# REDUCING PRODUCT VARIATION THROUGH IMPROVED THICK-STOCK MIXING

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## ABSTRACT

*Effective injection of thick stock into the silo white water and, ultimately, into the fan pump suction to the headbox is critical to paper machine performance. Vendor recommendations for thick-stock-injection systems—coupled with high production rates and decreasing headbox consistency—tend to create large piping systems. Unfortunately, these large piping systems may not fit into existing facilities with limited space. Mills that cannot comply with the vendor's design specifications can see an increase in basis weight variation after a machine rebuild. This paper presents an innovative design that increases the efficiency of thick-stock injection, thus reducing the length of the piping system. Results from a paper mill showed that the proposed design innovation reduced the conditioned-weight machine-direction variation in the paper by approximately 30% within the periodic range of 10–40 s.*

## INTRODUCTION

The injection of thick stock into the fan pump suction is an important design configuration. The efficiency of the mixing that occurs between the silo white water and the thick stock prior to entering the fan pump is critical to the cross-direction and machine-direction uniformity of the sheet.

## BACKGROUND

Early designs for the injection of thick stock into the silo white water involved the use of tees and elbows at various angles and positions around the transition piece between the fan pump inlet and the silo or wire pit. The current design standard for thick-stock injection in today's large paper machines is through the silo with a concentric piping arrangement. The flow through the concentric pipes decreases in consistency and velocity from the inner pipe to the outer pipe. The concentric pipe arrangement, illustrated in **Figure 1**, creates a jet pump, thereby creating a turbulent flow down the length of the transition piece *(1, 2)*. In cases where space is a limiting factor, the top entry of the thick stock into the transition piece is still used as an alternative design, as seen in **Figure 2** *(1)*.

