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Bachelor thesis

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OPTIMIZATION OF THE PILOT MACHINE INFRARED DRYER

Thesis Supervisor Arto Nikkilä (MSc)
Commissioning company TAMK Laboratorio
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TIIVISTELMÄ

Päällystetyn paperin kuivaus on monimutkainen prosessi, jossa väärällä kuivatusstrategialla voi pilata koko lopputuotteen. Kuivatus on aina syytä optimoida energian kulutuksen minimoimiseksi ja hyvän laadun varmistamiseksi.

Työni tarkoituksena oli optimoida paperilaboratorion infrapunakuivaimen toiminta ja selvittää sen vaikutuksia paperin poikkisuuntaiseen kosteusprofiiliin sekä paperin pinnan lujuuteen. Työtä tehdessäni suoritin kaksi koeajoa, joiden aikana muutin infrapunakuivaimen tehoa sekä etäisyyttä päällystettävästä paperista.

Paperin kosteusprofiili määritettiin ottamalla näytteitä päällystetystä paperiradasta. Otetut näytteet punnittiin, jonka jälkeen ne kuivattiin uunissa. Kuivauksen jälkeen näytteet punnittiin uudelleen. Paperin kosteusprofiili oli mahdollista määrittää näytteiden painon muutoksen avulla. Saadut tulokset osoittivat, että infrapunakuivaimella on mahdollista vaikuttaa paperin kosteuteen tehokkaasti sekä tasata mahdollisia kosteuseroja.

Paperin pinnanlujuuden määrittämiseen käytettiin IGT mittalaitetta, joka simuloi paperin painatusta. IGT laitteella on mahdollista käyttää erilaisen viskositeetin omaavia musteita. Itse käytin testeissäni mustetta, jolla oli matala viskositeetti. Tulokset jotka saatiin IGT mittalaitteella osoittivat, että tehokkaalla infrapunakuivatuksella on mahdollista jähmettää päällystetyn paperin pinta hyvin sekä parantaa paperin pinnan lujuutta.

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ABSTRACT

The drying of coated paper is an extremely complicated process where wrong drying approach is enough to ruin the final product. The purpose of drying is to remove the water that is absorbed to the base paper efficiently. Usually the drying is done with separate drying units after every coating unit.

The aim of this thesis was to optimize the infrared drying in the paper laboratorys pilot machine and find out the effects on the moisture profile and surface strength of the coated paper. The test runs were done by changing the distance of the infrared dryer from the coated paper and drying power of the infrared dryer.

The moisture profile of the paper was defined from the samples that were taken from the coated paper. These samples were weighed before and after drying them in the oven. Moisture profile was defined from the weight change of the samples.

Surface strength tests were done with the IGT tester which simulates printing. With the IGT tester it is possible to measure the printing speed where the picking of the surface begins. It is also possible do the tests with inks that have different kind of viscosities. The ink that was used in tests had low viscosity.

With the infrared dryer it is possible to get more even moistures CD profile than without it. Best CD profiles were gotten when the drying power of the infrared dryer was high and it was near to the paper web. The surface strength of the coated paper seemed to follow the heating power of the infrared dryer.

FOREWORD

I would like to thank my thesis supervisor Arto Nikkilä for all the help that he has given me during writing this bachelor thesis. I would also like to thank Tiina Kolari-Vuorio at the paper laboratory because she had always time to answer my questions and help me every way she could.

Arto Takanen

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EXPLANATIONS OF ABREVIATIONS AND CHARACTERS

cm	centimetre
µm	micrometer
bar	pressure unit
CMC	Carboxy Methyl Cellulose
PCC	Precipitated Calcium Carbonate
GCC	Ground Calcium Carbonate
PVA	Polyvinyl alcohol
IR	infrared
SB-Latex	Styrene-Butadiene latex
LWC	Light Weight Coated
OBA	Optical brightening agents
ÅA-GWR	Åbo Akademi Gravimetric Water Retention device

1. INTRODUCTION

Coating color is a mixture of different substances that have different tasks. The main raw materials of coating color are pigments, binders and additives. All these materials are mixed with water and combined to one slurry. Pigments and water is applied on the surface of the paper and the extra coating color is metered from the paper with a blade. The target in coating is to get even surface and this way to improve the appearance of the paper and achieve the desired properties on the paper surface so, that it is suitable for end use. The most important aspect is that the paper has good printing properties and appearance. Paper can be coated one, two or three times to get high quality papers.

Drying of the coated paper starts right after coating. The drying of the coated paper is done by using infrared dryers, airborne web dryers and drying cylinders. Typically infrared radiators are installed as the 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 color possible. Also the temperature of the web has some effect on the quality of the coating, so fast heating is desirable also from this point of view. The aim of this thesis was to find out the effects of the drying to the moisture profile and surface strength of the coated paper.

2. COMPONENTS IN COATING COLOR

2.1 Pigments

Pigments are used cover the fiber surface and change optical and absorption properties of the paper. The shear of pigments from dry matter content of coating color is 75-95 %. The quality and the properties of the coating color depend on the pigments particle shape and size distribution. The particle size distribution of the coating color should be quite steep to ensure a good coverage /4; 8/.

Kaolin is a widely used coating pigment. Coating kaolin normally contains between 50 and 99 % of their weight in particles that are less than 2 micrometers in size. The ISO brightness is typically in the 80-90 % range. Kaolin is used in coating colors as either the only pigment or together with various other pigments /4/.

Kaolin is relatively easy to disperse in water to a solids content of 62-72 %. Its small particle size and plate-like particle shape give kaolin coatings good coverage capacity and in supercalendering, a high gloss and good smoothness /4; 6, p.73-79/.

The calcium carbonate ($CaCO_3$) used in coating can be GCC (Ground Calcium Carbonate) or PCC (Precipitated Calcium Carbonate). The main difference between GCC and PCC is particle size and shape. Ground calcium carbonate products are rounder than kaolin. By precipitating calcium carbonate, the particle size can be controlled and the particle shape is usually rod-like or needle-like. Calcium carbonate brightness is normally higher than that of kaolin (90-95 %) /4/.

Calcium carbonate improves paper strength compared to kaolin at the same binder level. Calcium carbonate is easily dispersed in water. With the exception of the finer precipitated products, the viscosity of the calcium carbonate slurry is lower than that of kaolin slurry at the same solids content. Calcium carbonate needs more dispersion agents than kaolin. Compared to kaolin, calcium carbonate can improve coating brightness as well as increase coating layer porosity and printing ink absorption /4; 6, p. 100-101/.

There is also some other pigments that are used in coating but not so often than kaolin and calcium carbonate. Pigments like gypsum, talc and titanium dioxide help paper producer to achieve needed properties in coating but many times these pigments are too expensive or not so suitable for the coating process.

2.2 Binders

Another important component in coating colors is binders. The binder component of a coating color usually consists of a combination of binders, most commonly two. The binder amount depends on the printing method. The lowest amounts are used in rotogravure coatings and highest in offset coatings. The binder demand in offset printing is so high, because the surface strength of the paper has to be good. When paper is printed with rotogravure it does not need so many binders because the splitting forces between the printing plate and the paper are much lower. A binder can also affect the viscosity and flow properties of the coating color /3, p.188; 4; 6, p.189-190/.

The amount of the binders from the dry matter content of the coating color is 5-25 %. The main purpose of binder is to bind pigment particles to each other and to attach coating into the base paper. So it acts as glue in coating /3, p.188/.

Lateces are the main component of the binders. Because lateces have poor water retention capability they always need a co-binder or thickener. Commonly used Co-binders or thickeners are starch, CMC and synthetic thickeners.

There is different kind of lateces that differ to each other. One of the lateces is Styrene-Butadiene latex (SB-Latex). It gives the paper a high surface strength, good water resistance and dense surface structure but it has a higher yellowing tendency than other lateces. Polyvinyl acetate lateces give good brightness and porous surface structure. It has low tendency for mottling but one weakness is lower surface strength compared to SB-latex and Acrylate lateces. Acrylate lateces give also good brightness and dense surface structure but its surface strength is slightly lower compared to SB-latex /3, p.188-189; 4; 6, p.197-214/.

Starch is a most common water-soluble binder which is sensitive to water. It brings stiffness to the paper which is important for runnability. It is cheap and widely used in coatings for lightweight coated papers /8/.

CMC is a water-soluble co-binder and gives several important properties to the coating color. It is added to the coating a solution in water. It controls the rheological properties of the color and gives good runnability for the coating unit. The strong hydrophilic characteristic of CMC makes it an efficient water retention agent. CMC is a good carrier of optical brighteners and it also acts as a lubricating agent on the coating blade /3, p.188; 8/.

Synthetic co-binders and thickeners are both used for the same purpose in coating colors. They adjust the rheological properties and water retention. Various products have different effects; they might affect low shear viscosity more than high shear and have different effect on water retention /6, p.219-226/.

2.3 Additives

Besides pigments and binders, a coating color usually contains various additives, which have different functional roles. Coating additives are a group of coating color components that fulfil various functions in coating colors or coating layers. Some of the most common additives are pH control aids, dispersants, lubricants, optical brighteners and hardeners. The amount of an additive is usually below only 2 % of the coating colors total solids content /4; 6, p.289/.

Lubricants are used in the coating colors to improve the runnability of the coating color by reducing the friction between the machine and coating color, and also the friction between the base paper and the coating unit. Lubricants help to avoid, for example, scratches in the coating. They also give longer lifetime to the coater blades. The most commonly lubricant that are used is calcium stearate /3, p.189; 6, p.292/.

The purpose of dispersing is to make slurry which does not contain any agglomerates and where only primary particles are present. Dispersants keep primary particles evenly distributed in water, and the system stays stabile for a certain length of time. All the external surface of pigment particles must come into contact with water. Air must also be displaced from the internal surfaces between pigment particles in agglomerates /6, p.305-307; 8/.

In offset printing the paper surface will be contacted with water. If water soluble binders or additives have been used in the coating color they have to be treated with a hardener. It makes the water soluble binders and additives more resistant to water and it gives better picking resistance to the coated paper /8/.

The brightness of a coated paper can be increased by using optical brightening agents (OBA). Optical brighteners absorb light in the ultraviolet region and emit it in blue and green region. To work OBA always needs a carrier; usually water-soluble binders like CMC, for this purpose /8/.

3. PRINCIPLE OF PIGMENT COATING

3.1 General about coating

Different methods to coat paper has been developed. The most commonly used coating method is blade coating. In addition to blade coaters, coating can also be done by using film transfer coaters, air brush coaters or spray coaters. Coating can be done by on-machine coating or off-machine coating /4/.

The most important tasks for the coating station are to provide coating color on the paper uniformly and to adjust the coat weight in the desired range under given conditions. The whole coating process can be divided into three different phases:

- First coating color is applied to the paper with application unit.

- After that there is certain dwell time between application and metering.

- Finally coating color is metered with blade, rod, or air jet.

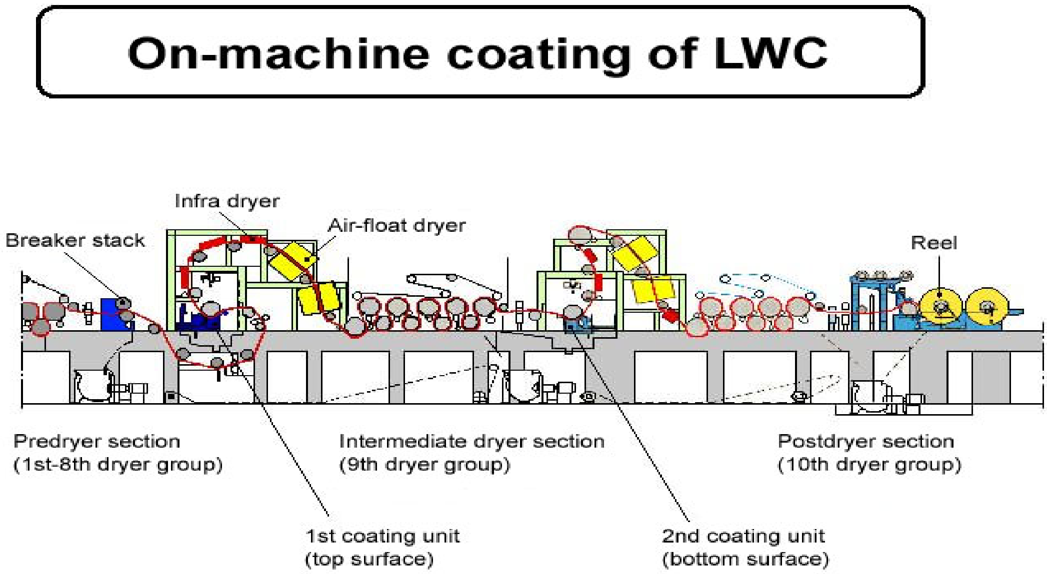

Figure 1 On-machine coating of LWC /4/

3.2 Roll applicator

The roll applicator coating head has two rolls with different diameters. Both rolls are motor-driven and rubber-covered. The coater backing roll with the larger diameter supports the paper web during the coating process. The roll applicator is located underneath the backing roll. In applicator roll application the coating color is conveyed from a roll rotating in a color tank onto the bottom surface of a paper web suspended by a backing roll. The applicator roll rotates typically at a speed of only 15-25 % of the machine speed. The gap between the applicator roll and backing roll is usually 0.5-1.5 mm. Because of the narrow gap between rolls there is a high pressure impulse in the nip during the application and color penetrates deep into the base papers porous structure /6, p.415-423/.

