Pulp and paper plants use stock chests with partial mixing and recirculation loops to reduce the magnitude of consistency fluctuations in pulp production. Minimizing these fluctuations provides a smoother, more uniform surface and significantly improves final sheet properties. This results in more first-quality tons and improved savings and revenue. The relationship between reduced fluctuations and lower costs is commonly acknowledged in the industry. It is also highly dependent on stock chest mixing/dilution.

Typical machine chest mixing is limited only to the chest bottom. This marginal mixing technique requires chest output consistency to be controlled by recirculation loops. These automatic consistency control loops have relatively long time constants and are unable to react to short-term consistency fluctuations.

The solution to paper stock consistency fluctuations is to create multiple areas of zonal mixing. These areas also improve residence time distribution (RTD) and prevent the short-circuiting of flow within the stock chest.

Pulp and paper plant engineers and managers have long held the perception that stock chest mixing equipment sufficient to mix entire volumes required an unmanageable capital investment. This prevented full-scale experimentation in the past. Due to the complex rheology of paper pulp, numerical simulations and small-scale experiments have not been fully persuasive enough for engineers and plant managers, especially in light of potential scale-up challenges.

Total chest mixing can be accomplished by utilizing a correctly sized top-entry agitator combined with modified impeller technology to create multiple areas of zonal mixing. This new approach not only mitigates the previously

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**Total Stock Chest Mixing**

Innovative mixing of 6% - 14% consistency stock vessels for improved quality and energy savings.

By Marc R. Moseley and Dr. Wojtek Wyczalkowski

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**Fig. 1. Test setup** Vessel measuring 0.91 m (3') diameter holding 0.606 m³ (160 gal) of pulp. Mixer has variable speed drive with three modified impellers. The shaft has strain gauges for torque and bending moment measurement.
high costs of full-chest mixing, it also delivers energy savings of 50% compared to standard side-entry mixers—the technique currently in use by most pulp and paper plants. The cost and installation of this technology can be returned in as little as 15 months of operation. Independent estimation of savings due to the lower paper consistency fluctuations varies, but can exceed $100,000.00 per month (USD).

**THE RHEOLOGICAL PROPERTIES OF PAPER STOCK**

The quantification of fluid properties is the single most important part of the mixer design process. Fiber suspensions are difficult to agitate—the common perception is that the limit for effective mixing is in the range of 6%-7% of fiber by weight. The friction between fibers is very high, resulting in enormously high yield stress. Under these conditions, Bennington and his colleagues report a yield stress value in excess of 2000 Pa.

In order to effectively mix the suspension, shear stress must exceed yield stress throughout the entire vessel. Since the stress gradient is high due to the nature of the shear thinning fluid, extreme power is required. The only other alternative is to employ large-diameter impellers located close to each other. This latter approach renders the fluid yield stress value insignificant for power calculations. Instead, power calculations are based on the relation between shear rate and viscosity. This is typically expressed as Power Law, but in the case of a high concentration of paper pulp, it does not correlate.

The data that correlates viscosity with impeller shear rates was obtained via calibrated impeller test (CIT). Pulp of a known consistency was mixed at different RPM using impellers with known characteristics. The mix viscosity was later calculated from the impeller power draw.

**THE PHYSICS OF MIXING YIELD STRESS FLUIDS**

Yield stress fluids require special treatment due to their unusual behavior. One example of such behavior is the formation of caverns as reported by Nienow and his colleagues. A cavern is a well-mixed turbulent region around the impeller. Away from the impeller, where shear stresses are low, the fluid becomes stagnant. The boundary of the cavern is where the local shear stress equals fluid yield stress.

**Fig. 2.** Cavern formation in yield stress fluids. The most simple and economical way to mix a yield stress fluid is to increase the impeller diameter. At the same torque values, increasing the impeller diameter significantly increases the cavern size. A standard turbine impeller produces primary flow that induces a secondary flow within the vessel. In shear thinning fluids, the primary flow weakens severely within a relatively short distance from the impeller. Therefore, induced flow may not be adequate to produce the necessary shear stress to overcome yield stress.

