HIGH EFFICIENCY IMPELLER FOR SLURRY STORAGE

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Mixing Equipment Co., Inc.

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INTRODUCTION

Slurry storage is a necessary part of a pipeline transportation system. The storage tanks are found at the beginning and the end of the pipeline, as well as along the route for longer pipelines.

The storage tanks perform many functions designed to ensure efficient operation of the pipeline system.

This paper will concentrate on the impact of a high-efficiency impeller as applied to slurry storage systems. This impeller has been developed to optimize performance in flow-controlled applications such as slurry storage. Results presented include data from small-scale as well as large-scale tests.

The operationg features of this impeller impact the design of the slurry storage tanks in several ways. The impeller is a high-efficiency device which can produce the desired degree of suspension at much lower horsepower than the conventional pitched-blade turbine. The operating torques and the fluid forces are also lower. Furthermore, the total mixer weight is less. Because of these reduced loads and weight, less expensive mixer support structures can be used. In addition, start-up torque for this high-efficiency impeller is significantly less than that for conventional pitched-blade turbines.

The first portion of the paper will review basic results obtained during the impeller development.

The development of the impeller was greatly accelerated by using a high-technology laboratory facility devoted exclusively to mixing studies (Figure 1).

TEST FACILITY

This sophisticated laboratory has made it possible to build improved mixers at lower capital costs, while still reducing the risk of design problems. The design of a mixer requires two essential elements: process result and mechanical integrity. For solids suspension, the process result is proportional to pumping rates.

The flow patterns and mixing eddies are factors in bending loads imposed on the components of the agitator and the mounting structure. The key element of the lab is the simultaneous measurements of flow and fluid forces.

FLUID FLOW

Fluid velocities are measured using a dual channel laser velocimeter. This instrument measures two components of the velocity vector, without interfering with the flow. The DISA Type 55X two-color system uses back-scattering and contains the transmitting and receiving optics in the same module, Figure 2. This is an important factor for scanning the flow field in the mixing vessel. The laser and the optical package are mounted on a three-axis traversing device. Stepping motors con-

