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FINAL THESIS

Matti Näätsaari

COAT WEIGHT AND DRYING POWER CONTROL

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Commissioning company	M-real Kemiart Liners, Mr. Erkki Kähkölä & Mr. Heikki Järkkälä

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ABSTRACT

Coating is a one special field in the paper making process and it is typically divided into four different phases. These are coating colour application onto the base paper, metering, drying and finishing. This thesis work focuses on the coat drying process and its effect on the coating quality.

The aim of this thesis work was to define the existing coat drying capacity and study the possibilities to increase coat weight. The target was also to develop a feedforward control for coat drying. The results of this work are based on the trials that were carried out on PK1 at M-real Kemiart Liners in Kemi and at Coating Technology Center in Raisio.

During the trials it was noticed that accurate feedforward control for a coat drying was impossible to develop with the existing equipment. Based on the trials, new instructions for coat drying were made and a relatively huge energy saves were achieved.

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TIIVISTELMÄ

Päällystys on yksi paperin ja kartongin valmistusprosessin osa-alue ja se on tyypillisesti jaettu neljään eri vaiheeseen. Nämä vaiheet ovat päällystyspastan aplikointi pohjapaperin pintaan, päällysteen annostelu, kuivaaminen sekä viimeistely. Tämä tutkintotyö keskittyi päällystyksen kuivatukseen ja sen laatuvaikutuksiin.

Työn tarkoitus oli määritellä nykyinen päällysteen kuivatuskapasiteetti sekä tutkia mahdollisuudet lisätä päällystemäärää raskaimmin päällystetyllä lajilla. Tavoitteena oli myös kehittää päällysteen kuivatukselle myötäkytketty säätömalli. Työn tutkimustulokset perustuvat koeajoihin jotka suoritettiin sekä linerkone PK1:llä Kemissä että Coating Technology Center:ssä Raisiossa.

Tarkka päällysteen kuivatuksen myötäkytketty säätö todettiin koeajojen aikana mahdottomaksi kehittää nykyisin laittein. Automaattisen säädön sijaan operaattoreille tehtiin koeajojen pohjalta uudet päällysteen kuivatusohjeet. Uusien kuivatusohjeiden myötä saavutetut energiasäästöt olivat suhteellisen suuret.

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1 INTRODUCTION

This thesis work is done for M-real Kemiart Liners. Kemiart Liners is a part of M-real's consumer packaging area and it is a leading producer of a coated white top linerboards. The purpose of this work is to define the existing coat drying capacity on liner machine PK1 and to develop an automatic control for a coat drying. Feedforward control for a coat drying and the limits for a coat weight are the aimed results of this work.

Mill presentation, Kemiart product range and liner machine PK1 are introduced in chapter 2 and 3. These chapters give information on a general level, just facts that are important for this study are explained in detail. Pigment coating theory is introduced briefly in chapter 4 and because of the nature of this work, the main attention is paid to coat drying. Chapters 5 and 6 constitute the most important theoretical part of this thesis work. Coating conditions and their effects on coat drying are explained in chapter 5. Chapter 6 is the last theoretical part and it focuses on different coat drying strategies and their effects on the quality properties.

2 MILL PRESENTATION

This chapter gives information about the mill and about the different products with their end uses. Especially end uses like printing methods are necessary to know to get a better understanding of the quality requirements. After all quality requirements and cost-effective board making process set the operating window for a coating and coat drying.

2.1 M-real Kemiart Liners

Kemiart Liners is part of M-real's consumer packaging area. The mill is focused on manufacturing white top linerboards. Products like electronics, toys, DIY products, branded food and beverages reach customer in corrugated packages. The primary function of the package is to protect the goods inside. The promotional function of the package is increasingly important and packages are an integral part of the product and the brand /1/.

Kemiart Liners is a leading producer of coated white top kraftliners. Pulp is the main raw material and it comes from the integrated pulp mill located on the same industrial site. Biological wastewater treatment system deals with the environmental impacts. The quality policy at the mill is strict. It is based on frequent test producers and on-line quality control. Kemiart Liners has ISO 9001 quality certification, and has long devoted special attention to protecting the environment. Kemiart Liners also has ISO 14001 /1/.

M-real Kemiart Liners in detail

- located in Kemi
- start-up 1971
- capacity 345 000 t/year
- products are coated and uncoated white top kraftliners
- grammage range from 110 to 250 g/m^2
- employees 150

2.2 Kemiart product range

Kemiart Liners has three different coated grades and one uncoated grade. All grades consists of two pulp layers, bottom and top layer. The bottom layer is a mixture of unbleached softwood pulp and broke, and the top layer is made from bleached hardwood pulp. End uses are flexo and offset printed packaging products.

The reason for using unbleached softwood pulp in the bottom layer is to give as high strength properties as possible, whereas bleached hardwood pulp in the top layer with shorter fibres gives better surface to coat and print. Another purpose of a bleached hardwood pulp in the top layer is to increase brightness.

3 LINER MACHINE PK1

Because the aim of this thesis work is to define the existing coat drying capacity and to develop a control model for drying, the main attention is paid to coating equipment and equipment that are directly related with the coating process. Even the base paper properties have significant effects on coating and its quality properties, equipment before 1^{st} softcalender are left out from the closer studies and this chapter is focused on 1^{st} softcalender and equipment after that.

Liner machine in detail

- width of jumbo reel 6900 mm
- speed 900 m/min
- 2 dilution controlled headboxes
- on-line OptiCoat Jet coater with Autoblade
- 2 softcalenders
- 2 moisture profiling units
- 2 cross-profile measuring frames
- rebuilds: Tampella 1986, Valmet 1990 and 1997, Voith Sulzer 1999, Metso Paper 2005

3.1 Softcalenders

There are two softcalenders in use. The first one is located right after the 5th drying cylinder group. The purpose of the first softcalender is to increase the smoothness of the base paper before it is coated. The second one is located before the reeler and it is used to finish the coating. Soft roll position is against the bottom side of the web in both cases.

3.2 Cross-profile measuring frames

There are two cross-profile measuring frames in use. The first one is located just before the coating station and the second one between the 2nd softcalender and the reeler. This thesis work utilise moisture measurement from the first frame, and coat weight and gloss measurements from the second frame.

3.3 Coating equipment

Coating unit is located between 5th and 6th drying cylinder groups. It is supplied by Metso Paper and the operating principle is a jet-application (figure 1). Coating unit is equipped with AutoBlade-metering, means that coat weight is automatically adjusted both in machine and cross direction. Drying of the coating is done by gas heated IR-dryers (infrared).