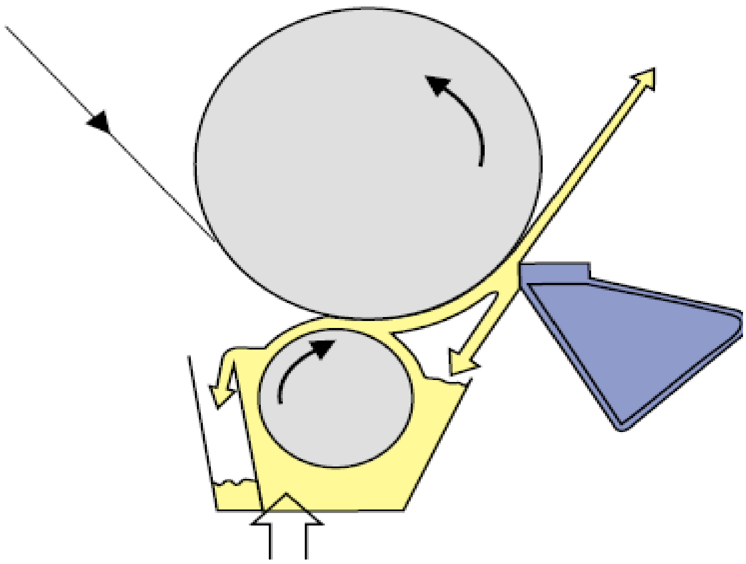

Figure 2 Principle of roll applicator /6/

3.3 Metering unit

After a certain dwell time, coat weight is adjusted by metering with a blade. There are two different blade-metering processes. A high-angle blade process coating typically uses steel blades at angle 25-50°. High-angle blades are commonly used on fast machines for small to medium coat weights. A low-angle blade process normally has a tip angle of 0-15°. Low-angle blades are commonly used in slow machines at medium to heavy coat weights /6, p.442-443/.

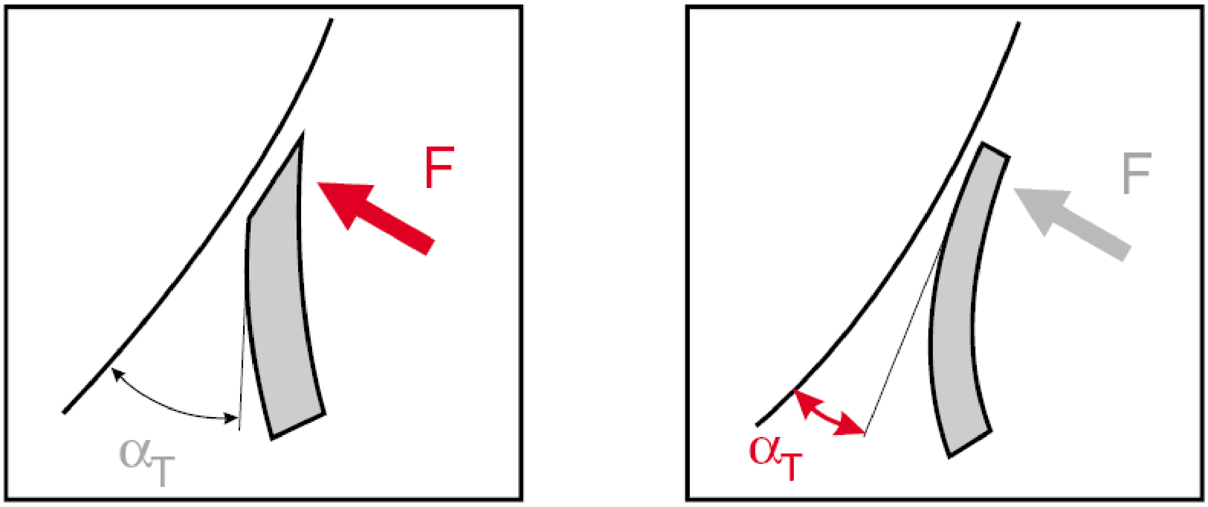

Figure 3 High-angled blade and low-angled blade /6/

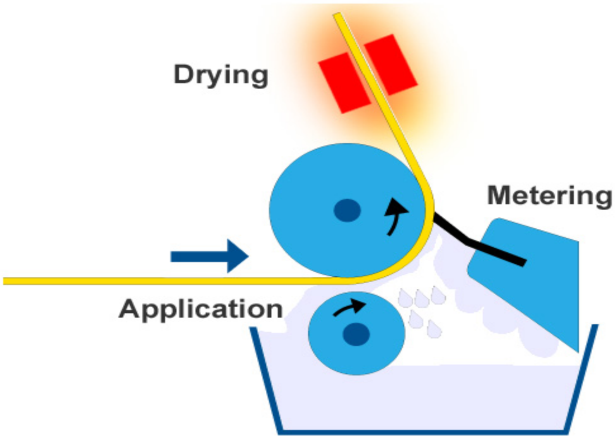

Figure 4 Principle of blade metering unit /4/

4. DRYING OF THE COATED PAPER

4.1 Drying

The drying of coated paper is an extremely complicated process where wrong drying approach is enough to ruin the final product. The purpose of drying is to remove the water that is absorbed to the base paper. Usually the drying is done with separate drying units after every coating unit. There are three common drying methods that are used: infrared drying, air drying and cylinder drying.

Often the first drying units are infrared (IR) radiators. After the IR dryer, there is an air dryer and finally, cylinder dryer.

The solids content of the coating color should be as high as possible, because the dewatering consumes a lot of energy. Increasing the solids content of the color, however, limits coating head runnability and the quality of the coated paper.

When the coated paper is dried it is possible to have an effect to the production economy, quality and the properties of the coated paper, like surface strength and printing ink absorption /4/.

4.2 Infrared dryers

In infrared drying, thermal radiation serves as the heat source. When radiation encounters another material layer, part of it goes through it, part is reflected back and part is absorbed into the layer itself.

By using a back reflector it is possible to improve the efficiency of the drying, because transmitted radiation can be partly reflected back to the web. One factor that also affects to the efficiency of the radiator and the proportion of the total energy which is absorbed by the web is the basis weight /4; 6, p.543-545; 9, p.98-99/.

Infrared drying is used almost exclusively for the drying of paper coatings. The infrared drying achieves a fast solidification of the coated surface and it can improve the quality. The infrared radiation that is got from the radiator is found at a wavelength of 1 -10 μm on the electromagnetic spectrum. The IR dryers are also used for improving the moisture profile by boosting the drying of wet areas /4; 6, p.543-545; 9, p.98-100/.

In drying, it is important to absorb the generated water vapor or to blow it away, because otherwise it will decrease the drying efficiency. The steam that is prevailing between the radiator and paper web absorbs part of the radiation aimed at drying. The greatest advantages of using IR drying are high power (up to 350-400 kW/m^2) and the low space needed /2, p.192; 4; 9, p.98-99/.

Both gas and electric-heated radiators are used in IR dryers. Electric heaters provide higher surface temperatures than gas-heated IR dryers, but they operate at a shorter wavelength /4/.

4.2.1 Electric infrared dryers

The main components that are used in electric infrared dryers are lamps, reflectors and a cooling system. The maximum temperature that can be achieved is 2200°C, but usually it changes between 1650-2200°C. IR dryers radiation has a wavelength (1.15-1.5 µm). Electric IR dryers use reflectors behind the lamps to improve their heating power, reflecting radiation back onto the web and it is really important that these reflectors are as efficient as possible. Counter-reflectors are only used on machines producing paper or thin board grades. Because some of the parts of radiators and reflectors cannot stand high temperatures, they have to be cooled /6, p.545-546; 9, p.98-99/.

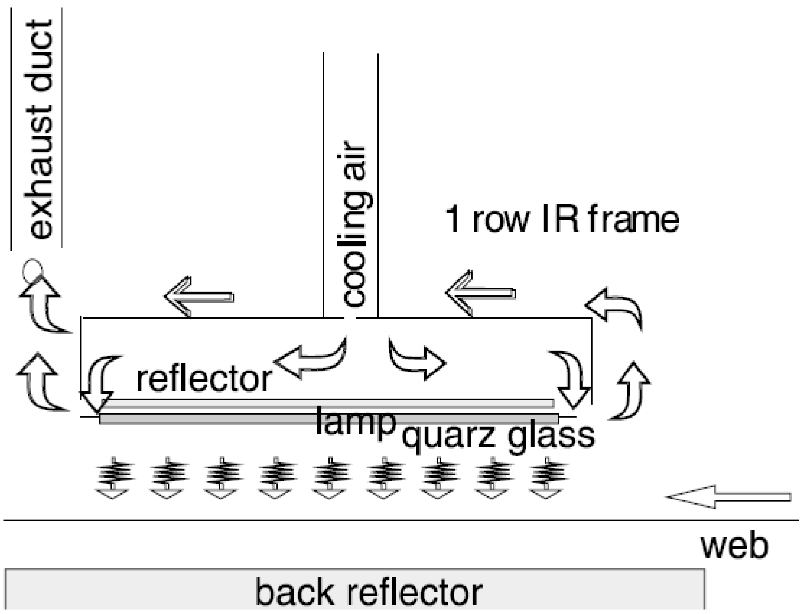

Figure 5 Principle of an electrical IR dryer /6/

4.2.2 Gas infrared dryers

IR radiators that use gas as an energy source are operated on natural gas. The principle of a gas IR radiator is that the flame heats the radiator surface, which directs the thermal radiation onto the web. The maximum radiator temperature that can be achieved is approximately 1200°C, which is about 1000 degrees lower than electric IR drying. Gas IR drying radiation has a longer wavelength (1.5-2 µm) and is less penetrative than electric IR drying, which is why counter-reflectors are not used /4; 6, p.547-548/.

4.3 Airborne web dryer

Airborne web dryers dry webs by blowing hot air onto the web surface. Air dryers used in coating machines can be divided into two categories: air flotation dryers and single-sided airborne dryers. The blower air is usually heated with a gas burner or hot steam. Gas-heated airborne dryers reach a temperature of approximately 300°C, while steam-heated airborne dryers remain at approximately 170°C /4; 6, p.548-549/.

Single-sided airborne dryers are advantageous when the drying of the uncoated side is not desirable. The nozzles are usually placed on the coating side and the web is often supported on the opposite side with supporting rolls. The rolls can be arranged to form a linear or a curved web path under the dryer. The nozzles are located in the airborne dryer cases, which contain incoming and exhaust air ducts. Air is blown through the nozzle slots or holes and exhausted between the nozzles. The dryer air balance should be adjusted in such a way that the web travels the same distance as the dryer. The solution with supporting rolls is useful in case of relatively low web speeds or high web strengths. /3, p.201; 4; 6, p.548-549/

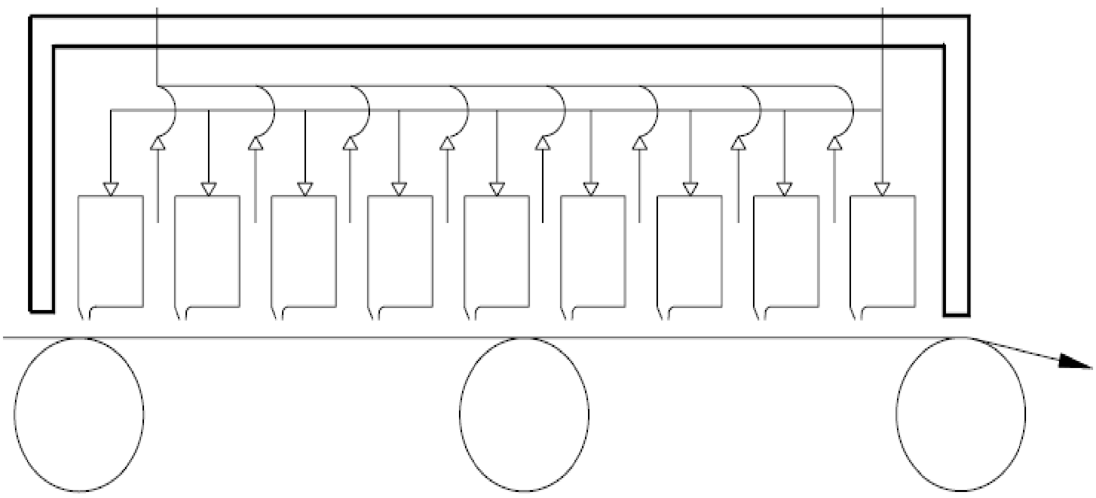

Figure 6 Single-sided airborne dryer, web supported by rolls /6/

In an air flotation dryer, the hot air is blown against both sides of the paper from several rows of nozzles inside the drying units and this way the web is supported on both sides by air jets or air cushions. Two-sided air flotation dryers are used mainly in drying coated paper webs because they have good and stable web runnability. That is why they can be used for all web speeds and basis weights and it is generally used in the drying of paper /6, p.548-549/.