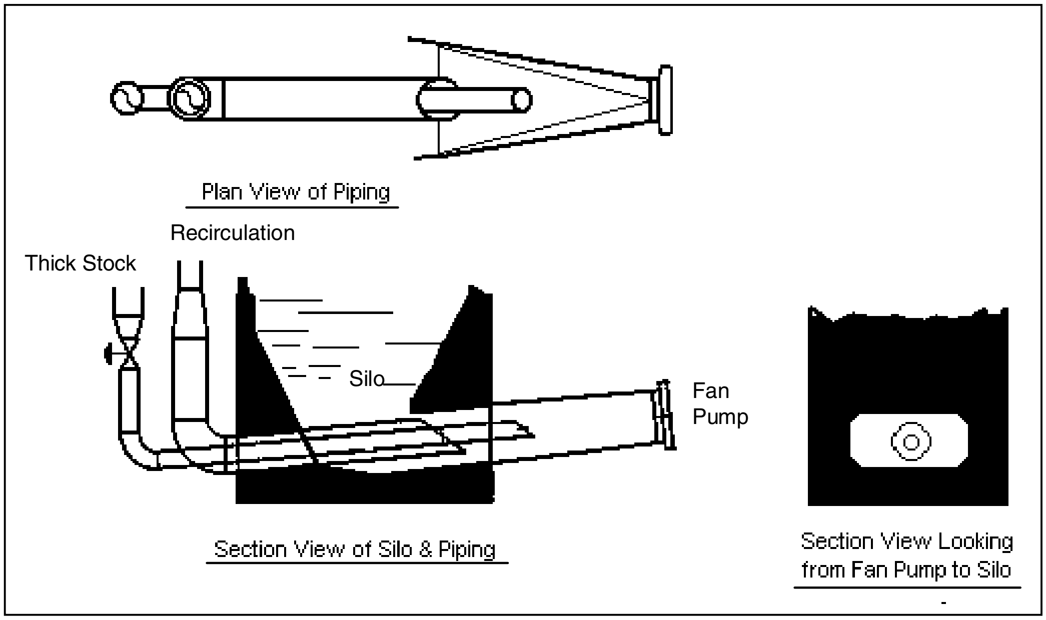



***Figure 1. Concentric thick-stock injection design (1).***

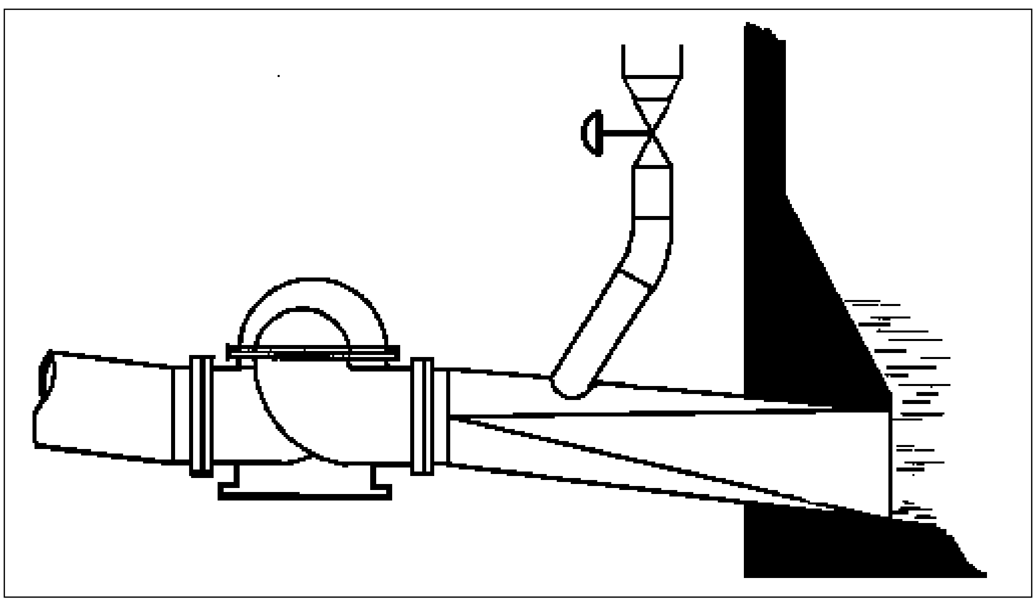


***Figure 2. Alternative thick-stock injection design (1).***

It is important to recognize the quality of the inherent mixing that occurs in the transition piece is affected by changes in the fan pump flow rate, the thick-stock consistency, the basis-weight-valve percent opening, and the production rate. Changes in these parameters produce different mixing patterns within the transition piece. If suboptimal mixing occurs, it creates consistency and flow variations that manifest as basis weight variations. On one paper machine that had a thick-stock side entry into the transition piece, the flow pattern changed dramatically during basis weight changes caused by the opening or closing of the basis weight valve. This change in the flow pattern caused the fan pump impeller and motor rotor to shift from its operating magnetic center, leading to increased maintenance on the fan pump and motor bearings.

## JET PUMP MIXING

Norman and Tegengren *(3)* demonstrated photographically that a velocity ratio of 5 (thick stock to white water) for the concentric pipes is the minimum acceptable for mixing, and a ratio of 10 is sufficient. In contrast, the major equipment suppliers stipulate a "greater than" range for the difference in velocity of thick stock to white water as opposed to a ratio. The velocity differences are less than the ratios. Current design recommendations for the silo transition create a velocity ratio in a range of approximately 3 to 6.

Another point of interest is the ratio of diameters in regard to the mixing length. Although this is not specifically addressed by Norman and Tegengren *(3)*, the visual implication of their photographs is that the standard minimum mixing length is not adequate for complete mixing. The photographs taken of the model suggest that at a velocity ratio of 5.3, the thick stock is not mixed well until approximately 25 thick-stock pipe diameters downstream. At the velocity ratio of 10.8, the thick stock is not mixed well until approximately eight thick-stock pipe diameters downstream. One supplier's recommendation is for a minimum mixing distance of four thick-stock pipe diameters. Note, however, that fan pump suctions are not straight pipes but transitions, and this would increase the turbulence and mixing slightly.