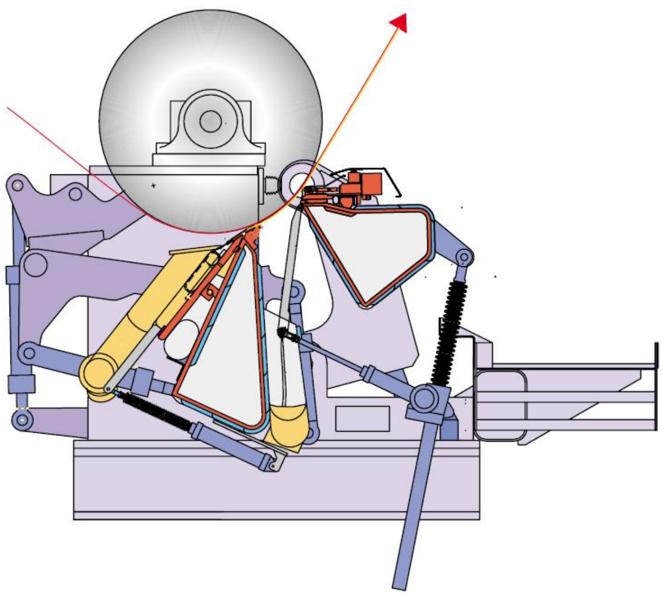

Figure 1 OptiCoat Jet /3/

There are two gas heated IR-units after coating unit (figure 2). Both of them have two segments. Emitters' manufacturer is Solaronics IRT and emitter type is Gem7 (Gas Emitter Module). The construction of the both units is the same, first comes a segment with three emitters in machine direction i.e. a 3-row segment, and immediately after that follows a segment with two rows.

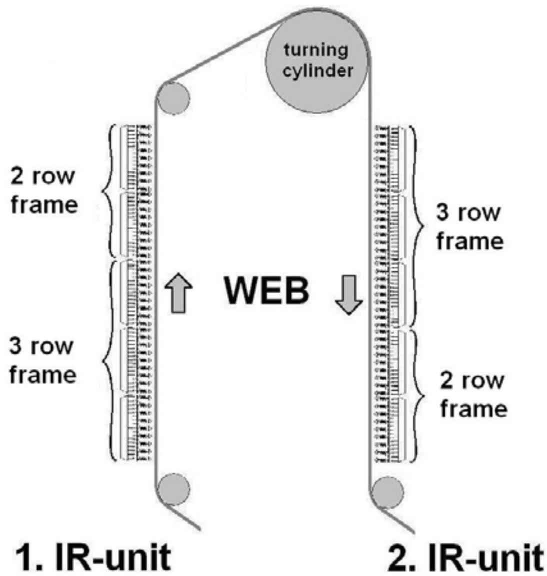

Figure 2 IR-drying units on PK1 (not in scale)

The number of emitters in cross direction is 50 and Solaronics provides 6.5 kW input power for each emitter. That equals 975 kW input power for a three row units and 650 kW input power for a two row units. Thus, total input power for whole system is 3.25 MW. There is also a turning cylinder between IR-units. It is heated by low-pressure steam /4/.

Gem7 emitters in detail

Input power	6.5 kW
Evaporation capacity	39 kg/hr/m_{cd} or 195 kg/m^2/hr
Operating temperature	1 150 °C
Efficiency (%)	55 to 63
Estimated life time	3 to 5 years
Dimensions	143 mm · 200 mm (cross direction · machine direction)
Power adjustment	by combustion air pressure

4 PIGMENT COATING

This chapter gives a general idea of the pigment coating. Because of the machine layout of PK1, the main attention is paid to jet-application, blade-metering and IR-drying. Thus, if there is not otherwise mentioned, when this thesis work is speaking about coating, it is meaning pigment coating with jet-application and blade-metering. And on the other hand, when coat drying is discussed, it is meaning drying with gas heated IR-dryers.

4.1 Basics of pigment coating

Coating is a process where the base paper is covered by coating colour. The aim is to improve both optical and printing properties of paper. Depending on the produced grade, paper is coated 1-3 times per one or both sides /5/.

Coating colour consists of several components. The most important of these components is the pigment (figure 3). Pigments are usually minerals and the share of pigment in the dry coating is about 80-95 % of its weight. Kaolin clay, calcium carbonate and talc are most commonly used as a pigment, but also gypsum and as called additional pigments like titanium dioxide and plastic pigments are used. The main differences between different pigments are brightness, shape, size, size distribution, density and price. These factors affects on rheological properties of coating colour, optical and printing properties of coated paper and structure of coating /5/.

Figure 3 Picture of ground calcium carbonate pigment particles /6/

Another important component in a coating colour is the binder. Common binders are polymer dispersions. Coating colour usually consists of a combination of binders, most commonly two. Functions of binders in the coating layer are shown in the figure 4. The main purpose of binders is to bind pigment particles to base paper (A) and to each other (B). Binders are also filling voids between pigment particles (C). The amount of binder in a coating colour is about 5-20 weight percent of the amount of dry pigment. Binders are also affecting on the rheological properties of the coating colour /5/.

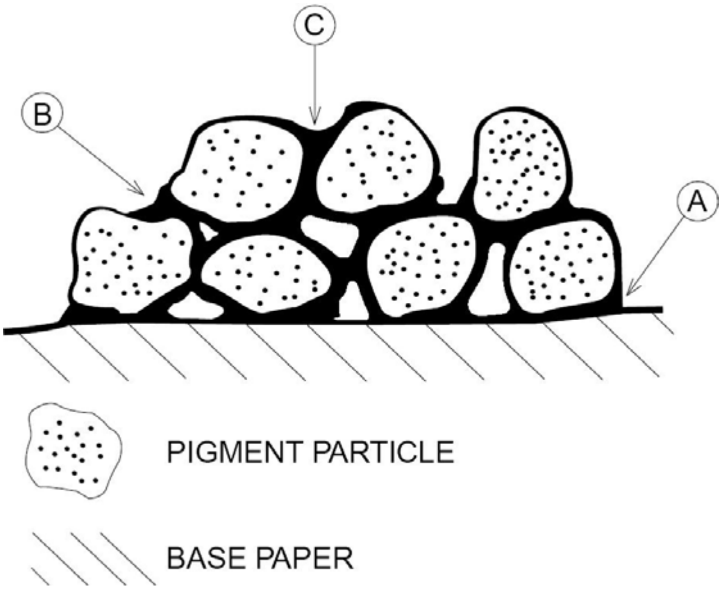

Figure 4 Functions of binders in the coating layer /5/

A component called thickener is used to modify the rheology and water retention of the coating colour. Thickeners can be fully synthetic, or they can be based on natural polymers. Typical dosage is no more than a few weight percent of the amount of pigment. A thickener can also have good binding properties, and then it is called co-binder /5/.

Coating colour usually contains several additives, which have different functional roles. They can be used to aid in dispersing of pigment, adjusting pH, acting as lubricant (in supercalendering), causing optical brightening, and being a microbiocide in a coating colour. The amount of an additive is usually less than 2 weight percent of the total solids in a coating colour /5/.

Water has an important role in a coating colour. Water makes it possible to mix different components in the coating colour uniformly, which is impossible in a dry state. Water also makes it possible to pump the coating colour to the coating unit and to apply it onto the base paper. But, because higher water content means more drying, it is desirable that coating colours contain only as little amount of water as the flow properties, runnability and mixing need /5/.

