OPPORTUNITIES FOR ENERGY SAVINGS IN THE DRYING SECTION

MOŽNOSTI PRIHRANKA ENERGIJE V SUŠILNI SKUPINI

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IZVLEČEK

Naraščajoče cene energije so štiri avstrijske papirnice spodbudile, da so pristopile k skupnemu projektu o prihranku energije v sušilni skupini papirnega stroja. Razvili so računalniški model za prenos toplote in snovi na štirih različnih papirnih strojih.

Pri modeliranju pretoka energije in vodne pare, ki izhaja iz papirnega traku v sušilni skupini, ter v sistemu rekuperacije toplote papirnih strojev so upoštevali fizikalne enačbe za prenos toplote in snovi. Modeli simulirajo različne nastavitve sušilne skupine in rekuperacije toplote na papirnem stroju. Uporabljajo se za optimiziranje nastavitev, ki se pozneje preverjajo s poskusi na strojih. Bistveni del računalniškega modela predstavlja grafični vmesnik, enak kot slika, ki jo ima papirničar, ko nadzira delovanje papirnega stroja. Tako je ta model simulacije papirničarjem preprost za uporabo ter primeren za poskuse in vajo.

Možnosti prihranka v sušilni skupini so obravnavane na osnovi modela in osnovnih znanj o poteku sušenja. Predstavljeni so trije primeri študije. Prvi je yankee sušilnik z vpihovalnikom vročega zraka, druga dva pa primera papirnih strojev z običajnima sušilnima skupinama. Obravnavani primeri so zahtevali nizke investicijske stroške in omogočili prihranke energije do 5 % oziroma 4.000 MWh/leto.

Ključne besede: papirni stroj, sušilna skupina, prihranek energije, računalniški model za prenos toplote in snovi.

ABSTRACT

Due to the increasing prices of energy, four Austrian paper companies started a joint project to save energy in the drying section. A computer simulation model of the heat transfer and mass transfer in four different paper machines has been developed. This model employs the physical relations for heat- and mass transfer to model the flow of energy and vaporized water from the web through the drying section and the heat recovery system of the paper machines. The models are simulating different settings in the paper machine drying section and heat recovery system. Simulations are used to define optimum machine settings which are then subsequently tested during machine trials. One of the key features of computer models is a graphical user interface identical to the operator screens used to control the specific paper machine. Thus, the simulation model is easy to use by mill staff and can also be applied for operator training.

Opportunities for saving energy in the drying section are discussed based on the model and some drying fundamentals. Three project case studies are presented, one study from a Yankee dryer with impingement hood and two studies from paper machines with conventional drying sections. The case studies presented require low investment costs and provide energy savings for up to 5 % or 4.000 MW$_{th}$ per year.

Keywords: paper machine, drying section, energy saving, computer simulation model, heat transfer, mass transfer.

1 INTRODUCTION

The drying process is a highly cost intensive part in paper production as up to 75 % of the overall thermal energy are applied there. Due to the fact that energy is getting more and more expensive a project has been started by the Institute for Pulp, Paper and Fibre Technology, Graz University of Technology, to optimise the drying section in terms of energy consumption.

As a basis to understand the mathematical model some drying fundamentals are discussed. Also the energy consumption necessary for evaporating the water out of the web in dependence of the dry content of the paper has to be determined. For each paper machine a physical simulation model of the drying group is developed. The models include the drying cylinders, IR and impingement dryers, heat recovery, condensate and steam system. It has been primarily developed by the company "Consulting Fisera" and by the project members of Graz University of Technology.

2 FUNDAMENTALS OF PAPER DRYING AND SIMULATION MODEL

The whole drying process can be split in several periods as shown in Figure 1 [1].

The heat up phase (A-B) is primarily used to increase the web temperature and only some energy is used for evaporating water out of the web. The first drying phase is identified by a more or less constant drying rate (B-C). Reaching a critical dry content (C), all water on the fiber surfaces has been evaporated and to further increase the dry content water has to diffuse through the dry paper web before evaporation. In the graph we see a decrease of the drying rate – this is the second drying phase (C-D). The third drying phase (D-E) starts at above 80 % dry content. The drying rate is decreasing rapidly in this third phase due hydrogen bonding and capillary effects, which are binding the water to the fibre surface. Additional evaporation energy is necessary to overcome these effects and this additional energy is called sorption enthalpy [2], see Figure 2. Water has a latent heat of 2.308,05 kJ/kg at 80 °C [5], this is equivalent to the heat of vaporization up to an equilibrium moisture content (EMC) of about EMC=0.3. At higher dry content the vaporization energy is increased by the heat of sorption, at e.g. 97 % dry content (EMC=0.03) the necessary heat for evaporation is about 2.900 kJ/kg instead of 2.300 kJ/kg implying that at this dry content we have a heat of sorption of 600 kJ/kg water. The integrated heat of sorption (shaded area) is up to 3 % compared to the latent heat of water, meaning that drying paper up to a dry content of 97 % the total heat of vaporization is about 3 % higher than the latent heat of water.