**Fig. 3.** (left) Paper pulp mixing concept with several mixing zones. Paper pulp is added through the top of the vessel, and water and recirculation loops are used to keep proper dilution and minimize consistency fluctuations. Each impeller creates its own mixing zone which is not connected to the adjacent one. The upper zone is open to help the release of air. (right) Traditional paper pulp mixing concept with a single mixing zone. In this method of mixing, the upper part of the vessel is unmixed and the material plug flows downward by gravity. Mixers at the bottom are used to dilute incoming pulp and reduce consistency fluctuations. Challenges with this traditional method are related to non-uniform mixing, consistency fluctuations, slippage between pulp and water, and high energy consumption.
By using a large impeller diameter to vessel diameter ratio (D/T), the cavern diameter follows the impeller size and reaches the vessel wall at low mixing power. The vertical size of the cavern can be controlled by applying the appropriate spacing between impellers and, to some extent, by the impeller RPM. Changing the impeller spacing and RPM enables the process to be adjusted from zonal mixing to complete batch mixing. Nienow et al. provide the formulas for the calculation of cavern sizes.

**MIXING OF HIGH-CONCENTRATION PAPER PULP IN MACHINE CHESTS**

High concentrations of paper pulp (6%-14% by weight) exhibit high yield stress. Proper mixing requires the use of large-diameter impellers to make caverns that reach the vessel walls. This can be accomplished at low impeller speeds using large D/T > 0.65.

Chest mixing is a continuous process that involves high flow through the vessel. To reduce consistency fluctuations, several mixing zones (caverns) must be created within the vessel that are networked together by the flow. The mixing zones are separate; the fresh material is mixed in the first zone, then is passed to the second zone, and so forth throughout the process. This method ensures proper mixing of fresh material before it is transported to the vessel outlet.

Paper pulp that has been dropped at surface impinges the top portion of the stock and is aerated. The top impeller rolls the surface and helps to release air.

In conclusion, three major requirements for proper high-concentration pulp mixing are:

- Thorough, uniform mixing within each mixing zone
- No short-circuiting of fresh material into vessel outlet
- Degassing of pulp at surface

The illustration of flow in Fig. 4 shows channeling and incomplete mixing while there is only a single mixing zone at vessel bottom. Unmixed pulp stays at vessel sides, which can dewater, agglomerate and fall, causing mechanical failures of side-entry agitators. In contrast, the modified impellers are capable of mixing the entire vessel volume.

**ENERGY SAVINGS OF 50%**

This example is for the mixing of high-consistency paper pulp in a 6.1 m (12’) diameter x 6.0 m liquid level pulp chest. The mixing was done with two traditional 56 kW (75 Hp) side-entry mixers. The mixing efficiency defined as the mixing time constant divided by residence time of the chest, was measured to be 41%.

Based on lab testing and pulp rheology, the power requirement for mixing with three modified impellers was calculated to be 56 kW (75 Hp).

In order to compare mixing efficiency for a single zone with side-entry mixers vs. zonal mixing with multiple modified impellers, a computational fluid dynamic (CFD) study was performed. Fluid rheology was set for Bingham fluid with a yield stress of 2000 Pa. Vessel retention time was seven minutes, and the subsequent flow was 0.44 m³/s (6950 gpm).

Standard residence time distribution (RTD) calculations were run for two cases (A and B as shown in Fig. 4). RTD was calculated based on response to sin wave of tracer concentration 0.5 for 150 s and 1.0 for 150 s. The average concentration was 0.75.

The rheology model used for this simulation is simplified. Paper pulp properties are more complex than those that can be applied for current CFD. Results therefore are for determining trends only.
Start-up torque estimation is an important factor of mixer design. A few simple experiments were performed on high-concentration pulp to determine start-up torque value.

The start-up torque for mixed pulp does not exceed the mixer running torque. For the fresh pulp, the startup torque exceeds running torque by factor of 2.7. This application can be handled by a standard motor.

**CONCLUSION**

Using large D/T modified impellers to mix paper pulp chests delivers significant advantages over traditional side-entry mixing methods. Mixing a 6.1 m diameter pulp chest with high fiber concentration exceeding 6.5% with modified impellers offers 50% power savings compared with traditional side-entry mixers, 56 kW vs. 112 kW.

This new approach mixes the entire vessel content with less power than required by side-entry mixers. CFD simulation indicated improved mixing quality and reduced consistency fluctuations compared to side-entry mixing. This leads to additional significant savings on pulp quantity that goes into process and paper quality. Independent estimation of savings due to the lower paper consistency fluctuations varies, but will exceed $100,000.00 per month (USD).

The most significant part of testing is the measurement of pulp properties. It was demonstrated that the calibrated impeller test is a preferred method of collecting data for scale-up.

Apparent viscosity of pulp does not follow Power Law or Herschel-Bulkley Law. Using both models for power calculations will lead to over-sizing the mixer.

The type of pulp and pulp consistency are not the only parameters that affect apparent viscosity. Additives and fiber length distribution may change the rheology, thus requiring more statistical data.

References:


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