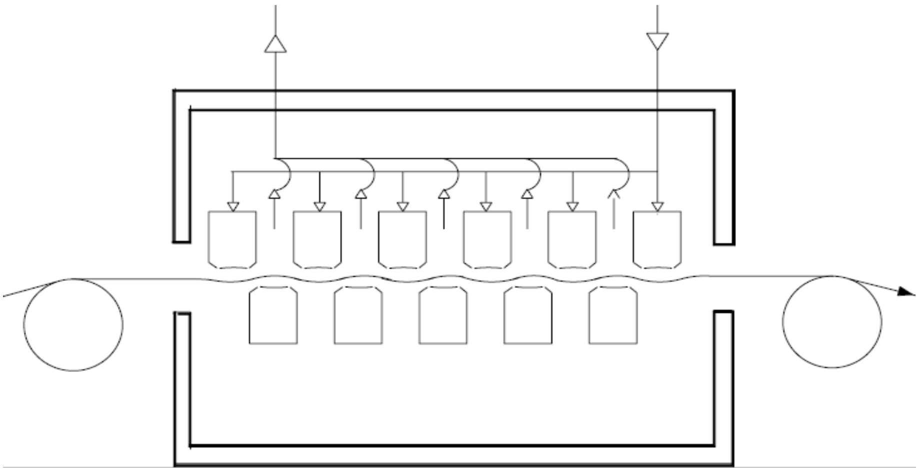

Figure 7 Air flotation dryer /6/

4.4 Cylinder drying

Cylinder drying is usually the last drying phase of the coating, because after the infrared drying and air drying the coating layer has been immobilized and can withstand mechanical contact. Cylinders are usually heated with steam, but oil and electricity can be used also. Cylinder sections used in coating machines are relatively short, including typically 2 to 6 cylinders /2, p.192; 6, p.557/.

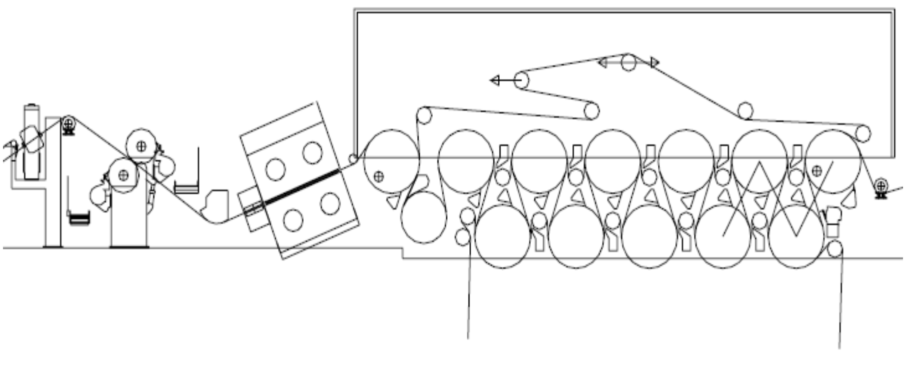

Figure 8 Air flotation dryer and cylinder group after film press coating /6/

5. FORMATION OF COATING LAYER DURING DRYING

5.1 Drying strategy

It is always important to plan a strategy for drying carefully, because it is still possible to ruin the papers coated surface in drying. It is recommendable to divide the drying process into three phases, because it is easier and more effective way to optimize the drying approach. As the wet coating layer moves to the dryer section of the coater, formation of the final structure of the coating begins. The printability of the coated paper then results from this structure /4; 6, p.559/

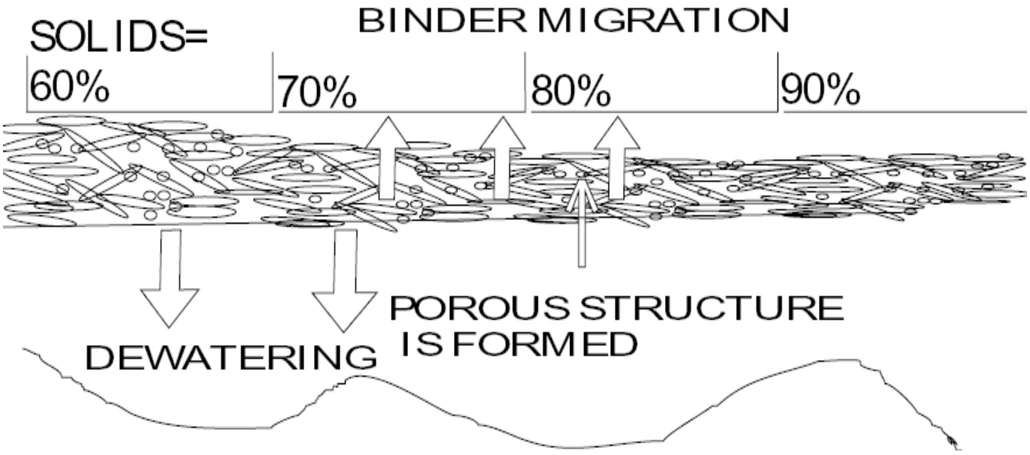

Figure 9 Structure of coating layer /6/

5.2 Initial drying

After the coating color is doctored with a blade it is important to start the drying as quickly as possible because it will reduce many negative quality effects. When the web is heated the absorption of water into the base paper accelerates, because an increase in temperature reduces water viscosity and increases evaporation, or steam diffusion, into the base paper. Heating the web accelerates also coating solidification, which is considered a positive factor in affecting coating quality. Initial drying is best performed using infrared radiation, because infrared dryers are effective touch-free equipment for initial drying. After the web is heated a steady phase of evaporation begins, when the web temperature depends on the humidity and temperature of the surrounding air /3, p.200; 4; 6, p.561-562/.

Water flow during initial drying causes the color fluid phase to flow into the base paper. Water-soluble binding agents and lateces are mobile as a result of the viscosity force caused by water flow. Binding agent mobility during initial drying does not cause unevenness on the surface, because binding agents move evenly in wet coating /3, p.200; 4; 6, p.561-562/.

5.3 Critical phase

After initial drying comes consolidation phase, where the viscosity of the coating increases so much that pigment particles stop moving. Consolidation phase takes place at the solids content of the coating layer is between 73-85 %. The solidification of the pigment particles begins and the particles are forced to get closer to each other and begin to form a structural network. During the solidification phase the pore structure of the coating layer is formed /3, p.200; 4; 6, p.563/.

The absorption of the coating color into the base paper is slowed considerably, because the capillary action in dry coating pores is reduced. Water flow is almost completely turned toward the surface of the coating. Water soluble binding agents in the color might migrate during this phase. Lateces can also migrate in such a way that the content in the coating surface is greater than within the coating layer /3, p.200; 4; 6, p.563/.

5.4 Final drying

When the critical phase is over consolidated coating is dried to the final moisture level. Absorption into the base paper ends and water starts to diffuse back onto the surface of the coating layer, where it evaporates. As the pores during coating are emptied of water as the drying continues, diffusion of vapor becomes an important transport mechanism of water. Capillary flow is simultaneously prohibited because water film inside the capillaries becomes noncontinuous /3, p.200-201; 4; 6, p.564/.

5.5 Effect of drying on final product quality

It is always possible that drying of the coated paper causes some quality problems. For example, if water is removed too fast from the paper it will deteriorate the quality of the final product. That is the reason why it is often recommended to perform a mild initial drying. Too harsh drying, especially at the consolidation or critical phase has been said to cause binder migration and then mottling /4/.

Mottling is the one quality parameter that is clearly connected to the drying approach employed. Mottling means uneven ink absorption at offset printing. The uneven coat weight distribution is the most important factor influencing the uneven print image. Binder migration is one factor behind this structure and surface energy formation. Mottling with coated papers is usually caused by backtrap mottling, fountain water, or gloss mottling /6, p.559-561/.

6. BASE PAPER AND ITS PROPERTIES

6.1 Base paper

The main task of the base paper in coating is to give good runnability of the coater and an optimal basis for paper finishing, as well as to form a base on which the coating layers demanded by the end users could be fixed. Base paper should have uniform quality, few defects in paper, and even paper profiles. Because if there is some problems in the base paper it is almost impossible to make coated paper that has good quality. Base papers roughness, porosity and water absorption properties have very big effect to the success of coating /6, p.31-32/.

Base paper that was used in test trials was a wood-containing 43.1 g/m² paper.

6.2 Roughness

The roughness volume between the blade and paper rules the amount of coating color on the paper. The denser and more hydrophobic the base paper is, the more the roughness has an effect on the coat weight formation and the higher the roughness is the more coating color stays on the paper with the same blade pressure. In blade coating, the blade runs on the top of the highest peaks of the paper and fills the gaps between these peaks.

The aim of the roughness measurement is to find out the paper surface topography. The principle of roughness measurement is based on the ability of the paper surface to resist an air stream flowing between the papers surface and measuring head pressed against it. The roughness of the paper was measured with the Bentsen apparatus which gives the results as ml/min and all the measurements were done to the side of the paper that was coated later the on with the pilot machine /10/.

6.3 Air permeability

Measuring the papers air permeability helps to determine the porosity of the base paper. It tells how much air can flow through paper sheet. If the porosity of the base paper is very high, absorption of coating is also high. This can increase the coating amounts and cause problems in drying.

6.4 Water absorption with the COBB test

The water absorbency of paper is defined as the amount of water absorbed in a given time, in this chase 30 seconds, by one side of a unit area of paper. This absorbency test is called COBB-test. Before starting the test, the dry samples have to be weighed.

In COBB 30-test 100 ml of distilled water is pored on top of the paper sample. After 20 seconds the paper sample is placed on top of the rubber mat and blotting paper is placed on top of the paper. After this the extra water is removed by rolling a specific weight cylinder over the paper. The amount of absorbed water can be counted by using the samples weighed before and after exposure to water /10/.

Table 1 Base paper properties

Measured property	Result
Basis weight, g/m²	43,1
Roughness, ml/min	185
Water absorption, g/m²	180
Air permeability, ml/min	100

7. COATING COLOR

7.1 The coating color preparation process

Water is an essential component of a coating color, because it makes possible to mix all the components of coating color. The target is to get all the pigment particles separated from each other uniformly dispersed. If the dispersing is poor it can lead to such problems as blade scratches, rheological fluctuations and runnability disturbances at coaters.

When the coating color is made, the various components of coating color are added one by one to a disperser. First dispersing agent and pH-controlling agent are added to the water. After these chemicals, pigments are added and dispersed carefully in order to achieve the best possible coating quality. Dispersing of pigments is needed because many times pigments are dried when they are made and pigment agglomerates are formed. It is important to break those agglomerates and to bring back the same pigment particle size distribution as each specific pigment had in its original stage before drying.

After the chemicals and pigments are mixed together, it is possible to add water-soluble co-binder such as CMC. Before CMC is put into the disperser it has to be mixed with warm water. Lateces, which are added next, are delivered by to the mill as a water-containing dispersion at dry solids levels of 40-50 % and they do not need separate dispersing. Finally, if some special properties are required it is possible to add some additives to the coating color.

7.2 Coating color preparation

Two coating colors were prepared for the test runs. The first coating color (Appendix 1) was made 10 liters and the second coating color (Appendix 2) 20 liters. The target of the solids content was approximately 60 %. The main components that were used as pigments were kaolin and calcium carbonate. Both of the coating color recipes included 70 parts of kaolin and 30 parts of $CaCO_3$. Styrene-Butadiene latex was used as the main binder and CMC as a thickener. The additives that were used were dispersion agent, pH control aid and hardener. Viscosity, water retention, dry matter content, pH and temperature were measured from the coating color before coating.

8. PROPERTIES OF THE COATING COLOR

8.1 Water retention

There is always water present in coating, absorbed into the coating color. When coating color is applied on the base paper, water starts to penetrate into the base paper. The contact time between water and the base paper specify the amount of penetration into the base paper. The water retention of the coating color defines the speed of the water penetration into the base paper. It is one of the most important properties of the coating color, because if the water retention is poor, the dry matter content of the coating color might increase and cause problems in the coating process. The most important things that affects the water retention are base paper, coating method used and the rheology of the coating color /5/.

The water retention properties of the base paper can be changed by sizing. Sizing prevents the absorption of the water to the base paper. Also the moisture and the temperature of the base paper have an effect to the water retention. In roll application the coating color penetrates deep into the base paper because of high pressure impulse in the nip. Also the dwell time between application and metering the coating color affect the water retention. It is possible to adjust the water retention by using thickeners, like PVA, CMC and starch.

The measurement of the water retention was made with the ÅA-GWR water retention meter. The method is based on pressure filtration of coatings under certain air pressure over a certain time period. Water penetrates through a filter and is absorbed by a paper sample /1, p.29; 10/.

8.2 Viscosity

It is important to measure the viscosity, because it has a big effect on the water retention and it is easier to forecast the coating color's behavior in coating units. Viscosity of the coating color can be measured by using Brookfield-viscometer. Brookfield viscometer has a spindel that rotates in pigment slurry. The viscometer is designed to determine the change in torque required to maintain a specific rotation speed of a spindle when it is in the slurry. So the resistance that the rotation causes in the slurry can be defined as the viscosity of the coating color. When the viscosity is measured one important thing is to do it in constant temperature, because if the temperature is too low the viscosity increases and if the temperature is too high it decreases. Temperature should be approximately 22-23°C.

8.3 Solids content

The solids content of the coating color is really important to measure, because it has a big effect to the success of coating. If the solids content of the coating color is too high or too low, it affects the coating amount immediately as well as the runnability of coating unit. The measurement of the solids content was done with Mettler Toledo apparatus. I put 1.5 grams of the measurable sample in the device and after that it started to heat it in 150°C. The Mettler Toledo apparatus evaporates the water from the sample and counts the solids content of the sample.

