

Aq-vanes: a new technology for stratified forming

Daniel Söderberg and Marco F. C. Lucisano
STFI-Packforsk AB
Box 5604, SE-114 86 Stockholm (Sweden)

STFI-Packforsk has recently patented the “Aq-vanes”, a new technology for stratified forming headboxes. In this new solution, a thin passive liquid layer (a liquid vane or “Aq-vane”) is injected in the headbox between neighbouring pulp streams through a narrow hollow channel, thereby preventing mixing between the layers.

One of the most interesting features of the Aq-vane technology is that layer purity and separation can be controlled externally by tuning a set of process parameters. This opens the field for a widespread industrial application of stratified forming, a papermaker’s quantum leap that may reduce energy and raw material consumption, lead to improved product properties and possibly even to the development of new grades. In fact, although the basic concept of producing an engineered layered structure is not new in papermaking, its application has been extremely limited to a few selected grades, such as high grammage paperboard or multilayer tissue.

The Aq-vanes have been implemented on EuroFEX, STFI-Packforsk’s research paper machine, for extensive pilot scale trials. Thereby a number of technical solutions for the injection of the liquid layer has been tested and evaluated. In a parallel project, a method for measurement of layer purity in stratified forming has been developed. It is based on sheet splitting using a heat-seal pouch lamination technique. An image analysis method is then used to identify the colour of the fibres and thus the layer mixing.

Introduction

The next quantum leap in papermaking will be the introduction of stratified forming in order to reduce energy consumption, improve product properties and possibly develop completely new products. Contrary to multiply forming, stratified forming produces a layered structure with one single headbox (**Figure 1**). By using a single headbox, sheet stratification can be applied even to low-grammage products, *e.g.* newsprint.

Stratified forming is not a new concept in the papermaking industry and several publications have appeared in the scientific and technical literature since the 1970’s (*e.g.* Bergström and Peel, 1979, Johnsen, 1984, Harwood, 1989, Häggblom-Ahnger, 1998, Tubek-Lindblom and Salmén, 2002). Because of its potential for product improvements combined with energy and raw material saving, the concept of stratified forming has been tried with a few mill installations. Yet, in spite of a rather extensive research activity, stratified forming has not reached industrial acceptance as a standard forming technique. Indeed, virtually all installations have been abandoned because of severe quality issues due to excessive mixing of the different layers. Therefore, a technical break-through is required in order to give superior layer purity and homogeneity and make stratified forming a successful industrial process.

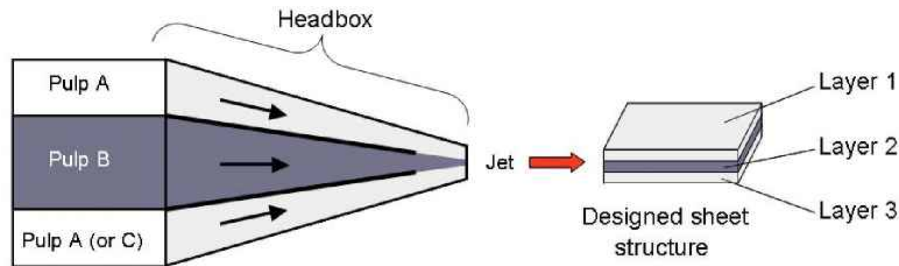


Figure 1. Schematic of a headbox for stratified forming and anticipated designed sheet structure.

Industrial Value of Stratified Forming

Stratified forming can be applied to paper grades of any grammage. Its industrial potential resides in the same set of considerations presented in the late 1970's by Bergström (1979) and Bergström and Peel (1979). In their analysis, they classified the potential advantages of stratified forming into aspects connected (i) with an improvement of the economy of the papermaking process and (ii) the design of new paper grades.

Energy and Process Economy

The use of stratified forming for the production of paper and paperboard introduces energy savings that potentially have repercussions on all papermaking unit operations. Already with the first studies of the 1970's, it was realized that a layered structure can replicate the properties of a traditional single-layer grade with a reduced basis weight. This is particularly interesting since the single most effective action for improving the economy of the papermaking process has always been a grammage reduction. Stratified forming gives the producer of printing paper and other low grammage grades the same tools for product design that have been available to the board maker. For example, a selective distribution of the fibre material in distinct layers in the thickness of the paper can preserve bending stiffness even with considerable reductions in basis weight.

