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Computational Fluid Mixing for Corn Wet Milling Applications

Computational Fluid Mixing (CFM), has broad applicability for fine tuning agitator designs used in the corn wet milling industry. It permits detailed analysis of flow patterns, allowing more precise designs. Some practical uses include: choosing good locations for sample ports, reagent injection, or discharge; predicting interfacial area and hold up in gas/liquid systems, and solids distribution in solid/liquid systems. This technology is available today, and has already been put to use in corn wet milling applications.

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Introduction

The purpose of this paper is to describe how Computational Fluid Mixing (CFM), a subset of Computational Fluid Dynamics (CFD), can be applied to agitation and mixing problems common in the Corn Wet Milling industry. A detailed treatise on computational methods will not be provided here, although more information is available in Reference 1.

Brief Theory

The flow in an agitated tank can be described by the same equations of motion as any other fluid flow. Conservation equations, momentum transport equations, and turbulence models all must be employed. To do this using numerical methods, the agitated tank is first divided up into grid cells (Figure 1). The equations of motion are numerically solved for every grid cell (Figure 2). The total number of grid cells varies from a few thousand to over 100,000, depending on the model. The total number of equations to be solved then varies between 10,000 and 1,000,000 depending on the model and the flow regime. The results can be shown pictorially, e.g. by means of velocity vector plots.

The most common way to get such results is to use a commercially available CFD code, manually generating the model and prescribing the appropriate boundary conditions. This method is time consuming, and requires an expert in CFM to accomplish the task. It is more efficient to generate agitator designs using an expert design system, as described in Reference No. 2, and then use a CFM expert system to automatically generate the CFM model and boundary conditions. This is the method commonly used by Chemineer. It eliminates the need for a CFM expert for routine problems, and reduces model setup time to less than a minute.

Besides generating velocity profiles, CFM is capable of a number of other tasks. These include the calculation of pressure distribution, temperature distribution, shear fields, power dissipation, eddy dissipation, and reaction yield in single phase systems. In multiphase reactors it is possible to predict such quantities as solids distribution, gas holdup distribution, bubble size distribution, and mass transfer coefficient distribution. This is achieved by modelling the reactor with Ghost!, which is a proprietary code owned by Chemineer, Inc. In the ensuing sections, we will illustrate some practical examples of this technology applicable to Corn Wet Milling agitation problems.

Use of CFM for Flow Controlled Applications

In some corn wet mills, horizontal cylindrical tanks are used in low headroom locations, such as below grind mills. Often, they are fairly long, and more than one agitator is needed. CFM can provide guidance to help choose the appropriate number of agitators.

To illustrate this, we modelled a 10′ diameter, 35′ straight side, horizontal vessel, with typical agitation intensity. Figures 3 and 4 show the vessel, equipped with two 3 hp and three 2 hp agitators respectively. Figure 5 shows vector plots of the flow in the vessel, for both the two agitator and the three agitator system. The velocity vectors point in the direction of the liquid velocity and the length of the vectors is proportional to the velocity magnitude. Figure 6 shows a raster plot of the same information, except only velocity magnitude is indicated. Sometimes it is easier to visualize "dead spots" this way. Although the total hp is the same, the fluid velocities are more uniform in the tank with three agitators. Two agitators may be adequate if only liquids are present, or if a permanent fillet of solids between mixers is acceptable. Otherwise, three units are recommended.

Similarly, in tall, thin tanks, it is necessary to choose the right number of impellers. We modeled a 12′ diameter, 36′ straight side, vertical cylindrical tank, with a 5 hp agitator. This is a fairly common geometry and agitation intensity in corn wet milling.

Figures 7 and 8 illustrate the flow pattern and velocity magnitude using both vector and raster plots, for dual and triple impeller systems. Deciding between the two is somewhat of a judgment call in this case. Two impellers would probably be adequate for simple, non-critical applications where negligible solids are present, such as continuous flow saccharification, or a dextrose solution storage tank where no additions are made. For slurry applications, variable liquid level, etc., three impellers provide more uniform mixing and would be the preferred choice.