Table 2 Properties of the coating color

	1. Coating color	2. Coating color
Temperature, °C	22	22
Dry matter content, %	60,3	60,4
pH	7,5	7,5
Viscosity, mPas	910	1012
Water retention, g/m²	180	178,5

9. TESTING OF THE COATED PAPER

9.1 Moisture content

Moisture variation affects to the coating amounts. If the moisture variation across the web is high there is a big risk of wrinkles. High moisture before coating can affect coating color penetration and the gloss of coated paper and also later on when the paper is printed, to the setting of ink. Too high moisture content can cause a web breaks on the coater or in supercalendering. /6, p.755/

In the first pilot machine test run the infrared dryers distance from the paper was changed and in the second test run the drying power of the infra. This way I tried to change the moisture of the paper and define how the drying affects the paper web. The moisture profile was defined by cutting 50 mm x 100 mm samples from the coated paper. Because the coated paper web was approximately 30 cm wide I took six samples from it. I weight all these samples and after that I dried them in the oven in 105°C for several hours. After drying, I weighed the samples again and after that I could count the moisture content and draw the moisture profile of the paper.

9.2 Coat weight

The measurement of the coat weight was done by cutting 100mm x 100mm samples from the coated paper. The samples were taken after every change that was done with the pilot machines drying units. Same sized samples were also taken from the base paper, so it was possible to compare the change in the papers weight.

All these samples were dried in the oven in 105°C for several hours and after drying the samples were weight. The base papers weight were subtracted from the coated samples weight and this way it was possible to get the coat weight of the paper.

9.3 Picking test

There are two strategies to improve the surface strength of paper and they are improvement of the inter-fiber bonding strength of the paper in general, and focusing most of the improvement near to the surface of the sheet.

Surface strength refers to the internal and surface bond strength of paper. It is important to know the surface strength of the paper, because it prevents fibers, fines, filler, or coating from being removed in printing or converting operations that involve ink and/or aqueous liquids such as in offset printing. A low surface strength may create problems like linting and cause runnability problems or even destroy the printing result /6, p.758/.

Generally for coated paper, the picking test is used. It is done with the IGT tester which simulates printing. IGT tester is designed to measure the papers resistance to picking. It tells the printing speed which is possible to use before the picking of the surface begins. The distance from the edge of the paper to the spot where the picking starts is measured. The result of the speed and the distance is a measure of the surface strength of the paper. The value is possible to look from the table (Appendix 12) by using these two values /6, p.758; 7, p.148-150/.

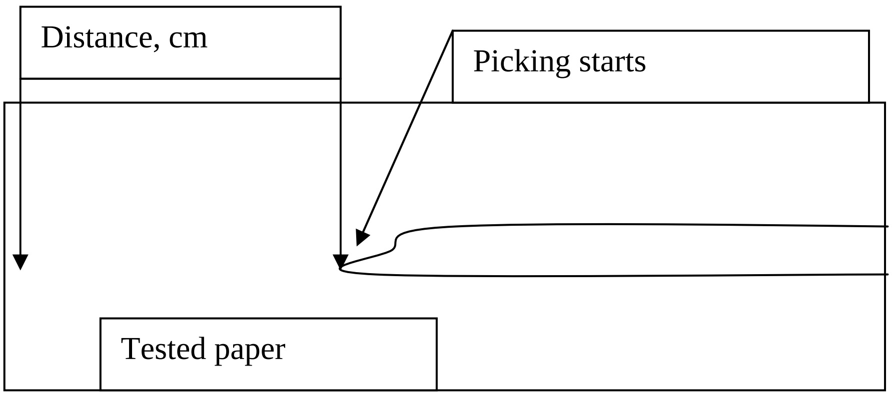

Figure 10 Principle of the surface pick measurement

With the IGT test, it is possible study the surface strength with different kind of inks. These inks that are used have different viscosities. Highest viscosity inks are the tackiest and the lowest viscosity inks are the least tacky. The ink that was used in my tests had low viscosity and all the test were done to the papers machine direction.

10. PAPER LABORATORY PILOT MACHINE

10.1 General about the machine

The coating unit of the paper laboratory pilot machine is equipped with long dwell application unit and doctor blade. The drying begins with infrared dryers and the drying is finished with single-sided airborne dryers. It is possible to adjust the drying power of the both dryers. Paper reel is placed to the unwinder where it is reeled with the re-winder.

Figure 11 Pilot machine

10.2 Application unit

The pump that takes care of the coating color circulation pumps it to the color tank underneath the application unit. From there, the coating color is conveyed with applicator roll onto the bottom surface of a paper web and suspended in the nip between applicator roll and backing roll. Both of the rolls are rubber covered. It is possible to change the gap between applicator roll and backing roll.

Figure 12 Applicator roll and bigger backing roll

10.3 Blade metering unit

In the paper laboratories pilot machine the coating color is metered with a blade. The blade is approximately 35 centimeters wide and it is attached to the blade beam. In blade coating, it is possible to adjust the coat weight by changing the blade pressure or angle.

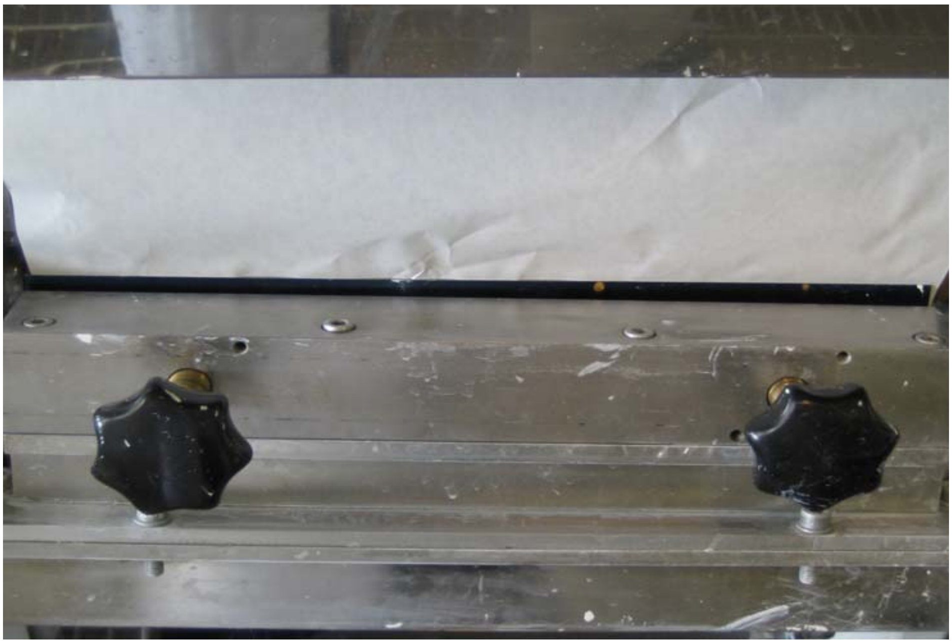

Figure 13 Blade beam and the blade

10.4 Drying units

The drying in the pilot machine starts with infrared drying. This drying unit has five lamps that are heated with electricity and cooled with air. It is possible to change the infrared dryers heating power in the scale of 1-10. Infrared dryer has reflector behind the lamps to improve their heating power and reflecting radiation back onto the web.

Figure 14 Infrared drying unit and control panel

After infrared drying the drying of the coated paper web is continued with single-sided airborne dryer. It has two dryer cases that blow the heated air to the coated side of the web. The web is supported on the opposite side with supporting rolls. The rolls are arranged a curved path under the dryer and the web travels the same distance all the way that it is dried. It is possible to change the drying power in a scale of 1-3.

Figure 15 Single-sided airborne dryer

11. VARIABLES DURING THE TEST RUNS

11.1 First test trial

In the first trial the target was to find out how the moisture profile changes when the infrared dryers distance from paper is changed and how it affects the surface strength of the coated paper. Also the thickness and coat weight were measured from the coated paper. There was four different drying phases during the second test run:

- Phase 1. The distance between paper and infrared dryer was 6.5 cm and the drying power was 3. Air dryer's drying power was 2.

- Phase 2. The distance between paper and infrared dryer was 3.8 cm and the drying power was 3. Air dryer's drying power was 2.

- Phase 3. The distance between paper and infrared dryer was 1.8 cm and the drying power was 3. Air dryer's drying power was 2.

- Phase 4. The infra was not used in the last phase and the air dryers drying power was 3.

11.2 Second test trial

In the second trial the target was to find out how the moisture profile changes when the infrared dryers drying power is changed and how it affects the surface strength of the coated paper. Also the thicknesses and coat weights were measured from the coated paper. The distance between paper web and infrared dryer was kept in 3.8 cm through the whole run. There was also four different drying phases during the second test run:

- Phase1. The infrared dryer drying power was 4 and air dryer's drying power was 2.

- Phase 2. The infrared dryer drying power was 5 and air dryer's drying power was 2.

- Phase 3. The infrared dryer drying power was 6 and air dryer's drying power was 2.

- Phase 4. Infrared dryer wasn't used in the last phase and the air dryers drying power was 3.

During both of the test trials the blade angle was 45° and the blade pressure 5 bars. Tables 3 and 4 include all the changes that were made during both of the test runs.

Table 3 Changes during the firs test trial.

	Distance (IR/web)	Drying power(IR)	Drying power(AIR)
Phase 1.	6,5cm	3	2
Phase 2.	3,8cm	3	2
Phase 3.	1,8cm	3	2
Phase 4.	1,8cm	0	3

Table 4 Changes during the second test trial.

	Distance (IR/web)	Drying power(IR)	Drying power(AIR)
Phase 1.	3,8cm	4	2
Phase 2.	3,8cm	5	2
Phase 3.	3,8cm	6	2
Phase 4.	3,8cm	0	3

12. TEST RESULTS

12.1 Coat weight variation

During the first test trial the dry matter content was 60.3 % and the coat weight varied with from 6.18 g/m^2 to 7.84 g/m^2. It is quite a big change because only the drying was adjusted not the blade. The blade angle was 45° and the blade pressure 5 bars.

Table 5 Papers coat weights after coating

	1.Test run	2.Test run
Phase 1	6,18 g/m^2	5,7 g/m^2
Phase 2	6,75 g/m^2	5,12 g/m^2
Phase 3	7,84 g/m^2	5,65 g/m^2
Phase 4	7,04 g/m^2	7,65 g/m^2

There can be some changes in the coating colors rheology that affects the coat weight. It is possible that the temperature of the color or the web changed during the test trial and this affected to the water retention of the coating color and the coat weight, but more probable cause is the dwell time between application and metering. Because paper webs surface picks up moisture from the coating color the color itself dewaters. This increases the solid content of the color and the coat weight during the coating. The time between application and metering was quite long, because of the slow speed of the machine. So, maybe higher speed in the pilot machine would help to avoid this kind of interactions.

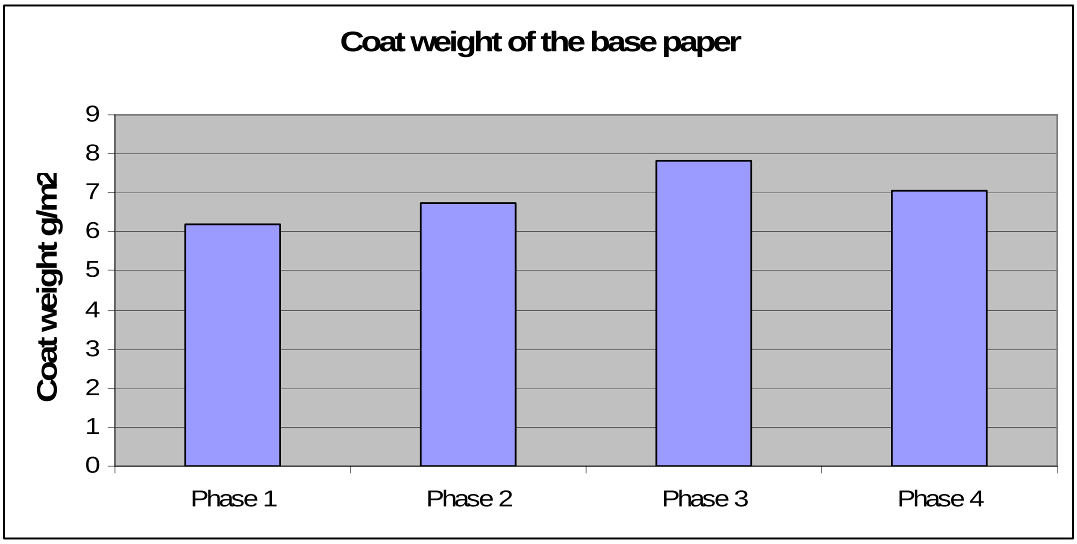

Figure 16 Coat weights after the first test trial.

In the second test trial the blade angle and pressure were kept the same as in the first test trial. During the second test trial the dry matter content were 60.4 % and the coat weight varied from 5.12 g/m^2 to 7.65 g/m^2 so the changes were even higher than in the first test run. Also in this test trial the paper web picked up moisture from the coating color and this increased the solid content and the coat weight during the coating.

