IR Dryers as a Tool in the Press Section

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Abstract

The perceived low energy efficiency of infrared has prevented its widespread adoption as a means to increasing moisture removal when applied to the sheet before the last press. The conversion efficiency of primary energy into infrared and subsequent absorption of this energy by the sheet is in the region of 60% when the energy is emitted at wavelengths longer than 1.35µm. Taken in isolation, this level of efficiency is too low when compared with the cost of steam in hot air dryers or cylinders. There has also been concern that the high intensity of infrared would have a detrimental effect on the quality of the fibre.

The quality and efficiency aspects of using high intensity short wave infrared to increase the moisture removal from the sheet have been the subjects of exhaustive trials by Andritz on their pilot plant in Graz using Compacts Infrared emitters.

The combination of pre-heating the sheet and increased dewatering at the last press increases the efficiency of primary energy use enormously. The sheet dryness increases significantly following infrared heating and press dewatering. This double effect, increasing both the sheet solids and sheet temperature prior to the main drying mode, contributes to an overall higher increase in drying capacity than the direct use of primary energy at 60% efficiency would suggest.

Heating the sheet prior to the last press requires a different approach to the application of infrared than if a surface effect were required, such as the drying of an aqueous coating on a thin sheet of paper. To be effective, the infrared needs to be able to penetrate the full bulk of the sheet, while at the same time minimising losses from the system due to reflection and transmission.

Gaining penetration to the middle of the sheet and maximising absorption of the infrared by the cellulose requires the generation of the correct wavelengths of infrared. If the wavelength is less than 1.2µm, the energy will pass straight through the sheet and if it is longer than 2.1µm, 80% of the output will be absorbed by the first 20µm of sheet thickness. Emitting the infrared at a peak output wavelength of 1.35µm ensures that the entire sheet mass is heated almost isothermally so overheating of the sheet surface will not occur. Furthermore, the free water present on the surface of the wet pulp where the infrared is applied evaporates and cools the sheet surface once the required sensible heat has been applied.

Short wave infrared dryers need to be cooled to optimise their performance and maximise the working life of the high temperature components. The cooling air absorbs up to 20% of the input energy and when it is exhausted from the dryers it has a very low %RH and a temperature in excess of 130ºC. Feeding this exhaust air in to the makeup air of the hot air dryers following the press section significantly increases the overall thermal efficiency of the infrared application.

Both of the concerns mentioned at the beginning have been tested and evaluated and some important findings and results will be part of the paper along with an overview of the equipment used.

Introduction

The energy used to dry the pulp web in pulp mills is huge. Nearly the same amount of water has to be evaporated as the mass of pulp produced. Although the efficiency of pulp drying equipment is high (nearly 80%) including power for air circulation, pulp drying is one of the biggest energy consumers in pulp mills. Pulp drying is also very often a production bottleneck.

Let’s suppose that we have a pulp line with a production of 1000 adt/d. A usual pulp web dryness before dryer is about 52%. The machine speed 200 m/min and web temperature 60°C. Pulp is dried to final dryness of 90%. This line will be used as base for energy calculation in this paper.
The energy needed do dry the pulp web to final dryness can be calculated as follows: -
Generally, the specific evaporation energy to remove water from a web with a temperature of 75 to 80°C is 2320 kJ/kg and this should be used for pulp when removing moisture between 52 and 80% solids. The evaporation heat increment (approximately 300 kJ/kg) can be applied as a mean value for pulp moisture removal from 80 to 90% solids. Steam diffusion is not included in this calculation. So the calculation results are more applicable to changes in machine speed than in basis weight.

Our pulp dryer works to its limit and evaporates 730 tons of water per day using 1720 GJ in energy absorbed by the web. The air dryer circulates hot air by convection and fans with total power consumption of 3,4 MW which corresponds to 295 GJ per day or 82 kWh/adt. About 60% of this energy (180 GJ) is transformed through friction into heat. Using a good efficiency of 80%, the steam will supply 1970 GJ to achieve final dryness. The LP steam condensing energy is about 2120 kJ/kg. The pulp dryer has to be supplied with 10,8 kg/s (38,7 t/h) of LP Steam.

