Optimize your mixing process and food quality by using CFD

CFD, computational fluid dynamics, is a powerful computer tool for simulating flows in processing equipment.

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Introduction

Who is this booklet for?

- Plant managers, who want to discover how a reliable mixer design can be obtained by employing computational fluid dynamics (CFD), and who also want to learn how this tool reduces time, and thereby cost, and increases quality.
- R&D managers, who need to consider food quality parameters in their production processes and want to know more about how mixing challenges are worked around in the design phase.
- Engineers in the food industry, who are interested in different mixers and want to know more about how a reliable mixer is designed.
Background
Most applications in the food industry include mixing. In order to achieve the desired product quality, the whole volume of product should be optimally mixed, and the mixer should not impact the fluids in ways that might jeopardize the final result.

In a production setting, the mixing conditions vary at different positions in the fluid volume in a stainless steel tank, but these variations are not visible. Thus, in order to optimize product quality, mixing time and power consumption, the liquid flow inside the tank often needs to be understood in more detail.

Tetra Pak investigates this by running physical experiments and, in addition, applying CFD by using computers and commercial software. We run numerical simulations of the conditions inside the mixing tank during our design. In other words, we use the software to construct a ‘virtual mixer’ and then perform virtual experiments with it. In this context, it is very important to ensure that the simulation results match the results from physical experiments – a validation procedure that requires some effort, but ultimately leads to a more reliable design.

Some of the advantages we encounter are that fewer physical trials are needed in the design phase, and fewer commissioning issues arise when the mixers are installed at our customers’ production sites. In addition, this way of designing mixers provides a broader range of testing opportunities, which means the final design and configuration are optimised for specific applications.

This white paper shows how Tetra Pak applies CFD in the design of mixers for highly viscous fluids such as tomato paste, cream cheese and hummus. Tetra Pak uses this method regularly to foresee the flow fields of the system and to forecast which design changes would make the greatest contribution to improving performance. Combining our thorough knowledge of food industry processes and broad experience of CFD for a variety of applications, Tetra Pak is able to offer improved performance guarantees for mixers to customers.
What is CFD?

CFD has been around since the early 20th century and many people are familiar with it as a tool for analysing the way that air flows around cars and aeroplanes. Nowadays, the tool is employed in a variety of industry sectors. It involves numerical solutions of partial differential equations and is used to generate flow simulations with the help of computers.

Values such as velocity, pressure, temperature and turbulence are obtained from the simulations. In fluid applications, these values are then used to visualize the fluid flow fields at different locations inside apparatus like heat exchangers, pipes and mixing tanks. Figure 1 shows a typical simulation of a pipe bend with a sensor mount.

![Figure 1. Results from a simulation of a pipe bend with a sensor in the bend. The streamlines show how the fluid flows upwards at low speed (in green) and turns 90° while passing the sensor, which induces a higher speed (in red) and swirls.](image)

Tetra Pak applies CFD in order to simulate what happens in a mixer. In practice, we create a ‘virtual mixer’ and use it to perform virtual experiments. Thereafter adaptations must be made that adjusts the simulations to the type of liquid the mixer is being designed to handle. For example, water behaves in a relatively straight-forward way, while tomato products and cream cheese – being more responsive to mixing forces, temperature and other impacts – require different simulation approaches.
Having constructed a ‘virtual mixer’, we can visualize the fluid flow fields for various mixing conditions, and optimize the design of the mixer by varying the parameters in subsequent computer simulations.

To conduct efficient, fast calculations requires substantial computing capacity, so Tetra Pak has invested in a computer cluster of 8000 CPUs connected in parallel. Since a typical mixer simulation takes a few weeks using 200 CPUs, this means we have the capacity to run numerous simulations within a short period of time.

**A comparison of physical and virtual experiments**

Running virtual experiments gives fast interactive feedback and provides additional information about what is going on inside the mixer – such as power output, mixing time, energy dissipation and turbulence intensity. Therefore, a combination of empirical trials and computer simulations adds considerable value. The two methods are compared in table 1.

<table>
<thead>
<tr>
<th>Performing physical experiments:</th>
<th>Added values when including ‘virtual experiments’:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+) Fewer parameters can be studied at a time. Some parameters are more accurate to measure than to simulate, such as droplet size.</td>
<td>(+) Multiple parameters can be studied simultaneously; even the ones that cannot be measured can be investigated.</td>
</tr>
<tr>
<td>(-) A limited number of positions can be studied in the vessel.</td>
<td>(+) Much higher resolution both in space and time, i.e. you can get information from anywhere at any time.</td>
</tr>
<tr>
<td>(-) Trials are often in laboratory or pilot scale models.</td>
<td>(+) Independent of scale.</td>
</tr>
<tr>
<td>(-) A limited range of operating conditions can be studied.</td>
<td>(+) Realistic operating conditions.</td>
</tr>
<tr>
<td>(+) Recipe proportions can be varied.</td>
<td>(-) Need to perform fluid measurements prior to simulations.</td>
</tr>
<tr>
<td>(+) Can obtain sensory parameters such as taste and appearance.</td>
<td>(-) Not applicable.</td>
</tr>
</tbody>
</table>

*Table 1. Comparison of physical and virtual experiments.*

6 (15)
Both types of experiments can lead to errors in the resulting data. In physical experiments, measurement errors and flow disturbances near the probes can cause deviations from the correct values. And computer simulation errors can be caused by the numeric algorithms and modelling methods used. It is therefore very important to perform a validation, which reduces the errors from the simulated ‘virtual mixer’.