Another interesting aspect connected to the industrial application of stratified forming is the energy input required for pulp refining. Given a two-step TMP process, the fraction of raw material flow to be directed to the core of the sheet could be refined in one single step (**Figure 2**). Only the furnish for the surface layers would be refined in two stages to achieve the required surface properties. In a correctly designed stratified forming process, this redefinition of the refining operation would give the same surface properties as the standard product but with a higher bulk (*i.e.* improved bending stiffness). Additionally, since part of the raw material is refined only once, the new process would save approximately 25% of the normal energy requirement. In the Swedish paper industry, with a total production of mechanical pulp of approximately 3 Mton/year and a typical energy consumption of 2500 kWh/ton, an energy saving of 500 kWh/ton corresponds to a national energy saving of 1.5 TWh /y.

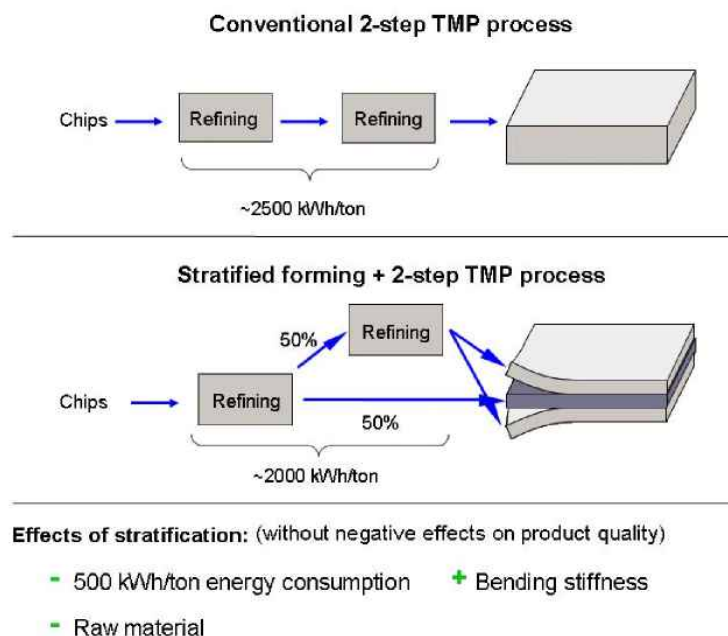


Figure 2. Example of application of stratified forming to the production of wood containing paper with consequent reduction in energy consumption.

New Paper Grades

Stratified forming gives the papermaker a new set of tools to design printing and packaging grades with new properties.

Printing Grades

Newsprint and other printing grades could be redesigned, either for new innovative needs or of needs of a traditional character. For example, an integration of fractionation and stratified forming could be a viable option for producing printing paper with different furnishes in the different layers (**Figure 3**). Another interesting possibility would be the use of wood containing pulp (virgin or recycled) in a middle layer sandwiched between two bleached surface layers, obtaining the same product properties that can be obtained with 100% virgin Kraft pulp today. A product with these characteristics would imply a significant environmental benefit while providing a tool for improving competitiveness against Asian manufacturers of fine paper.

Multiply Products

An industrial application of stratified forming can have an impact even for multiply grades, such as liner or board. In the simplest case, today's forming technology with multiple fourdrinier units could be replaced by a more compact stratified forming unit, resulting in a simpler process with lower investment costs (**Figure 4**). Additionally, taking advantage of the design freedom given by the non-symmetric nature of most liner and board qualities, product developers could introduce a larger number of functionalities. In the example of **Figure 5**, we present the case of the introduction of stratified forming for the top ply of a board for liquid

packaging. Here the product designer could introduce three different functionalities: a surface designed for printing quality, a layer for mechanical properties and one for hydrophobicity.