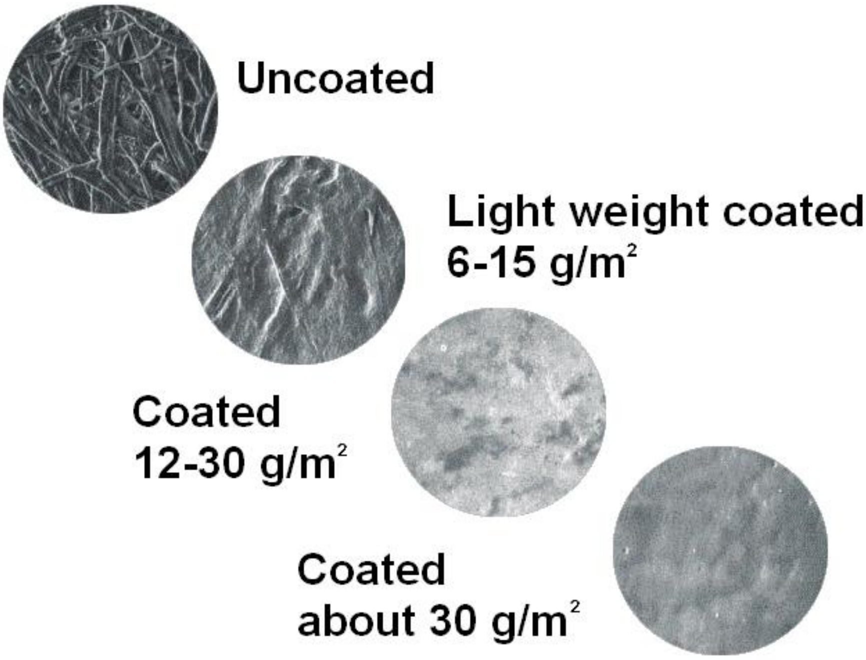

Figure 5 Paper surfaces with different coat weights /6/

Figure 5 shows images of uncoated and coated paper surfaces with different coat weights. Cross section picture of coated paper is shown in figure 6. Images illustrates very well, how coating affects the surface properties. It’s easy to see an improved quality when coating covers the surface and hide the cavities. The results of that are improved printing properties /5/.

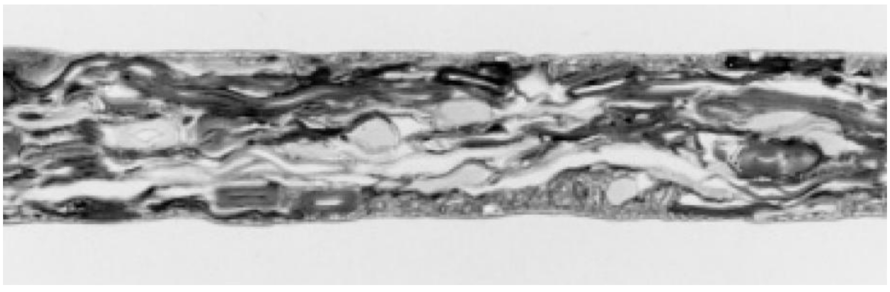

Figure 6 Cross section picture of coated paper /5/

4.1.1 Effects of coating on paper properties

As mentioned in the previous chapter, coating fills the cavities and covers the base paper surface. The result is a significant improvement in smoothness of paper. Besides this, the coating has the following consequences compared with uncoated papers

- ink absorption decreases
- surface strength increases and dusting decreases
- gloss increases
- opacity increases
- brightness increases
- Mechanical strength of paper decreases, when coated and uncoated papers are compared at the same basis weight.

The extent of these changes depends on the type and amount of various components in the coating as well as coating equipment and finishing treatments. But, one must bear in mind that the base paper properties are crucially important to the properties of the final product. The rule of thumb is that 80 % of the coated paper properties are dependent on the properties of the base paper. Coating emphasizes the defects of base paper rather than hides them /5/.

4.1.2 Coating quality and process runnability

Coating quality and coating process runnability are two important things in the economical and competitive manufacturing of coated paper. Runnability means the smoothness of the coating process. It includes the easiness to reach required coating quality and easiness to run coating process without web breaks. Bad runnability leads to inefficient and uneconomical production /5/.

Coating quality involves for example smoothness, gloss, and ink absorption. These quality factors are dependent on the composition of coating colour, coating structure as well as coating coverage. Coating coverage indicates how well the coating is able to hide the base paper under it /5/.

The runnability of coating colour is affected by several factors (figure 7). The main factors that are influencing runnability are solids content, rheology and water retention /5/.

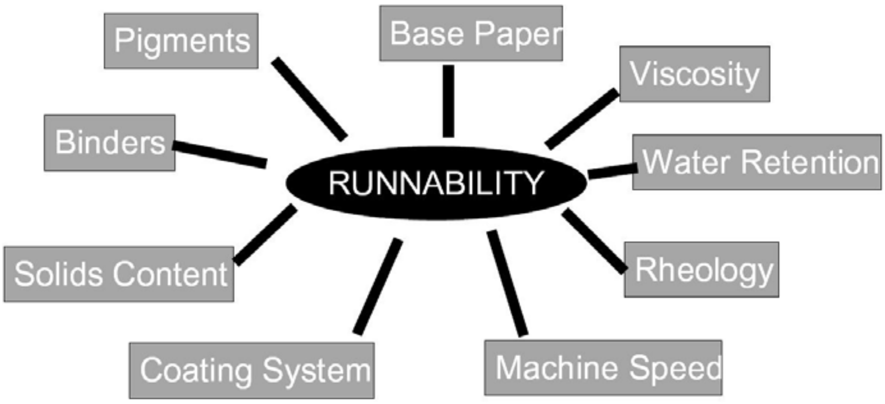

Figure 7 factors influencing runnability /5/

The same factors are involved also for quality. Thus, the word "runnability" in the figure 7 can be replaced by the term "coating quality". Figure 7 illustrates very well how many factors are affecting on the coating process and properties of coated paper. Besides those factors, there is variation inside each of them. All these many variables cause paper coating to be a challenge /5/.

4.2 Coating process at the mill

Coating process is typically divided into four different phases in a machine direction. Those phases are as follows:

- application of the coating colour onto the base paper (OptiCoat Jet)
- metering of the coating (AutoBlade)
- drying of the coating (gas heated IR-dryers, drying cylinders)
- finishing (softcalender)

On PK1, the phases above are done by equipment mentioned in parentheses. Following chapters focus on these equipment and different phases are gone through from their point of view.

4.2.1 Application of coating colour

A term "application of coating colour" is a process where the base paper is covered by coating colour. This can be done in many ways. One very typical method is jet-application (figure 8). In the jet-application, the required amount of coating colour is transferred onto the base paper surface through the nozzle. Applied amount of coating colour on the base paper is adjusted by pumping rate. There is no contact between application header and base paper, that's why it is as called non-contact application method /5/.

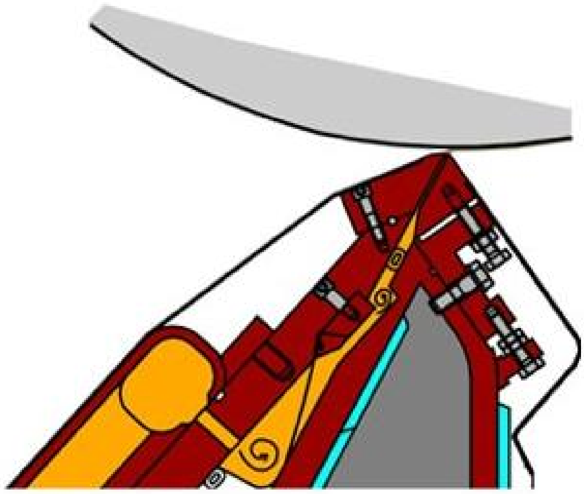

Figure 8 Operating principle of OptiCoat Jet /6/

4.2.2 Metering of coating colour

In blade metering, the blade is pressed against the paper and the desired amount of coating remains on the base paper. It must kept in mind, that the amount of coating which remains on the base paper is not the same thing than coat weight. This is because after metering coating still retains excess water which has to be removed by absorption and evaporation. When coating achieves its final moisture, we can talk about coat weight. The unit of the coating amount and coat weight is grams per square meter (g/m^2) /5/.

