Humidity and its effect on thermal efficiency of Yankee hoods

Vic Schukow and Andy Haberl

Significant energy savings can be obtained by controlling the air system dampers in response to the measured humidity.

During the tissue-drying operation, heat is transferred to the sheet by both the Yankee cylinder and the hood air system. Air-side drying rates have improved significantly in recent years, and the Yankee hood has developed to the point that it can handle over 80% of the drying load. The highest production rates and energy efficiencies are achieved through optimum design and operation of the air system.

The operating principles of Yankee hoods

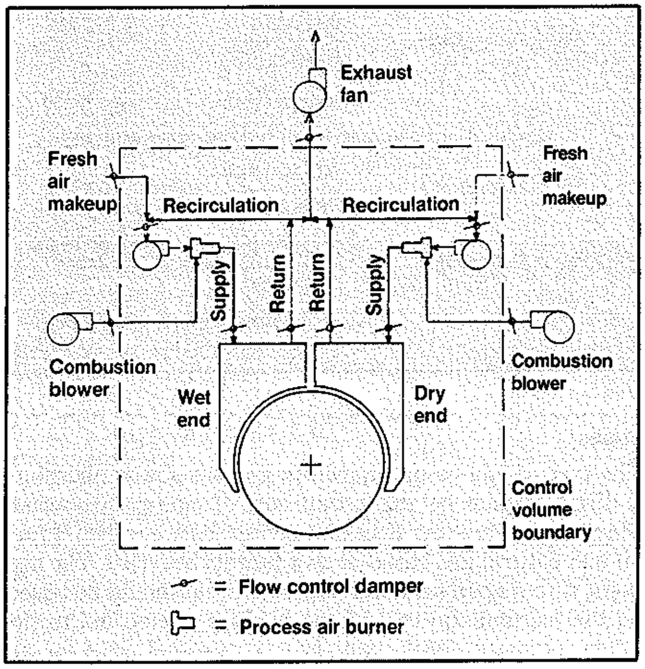
Yankee hood drying is a convective heat-transfer process. A series of nozzle boxes blow hot air at high velocity onto the paper web. The design is usually based on a blow-through system, illustrated in **Fig. 1**. The fans and operating controls are located on a mezzanine adjacent to the hood. Recirculated air and makeup air are mixed in the ductwork and then passed through the supply fans to the burner chambers. Hot air is then sent to the hoods. The flow in each of these air streams is controlled by dampers.

Yankee hoods consume two types of energy: electrical and thermal. The electrical energy consists of the horsepower consumed in operating the fan motors. Consumption of electrical energy is relatively constant during operation and accounts for approximately 15% of the total energy on a Yankee air system. Thermal energy, supplied by the burners, is consumed by:

- Raising the sheet temperature
- Evaporating water from the sheet
- Radiation and other losses from the hood and ductwork
- Heating the makeup air from room temperature to supply temperature.

Energy consumption in the first two instances is a function of production variables. Energy consumption in the third case—radiation losses—depends on the system temperature. The final item on this list of thermal energy consumers—the air system—offers an opportunity for energy savings. The only readily controllable parameter that can significantly minimize energy consumption in the air system is the flow of makeup air.

1. Air flow system in a typical Yankee dryer



The minimization of energy consumption must not disturb the net air balance of the system. In Fig. 1, a control volume boundary shown around the system helps to illustrate how the air mass balance behaves. The inputs to this control volume are the makeup ($m_{m/u}$) and combustion (m_{comb}) supply air streams to the hood. The output is the exhaust air (m_{exh}) to atmosphere. The difference between the input and output mass flows is either infiltration (to the hood) or spill (out of the hood). In summary,

$$(m_{m/u} + m_{comb})_{wet\ end} + (m_{m/u} + m_{comb})_{dry\ end} - m_{exh} = \text{net flow across boundary}$$

