ENERGY ECONOMY OF THE HEAT RECOVERY AT THE PAPER MACHINE

Adj. Prof. Dr. Nenad Milosavljevic[1,2], Ivan Jerbic[3], Dipl. Eng., Mario Milosavljevic[2], BA

[1]Abo Akademi University
Faculty of Science and Engineering
Laboratory of Process and Systems Engineering
Turku, Finland

[2] Sunnea Oy, Consulting &Engineering
Air Systems, Drying & Runnability of
Paper, Board and Tissue Machines
Jyskä, Finland

[3] DS Smith Croatia, Belisce
Paper Division
Belisce, Croatia

Energy economy on the paper and board machine requires a systematic "step-by-step" approach. It includes systematic project phases that should be followed to take full advantage of energy management on the machine. An example of good energy management is the optimization of the heat recovery systems on the paper machine at DS Smith Croatia.

In a situation where air system is not optimized and deviate from the design values, the steam consumption at the PM3 is around 3,8 t/h higher. It accounts for about 15% of the total annual steam consumption needed for papermaking and other processes on the machine.

Optimisation of the heat recovery system and an improved airflows balance in the dryer section of the PM3 (DS Smith Croatia) allowed the process conditions in which the paper drying takes place to be brought closer to the design values, resulting in energy savings and an improvement in paper production at PM.

USTEDA TOPLINSKE ENERGIJE REKUPERACIJOM TOPLINE NA PAPIRNOM STROJU

Adj. Prof. Dr. Nenad Milosavljevic[1,2], Ivan Jerbic[3], Dipl. Eng., Mario Milosavljevic[2], BA

[1]Abo Akademi University
Faculty of Science and Engineering
Laboratory of Process and Systems Engineering
Turku, Finland

[2] Sunnea Oy, Consulting &Engineering
Air Systems, Drying & Runnability of
Paper, Board and Tissue Machines
Jyskä, Finland

[3] DS Smith Croatia, Belisce
Paper Division
Belisce, Croatia

Odrzivost i upravljanje energijom u papirnoj industriji zahtijeva sistematski pristup "korak po korak". To uključuje sustavne faze projekta koje treba slijediti kako bi u potpunosti bile iskoristene prednosti upravljanja energijom na stroju. Primjer dobrog upravljanja energijom je optimizacija sustava rekuperacije topline na papirnom stroju PM3 u DS Smith Hrvatska, Belisce.

U uvijetima kada zračni sistem nije optimiziran i odstupa od projektiranih vrijednosti, potrošnja pare na PM3 veća je za oko 3,9 t/h. To cini čini oko 15% ukupne godišnje potrošnje pare potrebne za proizvodnju papira i ostale procese koji koriste paru na stroju.

Optimizacija sistema povrata topline rekuperacijskim procesom i poboljšanje bilansa zracnih struja u sušenom dijelu PS, omogućuju da se procesni uvjeti u kojima se odvija sušenje papira na PS približe projektiranim vrijednostima, što rezultira uštedom energije i povecanjem proizvodnje na PS.

INTRODUCTION

It is well-known that a substantial amount of energy in paper or board production is consumed in the dryer section, primarily in the form of live steam used in the cylinders. However, a significant portion of this energy is lost as the exhaust air carries away evaporated water. To optimize energy usage and achieve cost savings, it is economically advantageous to recover energy from the exhaust stream.

Heat recovery is a system of heat exchangers used to capture the high enthalpy of the moist exhaust air. The enthalpy of the exhaust air is several times higher than that of the dry supply air. By implementing heat recovery systems, it is possible to return this heat back into the system, leading to substantial energy savings. Proper optimization of the drying hood and the ratio of supply and exhaust air plays a crucial role in achieving these savings. The balance between exhaust and supply air in the drying hood is vital for effective paper drying and efficient heat recovery.

During the investigation, visual observations of the dryer hood and heat recovery system were conducted. Several areas for improvement in heat recovery were identified, and an action plan was developed to address these critical areas. The article provides detailed instructions for resolving these issues.

Measurements of the air flows revealed an imbalance between exhaust and supply air, particularly in the pre-dryer and after-dryer sections. The insufficient amount of supply air results in excessive leakage air and increased consumption of live steam to heat this air. This imbalance negatively impacts the energy efficiency and heat recovery of the dryer section.

To improve energy savings and heat recovery on the PM3 machine, it is recommended to address the identified issues. This includes mechanically repairing damage to the heat recovery systems, properly insulating the ducts, and adjusting the airflows to optimal design values. By implementing these measures, the energy consumption of the machine can be significantly influenced, leading to improved energy savings in the dryer section.

Overall, proper energy management in the drying process of the paper machine can result in substantial cost savings. Optimizing heat recovery systems and balancing exhaust and supply airflows are effective strategies to enhance energy efficiency and reduce energy consumption in the dryer section.

