High-humidity hoods conserve energy and improve runnability

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Modern hood design allows operation at higher exhaust humidities, requiring less air, consuming less heat, and recovering heat more efficiently.

Although 200 kg of water/kg of solids are delivered through the headbox slice on a typical paper machine, only 1.4 kg of water/kg of solids are removed in the dryer section. This last fraction of water is the most difficult and expensive to remove from the sheet.

Water removed in the forming and pressing sections can be recycled in the stock preparation and approach systems, but the water evaporated in the dryer section has to be absorbed by dry air and removed from the machine room by hood exhaust fans. This hood exhaust also carries away all of the heat that is supplied by steam in the dryer cans. Consequently, the heat in the exhaust stream offers a chance to save money through heat recovery.

Types of dryer hoods

The air flows required to ventilate the hood effectively are highly dependent on the construction of the hood and its operation. Enough heated air must be introduced to the hood to prevent condensation and to keep pocket humidities low enough to maintain high drying rates. Exhaust air flows must prevent vapor from spilling into the machine room. Vapor spill can cause uncomfortable working conditions in the operating room. It can also cause condensation on cool surfaces, which can deteriorate the equipment in the machine room and the construction materials of the building.

Open hoods

Open hoods capture most of the water vapor but require large volumes of air. Exhaust humidities of 0.04–0.065 kg of water/kg of dry air can be run in this type of hood without sweating and condensation. About 20–40 kg of dry air/kg of water evaporated must be supplied to the hood as heated ventilation air or as infiltration air from the machine room.

These large quantities of air cause high energy consumption and interactions with air systems in the machine room. These large air flows within the hood disrupt the sheet at higher machine speeds. Uneven pocket humidities can contribute to moisture profile problems.

Conventional closed hoods

The development of closed hoods resulted in major improvements in energy consumption and isolation of the paper machine air systems. Closed hoods with conventional tongue-and-groove insulated panels operate at 0.085–0.135 kg of water/kg of dry air. At 0.135 kg/kg, supply and infiltration air total 9 kg of dry air/kg of water evaporated, which is from 25% to 50% as much as an open hood handles. The more concentrated exhaust streams make heat recovery feasible.

High-humidity hoods

Until recently, air usage could not be reduced further because of the limitations of conventional hood construction. Higher exhaust humidities and higher hood dew points resulted in sweating and condensation on hood surfaces. New hood construction techniques have led to hoods that can operate at exhaust humidities up to 0.17 kg of water/kg of dry air without condensation and further extend the benefits of closed hood operation.

Supply and infiltration air requirements are only 6.5 kg of dry air/kg of water evaporated with the high-humidity hood, so there is less pocket ventilation air to heat and less infiltration of heated room air. The machine and building air systems are separated and are easier to control. The higher exhaust humidities also improve the potential for air-to-air and air-to-liquid heat recovery. Better heat insulation also provides better sound insulation, which makes the machine room quieter.

High-humidity hoods can be justified based solely on reduced energy consumption. However, an additional major benefit is improved runnability on high-speed machines. Air flows within the hood can be controlled to avoid sheet disturbances and improve runnability.

Requirements for high-humidity hood operation

Successful operation at high exhaust humidities requires more than simply reducing the exhaust volume from a conventional hood. The fixed panels in the hood need to be vapor tight and well insulated, hood penetrations must be well sealed, supply and exhaust air must be distributed

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effectively, and the hood balance and exhaust humidity should be controlled.

Panel construction

North American hoods commonly use tongue-and-groove panels. These hoods will not operate effectively over the long term at exhaust humidities over 0.135 kg water/kg dry air. Conventional hoods have fairly small panels with many joints, and it is difficult to control the quality of joint fabrication and installation. Tongue-and-groove panels are sealed to each other instead of being positively sealed to the hood steel. The outer surface of the panels does not breathe, so any trapped vapors that enter the panels can create condensation problems and damage the insulation value of the hood.

Dryer section hoods designed for high-humidity or high-performance operation must contain the heat and vapor. A one-piece, continuous sheet is used for the inside panel surface, to create a vapor-tight internal skin. The top surface of the panels is allowed to breathe to allow any vapors that do manage to enter the panels to escape to the machine room.

Large hood panels are used to minimize the number of joints. All panel joints are eliminated. The bolted construction ensures that the tightness of the hood is not dependent on the installer. Insulation that is 10.2 cm thick is used to provide a high insulation value and to allow hood operation at higher dew points without condensation or sweating. The inner panel surface temperature must be maintained above the dew point. Though metal is minimized, and thermal breaks are used on panel framing to maintain the insulation value.

Tight seals

Tight seals and a good basement enclosure are critical for operation at high humidities. The natural stack effect within the dryer enclosure will pressurize the hood above the operating floor unless the basement is tightly sealed. Penetrations through the hood should be minimized, and long-lasting, vapor-tight seals should be placed around all penetrations. Effective, reliable seals are also required around access doors, front lifting panels, and rear sliding panels. Operators also need to keep the rear sliding panels and basement access doors closed.

