

Computer Simulation Helps Increase Life of Impeller in Alumina Hydrate Precipitation from 2 to 8 Years

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The rate at which an impeller wears is a strong function of the velocity at the leading edge. Blades often fail due to extreme erosion. Simulating the impeller and tank of a draft tube mixer using computational fluid dynamics (CFD) helped extend the life of an impeller by two to eight years. The computer simulation, using FLUENT CFD software from Fluent Inc., Lebanon, NH, made it possible to quickly evaluate the leading edge velocity of several proposed new designs. The analysis helped identify the erosion problem by predicting the locations of wear patterns.

Keywords alumina precipitation, CFD, impeller, mixing

1. Introduction

LIGHTNIN is one of the leading producers of mixers with over 1 million units currently in the field. Among the variety of systems that are blended, alumina hydrate precipitation is one of the most difficult erosive mixing applications. In this case, a draft tube that separates the inside and outside of the tank is used to improve circulation. The tank is 10 m in diameter and 30 m tall. The single impeller is positioned at the top of the tank so that a short drive shaft can be used. This eliminates the need for a bearing within the fluid, which would cause maintenance problems. Fines are added to a supersaturated liquor to expedite crystal growth. The precipitative alumina particles are ~100 μm in diameter, have a density of 2,500 kg/m^3, and are abrasive. The solids concentration is typically 20% to 40% by weight.

The size of the tank requires a large impeller with a high tip speed. A 3.2 m high-efficiency airfoil-type circular impeller is mounted inside the draft tube. The impeller blades are constructed from an 8 mm thick top and bottom skin. The original blades had a NACA 4412 airfoil shape. The 4412 airfoil has 4% camber (meaning that the camber is 4% of the chord length or the width of the blade). The blades were failing due to erosion on the leading edge. If the blades were repaired, they would last another two years before being discarded. Field data showed the rate of erosion of the original blade was proportional to the radius with an exponent of 2.8. Because the velocity of the slurry impinging on the blade is proportional to the radius, erosion is proportional to velocity to this same 2.8 exponent, which is similar to that observed in other erosion phenomena.

2. Analysis of the Impeller

First, the existing blade was analyzed using FLUENT, to better understand the problem. Selecting the structure of the computational grid to use for the analysis of problems was critical. If a fine mesh in the areas of high-velocity gradients and fine geometry detail is not provided, then the simulation will not give accurate results. In order to minimize numerical problems, it is also important to minimize the skewness of grids. Therefore, we used an "O" type grid that wraps around the airfoil and helps significantly in minimizing the skewness at the trailing edge (Fig. 1). An axisymmetric model was created with 25,000 cells and with appropriate refinement to capture flow details near the airfoil surface.

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3. Validation of Modeling Results

Experimental data was available for the NACA 4412 airfoil (NASA, USA) showing that the maximum velocity occurs at the leading edge, which is also where the observed maximum erosion occurs (Fig. 2). The maximum velocity for this airfoil was 13.6 m/s for an upstream velocity of 6.5 m/s. The simulation results were compared with the NACA data, and correlation was found to be excellent (Fig. 3). The experimentally observed maximum erosion takes place at the leading edge,

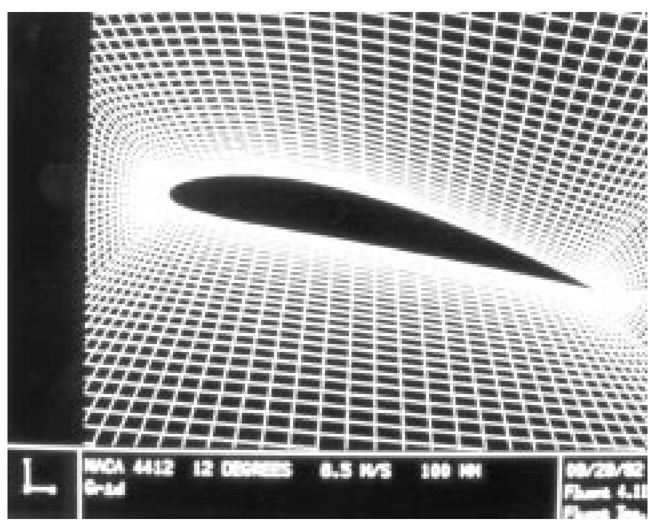

Fig. 1 Computational mesh used for the analysis of the impeller performance. The mesh used is a structured, O-type mesh with about 25,000 cells.

which is consistent with the position where maximum velocity occurs, according to the simulation (Fig. 3-4). These correlations provided a high level of confidence in using FLUENT software to predict maximum velocities and distributions for other airfoil shapes.

