New Insights into Gap Forming of Lightweight Containerboard

Frank Swietlik, Jukka Muhonen, Ari Puurtinen, Hannu Turpeinen, Teuvo Virkkunen

Metso, Paper business line

ABSTRACT

This presentation gives new insights into high-speed gap forming of lighter weight containerboard. A relationship between the forming roll wrap angle, forming roll capacity, and basis weight is established. The impact of headbox design and consistency together with forming roll dewatering on web properties will be discussed. The effect of machine speed on containerboard properties and dewatering capacity will also be examined.

Power consumption of the forming section will be studied as an entity consisting of pumping energy, vacuum system, and drives. When minimizing the total costs, the lifetime of forming fabrics is also considered.

The paper will also present experiences of production machines.

INTRODUCTION

According to the RISI study (2010), the basis weight of key linerboard grades in North America has been steadily declining, following the global trend toward lightweight containerboard grades [1].

While the basis weights have decreased, the use of recycled fiber as containerboard furnish has increased. This is especially so in Europe where strong testliner is made primarily from old corrugated containers (OCC) and other recovered paper grades.

This trend has gradually been adopted by North American producers. Between 1992 and 1999, close to 4 million tons of recycled linerboard capacity was started up in the United States. The number of 100% recycled mills has grown but so has also the number of mills that incorporate a significant amount of recycled fiber into furnish. Recycled medium has always represented a larger portion of all medium (fluting) produced in comparison with linerboard. The share of recycled medium today accounts for more than 40% of the medium produced for domestic consumption in North America. Of particular note is that almost all of the OCC used in North America comes from North America and the mix contains more long fiber softwood and less previously reprocessed shorter fiber.

The trend towards a more lightweight containerboard and a higher OCC content has opened the doors for high machine speeds through the use of a gap forming concept. When building fast containerboard machines, Metso has utilized the long and extensive experience of efficient, fast-running paper machines.

RETURN ON INVESTED ENERGY BY HIGH EFFICIENCY

High capacity at a high speed is the key feature of efficient lightweight containerboard manufacturing. Good runnability is a prerequisite. The paper must be produced with less and/or lower quality raw material, it must be strong and visually attractive, and perform well in corrugators.

A high machine speed is required to produce lighter weight grades economically. This is already evident in the higher design speeds of new installations, particularly in Europe. There gap forming technology is used to produce lower weight medium and testliner at a high speed often with 100% recycled fiber-based furnish.

Energy efficiency describes the amount of energy used per a ton of end product. Energy efficiency is influenced by various factors that interact strongly, including product properties (basis weight, furnish mix, chemicals), operating environment (know-how, cleanliness, preventive maintenance), geographical location (climate, raw materials, energy sources) and available technology (machine concept, energy generation and use, process controls and automation). Therefore energy efficiency can only be improved as an entity.

When efficiency is high, the share of consumed energy per ton is low. Any downtime due to breaks is a waste of time and resources. The best way to improve energy efficiency is to target the high total efficiency of production. In high speed containerboard manufacturing, this gives the best return on invested energy.

FORMING CONCEPTS – LAYERING VS. PLIES

Linerboard is mostly a two-ply product in the United States and in Europe. Fluting, or corrugating medium, does not require a multi-ply structure like linerboard. It is used between liners in corrugated board and its formation does not affect printability.

Conventional Fourdrinier forming is typically speed-limited to 1,000 m/min. New hybrid former installations with shoe blade hybrid forming technology are designed for speeds of up to 1,400 m/min. This concept uses vacuum shoe technology with special inlet geometry. This shoe blade concept can also be applied in the manufacturing of two-ply lightweight containerboard grades with only one hybrid former unit.

In order to enter the next speed level, gap former technology is required. A design speed level up to 1,800 m/min is typically used for the production of lower basis weight fluting and linerboard from 75 to 140 gsm. A roll and blade gap former with a two-layer headbox is an optimal wet end concept for these grades, and plays a significant role in creating the essential strength properties and formation of containerboard (Figure 1).

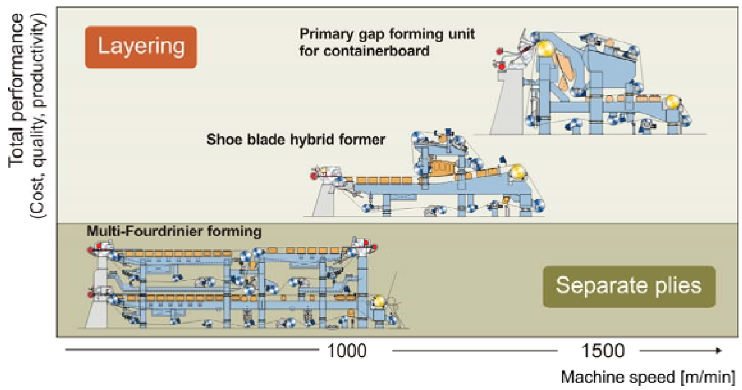


Figure 1. Board forming concepts with layering vs. separate plies.

Fluting and Linerboard with High-Speed Roll and Blade Gap Former

In most cases, gap formers of modern high-speed containerboard machines are of a roll and blade type. A well-defined and homogenous headbox jet is fed into a gap between two fabrics and water is removed as soon as possible in order to maintain the homogeneity of the web (Figure 2).

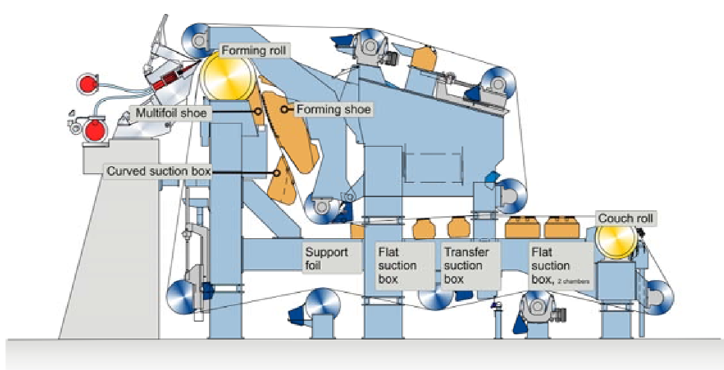


Figure 2. A two-layer headbox and a high open volume forming roll design are the key elements of containerboard high-speed gap forming. This is an optimal concept for recycled fiber-based fluting and linerboard in the basis weight range of 75 to 140 gsm and with speeds of up to 1,800 m/min.

This wet end concept is applied in the latest European testliner and fluting lines of Mondi Swiecie PM 7 in Poland, Propapier PM 2 in Germany, and Saica PM 11 in UK, the latter starting up in 2012.

HIGH-PERFORMANCE HEADBOX FOR SINGLE AND TWO-LAYER GAP FORMING

The right headbox hydraulics design produces optimized turbulence intensity and scale, minimized reflocculation and minimized disturbances, creating optimal conditions for good strength properties and formation.