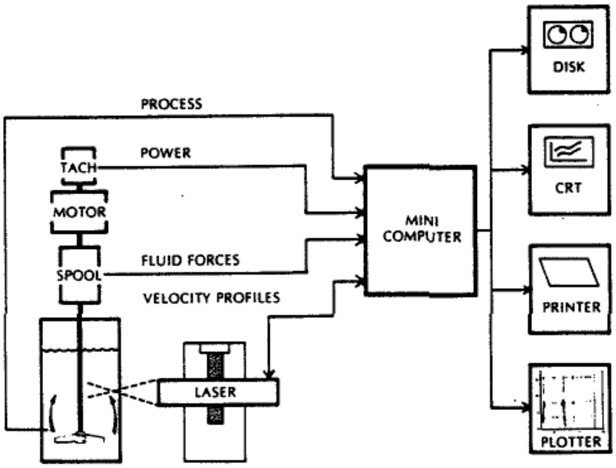

Figure 1. Integrated Lab

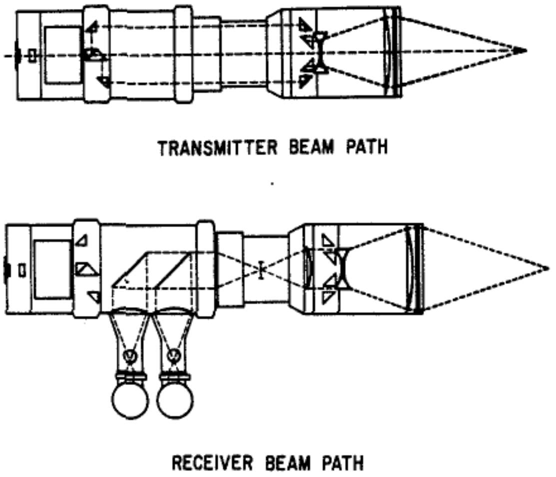

Figure 2. Laser Optics

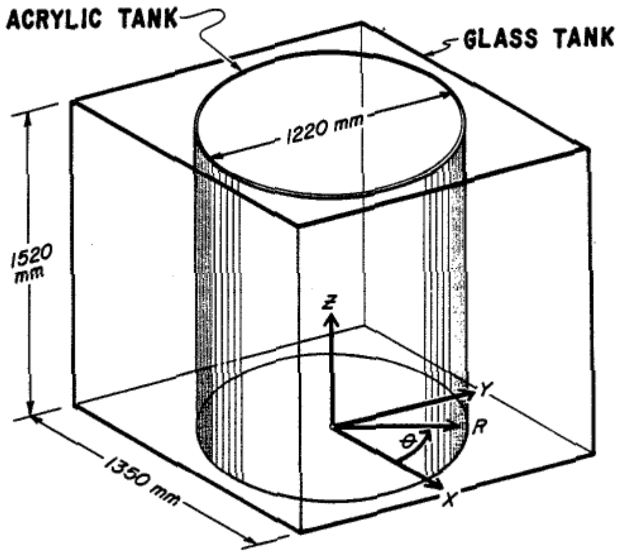

Figure 3. Mixing Vessels

trolled by the computer provide the motion for the laser traverse.

The research vessel is designed to use the full traversing range of the laser. The glass wall vessel, Figure 3, is 1,370 mm (54″) square by 1,520 mm (60″) high. For many applications this is the full-size mixing vessel. Circular cylindrical tanks are placed inside the square tank. This minimizes the optical distortions associated with the lense effect of the curved tank wall. The largest diameter cylindrical vessel which can be installed within the 1,370 mm square tank is 1,220 mm (48″). To generate scale-up data, progressively smaller vessels can be installed inside the square, glass-walled tank. The practical range of impeller diameters is 100 to 610 mm (4–24″).

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 constant torque and thrust loadings. Manufacturing tolerances on shaft and impellers, and the effect of closely confined flow, produce asymmetries in the flow field which cause unsteady forces on the impeller. The primary vector of these forces, acting perpendicular to the shaft, are identified as "fluid forces".

To determine the fluid forces, strain gauges are mounted between the drive and impeller shaft. For convenience, the strain gauge instrumentation is assembled on interchangeable shaft extensions identified as spool pieces, Figure 4. The spool is an instrumented shaft section mounted between the drive and the impeller shaft. Each spool piece is gauged for thrust, torque, and two axes of bending. An important feature of this circuitry is the shaft-mounted amplifiers, Figure 4.

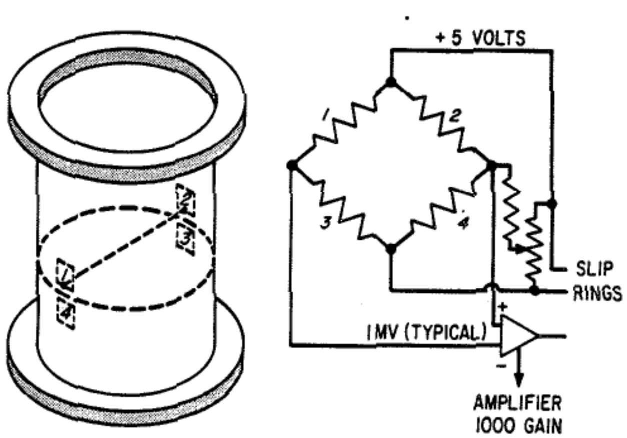

Figure 4. Fluid Force Measurements

The same technology used to design and build the spool pieces for the Integrated Lab has also been applied to larger spool pieces. These have been used in the large-scale LIGHTNIN test basin. This larger facility is suitable for testing 3,050 mm (120″) impellers drawing in excess of 200 shaft horsepower (150 Kw.). 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 model PDP-11/04 mini-computer manufactured by Digital Equipment Corporation. The computer is totally dedicated to the operation of the laboratory and serves several functions which 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. Operating the experiment (i.e. controlling the traverse of the laser velocimeter).
4. Recording data (fluid velocity, shaft torque, fluid forces, impeller velocity gradients, shaft speed, etc.).
5. Converting data to usable form.
6. Storing data for future use.

The last function is perhaps the most important. The system is capable of generating tremendous quantities of data; thus, it is essential that the results be organized in an easily understood form.