The pulp dryer capacity is 730 tons of evaporated water. Pulp makers use specific steam consumption figures as follows: -

Tons steam to adt Pulp = 0.93 or
Tons steam to 1 ton evap. water = 1.27

To evaporate more water from the existing dryers, MP steam could be used or higher sheet solids entering the dryer could be achieved. The second possibility is the topic of this paper.

Effect of pulp dryness on drying capacity

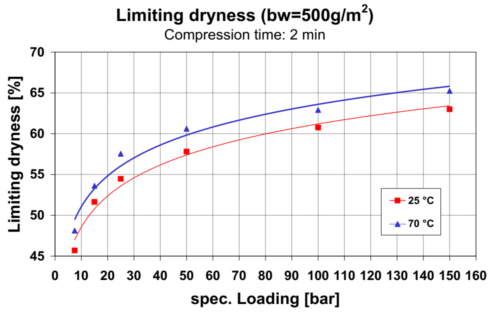
Increasing the pulp solids to 53% exiting the press section, our pulp dryer has to evaporate 690 tons water using 1640 GJ. This means there are 80 GJ free drying capacity to evaporate an additional 35 tons of water per day, which corresponds to a production increase of 45atp/d from 1000 adt/d to 1045 adt/d using the same evaporation capacity of 730 tons of water per day.

If the sheet solids can be increased to 54% at the pulp dryer inlet, the pulp dryer will evaporate only 667 tons water per day using 1570 GJ. The free drying capacity in this case is 150 GJ. This results in an increase of pulp drying capacity to 1090 adt/d.

This basic heat balance calculation documents the importance of the dewatering performance. All efforts should go to increasing dewatering in the presses before drying.

The dewatering limits are determined using the limiting dryness method. According to this method the pulp web with defined basis weight is subjected to growing pressure stress. The pressure stress time is of unlimited length. This means that after defined time the pressure and the dryness are plotted to produce a limiting dryness curve (see Fig.1)

Figure 1. Comparison of limiting curves done by 25°C and 70°C



Of course, in reality, the amount of time that the sheet benefits from the press impulse in the presses is limited by speed and roll nip length. This means that pulp dryness cannot reach the limiting dryness values, however, the limiting dryness method shows the limits for particular pulp species.

The press section consists of several roll nips. The fist two units are used to consolidate the web by careful removal of water. Once consolidated, the sheet can be subjected to heavy pressing. The particular nip results contribute to final dryness with different ratios. Rather unexpectedly, the dryness improvement in the preceding roll nip contributes to the dryness results after following roll nip by hardly a third. The closer to the limiting dryness curve then the lower the contribution of the preceding nip to the common dryness result. This behaviour is clearly documented by limiting dryness curve. In many cases an additional roll nip unit lined into the press section does not bring the expected increases in sheet solids, and sometimes there is no measurable increase.

Given the limitations imposed by the limiting dryness curve, the question is, how do you increase the dryness from press section in order to increase production capacity of the pulp drying line? The drying capacity of pulp drying equipment is not expressed by tons of pulp but by tons of water, which have to be evaporated from the pulp web.

Pulp web uniform formation results to higher dewatering efficiency

One of the most important issues to bring the dryness after the press section near to the limiting dryness curve is to improve web formation on the fabric. The more homogenous the web basis weight, the higher the dryness after the press section. An uneven CD basis weight profile decreases dewatering result enormously. Areas of the sheet with a high basis weight are pressed effectively, but lower basis weight areas miss out on the full effects of the press nip. Although the specific press impulse is linearly higher, the web compressibility decreases with the square of the basis weight [equation 1] and the dryness result is definitively lower than with uniform basis weight. Moreover, unequal basis weight results in a higher re-watering effect (see reference 1).

Andritz AG has developed a simulation of the dewatering process under nip. The simulated dryness results correspond with measured values with an accuracy of 0,5% absolute, which is the accuracy of laboratory method. The limiting dryness is an important part of the model formula: -

$$C_{out} = C_l - \frac{C_l - C_{in}}{\exp\left((\sigma /G)^2 * P_i * C_{kr}/(32 * \eta * C_l)\right)} \qquad [1]$$

Where:
Cout is pulp dryness after nip
Cin is pulp dryness before nip
C_{kr} is pulp critical dryness
C_l is limiting dryness value for used press P
P_i is pres impulse
G is basis weight
σ is specific weight of pulp web
η is water viscosity

Knowing C_l from laboratory measurement and C_{kr} from measurement in the nip, the model predicts very exact results to process variations in speed, line press, basis weight or different dryness values before nip. Using this model in conjunction with practical measurement, production calculated as multiplication of basis weight and speed brings higher dryness for lower basis weight and higher speed and vice versa. This observation is an important issue when looking for free drying capacity.