In the preceding examples, all flow patterns were based on Chemineer's HE-3, high efficiency axial flow turbine. This impeller provides an almost pure axial flow pattern. If impellers with a larger radial flow component are used, more impellers are needed to achieve equivalent results.

Critical Reactors

When fast reactions occur at the point of reagent injection, such as in starch modification and other critical reactors, process results are heavily influenced by local flow patterns and turbulence intensity. Benz (3) found, for example, that caustic concentration in starch reactors can be increased fivefold for a given agitator size by optimizing impeller type, size, and injection point, when compared to sub-optimum systems.

Today, using CFM, we can analyze in more detail local and global flow patterns and turbulence intensity. The flow pattern is shown by means of vector plots. Turbulence intensity is a scalar quantity proportional to rate of the energy dissipation, and will be shown using raster plots.

We modeled a 20,000 gallon starch reactor, using a 30 hp agitator, using two different impeller systems, in Figures 9-12.

The first system consists of dual HE-3 high efficiency impellers. This system provides the best overall liquid motion, but not necessarily a large turbulence intensity at any one point. Customarily reagents are added at the surface with this system, although best results are obtained injecting just above the tip of the lower impeller.

The second system employs the impeller series recommended by Benz, and confirmed by Fasano and Penney (4). It consists of an upper pitched blade turbine (P-4), a middle axial turbine (HE-3), and a lower concave disc radial turbine (CD-6). These are balanced in terms of flow and power for optimum process results with critical reagents injected at 90% of the CD-6 radius, 0.05 impeller diameters above it.

How do the two systems compare? At the recommended injection point, the turbulence intensity in the second, mixed impeller system is orders of magnitude larger than at the surface of the first, dual HE-3 system and at least 10 times the turbulence intensity at the blade tips of the HE-3 impellers.

For reagents that must be added at the surface, the upper turbine in the mixed impeller system provides a nominal advantage over the dual HE-3 system.

Field performance has consistently demonstrated the superiority of the mixed impeller system. The use of CFM in this case came after the field experience, but it can obviously provide considerable guidance regarding impeller types and injector location.

Use of CFM for Solid/Liquid Systems

Using the proprietary code Ghost!, Chemineer can predict solids distribution in an agitated tank. Although true heterogeneous suspensions are rare in Corn Wet Milling (most corn based slurries behave as single phase), this predictive ability can be useful, and can yield interesting results.

Figure 13 shows the solids distribution in a tank equipped with one impeller drawing 5 hp and in the same tank, using three impellers and a 3 hp motor. It is clear that with the single impeller, which draws more power (!) the solids are concentrated near the tank bottom. The triple impeller system, on the other hand, provides an almost homogeneous suspension. This can be explained by the fact that the large, single impeller generates only one small flow loop near the bottom of the tank, while the three impeller system provides excellent top to bottom mixing (Figure 14). This example shows that mixing quality is not only dependent on the horsepower draw, but that a well designed impeller system is equally or more important.

Because of mechanical reasons it is sometimes advantageous to use a single large diameter impeller, operating at a slow speed. However, when an impeller is mounted too far off the bottom and/or its diameter is too large, it will pump more radially and a "flow reversal" can occur. This is illustrated in Figure 15, showing the weak flow near the tank bottom. In such cases it can be advantageous to mount a small "tickler" impeller near the tank bottom (Figure 16). Provided it is well designed, a "tickler" impeller can create a strong local flow, preventing solids from piling up near the drain at the tank bottom.

Use of CFM for Gas/Liquid Systems

Since conventional Corn Wet Milling products are in a mature market, corn refiners have been looking for ways to add more value - added products to their roster. Some refiners have turned to aerobic fermentation, which can produce citric acid, amino acids, vitamins, antibiotics, and many other products using corn-based feedstocks.