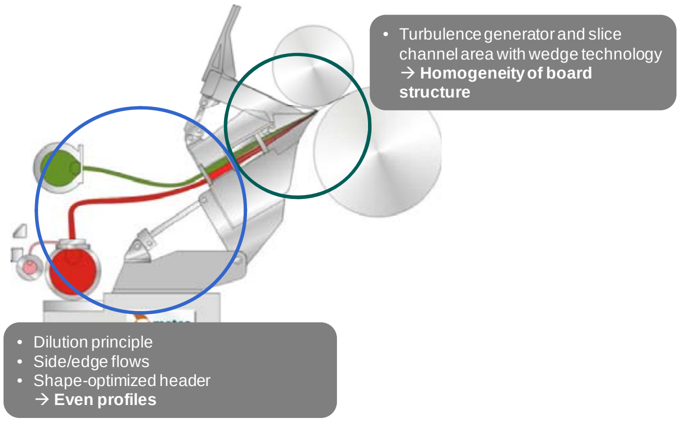


Figure 3. Modern high-performance headbox concept for single and two-layer gap forming.

The key elements of high-performance headbox hydraulics are the turbulence generator and the slice channel area built using composite wedge technology. The turbulence scale is optimized so that the maximum turbulence intensity coincides with the scale of the fiber length and floc size. This brings the flow structure and variations down to a very small scale and thereby generates a fully homogenized flow free of disturbances (Figure 3).

The wedges in the slice channel produce continuous acceleration that controls the rate of reflocculation and ensures a homogenous flow into the forming section.In two-layer headbox applications it is very important to verify the layer coverage. To reach an excellent layer coverage, all slice jet turbulence and velocity fluctuations in the direction of the slice jet thickness (the Z-direction) must be eliminated. All hydraulic components of the headbox have been designed to minimize slice jet and board web disturbances.

Experiences from the pilot and production machines indicate that homogenous slice jet quality yields excellent board properties. This gap forming headbox design maximizes the utilization of raw material strength potential, which enables the use of more cost-effective raw materials. Excellent formation without streaks or tiger stripes contributes to better smoothness and printability for linerboard (Figure 4).

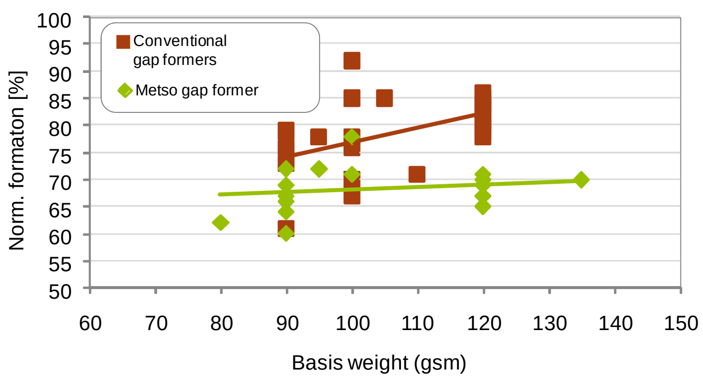


Figure 4. Formation of the modern containerboard gap former concept in comparison to conventional gap formers.

The two-layer headbox technology delivers good layer coverage. Figure 5A shows a topside view of a two-layer headbox sample with a 40 gsm brown top layer on a 40 gsm gray linerboard (total basis weight 80 gsm). The high-performance two-layer headbox can produce a two-ply web using only one gap forming unit. Figure 5B shows a topside view of a poor layer coverage sample produced using a conventional two-layer headbox.

Figure 5A. Good layer coverage with a high-performance two-layer headbox.

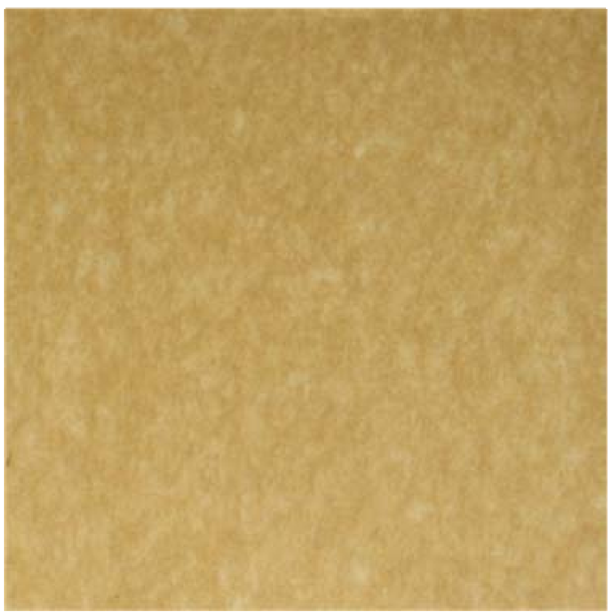


Figure 5B. Poor layer coverage produced using a conventional two-layer headbox.

The high-performance headbox provides a robust hydraulic performance and excellent board properties with uniform basis weight and fiber orientation profiles within an extended operating window with one headbox setup. This means a higher operating performance and adaptability to varying production conditions.

Effect of Speed Difference Between Layers on Strength Properties with a Conventional Two-Layer Rigid Separating Element Headbox

Some statements can be found in related literature concerning the conventional two-layer rigid separating element headbox and strength properties [2]. The design of a two-layer rigid separating element headbox allows different jet speeds for the top and bottom layers. Based on this literature, higher strength properties (geometric tensile strength, SCTCD and RCTCD) are achieved if the outer layer runs at a higher speed than the inner layer (Figure 6).

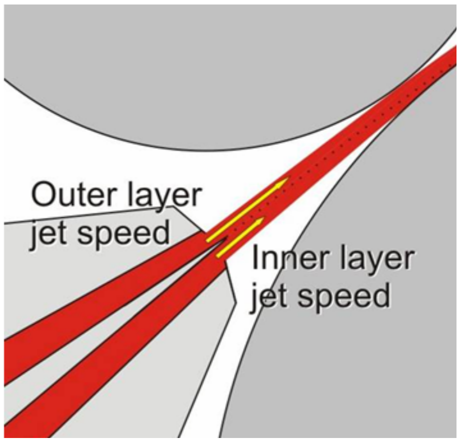


Figure 6. The outer layer runs at a higher speed than the inner layer.

Production Machine Results

Different layer speed differences were tested on a full-scale production machine. The test grade was Testliner III 125 gsm and the raw material was 100% recycled paper.

Figures 7 through 9 show the effect of speed difference levels between layers (+10 m/min and +30 m/min levels) on geometric tensile strength index, SCTCD index, SCTMD index, CMT 30 index, burst index, and internal bond index values. Figures 7 through 9 clearly indicate that a speed difference between the layers does not provide any improvement in strength properties within the same MD/CD tensile ratio window, contrary to what is claimed in related literature. Figure 10 shows a similar result with normalized formation. No other improvements, such as those affecting runnability, were found in these tests either.

