# MIXING INTENSITY ANALYSIS OF A 2-LAYER STRATIFIED HEADBOX JET

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## ABSTRACT

The mixing characteristics of a water jet as a function of the free jet distance from a stratified 2-layer headbox nozzle have been studied. The experimental technique used in this work involves the introduction of salt water into the top layer and then measuring the z-direction profile of the fluid conductivity at various points along the free jet. By incorporating a statistical model, the overall mixing characteristics are quantified in terms of a single parameter, $I_{MH}$, which represents the mixing intensity at a specific machine direction location in the free jet. From the mixing intensity data, it is apparent that $I_{MH}$ increases with the distance from the slice, and is reduced by increased slice opening and headbox flowrate. In general, a shorter divider sheet stickout tends to provide a lower degree of mixing, but a longer divider sheet stickout may be preferable in certain specified cases. These results are consistent with that found in the previous 3-layer studies. The mixing intensity analysis on the sheet sample has been performed to identify the significance of the headbox influence relative to the rest of the forming system.

## INTRODUCTION

Paper products must meet a wide range of requirements. Each product must exhibit good runnability through manufacturing, converting, and printing operations, and also satisfy the needs of the end user. However, it is often difficult to completely satisfy all these requirements while making a homogeneous sheet. The stratified forming technique has provided an additional tool for meeting this variety of needs by allowing surface, structural, or other physical properties to be optimized simultaneously. The sheet can be formed in a 2-layer or 3-layer stratification system, depending upon the end use of the product.

The focus of this work is to obtain a fundamental understanding of mixing characteristics associated with a 2-layer stratification system. A typical 2-layer stratification system allows the forming of a layered sheet with two different types of furnish (or different chemical additives) in the top and bottom layers, as illustrated in **Figure 1**. It is preferred that the final sheet has

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distinct layers, each with specific physical properties. The primary reasons for forming such a layered product are to enhance sheet properties of a specific surface, to lower costs of making the product, and ideally, to achieve a combination of both.

**Figure 1. The concept of a 2-layer stratification.**

In practice, mixing of furnishes does occur in the free jet and continues in the initial dewatering stage of the forming section. **Figure 2** presents a plot of measured hardwood content of a 2-layer sheet as a function of the sheet depth. The basis weight of this sheet sample is 20 gsm. The furnish information is also provided so as to reveal the degree of mixing generated in the forming process. The furnish contains almost 100% hardwood in the top layer, and 20% hardwood and 80% softwood in the bottom layer. The top layer contributes to 1/3 of the total basis weight and the bottom layer supplies the remaining 2/3 of the sheet weight. In view of the hardwood profile, it is apparent that the hardwood content drops from 100% to 93% at the top layer surface and increases from 20% to 33% at the bottom layer surface. From Figure 2, the overall hardwood profile appears to deviate significantly from that of the initial furnish condition as a result of the layer mixing occurring in the sheet thickness direction. The aim of this work is to improve the stratification system to maximize layer purity by minimizing interfacial mixing between the two layers. The results are applicable to tissue, graphic, and packaging grades.

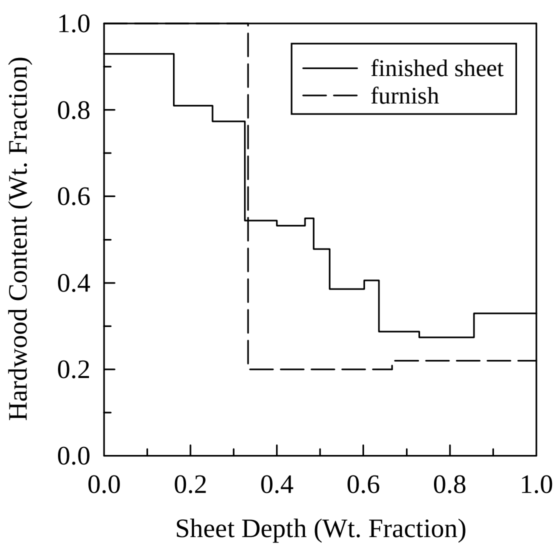



**Figure 2. Measured hardwood content of a 2-layer sheet sample as a function of sheet depth.**

Relevant work reported in the literature has mainly addressed the layer mixing associated with the 3-layer stratification system, and research studies on a 2-layer stratification system seem very limited. Extensive pilot machine work by Baker *et al*. [1] and Lloyd and Norman [2,3,4], and computational fluid dynamics modeling by Parsheh and Dahlkild [5] have provided a better understanding of the complex mixing behaviors during the merging of multiple fluid streams with different furnishes or chemical additives. It is believed that z-directional layer mixing is largely influenced by the boundary layer development along the divider sheets and the presence of vortices at the tips of the divider sheets. The layer mixing tends to propagate along the free jet in the machine direction (MD). Several key parameters, such as the divider sheet stickout, the slice lip geometry, and the divider sheet design, have been shown to have a significant impact on the mixing characteristics. However, none of the above work has addressed the issue how the mixing characteristics change as a function of the free jet length. Recently, Li *et al*. [6] have developed a conductivity technique to quantify the mixing characteristics of a water jet as a function of the distance from a stratified 3-layer headbox. Their results are in quantitative agreements with that reported by others [1-5]. In the present work, the conductivity technique has been employed to study the mixing characteristics associated with a 2-layer stratification system.