In such fermenters, it is important to distribute nutrients and oxygen as uniformly as possible for optimum microbial output. Chemineer's recommended impeller system for fermenters consists of multiple upper HE-3 turbines and a CD-6 impeller on the bottom. The CD-6 impeller efficiently disperses the gas, while the HE-3 impellers distribute both the gas and the nutrients evenly throughout the vessel.

The flow pattern in a typical fermenter is shown in Figure 17. Using Ghost!, we can calculate the distribution of the mass transfer coefficient ($k_L a$), volume fraction of gas (holdup), and bubble size, shown in Figures 18-20. This information can be used when designing the agitator system for optimum performance.

Conclusion

Computational fluid mixing is a new tool available to agitator designers, with broad utility in Corn Wet Milling applications. It is available now, and has been used in actual applications similar to the examples given herein.

References

1. Bakker, A, Fasano, J., Leng, D., "Pinpoint Mixing Problems with Lasers and Simulation Software", **Chemical Engineering Magazine**, January, 1994.

2. Bakker, A., Berg, G., Morton, J., "Computerizing the Steps of Mixer Selection", **Chemical Engineering Magazine**, March, 1994.

3. Benz, G., "Improved Starch Reactor Design", **1990 CRA Scientific Conference Proceedings**.

4. Fasano, J., Penney, W., "Cut Reaction By-Products by Proper Feed Blending", **Chemical Engineering Progress**, December, 1991.

5. Bakker, A., Fasano, J.B., and Myers, K.J., "A Gas Dispersion Using Mixed High Efficiency/Disc Impeller Systems", **ICHEME Symposium Series No. 136**, 1994.

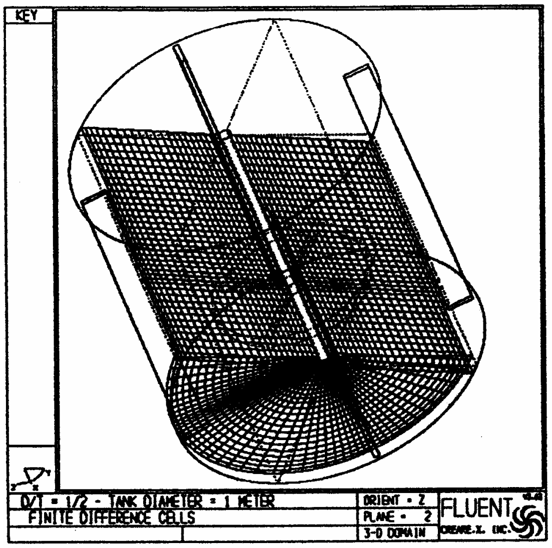

Figure 1: Grid Cells in a Typical Stirred Tank

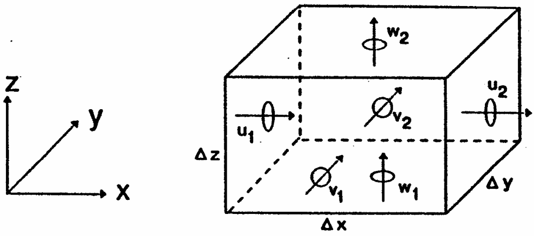

Figure 2: Illustration of the Conservation Principle, Showing Flows In and Out of a Grid Cell