Several pilot machine trials have confirmed the results discussed and shown in this section.

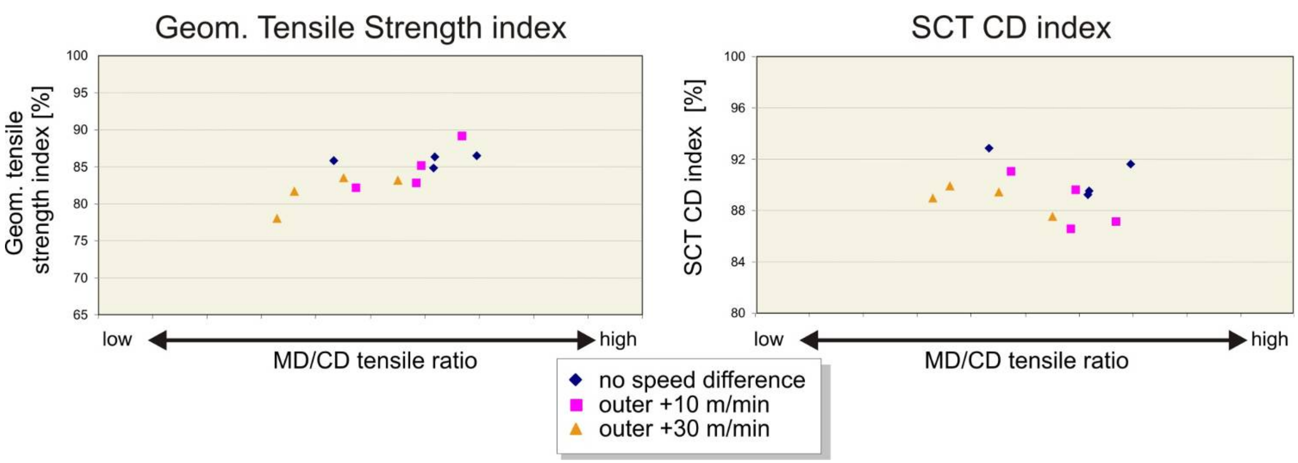


Figure 7. Effect of speed difference between layers on geometric tensile strength index (left) and SCTCD index (right). Pilot trials.

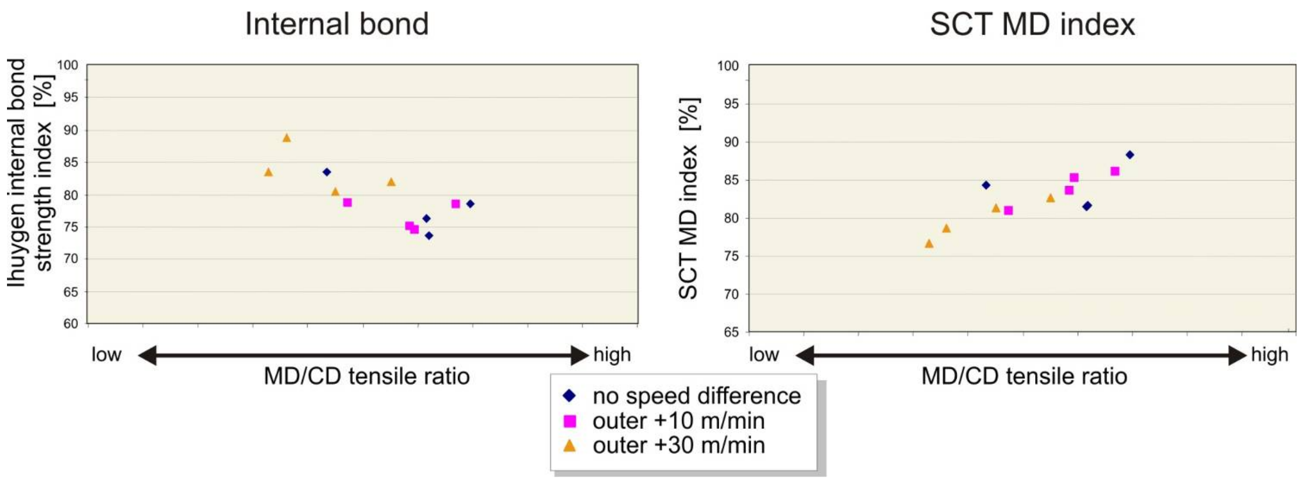


Figure 8. Effect of speed difference between layers on internal bond index (left) and SCT MD index (right). Pilot trials.

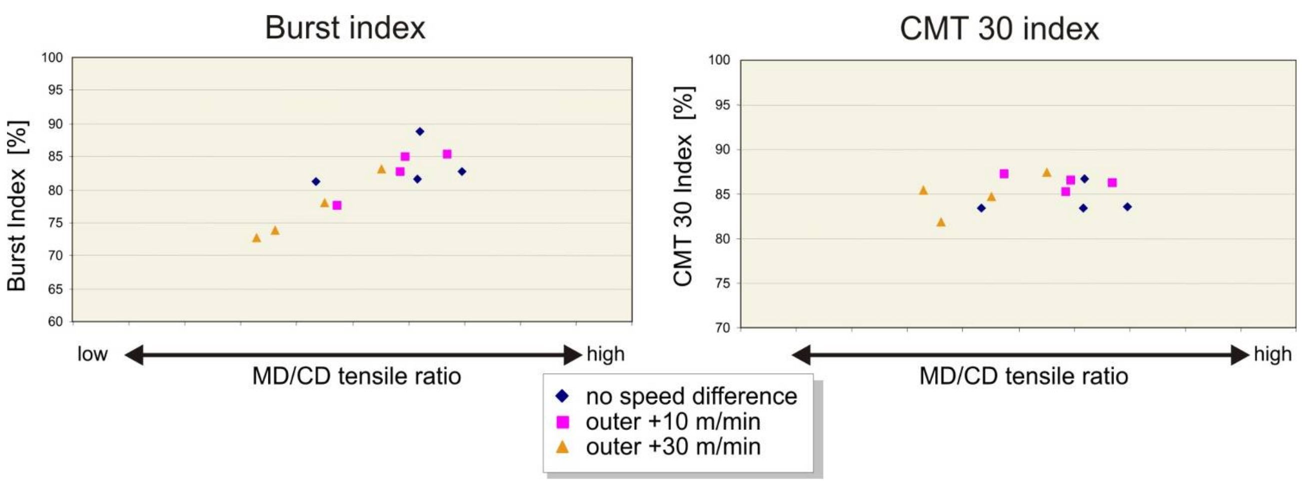


Figure 9. Effect of speed difference between layers on burst index (left) and CMT 30 index (right).Pilot trials.

