

Methods of evaluating hood drying rates

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ABB DRYING HOODS ARE USED primarily in the drying of tissue grades. These hoods, which are also known as high-velocity air caps, are typically mounted over a large-diameter steam-heated cylinder (<6 m). The tissue sheet is plastered to the steam-heated cylinder by one or two press rolls, which also serve to mechanically dewater the sheet. The sheet is then dried by the hot cylinder and by the high-temperature air impingement under the hood. The dried sheet is subsequently removed from the cylinder by the creping doctor. Figure 1 shows a schematic of a typical hood installation.

As tissue machine speeds have increased, the demands on the hood have also increased substantially. Today, the hood can contribute over 70% of the drying on the machine. This increase in drying capacity has been accomplished primarily by increasing the impingement velocity and temperature of the air in the hood. Air temperatures over 500°C are now the norm in modern hoods. Because of this, almost all modern hoods use combustion to heat the air. To improve the efficiency of the system, a high percentage of the air in the hood is recirculated, and heat recovery is often applied on the exhaust streams. Figure 2 shows a typical flow schematic for a hood and air system.

Because the hood now accounts for so much of the overall drying on a tissue machine, it has become more important to properly evaluate its performance, particularly the contribution of the hood to the overall drying rate. This, however, is no easy

task, considering that the sheet is dried both by the hood and the steam-heated cylinder at the same time. It is difficult to separate the contributions of these two components. There is presently no standard method for evaluating the drying rate of the hood on a tissue machine. In the past, the hood drying rate has often been inferred by evaluating the overall drying rate from grab samples of the sheet before and after the hood, and reducing this drying rate by the contribution of the steam-heated cylinder to the drying rate.

The cylinder contribution has been evaluated by measuring the condensing rate of the steam in the cylinder. Unfortunately, there are many more heat loads on a cylinder than just the drying load of the sheet. There is heat lost in the press roll nips and heat lost to evaporate some of the water in the glue spray, as well as radiation and convection losses from the various exposed surfaces of the cylinder. These losses, which are very difficult to evaluate, can easily account for over 30% of the heat load on the cylinder. For this reason, it is desirable to be able to evaluate the contribution of the hood to the drying rate directly, without resorting to measurements made on the cylinder. This paper describes two methods that we have developed to accomplish this.

TEST METHODS—HOOD HEAT BALANCE AND SYSTEM ENERGY BALANCE

Drying equipment is designed to transfer heat to the material to be dried. If the amount of heat transferred can be determined, then the

ABSTRACT

This paper describes two independent methods that the reader can use to determine the contribution of the hood to the drying rate on the tissue machine or other similar machine.

Two methods of determining the drying rate of a hood are presented. These methods do not rely on measurements taken on the cylinder. The measurements required on the hood and air system are summarized for both methods.

drying rate attributable to the equipment in question can also be determined by dividing this quantity of heat by that needed to evaporate water (latent heat). This paper describes two methods that are used to evaluate the drying rate of hoods. Both methods assess the heat transferred by the hood to the tissue sheet and then divide this heat by the latent heat of evaporation for water. Although both methods are similar, they are completely independent, making it possible to verify the two methods by comparing the results. Equations are given for both methods, along with a description of the measurements that are required on the machine.

Hood heat balance method

One method of determining the hood-side drying rate is referred to as the *hood heat balance method*. The heat transfer from the hood, and hence the drying rate, is determined by calculating the amount of heat given up by the supply air stream as it impinges onto the sheet and exits via the return duct. The humid air in the return duct consists of the humid air from the supply stream, now at the return temperature, together with the water that was evaporated from the sheet. Figure 3 illustrates this.

Calculations The flow rate of the supply stream is calculated based on the static pressures at the hood nozzles and the supply air properties as follows:

$$V_n = (2P_n/r)^{0.5} \quad (1)$$

$$M_{mix} = V_n \times A_{nozz} \times r \times C_d \quad (2)$$

$$M_{da} = M_{mix} / (1 + X_s) \quad (3)$$

Note that an accurate value of the nozzle discharge coefficient is required for this calculation, since the nozzles are used as the flow-metering device.