Ventilation system in paper and board industry

In the paper and board industry, ventilation systems play a crucial role in maintaining proper air circulation and controlling the working environment. However, it's important to note that these systems also consume a significant amount of energy. Here are some key points regarding ventilation systems in the paper and board industry:

Steam Consumption: Ventilation systems on board and paper machines typically account for approximately 5 to 8% of the total steam consumption. The majority of this steam is utilized for heating the supply air. The specific steam consumption depends on factors such as the desired air end temperature, the design of the heat recovery system, and the humidity of the exhaust air.

Heat Recovery: Heat recovery is an important aspect of ventilation system efficiency. By implementing heat recovery systems, a significant portion of the heat contained in the exhaust air can be captured and reused. The maximum heat recovery efficiency can range from 55 to 80%, leading to substantial energy savings.

Electricity Consumption: The electricity consumption associated with mechanical ventilation systems typically represents 6 to 12% of the total power usage in the production line. The main energy consumers are the fans employed in the drying section of the machine. To achieve significant energy savings, it is recommended to utilize variable speed drives (VSDs) for these fans. VSDs enable the adjustment of fan speed based on the actual ventilation requirements, reducing energy consumption during periods of lower demand.

By optimizing ventilation systems and implementing energy-efficient measures, significant energy savings can be achieved in the paper and board industry. This includes utilizing heat recovery to capture and reuse the heat from exhaust air, as well as employing variable speed drives to regulate fan speed and reduce electricity consumption. These practices contribute to improved energy efficiency, cost savings, and a more sustainable production process.

Energy balance in the dryer section

The energy input into the dryer section of paper machines is primarily comprised of fresh steam, accounting for approximately 80% of the total energy. The remaining energy is derived from the paper web itself and the supply and exhaust air.

However, it's important to note that a significant portion of this energy leaves the drying section with the exhaust air. The enthalpy of the moist exhaust air is considerably higher than that of the dry supply air. As a result, the moist exhaust air represents an excellent heat recovery opportunity.

By implementing effective heat recovery systems and ensuring a balanced supply and exhaust air, substantial energy savings can be achieved. Heat recovery from the moist exhaust air can contribute to both improved energy efficiency and higher paper production rates.

Conversely, an imbalance in air flows can lead to increased leakage of low-temperature air, necessitating additional energy consumption to heat this air to the temperature of the exhaust air. This imbalance results in higher fresh steam consumption, thereby reducing energy efficiency and potentially increasing operational costs.

To optimize energy usage in the drying section, it is crucial to maintain a proper balance between supply and exhaust air flows. This ensures that heat recovery systems can efficiently capture and reuse the energy contained in the moist exhaust air. By addressing any imbalances and implementing effective heat recovery measures, the need for fresh steam consumption can be minimized, resulting in significant energy savings and improved overall efficiency in paper production.

ENERGY MANAGEMENT OF THE AIR SYSTEMS

Energy management in the paper and board industry requires a systematic, step-by-step approach to ensure optimal results from an energy audit on the machine. This approach involves four main phases aimed at optimizing energy efficiency:

Phase 1: Process Measurements and Visual Observations

In this phase, data is collected from the machine's Distributed Control System (DCS) and the conditions during production are recorded. Measurement positions are predetermined and prepared to ensure accurate results. Visual observations are conducted to identify any mechanical damage or deviations from normal conditions.

Phase 2: Analysis of Measurement Results

This phase involves analysing the measurement data to assess the energy performance of the machine. Calculations of the ventilation system provide insights into the performance of the drying hood and estimate deviations from design values.

Phase 3: Process Understanding and Improvements

The primary objective of this phase is to respond promptly to the findings of the measurement audit. Mechanical damages are repaired, and efforts are made to bring the system as close as possible to its design values. The papermaking process can be demanding, leading to the accumulation of dirt and potential damage to sensitive measuring equipment. Operators are trained to understand the impact of dryer section conditions on process parameters and are encouraged to make necessary adjustments. This phase emphasizes the importance of everyone's contribution to creating better working conditions and understanding their role in the critical process chain.

Phase 4: Investment Plan

Once immediate issues have been addressed, longer-term improvement steps are planned. The investment plan can be divided into short-term, medium-term, and long-term goals. Short-term improvements involve repairing the system to function optimally under existing conditions. Medium-term goals focus on replacing components that hinder production efficiency, such as fans, ducts, and burners. The long-term plan encompasses significant investments to increase production capacity and replace outdated systems with modern ones. Typically, the return on investment (ROI) for a new ventilation and heat recovery system can be achieved in less than a year.