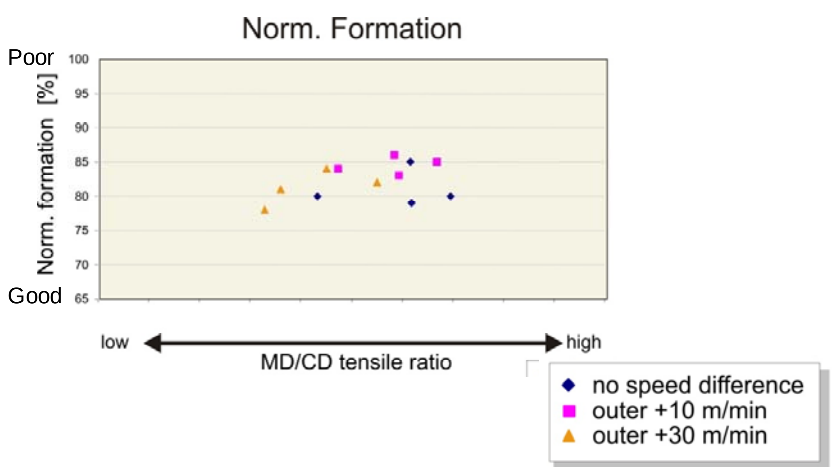


Figure 10. Effect of speed difference between layers on normal formation. Pilot trials.

GAP FORMING OF CONTAINERBOARD GRADES

Forming Roll Dewatering

In the case of containerboard grades made of 100% recycled fibers, good fines retention is required for good strength properties. Forming roll dewatering is non-pulsating and yields good retention. The pulsating drainage of blade forming reduces retention and can result in an uneven fines distribution, which has a negative influence on strength, especially on internal bonding.

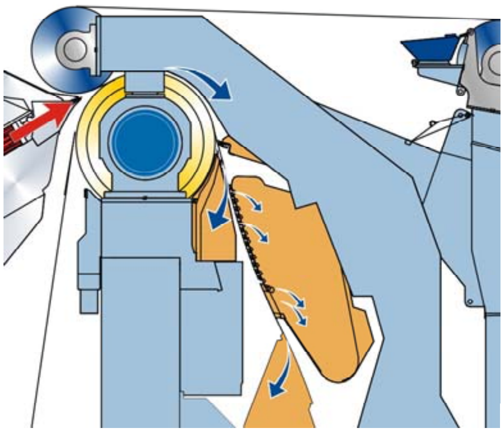


Figure 11. Gap former configuration for containerboard grades.

The modern gap formers used for containerboard grades (Figure 11) are similar to the roll and blade formers used for printing paper grades, but the forming roll diameter and wrap angle are larger [3].

The forming roll typically drains some 80% of the total headbox flow, which is why the drainage capacity of the forming roll is very important for the total dewatering capacity of the forming section.

Phases of Forming Roll Drainage

The forming roll drainage process can be subdivided into three separate phases. These phases are illustrated in Figure 12.

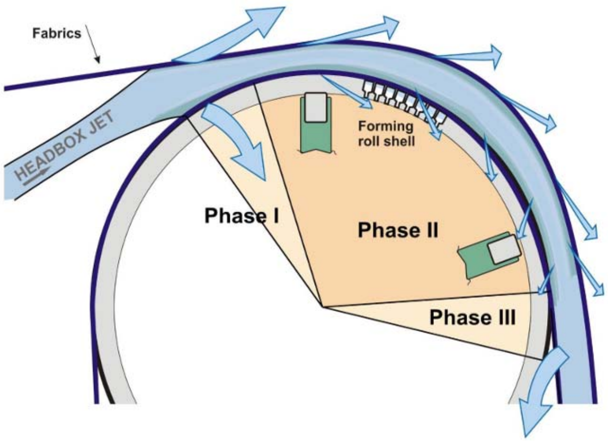


Figure 12. Forming roll drainage process.

The first phase consists of initial drainage at the jet impingement point, where the main driving force comes from the kinetic energy of the slice jet. A clear water jet comes out through the outer fabric at the impingement point. Water also runs through the inner fabric into the holes on the open forming roll surface.

In the second phase, covering most of the wrap area on the forming roll, drainage through the outer fabric is driven by the tension of the outer fabric and centrifugal forces. The speed of drainage is much slower than in the initial phase due to the rapidly increasing flow resistance of the web layers that have already been formed. In the second phase a vacuum can be used inside the forming roll to boost drainage through the inner fabric.

The third phase starts at the point where the inner fabric is separated from the forming roll. The third phase driving force is the vacuum generated in the opening gap between the roll surface and the inner fabric, and drainage takes place through the inner fabric.

All of the water drained through the inner fabric during the first and second phases goes into the holes in the forming roll shell. Previously published studies have covered the effect of the forming roll surface structure on drainage capacity. After the inner fabric is separated from the forming roll, centrifugal forces drive this water out of the holes and into the forming roll save-all.

Influence of Length of the Second Phase of Forming Roll Dewatering

The target of this study was to examine the effect of constant dewatering zone length on dewatering and board properties. The study was conducted on a pilot scale gap former for board grades. Containerboard rolls (corrugating medium made out of 100% recycled furnish) from Central Europe were used as furnish. The freeness level of furnish varied between 230–250 ml. The forming section was equipped with SSB-type forming fabrics. Retention was controlled to the level of 75–85% with a single polymer system. Wet end starch was not added and the samples were not surface sized.

The production rates used in this test were at the level of the fastest production machines. The grades produced and production rates are presented in Table I.

Table I.. Produced board grades, machine speeds and production rates

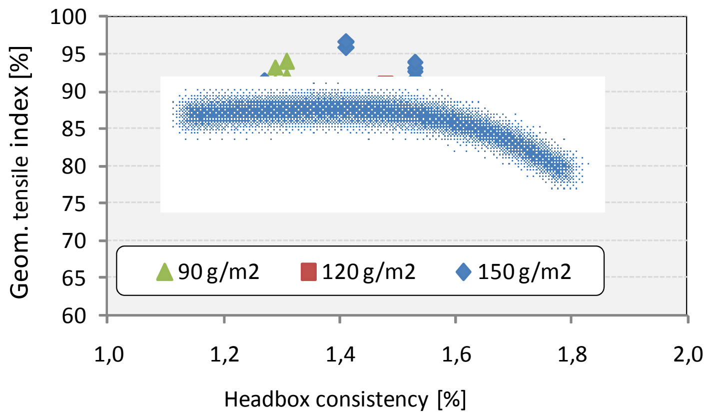
Grade **[g/m^2]**	**Reel speed** **[m/min]**	**Production rate** **[t/m*h]**
90	1550, 1750	8.4 – 9,5
120	1250, 1550	9.0 – 11.2
150	1250	11.2

Effect of Headbox Consistency on Strength Properties and Optimal Operating Point

Traditionally, headbox consistency and strength have been thought to have a strong negative correlation. The target has been to minimize headbox consistency, which has led to high pumping costs. Based on this study, it is possible to increase headbox consistency using recycled containerboard furnish up to 1.5 % without losing in-plane strength values. The influence of headbox consistency on the process and containerboard properties are presented in Table II.