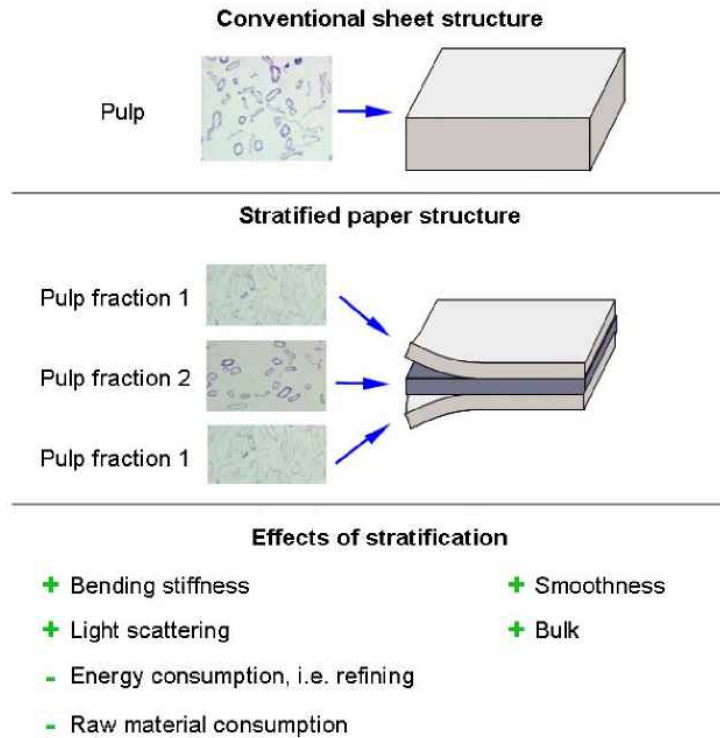


Figure 3. Application of pulp fractionation and stratified forming to printing grades.

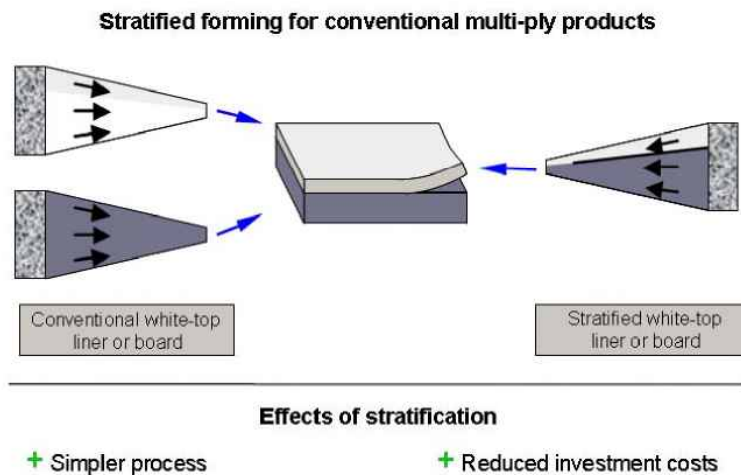


Figure 4. Process simplification after introduction of stratified forming for the production of a white-top liner or board. Two headboxes are replaced by a single stratified headbox for both layers.

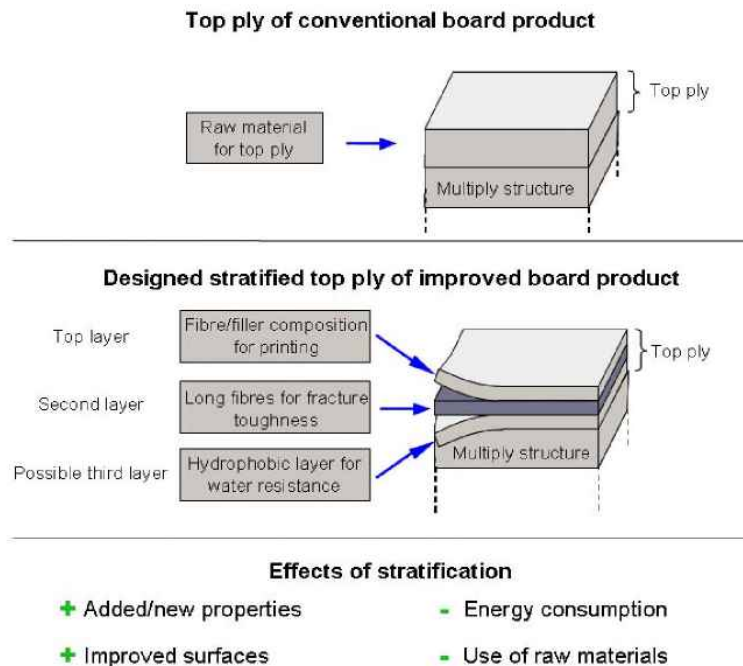


Figure 5. Improving the properties of the top-ply of a multiply board product. New functionalities are added through the application of stratified forming.

“Aq-Vanes”: The Liquid Vanes

The most important obstacle on the way towards an industrial implementation of stratified forming is due to the unacceptable degree of mixing between neighbouring pulp layers. Layer mixing is due to the fundamental hydrodynamic processes in the wakes that are formed at the point where the pulp streams are brought together (**Figure 6**). This type of instability would still be present even if the vanes were of infinitesimal thickness since it is connected to the interaction between the boundary layers on either side of the vanes.