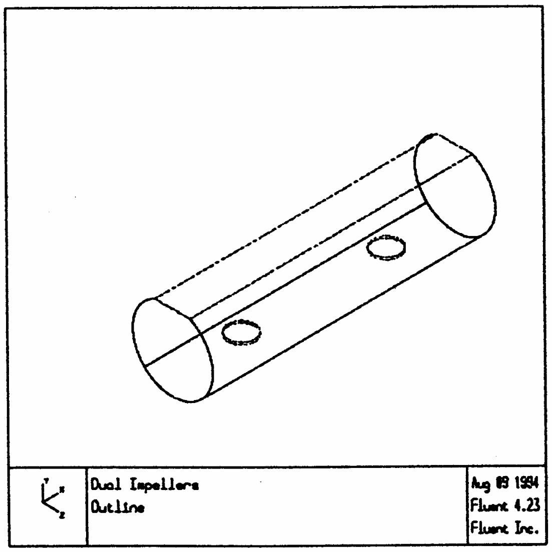

Figure 3: Outline of Horizontal Tank with Two Agitators

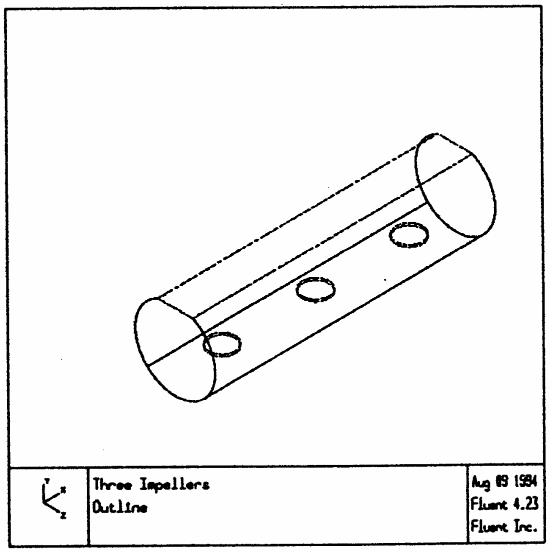

Figure 4: Outline of Horizontal Tank with Three Agitators

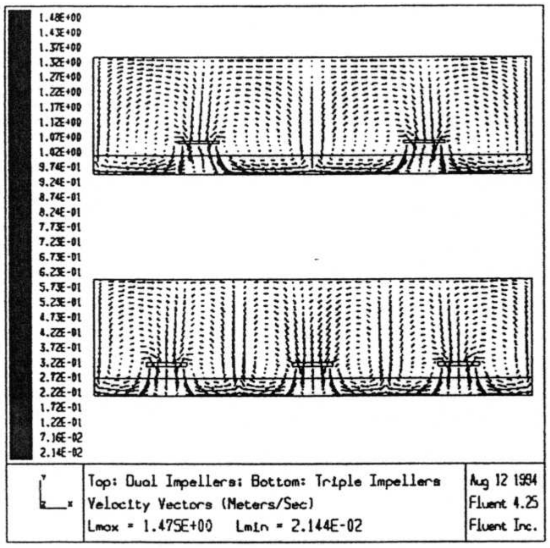

Figure 5: Velocity Vector Plot, Two and Three Agitators in a Horizontal Cylindrical Tank

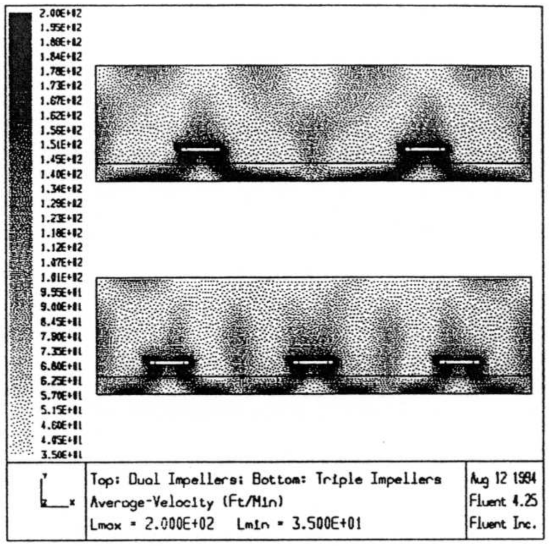

Figure 6: Raster Plot of Velocity Magnitude, Two and Three Agitators in a Horizontal Cylindrical Tank