By following this systematic approach, energy management in the paper and board industry can be effectively implemented, leading to improved energy efficiency, reduced costs, and a more sustainable production process.

MEASUREMENTS AND RESULTS

Basic data

Energy audit is performed from 7- 11.03. 2022. The production data are given in following table:

Table1. Production data

DATA	
Grade	Schrenz
Basis weights	91,3 g/m2
Absolut dry	83,8 %
Moisture content	8,2 %
Machine speed	575 m/min
Web width	4,44 m
Production	13,97 t/h

Paper Machine 3 incorporates two heat recovery towers, as illustrated in Figure 1. The purpose of these towers is to recover heat in different sections of the machine. Here is a breakdown of each tower and its function:

Pre-dryer Section Heat Recovery Tower:

The first heat recovery tower is dedicated to recovering heat in the pre-dryer section. It comprises three air-to-air heat exchangers (HE).

HE01: This heat exchanger preheats the fresh supply air using the exhaust air from the drying hood. It helps to increase the temperature of the incoming air before it enters the drying process.

HE02: The second heat exchanger is utilized for heating various areas, including the hall, annex, and double ceiling. Additionally, a portion of the air volume from the double deck is directed towards the runability boxes in the slalom group.

HE03: This heat exchanger preheats the supply air sourced from outside conditions. After HE03, the preheated air is divided into two streams: one for the supply air and the other for heating the rewinder area within the machine hall.

After-dryer Section Heat Recovery Tower:

The second heat recovery tower focuses on recovering heat in the after-dryer section. It consists of two-stage air-to-air heat exchangers.

HE01: The first air-to-air heat exchanger in this tower is responsible for preheating the supply air. It raises the temperature of the incoming air before it is utilized in subsequent processes.

HE02: The second air-to-air heat exchanger in this tower is employed for hall ventilation, contributing to maintaining suitable environmental conditions in the designated area.

By incorporating these heat recovery towers and utilizing air-to-air heat exchangers, Paper Machine 3 aims to capture and reuse heat from the exhaust air, increasing energy efficiency and reducing energy consumption in the drying process.

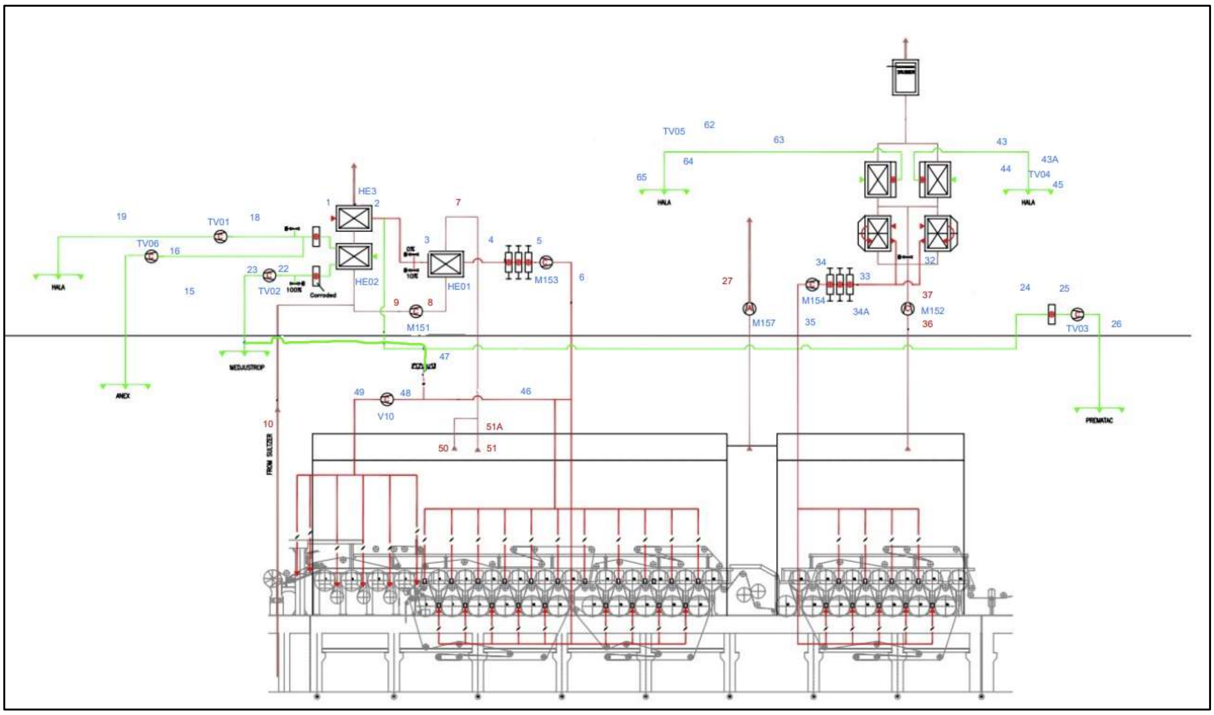

Figure 1. Schematic drawing of the air systems and heat recovery of PM3 with measuring positions

However, it's worth noting that there is room for improvement in terms of waste heat recovery. Currently, a considerable amount of waste heat is being released into the atmosphere due to the absence of air-water heat exchangers and the failure to preheat the fresh and process water. By implementing air-water heat exchangers and incorporating preheating for fresh and process water, the amount of wasted heat can be significantly reduced.