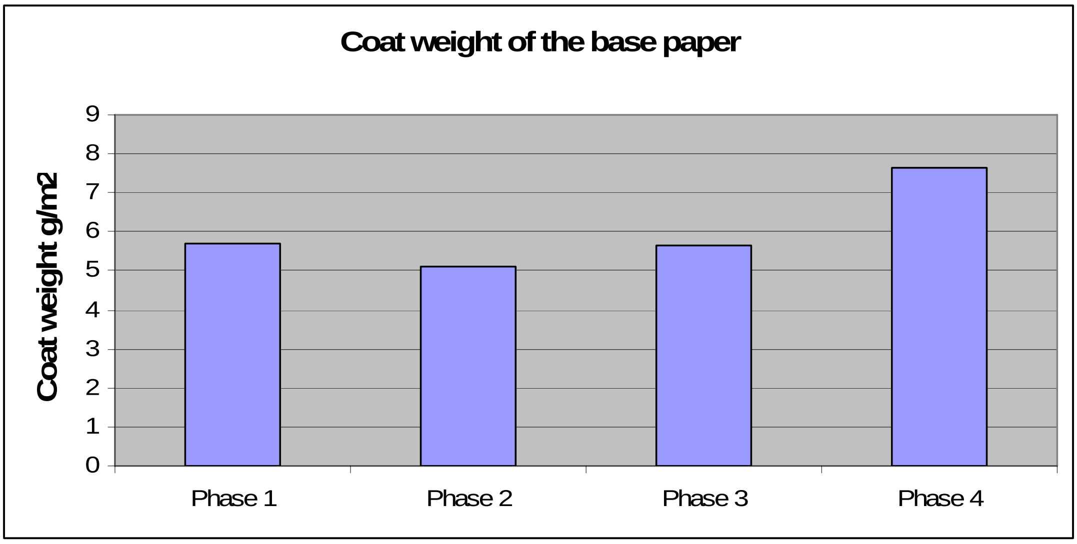

Figure 17 Coat weights after second test trial.

12.2 Picking test with IGT tester

Before the paper was tested with the IGT tester it was calendered. When the paper from the first trial was tested the suitable testing speed was 1.6 m/s. With higher speeds the paper could not bear the tearing force that was directed to it.

Table 6 The distance from the edge of the paper to the spot where the picking starts and the speed that was got from the table (Appendix 12)

	Phase 1	Phase 2	Phase 3	Phase 4
Distance, cm	8,2	9,4	10,6	8,8
Speed, m/s	0,68	0,75	0,89	0,75

In the first phase, when the distance of the infrared dryer from the web 6.5 cm the value that was got form the picking test was 0.68 m/s. There was little bit improvement in the second phase when the infrared dryer was moved to 3.8 cm from the web, the value rose to 0.75 m/s. The highest picking test value was got from the phase 3 when the infrared dryer was only 1.8 cm from the web. The value was 0.89 m/s. After phase 3, the infrared dryer was turned of and the value decreased 0.75 m/s.

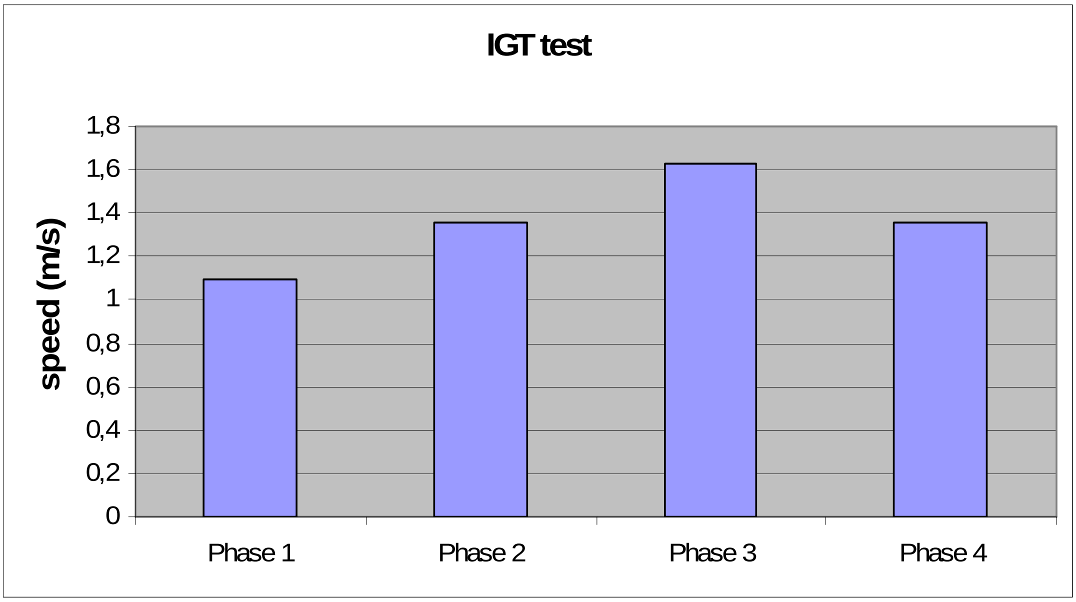

Figure 18 Printing speeds where the picking of the surface begins.

In the second trial the speed that was used for testing was 3.0 m/s. Also in the second test trial the development of the surface strength seemed to follow the drying power of the infrared dryer. In the first phase, when the drying power of the infrared dryer was 4 the value that was got form the picking test was 1.09 m/s. There was little bit improvement in the second phase with power 5 when the value rose to 1.36 m/s. The highest picking test value was got from the phase 3 when the drying power was 6. In the phase 3 the value was 1.63 m/s. After phase 3, the infrared dryer was turned of and the value decreased slightly to1.36 m/s.

Table 7 The distance from the edge of the paper to the spot where the picking starts and the speed that was got from the table (Appendix 12)

	Phase 1	Phase 2	Phase 3	Phase 4
Distance, cm	6,5	8,7	9,6	8
Speed, m/s	1,09	1,36	1,63	1,36

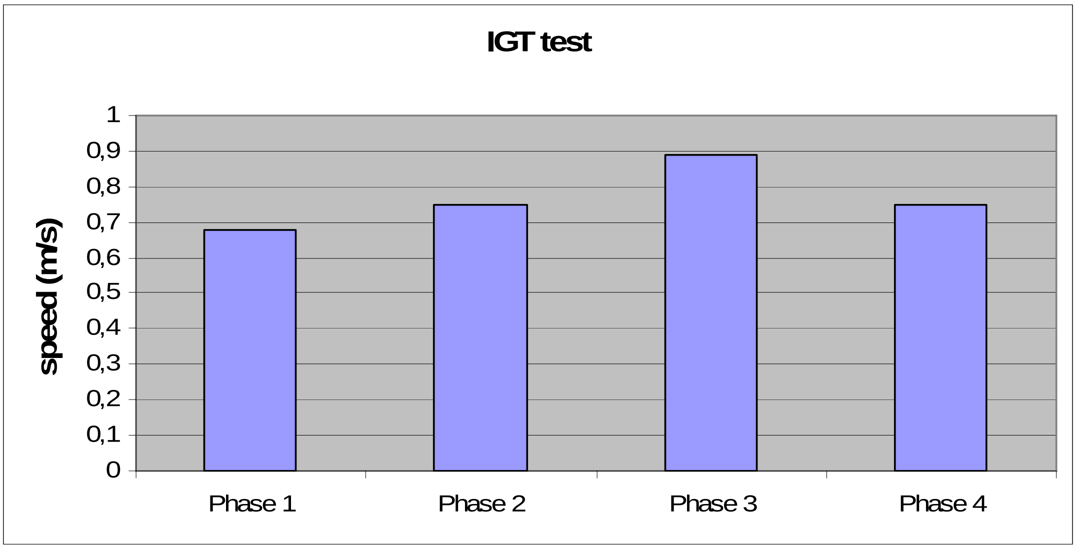

Figure 19 Printing speeds where the picking of the surface begins.

12.3 Thickness of the coated paper

There was also some variation in the thickness of the coated paper. The average values of thicknesses are collected to the tables 6 and 7 and seen in the figures 5 and 6.

Table 8 Coated papers thickness variation after first test run in micrometers (µm)

Phase 1	Phase 2	Phase 3	Phase 4
74,4	75,5	75,7	77,3
73,8	77,4	74,6	77,0
75,0	79,8	76,3	77,3
75,6	76,5	75,3	75,6
75,0	77,1	75,1	76,6
73,4	74,9	72,6	75,0

Table 9 Coated papers thickness variation after second test run in micrometers (µm)

Phase 1	Phase 2	Phase 3	Phase 4
75,3	74,5	74,5	75,9
75,6	72,0	72,5	75,5
76,2	73,0	74,4	76,3
74,6	71,6	73,2	74,4
75,9	71,6	72,0	75,3
74,7	71,5	72,5	71,7

In the first test run the coated papers thickness changed between 72.6-77.3µm and in the second test run between 71.5-76.3 µm. It is a quite big variation and the changes in the coat weight do not explain it, because the thickness of the coated paper does not change bigger when the coat weight increases. Maybe there have been some kind problems in the blade during the test run and that has caused streaks to the web and also the variation to the thickness. One possibility could be also fiber swelling which could cause unevenness to the paper structure. There can be some differences tendencies of coatings to penetrate the base paper.

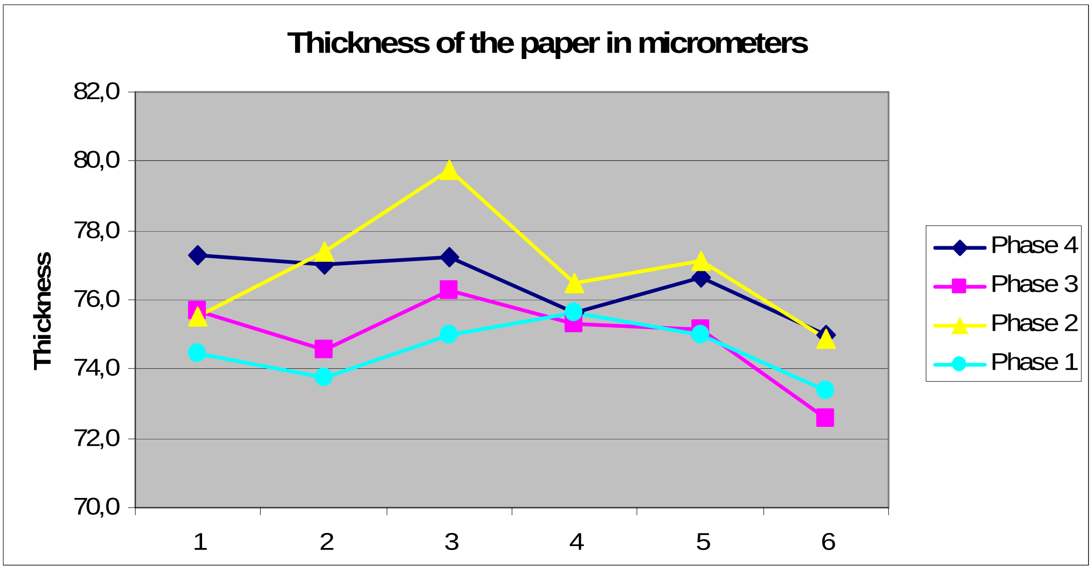

Figure 20 Thickness variation of the coated paper after first test trial

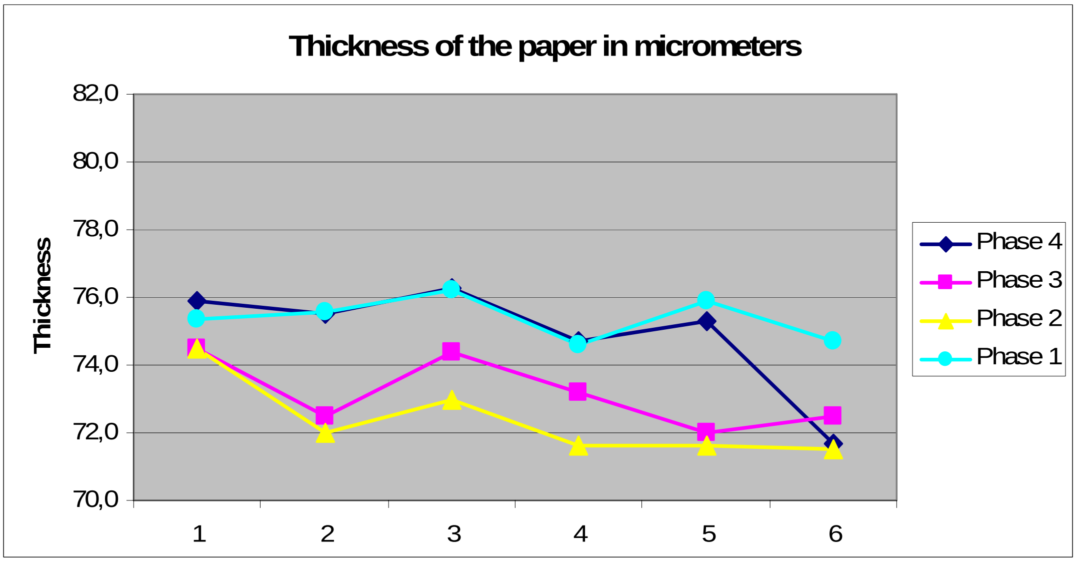

Figure 21 Thickness variation of the coated paper after second test trial

12.4 Moistures CD profiles

Infrared dryer is a profiling dryer which makes easier to control cross direction moisture profiles. The results after first test trial are good example from this. It is quite easy to see from the figure 8 that when the infrared dryer is moved closer to the web during the first test trial, there is not so big variation in the moistures CD profile.