**Validation before running computer simulations in the design of mixers**

Validation is crucial since it provides confidence in the design phase. The path for validating a ‘virtual mixer’ requires:

1. Good and controlled physical measurements of the flow field inside the tank
2. Simulations and the comparison of results with the physical measurements, and the correct selection of CFD parameters (to enable the most consistent results for the following simulations in the design of the mixer)

Using a validated ‘virtual mixer’, we can obtain reliable results and cover numerous aspects of the mixer’s performance. Just to mention a few: the mixer’s performance can be foreseen before it is built; we get increased knowledge of which adjustments to the design would yield the greatest performance benefits; and we get detailed information about the actual mixing process.
The mixing challenge

There are many different types of mixers, so here we have chosen to focus on one – the high-shear batch mixer. A high-shear mixer disperses ingredients that would normally be immiscible, like oil and water or particles and water. If it is a high-shear batch mixer, it consists of a tank with a rotor-stator system and agitators inside it. This unit is used to mix ingredients into a stable mixture (batch-wise) before transferring the fluid to the next process step.

Figure 2 shows a high-shear batch mixer. The rotor-stator system consists of a rotor, which pumps the mixture radially from the centre out towards the tank walls, and a stator that works with the rotor to create the high shear. This is the position in the mixer where the efficient mixing or emulsification occurs, and the shear forces are required to make it happen. The agitators’ role is to move the sheared mixture around in the tank and ensure the whole volume is mixed uniformly.

Figure 2. A high shear rotor-stator batch mixer consists of a tank, three types of agitators, a rotor and a stator. There are two distinct mixing regions in the tank: the high-shear region a few centimeters around the stator, and the global mixing region in the large tank volume.
Our customers often need to disperse powder efficiently, or mix oil into highly viscous mixtures like hummus. A high-shear batch mixer is suitable for the majority of these processes.

However, mixing highly viscous fluids is difficult and the mixer must be designed to ensure that the viscous ingredients are:

1. Flowing fast enough to and through the rotor-stator system
2. Homogeneously mixed throughout the tank
3. Exposed to enough shear forces through the rotor-stator

The key question is how to design a mixer that can handle a variety of fluids and still fulfil all these demands. In the following chapters, we will describe how Tetra Pak does this.

**Tetra Pak’s procedure for creating a validated ‘virtual mixer’**

First, a ‘virtual mixer’ is ‘built’ using software specifically designed for this purpose. Then a validation takes place. The validation is carried out in different parts of the mixer, from the crucial rotor-stator region to the global mixing region of the tank. During this procedure, we gradually introduce more complex fluids. We begin with plain water, progress onto a sugar-water solution and end up with very viscous and complex liquid. Before moving on to each successive step, we view the results from the computer simulation and make sure they are in line with our empirical measurements.

In the examples below, we validate the ‘virtual mixer’ that is to be used later on, when designing mixers for viscous solutions.

**Validation step 1: Rotor-stator region**

We study the flow of water through a stator hole in a high-shear batch mixer (see figure 2). In this instance, a small but crucial high shear region is thoroughly investigated. One stator hole is approximately one centimetre wide.

We conduct empirical experiments in a tank using a sight glass to enable measurements of the fluid velocity in the rotor-stator region by laser. Results from the trials are shown in the illustration to the left in figure 3. This shows the velocity flow field close to the stator hole while the rotor is passing. Each time the impeller reaches the stator hole, a high-speed jet is formed and flows through the hole on the right-hand side. A moment later, when the impeller blocks the hole, there is still a jet but it is much weaker.
Corresponding tests are carried out using computer simulations of the ‘virtual mixer’. The results can be seen in the illustration on the right in figure 3. In his step, the focus is to modify several parameters in the software version of the mixer in the following simulations, in order to get similar results as in the empirical trials. For example, different turbulence models and different resolutions are tested. The choice of resolution has a huge impact on the level of detail we capture in the flow field and also on how many calculations each simulation requires. Therefore, choosing a value for these parameters influences both how well the actual mixing performance is represented by the results from simulations in the ‘virtual mixer’, and how much computer capacity is needed to run the simulations.

Having adjusted the ‘virtual mixer’ so that it will yield comparable results in the rotor-stator region, we can start to investigate how well the results match in the rest of the tank.