STFI-Packforsk has recently patented the “Aq-vanes”, a new technology for stratified forming headboxes. In this new solution, a thin passive liquid layer (a liquid vane or “Aq-vane”) is injected between neighbouring pulp streams through a narrow hollow channel, thereby preventing mixing between the layers (Söderberg, 2003a, 2003b). Additionally, this technique gives the operator a new set of process parameters, by which the stratification process can be controlled and fine-tuned.

The optimisation of process design and the choice of a constructive solution for the application of the “Aq-vanes” to stratified forming of paper are at the core of STFI-Packforsk’s new project “TESS – The Engineered Sheet Structure”, co-financed by a group of STFI-Packforsk’s industrial partners and by STEM, The Swedish Energy Agency. Additionally some of the activities of the TESS research program will be accompanied by research activities within ECOTARGET, an integrated European project financed through the 6th framework program.

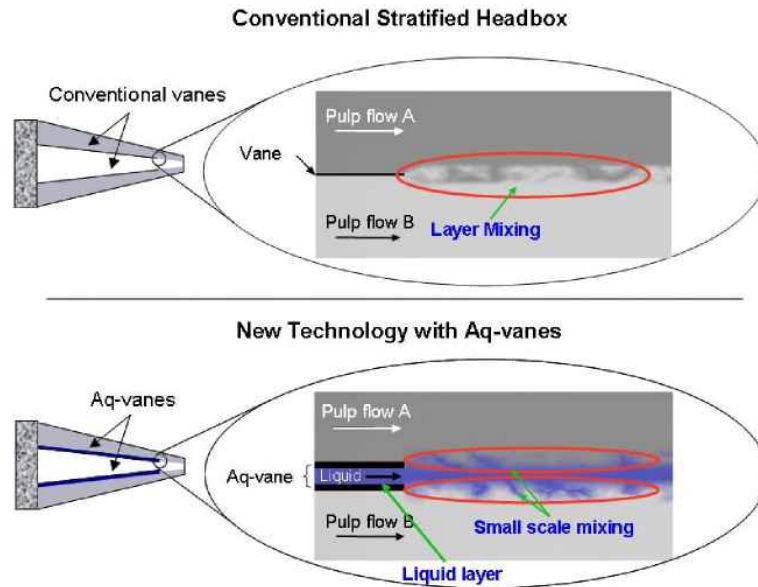


Figure 6. Layer mixing is the most important obstacle on the way towards the industrial implementation of stratified forming. In the Aq-vanes technology, a passive thin liquid layer is injected between any two neighbouring pulp flows. This results in improved layer purity and homogeneity.

During its first year of research, the TESS project has focused on two main objectives: (i) the pilot scale implementation of the Aq-vanes and ranking of different constructive solutions; (ii) the development of an objective and quantitative method to characterize layer purity and stratification.

Pilot Scale Implementation

The main aim of the TESS research project in 2003 has been to show that the Aq-vanes technology can be implemented in a viable industrial process. We have evaluated the Aq-vanes technology at pilot scale on EuroFEX, STFI-Packforsk's research paper machine. (**Figure 7**). The wide range of operating speed (250-2500 m/min) and the flexibility in machine configuration given by the three forming units (one fourdrinier and two different twin-wire units) allowed testing of the Aq-vanes over a wide range of modes of operation.

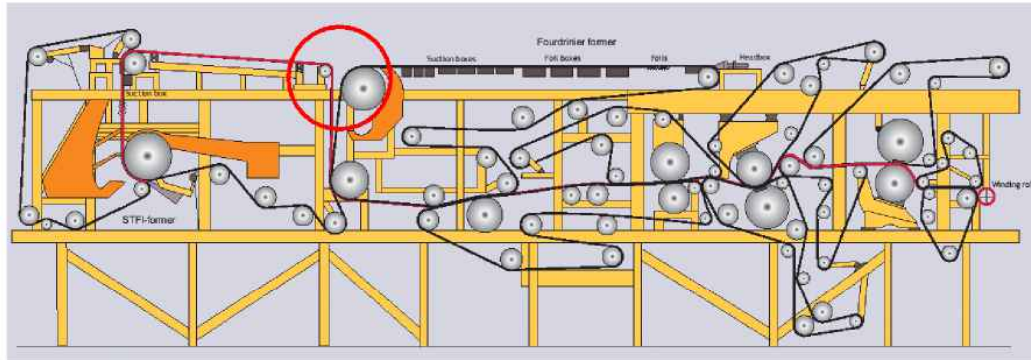


Figure 7. Schematic of the EuroFEX pilot paper machine. The red circle shows the position in which the single sided roll forming unit was installed (**Figure 8**).