## PROCESS VARIATION AND REBUILD ISSUES

The possibility that a paper machine will experience greater basis weight variation after a rebuild can be minimized by:

- Installing better on-machine gauging sensors and systems
- Replacing the stream flow valve and/or fan pump recirculation valves with a variable-speed fan pump
- Enhancing the thick-stock consistency controls and system mixing parameters
- Replacing an air-padded headbox with a hydraulic headbox
- Replacing an end-suction headbox supply pump with a double-suction pump
- Enhancing the mixing ability of a short silo-to-fan-pump transition piping

Preliminary variation studies of the existing wet-end process capability, machine gauging system, and future grade mix will help in identifying and reducing basis weight variation, thereby reducing the possibility of disillusionment after a rebuild.

The rebuild and/or speed-up of a paper machine usually involve modifications to the white-water system. In some cases, this involves replacing the white-water silo and fan pump. However, in other cases, reusing the existing silo and physical building limitations create compromises of arrangement. When the distance between the thick-stock injection point and the fan pump inlet is less than the design criteria, additional turbulence is required for appropriate mixing. In this situation, creative solutions are required to maintain the integrity of the papermaking process.

## MIXING CONE

The mixing cone promotes mixing of white water and thick stock by breaking up the low-velocity white-water stream with a perpendicular stream of high-velocity thick stock, as seen in

**Figure 3**. The mixing cone dampens the flow and pressure fluctuations by absorbing the process spikes, similar to the way a valve does, rather than sending them directly downstream through the fan pump. The mixing cone can also decouple the effect of silo level variation with the thick-stock flow rate.

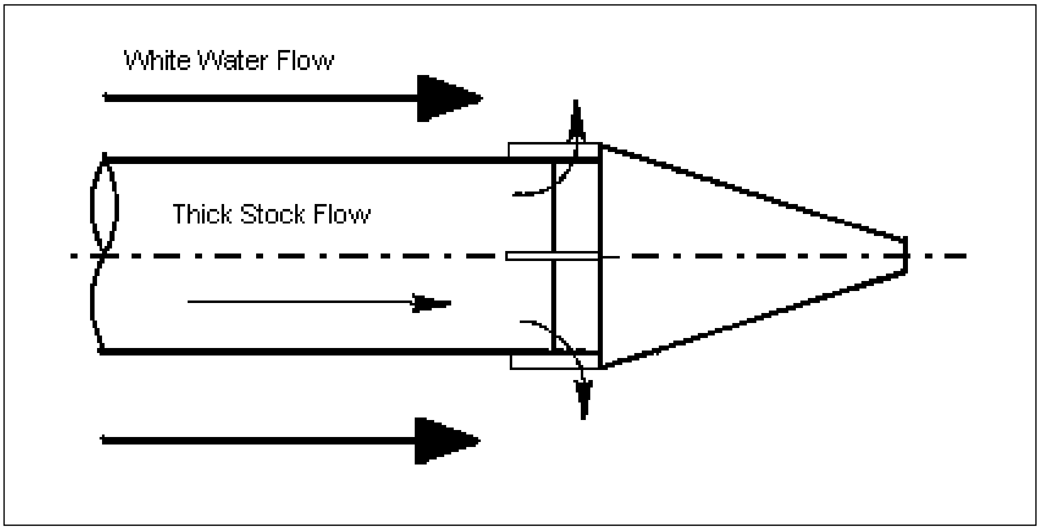



***Figure 3. Mixing cone.***

As stated in the Beloit's piping design recommendations *(1)*:

"There are a few installations where a 'mixing cone' has been used on the end of the heavy stock line. The idea here is to develop a more turbulent mixing action. This is not presently a Beloit recommendation, but can be considered as a possible option for use in specific cases. One application might be when the fan pump transition piece is too short to provide adequate mixing length."

The use of a mixing cone is appropriate where any of the following criteria may be present:

- The standard dimensional criteria for injection of thick stock into the fan pump suction cannot be accomplished.
- The thick-stock pressure at the injection point has short-term variation.
- The thick-stock consistency has short-term variation.
- The thick-stock consistency is 3 points greater than the thin-stock consistency.
- The fan pump speed approaches the minimum recommendation in certain scenarios.
- Centrifugal cleaners are not present in the approach flow system to dampen process variation.
- Strong process coupling exists between the silo level or Deculator (thin stock deaeration chamber) overflow level and the thick-stock flow rate.