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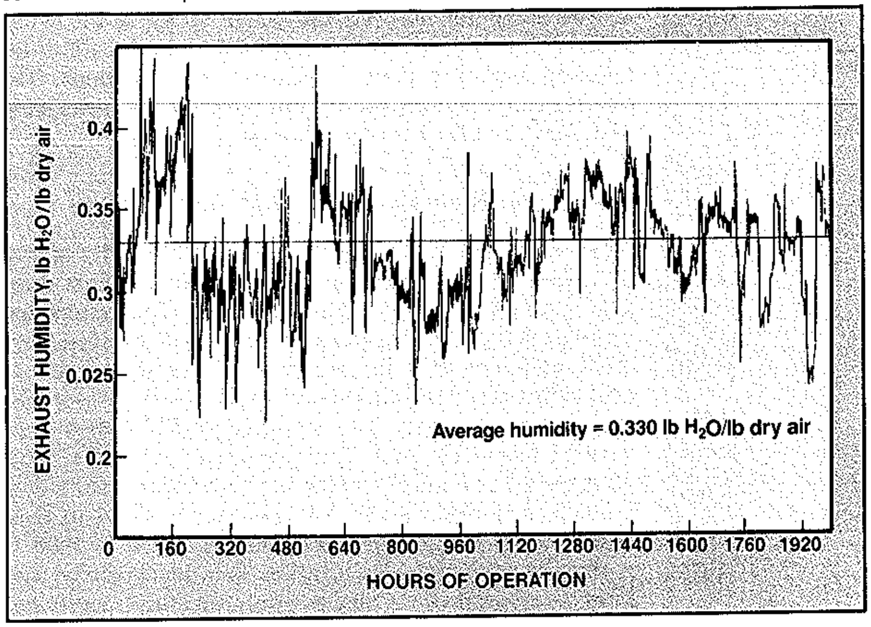
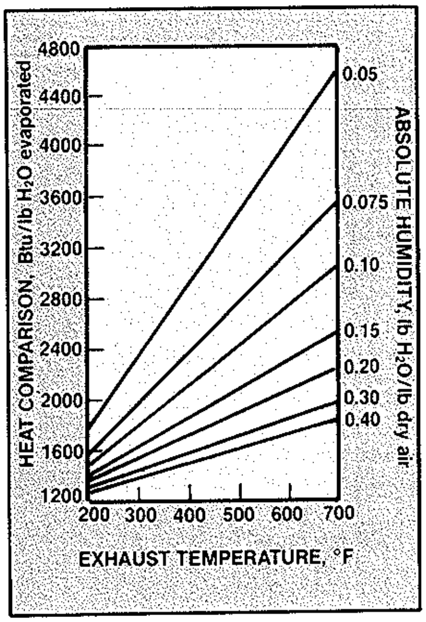
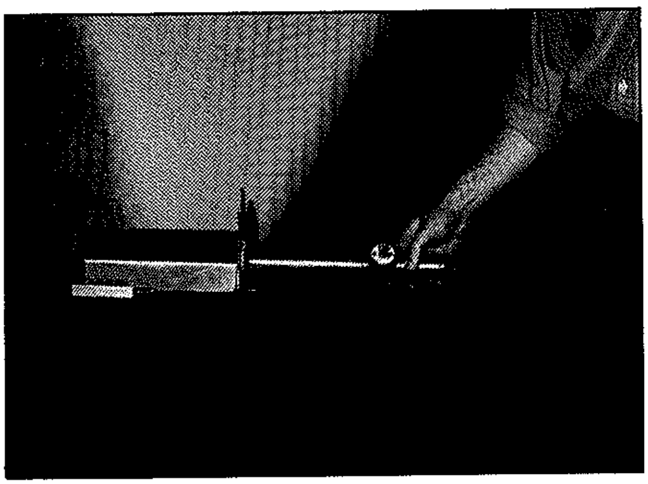
2. Exhaust humidity from a Yankee hood varied between 0.22-0.45 lb H_2O/lb dry air over several months of operation.



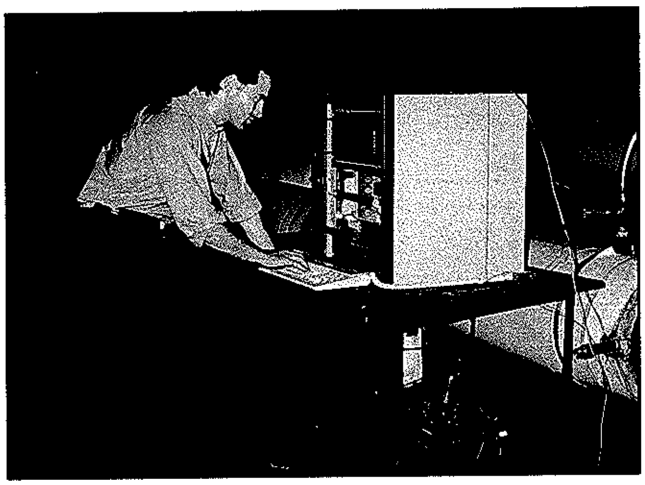
3. Effect of system humidity on heat consumed per pound of water evaporated



4. High-temperature humidity sensor



5. The sensor is controlled by a computer that controls the water spray to the wick, determines the wet-bulb depression, and calculates absolute humidity. The software also includes the control functions for measuring air flows and for adjusting damper positions.



It is important to maintain a balanced flow across the boundary. This prevents overdrying at the edge of the web (caused by thermal infiltration) or machine room discomfort (caused by thermal spill). Minimum energy consumption and optimum air balance are achieved by adjusting the appropriate dampers.