To ensure accurate measurement of the air systems on the machine, careful selection and preparation of measuring points are essential. This ensures that the measurements reflect the existing conditions on the machine accurately. Figure 1 provides an overview of the measurement positions for the air systems and heat recovery systems on PM3.

Process measurements – Pre-drying and after-drying section

The two measured parameters used to calculate the thermodynamic properties of moist air are the dry bulb temperature and the wet bulb temperature. These measurements allow for the determination of important properties such as relative humidity, specific enthalpy, and specific volume of the air.

The dry bulb temperature represents the actual air temperature without considering the moisture content. On the other hand, the wet bulb temperature is the temperature recorded when a wetted wick is exposed to the air, and it reflects the cooling effect of evaporation. By comparing the dry bulb temperature with the wet bulb temperature, it is possible to calculate the relative humidity and other thermodynamic properties of the air.

Additionally, dynamic pressure measurements using a pitot tube are employed to determine the air flows of the supply and exhaust air. The dynamic pressure provides information about the velocity of the air flow, which, when combined with the cross-sectional area, allows for the calculation of volumetric flow rates.

By utilizing these measurements, it becomes possible to analyse and understand the thermodynamic behaviour of the moist air in the system, assess its energy content, and make informed decisions regarding the optimization and management of the air systems in the pre-drying and after-dryer sections. Tables 2 and 3 show results of the measurement for the supply and exhaust air process parameters for the pre-drying section, and Table 4 for after-dryer section.

Table 2. Measured and calculated process parameters for the predrying section (supply air)

No.	Position	Td (°C)	Tw (°C)	(%RH)	X (g/kg)	Tdew (°C)	vp (mbar)	h (kJ/kg)	**m(kg/s)**	V(m³/s)	pst (Pa)
	PREDRYING SECTION (SUPPLY AIR)										
1.	Before HE3 (outside air)	5	3,3	75,8	4,1	1,1	6,613	15,167			
2.	After HE3 (heated air) Supply	31,7	15,9	16,6	4,8	3,3	8	43,6	14,67		-120
3.	After HE3 mixing with fresh air (before HE1)	9,1	5	52,1	3,7	0	6	18,34	14,67		-128
4.	After HE1	58,7	25,3	5,7	6,6	7,96	10,69	74,9			-285
6.	Supply air (After fan M153)	110	41	2,34	21,5	26,4	33,9	159,9	14,67	16,14	305
24.	Before Steam coil and fan TV03	32,9	15,6	12,85	3,97	0,7	6,42	42,8	17,89	15,61	-382
25.	Before ventilator TV03	27	13,6	19,1	4,2	1,5	6,8	37,43			
26.	After ventilator TV03	20,4	15,9	63,12	9,4	13,1	15,1	43,52			
	VENTILATION - DOUBLE CELL (MEDUSTROP)										
22.	Before TV02	28,8	20,8	48,9	12	17	19,36	58	11,99	10,47	-1055
23.	After TV02	31,6	21,3	40	11,66	16,4	18,64	60			
	HOOD VENTILATION- SLALOM										
46.	Air split from supply air (after 6)	108,5	40,3	2,3	20,1	25	31	155	6,08	6,79	-710
47.	Air split from 23 (double cell)	30,15	21,6	45,9	12,5	17,5	20	61	5,17	4,54	-570
48.	MIX Before fan V10	78	34,5	6,2	17	22,3	26,9	118	9,66	9,88	-1150
49.	MIX After fan V10	78	31,1	3,46	9,4	13,1	15,1	101			
	VENTILATION- HALL TV07										
19.	After TV01 TV07	24,6	15,2	36	6,9	8,5	11,12	41,6	10,47	8,94	225
	VENTILATION- ANEX										
15.	fresh air										
16.	Before TV06	35,2	23,6	38	13,6	18,7	21,6	68	11,18	9,98	-425

Table 3. Measured and calculated process parameters for the predrying section (exhaust air)