## CASE HISTORIES

At Mill A, a multi-ply paper machine was originally installed with a mixing cone in each ply's approach piping. When the machine was rebuilt, the approach piping was replaced as the result of a production rate increase, and new mixing cones were installed.

At Mill B, a mixing cone was installed in the approach flow system of two paper machines. The results were a 20% and 25% reduction of total 2-sigma basis weight variation.

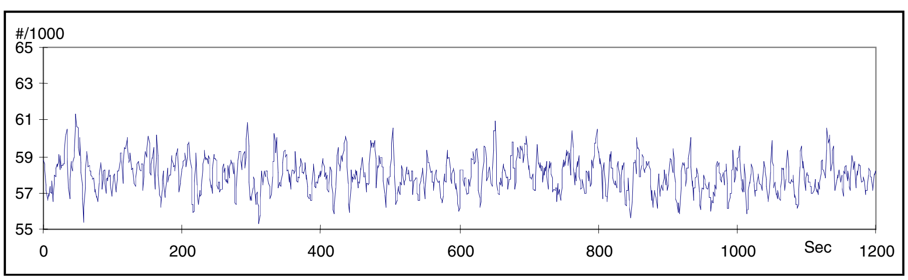
At Mill C, a rebuilt paper machine was experiencing machine-direction basis weight variation. During the course of the investigation to reduce the variation, the thick-stock injection nozzle in the silo-to-fan-pump transition was shortened, and a mixing cone was installed at the end of the nozzle. **Figure 4** is a photograph of the mixing cone before installation in the base-sheet approach flow system.

***Figure 4. Mixing cone.***

The result of the mixing cone installation was a 35% reduction in the conditioned-weight 2-sigma variation, as seen in **Figures 5** and **6**. The source of the raw data for Figures 5 and 6 was the reel cross-direction quality scanner placed at a single reference point for 1200 seconds. A similar mixing cone was later installed in the top-ply fan pump suction.

*Conditioned weight before mixing cone installation*

| | |
|---|---|
| Mean | 58.01 lb |
| Range | 6.04 lb or 10.4% |
| 2-sigma | 1.89 |




*Conditioned weight after mixing cone installation*

| | |
|---|---|
| Mean | 58.83 lb |
| Range | 4.00 lb or 6.8% |
| 2-sigma | 1.23 |