I. Paper machine operating conditions

Machine speed, m/min	1067
Basis weight, g/m²	75
Press moisture, %	58
Size press moisture, %	2
Size pickup, g/m²	3
Starch solids, %	5
Main section dryers, no.	50
Dryer diameter, mm	1830
Sheet width, m	7.62
Main section evaporation, kg/min	749
Average steam temp., °C	143
Entering sheet temp., °C	49
Exiting sheet temp., °C	93
Average outdoor temp., °C	4

II. Main section supply and exhaust conditions for the paper machine main section

	Open	*Closed*	*High humidity*
Exhaust			
Flow rate, kg/min	92,700	32,900	23,700
Temp., °C	57	82	85
Humidity, kg/kg	0.0571	0.1286	0.1714
Supply			
Flow rate, kg/min	27,800	23,000	16,600
Temp., °C	93	93	93
Humidity, kg/kg	0.0179	0.0179	0.0179
Infiltration			
Flow rate, kg/min	64,900	9,900	7,100
Temp., °C	32	32	32
Humidity, kg/kg	0.0179	0.0179	0.0179

Air distribution

Effective supply and exhaust air distribution becomes more important with the lower air volumes used in high-humidity hoods. Most of the supply air is needed in the dryer pockets to keep pocket humidities uniformly low and drying rates high. Additional air is used in blow boxes and wet-end runnability components on high-speed machines.

The remaining heated supply air is required to prevent condensation in the basement and at troublesome locations such as wet- and dry-end sheet openings, under single-felted sections and at the front-lifting panel glass. Cross-machine hood baffles are used to prevent excessive air pumping from the dry end to the wet end by return fabric loops. Dead areas with no air flow must be avoided.

Exhaust distribution should be tailored to the drying curve, with the most exhaust towards the middle of the dryer section in the prime drying zone and less exhaust in the wet-end warm-up zone and dry-end falling-rate zone. Proper exhaust distribution can be ensured through the use of false-ceiling damper adjustments or internal hood exhaust ductwork. Control of both machine-direction and cross-machine-direction exhaust flow is required.

Humidity controls

One of the reasons high-humidity hoods have not been commonly used in North America is that until recently there were no reliable ways to monitor and control exhaust humidity and the hood air balance. Humidity controls have now been developed that allow automatic adjustment of exhaust and supply fans for varying evaporation loads.

Exhaust volumes can be regulated with fan volume dampers or variable-speed fan motors. A uniformly high exhaust humidity can be controlled to match varying production rates. Supply air is controlled to provide the optimum hood balance. Hood exhaust rates can be increased to provide lower humidities when momentary

III. Specific energy consumption for the paper machine main section without heat recovery

	Open	Closed	High humidity
Evaporation	2405	2405	2405
Sheet heating	57	57	57
Radiation	168	102	97
Pocket ventilation	484	401	289
Venting	70	70	70
	...	...	...
Subtotal[a]	3184	3035	2918
Room air heating	432	153	109
	...	...	...
Total	3636	3188	3027

[a]Subtotal is the total consumption for the dyer section.

IV. Specific energy consumption for the paper machine main section with heat recovery

	Open	Closed	High humidity
Evaporation	2405	2405	2405
Sheet heating	57	57	57
Radiation	168	102	97
Pocket ventilation	405	241	150
Venting	70	70	70
	...	...	...
Subtotal[a]	3105	2785	2779
Room air heating	432	153	109
	...	...	...
Total	3537	3028	2888
Potential recovery	-158	-1313	-1687
Potential net consumption	3379	1715	1201

[a]Total energy consumption for the dryer section.

hood access is needed and can then be returned to normal operating settings.

Runnability

Open hoods cannot be operated at high machine speeds because the high air flows through the dryer section create edge flutter and sheet instability. Reduced air flows have been observed to improve runnability in closed hoods. As machine speeds continue to increase, the reduced air flows and improved control of high-humidity hood operation will become more important.

Drying rates

High-humidity operation will generally not adversely affect drying rates on machines with good pocket ventilation. However, increased pocket humidities and decreased drying rates may occur on some machines with high evaporation loads and poor ventilation.

Dryer section energy consumption

Energy is consumed in the dryer section in several ways:

- By heating the fiber and water to the evaporation temperature
- By evaporating the water
- By radiation and convection from the dryer cans and fabrics
- By desorption of water vapor from fiber bonds
- By steam venting and condenser losses.

All of this heat is supplied by steam in the dryer cans.

Heat must also be added to the supply air to increase its capacity to absorb and remove the water vapor from the hood without condensation. This heat is generally supplied by steam coils.

Reducing the volume of air flowing through the hood reduces the heating requirements of the hood supply air. Since hood supply air and infiltration air are provided by the building ventilation system, reducing the air flows through the hood can also reduce the heating requirements of the room supply air.