In order to understand the drying process the Stefan equation [4] (Formula 1) is discussed which describes the mass transfer of water evaporating from the web and is valid up to a dry content of about 75 %.

$$\dot{m}_V = \frac{\beta \cdot p_0}{T_{Paper} \cdot R_v} \ln\left(\frac{p_0 - p_v}{p_0 - p_{vp}}\right) \cdot A_{contact}$$

(Formula 1)

β – mass transfer coeff.[m/s]
m_v – evaporation rate [kg/s]
A_{contac} – paper surface area [m²]
p_o – total pressure [Pa]
p_v – vapour partial pressure of air [Pa]
p_{vp} – vapour partial pressure of the paper web [Pa]
T_{Paper} – temperature of paper web [K]
R_v – gas constant of vapour [J/kgK]

When the dry content is above about 75 % we have to consider diffusion effects because the moisture of the web has to permeate through dry paper areas to reach the web surface to be evaporated. The mass transfer at high dry content is denoted β*, it is given in Formula 2 [2]. Substituting β with β* leads to the modified Stefan equation (Formula 3) [4] for high dry content.

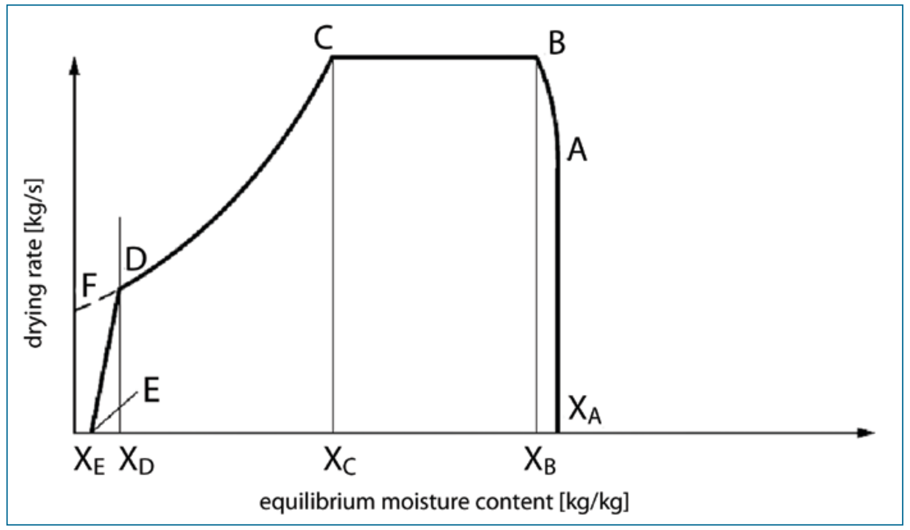

Figure 1: Moisture content changes as a function of paper moisture during paper drying. The x-axes shows the equilibrium moisture content X [kg/kg], y-axes shows the drying rate [kg/kgs]
Slika 1: Hitrosti sušenja v odvisnosti od ravnotežne vsebnosti vlage