Web temperature as tool to increase pulp web compressibility

The other well-known method to increase dryness from the press section is to increase web temperature. According to many publications, higher web temperature lowers the water viscosity, which leads to lower dewatering resistance. There are not many publications describing the increase of web “elasticity” caused by higher pulp fibre temperatures. The compressibility of the pulp web contributes more to increased sheet solids than the lowering of water viscosity. This fact can again be seen on the limiting dryness curve. A 10ºC increase in web temperature increases limiting dryness results by about 1%. Change in water viscosity is not relevant for these laboratory tests.

Also in the press section the web temperature difference of 10°C results (according to experience) to dryness difference of 1%. The higher web temperature, the higher web dryness after the last nip roll. Of course, this dependency is not linear. To maintain high web temperature by heating the whole water system is limited by evaporation, heat convection and conduction losses in the dewatering area. The high web temperature supports evaporation and the web surface is cooled down. The pulp and water are not good temperature conductors (0,12 W/m°K) and it takes time to conduct heat from web bulk to web surface. Nevertheless, the heat energy should be applied just before press nip in order to minimize any temperature loss. Water evaporation depends on the difference between steam pressure in the web and vapour partial pressure in the surrounding air. High web temperatures over 85°C leads to high evaporation rates and additional heating energy used over a certain web temperature does not contribute to web compressibility.

Targets of trial tests

Obviously the main temperature effect can be achieved by gaining a higher web temperature just before the last press roll nip. Heat energy applied in front of the previous nip contributes a third to the total dryness exiting the press.

Thus there are 2 clearly defined conditions:

1. To increase web temperature just before last roll nip using the minimum amount of heating energy
2. To avoid heavy evaporation from web surface before the roll nip

Knowing these basic “rules” Andritz has started web temperature trial tests on its’ pilot machine. Compact Engineering Ltd supplied the electric infrared (IR) heating equipment. The last press in the press section of the pilot machine was a shoe press. IR was mounted just before the leading roll of shoe press about 1 m MD direction from the nip. The results of the trial tests should answer the three following basic questions: -

1. What is the maximum achievable increase in sheet solids?
2. What is the temperature homogeneity in the web Z direction?
3. Is there any tendency to loose brightness in the fibres due to the use of the IR to heat the sheet?

The principles of heat transfer by IR radiation are well known in the paper industry. Infrared equipment is used to heat coated web surfaces to increase temperature of coating layer and to dry coating mass according to the drying recipe (time and evaporation speed). In the majority coat drying cases gas IR is used. Gas IR produces IR temperatures in the range of 900 – 1100°C. According to Planck’s law, the main IR energy is concentrated in a band of wavelengths between 2,5µm and 3,5µm. This radiation has low transmissivity and is absorbed exactly where it should be, in the coating layer, with 80% of the energy being absorbed in the first 20 µm of product thickness.

Quiet a different goal is wanted when heating a pulp web with basis weight over 1000 g/m^2. In this case evaporation is not required. All heat energy should stay in the web to support the dewatering process at the presses. The homogeneous temperature profile in the web Z direction is an important target to intensify web compressibility. This means the IR is required to penetrate deep into the sheet. To achieve a homogeneous temperature profile through the sheet IR has to be applied simultaneously from both sides of the web (face to face implementation).

The available publications give quite different transmissivity values depending on the pulp species. But there is one clear message in the public knowledge: the shorter the IR wavelength the higher transmissivity through the pulp web. Wien's displacement law defines the relationship between wavelength and IR temperature. Burning gas is cooled by nitrogen and can theoretically achieve a temperature of about 1300°C. The IR temperature of electric IR is not limited by burning air and temperatures over 2600°C can be achieved. However, IR absorption by water or pulp is limited to wavelengths longer than 1.3µm. Running an emitter at 2600ºC produces a wavelength of 1.1µm. This issue is described in the publication 2.