Table II. Effect of consistency on board properties

Property	Effect of lower headbox consistency
Pumping costs	Increase
Retention	Decrease
Tensile and burst strength	No effect below 1,5 %
Internal strength	Decrease



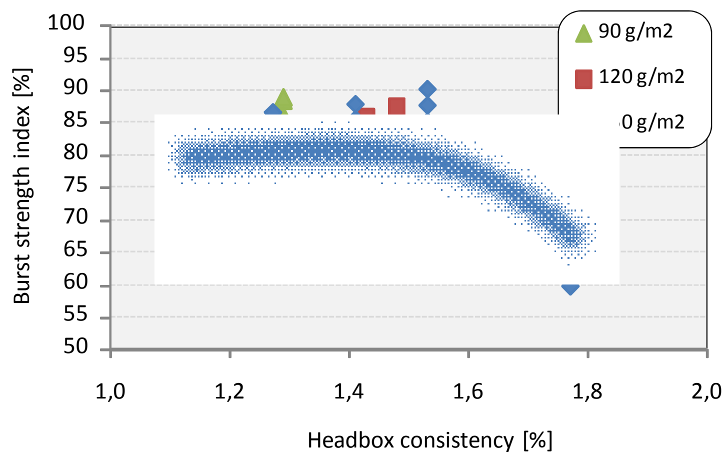


Figure 13. Effect of total headbox consistency on in-plane tensile and burst strength

Effect of Forming Roll Wrap Angle on Forming Roll Dewatering

Basis weight has a major influence on the proportion of forming roll dewatering. Drainage resistance of drained fiber mats is determined by their permeability and thickness (basis weight). As drainage resistance reaches the drainage pressure, no more dewatering takes place. The required drainage distance is significantly smaller with lower grammages than with extremely high basis weights. The effect of the forming roll wrap angle on the proportion of forming roll dewatering is presented in Figure 14.

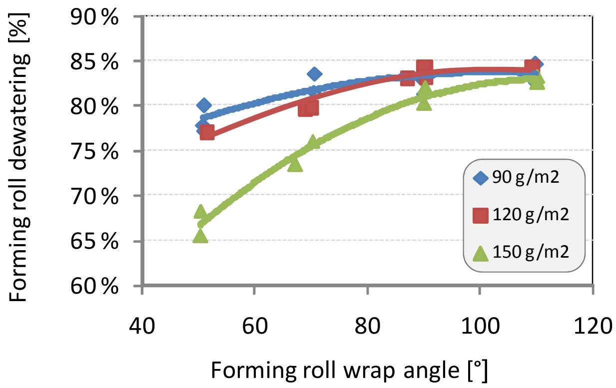
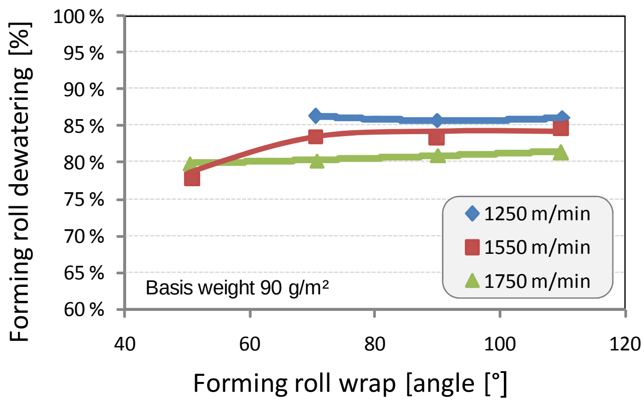


Figure 14. Effect of forming roll wrap angle on drainage.

Effect of Machine Speed

As the machine speed increases, dewatering time at the forming roll decreases respectively. The drainage force toward the forming roll decreases as the centrifugal forces increase. Dewatering pressure toward the outer fabric remains constant, as fabric tension is constant. A higher machine speed decreased slightly the proportion of forming roll dewatering. A higher forming roll wrap angle did not compensate for the effect of machine speed. The effect of machine speed on the proportion of initial dewatering is presented in Figure 15.



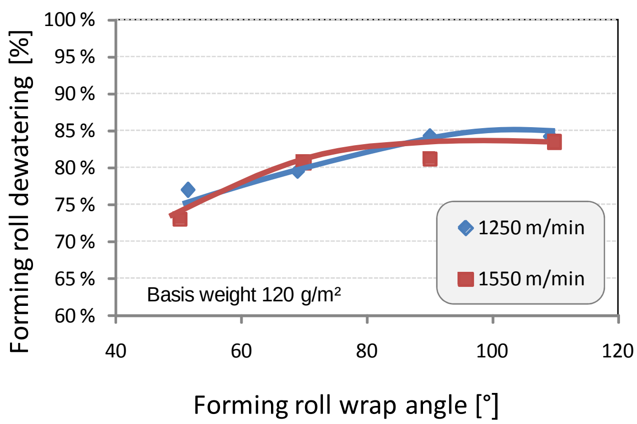


Figure 15. Effect of machine speed on the proportion of forming roll dewatering with 90 g/m² and 120 g/m².

Z-directional and In-Plane Strength Values

Highest influence of initial dewatering was found from the z-directional strength values. Forming roll wrap angle should be high enough to reach the maximal values. After reaching maximum values defined by headbox consistency and furnish properties, differences between wrap angles were found to be small. The influence of headbox consistency on internal strength was also high. This is the reason why the product with a basis weight of 150 g/m^2 had the highest internal strength. Maximizing headbox consistency proved to be beneficial for internal strength. The influence of wrap angle and basis weight on internal strength are presented in Figure 16.

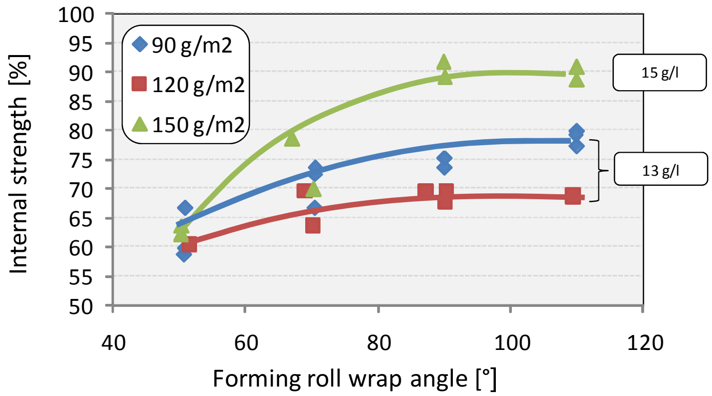


Figure 16. Internal strength as a function of forming roll wrap angle

The geometrical tensile index showed a slight dependency on the forming roll wrap angle. Similar to internal strength, at a certain wrap angle the maximum strength level is reached. As the figures indicate there is no significant difference between 90 and 100 degrees. The influence of the forming roll wrap angle on the geometrical tensile index and burst strength is presented in Figure 17