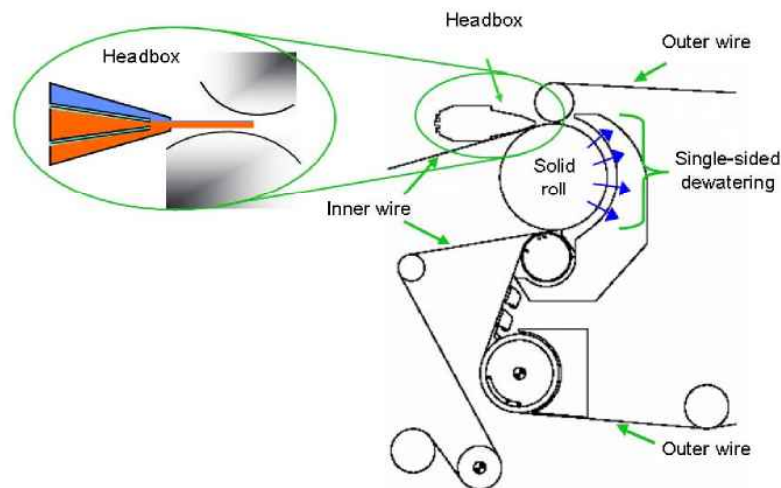


Figure 8. Schematic of the trial setup on the EuroFEX pilot paper machine. The detail of the headbox shows the set-up for a specific case with the blue layer positioned towards the outer wire and two red layers towards the solid roll.

During the first year of activity in the TESS project, we have installed a headbox equipped with Aq-vanes on both twin-wire units. All experiments discussed in this paper are relative to the forming set-up of **Figure 8**. Here the geometry of forming is simplified by the use of a solid forming roll, which results in single-sided dewatering towards the outer forming wire. In our studies we investigated both (i) constructive parameters, connected to the design and geometry of the Aq-vanes and (ii) process parameters, such as the thickness and velocity of the passive water layer or the jet-to-wire speed difference.

Layer Purity Evaluation

A major activity, complementary to the pilot scale trials, has been a project aiming at the development of an objective and quantitative study of layer purity. The absolute necessity of such a tool for objective evaluation was proven by our initial investigations, which showed that the correct classification of samples of different layer purity is a complex task for a non-expert human observer.

The approach we adopted during our pilot scale trials was to dye the core of the sample with a red dye, whereas the surface layers were dyed in blue. Preliminary laboratory experiments showed that the dyes had no significant impact on furnish flocculation and sedimentation properties, at the concentrations used in our experiments.

The results of our experiments with stratified forming have been evaluated by studying the *stratification profile*. This was defined as the relative frequency of (blue) fibres destined to the surface layer(s) of the sheet and its evolution in the thickness direction of the sample. Therefore, this evaluation approach required a quick and reliable technique for parallel splitting of paper into thin layers.

The literature reports a number of methods for parallel splitting of paper; among them heat-seal pouch lamination is one of least known, although possibly the most effective. This technique, mentioned by Danby in several occasions (e.g. Danby, 2001 and Danby and Zhou, 2003), has been discussed in some details in Knotzer (2000) and Knotzer et al. (2003). According to this method, a paper sample is sandwiched between two laminated sheets, composed of a melting glue layer (e.g. EVA – Ethylene VinylAcetate) on a support layer of PET (Poly Ethylene Terephthalate). When heat and pressure are applied in a commercially available laminator, the adhesive softens allowing the plastic to adhere to and encase the paper. The laminator is composed of a pair of heated, rubber-covered rollers, a pair of stationary heated bars, a second set of (cold) rollers and a control system for setting temperature and lamination velocity (**Figure 9**). After lamination the sample is split with a pair of counter-rotating rollers. The operation of lamination and splitting can then be repeated for an arbitrary number of times, until the desired number of splits is obtained. Typically, a 60 g/m² paper sheet can be split into 10 layers.

