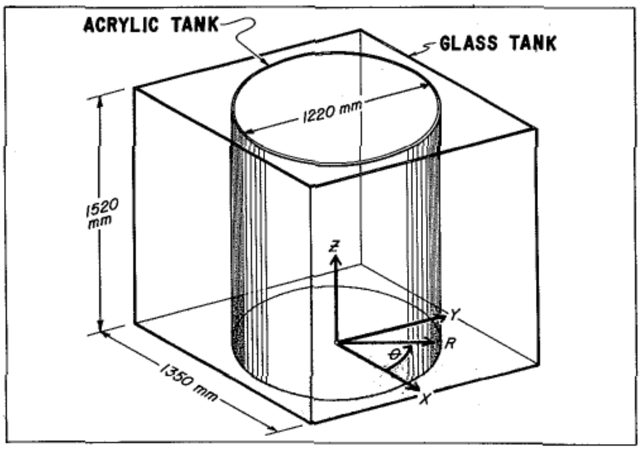


Figure 8. Mixing vessel.

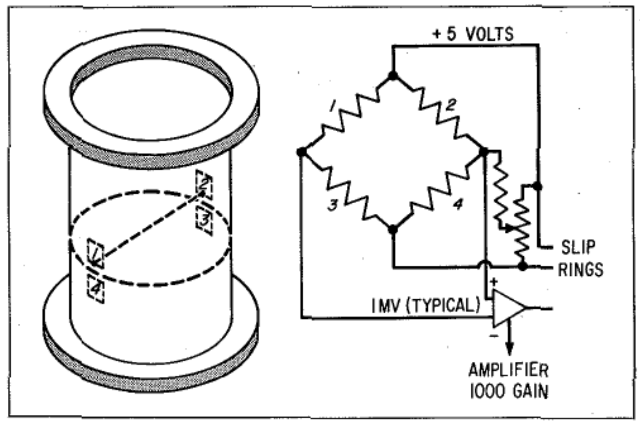


Figure 9. Fluid force measurement.

represents the limits of pumping reproducibility. The quality of the average velocity measurement is strongly dependent on the time spent at each sampling point. In order to run eight to 10 tests per day, we had selected a 10-second sampling time at each point. The standard deviation value previously reported could be improved by increasing the total test time. The limiting degree of precision has not been defined, but the value reported was considered adequate for the requirements of this side flow test.

The fluid force instrumentation has been reviewed in a similar fashion. During the series of tests to determine the variations of pumping measurements, the observed standard deviation of the fluid force was 2.2% of the mean value. Thus, the repeatability of fluid forces is even better than the flow measurements. The accuracy of the force measurements is determined by purely mechanical calibration procedures. Known forces are applied to give bending moments, torque, and thrust. The output of the fluid force instrumentation is calibrated against these inputs. Thus, a bending moment is defined by the response due to an effective lateral force acting at the impeller. Using the shaft transfer function, the magnitude of that force is then calculated.

Reproducibility of the data is an important factor determining the significance of the results for Table 1. The ratios presented are based on three to five measurements. Because of the proven repeatability, the tabulated values represent meaningful differences in flow and forces.

Test facility

The key to successfully constructing a commercial plant, based on a bench-scale data, is high-quality scale-up data. These data must include both process and mechanical sizing information. To meet this challenge, LIGHTNIN has built a complete mixing laboratory utilizing state of the art measuring techniques, Figure 5. The "Integrated Laboratory" gives a complete overview of the mixing process for each test. Data are simultaneously obtained on fluid flow and mechanical loads.

Fluid velocities are measured using a dual channel laser velocimeter. This instrument has the capacity for measuring two components of the velocity vector, with no mechanical interference to the flow.

Mechanical strain on the agitator shaft is measured using bonded straingages. Shaft-mounted amplifiers are used to amplify the straingage bridge signal before passing through the slip rings. This technique gives excellent signal to noise ratio. The recent availability of stable amplifiers, able to stand high G loads is a technical spin-off from the space program.

The heart of the system is a minicomputer dedicated to the laboratory. This computer operates the experiments; records data; and performs fundamental data analysis. The software has been developed so that the researchers are able to concentrate on understanding results, rather than laborious data manipulation.

The facility has been designed so that long-term research and customer/sales support projects can be carried out simultaneously. Two separate mix stations, Figure 6, have been designed into the laboratory. While tests are being conducted on one side, mechanical preparations are performed on the second stand. At the appropriate time, the laser traverse is rolled to the alternate station and data are obtained. One station is devoted to long-term research and has a relatively permanent configuration. The second test stand is quite flexible and can be readily changed to model almost any type of mixing design. This flexibility is essential for testing the new and innovating developments that may occur at any time.

Laser Velocimeter. The DISA type 55X two color system is used for velocity measurements. The optical package uses back scattering and contains the transmitting and receiving optics in the same module, Figure 7. This is an important factor for scanning the flow field in the mixing vessel.

If a forward scattering mode were required, it would be necessary to realign the receiving optics at each sampling position. Thus, instead of scanning the complete vessel in 10–15 minutes, it would be necessary to spend several working days to obtain the flow data. The laser and the optical package is mounted on a three axis-traversing, computer-controlled mechanism. Stepping motors provide the motion for the laser traverse.