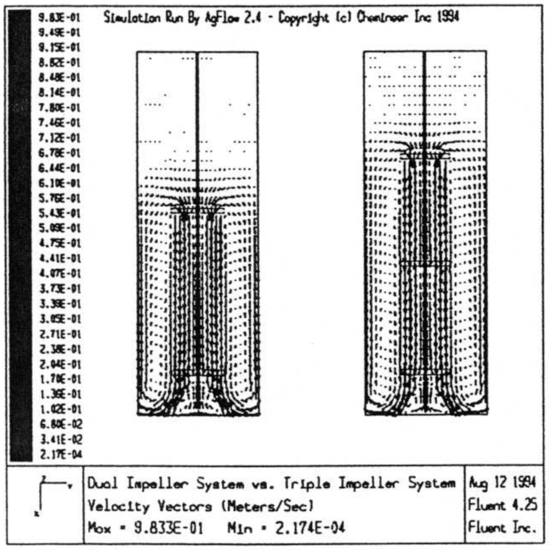

Figure 7: Velocity Vector Plot, Two and Three Impellers in a Vertical Cylindrical Tank

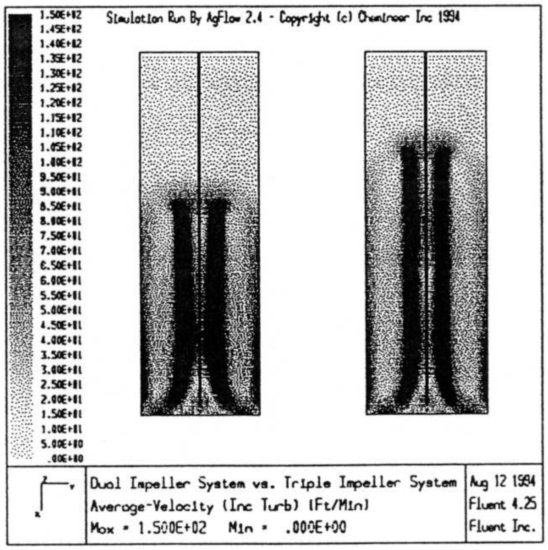

Figure 8: Raster Plot of Velocity Magnitude, Two and Three Impellers in a Vertical Cylindrical Tank