## FLOW LOOP STUDIES

Although the stratification process can be studied using a pilot paper machine, the intent of this work is to isolate the headbox effects from the rest of the forming system, so these effects can be more accurately quantified. In studying the mixing characteristics, a 2-layer headbox model with two rows of tubes per layer and a converging angle of 7° has been used. This is illustrated in **Figure 3**. The headbox model has two separate headers that allow the merging of two dissimilar fluid streams to form a single free jet. A long, flexible divider sheet is used to prevent mixing between layers until the merging of fluid streams starts to occur. The sheet tip ends either inside the headbox (negative sheet stickout) or outside the headbox (positive sheet stickout). The sheet is 1 mm thick and is tapered over a 12 mm distance to 0.5 mm at the tip. Additionally, there are two short internal sheets (3 mm thick tapered to 0.5 mm) separating the channels in each layer, whose tips end 203 mm before the slice opening.

In this study, fresh water was introduced in the bottom layer and salt water in the top layer. The amount of salt used has a negligible effect on the water density and viscosity, but is sufficient to create a marked difference in the conductivity levels. A 0.8-mm sampling tube is used to extract an approximately 60 $cm^3$ of fluid from the free jet for conductivity analysis. The sampling tube is mounted on a traversing system that ensures precise movements. The data include the measurements of the time-averaged conductivity in various z-direction positions at different MD locations in the free jet. With the availability of this information, the mixing characteristics can be quantitatively determined in terms of the relative changes in the conductivity profile along the free jet.

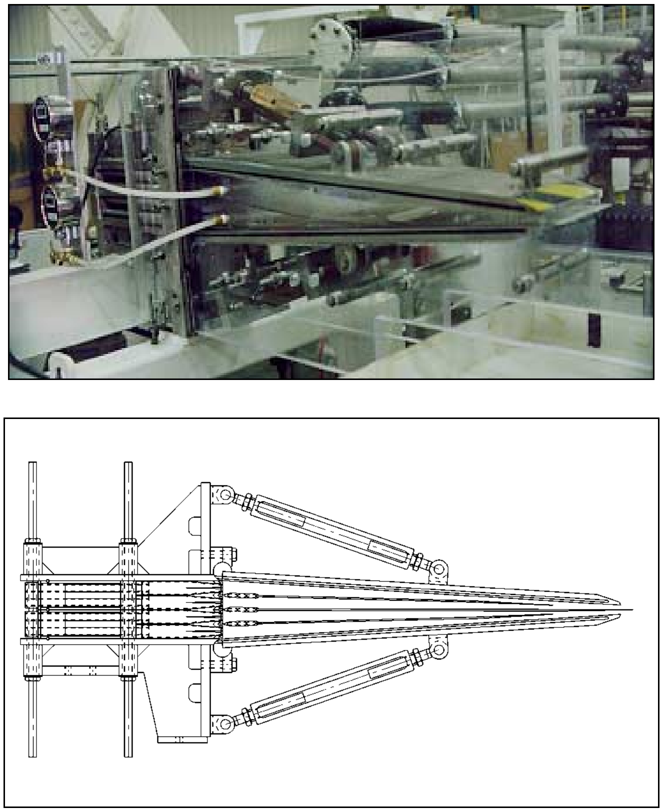


**Figure 3. A 2-layer stratified headbox model with a flexible divider sheet**.

To validate this technique, the mixing behaviors obtained from the salt water/fresh water system to that of a softwood/hardwood fiber system were compared. In this work, the jet speed is 290 m/min and the sheet stickout is 13 mm. The fiber consistency of 0.2% is used. A 5-mm sampling tube is employed for runs with the fiber system. The softwood (SW) content in the sample is measured using Kajaani fiber analyzer. **Figure 4** shows the profile of the normalized conductivity or SW content in the jet thickness direction taken at 51 mm from the sheet tip. From Figure 4, it can be observed that the SW data is comparable to the conductivity curve. These results show that this conductivity technique gives good agreement with fiber slurry mixing at the consistencies studied.

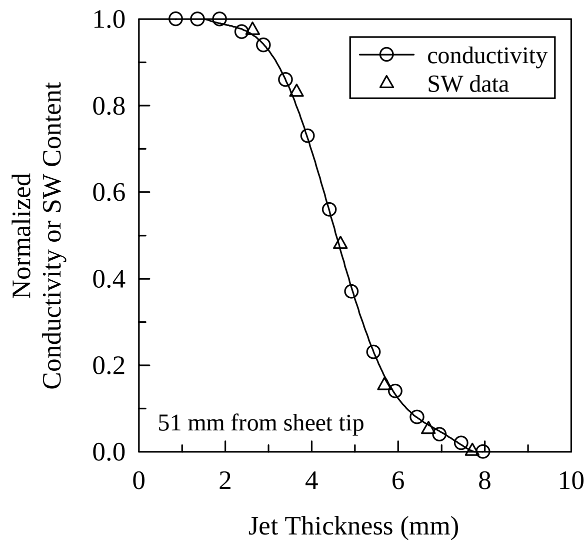



**Figure 4. Layer purity profile using salt water/fresh water and softwood/hardwood in a 2-layer simplified flow model (equal flow to each layer)**

## STATISTICAL MODEL

Based upon an early work by Danckwerts [7,8], Li *et al.* [6] have developed a more robust statistical model to allow proper evaluation of the overall change in the conductivity profile. A typical situation is considered for a 2-layer stratified headbox, as shown in **Figure 5**. The mixing phenomena occur during the merging of two dissimilar fluid streams to form a single jet with a thickness, m. This analysis is based upon the case where the salt water is introduced in the top layer and the fresh water is fed into the bottom layer.