The target of the metering is to adjust the desired amount of coating uniformly across the web. It is peculiar for blade metering, that thickness of the coating layer is not even. Figure 9 illustrates how the compressibility of the base paper affects on the coating layer thickness /5/.

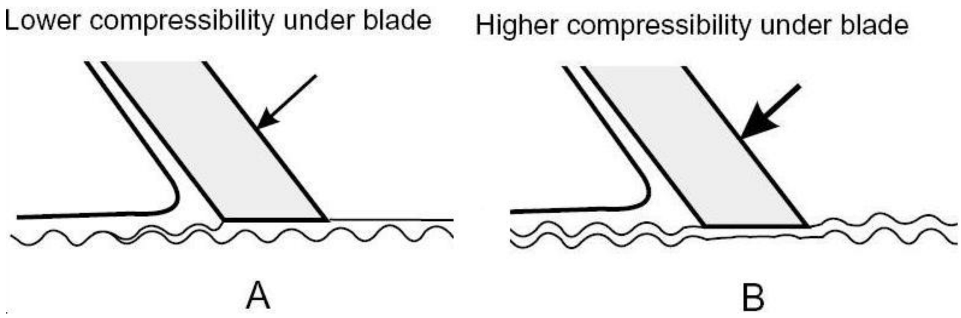

Figure 9 Levelness of blade coated surfaces and the impact of blade load and compression /5/

4.2.3 Drying of coating

The drying phase follows the coating colour application and metering. Coating dries by drainage into the base stock and by evaporative dryers. The purpose of drying is to remove the excess water from coating by using the right drying strategy. Coating is dry enough when coating is touch-dry i.e. coating can touch rolls and cylinders without sticking to them. The excess water can be evaporated in many ways, most common methods are electrically and gas heated IR-dryers, air dryers and drying cylinders /5/.

Gas heated IR-dryers

IR-dryers are very typical dryers for a coat drying. Reason for that is a small space demand. In some cases IR-drying has also advantages in the form of coating quality. Because it is possible to direct the radiation at a limited area, profiling in the cross direction is an area of remarkable utilization. Because there is no contact between web and dryer, it makes IR-dryers ideal for initial drying of wet coating before it comes into contact with cylinders /5/.

Typically IR-dryers are installed as first dryers after the coating station. Their function is to increase the web temperature to the level where fast dewatering makes quick consolidation of the coating colour possible. Web temperature has also some effect on the coating quality, so fast heating is desirable also from this point of view /5/.

Advantages of using IR-dryers

- their small size makes possible to install dryers near the coating station
- they are effective in small spaces
- they are quickly heated to the operating temperature, e.g. after web breaks

Disadvantages of using IR-dryers

- low efficiency
- emitters have a short life time
- maintenance costs
- fire risk during web breaks
- difficult to adjust drying rate
- their high power density restricts the amount of rows it is possible to use without quality problems

The composition of the web defines how large a portion of the radiation is absorbed to the web. As figure 10 shows, it is typical that radiation of wavelengths 2-6 mm is absorbing into coated paper. Water has two absorption maximums at wavelengths of 2.95 and 6.1 mm, and the fibres are absorbing radiation with wavelengths between 3 and 8 mm /5/.

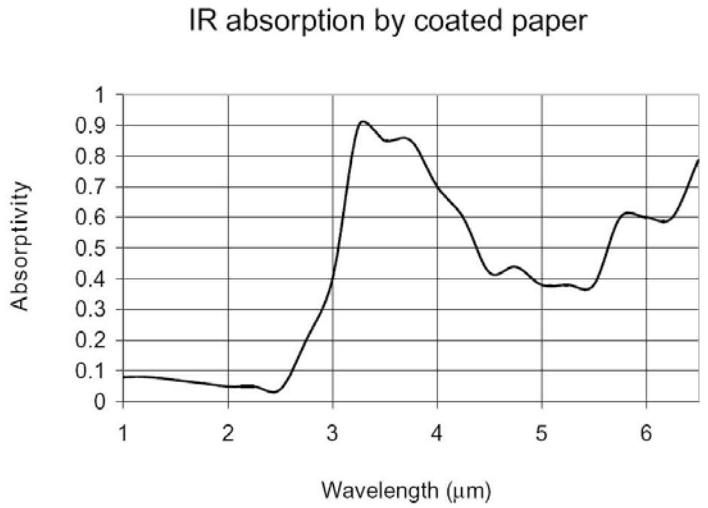

Figure 10 Spectral properties of a coated LWC paper /5/

The burner usually has a circulation air system, which collects hot combustion products and evaporated water. Figure 11 shows the principle of the system. Combustion products contain water vapour and carbon dioxide. Water and carbon dioxide both absorb thermal radiation, therefore, removing them from the space between the radiator and the web will increase the drying efficiency /5/.

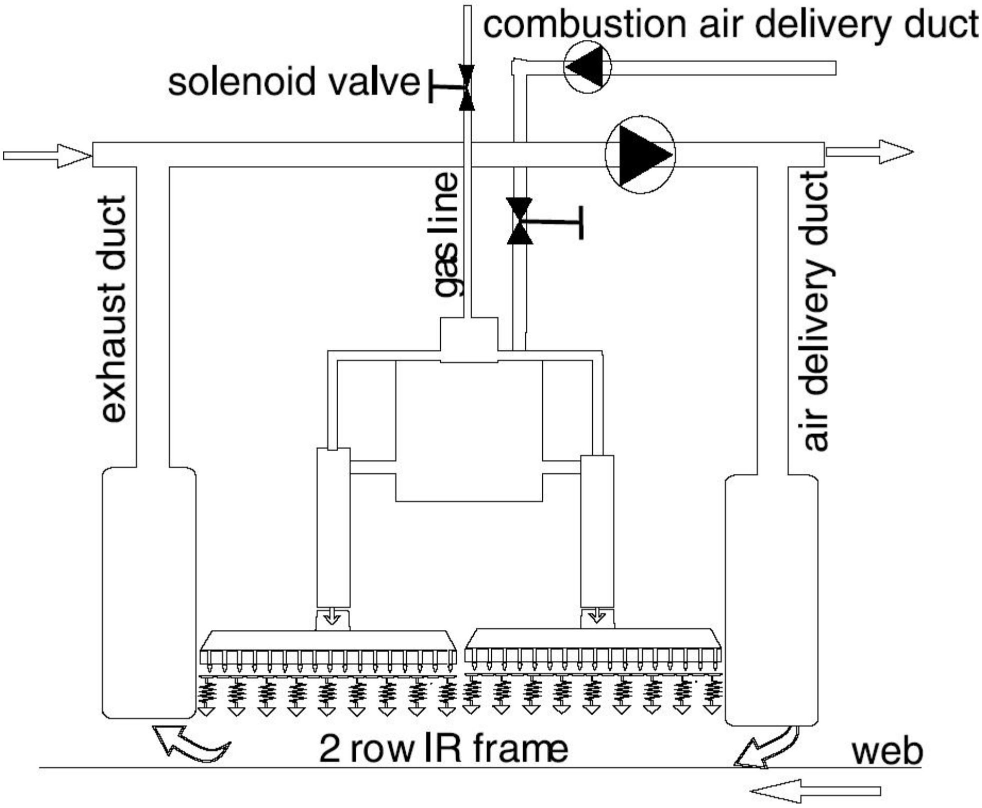

Figure 11 Principle of a gas IR-dryer /5/

Air drying

The operating principle of air dryers is to dry coating by hot air. Air can be heated in two ways, both, gas and steam heated dryers are widely used. Gas heated air dryers are more powerful than steam heated. When gas heated dryers are reaching air temperature as high as 450 °C, steam heated (overpressure about 10 bar) are operating at temperature level below 200 °C /5/.