No.	Position	Td (°C)	Tw (°C)	(%RH)	X (g/kg)	Tdew (°C)	vp (mbar)	h (kJ/kg)	**m(kg/s)**	V(m³/s)	pst (Pa)
	PREDRYING SECTION (EXHAUST AIR)										
7.	Exhaust before HE1	90,5	58,4	23,1	121	56	165	344			-353
8.	Before fan M151	58,7	54,5	80,6	109	54	151	295	**28,97**	32	-1347
9.	After fan M151	54,6	54,6	100	111,2	54,6	154	296			370
50.	Ehaust inside hall (left)	84,7	60,2	32,5	139,7	58,5	185,9	373,8			
51.	Ehaust inside hall (right)	88,3	59,9	27	135	57,9	180,7	368,1			
51A.	Ehaust inside hall (right) close to instrument HIC 1	88,6	57,5	23,7	115	55,1	158	331			
HIC 151.	Humidity instrument HIC-151				169						
	SULZER										
10.	Before sulzer fan	160,4	56,7	1,7	72,8	47	106,3	313	**6,75**	9,31	475
	EXHAUST SIZE SECTION										
27.	Before fan M157	77,3	47,3	21	59,8	43,5	88,8	211	**5,09**	5,55	-157

Table 4. Measured and calculated process parameters for the after-drying section (supply and exhaust air)

No.	Position	Td (°C)	Tw (°C)	(%RH)	X (g/kg)	Tdew (°C)	vp (mbar)	h (kJ/kg)	**m(kg/s)**	V(m³/s)	pst (Pa)
	AFTER DRYING SECTION (SUPPLY)										
32.	Direct after HE1	63,8	30	8,7	13	18	20,7	94,89			
33.	After HE 1 (before steam HE) before fan M154	34	23,4	41,2	13,7	18,9	21,9	67,3	5,33	4,75	-220
34.	After Steam HE	122,2	40,1	1,04	13,9	19,1	22,1	154,6			-805
35.	After fan M154	112,2	39,4	1,63	15,88	21,25	25,2	149,2	5,25	5,89	1643
	AFTER HE2 FOR HALL VENTILATION (TV04)										
44.	Outside air	5									
45.	After fan TV04	24	12,2	21,7	4	0,805	6,47	33,94			105
	AFTER HE2 FOR HALL VENTILATION (TV05)										
62.	Outside air	5									
63.	After HE2 warm air	22,2	10	15,9	2,6	-4,3	4,26	28,7			4
64.	before Fan TV05	23	11,5	21,4	3,7	-0,166	6,1	32			14
65.											62
	AFTER DRYING SECTION (EXHAUST)										
36.	Before fan M152	81,4	60,5	38	144,4	59	190	379,7	13,21	16,38	-343
37.	After fan M152	82	60,9	37,9	147,8	59,5	194,6	386,3	6,49	8,09	528

By measuring the wet and dry bulb temperatures, the other parameters needed for the heat and mass balance are calculated.

LEGEND

T_d	Air temperature (°C)
T_w	Air wet bulb temperature (°C)
RH	Relative humidity (%)
X	Absolute moisture content (g_{H2O}/kg_{da})
T_{dew}	Dew point temperature (°C)
vp	Partial pressure of water vapor in air (mbar)
H	Specific enthalpy (kJ/kg)
m	Air mass flow (kg/s)
V	Air volume flow (m^3/s)
P_{st}	Air static pressure (Pa)

RESULTS ANALYSE

Visual observation and measuring diagnostic

Table 5 is showing visual observations and measuring diagnostic of actual situation of the heat recovery at the PM3.

Observations are presented according to the measurement points on the heat recovery systems of PM3. Observations 1-11 represent the situation at recuperator no. 1 (pre-dryer section) and observations from 12-27, situation at recuperator 2 (after-dryer section)

Table 5.