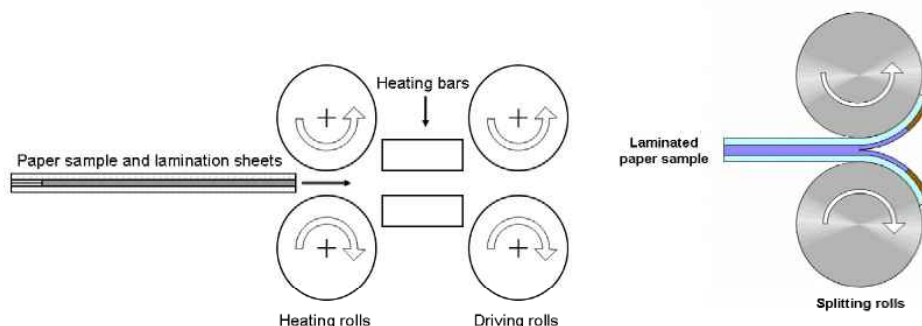


Figure 9. Lamination of a paper sample in a commercial hot laminator (left) and use of two counter-rotating roller to split the laminated paper sheet (right).

After splitting, all layers are relaminated for protection of the fibre material and stability. A flatbed scanner is used to acquire digital images of both faces of the splits whereby the relative frequency of blue pixels is calculated in each layer using the image analysis algorithm developed by Sannes Lande (2004).

Results

The Aq-vanes technology has been tested at pilot scale on the EuroFEX research paper machine during 2003, with the main goal of assessing the potential of STFI-Packforsk's technical innovation. We have investigated the effect of both constructive and process parameters, generating a detailed matrix of experimental conditions, an extended discussion of which remains outside the scope of this paper. Here we present the results relative to the effects of a few constructive and process parameters, with the purpose of showing that the Aq-vanes can be the technical innovation needed for a successful industrial application of stratified forming in papermaking.

For the sake of simplicity, we limit our discussion to two-layer structures with a red core and blue surface, where the two furnishes have been separated by a single Aq-vane. In all cases, we refer to single-sided dewatering through the (blue) surface layer, as in **Figure 8**. **Figure 10** gives a schematic illustration of the shapes of the measured stratification profiles: the horizontal axis gives the position in the thickness of the sample, whereas the vertical axis reports the relative fraction of blue fibres (furnish for the surface layers). All possible stratification profiles are included between the (red) line for complete mixing and the (blue) line for perfect layer purity. Thereby, the objective of our research activities is to produce paper with stratification profile as close as possible to the (blue) line for perfect layer purity.

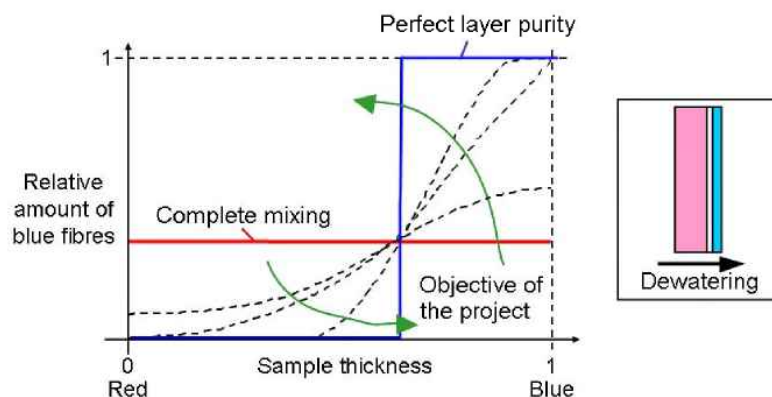


Figure 10. Schematic layer purity profiles evaluated by sheet splitting and image analysis. The graph shows the relative amount of blue fibres (pixels) in the scanned images of the split layers. The graph illustrates the ideal cases of perfect layer purity (blue line) and complete mixing (red line).

Our pilot machine studies show that some parameters have major effects on the stratification profile. For example, the difference in mean flow velocity between the passive water layer and furnish containing layers, calculated at the tip of the Aq-vane (**Figure 11**). Here we tested Aq-vanes with two different lengths. We termed “Short” the Aq-vanes ending at a distance of 150 mm from the slice opening and “long” those that end 50 mm from the slice opening. The pilot trials showed that the correct setting of the velocity of the passive liquid layer, relative to the velocity of the furnish flows is of major importance, particularly in the case of short vanes. The speed of the water layer alone can result in the significant difference between rather well stratified structures (such as samples 0814I and 0814J in **Figure 11**) and the relevant interlayer mixing of sample (0814F in **Figure 11**).