Table 10 Average values of the papers moisture (%) after first test trial

	1	2	3	4	5	6
Phase 4	4,81	3,83	4,98	6,63	4,56	4,38
Phase 3	4,80	5,12	5,51	5,52	5,39	5,43
Phase 2	5,40	5,75	5,48	5,47	6,01	5,66
Phase 1	5,77	6,26	4,44	6,04	5,84	7,03

In the phase 1, the moisture was quite high and also the variation in the moisture was high, from 4.44 % to 7.03 %. Also in the second phase the variation in the moisture profile got more even to 5.40-6.01 %. In phase 3, when the infrared dryer was the closest to the web the moisture was in the lowest level and changed between 4.80-5.55 %. This is quite small variation if it is compared to the phase four when the infrared dryer was turned off and only the airborne dryer was used, the moisture fluctuated between 3.83-6.63 %.

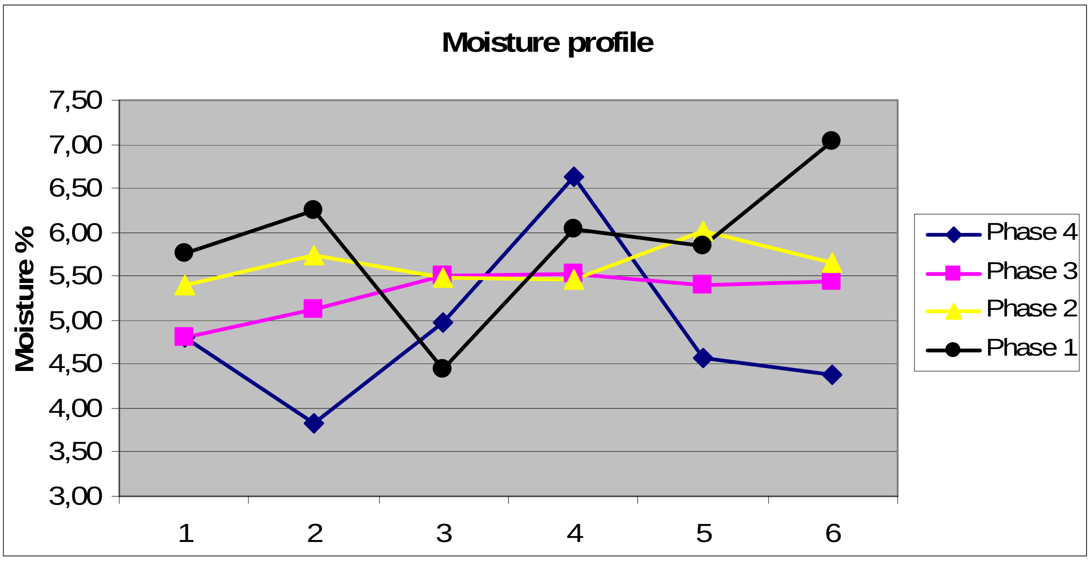

Figure 22 CD profile of the moisture after first test trial

In the phase 1, the moisture already decreased compared to the first test run, to 4.24-5.20 %. In the second phase the variation in the moisture profile got more even to 5.40-6.01 %. In phase 3, when the infrared dryers drying power were six the moisture changed between 3.80-4.39 %. This was the best moisture profile in the both test trial. After phase 3, when the infrared dryer was turned off and only the airborne dryer was used the moisture content rose immediately approximately 1 %. In the phase 4 it changed between 4.24-5.20 %.

Table 11 Average values of the papers moisture (%) after second test trial

	1	2	3	4	5	6
Phase 4	4,38	4,57	4,77	4,58	5,00	4,66
Phase 3	4,03	4,39	3,80	3,84	3,80	3,88
Phase 2	4,52	4,41	4,07	4,21	3,84	4,05
Phase 1	4,68	4,65	4,35	4,24	5,20	4,30

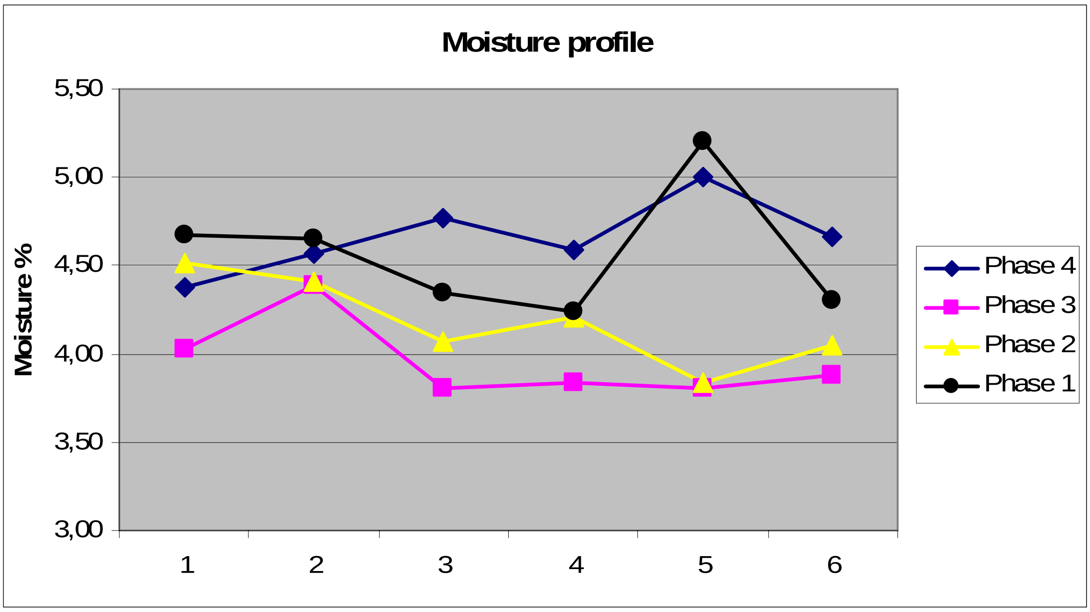

Figure 23 CD profile of the moisture after second test trial

13. CONCLUSIONS

The target of my thesis was to investigate is the pilot machines infrared dryer really useful and if it have an effect to coated papers surface strength. The results were quite clear. It is a very important part of the drying process and it is possible to regulate papers cross directional moisture profiles with the dryer. In these two test trials that were done with the pilot machine the changes in the infrared dryer were different but the end result was the same.

In phase 3, when the infrared dryers distance from the web was 1.8 cm and the infrared dryers power was 3 and airborne dryers drying power was 2 the moisture changed between 4.80-5.52 %. Although this is a good result, safety aspects has to be considered. Because if the infrared dryer is near the web and the pilot machine suddenly stops middle of the run it can quite easily cause fire. Maybe it would be wise to put some kind of system to the pilot machine that turns the infrared dryer off after couple of seconds if the pilot machine stops.

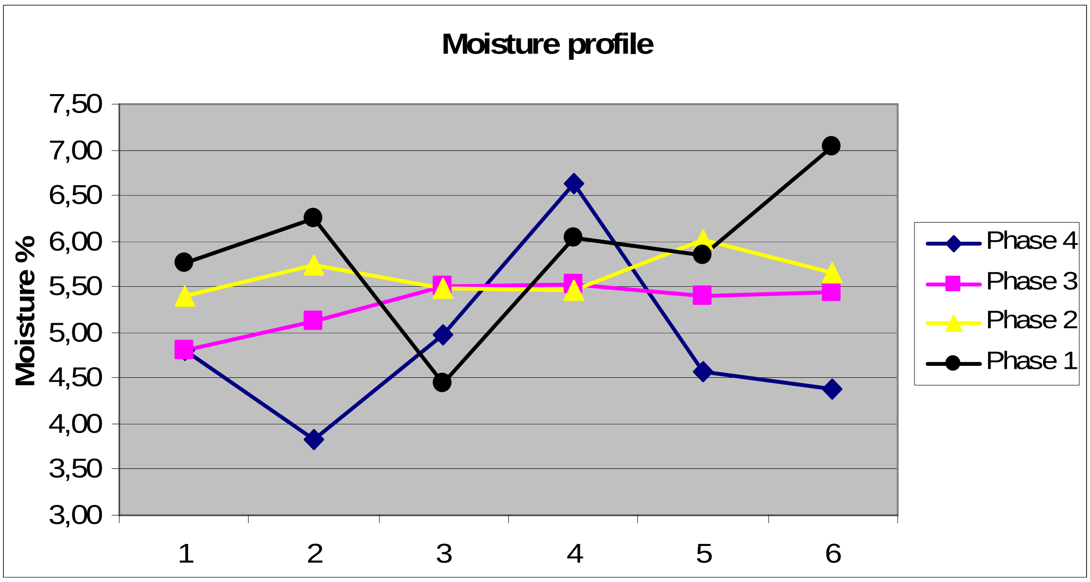

Figure 24 Moistures CD profile after first test run

Safety is the one reason why the infrared dryer should be kept at least 3.8 cm from the web like in phase 2. This is also the distance where the infrared dryer usually is. We can see from the figure 4 that also the CD profile of the moisture is quite even in phase 2. The variation is only between 5.40-6.01 %. Of course the moisture is still quite high, but it is possible to decrease it by increasing the airborne dryers drying power to the position 3.

During the second test trial the moisture content of the paper dropped generally. Reason for this is higher drying power in the infrared dryer. If the pilot machine is used in slow speed, 5 and 6 is enough for the infrared dryers drying power and if the airborne dryers drying power would be 3 it would improve the moisture profile even more.

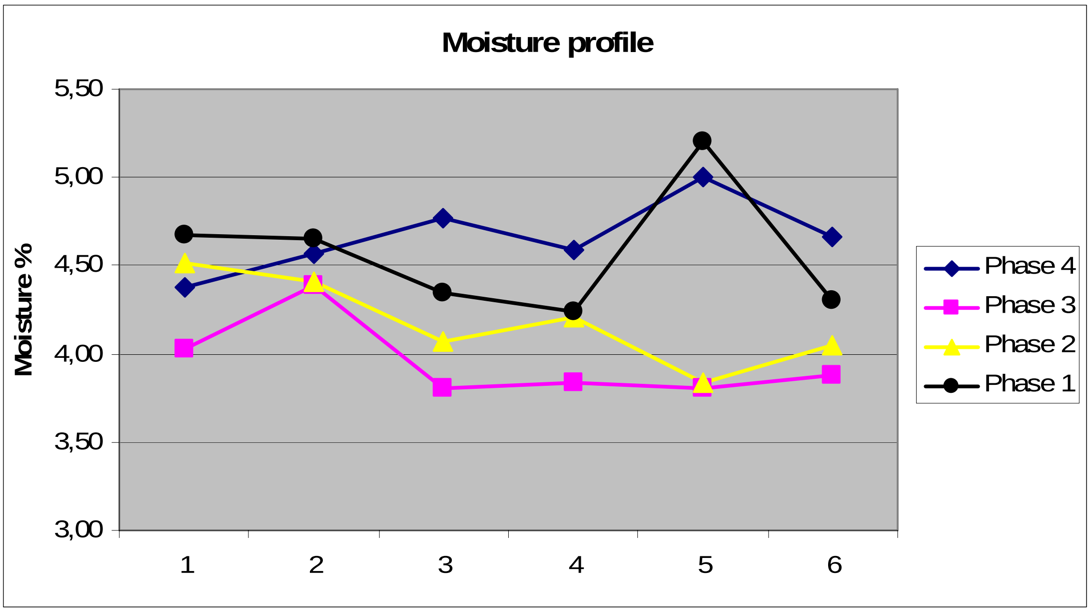

Figure 25 Moistures CD profile after second test run

When I started my test trials the first thing that I noticed was that the infrared dryers reflectors were very dirty and covered with coating color. These reflectors should be cleaned regularly because if they are dirty it could decrease the drying power and efficiency of the infrared dryer.

In the results that were gotten from picking tests it seems that the temperature in the beginning of the drying has a big influence to the surface strength and the picking resistance of the paper. When the infrared dryer was near to the web and the drying power was the highest, also the results that I got with the IGT tester were in the highest level. One reason for this development could be that higher temperature gave better binder distribution through faster immobilization. If the binder distribution is not even there can be some places in the paper that does not have binders and then the picking strength decreases.

The faster the evaporation begins, the less water and binder will migrate into the base sheet. These binders are one very important part of the surface strength of the paper, because they bind pigment particles to each other and anchor the coating into the base paper.

The picking strength of the paper is much better in the second test run than in the first. One reason for this could that there has been some rheological changes between the two coating colors that were prepared.