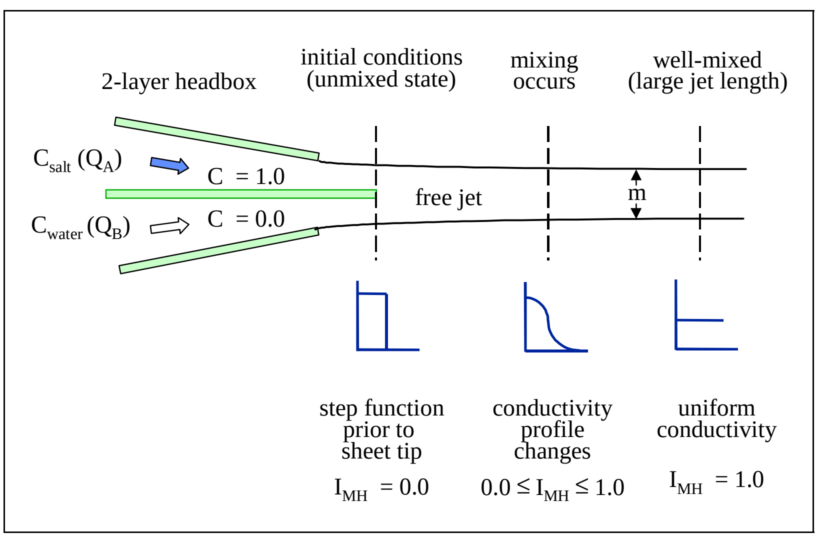



**Figure 5. Statistical analysis of a jet from a 2-layer headbox**.

From Figure 5, the conductivity of the incoming salt water ($C_{salt}$) has been normalized to C = 1.0 by:

$$C = \frac{C_{measured} - C_{water}}{C_{salt} - C_{water}} \qquad (1)$$

The flowrate of the top layer is $Q_A$. The water entering the bottom layer, with a flowrate of $Q_B$ and a conductivity of $C_{water}$, has no salt content initially and thus C = 0.0. The salt water contributes a volume fraction of $f_A = Q_A/(Q_A + Q_B)$ and the water provides a volume fraction of $f_B = Q_B/(Q_A + Q_B)$ to the jet. It has been experimentally observed that the conductivity profile across the jet thickness will vary in the machine direction due to the mixing downstream of the sheet tip. At a sufficiently long free jet length where uniform conductivity through the jet thickness is attained, the mean conductivity level, $C_M$, is equal to $f_A$.

To quantify the degree of mixing, a new parameter, the mixing intensity $I_{MH}$, is introduced to account for the overall change of the conductivity profile along the free jet. Explicitly, $I_{MH}$ is expressed in terms of the relative variance of C:

$$I_{MH} = 1 - \frac{\sigma^2}{\sigma_o^{\,2}} \qquad (2)$$

where $\sigma^2$ is the variance of C at a specific distance downstream of the sheet tip relative to a complete mixing condition defined by:

$$\sigma^2 = \int_0^m (C_M - C)^2 \, dz \qquad (3)$$

and $\sigma_o^2$ is the maximum variance of C determined from an initial unmixed condition and a complete mixing condition and is represented by the following equation:

$$\sigma_o^{\,2} = f_A \, (C_M - 1)^2 + f_B \, C_M^{\,2} \qquad (4)$$

The goal is to use $I_{MH}$ as a single indicator that fully describes the degree of mixing for a given set of operating conditions. For example, we illustrate a simple 2-layer situation with equal flowrate in all layers. With an equal mean velocity and the same net slice opening in each layer, it can be determined that $f_A = f_B = 0.5$, $C_M = f_A = 0.5$, and $\sigma_o^2$ has a maximum value of 0.25. At the initial condition where there is no mixing, $\sigma^2 = \sigma_o^2$ and $I_{MH}$ has a value of 0.0. For a completely mixed situation, $C = C_M = 0.5$ and $I_{MH} = 1.0$. For any condition between the initial unmixed state and the completely mixed state, $I_{MH}$ will be a value between 0.0 and 1.0 that will rank the degree of mixing at that particular condition.

## RESULTS AND DISCUSSIONS

### 1. Conductivity Profiles

As illustrated in **Figure 6**, several conductivity profiles are plotted as a function of z/h, where z is the location in the jet thickness and h is the net slice opening (without divider sheet). Several profiles are shown for various MD distances measured from the tip of the divider sheet, d. The divider sheet extends 25 mm outside the headbox and the jet speed is maintained at 914 m/min. The total headbox flowrate per unit cross machine width is 7.7 l/min-mm with equal flow to each layer. In view of these profiles, it can be demonstrated that the mixing characteristics developed downstream of the sheet tip tend to promote the transport of the salt solution from the top layer to the bottom layer. As d further increases, the overall gradient of the profile gradually decreases. Additionally, the conductivity level at the jet surface continually decreases at the top layer and increases at the bottom layer. Note that the curves shown in Figure 6 are the best-fit of the conductivity data. With the use of the statistical model described in the last section, these curves will be utilized to compute $I_{MH}$ at a specific MD location in the free jet.

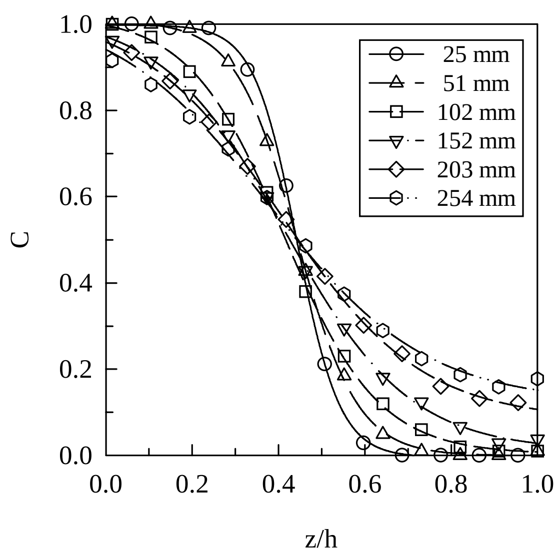



**Figure 6. The conductivity profiles at various free jet lengths.**

### 2. Effects of Slice Opening

One of the key parameters evaluated in this work is the impact of the slice opening on $I_{MH}$. In these trials, the jet speed is kept at 762 m/min and the sheet stickout is 76 mm. The net slice openings (without the divider sheets) are found to be 8 mm, 11 mm, and 15 mm, respectively. To maintain the same jet speed, the total headbox flowrate needs to be increased to compensate for the difference in the slice opening. **Figure 7** shows a plot of $I_{MH}$ as a function of the distance from the sheet tip (d) for various slice openings (h). As a reminder, $I_{MH} = 0$ indicates no mixing and $I_{MH} = 1$ indicates a complete mixing. From Figure 7, it is apparent that the smallest slice opening generates the most mixing.