Mixing Vessel. The research vessel is designed to fully utilize the traversing range of the laser. The glass wall vessel, Figure 8, is 1,370 mm (54 in.) square by 1,500 mm (60 in.) high. For many applications this is a full-size mixing vessel. Circular cylindrical tanks are placed inside the square tank. This minimizes the optical distortions associated with the lensing effect of the curved tank wall. The largest diameter vessel which can be installed in the lab is 1,220 mm (48 in.) in diameter. To generate scale-up data progressively, smaller vessels are installed inside the square glass walled tank. The practical range of impeller diameters is 100 to 600 mm (4–24 in.).

Fluid forces

The mechanical loads on the shaft are the direct result of asymmetrical flow field components. An ideal impeller in an infinite fluid would experience a constant torque and thrust loading. Manufacturing tolerances on shaft, impellers, and the closely confined flow produce asymmetries in the flow

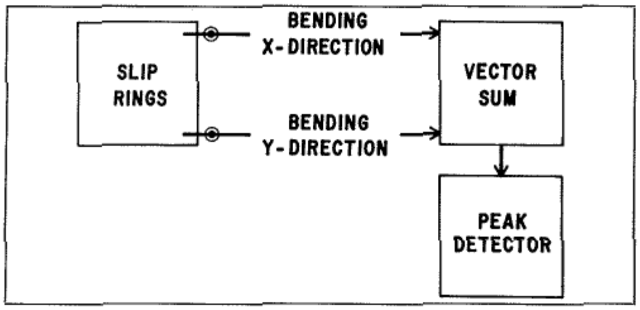


Figure 10. Fluid force—signal processing.

field which cause unsteady forces on the impeller. These forces acting perpendicular to the shaft are identified as "fluid forces."

To determine the fluid forces, straingaged bridges are mounted between the drive and impeller shaft. For convenience, the straingage instrumentation is assembled on interchangeable shaft extensions identified as spool pieces, Figure 9. The spool is an instrumented shaft section mounted between the drive and the impeller shaft. Each spool piece is straingaged for thrust, torque, and two axes of bending. An important feature of this circuitry is the shaft-mounted amplifiers, Figure 9.

The amplifiers are capable of operating under high-G loads associated with speeds in excess of 1,000 rpm. The amplifiers make it possible to measure microvolt signals from the strain bridge.

Amplifying the signal before passing through the slip ring is quite important, because there is substantial electronic noise generated by the slip ring contacts. The net result of the spool piece and amplifier circuits is a high-quality signal with an excellent signal to noise ratio.

The design of the spool piece requires a trade-off between shaft flexibility and instrument sensitivity. A very stiff spool would have a minimum effect on total system dynamics, but would give a very small strain signal. If the spool becomes too flexible, a large straingage signal would be obtained but the spool becomes a major factor in the shaft dynamic response. In order to accommodate the range of impeller diameters, speeds, and sensitivities, three fully instrumented spool pieces have been fabricated for the laboratory.

The bending signals require additional signal processing, Figure 10. Shaft-mounted straingage bridges measure the bending at two orthogonal planes fixed on the shaft. The instantaneous bending load is the vector sum of the two components. The signal processor performs the vectorial addition function on the two bending signals. Design is based on the peak value of this vector sum. Therefore, an electronic peak detector is used to record and hold the largest values.

The same technology used to design and build the spool pieces for the Integrated Lab has also been applied to a large spool piece. This instrument will be used in the large-scale LIGHTNIN test basins. This later facility is suitable for testing 3,000 mm (120 in.) impellers drawing up to 200 shaft horsepower. The ability to perform precise measurements over such a wide range of scales is critical to reliable mechanical scale-up.

Computer

The heart of the Integrated Laboratory is a Digital Equipment Corp. PDP-11/04 mini-computer. The computer is totally dedicated to the operation of the laboratory and serves several functions. These functions include:

1. Experimental design (matching impeller, tank, and spool piece).
2. Real time analysis of data. (The use of the graphic CRT assures proper system operation before initiating a run.)
3. Operates the experiment (i.e., controls the traverse of the laser velocimeter).
4. Records data (fluid velocity, shaft torque, fluid forces, impeller velocity gradients, shaft speed, and etc.).
5. Converts data to usable form.

The last function is perhaps the most important. This system is capable of generating tremendous quantities of data; thus, it is essential that the results be organized in an easily understood form. The graphical outputs shown in Figures 1 through 4 permit the researcher to apply his time to understanding the results, rather than laborious data manipulation.

In conclusion

The process of sparging a feed stream directly into an impeller has been experimentally analyzed. For an axial flow impeller, the most significant design consideration is related to shaft-bending loads. There were small increases observed in primary and total pumping as a result of the jet.

The side flow substantially affects a radial flow impeller. For this mixer, in addition to the increased bending loads, there was a substantial impact on the pumping. The primary pumping was decreased by 20% and the tank turnover was decreased by 30%.

These results demonstrate the importance of making simultaneous measurements of flow and forces. The data required to scale-up process results must be made at the same time as mechanical measurements. Having all this information is the key to obtaining process efficiency and mechanical reliability in the full-scale installation.

The LIGHTNIN test facility has the capability of looking at the total mixing process during a single test. Its accuracy and repeatability are substantially better than those of any techniques used in the past. #

Nomenclature

D = turbine diameter
X,Y,Z = right hand cartesian coordinate system centered on tank bottom
R,θ,Z = right hand cylindrical coordinate system centered on tank bottom
A200 = LIGHTNIN 45° pitch blade turbine
R321 = LIGHTNIN back-swept lifter turbine

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