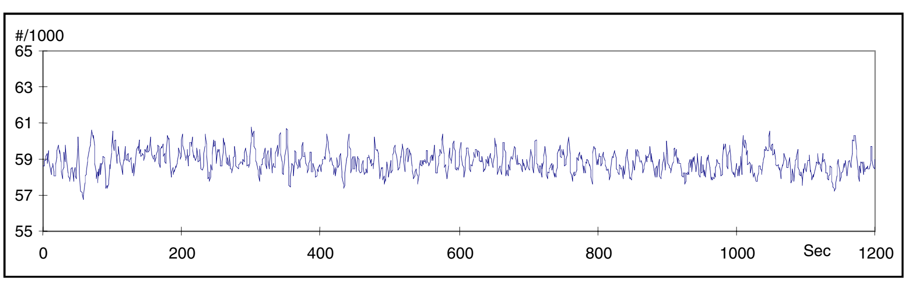



***Figure 5. Conditioned-weight time trace before and after mixing cone installation.***

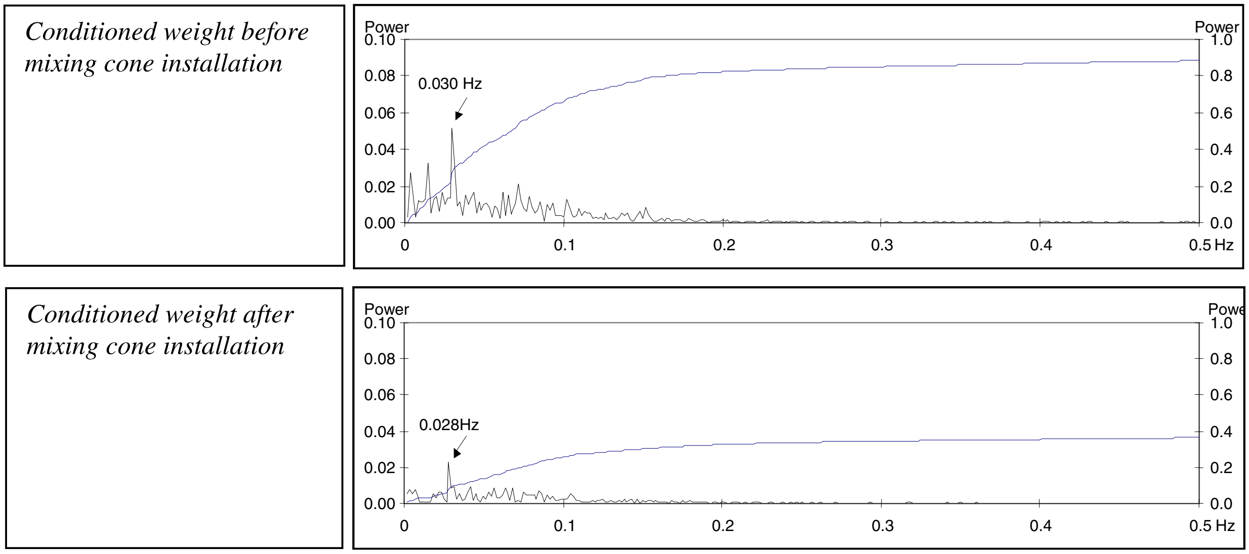



***Figure 6. Conditioned-weight power spectra before and after mixing cone installation.***

Mill C sought to continue the improvement by investigating the possibility of modifying the thick-stock injection mixing because of the low risk, known deficiencies in the wet-end system, and previous substantial improvement in basis weight uniformity with the mixing cone.

## BACKGROUND, INVESTIGATION, AND MODIFICATION TO DESIGN THE MIXING WEDGE

The headbox fan pump for the base sheet is a large double-suction fan pump that does not efficiently mix thick stock and white water. The system does not have cleaners or a stuff box to dampen pressure and consistency variations coming from stock prep.

Reviewing the cross section of the existing silo-to-fan-pump transition piping—where the thick-stock pipe ends and the flat plate of the mixing cone begins—it is clear that there is a significant difference in the distance between the edge of the cone and the vertical and horizontal walls of the transition. Based on the installation drawing in **Figure 7** (Section A–A), the horizontal distance between the cone and the transition wall is approximately two times the vertical distance. Given this physical configuration, and using a conservation-of-momentum model, it is reasonable to assume that there is a ring of diluted thick stock around the mixing cone and two vertical layers of white water on each side of the diluted thick-stock ring.

