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## Methods of evaluating high velocity dryers

### Scope

This Technical Information Paper provides guidelines for evaluating the performance of high velocity air impingement dryers used in the manufacture of paper products.

### Significance

High velocity air impingement dryers are used throughout the paper industry and have numerous applications. High velocity dryers are used in the drying of coating on paper and to dry tissue, towel and machine glazed papers in conjunction with steam heated (Yankee and MG) cylinders.

High velocity air impingement dryers transfer heat to the web by convection and, to a lesser degree, by radiation.

High velocity air impingement dryers can be broken down into two types: those with and those without external heat addition. An external heat source is any source of heat other than that used to heat the hood's impingement air. An example of a hood without external heat addition is a coating dryer where the air impinges onto the paper web with no other heat source. An example of a hood with external heat addition would be a Yankee high-velocity hood with a Yankee cylinder providing contact heating of the opposite side of the paper web.

### Safety precautions

The measurements required for the tests described in this document may expose the person(s) carrying out the work to personal discomfort due to high ambient temperatures. The risk of severe burns due to exposure to high temperature air and equipment exists. In addition, risk of injury due to proximity to rotating machinery exists. The measurements described herein should be carried out with due care. Particular care should be taken to avoid direct contact with rotating components and with hot ducts, burners, dampers, and fans.

### Nomenclature

Refer to Appendix A.

### Description

A typical high velocity dryer system consists of a hood (Yankee hood for example) that encloses a system of supply air distribution nozzles. The surface of the dryer facing the paper consists of an array of holes or nozzles or slots for blowing hot air onto the paper. Return air slots or tubes are provided in the hood to allow moist spent air to flow back to a suction plenum in the hood.

The air system consists of a supply fan, air heater (usually equipped with an oil or gas burner), and ductwork. The air system is used to heat the air to the necessary temperatures and increase its pressure to achieve the desired

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impingement velocities. An exhaust fan is provided to remove a part of the circulating air and the water vapor. Fresh air is introduced into the circulation system to replace the exhausted air. In order to improve fuel economy, the fresh “make-up” air and the combustion air are often pre-heated in a heat exchanger thereby recovering a part of the heat in the exhaust air. A typical hood system is shown in Fig. 1.

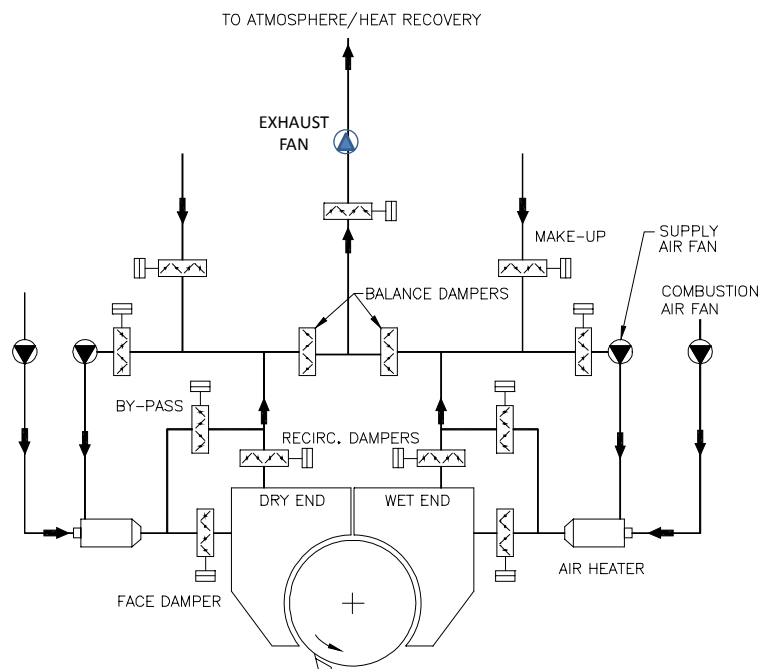


**Fig. 1.** Schematic of a hood air system

## Theory

In a typical drying process, heat for drying the paper web is required for the following:

- Heating the web and its water to an initial equilibrium temperature.  
In a purely convective drying process, the equilibrium temperature of a wet web is the wet bulb temperature of the blowing air, providing that the web contains free water (as opposed to bound water in the fiber cell). As the web dries, its temperature will begin to rise. In a convective drying process with external heat addition, the wet web temperature will be slightly higher than the wet bulb temperature.
- Evaporation at the equilibrium temperature.
- Superheating of the water vapor from the equilibrium temperature to the exhaust temperature.
- Heating of the web and any residual water to its final temperature.