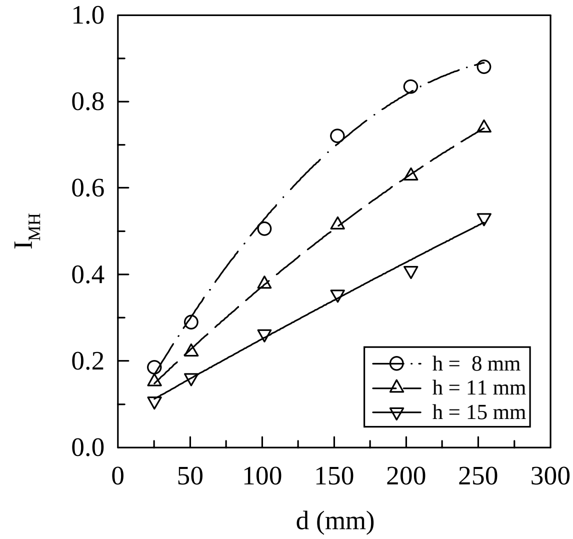



**Figure 7. $I_{MH}$ as a function of distance from the sheet tip (d) for various slice openings (h).**

### 3. Empirical Relation — $I_{MH}$ vs. $d_M$

In view of Figure 7, the slice opening can have a significant impact on the results. Hence, it first seems necessary to use the same slice opening for all flow loop runs to make other valid comparisons. However, our intent is to simplify the experimental design by seeking a simple expression that correctly relates $I_{MH}$ to the slice opening, h, the distance from the sheet tip, d, and the headbox flowrate per unit width, Q. This would allow us to compare cases, even though different slice opening and flowrate are used in the trials.

Based upon the boundary layer flow along a flat plate [8], the boundary layer thickness is proportional to $x^{0.5}$ for a laminar flow case and to $x^{0.8}$ for a turbulent flow case, where x is the distance from the zero incidence in the flow direction. For a turbulent free jet exiting the nozzle, the characteristic length scale of the mixing region is proportional to x. With this in mind, a dimensionless variable, $d_M$, is related to $I_{MH}$ where

$$d_M = \frac{d}{h} \times \mathrm{Re}^{-n} \tag{5}$$

where $\mathrm{Re} = \rho Q/\mu$, $\rho$ = density, $\mu$ = fluid viscosity, and n = empirical constant. It appears that n = 0.5 gives the best-fit of the $I_{MH}$ data, as illustrated in the **Figure 8**. Furthermore, the empirical correlation in Equation (5) for 2-layer work is consistent with that obtained from the previous 3-layer work [6]. To improve the 2-layer stratification process, Equation (5) strongly suggests that the degree of mixing between the top layer and the bottom layer can be reduced by shortening the free jet length, increasing the slice opening, and increasing the headbox flowrate.

### 4. Effects of Equal and Unequal Jet Velocity Between the Layers

To examine the validity of the empirical correlation in Equation (5) to a different flow condition, a higher headbox flow is supplied to either the top layer or the bottom layer. Due to the flexibility of the divider sheet, the region with a higher headbox flow tends to expand slightly up so there is no pressure difference between the layers. It has been determined that the jet velocities from the top and bottom layers, $U_A$ and $U_B$, are very close at 914 m/min, even though unequal flowrate has been used. The mixing intensity data for cases with $Q_A/Q_B$ = 1.18, $Q_A/Q_B$ = 1.0, and $Q_A/Q_B$ = 0.87 are plotted in **Figure 9**. In general, these three sets of data fall on the same curve, concluding that there is no apparent increase in the non-dimensional mixing characteristics associated with this unequal flowrate situation.