There is a trade off between absorption, transmission and emitted energy. It is well known that the total mount of energy emitted from a body is calculated by multiplying the emissivity of the emitting body by the fourth power of the temperature. Thus the higher the emitter temperature then the greater the energy output. However, it is important to match the output wavelengths with the absorption characteristics of the matter being heated. A compromise between absorption and transmission has to be achieved to maximize IR energy absorption throughout the web thickness. This compromise can only be realized using electric IR with an emitter temperature of around 1880°C with a peak wavelength of 1.35µm.

Bouguers law determines the pulp web absorptivity as function of pulp web bulk

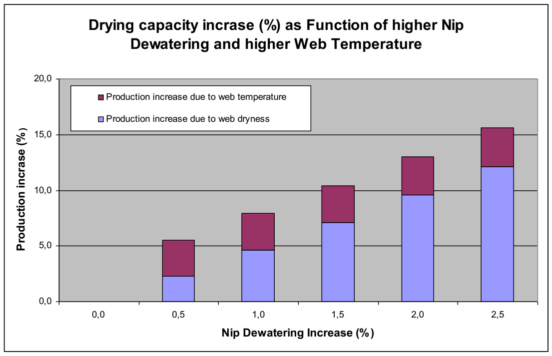
$$E_{abs} = E * (1 - \exp(-a_{pw} * L)) \qquad [2]$$

Where:
E_{abs} is absorbed IR energy in pulp web
E is IR energy emitted from IR heater
a_{pw} is absorption coefficient of pulp and water (depending on IR wave length)
L is bulk of pulp web

Pulp drying machines run at a speed of 200 m/min. This is about 10 times below the speed of today's coating machines. The high IR energy density 500kW/m^2 wakes up the question concerning web surface temperature. High temperatures over 120°C can irrecoverably change fibre properties. Therefore both web surface temperature and brightness had to be measured during trial tests. On the one hand the pulp web in the tested position contains enough free water so the relative web moisture is equal to 1 and water evaporated from web surface has a significant cooling effect. On the other hand the web surface is not uniformly flat and microscopic pulp picks can be overheated. Therefore the web surface has to be observed carefully.

Using IR heating energy to increase web compressibility brings secondary effect: The web after the press section is transported into Pulp dryer with higher temperature. Supposing the web mean temperature increases (after all losses) by about 12°C our pulp dryer is additionally fed with heat of 60GJ per day. This means that the sensible heat requirement of the pulp web is reduced and so frees-up capacity in the pulp dryer. The additional heat in the sheet makes better use of the pulp dryer, which is more effective at evaporating than getting the sensible heat to the centre of the sheet. Using dryness improvement of 1,5 % and adding an increase in web temperature of 12°C production capacity increases of about 10 % will be achieved. The figure 2 shows production capacity improvement as function of dryness and temperature gain from press section.

Figure2. Dryness and temperature contribution to drying capacity



These examples show a significant potential for capacity improvements in the drying line increasing pulp compressibility by higher web temperature. A usual web temperature in the press sections is about 60°C. Heavy evaporation from web surface begins at temperature between 75 to 80°C (depending on surrounding air humidity). To increase web temperature about 18°C (supposing production 1100 adt/d and web dryness before last nip 45%) an energy input of 120GJ will be needed. This energy corresponds with IR power of 2800 KW installed (assuming 50% absorption efficiency). This example shows that contrary to expectation the specific energy consumption without and with IR heating will not change.

Our dryer needs 2265 GJ per day, this means 2,27 GJ/adt or 630 kWh/adt without IR heating to realize production 1000 adt/d or; 2265 + 240 GJ per day, this means 2,28 GJ/adt or 633 kWh/adt with IR heating to realize production 1100 adt/d.

IR Trial methods conditions and results

Two electric short wave IR heaters from Compact Engineering each 550kW/m^2 were fixed face to face at the free draw location approximately 1 m MD direction before the last shoe press unit. 3 different pulp species were used to run machine in various conditions changing basis weight, speed, dryness before shoe press and web temperature. Basic pulp properties were investigated in the laboratory at the beginning and end of the trial (including limiting dryness and brightness loss phenomena).