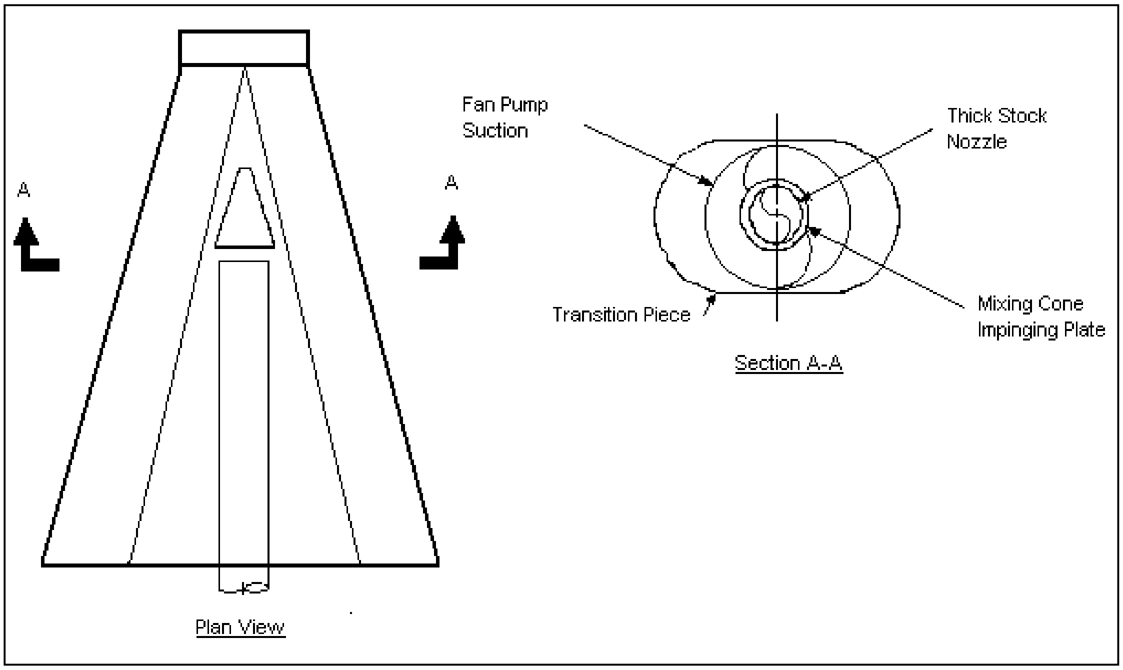



***Figure 7. Plan and section views of installed mixing cone.***

The changes required to improve the mixing in the silo entailed modifications to the thick-stock nozzle and replacement of the existing mixing cone. The new thick-stock nozzle shape was modified to create a shape similar to the shape of the transition piece where the thick-stock nozzle ends, as seen in **Figure 8** (Section B–B). The modified shape created equal distances between the nozzle and transition piece in both the vertical and horizontal directions without affecting the cross-sectional flow area, which was the same for both the existing and the improved thick-stock injection nozzles. The continuity of the thick-stock flow cross-sectional area maintained a constant velocity down the length of the thick-stock nozzle for both configurations. A conservative ratio of divergence of the thick-stock nozzle transition piece was used to minimize the potential of creating eddy currents along the inside and outside surfaces of the thick-stock nozzle (Figure 8).