No.	Measuring point	DIAGNOSTIC
1	Point 2-3	The supply air is heated to 31.7 °C and then cooled to 9.1 °C (leakage).
2	Point 4-6	Possible steam coil leak (The humidity from X(4) = 6.6 g/kg to X(6) = 21.5 g/kg via steam heat exchanger). Increasing water content of the supply air.
3	Point 5	Too high supply air temperature T=117°C.
4	Point 46-48	Hot supply air T(46) = 117°C is mixed with cold air T(47) = 31.6°C and fed into the dryer hood at T(48) = 78°C.
5	Point 49	Low supply air temperature T(49) =78°C.
6	Point 8	Damaged compensator of the fan M151 (cooling of the exhaust air).
7	Point 9	Due to the low temperature of the exhaust air, 54.6°C, the dew point is reached, and condensation occurs at Ts=54.6°C. CONDENSATION
8	Point 51A	Difference between manual and instrumental (HIC) measurement. X51A = 115 g/kg and X(HIC151) = 162 g/kg. Influence on the hood balance.
9	Point 18	Mixing of preheated air with fresh air and cooling supply air for annex, hall and double roof ceiling to set value (points 16, 18, 22).
10	Point 22	Humidity increase from outside air X(1)=4 g/kg to X(22)=12 g/kg (leakage-broken steam exchanger)
11	Point 16	Humidity increase from outside air X(1)=4 g/kg to X(16)=14 g/kg (leakage-broken steam exchanger)
12	Point 36	M152 exhaust fan compensator broken on after drying section.
13	Point 37	Very low flow compared to point 36 (after fan M152), m(37) = 6.49 kg/s compared to m(36) = 13.21 kg/s. (compensator damage)
14	M154	Safety/security conditions. Rotating shaft without protective net.
15	Point 34A	The ducts for steam and condensate without insulation (heat loss).
16	Point 35	The humidity of the supply air increased from X(1)=4g/kg to X(35)=15.88 g/kg (leakage).
17	Point 35	Large hole in the supply air duct (energy loss).
18	Point 27	The exhaust air from size-press, possible source for energy utilization and recuperation T= 77°C, h=211 kJ/kg.
19	Point 34	Supply air temperature too high, T(34)=122,2°C. Recommended temperature of supply air 95 °C (energy loss).
20	Point 32	After the first HE in recovery tower no.2 (after-drying section), the air is heated from T(1)=5°C to T(32)=63.8°C (energy loss)
21	Point 32-33	After the first HE in recovery tower no.2 (after-drying section), intensive cooling of supply air from T(32) = 63.8°C to T(33) = 34°C (energy loss).
22	Point 32-33	The construction of the heat recovery tower is broken. Bottom plate completely destroyed and huge leakages of cold air.
23	HIC-152	The humidity value of the exhaust air from the instrument X=256 g/kg and the measured value X(36)=144 g/kg differ significantly. (Incorrect hood adjustment. Air systems in disbalance. The wrong ratio of supply and exhaust air caused huge leakage air and loss in fresh steam).
24	Point 43	The second HE (air-air) heats the outside air from T(1)= 5°C to T(43)= 55.2°C (hall ventilation) and then air is cooled to T(45)=24°C (energy loss).
25	Point 63	Low air flow of TV-05 - positive static pressure on suction sideof the fan - possible rotation in the wrong direction or improper fan operation (pst= +4 Pa/Pst= +14Pa).

26	SCRUBBER	Not in use. (Huge saving potential in heating process water).
27	Point 45	Compensator is not in good condition

The found observations serve as a basis for an action plan to solve the problems on the recuperation system and improve energy economy on the PM3.

Air balance calculation

Based on the information provided, the supply/exhaust air ratio in the pre-dryer section is 63%, which is close to the recommended ratio of 70% for this type of drying hood (as indicated in Table 6). This suggests that the pre-dryer section has a relatively good balance between supply and exhaust air. A higher supply air ratio ensures efficient drying and heat recovery in this section.

However, in the after-drying section, the supply/exhaust air ratio is 36%, which is considered low. This indicates a significant amount of leakage air entering the drying hood. The leakage air is cold and needs to be heated by the heat from the drying cylinder, resulting in increased consumption of primary energy sources, such as fresh steam. This higher energy consumption can lead to economic losses and inefficiencies in the drying process.

To improve energy efficiency and reduce energy waste, it is important to address the issue of air leakage in the after-drying section. Proper sealing and maintenance of the drying hood can help minimize the entry of cold leakage air. By reducing the amount of leakage air and achieving a higher supply/exhaust air ratio, energy consumption can be optimized, leading to cost savings and improved overall efficiency of the drying process.

Table 6.

HOOD BALANCE					
PREDRYING					
SUPPLY					
Position	Td (°C)	X (g/kg)	m(kg/s)	V(m³/s)	m (H2O/s)
No.6	110	21,5	14,67	16,14	0,32
No.46	108,5	20,1	-6,08	-6,79	-0,12
No. 49	78	9,4	9,66	9,88	0,09
SUPPLY TOTAL			18,25	19,23	
EXHAUST	90,5	121	28,97	32	3,51
AFTERDRYING					
SUPPLY					
No.35	112,2	15,88	5,25	5,89	0,08
EXHAUST	81,4	144,4	13,21	16,38	1,91

PREHEATED BALANCE Supply air is 63% from the exhaust air. Good relation is 70%. It is supposed that leakage air has temperature of 25-35 °C. Additional leakages to heat from T=30°C to exhaust temp 90,5°C.

AFTER DRYING THE HOOD BALANCE. The actual amount of supply air consists of 36% of exhaust air. A good ratio should be around 70%. Additional leakage air to meet the hood balance is to be heated from T = 30 °C to an exhaust air temperature of 81.45 °C.