The enthalpy of the supply stream is then calculated based on its temperature and humidity. To determine the heat given up by the supply stream, its enthalpy is calculated at the return temperature. The amount of heat given up by the supply stream is determined as follows:

$$Q_{supply} = M_{da} \times (h_{s(in)} - h_{s(out)}) \quad (4)$$

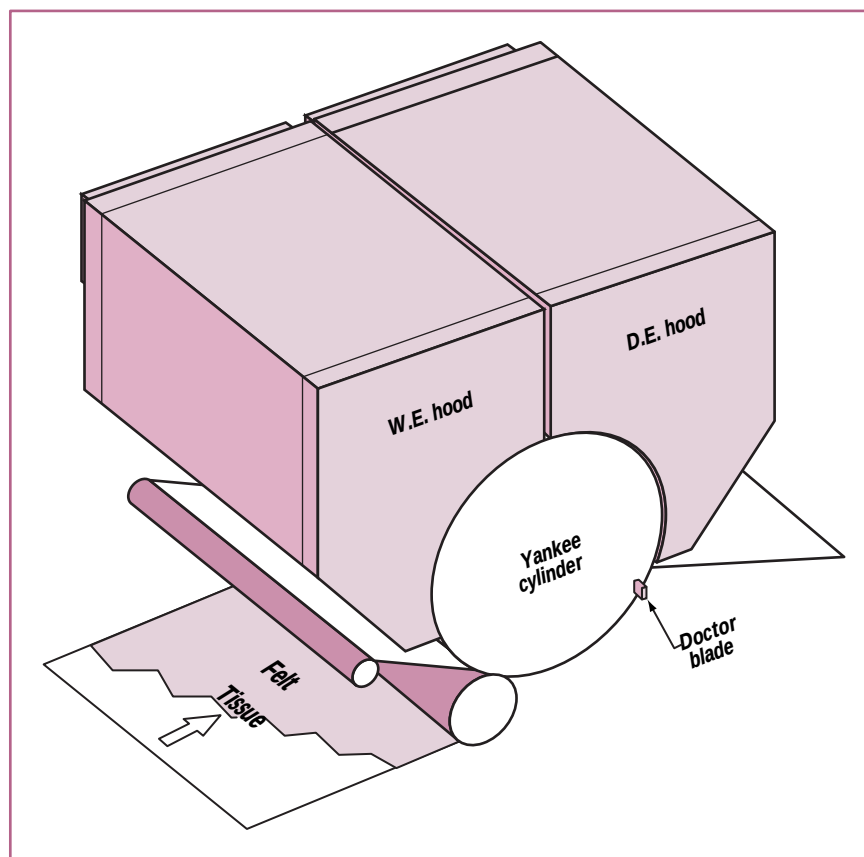
This heat goes to four sources as follows:

- Evaporating water. The heat required is h_{fg} (at T_{sheet} from the steam tables).
- Superheating the water evaporated by both the hood and the cylinder to the return temperature:

$$Q_{superheating} = M_{evap} \times (h_{gT(r)} - h_{gT(sheet)}) \quad (5)$$

where M_{evap} is determined from grab samples taken of the sheet before and after the hood.

- Losses from the hood due to radiation and convection ($Q_{losses hood}$). These can be estimated and are very small compared to the total heat transferred.



1. Dryer

- Heating of ambient-temperature air, which is infiltrated into the hood (the hood should be adjusted to be exfiltrating slightly before undertaking this analysis to minimize the amount of infiltration):

$$Q_{infiltr.} = \text{Inf}\% / 100 \times M_{da} \times (h_{room out} - h_{room in}) \quad (6)$$

The evaporation by the hood is then calculated as:

$$E_{hood} = (Q_{supply} - Q_{superheating} - Q_{losses hood} - Q_{infiltr.}) / h_{fg} \quad (7)$$