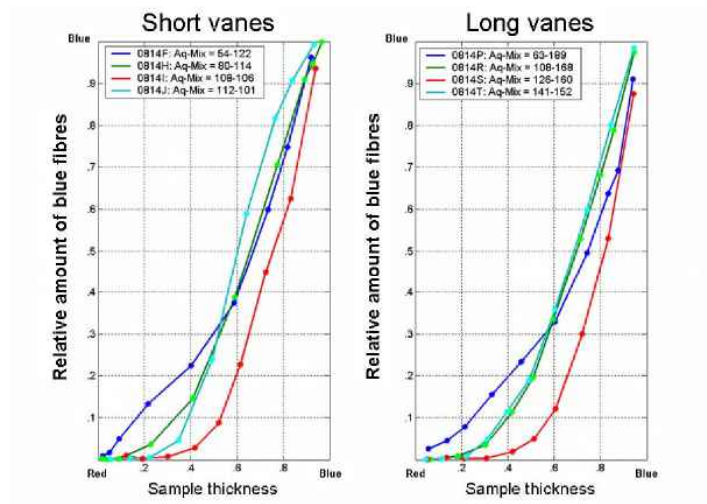


Figure 11. Examples of stratification profiles as a function of the difference in linear velocity between the passive water layer and the furnish flow, calculated at the tip of the Aq-vane.

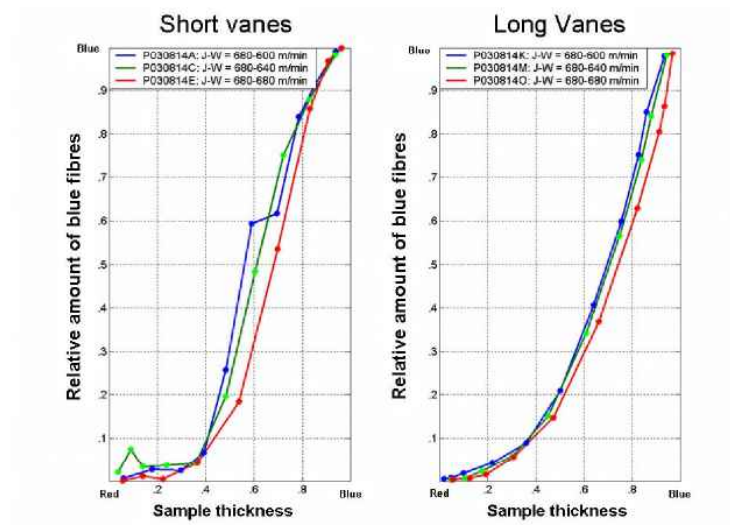


Figure 12. The jet-to-wire speed difference has little or no influence on the stratification profile for both short and long Aq-vanes.

Some of the investigated process parameters had no influence on layer mixing in stratified forming. **Figure 12** shows one example of parameter with virtually no influence on layer purity, namely the jet-to-wire speed difference.

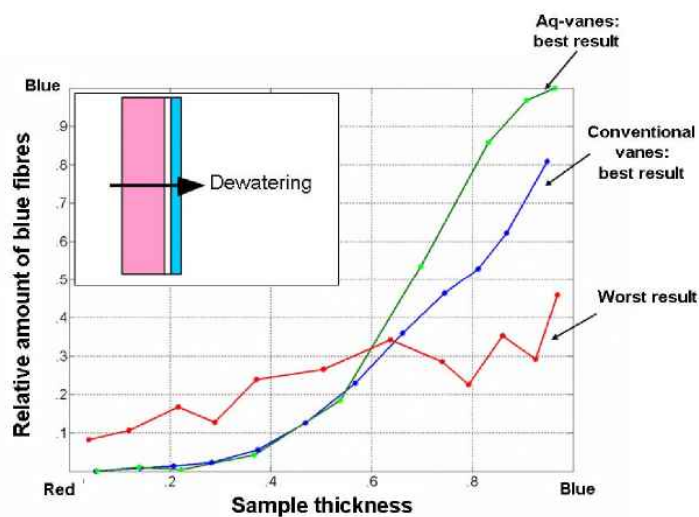


Figure 13. Comparison between the Aq-vanes technology (green profile) and conventional separation vanes installed in the same headbox (blue profile). The red profile is relative to a sample with high degree of layer mixing, produced with the Aq-vanes technology.