During trial tests the pulp samples for lab dryness determination were taken from web before IR, after IR and after shoe press. In the same places and same time the web surface temperature on the top and bottom of the web were measured. The pulp was re-circulated and due to this the pulp properties was continuously changed. To keep results comparable the samples and measurements were performed for the unchanged conditions twice (with and without IR heating). It was necessary to stabilize test conditions before each measurement set (e.g. felt temperature). After measurement work was done the new test conditions were stabilized (e.g. speed or basis weight). Always only one condition was changed.

The most important information was dryness increase after the shoe press. Table 1 summarises the results of the trial tests. The different results are partly caused due to different fibre compressibility and also due to unequal web formation. Specific production means production per 1CDm. The abbreviation HW means hard wood and SW means soft wood.

Table 1. Summarized results of trial tests

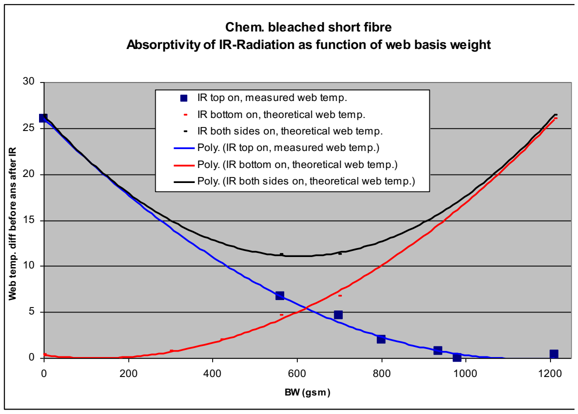
Web heating by electrical IR, summarized trial results	Spec. prod. adt/d	Web temp. incr. °C	Web dryness incr. %	Production incr. %
Pre dried HW	200 to 280	15	1,5	10
Fresh HW	200 to 250	16	2	12,5
Fresh SW	200 to 270	15	0,95	7,5

The best results have been achieved for fresh (not previously dried) short fibres. An increase in pulp dryness of greater than 2% has been achieved. This represents an enormous increase of production capacity. This trial shows a real potential to increase production capacity with an easy upgrade with marginal production down time.

In order to investigate IR transmissivity, the IR box placed below the web was switched off. After basis weight was reached and stabilized the top and bottom web temperatures were measured. Trial tests started with basis weight 450 g/m^2. The results are plotted in the figure 3. The temperature increase on top of the web was always 26°C independent of basis weight. This means the reflectivity phenomena from web bulk can be neglected. Above a basis weight of 1000g/m^2 has been reached no measurable temperature increase could be recorded on the underside of the web.

The measured temperature curve for one IR box placed on top of the web can be projected to opposite side as if the IR box were placed at the web bottom. The addition of these two curves is calculated temperature distribution in the case of face-to-face installation. Heat conductivity levels temperature in the bulk and evaporation will partly cool down the high surface temperature. So the realistic temperature distribution in Z direction can be taken as +/- 2.5°C.

Figure 3. Temperature distribution in web z direction



IR experience

No brightness loss effects have been observed during trial test in all three pulp species tested.

Efficiency of IR equipment

The overall efficiency of electric IR heating is calculated differently by different authors and depends on the evaluation method. Generally two efficiencies are subject to investigation

1. The conversion efficiency of power versus IR radiation energy
2. Absorption efficiency IR radiation energy versus absorbed energy.

In Compact Engineering's IR emitters, the converting efficiency is generally assumed to be 80% this means 80% of the power goes to IR radiation and 20% is lost to the cooling air. However, not all of the radiation generated is available for absorption by the web, resulting in a loss of total efficiency. Typically, 20% of the energy that is converted into radiation will be at wavelengths that are too short for absorption by cellulose fibre or water. The cooling air is needed to protect the lamps and other components in the dryer and is heated to 120 - 140 °C as it passes through the dryer.

Part of this air is blown to the web surface and contributes to overall heat efficiency by convective heat transfer stabilizing web position.

The IR radiation is distributed in wave spectrum between 1,2 to 3µm. Again, the longer waves are "immediately" absorbed by web water and its transmissivity is low. The shorter waves are absorbed more by fibres than by water molecules and carry IR energy deep in to the web bulk. Very short waves are not absorbed and the energy is lost. The IR lamp construction is a critically important factor for overall converting efficiency of power into absorbed heat.