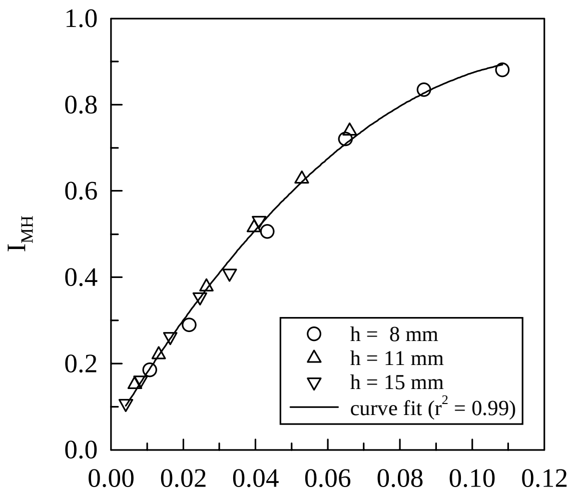



**Figure 8. Relation of $I_{MH}$ vs. $d_M$ for various slice openings (h) with n = 0.5.**

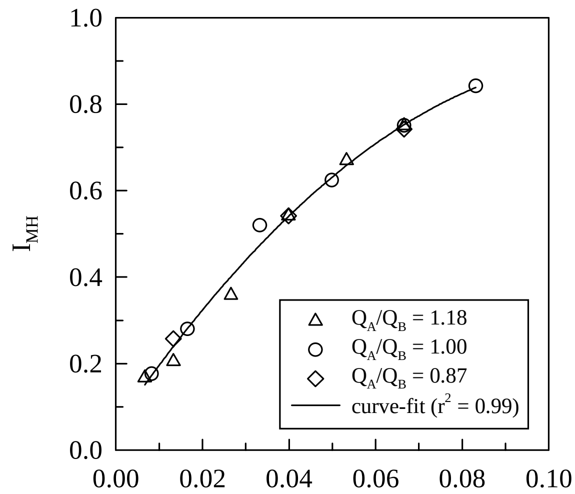
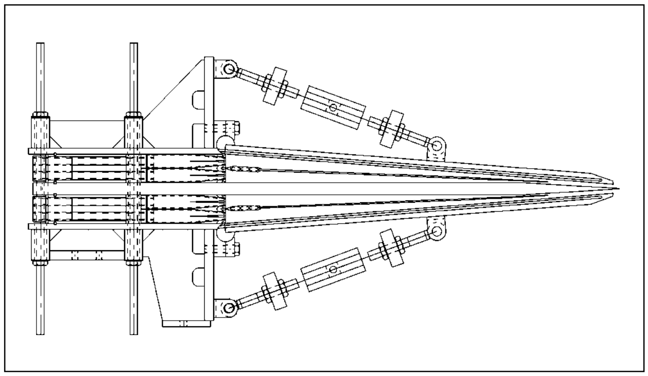



**Figure 9. $I_{MH}$ vs. $d_M$ for the case of a flexible divider using equal and unequal flowrates between the layers ($U_A/U_B$ = 1.0).**

It seems that the flow model with a flexible divider sheet in Figure 3 is unable to achieve the condition where there is a significant difference in the jet velocity between the top layer and the bottom layer. To create such a jet velocity difference between the layers, the 2-layer stratified flow model is modified to accommodate the use of a stainless steel rigid divider, as illustrated in **Figure 10**. This rigid divider having a thickness of 25 mm is firmly supported in the tubebank section and extends 11 mm beyond the slice of the headbox model. The divider tip is tapered from 25 mm to 0.5 mm over a distance of 203 mm. To examine the mixing characteristics under an unequal jet velocity situation, a 30% higher headbox flow is supplied to the bottom layer. With this flow condition, the ratio of $Q_A/Q_B$ now becomes 0.77. The mean jet velocity is found to be 798 m/min from the top layer ($U_A$) and 928 m/min from the bottom layer ($U_B$), creating a jet velocity ratio of $U_A/U_B$ = 0.86. This set of mixing intensity data is plotted in **Figure 11** together with the results obtained from the case of $Q_A/Q_B$ = 1 and $U_A$ = $U_B$ = 775 m/min. In view of these two profiles in Figure 11, it is apparent that the unequal jet velocity situation generates a higher degree of mixing that that of an equal jet velocity situation. It is apparent that the unequal jet velocity situation tends to increase the momentum transfer from the bottom layer to the top layer in the free jet.

## 5. Effects of Jet Speed

The dependency of the mixing intensity upon the jet speed is illustrated in **Figure 12**. The jet speeds are 762 m/min and 914 m/min. The divider sheet stickout is 76 mm past the slice. With the two speeds considered here, it has been determined that the jet speed has no significant influence on the mixing intensity. These 2-layer results are in good agreement with that of the previous 3-layer studies by Li, *et al*. [6]. In addition, Lloyd and Norman [2] have also found from their 3-layer stratification trials that a change of the flow speed from 540 m/min to 830 m/min has relatively small effect on the scale of the layer mixing.



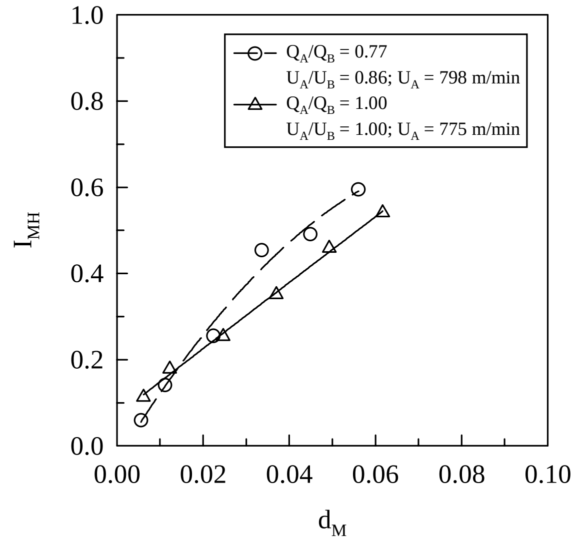



**Figure 10. A 2-layer stratified headbox model with a rigid divider separating the top and bottom layers.**

**Figure 11. $I_{MH}$ vs. $d_M$ for the case of a rigid divider using equal and unequal jet velocities between the layers.**