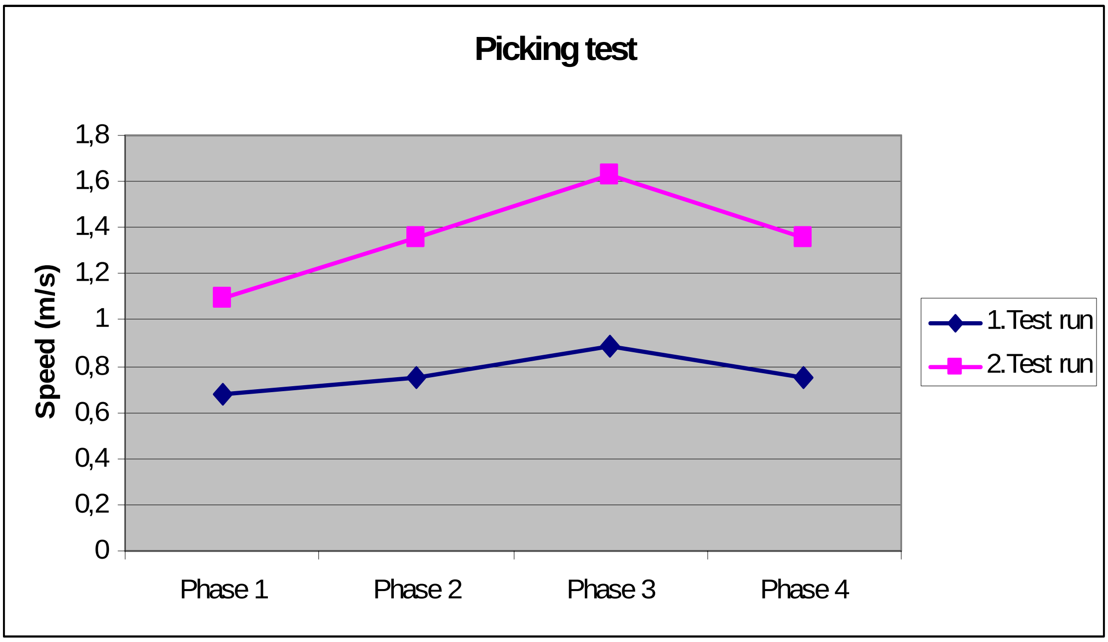

Figure 26 Results from the picking tests

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APPENDICES

…reseptin laskeminen

Appendix 1.

…ähtötiedot		resepti	kuivana, g	vettä, g
Määrä / g		10000		**4000**
Pastan KAP /%		60	**6000**	

Pigmentit (yht 100 osaa)	**Tuotenimi**	Osaa	KAP %	koko määrä, g
Kaoliini	SPS-Kaolin	70,0	58,5	**6444,78**
Kalsiumkarbonaatti	Hydrocarb 60	30,0	70,4	**2295,17**
Talkki		0,0	1	**0,00**
Kipsi		0,0	1	**0,00**
Titaanioksidi		0,0	1	**0,00**
Kalsinnoitu kaoliini		0,0	1	**0,00**
Alumiinihydraatti		0,0	1	**0,00**
Saostettu kaoliini		0,0	1	**0,00**
Satiinin valkoinen		0,0	1	**0,00**
Natriumaluminiumsilikaatti		0,0	1	**0,00**
Muovipigmentti		0,0	1	**0,00**

Sideaineet (5-12osaa)		Osaa	KAP %	koko määrä, g
PVA		0,0	50	**0,00**
Styreeni-butadieeni		10,0	50	**1077,20**
Cmc (ei yli 1,0 osaa)	Finnfix 10	1,0	98	**54,96**
Tärkkelys		0,0	1	**0,00**

Apuaineet (0-3osaa)		Osaa	KAP %	koko määrä, g
Dispergointiaine	Fennodispo A-48	0,30	50	**32,32**
Kovetin	Glyoksal	0,10	50	**10,77**
Kalsiumstearaatti		0,00	50	**0,00**
Optinen kirkaste OBA		0,00	50	**0,00**

yhteensä		**111,40**		**9915,20**
Aineiden mukana vettä, g			3915,20	
Lisävesi, g			**84,80**	

tiedot		resepti	kuivana, g	vettä, g
läärä / g		20000		8000
Pastan KAP /%		60	12000	

Pigmentit (yht 100 osaa)	**Tuotenimi**	Osaa	KAP %	koko määrä, g
Kaoliini	SPS-Kaolin	70,0	59,1	**12758,71**
Kalsiumkarbonaatti	Hydrocarb 60	30,0	74,4	**4343,55**
Talkki		0,0	1	**0,00**
Kipsi		0,0	1	**0,00**
Titaanioksidi		0,0	1	**0,00**
Kalsinnoitu kaoliini		0,0	1	**0,00**
Alumiinihydraatti		0,0	1	**0,00**
Saostettu kaoliini		0,0	1	**0,00**
Satiinin valkoinen		0,0	1	**0,00**
Natriumaluminiumsilikaatti		0,0	1	**0,00**
Muovipigmentti		0,0	1	**0,00**

Sideaineet (5-12osaa)		Osaa	KAP %	koko määrä, g
PVA		0,0	50	0,00
Styreeni-butadieeni		10,0	50	**2154,40**
Cmc (ei yli 1,0 osaa)	Finnfix 10	1,0	98	**109,92**
Tärkkelys		0,0	1	**0,00**

Apuaineet (0-3osaa)		Osaa	KAP %	koko määrä, g
Dispergointiaine	Fennodispo A-48	0,30	50	**64,63**
Kovetin	Glyoksal	0,10	50	**21,54**
Kalsiumstearaatti		0,00	50	0,00
Optinen kirkaste OBA		0,00	50	0,00

yhteensä		111,40		19452,74

APPENDIX 3

Coated paper weights from the first test run before and after drying

Phase 1

1	2	3	4	5	6
0,258	0,247	0,260	0,251	0,264	0,243
0,258	0,244	0,264	0,236	0,254	0,232
0,257	0,234	0,260	0,250	0,258	0,250
0,252	0,243	0,244	0,247	0,254	0,247
0,250	0,242	0,268	0,254	0,273	0,236
0,251	0,233	0,256	0,254	0,257	0,249
0,245	0,235	0,230	0,246	0,263	0,231
0,253	**0,240**	**0,255**	**0,248**	**0,260**	**0,241**

Phase 1

1	2	3	4	5	6
0,231	0,221	0,238	0,232	0,248	0,231
0,238	0,229	0,245	0,238	0,236	0,222
0,243	0,227	0,254	0,237	0,243	0,234
0,244	0,225	0,232	0,222	0,243	0,233
0,233	0,221	0,245	0,234	0,257	0,234
0,239	0,220	0,243	0,232	0,251	0,218
0,241	0,230	0,246	0,238	0,239	0,219
0,238	**0,225**	**0,243**	**0,233**	**0,245**	**0,227**

Phase 2

1	2	3	4	5	6
0,246	0,247	0,264	0,251	0,260	0,238
0,249	0,254	0,267	0,265	0,271	0,259
0,256	0,251	0,287	0,256	0,272	0,255
0,266	0,242	0,254	0,264	0,260	0,241
0,260	0,235	0,260	0,244	0,265	0,240
0,253	0,250	0,277	0,258	0,265	0,255
0,259	0,250	0,296	0,240	0,258	0,255
0,256	**0,247**	**0,272**	**0,254**	**0,264**	**0,249**

Phase 2

1	2	3	4	5	6
0,250	0,236	0,251	0,228	0,252	0,226
0,235	0,228	0,238	0,250	0,245	0,244
0,243	0,239	0,272	0,244	0,241	0,228
0,240	0,220	0,247	0,251	0,256	0,238
0,246	0,233	0,248	0,244	0,241	0,222
0,234	0,236	0,281	0,228	0,252	0,242
0,244	0,238	0,260	0,239	0,253	0,245
0,242	**0,233**	**0,257**	**0,241**	**0,249**	**0,235**

APPENDIX 4

Coated paper weights from the first test run before and after drying

Phase 3

1	2	3	4	5	6
0,259	0,251	0,269	0,269	0,274	0,253
0,257	0,240	0,268	0,268	0,272	0,244
0,264	0,243	0,265	0,265	0,270	0,256
0,250	0,244	0,243	0,243	0,258	0,241
0,263	0,244	0,273	0,273	0,279	0,259
0,254	0,243	0,267	0,267	0,259	0,260
0,262	0,232	0,253	0,253	0,259	0,240
0,258	**0,242**	**0,263**	**0,263**	**0,267**	**0,250**

Phase 3

1	2	3	4	5	6
0,244	0,229	0,242	0,251	0,252	0,240
0,241	0,229	0,252	0,229	0,256	0,231
0,251	0,233	0,261	0,250	0,261	0,241
0,246	0,239	0,269	0,253	0,247	0,245
0,249	0,231	0,266	0,259	0,265	0,228
0,249	0,222	0,242	0,252	0,245	0,246
0,242	0.232	0,252	0,242	0,244	0,227
0,246	**0,231**	**0,255**	**0,248**	**0,253**	**0,237**

Phase 4

1	2	3	4	5	6
0,250	0,246	0,257	0,264	0,256	0,263
0,264	0,249	0,248	0,248	0,258	0,255
0,255	0,255	0,270	0,260	0,263	0,260
0,261	0,253	0,253	0,261	0,257	0,260
0,243	0,258	0,258	0,251	0,241	0,266
0,252	0,255	0,255	0,259	0,264	0,246
0,254	0,250	0,250	0,263	0,263	0,251
0,255	0,248	0,248	0,257	0,263	0,261
0,253	0,236	0,236	0,281	0.265	0,253
0,269	0,255	0,255	0,263	0,255	0,245
0,256	**0,251**	**0,253**	**0,261**	**0,258**	**0,256**

Phase 4

1	2	3	4	5	6
0,242	0,235	0,239	0,248	0,250	0,247
0,240	0,238	0,242	0,252	0.247	0,233
0,246	0,237	0,257	0,246	0,248	0,253
0,242	0,240	0,255	0,250	0,244	0,254
0,239	0,243	0,243	0,242	0,246	0,239
0,250	0,244	0,243	0,249	0,251	0,248
0,254	0,238	0,249	0,249	0,231	0,239
0,243	0,245	0,247	0,248	0,251	0,250
0,241	0,246	0,252	0,247	0,252	0,252
0,236	0,244	0,235	0,235	0,247	0,233
0,243	**0,241**	**0,246**	**0,247**	**0,247**	**0,245**

APPENDIX 5

Coated paper weights from the second test run before and after drying

Phase 1

1	2	3	4	5	6
0,257	0,233	0,252	0,231	0,247	0,232
0,245	0,247	0,260	0,252	0,249	0,245
0,256	0,239	0,257	0,237	0,256	0,240
0,251	0,238	0,252	0,238	0,251	0,238
0,241	0,250	0,249	0,240	0,249	0,235
0,235	0,246	0,249	0,237	0,245	0,238
0,246	0,245	0,253	0,239	0,231	0,243
0,247	**0,243**	**0,253**	**0,239**	**0,247**	**0,239**

Phase 1

1	2	3	4	5	6
0,248	0,225	0,243	0,223	0,236	0,225
0,244	0,238	0,251	0,242	0,237	0,236
0,237	0,229	0,249	0,226	0,245	0,232
0,225	0,226	0,240	0,226	0,235	0,224
0,228	0,235	0,236	0,225	0,235	0,230
0,234	0,234	0,236	0,234	0,231	0,227
0,234	0,232	0,240	0,227	0,219	0,225
0,236	**0,231**	**0,242**	**0,229**	**0,234**	**0,228**

Phase 2

1	2	3	4	5	6
0,255	0,236	0,255	0,235	0,244	0,237
0,257	0,238	0,258	0,229	0,236	0,250
0,239	0,247	0,257	0,230	0,242	0,232
0,250	0,236	0,238	0,253	0,236	0,248
0,250	0,234	0,261	0,225	0,243	0,234
0,247	0,252	0,256	0,229	0,247	0,241
0,252	0,234	0,243	0,245	0,245	0,237
0,250	**0,240**	**0,253**	**0,235**	**0,242**	**0,240**

Phase 2

1	2	3	4	5	6
0,235	0,225	0,246	0,226	0,238	0,226
0,241	0,227	0,246	0,219	0,227	0,240
0,244	0,236	0,248	0,213	0,233	0,224
0,245	0,226	0,227	0,242	0,225	0,238
0,228	0,223	0,250	0,215	0,233	0,225
0,238	0,224	0,232	0,220	0,237	0,231
0,239	0,242	0,247	0,235	0,235	0,227
0,239	**0,229**	**0,242**	**0,224**	**0,233**	**0,230**

APPENDIX 6

Coated paper weights from the second test run before and after drying

Phase 3

1	2	3	4	5	6
0,262	0,244	0,257	0,236	0,245	0,243
0,246	0,246	0,252	0,239	0,248	0,241
0,259	0,238	0,259	0,234	0,248	0,238
0,259	0,241	0,255	0,239	0,248	0,240
0,252	0,237	0,254	0,235	0,249	0,244
0,253	0,245	0,254	0,237	0,243	0,246
0,254	0,242	0,256	0,241	0,252	0,247
0,255	**0,242**	**0,255**	**0,237**	**0,248**	**0,243**

Phase 3

1	2	3	4	5	6
0,252	0,234	0,248	0,227	0,236	0,235
0,235	0,238	0,242	0,229	0,239	0,231
0,248	0,229	0,248	0,225	0,239	0,230
0,248	0,232	0,245	0,230	0,238	0,231
0,242	0,227	0,244	0,226	0,243	0,234
0,243	0,235	0,244	0,231	0,239	0,236
0,245	0,232	0,248	0,229	0,233	0,236
0,245	**0,232**	**0,246**	**0,228**	**0,238**	**0,233**

Phase 4

1	2	3	4	5	6
0,262	0,248	0,259	0,252	0,253	0,245
0,267	0,238	0,271	0,235	0,271	0,232
0,263	0,258	0,282	0,278	0,244	0,259
0,261	0,257	0,241	0,266	0,270	0,232
0,258	0,263	0,273	0,253	0,258	0,247
0,255	0,247	0,255	0,243	0,259	0,244
0,262	0,240	0,262	0,239	0,264	0,234
0,261	**0,250**	**0,263**	**0,252**	**0,260**	**0,242**