Optimization of the heat recovery

The example of the balanced drying section is given in Table 7. The drying hood balance, evaporation and dimensioning is done for 81,2 g/m2 fluting/liner paper grade. The Tdew=58,5 °C is assumed to be optimal for the existing type of the drying hood. Paper machine speed used in calculation is 606 m/min and total production of 345 t/24h.

The hood air balance system calculation for the pre-drying and after-drying section is given in Table 7.

Table 7. The hood air balance

PREDRYING					
P		312	t/24h		
BW		81,2	g/m2		
DCin		49	%		
DCout		99,9	%		
ww		4400	mm		
Speed		606	m/min		
Evaporation		3,75	kg H2O/s	13500	kgH2O/h
Exaust	T	82	°C		
	X	140	g/m2		
	Dew point	58,5	°C		
	m	28,85	kg d.a/s		
	m(h.a)	32,9	kg h.a/s		
	V(h.a)	34	m³/s	122400	m³/h
Supply	T	95	°C		
	X	10	g/m2		
	m	20,2	kg d.a/s		
	m(h.a)	20,4	kg h.a/s		
	V(h.a)	24,1	m³/s	86760	m³/h

SIZE PRESS		
STARCH	4,5	g/m2
CONC	10	%

AFTERDRYING					
P		345	t/24h		
BW			g/m2		
Dcin		59	%		
Dcout		91,8	%		
WW		4400	mm		
Speed		606	m/min		
	Evaporation	2,22	kg H2O/s	7992	kgH2O/h
Exaust	T	82	°C		
	X	140	g/m2		
	Dew point	58,5	°C		
	m	17,8	kg d.a/s		
	m(h.a)	19,5	kg h.a/s		
	V(h.a)	21	m³/s	75600	m³/h
Supply	T	95	°C		
	X	10	g/m2		
	m	11,95	kg d.a/s		
	m(h.a)	12,1	kg h.a/s		
	V(h.a)	12,1	m³/s	43450,2	m³/h

In the case of the correct ration between supply/exhaust at both drying hoods, the steam consumption should decrease at PM3. The calculation shows 1,05 kg/s or 3,77t/h steam saving.

CONCLUSIONS

Heat tower no. 1

The heat recovery systems of PM 3 consist of two heat recovery towers (HT) for recovering exhaust air. The potential energy for recovery in HT #1 is approximately 10 MW, while in HT #2, it is around 5 MW. Additionally, the power from Sulzer contributes about 2.1 MW. Therefore, the total exhaust energy at Tower #1 is 12.1 MW.

In the first heat recovery tower (HT #1), which includes three stages of air-to-air heat exchangers, only 1.53 MW or 12.7% of the total available exhaust energy is currently being recovered. This percentage is relatively low, indicating that a significant amount of energy is still being lost through the exhaust air. Moreover, some of the recovered energy is being used to heat already heated air, which is then unnecessarily cooled from 31°C to 9.1°C, resulting in an additional heat loss of 370 kW.

It is mentioned that the exhaust air from the size press represents a potential source for heat recovery, with approximately 1 MW of heat available for recovery. This indicates an opportunity to capture and utilize this heat to further improve the overall energy efficiency of the system.

To optimize heat recovery and maximize energy savings, it is recommended to assess and potentially enhance the efficiency of the heat recovery systems. This can include optimizing the design and operation of the heat exchangers, minimizing unnecessary cooling or reheating of already heated air, and exploring additional heat recovery opportunities from different sources within the paper machine. By implementing these measures, the overall energy consumption can be reduced, leading to cost savings and improved sustainability.

Heat tower no. 2

Heat tower no. 2 at PM 3 consists of two air-to-air heat exchangers used for preheating the supply air and conditioning the machine hall. However, it has been observed that the heat tower is in poor condition, particularly the lower part, which is damaged. This damage results in already preheated air being cooled with fresh air, leading to significant energy losses.

The potential energy for recovery in HT #2 is estimated to be around 5 MW. In the first air-to-air heat exchanger (HE) responsible for supply air preheating, the supply air is initially heated from an outside temperature of 5°C to 63.8°C. However, due to the broken design of the heating tower's lower part, the air is then cooled back down to 34°C. As a result, only 276 kW of energy savings are achieved in the first heat exchanger (heating from 5°C to 34°C).

In the second air-to-air heat exchanger, a total of approximately 380 + 190 kW of energy is recovered. However, it has been identified that the ventilator for hall ventilation is possibly rotating in the wrong direction or is damaged, as positive static pressure of 14 Pa is measured at the suction side of the fan.

Overall, the total energy savings in HT #2 amount to approximately 850 kW, which corresponds to 16.9% of the total possible energy contained in the exhaust humid air.