4. Particulate Interactions

In addition to examining velocities, the solid particle interactions with the airfoil were also examined using the computational analysis results. A stagnation point was observed on the bottom side of the airfoil at the leading edge, where the particles diverge. Some of the particles then wrap around the top surface at the leading edge in the very high velocity region. Some of these particles move away from the airfoil near the trailing edge. The analysis results show that the bottom surface at the leading edge receives high erosion from the impinging particles, and the top surface, or suction side, receives high erosion from sliding erosion (Fig. 5). This information was useful in selecting an alternative airfoil design in order to reduce erosion.

Fig. 2 C100 blade erosion after four years

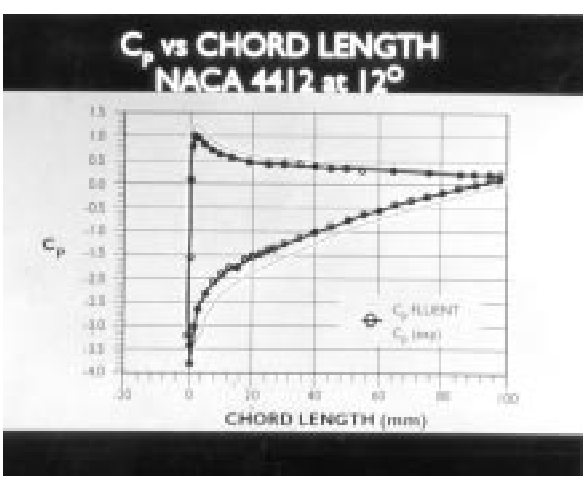

Fig. 3 Comparison of experimental observations of the NACA 4412 airfoil impeller and the FLUENT simulation results

Based on these results and engineering judgment, a new airfoil was selected as a proposed impeller design. The author's background in aerospace engineering was useful during this process. The new airfoil is symmetric and thinner near the leading edge, and has a larger amount of camber, reducing the airflow velocity in the vicinity of the leading edge. Analyzing the new design with FLUENT at the same 6.5 m/s upstream velocity showed a reduction in maximum velocity to 10.7 m/s, which is 20% less than the original design (Fig. 6). With nearly a cubic relationship between velocity and erosion, this change, in itself, reduces erosion by 50%.

5. Applying Coating Optimally

Coating the blades was also considered. Generally, applying a 0.040 in. wear-resistant coating increases life by 100%, but also increases the cost of the blade by the same amount.

Knowing exactly where high velocities would be experienced made it possible to cover the critical areas, coating only 20% of the blade. Protecting the leading edge of the blade prolongs the life of the leading edge and also prevents erosion from occurring downstream of this layer. With the application of the coating, it was predicted that the life of the blade would be extended by a factor of four. A test apparatus was used to validate the prediction. Two steel coupons were run in a sand slurry for 24 hours. The coupons (one coated and one uncoated) were then weighed to determine material loss. These tests showed dramatic reductions in wear on the order of the amount that had been predicted.

6. Testing the Redesigned Impeller

Next, a full tank model of the blade was created, in order to determine whether particle distribution in the tank would be sufficient with the new blade. A full-size prototype of the impeller was built and tested in water in a 15 m square tank (Fig. 7) in our lab and at an alumina installation in Australia. Flow measurements were obtained using an Ott propeller meter and

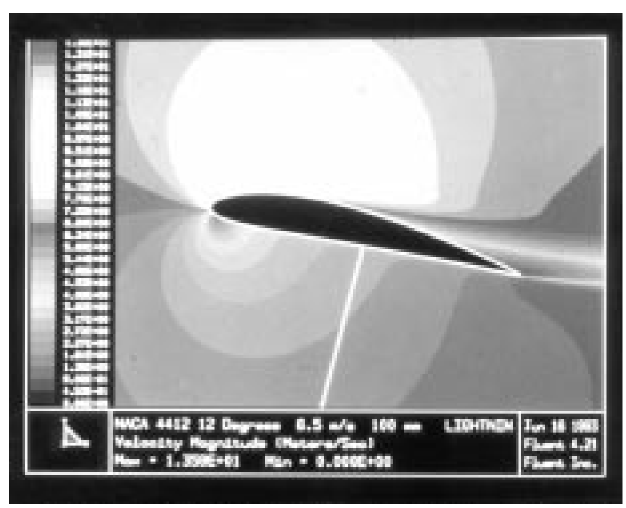

Fig. 4 CFD simulation showing velocities in Fig. 3

a Marsh McBirney eddy current velocity meter. The full-scale measurements were obtained either at the outlet of the draft tube or over the vertical section above the lip of the draft tube (Fig. 8). A laser Doppler velocimeter (LDV) was also used to generate velocity profiles in a 1.2 m tank with a 0.41 m impeller. A two-dimensional DANTEC Series 60 fiber optic system with enhanced burst spectrum analyzers was used for processing. The flow number of 0.62 that was measured with the LDV was within 5% of the measurements taken in the 15 m tank and in the field installation.