Overall efficiency improvement

Our IR is supplied by power of 2800KW. IR converting efficiency is assumed to be 80%, with 20% lost to the cooling air. This means the air contains energy of 560kW and its temperature is 130°C. This represents useable energy of 48GJ per day. This air is dry, hot and has to be used in air dryer replacing 22.5 ton of steam per day or 0.25kg/s (0.95 t/h)

This air has to be connected to fresh air pipe after heat recuperation.

Added values

Using the IR equipment to increase production capacity brings additional benefits and possibilities into the pulp drying process. One of the added values is MD dryness control. IR equipment reacts incomparably quicker than air dryers. The broke (final dryness out of limits) can be minimize using corresponding control software. Especially grade change, speed change and start up are situations where efficient MD control can significantly decrease off production time.

In some case also the CD dryness profile control can be important issue. IR control zones in CD direction are narrow and react more efficiently than steam CD control equipment.

The installation of IR heaters can take place in a standard maintenance shut, minimising machine downtime. Most of the major installation work can be done while the machine is still running on normal production. High energy density on the machine minimizes space required for installation.

The maintenance costs are minimal and are concentrated mainly to lamp exchange (mostly 2 years guarantee time) and maintaining the porosity of the air filters.

Economical conclusion

Thorough research of prices and investment costs has been made for several variants of rebuilds The ROI calculation has been calculated based on customer profits. Some further economic advantages of IR technology have been included.

- The IR equipment is relatively light and small compared to other equipment and the mounting of the equipment does not require major machinery reconstruction.
- It also enables short shut down time. A 10% production increase can be realized within a 3 day shut down time.
- By cooling IR lamps the IR equipment produces hot exhaust air of 130°C. This air is dry and can be used directly in the pulp dryer saving about 4% of steam consumption
- The ROI (including all needed project activities including power price and production lost within production shut down) when calculated according to customer profit, in many cases is shorter the 6 months.

Conclusion

In many mills, drying is the limiting production factor. One of the possible solutions to increase pulp line production capacity in the range of 10% is an IR heating unit installed just before last press nip. High energy density improves pulp web compressibility, which results in higher web dryness from the press section. The removed water creates free capacity and more pulp can be passed through the pulp dryer keeping final dryness within the given limits.

The heat balance is additionally improved by higher web temperature leaving press section.

Web temperature limits the amount of energy that the IR can be used to add to the sheet. High web temperature supports high evaporation rates resulting in a significant cooling of the web surface. Evaporation from the web in the press section using IR heat is expensive and decreases overall efficiency of the infrared installation.

IR equipment effectively supports MD and CD dryness control that minimizes off quality pulp. Especially for situations like grade change and start up, production time can be significantly improved.

Experience shows that the combination of IR heat transfer and air drying gives the most efficient drying performance. Heat from the air exhausted from IR can be efficiently used in the Air Dryer increasing drying capacity.

The project costs calculation gives short ROI time and the short installation time contributes to customers' profit. High energy density means that the infrared needs only a small area on the machine for installation and limited changes to the pulp machine.

Literature researched

Infrared drying technology is widely used in the paper industry. Despite this fact only several theoretical works have been made, where IR heat penetration and absorption have been investigated. Most of them have been written in the past 15 years from different universities. The results have been obtained using laboratory equipment and methods. The works in references are directly dedicated to the absorption of infrared by pulp webs with higher basis weights.

In all the publications, the absorption of IR radiation by pulp sheets has been investigated. There is one unique conclusion that the penetration in Z direction of gas IR is significantly shorter then penetration of electric IR. Therefore, the gas IR equipment more commonly used for drying coating layers and electric IR for heavy board drying technology and CD moisture profile control.

The temperature distribution in Z-direction influences 3 phenomena: IR heat absorption, heat convection and evaporation. According to the published laboratory data, the majority of the short wave infrared takes place in the first 0,4mm of web thickness. Heat transfer by conduction in the web contributes to the equalization of the temperature profile. The conduction speed of heat transfer in web is about 0, 3 mm/s or 0, 58 W/m°C (COMPACT laboratory measurement on board). Total Z direction temperature equilibrium happens after 5 to 6 second (COMPACT data). According to the surrounding air conditions, evaporation from web surface will occur if the surface temperature rises significantly over 75°C.

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