To optimize energy recovery in HT #2, it is recommended to address the damaged lower part of the heat tower to prevent the unnecessary cooling of preheated air. Additionally, the issue with the hall ventilation fan should be investigated and resolved to ensure proper operation and energy efficiency. By improving the condition and performance of the heat tower and associated components, further energy savings can be achieved, leading to improved overall energy efficiency of the system.

PROPOSAL AND RECOMMENDATION

The maintenance and annual service of air systems, drying, and runnability of paper machines are indeed crucial aspects of a company's business strategy. Neglecting these points can lead to significant economic losses through unplanned shutdowns and wastage of energy sources. Furthermore, the working conditions, such as high heat stress and humidity in the workplace, can adversely affect work efficiency and increase the risk of injuries.

To address these issues and ensure the proper functioning of the paper machine system, it is recommended to implement systematic visual observations of the machine, air system checks, and runnability system checks. Additionally, preventive maintenance should be conducted regularly. The suggested frequency for these systematic audits is at least twice a year. By performing these audits, you can identify and address potential issues before they escalate, minimizing unplanned shutdowns, production losses, and energy wastage.

To facilitate the systematic audits, it may be beneficial to establish a special service agreement between supplier and Paper Mill. This agreement would outline the responsibilities and expectations of both parties regarding maintenance and audits. A list of specific parameters and devices that need to be checked and measured during each audit can be defined. These audits will help optimize the system's performance and energy efficiency, contributing to better economic outcomes for the paper machine.

Implementing these recommendations will not only ensure the smooth operation of the paper machine but also contribute to a sustainable approach to control and improve the efficiency of air systems, drying, and runnability. By proactively addressing maintenance needs and optimizing performance, you can minimize economic losses, improve work conditions, and enhance overall productivity.

LITERATURE

Milosavljevic, N., and Skansi, D., (1993), Research of Heat Recovery Systems in Paper Mill Belisce, Second Symposium on Ecologically Rational Development of Chemical Technologies, Zagreb, Croatia.

Milosavljevic, N., Malinen, P., Heikkilä, P., Jokioinen, I. and Edelmann, K., (1997), Experimental and Theoretical Investigations for the Design of Scrubber in Heat Recovery from Paper Machines, Applied Thermal Engineering, Elsevier Science, Great Britain, vol.17, No.6, pp. 569-581.

Milosavljevic, N., Skansi, D. and Karlsson, M., (1998), Semiempirical Study of the Kinetics of Paper Drying on the Conventional Seam-Heated Cylinders, Drying '98 – Proceedings of the 11th International Drying Symposium (IDS '98), Halkidiki, Greece, August 19-22, vol. B, pp. 1563-1570.

Milosavljevic, N., (2000), New Aspects of Energy Utilization in the Paper Industry, Experimental and Theoretical Work, Academic Dissertation, Åbo Akademi University, Turku, Finland.

Milosavljevic, N., Heikkilä, P., Ojanen, M. and Saari, J., (2000), Influence of Fabric Structure on the Drying Rate and Cylinder-Paper Contact Heat Transfer Coefficient, Proceedings of the 12th International Drying Symposium (IDS 2000) - Advances in Paper Dewatering 2000, August 28-31, Noordwijkerhout, The Netherlands.

Heikkilä, P. and Milosavljevic, N., (2003), Influence of impingement temperature and nozzle geometry on heat transfer – EXPERIMENTAL AND THEORETICAL ANALYSIS, Drying Technology, 21(10), 1957-1968, by Marcel Dekker,Inc.

Milosavljevic, N., (2004), New aspects of fabric selection for improved drying and runnability, Paper Technology, v.45, no.4, pp.47 –51.

Milosavljevic, N., (2006), Quality and runnability with energy-efficient Air Systems, International Austrian Paper Conference, APV Graz, Austria, 30th May-1st June 2006.

Milosavljevic, N., and Timofeev, O., (2007), Simulation of the Drying in Paper Making Process by Using Experimentally Determined Contact Heat Transfer Coefficient, The Proceedings of the 5th Asia-Pacific Drying Conference, 13-15 August 2007, Hong Kong, China, pp. 967-973.

Milosavljevic, N., (2008), Air Impingement drying – Technology for Future Paper Machines, Keynote Lecture, 16th International Drying Symposium 2008, 9th - 12th November 2008, Ramoji Film City, Hyderabad – India.

Milosavljevic, N., Sundqvist, H., Pettersson, H., (2012), ENERGY ECONOMY OF THE DRYER SECTION OF PAPER AND BOARD MACHINES, 18th International Symposium in the Field of Pulp, Paper, Packaging and Graphics, June 19th-22nd 2012, Zlatibor, Serbia, pp. 159-165.

Timofeev, O. and Milosavljevic, N., (2013), An experimental study of board sticking to the hot metal surface, EuroDrying'2013, 2-4th October 2013, Paris.