The principle of air drying is to blow hot air against both sides of the paper from several rows of nozzles inside the drying units. Air dryers used in coating machines can be divided into a two categories: air flotation dryers (figure 12) and single-sided air impingement hoods (figure 13). In the case of an air flotation dryer, the web is supported from both sides by air jets or air cushions. Special flotation nozzle constructions have been developed in order to maintain good web stability and efficient heat transfer /5/.

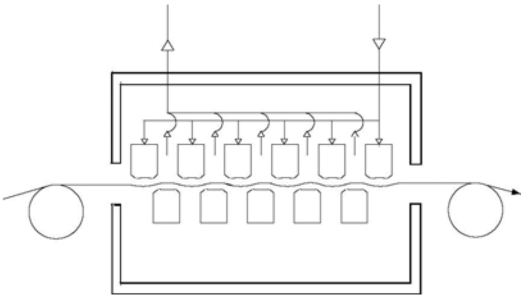

Figure 12 Schematic diagram of an air flotation dryer /5/

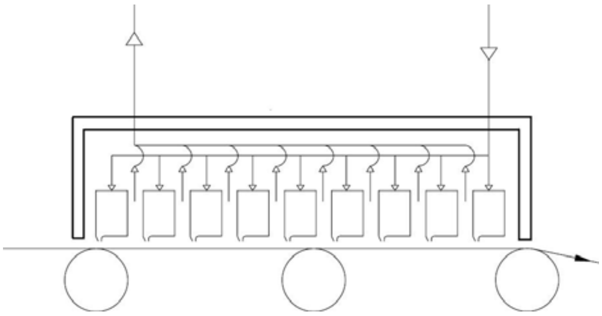

Figure 13 Impingement dryer, web supported by rolls /5/

Single-sided impingement dryers are advantageous when the drying of the uncoated side is not desirable. The web is often supported from the opposite side with supporting rolls. Metso Paper has developed one this kind of dryer called PowerDry Plus. It is designed for drying of coated boards /5, 7/.

Benefits for replacing IR-dryer by PowerDry Plus

- higher operation efficiency
- higher evaporation capacity
- maintenance-free
- easier to adjust drying rate
- less fibre roughening, less water into the base paper, because water is evaporated upwards through the coating
- higher and more uniform binder concentration in the top of the coating, higher picking resistance and less mottling
- does not warm base paper, just coating is warmed

Cylinder drying

Cylinder drying can be used when coating layer can be in contact with drying cylinders i.e. gel point is achieved and coating layer is touch-dry. Therefore, the cylinder section is the last drying phase and the aim is to adjust final moisture of the paper. Cylinder sections used for finishing of coating are relatively short, including typically just 2 to 6 cylinders /5/.

4.2.4 Finishing of coating

Softcalendering is a very typical option for finishing of coated boards, because it does not decrease bulk as much as hard nip calender does. The purpose of calendering is to give the final smoothness and gloss for a coated paper. Higher nip load increases smoothness and gloss, but on the other hand e.g. thickness, stiffness, and opacity decrease when nip load increases /9/.

Process variables in the softcalendering process are as follows

- linear pressure
- running speed
- hot roll surface temperature
- soft roll cover material
- steaming
- soft roll position (against top or bottom side of the web)

5 COATING CONDITIONS AND THEIR EFFECTS ON DRYING

The purpose of coat drying is to evaporate excess water from coating. Dry solids content has to be increased to the level where coating layer does not stick to roll or cylinders. The input energy of dryers is consumed in the following ways

- heating the base paper and coating colour
- heating the evaporated water to the evaporation temperature
- evaporate water
- energy losses that are dependent on the efficiency of drying process

5.1 Effects of coat weight and dry solids content on drying

Coat weight and dry solids content of coating says the amount of excess water which has to be removed that aimed dry solids can be achieved. Equations below shows how the coat weight and dry solids content are related with each other

$$m_w = m_c \left(DSC_{tar} - DSC_c \right) \tag{1}$$

m_w = the amount of water to be removed per square meter [g/m^2]
m_c = the amount of coating per square meter [g/m^2]
DSC_{tar} = target dry solids content of coating [%]
DSC_c = prevailing dry solids content of coating [%]

The amount of coating can be calculated by using the equation below

$$m_c = \frac{cw \cdot DSC_{end}}{DSC_c} \tag{2}$$

cw = coat weight [g/m^2]
DSC_{end} = final dry solids content of coating [%]

Equation 3 shows how much water has to be removed that target solids is achieved.

$$m_w = \frac{cw \cdot DSC_{end}}{DSC_c} - \frac{cw \cdot DSC_{end}}{DSC_{tar}} \tag{3}$$

$$\Rightarrow m_w = cw \cdot DSC_{end} \left(\frac{1}{DSC_c} - \frac{1}{DSC_{tar}} \right)$$

Figure 14 is drawn based on the equation 3. The idea of the figure is to show the amount of excess water at different dry solids. There are 5 lines which are different coat weights mentioned at the bottom of the figure.

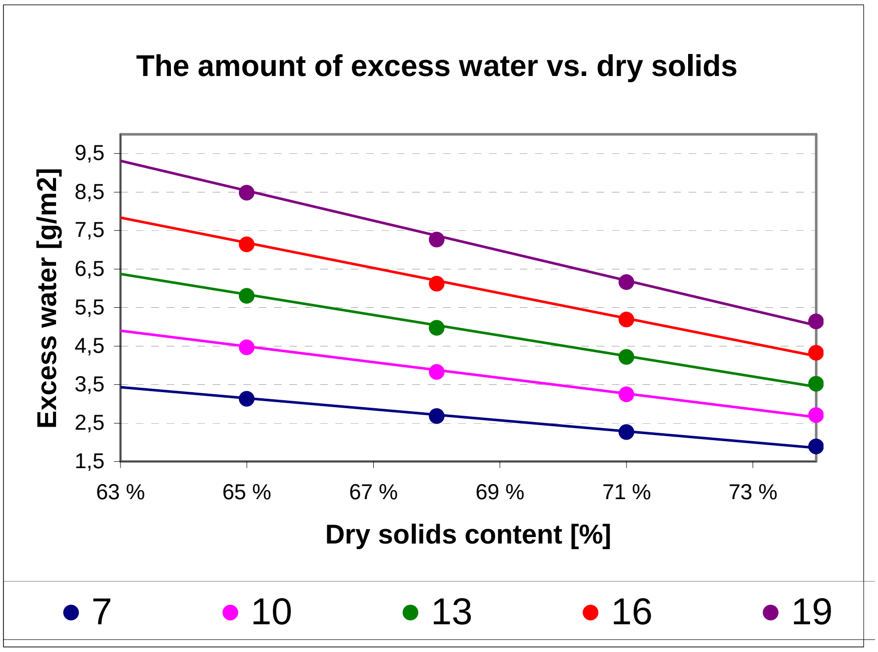

Figure 14 The amount of excess water vs. dry solids content. Target dry solids content is set to be at 83 %.