Heat from the evaporation of water, air heating, and dryer can radiation and convection losses are all carried away in the hood exhaust. Higher hood exhaust humidities increase the heating value of the exhaust stream and allow more heat recovery for a given heat exchanger area.

Case study

Let us take a hypothetical fine paper machine to demonstrate energy consumption under various hood conditions. **Table I** shows operating conditions for the case study machine. The data are based on operating conditions on actual machines.

Air flows

Table II shows the required exhaust and supply air conditions for an open hood, a conventional closed hood, and a high-humidity hood. An actual machine could not be run with an open hood at these speeds, but the calculations were included for comparison.

Total air flow through the hood for high-humidity operation is 74% less than through an open hood and 28% less than through a conventional closed hood. Lower air volumes mean less supply air to heat and less uncontrolled infiltration air. Machine room ventilation requirements are also lower.

Energy consumption

Table III shows steam energy consumption for the three hood types. The evaporation category includes the energy required to heat water to the evaporation temperature and the heat of vaporization. The sheet heating category includes the energy required to heat the sheet from entering temperature to the reel temperature. Both categories depend on the sheet temperature entering the dryer section and are not affected by exhaust conditions.

The radiation category includes radiation and convection from the dryer cans and fabrics. This radiation helps to heat the hood infiltration air to exhaust conditions. Radiation and convection losses are higher in open hoods because of the lower temperatures.

Pocket ventilation and hood supply air is heated from a machine room temperature that is typically 32°C to a final temperature of 95°C. When no heat recovery is used, all of the heat is supplied by steam coils. Operation at higher exhaust humidities requires less heating of pocket ventilation air because of the lower supply volume required.

The steam venting and condenser losses vary greatly, depending on the design and operation of the steam and condensate system. For this analysis, we will assume that these losses are constant at a typical level.

Total drying energy costs are lower with high-humidity hood operation. The high-humidity hood in this example offers direct energy savings of $300,000/year over the open hood and $130,000/year over the conventional closed hood. An energy cost of $3.22/10^6 kJ, 355 operating days/year, and an up-time efficiency of 92% were used for all calculations of energy savings.

Reducing air flows through the dryer section allows a reduction in air flows through the building and in the heating requirements. The actual energy savings will depend on the outdoor ambient temperature at the mill.

A northern mill with a yearly average outdoor temperature of 4°C was used for these calculations. The room supply air is assumed to have a temperature of 21°C. Under these conditions, annual savings for the high-humidity hood would be $365,000 over the open hood operation and $50,000 over the conventional closed hood operation.

Heat recovery

Heat recovery from the hood exhaust increases the benefits of high-humidity hood operation. The higher humidity allows more condensation in the air-to-air or air-to-liquid heat exchangers. It also provides more heat recovery with less heat exchanger area. The recovered heat can be used to preheat pocket ventilation air and in room air or water heating systems.

In our example, the pocket ventilation air could be heated from 32°C to 62°C with a two-pass, air-to-air economizer from the exhaust stream of the high-humidity hood. The exhaust from the conventional closed hood would preheat the supply air to 57°C in the same heat exchanger. The open hood would preheat pocket ventilation air to 42°C. **Table IV** shows the breakdown of the resulting energy consumption in the dryer section.

Heat recovery from hood exhaust to the pocket ventilation system would save over $160,000/year in dryer section operating costs with the high-humidity hood. These savings would be applicable regardless of the mill's location.

After the air-to-air economizers have preheated the pocket ventilation air, additional heat recovery can still offer savings with the high-humidity hood. The heat recovery potential listed in Table IV would take the hood exhaust through additional heat exchangers to achieve a final temperature of 49°C. It is generally not practical to take the exhaust stream to a lower temperature. Common uses for the heat would be building supply air and process water heating.

V. Energy savings in $/year

	Open	*Closed*	*High humidity*
Room air heating	Base	325,000	375,000
Dryer section			
No recovery	Base	300,000	425,000
With recovery	Base	280,000	370,000
Potential additional recovery	185,000	1,500,000	2,000,000

The amount of the potential heat recovery that could be used depends on the mill climate and operation. Savings as high as $2 million/year could be recovered from the high-humidity hood exhaust if all of the heat recovery potential could be used. Additional heat recovery from a conventional closed hood could total $1.5 million/year and open hood heat recovery could save $185,000/year on the case study machine.

Table V summarizes the energy savings potential for conventional closed hoods and high-humidity hoods compared to open hood operation for our hypothetical machine.

Conclusions

High-humidity hoods and air systems have been developed that can operate at higher dew points than conventional hoods without sweating or condensation. The lower air flow requirements through the hood can reduce sheet disturbances and improve runnability. Dryer section energy savings are available through lower supply air heating requirements. The increased heat recovery potential of the concentrated hood exhaust stream can provide additional energy savings.□

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