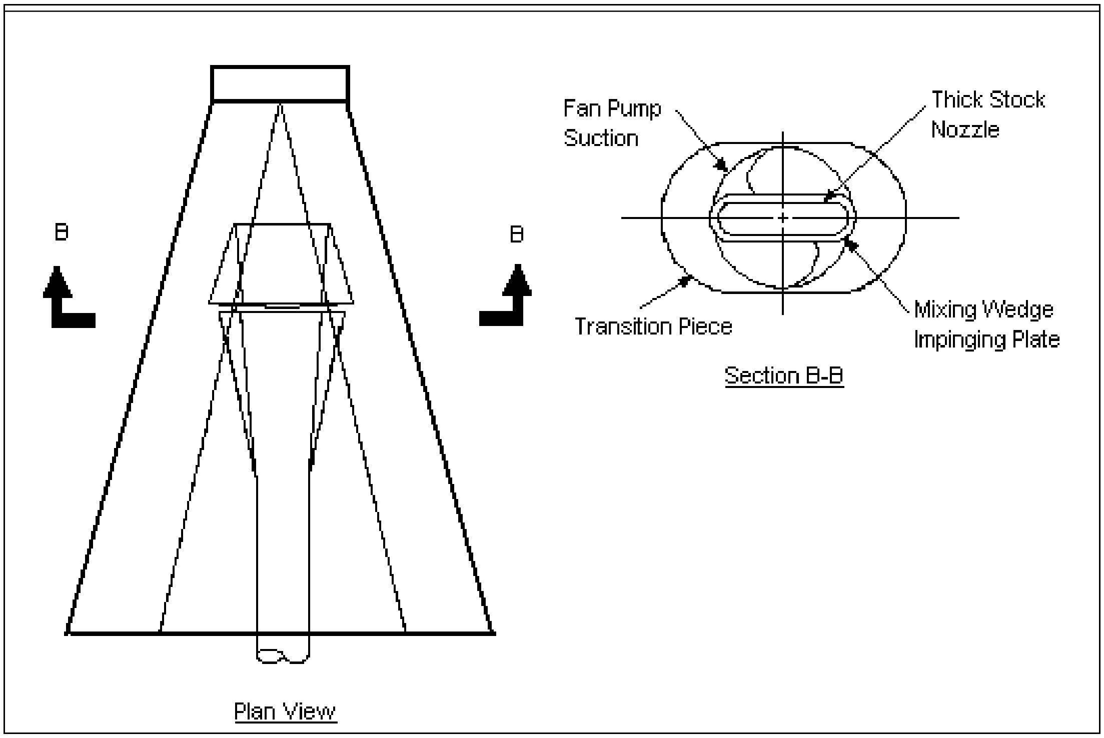



***Figure 8. Plan and section views of installed mixing wedge.***

The shape of the mixing cone was modified to match the shape of the thick-stock nozzle with an overlap, similar to the existing mixing cone. The improved "mixing cone" actually resembles a "wedge," as seen in **Figure 9**. The area of the "mixing wedge" impinging surface is greater than that of the mixing cone. The original mixing cone had a flat impinging surface. For the mixing wedge, the impinging surface has a slight cone shape to prevent the flow from wandering. **Figure 10** is a photograph looking into the suction of the fan pump.

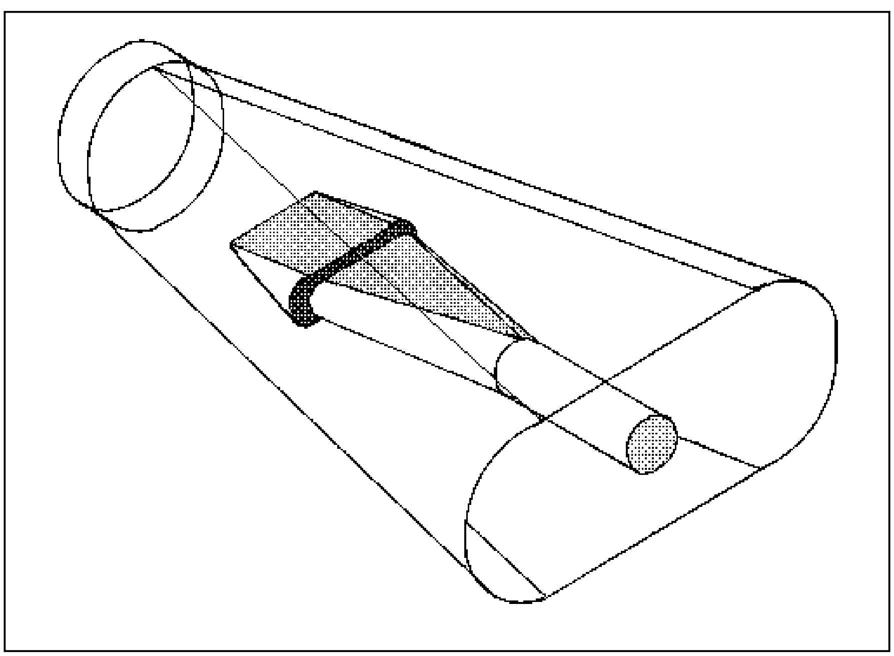


***Figure 9. Mixing wedge installation sketch.***

***Figure 10. Mixing wedge installation photograph.***

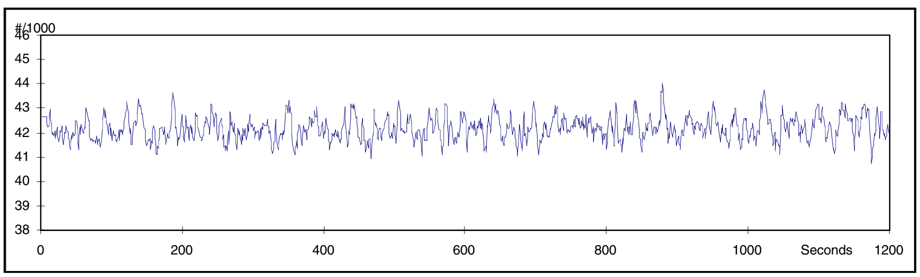
Computational fluid dynamics (CFD) modeling techniques were unable to predict the results of either the standard mixing cone or the "mixing wedge."