5.2 Effects of web temperature on drying

Figure 15 shows how the web temperature affects drying. Increased web temperature hastens dewatering and therefore it is one of the most effective process variable in the coat drying process. Figure 15 is based on the trials where coating samples have been scraped from the paper surface 3 m after blade. IR-dryers (pre-dryers) have been on three different power levels. CMC-Clay based coating colour and the base paper has been wood-containing 45 g/m^2 /5/.

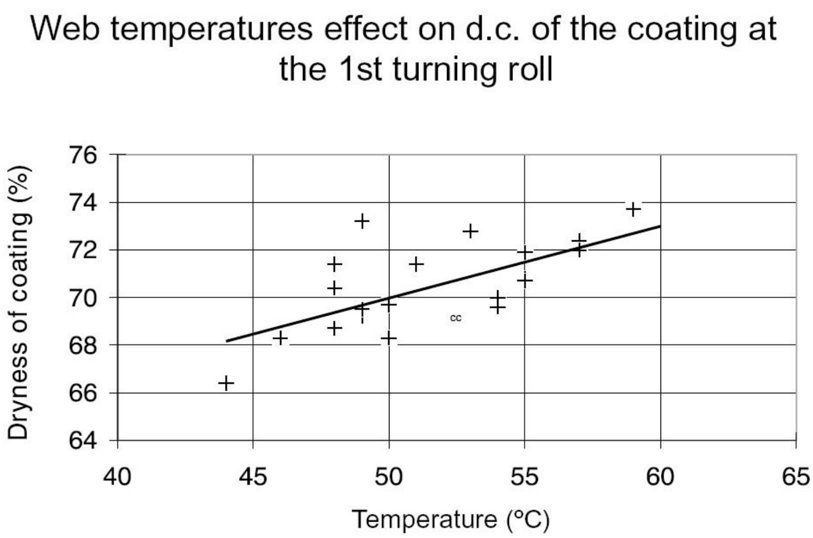

Figure 15 Dryness of coating vs. web temperature /5/

5.3 Effects of machine speed on drying

Machine speed has to kinds of effects in drying. Higher machine speed shortens the time under dryers and that way decreases the evaporation capacity per square meter. Increased machine speed also shortens the time from the metering blade to the evaporative dryers. It means that there is more retained water left when coating reach the evaporative dryers. So, machine speed affects mainly in two ways to the coat drying. Both of the changes are inversely proportional to the coat drying capacity.

Drying energy of the dryers as a function of machine speed can be calculated by the following equation

$$E = \eta \cdot P \cdot t \qquad (4)$$

$$E = \eta \cdot P \cdot \frac{l_{dryer}}{v}$$

where

E = drying energy [J]

η = efficiency of drying process [%]

t = drying time [s]

l_{dryer} = length of the dryer/dryers in the machine direction [m]

v = machine speed [m/s]

5.4 Effects of chosen pigment on drying

The effect of pigments is not actual process variable, but their effect on drying is good to know. Pigment type and pigment particle size distribution (PSD) affects on drying capacity. It is commonly believed that narrow PSD pigments increases energy costs. That belief is based on the fact that coating colours including narrow PSD pigments cannot reach as high dry solids content as coating colours which are including broad PSD pigments. According to Rajala’s studies in his doctoral thesis, for example the change from the broad PSD ground calcium carbonate (GCC) to a narrow PSD precipitated calcium carbonate (PCC) resulted 26 percent energy savings. Also replacing clay by PCC in formulation will require less specific energy to dry. These results were statistical without theories behind them, but the fact is that a narrower pigment PSD has been proven to need less energy to dry /8/.

6 DRYING THEORY AND ITS EFFECTS ON QUALITY

Drying theory and its effects on the quality of coated paper are explained in this chapter. Mottling is a one well known defect what drying can cause if the coating is dried by using an incorrect drying strategy. Drying is also affecting the other quality properties like roughness and gloss.

6.1 Drying theory

When the wet coating layer moves to the dryer section, formation of the final structure of the coating begins. It has been proven in several studies that the drying strategy plays a vital role in the formation of the coating layer structure, and consequently, in the properties of coated paper. The drying strategy in each phase is different and can be clearly linked to the formation mechanism of the coating layer structure. The simplest and the most practical way to visualise the drying process is to divide it to three phases as shown in figure 16. These phases are as follows:

1. Initial drying phase
2. Critical drying phase
3. Final drying phase

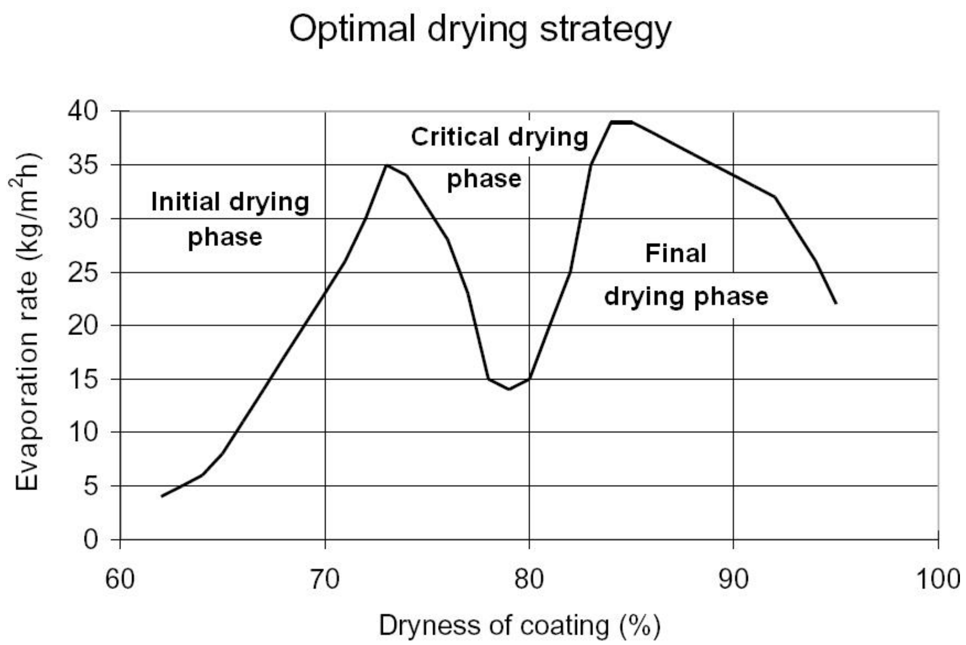

Figure 16 Drying process divided into three phases /5/

Initial drying phase

During the heating period at the beginning of the initial drying phase, energy is transferred to the web. This increases the vapour partial pressure inside the web above the vapour pressure in the drying medium. Evaporation tends to compensate this pressure difference. In this phase, diffusion of vapour starts a remarkable dewatering process. Capillary flow into the base paper starts immediately after the application of coating colour onto the base paper surface. Capillary flows continue during this phase. Increasing the temperature, viscosity decreases and eases the drainage. However, when the thickness of the filter cake grows, water retention improves, and the importance of capillary flow decreases /8/.