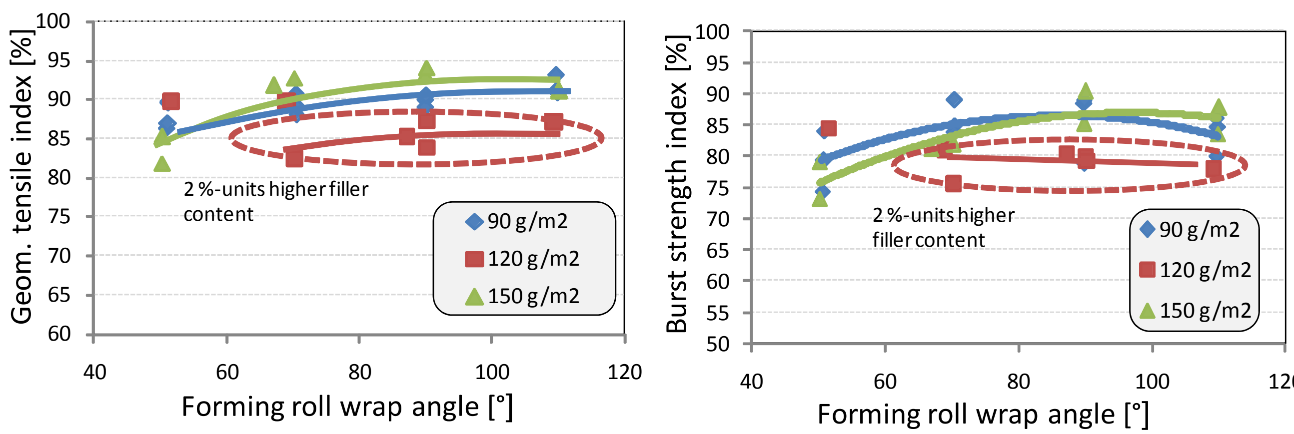


Figure 17. Geometrical tensile index and burst strength as a function of forming roll wrap angle.

Web Look-Through - Formation

In the previous chapters it was stated that printability of the packaging grades is becoming more important. The study shows a clear dependency between beta-formation and the forming roll wrap angle. It was found that beta-formation tended to weaken especially with high grammages at very high forming roll wrap angles. Beta-formation is one of the main factors contributing to the smoothness of the final product. The effect of the forming roll wrap angle on beta-formation is presented in Figure 18.

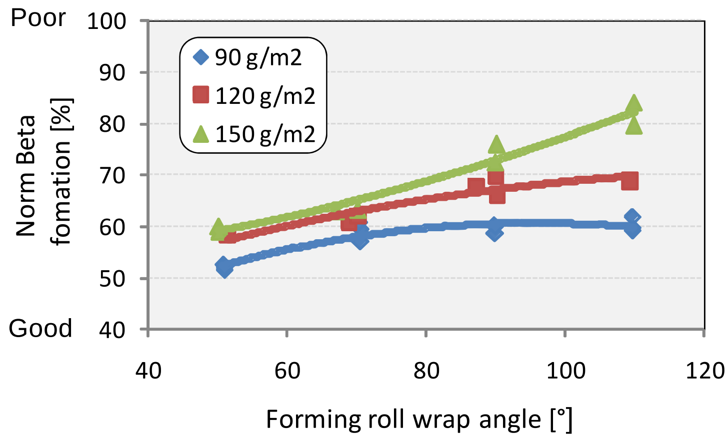


Figure 18. Effect of forming roll wrap angle on beta-formation.

POWER CONSUMPTION ON FORMING SECTION

When talking about the forming section power consumption, the drive power and vacuum system power demand are often referred to, but the power demand for the short circulation equipment needs to be considered as well.

Figure 19 shows how the combined power demand of the short circulation fan pump and the 1st stage feed pump is of the same magnitude as the drive power of the forming section. This underlines the fact that the forming technology that enables a higher headbox consistency gives a clear advantage in energy efficiency.

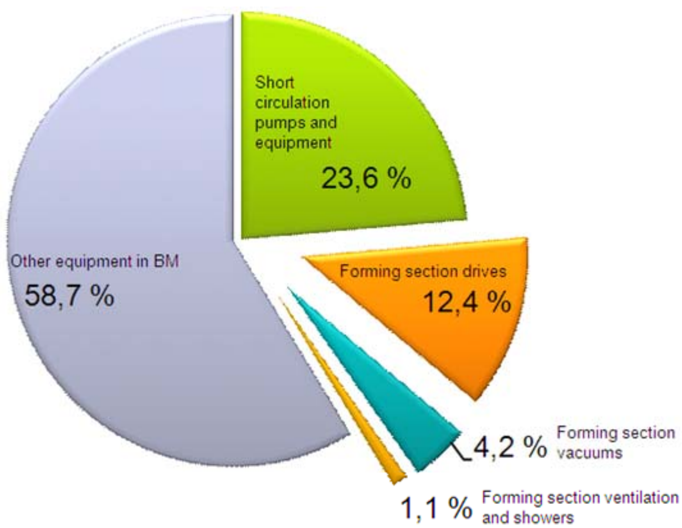


Figure 19. Typical power demand distribution of a high speed containerboard machine.

Vacuum generation on the forming section is about one third of the power demand of the drives, but the vacuum assisted drainage elements are in a key role as they contribute both to the drive power and the power demand of the vacuum system.

The lifetime of ceramics and forming fabrics is also influenced by the vacuum load. High-vacuum elements typically create friction that shortens the lifetime of fabrics. To ensure an even dewatering profile through the forming section, vacuum levels need to be optimized.

Let us first take a look at how the drainage level of an individual suction box depends on the vacuum level and duration. Figure 20 shows a theoretical example of how the dryness level increases with time with two different vacuum levels P_1 and P_2. A higher vacuum level enables a higher dryness level only if the dwell time of the vacuum is long enough. In the case of P_1, dryness no longer increases after T_1. Based on Figure 20, it can be stated that for a given suction length (=dwell time) T_x there is an optimal vacuum level P_x, which maximizes an increase in the dryness level with a minimum power consumption.