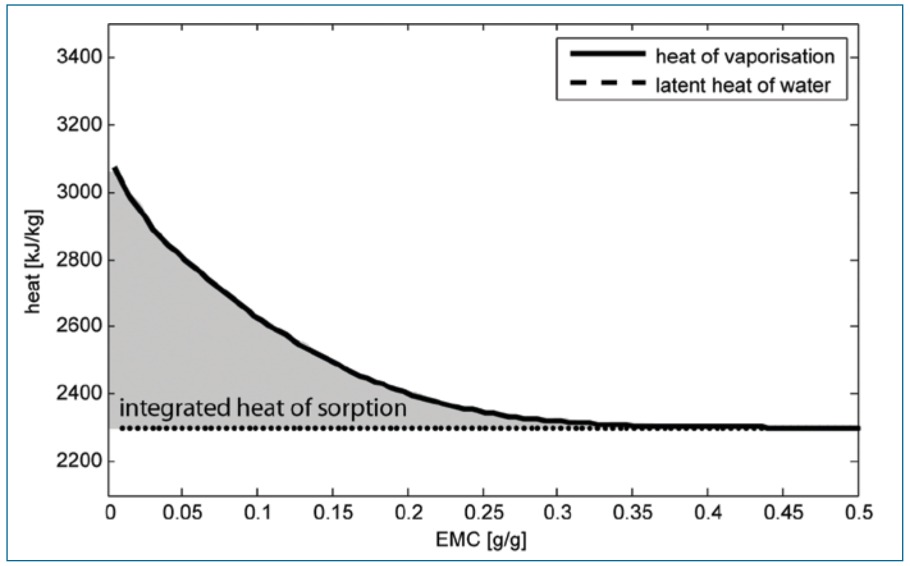

Figure 2: Heat of vaporization of unbleached Kraft pulp at 80 °C as a function of equilibrium moisture content (EMC) [3]. The heat of sorption is the difference between the latent heat of water (2308 kJ/kg) and the vaporization energy.
Slika 2: Toplota izhlapevanja nebeljene sulfatne celuloze pri 80 °C kot funkcija ravnotežne vsebnosti vlage (EMC). Sorpcijska toplota je razlika med vsebnostjo navidezne latentne toplote vode in energije izhlapevanja.

$$\beta^* = \frac{1}{\frac{1}{\beta} + \frac{\mu * s}{D}}$$

(Formula 2)

μ – diffusion resistance number [-]
D – diffusion coefficient [m²/s]
s – distance from water level in web to web surface [m]

$$\dot{m}_V = \frac{1}{T_{Paper} \cdot R_v} \cdot \frac{1}{\frac{1}{\beta} + \frac{\mu * s}{D}} \ln\left(\frac{p_0 - p_v}{p_0 - p_{vp}}\right) \cdot A_{contact}$$

(Formula 3)

According to equations 1 and 3 the evaporation rate is strongly depending on the constant parameters such as R_v, the paper surface area $A_{contact}$, the total pressure p_o and the variable parameters β, p_v and p_{vp}. The mass transfer coefficient β depends on different diffusion, mass transfer and paper surface parameters and cannot be influenced easily. The two remaining parameters give the major possibilities to influence the drying rate in a paper machine.

- 1.) Decreasing vapour partial pressure of the air (p_v)
  Vapour partial pressure of the air can be decreased by increasing the temperature or the dry content of the supply air in the drying hood or by improving supply air amount using blow boxes which are bringing fresh air to the paper surface.
- 2.) Increasing vapour partial pressure of the paper web (p_{vp})
  can be influenced by changing the web temperature. Increasing the drying rate can be achieved by increasing the temperature of the cylinder surface. Furthermore web temperature can be raised by increasing the draw of the drying fabrics which presses the paper web to the cylinder surface leading to a better heat transmission to the paper. In both cases the steam pressure has to be increased so that more temperature difference between cylinder surface and paper web is achieved and thus the heat flux to the paper web will be increased.

The impact of these possibilities for influencing the drying rate will be further discussed in the case studies (see chapter 2.1). To optimize a drying section one has to know the actual status of the machine. Therefore a mass and heat balance of the existing drying group including steam and condensate system is necessary. Based on the accurate heat and mass balance the physical drying simulation model is developed. The model is validated by

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online DCS measurements and manual control measurements of temperature, air moisture and air flow at various positions in the drying section and the heat recovery system. The model is optimised and validated until a maximum deviation between model and DCS values of lower than 5 % is achieved.

The simulation model includes following parameters

- All paper machine parameters like machine speed, grammage, machine width and surrounding conditions of air and paper web.
- Drying equipment like steam cylinder, impingement dryers, IR-dryers
- Heat recovery system with heat exchanger, fans and air streams
- The steam and condensate system for each drying group