In the past, there have been some conflicting theories on the effect of initial drying on the paper quality. However, now it is generally accepted that effective initial drying has mainly a positive influence on the coated paper quality. This is because strong heating of the web during the initial phase accelerates consolidation of coating which is considered to positively affect on the quality. After the heating period, constant rate drying starts /8/.

Critical drying phase

At consolidation phase, the viscosity of the coating layer increases so much that the pigments stop moving. The final pore structure of the coating is developed. Theories how drying affects on mottling are presented in several studies. According to the generally accepted theory, the consolidation phase takes place when the dry solids content of the coating is between 73-85 %. During that phase the end quality of coated paper is very sensitive on drying conditions /8/.

Final drying phase

At the final drying phase, the coating is stabilized. Pigment and binder movements in the coating layer have stopped and the aim of this phase is to adjust the final moisture. Many studies have proved that the effect of this phase on the final quality is minor and drying power can be maximized /8/.

6.2 Mottling

Uneven ink absorption in offset printing is called mottling. Mottling is low contrast and low frequency (0.1-10 mm) printing unevenness (figure 17). Frequency range from 2 to 7 mm is the most disturbing for a human eye. Mottling in linear multicolour offset press, called “back trap mottling”, is a phenomenon where paper absorbs the solvent of the printing ink unevenly. While printing, film splitting and ink setting are dependent on the state of the former ink layer. If the previously printed ink has settled incompletely, splitting of new layer is also incomplete and ink will be transferred to the cylinder. This leaves the ink layer on the paper mottled /8, 10/.

Figure 17 Mottled printing image (Black 50%)

In the majority of studies, it has been suggested that mottled offset print is caused by binder migration which causes uneven binder distribution on paper surface. If coating colour includes starch, evaporation rate at critical phase defines the level of mottle (figure 18). But, the situation changes when coating colour does not include water soluble binders (22), it seems that the effect can be even reverse. So, uneven binder migration seems not to be the basic reason for mottle, although it is commonly believed to be. It is assumed that coating structure formation gives the best explanation for mottle /8/.

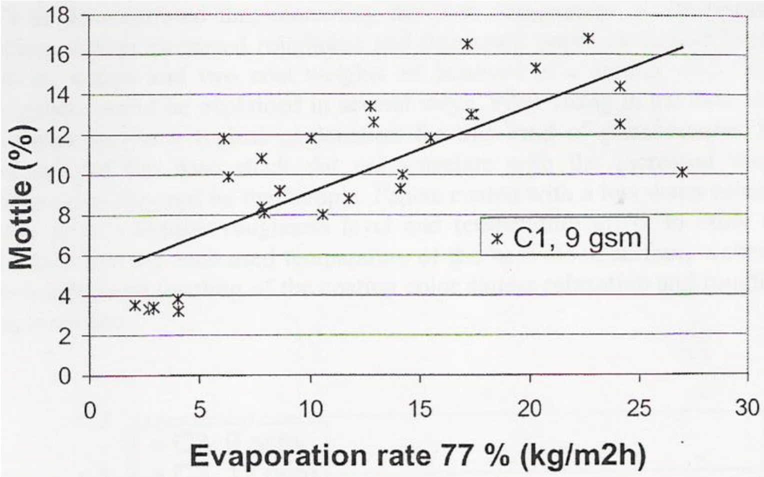

Figure 18 Mottle vs. evaporation rate at 77 % solids /8/

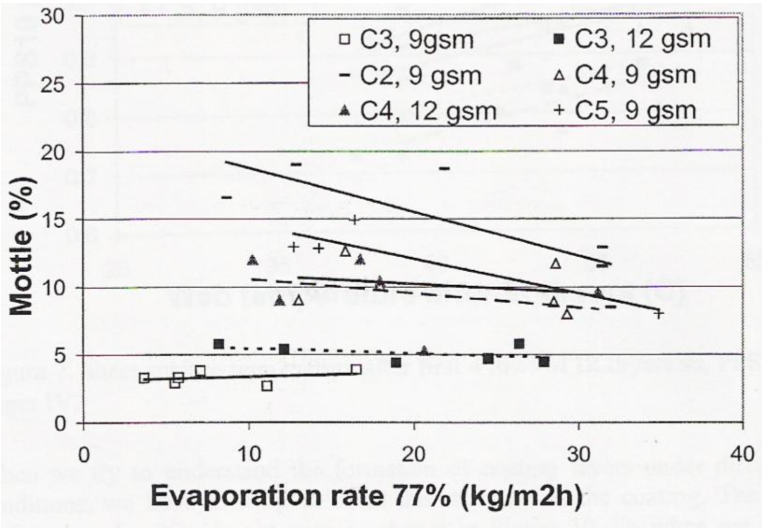

Figure 19 Mottle vs. evaporation rate at 77 % solids /8/

In practice, mottling appears when coat weight variation in the surface direction is so wide that some parts in the coating layer consolidate quickly after the blade by drainage and the rest of coating later at drying section. Coating which is quickly consolidated by drainage, get more porous structure than coating which is consolidated at dryers. Porosity variations in the coating cause variation in the ink-setting time. Result is a mottled print /8/.

Mottling is affected by more than one factor, and because of the complexity of the formation of mottling, it has not been possible to build a comprehensive theory of its origin. It is clear that base stock formation and ink absorptivity variation are the factors affecting mottling. Coating colour pigment-binder system defines coating colour's sensitivity for mottling. Size distribution and form factor of pigment, interaction between pigment and thickeners, and the behaviour of latex and water soluble binders are factors affecting the structure of coating, and thus coating colour's sensitivity for mottling /8/.

6.3 Roughness and gloss

There are several studies made which are showing that web temperature has a clear effect on the roughness and gloss. Increasing the web temperature during drying increase roughness and decrease paper gloss (figure 20 and 21). The increased roughness can be explained in several ways. Typical explanation for that is a fibre rising in the base stock, this is the theory commonly believed. But in the latest studies it was noticed that paper roughness does not correlate with the drainage into the base stock (figure 22), so the explanation may not be that simple. It is assumed that the increased temperature of the base stock surface, wetted during the application and levelling of the coating causes relaxation and roughening of the paper surface /8/.