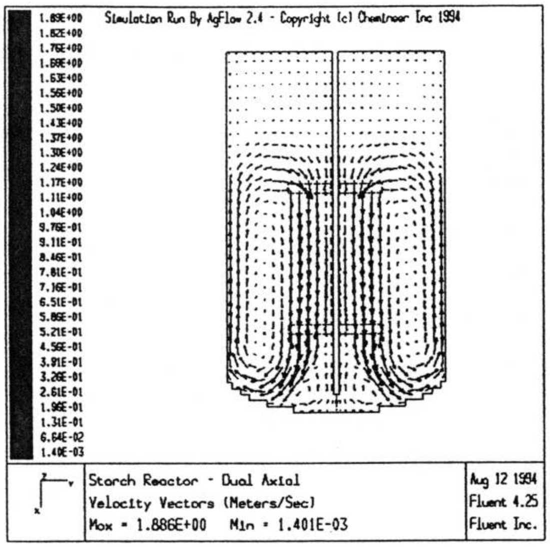

Figure 9: Starch Reactor, Dual HE-3, Vector Plot

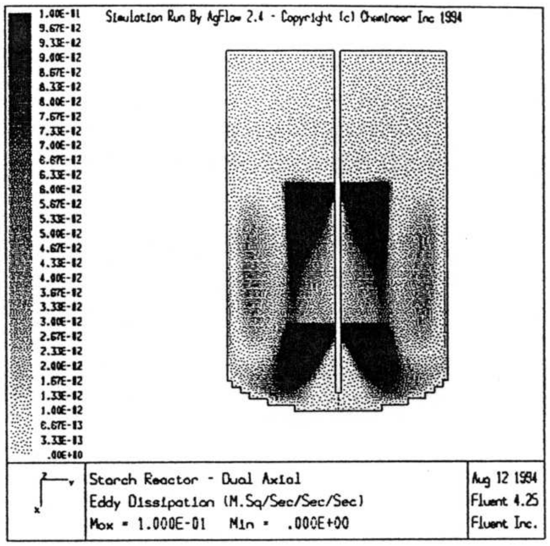

Figure 10: Starch Reactor, Energy Dissipation Rate, Raster Plot

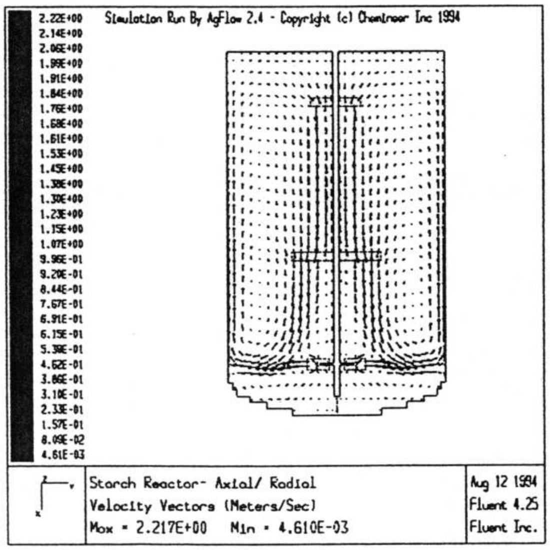

Figure 11: Starch Reactor, P-4/HE-3/CD-6, Vector Plot

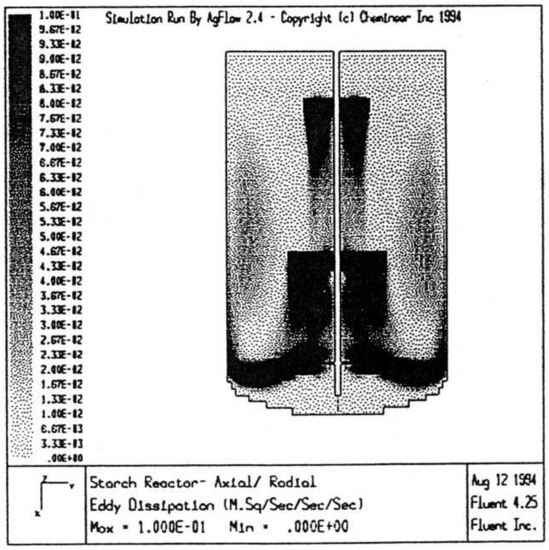

Figure 12: Starch Reactor, P-4/HE-3/CD-6, Raster Plot

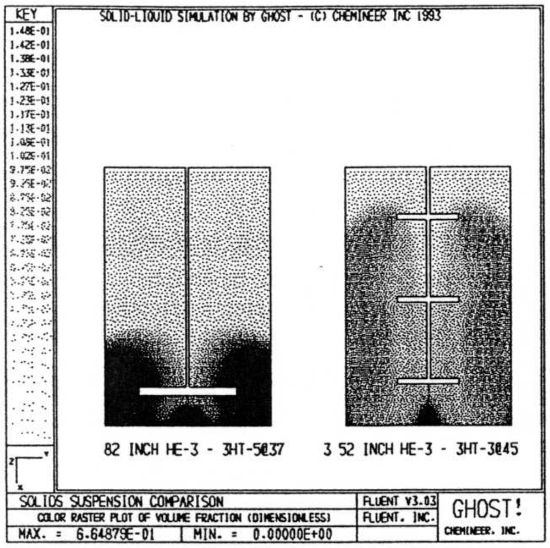

Figure 13: Solids Distribution in a Tank Equipped with One Impeller at 5 HP with 3 Impellers at 3 HP Total