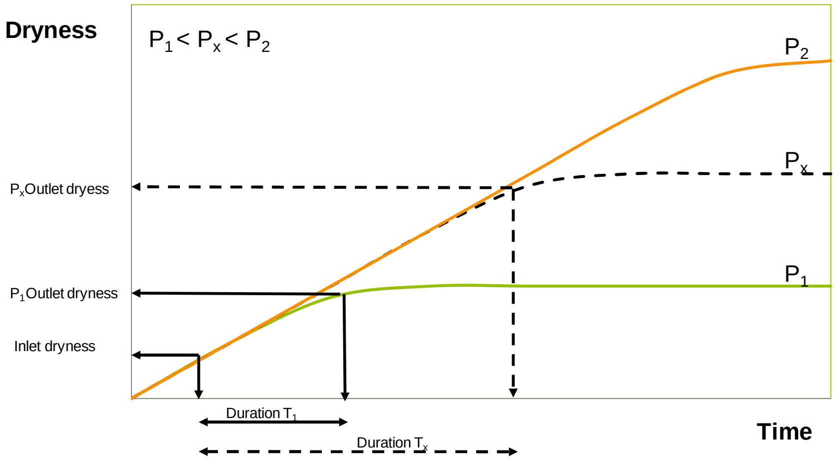


Figure 20. Dryness increase versus dwell time (forming section).

A board machine contains several suction boxes one after another so the optimization is naturally more complicated because of the interaction between consecutive boxes. Figure 21 is a simplified illustration of an optimized system where the vacuum levels in each box are fitted to produce a maximum dryness increase with minimum power consumption.

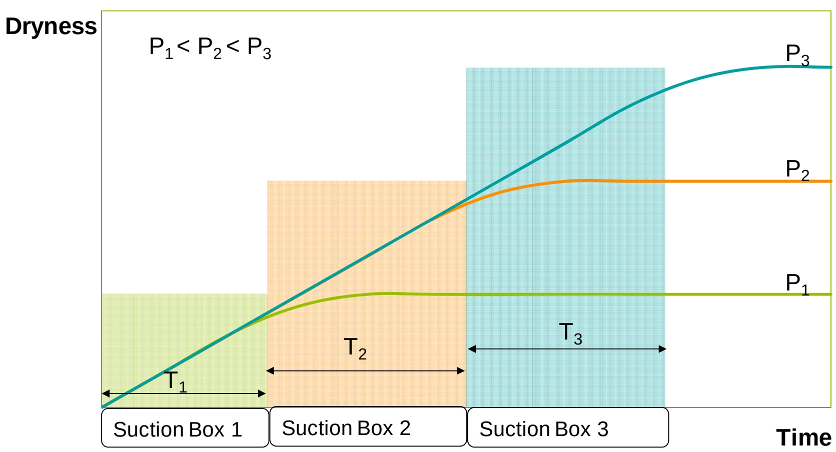


Figure 21. Optimized scaling of suction box vacuums. Containerboard machine, production data.

The following practical example of a production machine shows how significant savings in drive power can be achieved without sacrificing anything in the final dryness level when vacuum levels in the suction boxes are optimized. The machine was producing 100 g/m^2 linerboard from 100% recycled fibers. The machine speed varied between 1220–1285 m/min. In this test, the vacuum setup typical for this machine was used as a reference. Vacuum levels in the boxes were then reduced, starting from the first one (multifoil shoe). Table III shows all vacuum setups run during the test.

Table III. Suction box vacuums in the tests (gap forming concept. 100 g/m2 linerboard, 100 % recycled fiber-based furnish; production data).

Test point number	Multi foil shoe [kPa]	Forming shoe 1 [kPa]	Forming shoe 2 [kPa]	Forming shoe 3 [kPa]	Curved box 1 [kPa]	Curved box 2 [kPa]	Suction box [kPa]	Transfer box [kPa]	Suction box 1/1 [kPa]	Suction box 1/2 [kPa]	Suction box 2/1 [kPa]	Suction box 2/2 [kPa]
Ref	-10	-12	-14	-18	-20	-22	-23	-22	-27	-32	-41-	-43
1	-5	"	"	"	"	"	"	"	"	"	"	"
2	"	-10	-15	-15	"	"	"	"	"	"	"	"
3	"	-5	-10	-15	"	"	"	"	"	"	"	"
4	"	"	"	"	-10	-15	"	"	"	"	"	"
5	"	"	"	"	"	"	"	"	-20	-25	"	"
6	"	"	"	"	"	"	"	"	"	"	-35	-40

In the first four tests, the vacuum level was reduced in the twin wire zone before the turning roll. Vacuum levels in the two chamber boxes before the couch roll remained unchanged. Figure 22 shows how the dryness level increased both after the turning roll and before the couch roll.

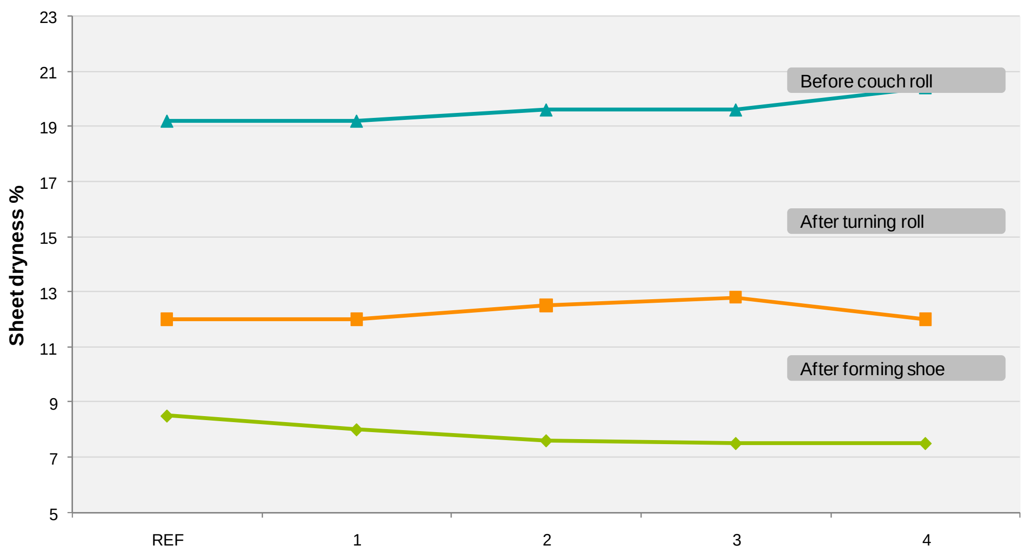


Figure 22. Dryness level development of a gap forming section. Containerboard machine, production data.

The results suggest that a so-called web sealing effect has taken place in the twin wire zone. A high vacuum level at the beginning of the forming section increases the drainage resistance at the end of the forming section, which results in a lower final dryness level. In Figure 23, the drainage of individual suction boxes is compared between the reference point and test point 4. As the figure indicates, too high a vacuum level in the forming shoe results in poor drainage in the two chambers of the curved suction box on the bottom wire side. In this case the lack of lubrication increases friction and increases drive power. A more gentle approach in the forming shoe gives a more even distribution of drainage and a higher final dryness level with lower energy consumption. In general even distribution of drainage between the individual elements gives better dryness results with lower energy consumption.