RESULTS

An example of the results of a single test is given in Figure 5. This diagram shows the flow pattern of a LIGHTNIN A310 Impeller in a round tank with a flat bottom. (A310 is the designation for this high-technology

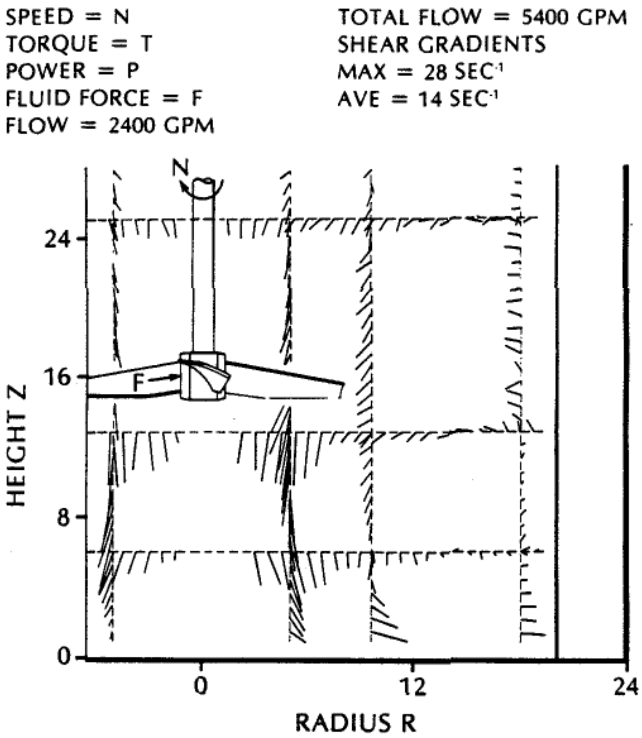

Figure 5. A310 Flow Scan

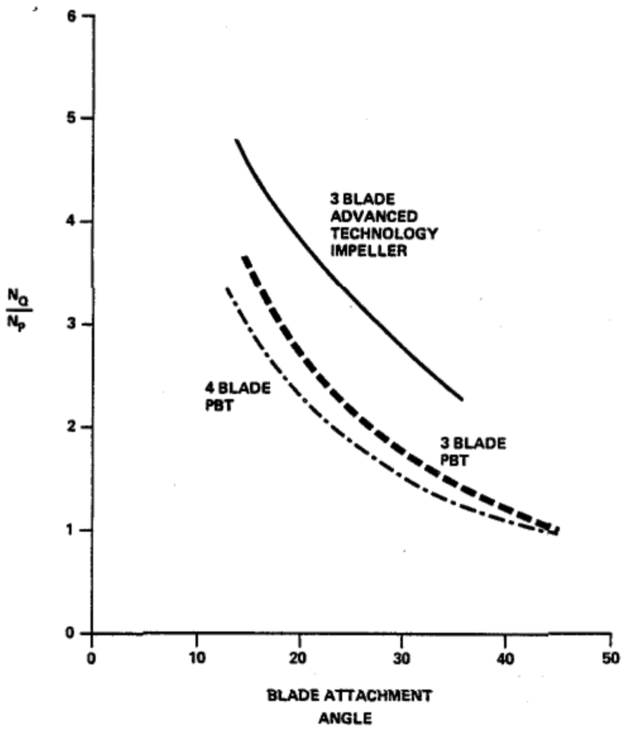

Figure 6. Relative Flow Per Power

impeller.) The vertical mark at zero is the tank's centerline. The vertical line at 20 represents a sidewall baffle, one of four equally spaced. This flow diagram was made by scanning the tank with a laser beam. The scattered light was analyzed to determine fluid velocities at each point. The vectors indicate direction of flow and the length of the vector is proportional to the velocity. Pumping and shear rates are calculated from these velocity vectors.

The design selection process involved analysis of flow, power, and fluid forces for hundreds of impellers. In addition to the high-technology impellers, pitched-blade turbines (PBT) with three and four blades were extensively evaluated.