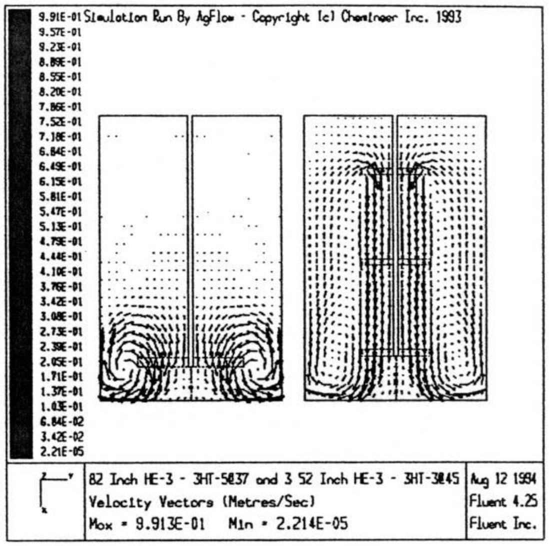

Figure 14: Velocity Vector Plot of the Flow Field for the Reactor in Figure 13

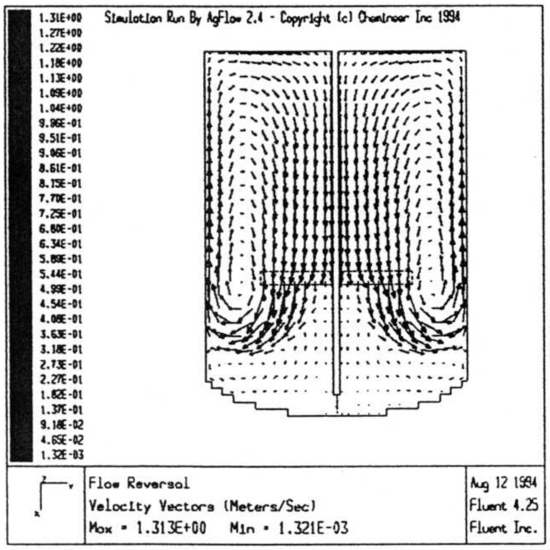

Figure 15: Flow Reversal in a Reactor with One Large Diameter Impeller

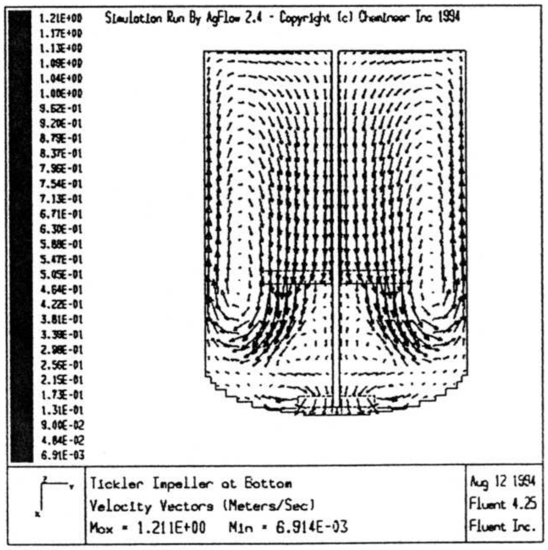

Figure 16: Flow Pattern in the Reactor of Figure 15, Now with a "Tickler" Impeller Added at the Bottom