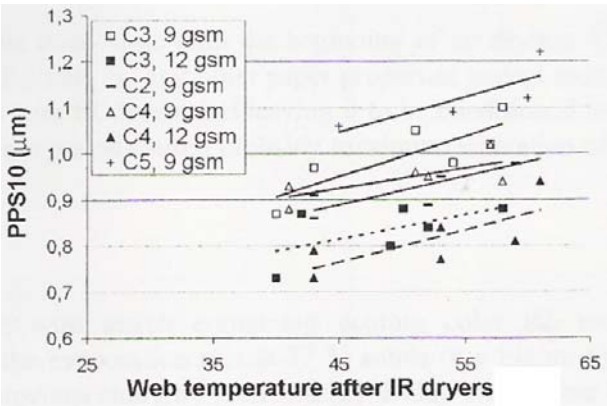

Figure 20 PPS10 vs. temperature after IR-dryers /8/

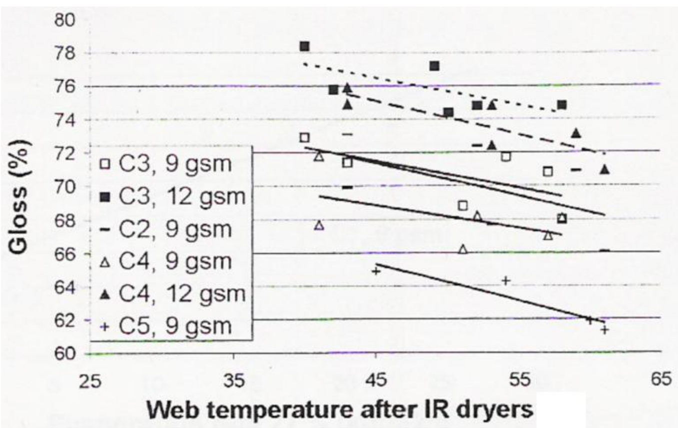

Figure 21 Gloss vs. temperature after IR-dryers /8/

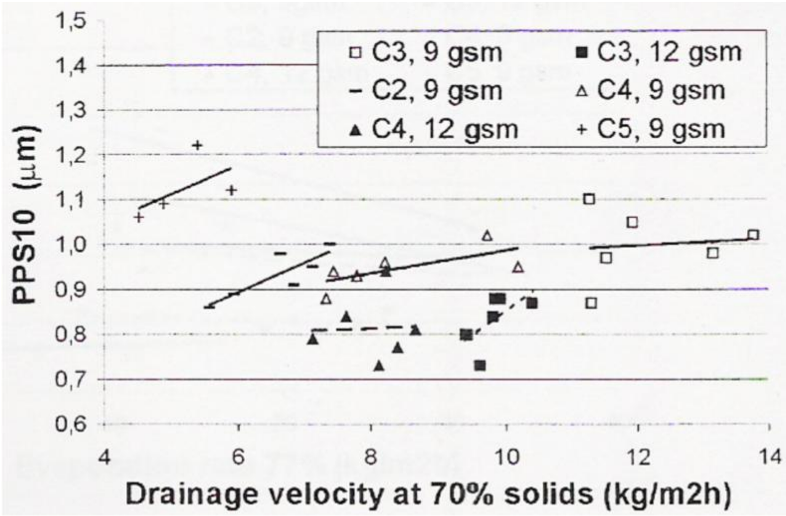

Figure 22 PPS10 vs. drainage velocity at 70 % solids /8/

Increased coat weight can also explain the increased roughness in some cases. Increased coat weight does not always improve smoothness, it can also have a negative effect. This is explained by shrinkage of the coating during drying. It is noticed that coating colour which includes latex, calcium carbonate and clay, shrinks remarkably during drying. When there is more latex, there is also more flexibility in the coating structure and therefore also more shrinkage. So, coating layer with higher coat weight shrinks more and therefore smoothness can get worse. Gloss is dependent on the micro-roughness of the coating surface, therefore, there can be also a situation that increased coat weight improves gloss, but makes smoothness worse /8/.

6.4 Summary of drying strategies

The theory how drying affects the coating layer structure is based on the belief that there is certain critical drying phase which is probably located between first critical concentration and second critical concentration i.e. solids content of the coating is between 73 and 83 %. Evaporation rate should be low at this phase to avoid binder migration. This theory has been tested at different pilot and production machine trials. The High-Low-High theory is valid in some cases. But, when water soluble binders are not used or when the delay time between application and drying is short enough, the quality formation mechanism changes and even extremely hard drying conditions gives better results i.e. High-High-High strategy can be used /8/.

Different studies differs from each other and, as mentioned before, correct drying strategy depend on the layout of the coater, coating colour composition and the base paper properties. However, guidelines for drying are clear /5, 8/.

Guidelines for drying

- Initial drying has to be started quickly after the blade and it has to be effective.
- The existence of a certain critical phase is accepted.
- Final drying has a minor effect on quality, the drying rate could be maximized.

Pay attention also for these matters

- High web temperature after coating increases paper roughness and decreased paper gloss.
- When coating colour contains latex as a major or sole binder, mottle is caused by uneven coating structure formation in the surface direction.
- Because coating shrinks during drying, higher coat weight does not always mean better quality, increased coat weight can result in even worse quality.
- Mottling values are affected by drying and correct drying strategy improves mottling values remarkable.
- In some cases coater layouts restrict the capabilities to follow correct drying strategies. Too long delay before evaporative dryers lead to situations where some parts of the coating are consolidated by drainage before proper drying. This kind of situation hide the impacts of different drying strategies and make it difficult to analyse the effect of drying.
- Coat weight variation is often so wide, that when using the average coat weight as a variable in drying studies, it can lead to questionable conclusions.

7 COAT WEIGHT AND DRYING POWER CONTROL

7.1 Drying power control with existing equipment

During the trials it was noticed, that an accuracy feedforward control for a coat drying is impossible to develop with existing equipment. A poor controllability of the IR-dryers is limiting the possibilities too much. Drying power control is possible to do by adjusting the combustion air pressure or by changing the number of heated IR-rows. The idea of a combustion air pressure control is adjusting the temperature of a thermal radiation. It does not affect on gas consumption. Because the effect of combustion air pressure on drying power is not clear, and because there is always some variation in process variables, its effect on drying power is too difficult to measure. It was decided that the best way to control drying power is keeping the combustion air pressure at the maximum and change the number of heated IR-rows.

7.2 Possibilities with an on-line gel point measurement

Honeywell has developed an on-line measuring device called GelView (figure 23). It is measuring dry solids content from the coating along the drying section. It makes it possible to have a feedback control for a coat drying. Its operating principle is based on the surface reflectivity of the coating, which is directly related with dry solids content of the coating. A typical installation consists of six sensors. First sensor is usually located before the first dryer, followed by sensors between IR-drying units, and inside or between air dryers /11/.

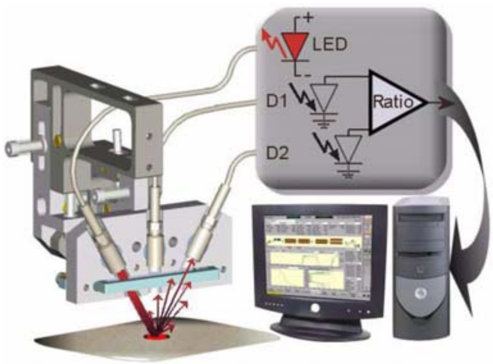

Figure 23 System overview and sensor schematic /11/

New drying instructions should reduce over-drying and that is why benefits of GelView are not so remarkable for now. But, the situation changes if one IR-unit will be replaced by an air dryer. It has been proved in practice that without an automatic control, operators over-dry the coating to avoid "painting" the machine. If IR-unit is replaced by PowerDry Plus, then its full power range should be reachable to avoid both over-drying and wasting of energy. Drying power of PowerDry Plus is adjusted by chancing the air temperature and velocity. It has a gas heater which heat just that much air as it is needed. So, if there is no automatic power control, operators will probably use too high drying powers.

Benefits of GelView

- Make it possible to have a feedback control for a coat drying. → less over-drying → energy saves
- Make it possible to follow correct drying strategy. → better quality
- Make it possible to calculate dryers' real drying rates and to avoid too harsh drying conditions. → better quality

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