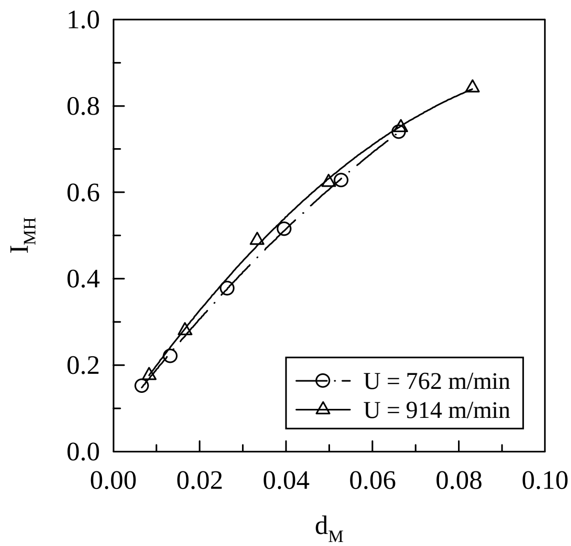



**Figure 12. $I_{MH}$ vs. $d_M$ for various jet speeds.**

## 6. Effects of Divider Sheet Design

Mixing control can be achieved through the sheet tip design. Turbulence will be generated in the wakes behind the sheets. With a blunt tip sheet, more turbulence and more mixing will occur than with a thinner tip sheet. The effects of the tip thickness to the mixing intensity have been investigated using a rigid divider with an interchangeable flexible extension, as shown in **Figure 13**. The thicknesses of the flexible extensions used in this study are 0.13 mm, 0.25 mm, 0.51 mm, and 1.02 mm, respectively. The jet speed is 914 m/min and the stickout past the slice is 76 mm. **Figure 14** shows $I_{MH}$ profile as a function of $d_M$ for various tip thicknesses. It is apparent that the flexible extension with a tip thickness of 1.02 mm generates the highest degree of layer mixing. The other three cases generate similar mixing characteristics. With a 1.02 mm flexible extension, it has been observed that the surface of the jet is very rough and the jet thickness expands along the free jet. Additional, an air wedge has been formed adjacent to the tip of the extension. For a very thin divider sheet, it is anticipated that there will be some concerns of the cross machine uniformity problems and the sheet life. In general, the divider sheet with a tip thickness of 0.51 mm is recommended for 2-layer and 3-layer stratification applications.

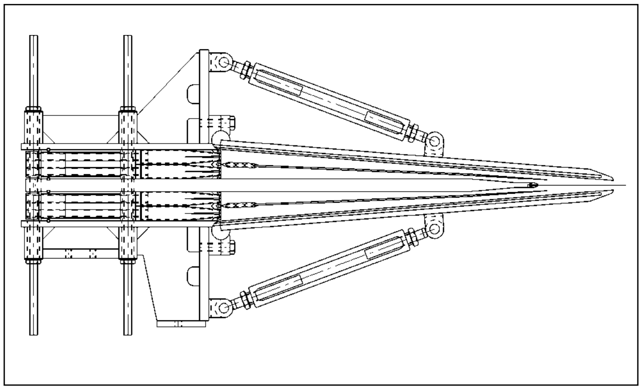


**Figure 13. A 2-layer stratified headbox model using a rigid divider with an interchangeable flexible extension.**

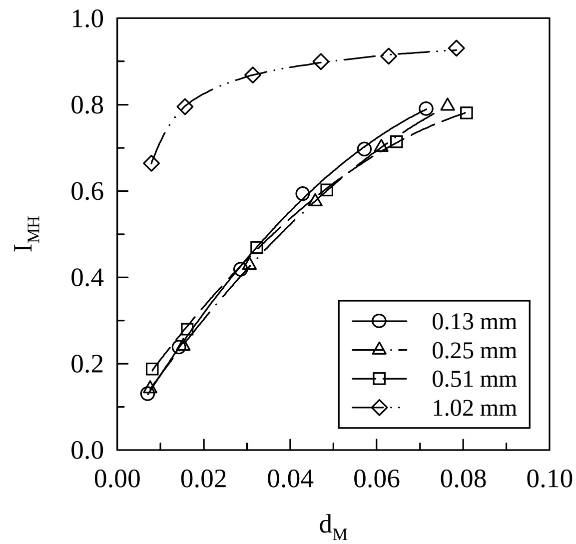



**Figure 14. $I_{MH}$ vs. $d_M$ for different tip thickness.**

Previous flow visualization studies have also supported our present work that the tip thickness of the divider sheet separating the layers plays a significant role in influencing the layer mixing. Figures 15 and 16 illustrate the mixing of two different color dyes inside a 3-layer headbox model. This headbox model has a nozzle convergence of 6°. The flow in both cases is from the right to the left. The red dye is fed into the middle layer and the blue dye is introduced into the top and bottom layers. The only difference between these two cases is that in **Figure 15**, 1 mm sheets that were tapered down to 0.5 mm tip thicknesses, while in **Figure 16**, 1 mm thick blunt tip sheets were used in the headbox. The sheet is 25 mm inside the headbox for both cases. As shown in Figures 15, the flows merge smoothly and very little mixing occurs with the thinner sheet tips. This condition tends to produce good layer purity. In contrast, Figure 16 illustrates that vortex shedding is occurring with the thick sheets, and eventually breaks down into micro-turbulence, while in turn generates some mixing between the layers.