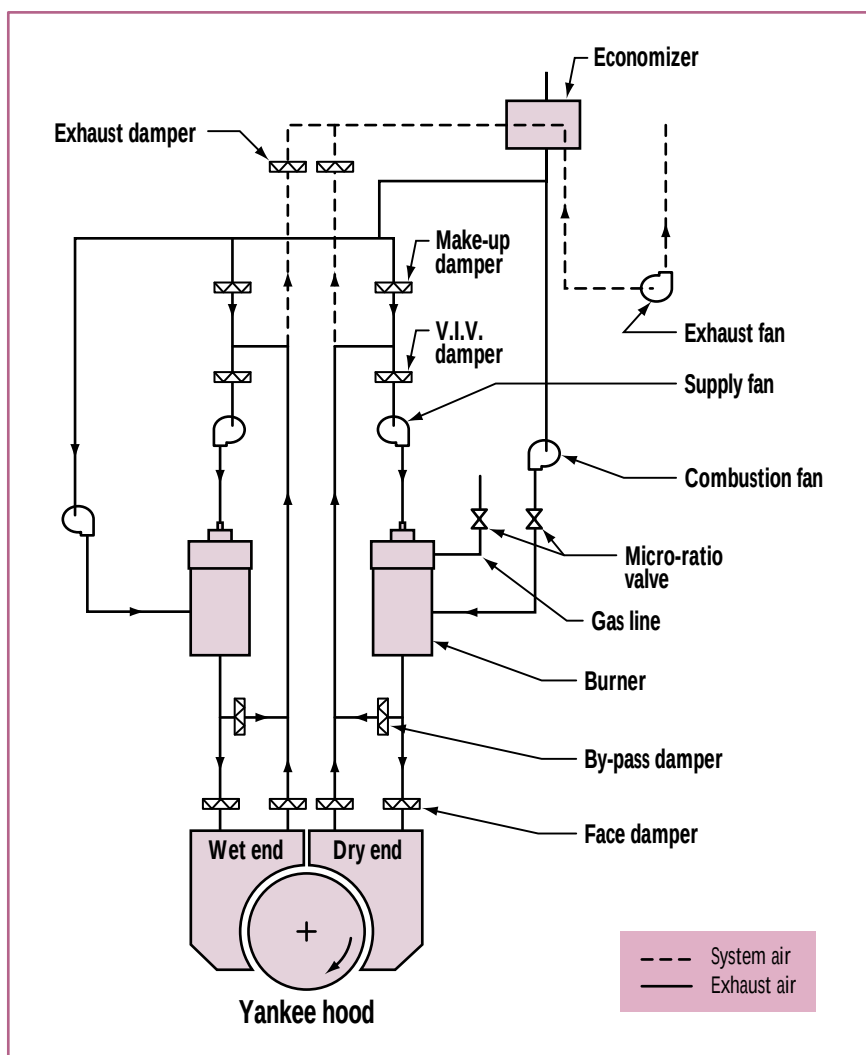
Field measurements required for hood balance method The advantage of the heat balance method is the relatively low number of field measurements required; this reduces the likelihood of measurement errors. The field measurements required are:

- Hood nozzle static pressures
- Hood supply dry-bulb temperatures
- Hood return dry-bulb temperatures
- Hood supply humidities (i.e., dry-bulb, wet-bulb)
- Sheet moisture after the pressure roll and at the creping doctor.

The sheet moisture content is determined by taking samples off the cylinder after the pressure roll and at the creping doctor. The samples at the creping doctor are taken by simply breaking the sheet between the doctor and the reel, and manually grabbing and bagging the samples. The samples between the pressure roll and the hood are somewhat more difficult to take as they must be scraped off the cylinder.

System energy balance method

The hood drying rate can also be calculated from an energy balance over the complete process air system.



2. Flow schematic of a hood air system

This involves determining the heat added to the system by the burners, the fans, and the blowers as well as the heat removed from the system through the exhaust stream of air and losses from the system. The remaining heat is the amount of heat that evaporates water from the tissue sheet. Figure 4 illustrates the system energy balance method schematically.

Calculations. The heat added to the system is calculated as:

- Heat from combustion (Q_{gas}):

$$Q_{\text{gas}} = M_{\text{gas}} \times \text{HHV} \quad (8)$$

- Heat from supply fans, Q_{fans}

- Heat from blowers, Q_{blowers} .

Note: If the exhaust temperature is measured after the exhaust fans, the heat added by the exhaust fans must also be added.

The heat lost from the system is calculated in the following sections.