## RESULTS

The "mixing wedge" has reduced the conditioned-weight machine-direction variation in the 10–40-s time period range by approximately 30%, as seen in **Figures 11** and **12**. The thick-stock nozzle has not plugged. A visual inspection following operation revealed that the thick stock flows into the thin-stock flow stream approximately 8 inches, as indicated by a discoloration and deposit buildup on the wedge supports. The head loss caused by the wedge is slightly higher than that caused by the cone, as demonstrated by the need to increase the "percent open" of the basis weight valve.

*Conditioned weight with mixing cone*

| | |
|---|---|
| Mean | 42.18 |
| Range | 3.28 lb or 7.8% |
| 2-sigma | 0.98 |




*Conditioned weight with mixing wedge*

| | |
|---|---|
| Mean | 41.98 |
| Range | 2.82 lb or 6.8% |
| 2-sigma | 0.80 |

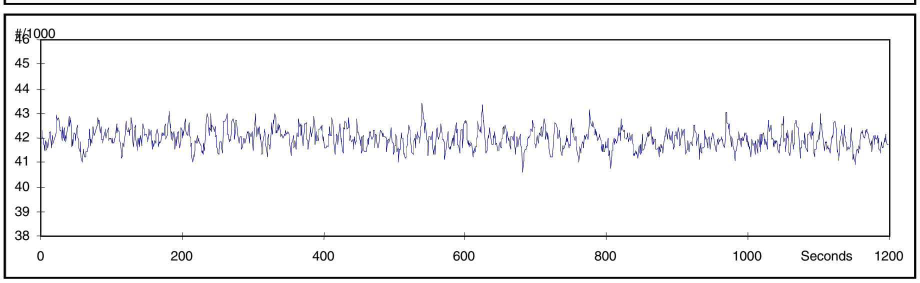



***Figure 11. Conditioned-weight time trace with mixing cone and mixing wedge.***

*Conditioned weight with mixing cone*

*Conditioned weight with mixing wedge*

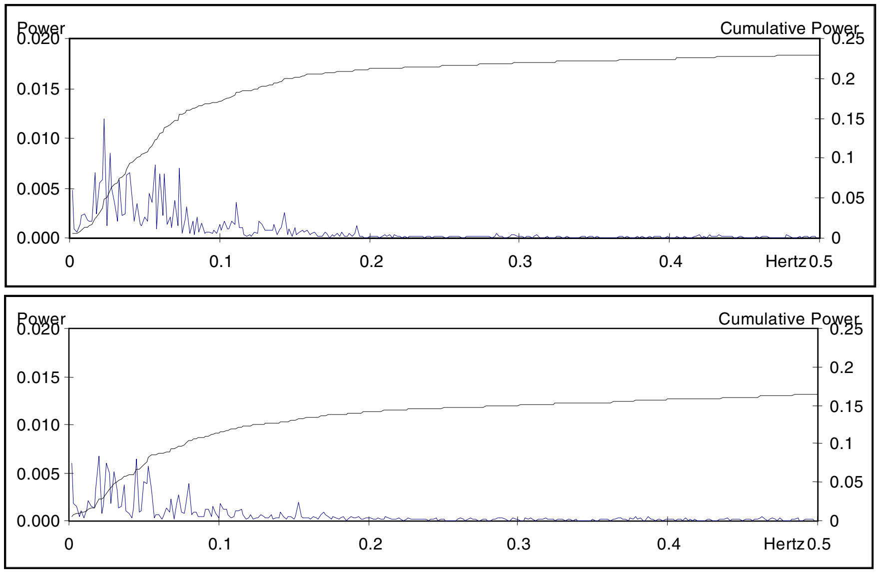



***Figure 12. Conditioned-weight power spectra with mixing cone and mixing wedge.***

## CONCLUSIONS

New and rebuilt paper machines can utilize new thick-stock injection design options to reduce capital costs while maintaining or improving paper machine runnability and product quality.

The investigation of all paper machine components is required to design appropriate solutions that minimize variation in paper quality parameters. The mixing wedge can provide a solution to the common problem of inadequate mixing before the fan pump.

Many older paper machines experience degradation in product quality because of machine-direction variations that cannot be measured using antiquated gauging systems. Off-machine analysis of basis weight can provide the data needed to determine whether a mill needs a variation fix.

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