We have compared the stratification obtained with the Aq-vanes with that of a conventional separation vane installed in the same headbox and run with the same machine settings. For the purpose of a fair comparison of the two technologies, we have followed the recommendations of Lloyd (1997) for the set-up of conventional separation vanes. **Figure 13** reports the best stratification profile obtained in 2003 with the Aq-vane technology (green profile), as well as the best results obtained with conventional vanes, set up as in Lloyd (1997, blue profile). Additionally, we have reported the profile with worst separation obtained during our experiments with the Aq-vanes (red profile). The comparison between the best and worst result obtained with the Aq-vanes is an indication of one of the main process-related advantages of the Aq-vanes, namely its nature of being controllable through the tuning of process settings.

In conclusion, the profiles presented in **Figures 11–13** clearly show that the results of stratified forming with the Aq-vanes are strongly influenced both by constructive and process parameters. Moreover, in spite of the “trial-and-error” of our first application trials, it appears evident that the Aq-vanes technology has a strong potential as a technical solution for stratified forming.

Conclusions

This study describes the first application examples of the Aq-vanes technology for stratified forming of paper. In this new technical solution, patented by STFI-Packforsk, a thin passive liquid layer is injected in the headbox between neighbouring layers of different composition.

Our pilot scale trials show that the layer purity obtained with the Aq-vanes is significantly better than that obtained with separation vanes of conventional design. Additionally, the degree of stratification is controllable by the machine operator by the on-line tuning of appropriate process parameters.

References

- Attwood, D. and Bridge, N. K. (1979) "Web Forming – The Future", EUCEPA Conference, Vol. 1, pp. 238-245, London.
- Bergström, J. I. (1979) "Stratified Web Formation, Current and Potential Applications", Norsk Skogsindustrin, 31(5):133-137.
- Bergström, J. I. and Peel, J. D. (1979) "Fundamentals of Structured Web Forming" EUCEPA Conference, Vol. 2, pp. 120-130, London.
- Bringman, D. J. and Riddick, I. W. (1977) "The Stratified Web Approach to Single Ply Grades", New Technology in Water Removal, Paper 17, BPBIF, London.
- Erickson, L. D. (1977) "Physical Properties of Stratified Sheets", Tappi, 60(10):113-115.
- Harwood, J. W. (1989) "Stratification of Paper Grades", Engineering Conference, Vol. 1, pp. 57-63, TAPPI, Atlanta.
- Häggblom-Ahnger, U. (1998) "Fractionation of Softwood Sulfate Pulp in Three-Ply Copy Paper", EcoPaperTech, pp. 195-206, FAPET, Helsinki.
- Johnsen, R. (1984) "Structured Tissue", Engineering Conference, Vol. 1, pp. 95-100, TAPPI, Atlanta.
- Knotzer, U. (2000) "Image Analysis Using Microscopy to Improve Product Quality". In: "Scientific and Technological Advances in the Measurement and Control of Papermaking", Paper 15, Pira International, Leatherhead, UK.
- Knotzer, U., Wilsche, M. and Stark, H. (2003) "Papirstruktur i z-Richtung", Wochenblatt für Papirfabrikation, 131(11-12):688, 690, 692, 694, 696-699 (In German).
- Lloyd, M. (1997) "Turbulent Layer Mixing During Stratified Forming of Woodfree Paper", Licentiate Thesis, Department of Pulp and Paper Chemistry and Technology, The Royal Institute of Technology, ISRN KTH/PMT/R--97/8--SE.
- Sannes Lande, M. (2004) "A Study of Mixing and Layering to Characterize Stratified Forming", M. Sc. Thesis, Centre for Image Analysis, Uppsala University.
- Stöckmann, V. E. (1974) "Performance of Stratified Sheets", Tappi, 57(10):108-110.
- Söderberg, D. (2003a) "Metod för att forma en skiktad fibrig bana och maskin för utförande av denna", Swedish Patent no. 520 520 (In Swedish).
- Söderberg, D. (2003b) "Method of Forming a Fibrous Web and Machine Therefor", International Patent Application WO 03/048452 A1 (2003).
- Tubeck-Lindblom, A. and Salmén, L. (2002) "Wood-Containing Multi-Ply Paper – Improved Properties", 7th International Conference on New Available Technologies, SPCI, Stockholm.