Heat to superheat water evaporated under hood to exhaust temperature. This includes water evaporated by the cylinder as well as by the hood:

$$Q_{\text{w(superheat)}} = M_{\text{evap}} \times (h_{\text{gT(exhaust)}} - h_{\text{gT(sheet)}}) \quad (9)$$

Heat to evaporate and superheat water generated during combustion process. This heat is calculated as follows:

$$Q_{\text{comb.w}} = W_{\text{T}} \times (h_{\text{gT(exhaust)}} - h_{\text{f}}) \quad (10)$$

Heat to the process air. The air exhausted from the process air system is heated from ambient temperature to the exhaust air temperature. The mass of dry air exhausted (including any air that is exfiltrated from the hood) is calculated based on a water mass balance on the system. The mass of water to be evacuated is:

$$M_{\text{water added}} = M_{\text{evap}} + W_{\text{T}} \quad (11)$$

The mass of ambient dry air is calculated from $M_{\text{water added}}$ and the humidity of the air entering the system (X_{ambient}) as well as the humidity of the air leaving the system ($X_{\text{avg exhaust}}$) as:

$$M_{\text{da(ambient)}} = \frac{M_{\text{water evap}}}{(X_{\text{avg exhaust}} - X_{\text{ambient}})} \quad (12)$$

The heat required to warm this air is:

$$Q_{\text{ambient}} = M_{\text{da(ambient)}} \times (h_{\text{ambient out}} - h_{\text{ambient in}}) \quad (13)$$

Total heat losses from hood and process air system. The losses from the hood and process air system are estimated based on the amount of insulation, exposed surface area, and air temperatures. Again, these losses (Q_{losses}) are relatively small compared to the total heat transferred.

The remaining heat is:

$$Q_{\text{w(superheat)}} = Q_{\text{gas}} + Q_{\text{fans}} + Q_{\text{blowers}} - Q_{\text{comb.w}} - Q_{\text{ambient}} - Q_{\text{losses}} \quad (14)$$

This heat goes to evaporate water. The evaporation rate is calculated as:

KEYWORDS

Air driers, capacity, drum driers, drying, energy balance, heat balance, hoods, test methods, yankee driers.

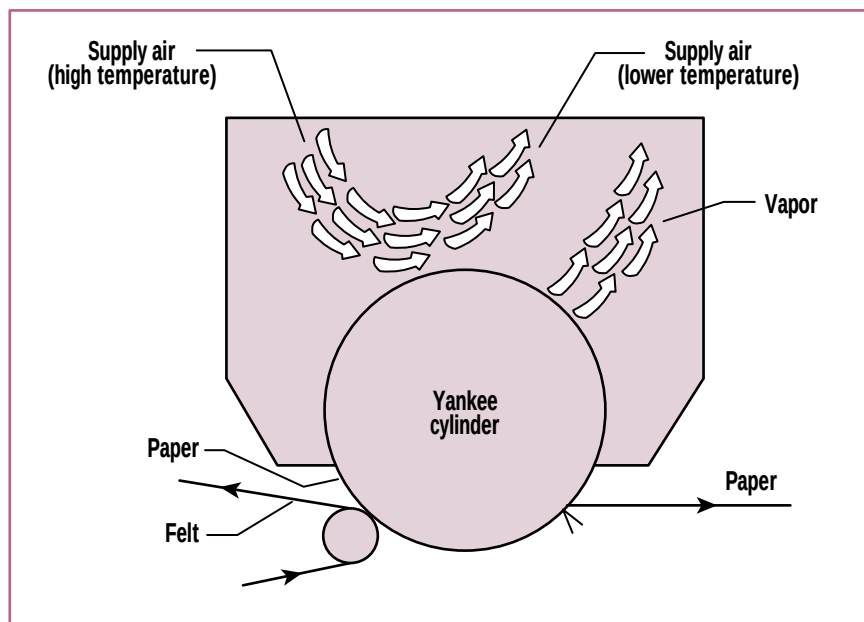
$$E_{\text{hood}} = Q_{\text{evap hood}} / h_{\text{fg}} \quad (15)$$

Field measurements required for system energy balance method. The system energy balance method also requires relatively few field measurements. They are as follows:

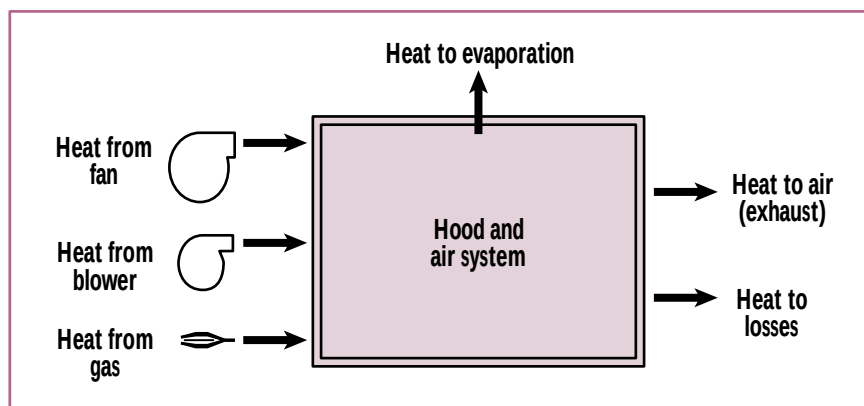
- Exhaust air humidities and temperatures. Humidities are determined from wet- and dry-bulb temperatures.
- Sheet moisture entering the hood and at the creping doctor. The sheet moisture content is determined as described in the heat balance method.
- Gas flow rates. Perhaps the most critical measurement for this method is the gas flow rate. For this reason, the mill must have a properly calibrated metering device on the gas line.
- Fan and blower power usage. The fan and blower power (and the exhaust fan power if the exhaust temperature is measured after the exhaust fans) is determined by measuring the current, voltage, and power factor for each of the motors.

FIELD TEST RESULTS

The results of these methods applied to four field surveys are presented in this section. All of the reported drying rates are normalized by dividing by the maximum drying rate measured. In one case, it was not possible to apply the system energy balance method due to a faulty gas meter.



3. Hood heat balance schematic



4. System energy balance method

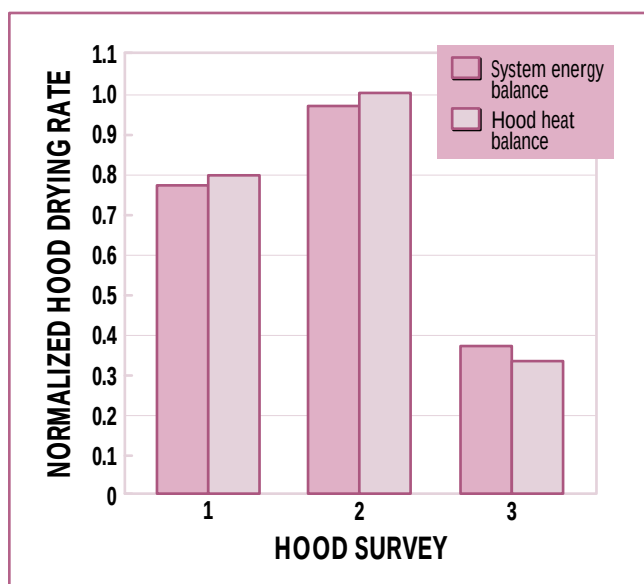
Figure 5 shows the results for the three surveys where both methods were used. In all three cases, the two methods give results that are very similar. Considering that the two methods are completely independent, this indicates the validity of the two methods.

Figure 6 shows a comparison of the measured results with our predicted drying rates for four surveys. The predicted drying rates are based on heat transfer correlations that have been developed in our laboratory for our hoods. These correla-

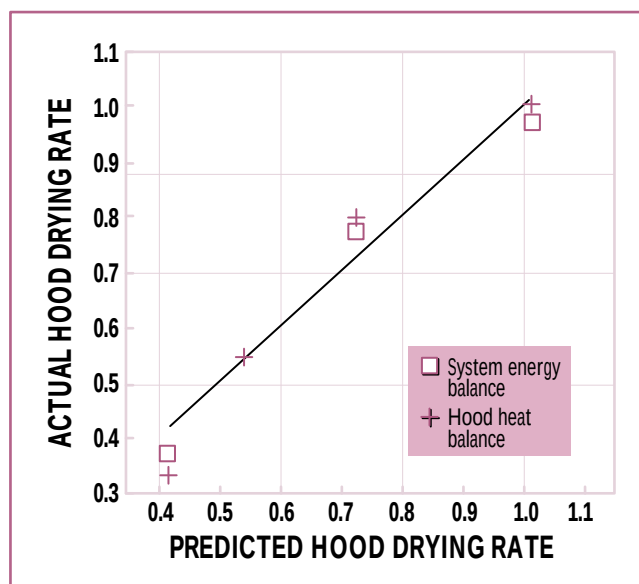
tions account for the effect of variables such as impinging air temperature, humidity, and temperature. The measured results follow the predicted values very well.