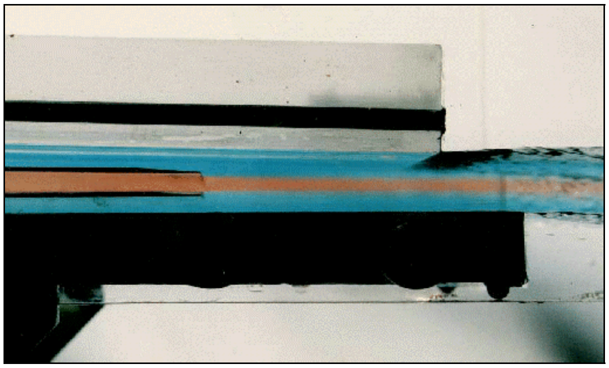


**Figure 15. Mixing of dyes in a 3-layer headbox model with 1 mm sheets tapered to 0.5 mm tip thicknesses.**

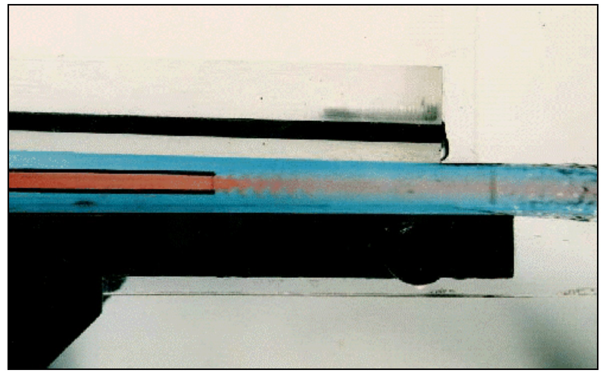


**Figure 16. Mixing of dyes in a 3-layer headbox model with 1 mm thick blunt tip sheets.**

## 7. Effects of Sheet Stickout

Based upon the 3-layer data from the pilot machine trials, Lloyd and Norman [3] suggest that a positive sheet stickout produces comparatively more mixing than that of a negative sheet stickout. Parsheh and Dahlkild [5] have also reached the same conclusions from the computer simulations. In contrast, Baker *et al.* [1] give different recommendations based upon the evaluation of their pilot machine studies. Their 3-layer results have revealed that the divider sheet with a +150 mm stickout gives better surface layer purity than the one with a –95 mm stickout. From the 3-layer conductivity studies, Li *et al.* [6] can explain why the pilot machine data by different investigators yield different conclusions, as the free jet length has a strong influence on the optimum choice of the divider sheet stickout.

Part of this work is to understand the influence of the sheet stickout in a 2-layer stratification process. A total of four sheet packages has been used. The divider sheet stickouts are –25 mm (i.e., 25 mm inside the slice), 0 mm, +25 mm, and +76 mm. The jet speed is maintained at 914 m/min. **Figure 17** illustrates a plot of $I_{MH}$ as a function of $d_M$ for various divider sheet packages. The results have revealed that the degree of mixing is a strong function of the sheet stickout. By evaluating the profiles in Figure 17, it can be shown that the sheet package with a shorter stickout is generally preferred. The case with the sheet 25 mm inside the slice gives the lowest degree of mixing, followed by the sheet even with the slice, the sheet with a +25 mm stickout, and lastly the sheet with a +76 mm stickout.

However, the recommendations might be different if $I_{MH}$ is plotted as a function of the free jet length measured from the slice, as shown in **Figure 18**. For the free jet length greater than 165 mm, it clearly shows that the shortest sheet gives the lowest mixing characteristics. For a free jet length less than 165 mm, the longest sheet stickout produces the least mixing. It should be noted that the plot in Figure 18 is for a specific case of 8 l/min-mm flowrate. At other flowrates and slice openings, the shape of the curves will be slightly different.

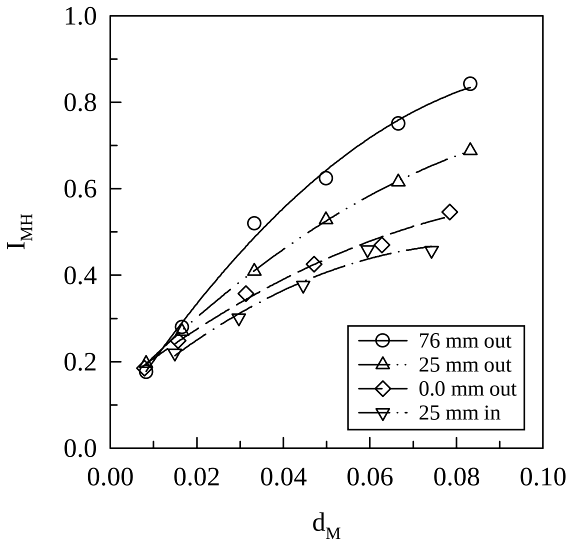



**Figure 17. $I_{MH}$ vs. $d_M$ for various divider sheet packages.**

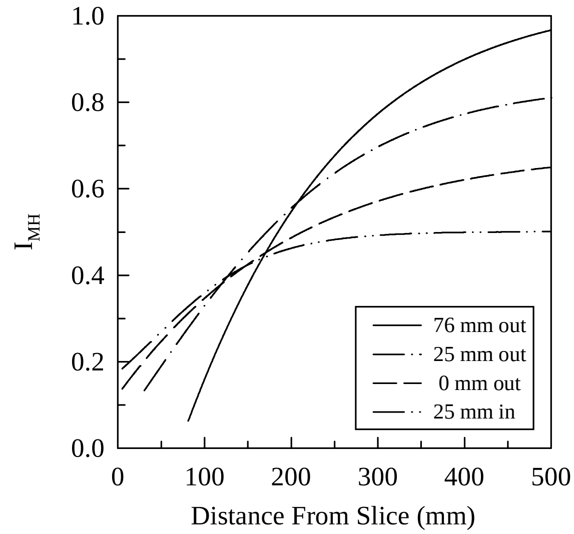



**Figure 18. $I_{MH}$ as a function of the distance from the slice for various sheet stickouts.**

## 8. Mixing Intensity Analysis on Sheet

From the pilot machine trials, it is apparent that many factors can indeed influence the purity of an individual layer. With the aid of the present conductivity technique, the headbox influence has been isolated from the rest of the forming system, and thus the mixing intensity developed in the headbox and along the free jet ($I_{MH}$) can be accurately quantified. One of our interests is to apply the same statistical analysis on the sheet sample so that the total mixing intensity, $I_{MS}$, required to attain a specific layer purity profile can be determined. Consequently, the mixing intensity contributed by the rest of the forming system, $I_{MF}$, can be approximated by