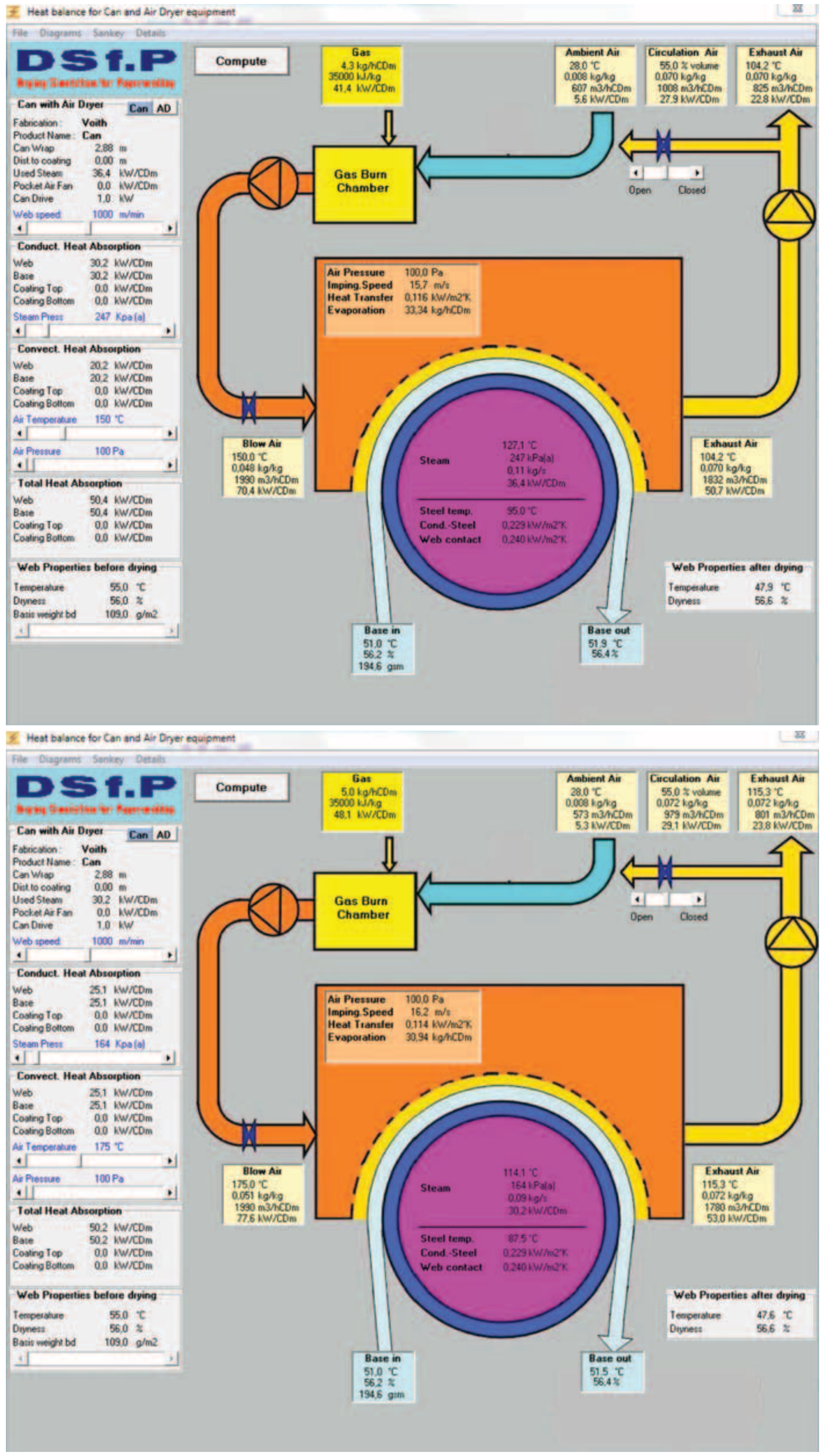

Figure 3: Example for Yankee machine. Case A: T= 175 °C, P=1.7 bar; Case B T= 150 °C, P=2,5 bar
Slika 3: Yankee stroj, primer A in B

- All relevant paper parameters in terms of drying (fibre mix, filler content, dry content before and after drying section)
- All the necessary equations for the heat and mass transfer during the drying process in the drying hood and heat recovery system.
- The images from the DCS user interface in order to facilitate application of the simulation model by operators as the program looks like the DCS system.
- Several paper properties at each cylinder like evaporation rate on cylinder, evaporation rate to next cylinder, paper and cylinder temperature, heat transfer coefficient.
- The prices for different energy sources (gas, steam, oil …) can be integrated in the simulation in order to simulate varying energy prices.