![Figure 3](image.png)

*Figure 3. Flow velocity inside a stator hole ≈ 1 cm wide. Computer simulated results (right) match results from the physical trial (left). The colours represent different velocities: dark blue (lowest), blue, green, yellow, red (highest velocity).*
Validation step 2: Tank flow

A highly viscous sugar solution is used to study the flow further away from the rotor-stator.

In this region we investigate the global mixing induced by turbulence. These experiments are in many ways similar to those carried out in the previous step. Once again, the results obtained are compared to the results from the computer simulations. Then the parameters in the ‘virtual mixer’ are adjusted until the results correspond sufficiently accurately.

The illustrations below show what happened when two different turbulence models were implemented in consecutive simulations during validation. To the left of figure 4 we show a simulation in which a concentrated jet moves in a large loop before flowing back to the rotor-stator system. This is not comparable to the fluid motions in the empirical experiments. To the right of figure 4 the fluid motions in the simulation more closely resemble those of the empirical experiments: a concentrated jet flows upwards and diffuses when recirculating back to the rotor. Based on this information, we now can decide which turbulence model to choose in our ‘virtual mixer’ in order to get representative flow fields out in the tank volume.

Figure 4. Results from simulated flow field inside the batch mixer with two different turbulence models. The left image shows a more concentrated jet. The image to the right shows a more diffused jet, which resembles to the actual flow.
Validation step 3: Very high-viscous fluid

Next step involves an even more viscous fluid. Since we use an opaque fluid for this step, the surface velocity is the only measurable parameter. Hence, particle tracking velocimetry (PTV) is used onto the liquid surfaces during the empirical experiments and the surface velocities are obtained and compared with results from the ‘virtual mixer’ simulations, as shown in figure 5.

The validation showed a clear match between the physical and simulated test results. The difference was less than 11%. Below, the right hand image shows the flow field in a sector of the liquid surface in the tank. The colours represent different velocities: red imply highest velocity, which is near the tank walls, whereas blue indicate a slower movement, as is the case closer to the centre of the tank. Overall, the flow field is directed towards the centre, which was also seen in the experiment.

Figure 5. The velocities at the liquid surface are studied (left) and a sector of the surface is shown (right).
How Tetra Pak uses the validated ‘virtual mixer’

Once the ‘virtual mixer’ has been validated for the behaviour of highly viscous fluids, we can use it for simulations, and hence optimize the design of the specific mixer.

In this instance, before starting the simulations, we applied our experience of fluid mixing in the food industry to identify several possible design solutions. These were implemented in the ‘virtual mixer’. We know, for instance, how to get the desired movement in very viscous fluids by using rotating blades and scrapes that help move the fluid upwards in the tank. Also, in some cases, adding extra propellers and baffles has proved to be a good solution. We put this knowledge into the ‘virtual mixer’ in our first design attempt.

The first computer simulations showed some improvement potential. For example, we realised from the results that the fluid was flowing in the wrong direction in some parts of the tank. In addition, the simulations revealed two recirculation zones in the tank: one in the top and another in the bottom. The fluid was not moving in one large recirculation loop throughout the whole tank, as was intended.

In the next set of simulations, we made adjustments until we were satisfied with the mixing performance. These included:

1. Removing one propeller
2. Increasing the speed of one agitator
3. Reducing the speed of another agitator

When we had optimized the flow in the tank with the above adjustments, the results from the last computer simulation showed an increased mass flow through the rotor-stator, which was positive. In addition, the simulation confirmed that the final mixer design fulfilled all our requirements – as described earlier in the chapter “The mixing challenge” – and the mixer was now optimized for viscous fluids.
Benefits of using CFD in the food processing industry

Below is a summary of the benefits Tetra Pak obtains from using computational simulations when designing a mixer.

- Firstly, by using validated ‘virtual mixers’ we can see that our fluid dynamic simulations differ only minimally from experimental data, and that true physics are captured. This means we are confident that the mixers we design will give the desired results.
- Secondly, making a ‘virtual mixer’ takes way less time than actually building several mixer prototypes and performing consecutive tests. Furthermore, it is faster and cheaper to vary the process parameters in computer simulations than it would be to stop on-going production and run physical tests. We have seen that using CFD can reduce the time plan by up to half a year. In addition, the end design is optimised and the mixer requires less power, reducing the cost of ownership for our customers.
- Thirdly, computational simulations provide us with detailed information that contributes to our understanding of the mixing process. Important process parameters are identified and can be improved. The result is a rapid, reliable mixing process that is, most importantly, adapted to produce an end product of the desired quality.
- Fourthly, the mixers developed using ‘virtual’ tools generally perform well from the very first tests after the apparatus has been installed at the customer’s site. This saves time and money during commissioning.
Tetra Pak – your mixing partner

Tetra Pak food technologists and process engineers have very thorough knowledge in the field of mixing, thermal treatment, deaeration, water removal, powder handling, buffering, cleaning, packaging and storage. For more insights into the optimization of mixers – and particularly if you need advice about specifying processing parameters or integrating processing equipment into a line – please don’t hesitate to contact your Tetra Pak representative.