$$I_{MF} = I_{MS} - I_{MH} \tag{6}$$

Let's begin by considering the layer purity of a sheet sample illustrated in Figure 2. Note that this sample is obtained from a stratified headbox with one divider sheet separating the top layer and the bottom layer. The top layer has 2 rows of tubes and the bottom layer has 4 rows of tubes. The total headbox flowrate is 19 l/min-mm with equal flow and consistency to each row of tubes. The jet speed is 1372 m/min and the sheet stickout is 76 mm outside the headbox. The average free jet length is found to be 211 mm. Hence, the complete mixing condition, $C_M$, can be computed from the actual flow conditions and is included in **Figure 19**. It is apparent that the measured hardwood profile is bounded by the lower limit of an initial unmixed state (furnish) and the upper limit of a complete mixing condition ($C_M$). By utilizing the similar statistical approach used in these flow loop studies, the mixing intensity, $I_{MS}$, required to achieve this hardwood profile is computed and found to be 0.54.

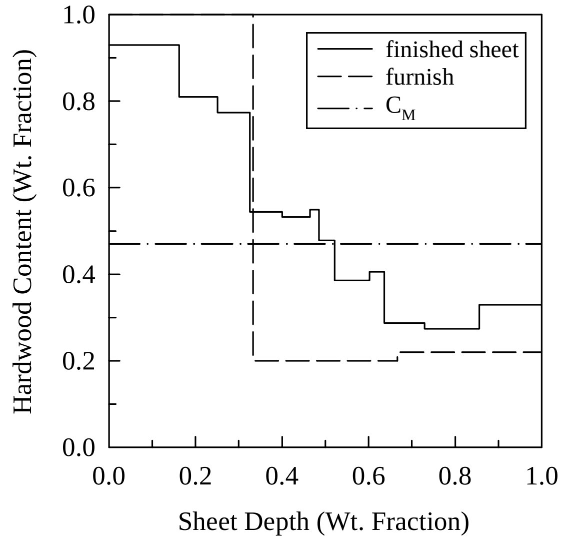



**Figure 19. The measured hardwood profile is bounded by the furnish data and the complete mixing condition.**

Due to differences in the headbox configuration, the flow loop data from the 2-layer headbox with a 2-channel per layer arrangement cannot be used. Hence, additional runs have been made with a 3-layer headbox. This headbox is arranged to a 2-layer configuration with the top layer having 2 rows of tubes and the bottom layer having 4 rows of tubes. In the experiment, salt solution is introduced into the top layer and fresh water is fed into the bottom layer. **Figure 20** shows the mixing intensity, $I_{MH}$, as a function of the distance of the slice for a specific jet speed of 1372 m/min and a flowrate of 19 l/min-mm. As a reminder, the shape of this curve will be slightly different at other flowrates and jet speeds. At a free jet length of 211 mm, the mixing intensity, $I_{MH}$, developed in the headbox and along the free jet is determined to be 0.32. From Equation (6), the mixing intensity, $I_{MF}$, by the rest of the forming system is estimated to be 0.22. **Table 1** summarizes the results of the mixing intensity analysis.

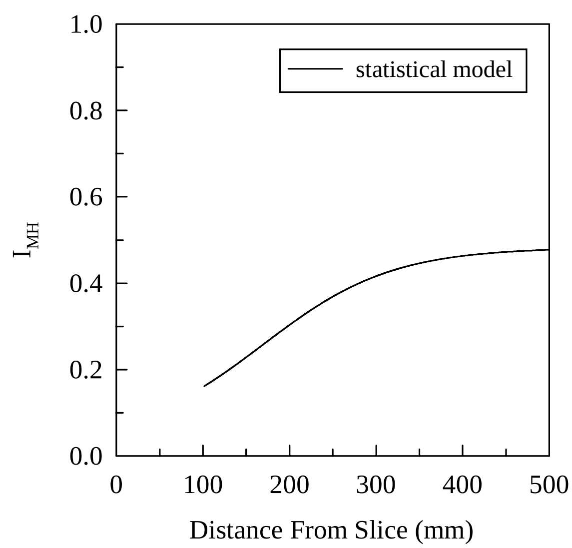



**Figure 20. $I_{MH}$ as a function of the distance from the slice for a 2-layer headbox with 2 rows of tubes in the top layer and 4 rows of tubes in the bottom layer (jet speed = 1372 m/min; flowrate = 19 l/min-mm; sheet stickout = 76 mm).**

| Statistical Analysis | Mixing Intensity Level |
|---|---|
| Sheet sample ($I_{MS}$) | 0.54 |
| Headbox and free jet ($I_{MH}$) | 0.32 |
| Rest of forming system ($I_{MF}$) | 0.22 |

**Table 1. Mixing intensity analysis of a 2-layer stratification process.**

## SUMMARY

The mixing intensity of a water jet as a function of the distance from a stratified 2-layer headbox nozzle has been studied at the research flow loop station. The technique involves the introduction of a salt solution into the top layer and then measuring the z-direction profile of the conductivity at various points along the free jet. The overall mixing characteristics can be quantified in terms of the mixing intensity, $I_{MH}$. In view of the mixing intensity profile, it is apparent that $I_{MH}$ increases with the distance from the slice, but is inversely affected by slice opening and headbox flowrate. In general, a shorter sheet stickout tends to provide a lower degree of mixing. However, a longer sheet stickout may be preferable for the situation with a short free jet length. Similar mixing intensity analysis has been done on the sheet sample to identify the significance of the headbox influence relative to the rest of the forming system. Based upon the data, the majority of mixing occurs in the headbox and along the free jet.

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