The benefits of humidity control

Changes in machine speed, paper grade, or entering moisture can have a considerable effect on system humidity. **Figure 2** shows actual hood humidities measured over several months of operation. The exhaust humidity varied dramatically (0.22-0.45 lb H_2O/lb dry air). As a result, the thermal efficiency was often less than optimum. **Figure 3** outlines the effect of system humidity on heat consumed per pound of water evaporated.

Table I compares the annual operating costs for a typical Yankee hood operating at average exhaust humidities of 0.30 lb H_2O/lb dry air and 0.45 lb H_2O/lb dry air. Although electrical consumption is slightly higher at the higher humidity, there is a considerable reduction in thermal energy consumption. This is due to the increased use of recirculated air and the consequent reduction in the amount of cool makeup air introduced to the system.

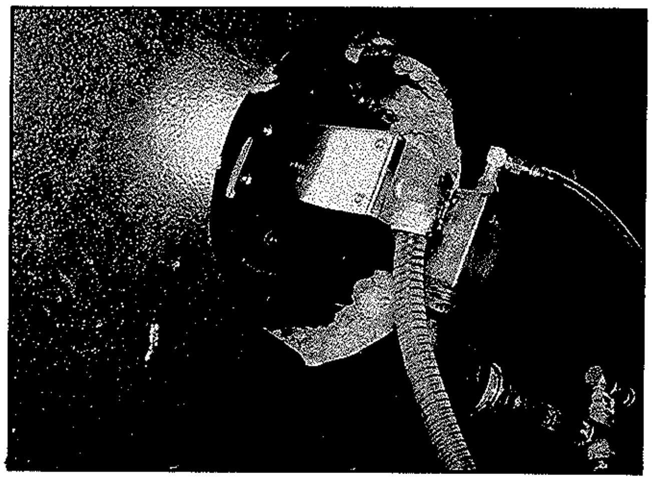
A control system with a humidity sensor would respond to a humidity set point by reducing the flow of makeup air. This would maintain the highest possible humidity in the system (approximately 0.45) and thus minimize its energy consumption. However, if the humidity is set too high, the driving force for evaporation (the gradient

1. Annual energy consumption and operating costs for a typical Yankee hood operating at different levels of humidity

	Low humidity	High humidity
Exhaust humidity, lb H_2O/lb dry air	0.30	0.45
Electrical energy consumption, hp		
Wet end		
Supply fan	219	239
Combustion blower	39	35
Dry end		
Supply fan	219	239
Combustion blower	39	35
Exhaust fan	49	36
Total	565	584
Annual cost (@ $400/hp/year), $	226,000	233,600
Thermal energy consumption		
Operating burner capacity, 10^6 Btu/h	49.951	41.603
Annual cost* (@ $4/million Btu), $	1,750,283	1,457,769
Total annual operating costs, $	1,967,283	1,691,369

*365-day basis.

6. Sensor installation in Yankee hood exhaust duct



between the sheet and the impinged air) decreases. A control system would constantly maintain the design humidity in a Yankee hood.

The principle of the sensor

Our company has developed a control system that uses feedback from a sensor that can measure humidity at high temperatures. The sensor device uses a porous metal wick with an internal spray nozzle to measure actual wet-bulb temperature. The assembly is encased in a hood to protect it from fouling. An adjoining thermocouple measures the actual dry-bulb temperature. Because the unit acts as a direct wet-bulb thermometer, it requires no calibration. Its stainless steel design and simple operating principle make it virtually maintenance-free. The sensor is illustrated in **Fig. 4**.

The sensor is controlled by a computer, as shown in **Fig. 5**. The computer controls the water spray to the wick, determines the wet-bulb depression, and calculates absolute humidity using psychrometric equations. The software also includes the control functions for measuring duct flows and for adjusting damper positions.

Sensor performance in a mill installation

After extensive laboratory testing, the humidity sensor was installed on an existing Yankee hood exhaust duct. The installation is illustrated in **Fig. 6**. The system has undergone over 20,000 successful testing cycles since April 1987, and it is still in operation. There have been no problems with contamination, even though the sensor uses recycled mill water. The sensor's precision has been verified repeatedly by testing samples of exhaust air that were cooled down using a standard laboratory technique.

Tests show that the sensor's accuracy is ±0.01 lb H_2O/lb dry air in the temperature range of 200°F to 1000°F, with no necessity for recalibration. This device can be used in any drying process that requires constant monitoring of air humidity.

Summary

Optimum energy performance in a Yankee hood can be obtained by controlling the air system dampers in response to the measured humidity. A control system can adjust makeup air flow based on feedback from a humidity sensor. A recently developed high-temperature humidity sensor has operated reliably throughout its first ten months of mill testing.

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