Figure 6 shows the ratio of flow number to power number for a range of impellers. The results are normalized to a four-blade PBT at 45° which is the industry standard. Flow per power is strongly dependent on both blade attachment-angle and type of blade. The high-technology impeller performs significantly better than either the three-or four-blade PBT. Note that the impeller used for Black Mesa installations is a four-bladed PBT.

The mechanical measurements demonstrate the long term benefit of the high-technology blade. Although better for flow/horsepower, a three-blade impeller is inherently less stable than a four-bladed device, as seen in Figure 7. However, the contoured airfoil of the high-technology blade results in 50% reduction of fluid forces, compared to a three-bladed PBT. This combines mechanical reliability and high pumping efficiency.

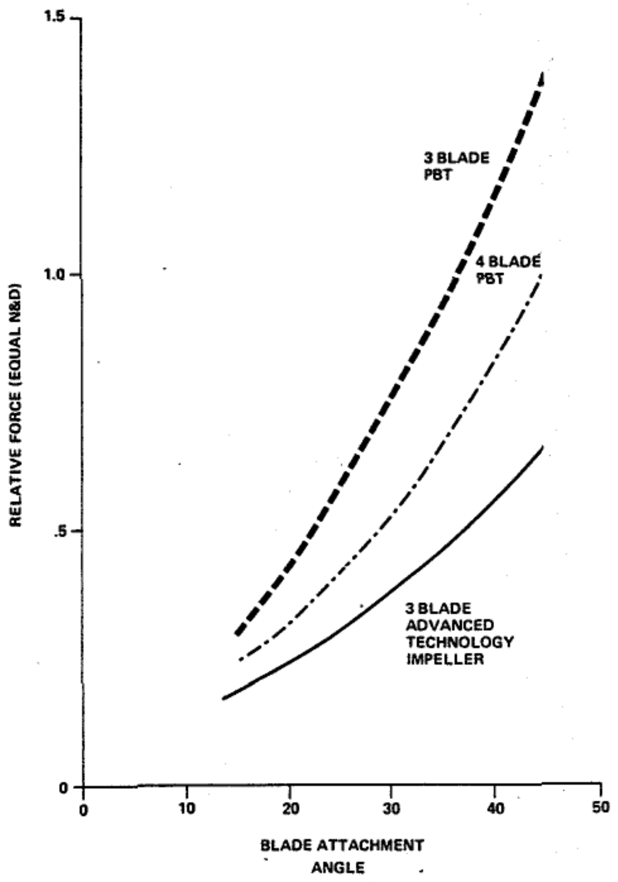

Figure 7. Fluid Force Ratio

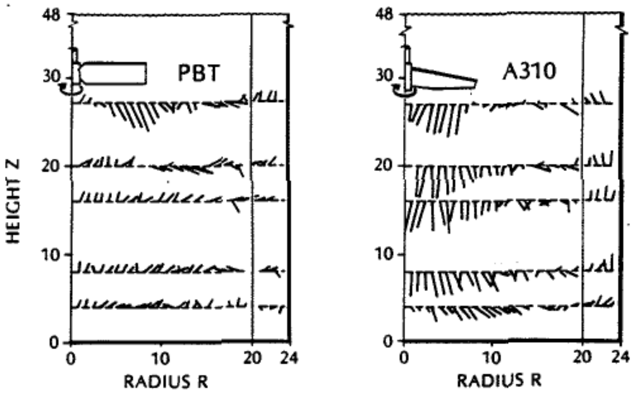

Figure 8. Comparative Flow Patterns For An A310 & PBT

The relative performance of the A310 and 45° PBT for higher off-bottom locations is shown in Figure 8. Note that the high-technology impeller directs the flow to the bottom of the tank. By comparison, the PBT has a strong radial flow component, which causes an inefficient reverse flow pattern below the impeller. In solid suspension applications, solids would form a mound under the PBT impeller. Thus, the PBT would have to be mounted much closer to the tank bottom than the A310 in order to maintain the same degree of suspension. This shows that suspension results depend not only on flow produced by the impeller, but also on its velocity profile created throughout the mixing vessel.