SUMMARY

The hood heat balance and system energy balance methods are simple and accurate methods of determining the drying rates of hoods. Because they are independent of each other, it is possible to compare the results of the two methods to validate the results.



5. Results from three surveys of hoods. Drying rates have been normalized by dividing by the maximum value measured.



6. Comparison of measured results with predicted results for the hood drying rates. All drying rates have been normalized by dividing by the maximum value measured.

Presently, standard methods of determining the contribution of the hood to the overall drying on a machine do not exist. We hope that by presenting these methods, others will try them, and eventually they

may become accepted standards for the industry. TJ

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APPENDIX

Nomenclature

The following nomenclature is used throughout this paper:

A_{nozz}	= Nozzle area, m^2	h_f	= Enthalpy of liquid water at ambient temperature, kJ/kg	$h_{\text{room in}}$	= Enthalpy of machine room air, kJ/kg
C_d	= Nozzle discharge coefficient	h_{fg}	= Enthalpy of evaporation of water at sheet temperature, kJ/kg	$h_{\text{room out}}$	= Enthalpy of air at machine room humidity and return temperature, kJ/kg
E_{hood}	= Water evaporated by hood, kg/s	$h_{gT(\text{exhaust})}$	= Enthalpy of water vapor at exhaust temperature, kJ/kg	$h_{s(\text{in})}$	= Enthalpy of supply air stream at supply temperature and humidity, kJ/kg
$h_{\text{ambient in}}$	= Enthalpy of ambient air at ambient temperature and humidity, kJ/kg	$h_{gT(r)}$	= Enthalpy of water vapor at return temperature, kJ/kg	$h_{s(\text{out})}$	= Enthalpy of supply air stream at return temperature and supply humidity, kJ/kg
$h_{\text{ambient out}}$	= Enthalpy of ambient air at exhaust temperature and ambient humidity, kJ/kg	$h_{gT(\text{sheet})}$	= Enthalpy of water vapor at sheet temperature, kJ/kg	Inf%	= Infiltration (% supply dry air), %
		HHV	= Gas higher heating value, kJ/m^3	M_{da}	= Mass flow of dry air, kg/s

$M_{da(ambient)}$	= Mass flow of ambient dry air into system, kg/s	$Q_{comb.w}$	= Energy to evaporate and superheat combustion water, kW	$Q_{w(superheat)}$	= Energy to superheat evaporated water to exhaust temperature, kW
M_{evap}	= Total evaporation under hood (from grab sample), kg/s	Q_{fans}	= Fans energy consumption, kW	T_{sheet}	= Temperature of the sheet, °C
M_{gas}	= Gas flow, m ³ /s	$Q_{infil.}$	= Energy to heat infiltrated air to return temperature, kW	V_n	= Impingement velocity, m/s
M_{mix}	= Mass flow of mixture, kg/s	$Q_{losses hood}$	= Losses from hood due to radiation and convection, kW	W_T	= Total mass of combustion water, kg/s
$M_{water added}$	= Water added to system, kg/s	$Q_{superheating}$	= Energy to bring water vapor from sheet temperature to return temperature, kW	$X_{ambient}$	= Ambient (room) humidity, kg/kg
$M_{water evac}$	= Water evacuated from system, kg/s	Q_{supply}	= Energy released by supply air stream in hood heat balance, kW	$X_{avg exhaust}$	= Average exhaust humidity, kg/kg
P_n	= Nozzle static pressure (measured), Pa			X_s	= Hood supply air humidity, kg/kg
$Q_{ambient}$	= Energy to heat ambient air to exhaust temperature, kW			r	= Density of supply wet air stream, kg/m ³
$Q_{blowers}$	= Blowers energy consumption, kW				

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