Phase 4

1	2	3	4	5	6
0,247	0,236	0,246	0,238	0,240	0,233
0,249	0,227	0,258	0,223	0,257	0,221
0,248	0,245	0,269	0,241	0,232	0,248
0,256	0,245	0,228	0,265	0,257	0,220
0,251	0,251	0,260	0,254	0,246	0,235
0,245	0,236	0,243	0,231	0,246	0,223
0,252	0,231	0,251	0,227	0,250	0,234
0,250	**0,239**	**0,251**	**0,240**	**0,247**	**0,231**

APPENDIX 7

Base paper properties

	Roughness, ml/min
1	214
2	183
3	167
4	207
5	208
6	173
7	205
8	201
9	163
10	185
11	163
12	148
Average	**185**

	Air permeability, ml/min
1	97
2	110
3	110
4	94
5	99
6	101
7	87
Average	**100**

	Basis weight, g/m
1	0,421
2	0,443
3	0,444
4	0,422
5	0,431
6	0,425
7	0,426
8	0,430
9	0,429
10	0,435
Average	**0,431**

	COBB, g/m²
1	52,8
2	50,2
3	50,1
4	50,1
Average	**50,8**

APPENDIX 8

Coat weights after test runs

Test run 1

	Phase 1	Phase 2	Phase 3	Phase 4
1	0,477	0,516	0,520	0,504
2	0,486	0,504	0,496	0,517
3	0,489	0,482	0,499	0,488
4	0,496	0,488	0,529	0,495
5	0,485	0,495	0,499	0,499
6	0,513	0,497	0,492	0,492
7	0,486	0,483	0,534	0,506
8	0,509	0,477	0,516	0,517
9	0,479	0,529	0,508	0,493
10	0,508	0,514	0,501	0,503
Average	**0,493**	**0,499**	**0,509**	**0,501**

Test run 2

	Phase 1	Phase 2	Phase 3	Phase 4
1	0,491	0,478	0,491	0,519
2	0,493	0,481	0,485	0,5
3	0,493	0,477	0,485	0,533
4	0,489	0,48	0,489	0,497
5	0,486	0,485	0,486	0,498
6	0,488	0,483	0,487	0,493
7	0,486	0,483	0,5	0,513
8	0,47	0,487	0,481	0,499
9	0,494	0,488	0,492	0,522
10	0,49	0,48	0,479	0,501
Average	**0,488**	**0,4822**	**0,4875**	**0,5075**

APPENDIX 9

Papers thickness variations after first test run (μm)

Phase 1

	1	2	3	4	5	6
1	73,3	74,0	74,3	75,6	75,1	73,0
2	75,7	74,6	75,0	74,9	75,1	73,6
3	75,5	73,4	75,2	75,5	75,3	73,9
4	74,3	73,5	75,3	75,6	75,1	73,4
5	74,0	73,0	74,8	75,3	75,2	73,6
6	74,2	73,6	74,3	75,9	75,2	73,2
7	74,2	75,5	74,4	75,7	74,8	72,7
8	73,5	73,5	75,6	75,7	74,8	73,5
9	74,1	73,0	75,0	75,6	74,9	74,5
10	75,3	73,6	75,9	75,9	74,8	73,1
Average	**74,4**	**73,8**	**75,0**	**75,6**	**75,0**	**73,4**

Phase 2

	1	2	3	4	5	6
1	77,3	77,0	80,3	75,6	76,6	75,0
2	75,7	76,6	80,3	77,3	75,1	74,6
3	75,5	77,4	79,8	76,5	77,1	74,9
4	75,0	77,5	79,0	76,6	77,0	75,4
5	75,0	78,0	80,1	77,3	79,0	75,6
6	74,9	78,6	80,5	76,9	78,4	75,2
7	75,9	75,5	79,3	76,7	76,3	74,7
8	75,5	77,5	79,4	76,2	78,3	74,5
9	74,9	77,0	80,0	75,6	76,6	74,5
10	75,3	78,6	79,9	75,9	76,9	74,7
Average	**75,5**	**77,4**	**79,8**	**76,5**	**77,1**	**74,9**

Phase 3

	1	2	3	4	5	6
1	75,6	74,3	75,6	75,7	75,3	72,0
2	75,9	75,7	76,3	75,6	75,0	72,6
3	75,5	75,5	76,5	75,3	75,2	73,0
4	75,6	74,3	76,6	75,1	75,3	72,4
5	75,3	74,8	76,3	75,2	74,8	72,6
6	75,9	74,2	76,9	75,2	74,3	73,2
7	75,7	74,2	76,7	75,8	75,0	72,7
8	75,7	73,5	76,2	75,4	75,0	72,5
9	75,6	74,1	75,6	74,9	75,0	72,5
10	75,9	75,3	75,9	74,8	75,9	72,5
Average	**75,7**	**74,6**	**76,3**	**75,3**	**75,1**	**72,6**

APPENDIX 10

Papers thickness variations after first test run (µm)

Phase 4

	1	2	3	4	5	6
1	76,7	77,0	76,6	77,3	75,6	75,1
2	75,1	76,6	75,1	75,7	77,3	75,1
3	77,1	77,4	77,1	75,5	76,5	75,3
4	77,0	77,5	77,0	75,5	76,6	75,1
5	79,0	77,2	79,0	75,6	77,3	75,2
6	78,4	77,6	78,4	74,9	76,9	75,2
7	77,3	75,5	77,3	75,9	76,7	74,8
8	78,3	77,5	77,3	75,5	76,2	74,8
9	76,9	77,0	76,9	74,9	76,6	74,9
10	76,9	76,6	77,9	75,3	75,9	74,8
Average	**77,3**	**77,0**	**77,3**	**75,6**	**76,6**	**75,0**

Papers thickness variations after second test run (µm)

Phase 1

	1	2	3	4	5	6
1	75,5	75,3	76,3	74,8	76,0	74,3
2	75,6	75,7	76,2	74,7	75,9	75,7
3	75,1	75,5	76,1	74,4	75,8	75,5
4	75,2	75,5	76,0	74,5	75,8	74,3
5	75,3	75,6	76,3	74,6	75,7	74,8
6	75,6	75,9	76,1	74,5	75,9	74,2
7	75,8	75,9	76,4	74,6	75,8	74,2
8	75,5	75,5	76,1	74,5	76,3	74,5
9	74,6	75,9	76,3	74,7	75,9	74,1
10	74,6	75,3	76,4	74,5	75,7	75,3
Average	**75,3**	**75,6**	**76,2**	**74,6**	**75,9**	**74,7**

Phase2

	1	2	3	4	5	6
1	73,3	72,0	73,0	71,7	71,7	71,5
2	75,7	72,2	73,0	71,2	71,7	71,3
3	75,5	72,0	73,1	71,5	71,5	71,4
4	74,3	72,4	73,4	71,4	71,6	71,4
5	74,6	71,5	73,0	71,5	71,5	71,2
6	74,2	72,2	73,2	72,1	71,9	71,5
7	74,2	72,0	72,7	71,9	71,9	71,8
8	73,5	71,6	73,5	71,6	71,8	71,6
9	74,1	72,1	72,5	71,6	71,6	71,5
10	75,3	72,2	73,1	71,6	71,6	71,3
Average	**74,5**	**72,0**	**73,0**	**71,6**	**71,6**	**71,5**

Papers thickness variations after second test run (μm)

Phase 3

	1	2	3	4	5	6
1	74,3	72,0	73,8	73,4	72,1	72,6
2	75,7	72,6	74,7	73,5	72,1	72,6
3	75,5	72,9	75,5	73,1	72,3	72,1
4	74,3	72,4	74,3	73,4	72,2	72,4
5	74,2	72,6	74,0	73,0	71,5	73,0
6	74,2	72,2	74,2	73,2	72,2	72,8
7	74,2	72,7	74,2	72,7	72,0	72,7
8	73,5	72,5	74,5	73,5	71,7	72,3
9	74,1	72,5	74,1	73,5	72,1	72,5
10	75,3	73,1	74,3	73,1	72,1	72,1
Average	**74,5**	**72,5**	**74,4**	**73,2**	**72,0**	**72,5**

Phase 4

	1	2	3	4	5	6
1	76,0	75,3	76,6	74,8	75,3	71,6
2	75,9	75,7	76,3	75,7	75,0	71,7
3	75,8	75,5	76,2	75,5	75,2	71,6
4	75,7	75,5	76,1	74,3	75,3	71,6
5	75,7	75,6	76,0	74,4	75,8	71,5
6	75,9	74,9	76,3	74,3	75,3	71,8
7	75,7	75,9	76,3	74,4	75,0	71,7
8	76,3	75,5	76,2	73,5	75,0	71,7
9	75,8	75,3	76.4	74,7	75,0	71,6
10	75,9	75,6	76,3	75,3	75,9	71,6
Average	**75,9**	**75,5**	**76,3**	**74,7**	**75,3**	**71,6**

Afstand in cm/Distance in cm/Abstand in cm/Distance en cm

Snelheid in m/s - Velocity in m/s - Geschwindigkeit in m/s - Vitesse en m/s

BOEKDRUK/LETTERPRESS/ BUCHDRUCK/TYPOGRAPHIQUE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Vallend gewicht/Pendulum drive/Fallgewicht/Avec pendule			0.27	0.36	0.44	0.52	0.59	0.66	0.73	0.79	0.85	0.91	0.96	1.01	1.06	1.10	1.14	1.17	1.20	1.23	1.25
Veer A / Spring A / Feder A / Accélération A			0.84	1.06	1.26	1.44	1.61	1.77	1.91	2.03	2.14	2.24	2.33	2.39	2.44	2.47	2.49	2.50	2.50	2.49	2.48
Veer M / Spring M / Feder M / Accélération M			0.94	1.20	1.43	1.64	1.83	2.01	2.17	2.32	2.45	2.57	2.68	2.76	2.84	2.90	2.95	2.99	3.01	3.03	3.03
Veer B / Spring B / Feder B / Accélération B			1.05	1.34	1.59	1.82	2.04	2.24	2.43	2.60	2.75	2.88	3.01	3.12	3.22	3.30	3.36	3.41	3.44	3.45	3.47
OFFSET																					
Vallend gewicht/Pendulum drive/Fallgewicht/Avec pendule			0.28	0.36	0.43	0.50	0.57	0.64	0.70	0.76	0.82	0.88	0.93	0.97	1.01	1.04	1.07	1.10	1.12	1.14	1.16
Veer A / Spring A / Feder A / Accélération A			0.76	0.96	1.14	1.30	1.44	1.58	1.69	1.79	1.88	1.96	2.02	2.06	2.08	2.09	2.08	2.07	2.04	2.01	1.96
Veer M / Spring M / Feder M / Accélération M			0.84	1.08	1.28	1.47	1.65	1.80	1.95	2.08	2.19	2.29	2.38	2.46	2.52	2.56	2.58	2.59	2.59	2.58	2.56
Veer B / Spring B / Feder B / Accélération B			0.95	1.20	1.43	1.64	1.83	2.01	2.18	2.33	2.47	2.60	2.71	2.80	2.88	2.93	2.98	3.01	3.03	3.03	3.01

3. Nopeustaulukko A1, A2, A1-3 ja A2-3 laitteille

Afstand in cm/Distance in cm/Abstand in cm/Distance en cm

Snelheid in m/s - Velocity in m/s - Geschwindigkeit in m/s - Vitesse en m/s

Ingestelde eindsnelheid / Pre-set ultimate velocity / Eingestellte höchstgeschwindigkeit / Vitesse finale ajustée	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.5 m/s				0.12	0.14	0.16	0.18	0.20	0.23	0.25	0.27	0.30	0.32	0.34	0.36	0.39	0.41	0.43	0.45	0.48	0.50
1.0 m/s				0.23	0.27	0.32	0.36	0.41	0.45	0.50	0.54	0.59	0.64	0.68	0.72	0.77	0.82	0.86	0.91	0.95	1.00
1.5 m/s					0.41	0.48	0.54	0.61	0.68	0.75	0.81	0.89	0.96	1.02	1.10	1.16	1.23	1.29	1.36	1.43	1.50
2.0 m/s						0.64	0.73	0.82	0.91	1.00	1.09	1.18	1.27	1.36	1.45	1.54	1.64	1.73	1.82	1.91	2.00
3.0 m/s						0.96	1.09	1.23	1.36	1.50	1.63	1.77	1.91	2.04	2.17	2.31	2.46	2.59	2.73	2.86	3.00
4.0 m/s						1.27	1.45	1.64	1.82	2.00	2.18	2.36	2.54	2.73	2.91	3.09	3.27	3.45	3.64	3.82	4.00
5.0 m/s						1.59	1.81	2.06	2.28	2.50	2.72	2.95	3.18	3.41	3.64	3.86	4.09	4.31	4.55	4.78	5.00
6.0 m/s							2.17	2.46	2.73	3.00	3.27	3.54	3.81	4.09	4.36	4.63	4.90	5.18	5.46	5.73	6.00
7.0 m/s							2.54	2.87	3.18	3.50	3.81	4.13	4.44	4.78	5.09	5.41	5.72	6.04	6.37	6.68	7.00

4. Nopeustaulukko AC2, AIC2 ja AIC2-5 laitteille

IGT/Reprotest B.V.

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