A new FLUENT model of the entire tank was also constructed. The integrated flow measurements were then used as inputs through the draft tube. Specific details, such as the thickness of the draft tube, were critical in this model as well. Care is needed when modeling the draft tube inlet because highly skewed cell structures (that will give numerical instabilities in the computational model) need to be avoided. The axisymmetric model had over 9,000 cells. The software produced a predicted path of 100 μm particles, which were injected into the flow field. Based on previous particle studies, it appeared that performance would be good. The new impeller was installed in the application and has provided excellent performance.

7. Conclusion

The author has used FLUENT since 1989 and has found it considerably easier to use than other programs he has looked at. The FLUENT code is user-friendly and accommodates complex simulations. The program provides immediate graphical feedback during grid generation, model creation, and the solution process. Additionally, Fluent Inc. has provided the author with outstanding technical support. The developer listens, and has made a number of enhancements to the software based on the author's needs.

The program has been used in a number of other areas, including blending studies where a second species was introduced into the tank, to determine how it is redistributed over time. Gas dispersion, transitional flow, solids suspension, and blending have been looked at, in other analyses. In the future,

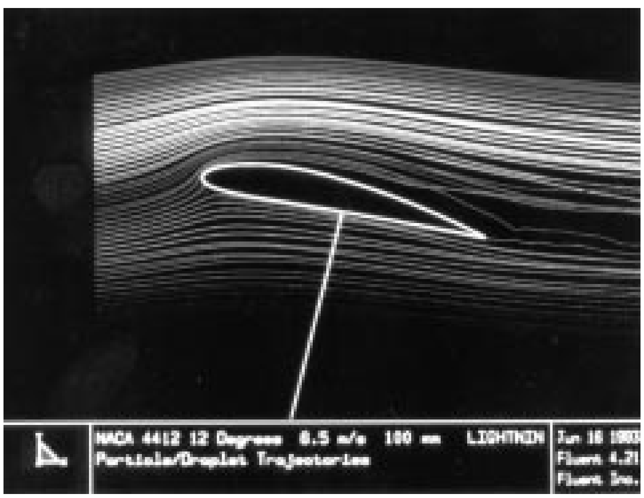

Fig. 5 Particle trajectories and the interactions with the impeller as predicted by FLUENT. This detailed information on particle motion and interactions helped select alternative airfoils.

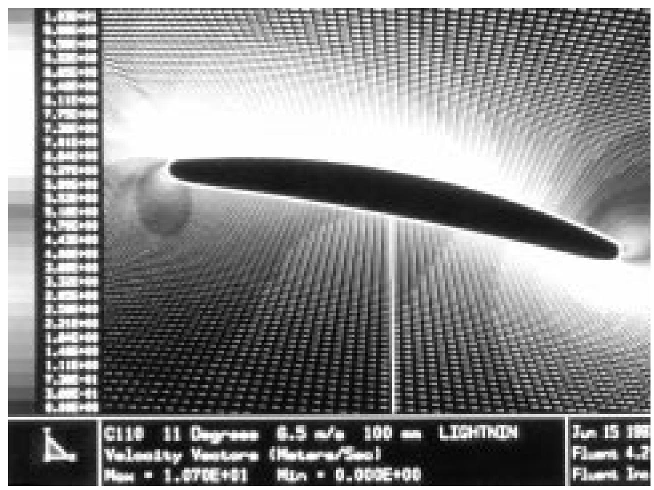

Fig. 6 CFD C110 velocity field

Fig. 7 C110 3.2 meter impeller in 50 ft tank

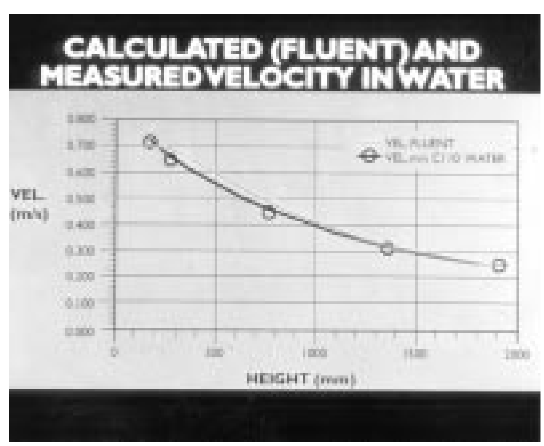

Fig. 8 Calculated (FLUENT) and measured velocity in water

creation of a model is planned that will include the full tank yet provide fine enough detail to cover the impeller, thus minimizing the need for the experimental measurements described above. FLUENT has recently introduced the sliding mesh and unstructured grid capabilities needed for this type of analysis. Beyond that, the author plans to incorporate chemistry into the CFD analysis in order to measure the effect of the mixer on the reaction. All in all, the use of CFD has given LIGHTNIN a competitive advantage in improving its product line, and in developing custom products for specialized applications.

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