A310 SLURRY APPLICATIONS

Results presented to this point have been stated for clean, water-like fluid. However, high solids concentration gives the solid/liquid mass very different properties. The questions is how effective is a high-efficiency impeller in these applications. The answer is—performance in slurry is consistent with Laser Lab data in water-like fluids.

Case I

The most dramatic example is an application for suspending metal oxides. These metal oxides are used for coatings on video tapes and computer data storage tapes. The quality of the coating is strongly dependent on the uniformity of the batch. The requirements for both maximum coverage (minimum coating thickness) and also coating uniformity make this mixing application very critical.

The mixers designed for this installation were manufactured in the late 1960's. Radial flow turbines were installed to operate close to the tank bottom. To achieve acceptable slurry uniformity a very high power level was installed. As the process requirements changed, the oxide coating applications became more sensitive to temperature. The mixer power levels were so high that the temperature build-up was a problem. To avoid this, the mixers were typically operated 15 minutes each hour. This procedure solved the temperature problems but simultaneously created suspension uniformity problems during the remaining 45 minutes of each hour.

The solution was to replace the radial flow impellers with high-efficiency A310's. The motor size was one-seventh of the original (1.5 versus 10 HP), yet pumping was simultaneously increased by 50%. The mixers now operated continuously with no temperature problems. The product uniformity is excellent at all times. In addition to product quality improvements there are also significant power cost savings. Because the A310's are operated continuously, the user realized a net 40% reduction in power cost. The savings are $476 per year for continuous operation at $0.76/kw hr.

Case II

The second application is the suspension of gypsum for flue gas desulfurization. The mixer must provide sufficient mixing to prevent plugging the pump suction inlet pipe. This pipe is located very close to the vessel bottom. There is also a requirement that the mixer performs over a wide range of liquid levels. The original mixer was a PBT in a square unbaffled tank. Under normal operating conditions the inlet occasionally became blocked. This marginal mixing performance was totally unacceptable to plant operating personnel.

The solution was to replace the PBT with an A310 at the same speed and power. Pumping was increased over 100% with this selection. The problem of the inlet pipe plugging has been totally eliminated. In addition, operating personnel observed "better looking surface agitation" with the A310.

Case III

The final example is an application in clay make-down operation. This requires the addition of dry clay to a fluid (water). The mixer must wet the clay and produce a well blended batch. Several different clay ingredients are added during this operation. The final mixture is very near to the ultimate settled solids concentration. The fluid viscosity is in the range of 4,000–5,000 cp., a viscous high density slurry.

The original installation was 15 HP with pitched-blade turbines. The normal operation resulted in 8 to 10" of solids on the bottom after each batch.

An A310 was installed at 50% of the power. Results have been completely satisfactory, maintaining a clean tank bottom and uniform slurry.

Coal Slurry

Recent pilot plant tests have shown that potential benefits of the A310 also apply to coal slurry storage tanks. The results of these coal tests are consistent with the applications just reported. This part of the study involved modeling the Black Mesa Plant. We scaled-down the slurry storage tank diameter from 125′ to 30″ (2.5′) or a 125,000:1 volumetric scale-down. The impellers and

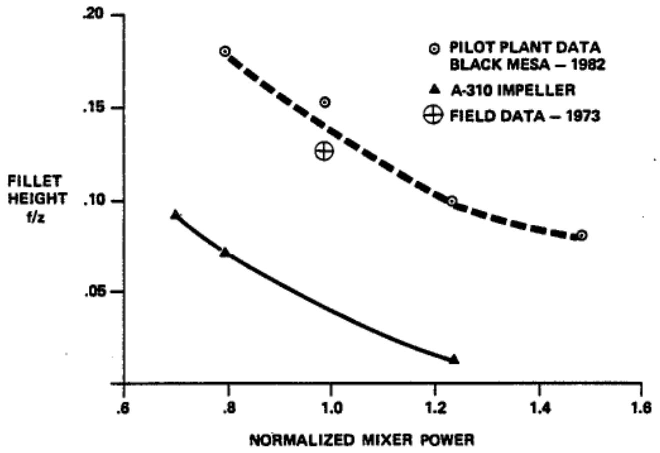

Figure 9. Pilot Plant Fillet Height

placement were scaled-down to maintain exact geometric similarity.