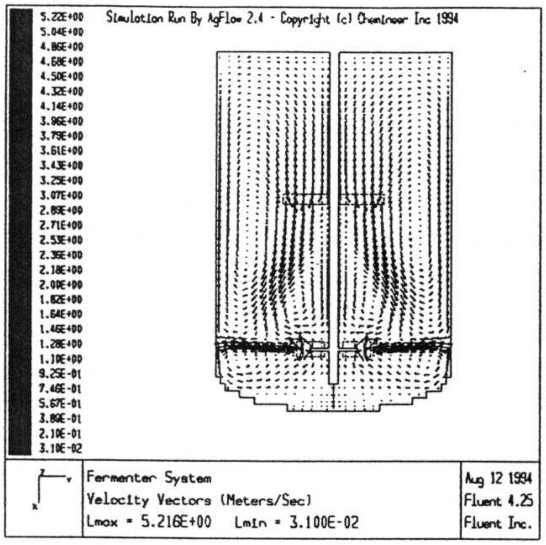

Figure 17: Flow Field in a Typical Fermenter

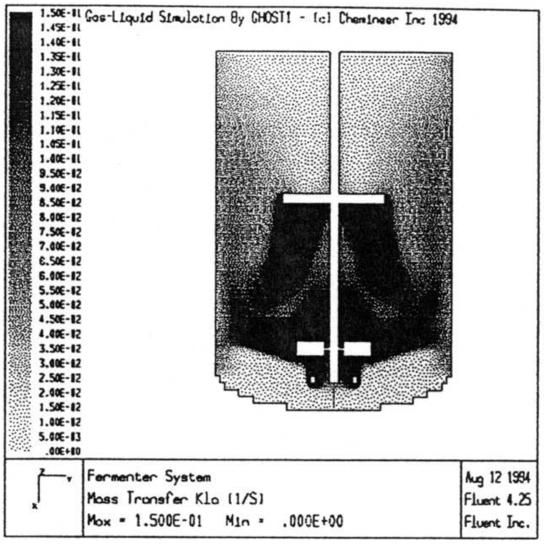

Figure 18: Mass Transfer Coefficient k_La in a Typical Fermenter

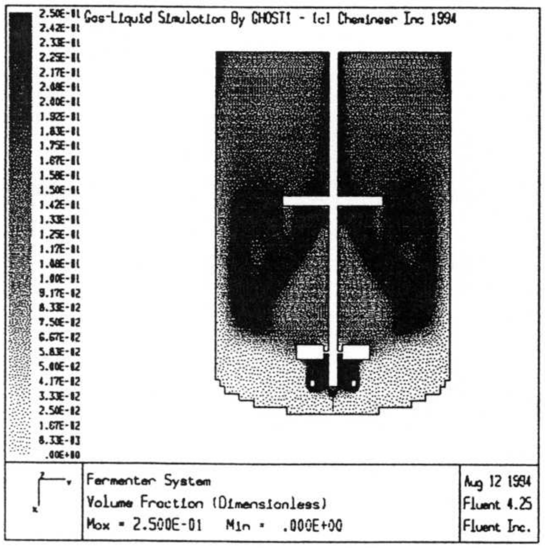

Figure 19: Local Gas Holdup in a Typical Fermenter

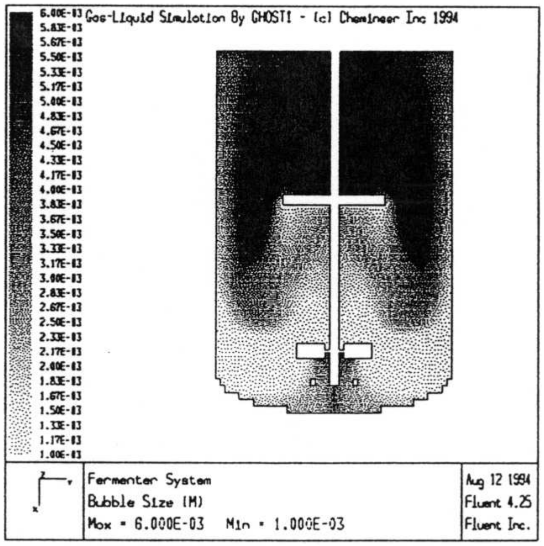

Figure 20: Local Bubble Size in a Typical Fermenter