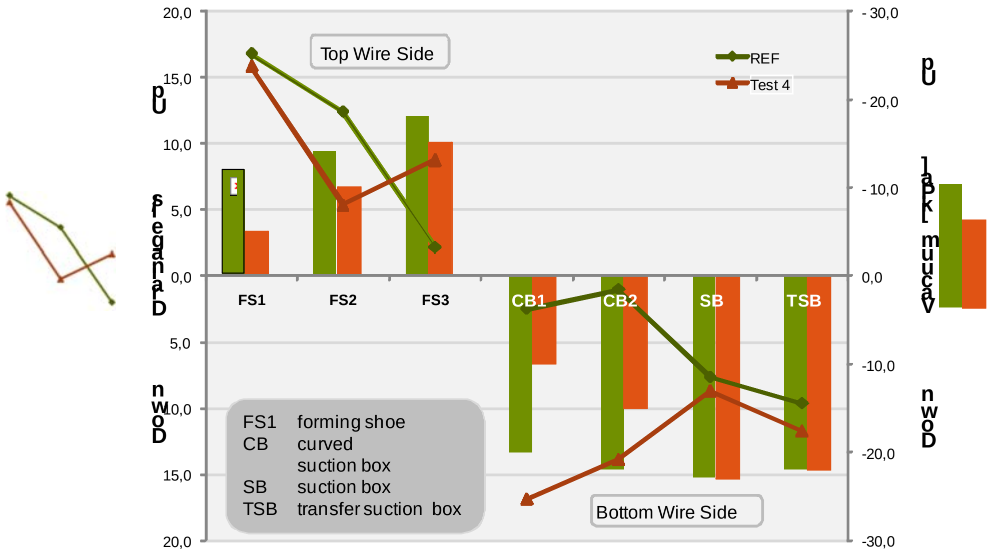


Figure 23. Suction box drainage in a twin wire zone. Containerboard machine, production data. Abbreviations: FS = forming shoe, CB = curved suction box, SB = suction box, TSB = transfer suction box.

In the last two test points, the vacuum level in the two chamber boxes was reduced so that it was possible to reach nearly the same final dryness level as in the reference point. Figure 24 shows the development of forming section drive power and web dryness before the couch roll during the tests.

Reducing vacuum in the twin wire zone gave a 10% reduction in drive power and a higher final dryness level. The overall reduction in drive power, without any reduction in the final dryness was approximately 17%.

There is a direct link between the forming section drive power and the life time of both the fabrics and the ceramics. When vacuum optimization is performed throughout the basis weight range, a corresponding reduction can be expected in fabric wear.

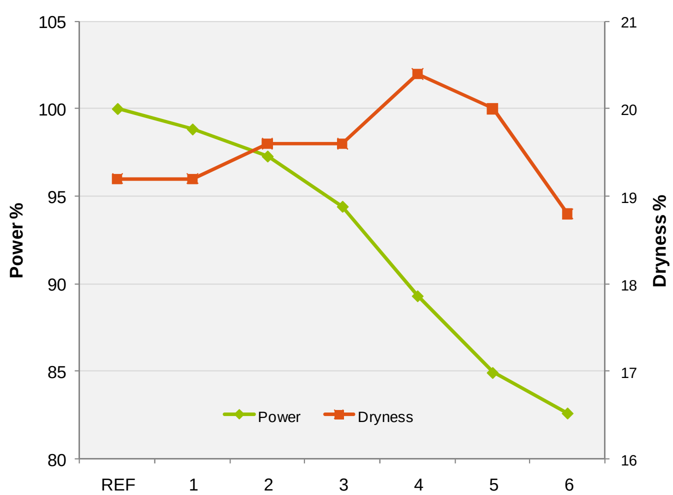


Figure 24. Development of drive power and dryness before the couch roll. Containerboard machine, production data.

Traditionally the final dryness increase on the forming section is created with the couch roll. Discussion can be found in related literature on how replacing the couch roll with high vacuum suction box will improve the energy efficiency of the forming section.

The main disadvantage of the couch roll in comparison with the high vacuum suction is its higher air flow, which means higher power consumption in vacuum generation. Air has to be removed from the suction roll shell drilling each time the drilling passes the suction zone. On the other hand drive power of the couch roll is in practice independent of vacuum level.

The energy efficiency of the high vacuum suction box depends heavily on its influence on drive power. The drive load is influenced by sheet dryness at suction box inlet, vacuum level and suction box cover design. The outcome of the comparison in energy efficiency depends heavily on these boundary conditions and there is no simple answer to the question which one is more energy efficient. Once again the lifetime of both fabrics and ceramics needs to taken into account in this comparison.

CONCLUSIONS

The proportion of initial dewatering at a roll and blade gap former can be very effectively controlled by the forming roll wrap angle. The requirement for the dimensioning of initial dewatering is set by drainage resistance of the drained fiber mats. This depends mainly on the basis weight of the product being produced.

A high-performance headbox delivers numerous benefits compared to other headboxes on the market, such as improved strength properties, excellent formation, no streaks or tiger stripes, and good layer purity within an extended operating window.

Based on production machine testing, speed differences between the layers of a two-layer headbox do not provide any improvement in strength or other properties within the same MD/CD tensile ratio window, contrary to what is claimed in related literature.

The effect of headbox consistency on the strength properties was also examined. It was found that under the practical operating window of 1.0…1.5% there was not any significant influence on the in-plane strength properties, whereas internal strength (Huygen) was found to increase with a higher headbox consistency.

The forming roll wrap angle had an influence on strength properties, if the wrap angle was significantly too small and the produced basis weight was high. A very low wrap angle decreased the in-plane strength properties slightly. The most dramatic effect was detected in internal strength. However, if the wrap angle is between 90 and 110 degrees, there is no significant difference in strength values.

Ambertec beta-formation was found to improve at lower forming roll wrap angles. This is due to a lower consistency in the middle layers of the web and the resulting higher fiber mobility as the web is led to the blade dewatering phase.

Simply maximizing the forming roll wrap angle does not give the best result. The optimal forming roll wrap angle is influenced by a combination of several containerboard properties.

Power consumption of a high-speed containerboard machine forming section is typically one third of the total consumption of the entire machine. This includes also the power consumption of the fan pump and the 1st stage feed pump. The combined power demand of these pumps is of the same magnitude as the drive power of the forming section. It was demonstrated through a production machine example how optimal set up of forming section vacuums can give significant savings in forming section power consumption without any loss in web dryness after the forming section. Replacing the couch roll with a high vacuum suction box was also discussed.

References

1. RISI Multi-Client Study – The Future of Lightweight Containerboard in North America, 2010.

2. Thomas R. Kast: Advancements in Gap Forming for Lighter Weight Board and Packaging Papers. TAPPI Paper Con 2010, Atlanta, GA, USA

3. Kari Räisänen: Headbox and forming roll – the key elements of gap forming. Metso Paper Technology Days 2006, Jyväskylä, Finland.