The main advantages for using such a simulation model are:

- Testing different machine settings for energy optimisation without any risk for troubles in production. The settings found in the simulation can then be tested in machine trials.
- Additional equipment can be added to the model fairly easy, like additional heat exchangers, additional impingement hoods et cetera. So the model can be used to calculate different scenarios for machine rebuilds and investments for new equipment.
- Application of the model as a training tool for operators.
- Increased cost awareness of operators. True costs for energy (gas, fuel, steam) can be integrated in the model and thus true cost results are obtained directly from the simulation.

3 APPLICATION CASE STUDIES

Three project case studies to save energy are discussed in this chapter

3.1 Influence of supply air temperature on a yankee machine

As discussed in chapter 3 there are two possibilities to influence the evaporation rate of a paper web. In term of a Yankee machine we can increase the absorbed heat of the paper web by increasing the steam pressure or by increasing the temperature of the air in the impingement hood. The example below in Figure 3 shows these two possibilities by the simulation model:

- Case A, the impingement temperature is 175 °C, cylinder steam pressure is 1.7 bar gauge
- Case B, the impingement temperature is 150 °C, cylinder steam pressure is 2.5 gar gauge

In both cases the heat absorption of the web and the drying performance are the same. The heat flux from the Yankee cylinder in case B however turned out to be more energy efficient than increased convection via impingement drying. The simulation model shows an energy advantage of about 1.8 % for case B. Another disadvantage of the impingement hood is that the supply air for the impingement dryer has to be heated by a gas burner and the energy prices for gas is 2,5 as high as for steam in the considered paper mill which adds another 3.5 % of cost difference. The combined effect leads to reduced energy costs of 5 % only due to increasing the steam pressure in the Yankee cylinder and lowering the temperature of the supply air in the impingement hood.

3.2 Possibilities to use exhaust air of infrared dryer

In some machines the exhaust air of an infrared dryer is not used in the heat recovery system. The amount of the exhaust air, in our case was close to 10.000 m³/h with a temperature of 165 °C and a moisture content of 0.01 kg/kg. This corresponds to an energy amount of close to 4.000 MW_{th}/year compared to fresh air. This heated air with low moisture content can be used in air hoods. This will lead to direct energy savings of 4.000 MW_{th}/year. Therefore the investment is just some piping and valves for redirecting the air stream, payback time for this investment is far below one year.

3.3 Optimisation of leakage air and recirculated air

In another case study the mass balance of exhaust and supply air turned out to be incorrect during our measurements. The amount of leakage air was more than 40 % of total air volume. The balance was somewhat complicated because exhaust air from the drying section was partly recirculated. With the simulation model it was demonstrated that the recirculation stream negatively influenced the energy demand for heating up the supply air. Also too much supply air was injected to the hood in order to avoid condensation. It turned out that the supply air stream had remained unchanged for several years although considerable modifications of the paper machine had been undertaken during that time.

The recirculation stream has now been closed and the supply air flow has been adapted to a value of 20 % leakage air, which turned out to be optimal according to modelling results. This lead to energy savings due to reduction of steam consumption for air heating and reduction of electric energy consumption from turning down the supply air fans. The energy savings were about 4.000 MW per year (thermal and electric combined), without any major investment in machine infrastructure.

4 CONCLUSIONS AND OUTLOOK

Based on an exact mass- and heat balance different approaches for energy optimization can be worked out and subsequently quantified using the developed simulation model. Evaluation of different settings in the model is easy because the simulation software has the same graphical user interface as the computer screens for controlling the paper machine. The results from the simulations are directly displayed on the screen and additionally the financial results are shown. A variety of optimization approaches and scenarios can be analyzed within a short time and the most promising machine settings found in the simulations can be verified in machine trials.

Project work so far identified two general aspects of energy savings. The first one is rather straightforward: it is beneficial to use the heat of the exhaust air for heating up supply air or process water. While this idea seems rather obvious, it is not fully implemented in all paper machines, especially not in older ones. Many paper machines run with high supply air temperatures. As shown in case study 4. 1 it is more cost effective to decrease the temperature in the supply air to lower energy costs. This effect is also confirmed by [4].

Application of the simulation model in four paper machines revealed so far an energy optimisation potential of 1 % to 5 % of total drying energy consumption. Payback time for the optimization was calculated to be between 0 months and two years, depending on the paper machine. Currently the optimization measures obtained from simulations are verified in machine trials at the participating companies. Results so far are in line with the predicted savings from simulations.

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