Tests were run using fresh Black Mesa coal and fillet height at the wall was measured. Fillet height was chosen as it is a measurable result at the lowest velocity region of vessel. The test results are compared with a reported field experience on Figure 9. With PBT's, the results from the pilot plant would predict approximately 10% greater fillet height at the scaled-down power. Considering the range of scale-down, this 10% difference is well within the experimental tolerances. It also demonstrates that the scale-down or scale-up procedure is appropriate and that the pilot unit does model full-scale performance.

This same test sequence was repeated using A310 impellers instead of the PBT's installed at Black Mesa. The very high degree of improvement is shown in Figure 9. At the same horsepower fillet size ranges from 25% to 40% of that observed with PBT's. For the same fillet size the power requirement was reduced by nearly 50%. These results are consistent with many other slurry applications with the A310.

Start-Up Torque

Start-up torque is difficult to measure on a small-scale because the particle-to-particle contact for the full bed height is critical. The effect of 30′ of solids on particle-to-particle contact is not easily extrapolated for a 30″ deep tank. Two 32′ high columns were erected for these tests. An A310 was mounted in one and a Black Mesa PBT in the other. Well mixed slurry was added and the material allowed to settle. Start-up torque was measured with a torque wrench. The results are plotted in Figure 10. There was a consistent ratio of torque loading between the two units. The A310 required less than half the applied torque needed to free the Black Mesa PBT. This factor of 2 on start-up torque can have a significant impact on the design of all mixer components, as well as the mixer mounting structure.

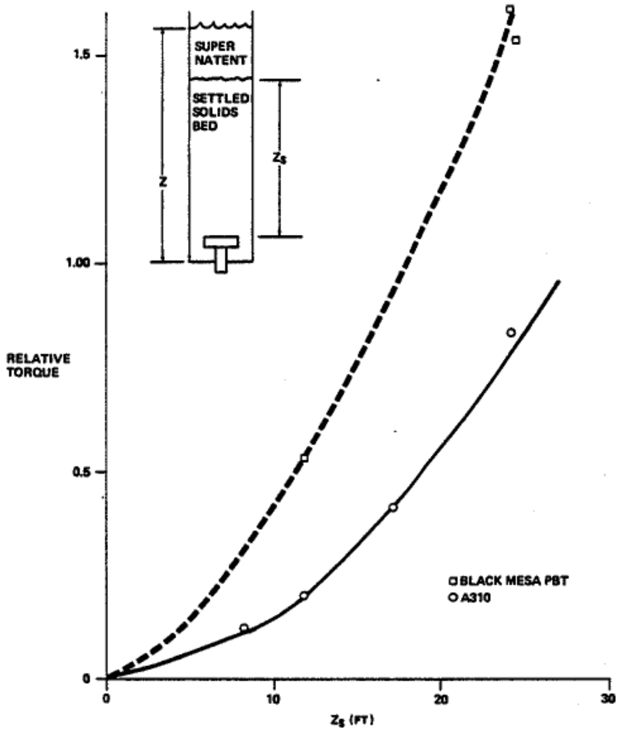

Figure 10. Start-Up Torque

Baffles

Another advantage of the A310 is the low torque per pumping when compared with a PBT. The baffle requirements are related to mixer torque. The lower the torque, the less baffling required. This new high-technology impeller requires significantly smaller baffles than the standard PBT. This can be a big advantage for slurry applications as well as vessels requiring expensive, exotic materials of construction.

CONCLUSION

The A310 high efficiency impeller is a proven reality, not just an engineer's dream. Impellers have been manufactured, shipped and installed in all forms of slurry service—from gold leach to alumina slurry storage. These installations are not pilot plants but large industrial installations with impeller diameters of 3 meters, 4 meters, or larger!

The following says it best—

In one design option for the ETSI Pipeline Project, 10,000 mixing hp is required when using the "Black Mesa PBT". The A310 high efficiency impeller would require only 7,500 hp or a 2,500 hp savings!!

At $2,000/hp present value over 20 years, that is a savings of $5 million dollars. At $300/hp/year actual cost—that is a reduction in the annual electrical bill of $750,000.