For the case of a purely convective dryer process (one without external heat addition), the heat input comes solely from the high velocity hood.

For the case of convective drying with external heat addition, as in the case of a Yankee hood–Yankee cylinder combination, the heat input to the web is split between the hood and cylinder. This “special case” is slightly more difficult to analyze because of the need to “split” the contribution between the two sources.

## Evaluation of drying rate

The drying rate can be evaluated by one of five methods: Paper Mass Balance, Air Mass Balance, Hood Energy Balance, Air System Energy Balance, and External Energy Balance. The first two methods (Paper Mass

Balance and Air Mass Balance method) determine the combined drying rate from the hood and external heat sources. The Hood Energy Balance, Air System Energy Balance, and External Energy Balance methods can be used to attribute relative drying rates to the hood and to external heat sources.

### Paper mass balance

The Paper Mass Balance method determines the total evaporation under the hood-covered area. This method requires that the moisture content of the web be determined at the hood inlet and outlet. Samples should be taken as close to the hood as possible to exclude drying outside the hood-covered area.

**Caution** - extreme care should be exercised when taking grab samples to avoid contact with machinery.

The total evaporation under the hood can be determined as follows:

$$R = B \times S \times W \times \left[ \frac{L}{E} - 1 \right] \frac{1}{1000} \quad (1)$$

This equation can be used to calculate the evaporation for the case of a hood with or without external heat addition. For the case of a hood with external heat addition (such as the case of the Yankee hood and cylinder), R is the total evaporation by the hood and hood covered part of the cylinder and does not distinguish between the two.

### Air mass balance

The Air Mass Balance method also determines the total evaporation under the hood-covered area. This method requires the measurement of the supply air flow rate and supply and exhaust humidity. As with the paper mass balance method, the calculated evaporation is the total hood evaporation under a hood with or without external heat addition. For a hood with external heat addition, it is the total evaporation by the hood and hood-covered part of the cylinder.

The total evaporation under the hood can be determined as follows:

$$R = M_{Sdryair} (X_R - X_S) \quad (2)$$

The flow rate of supply air can be calculated from the air velocity found from pitot tube measurements across the area of the air supply duct. It can also be determined by considering the hood nozzles as flow measurement orifices and determining velocity and flow from nozzle box pressures, supply temperatures and humidity as follows:

**Caution** - Extreme care should be exercised when taking flow measurements to avoid exposure to high temperature air.

$$\text{Perforation Fraction} = \frac{\text{geometric area of holes}}{\text{nozzle covered area}} \times C_d^* \quad (3)$$

**NOTE 1:** The perforation fraction (or open area) is based on the reduced area of the nozzle. This compensates for the “necking down effect” of the jet flowing through the nozzle. It is important that the precise nozzle discharge coefficient be used in this calculation. Values listed in Figure 2 are for reference purposes only. Consult the hood manufacturer for the actual discharge coefficient.

$$\text{Net Nozzle Area} = (\text{Nozzle Covered Area}) \times (\text{Perforation Fraction}) \quad (4)$$

$$V_n = \sqrt{2P_n / \rho} \quad (5)$$

$$M_{Smix} = V_n \times \text{Net Nozzle Area} \times \rho \quad (6)$$

$$M_{S\ dryair} = M_{Smix} / (1 + X_s) \quad (7)$$

The humidity  $X_s$  and density  $\rho$  of the supply air can be determined with the aid of psychometric charts or tables given the dry bulb and wet bulb temperatures of the supply air.

\* Discharge coefficients,  $C_d$  for different types of nozzle are shown in Fig. 2.

**NOTE 2:** This method requires that the hood be balanced or in a slight over-pressure condition (spilling) to avoid infiltration of fresh air into the hood (where the paper enters and exits and around the sides), so as to not affect the humidity of the return air. The flow rate of the return air may also be measured to check the system balance.

### Hood energy balance method

Another method of determining the evaporation is the Hood Energy Balance method. This method determines the drying rate of the hood by calculating the amount of heat given up by the supply air for evaporation. This method is particularly useful for the case of convection drying with external heat addition because it allows for the hood evaporation to be calculated independently of the cylinder contribution. A schematic overview is shown in Fig. 3.

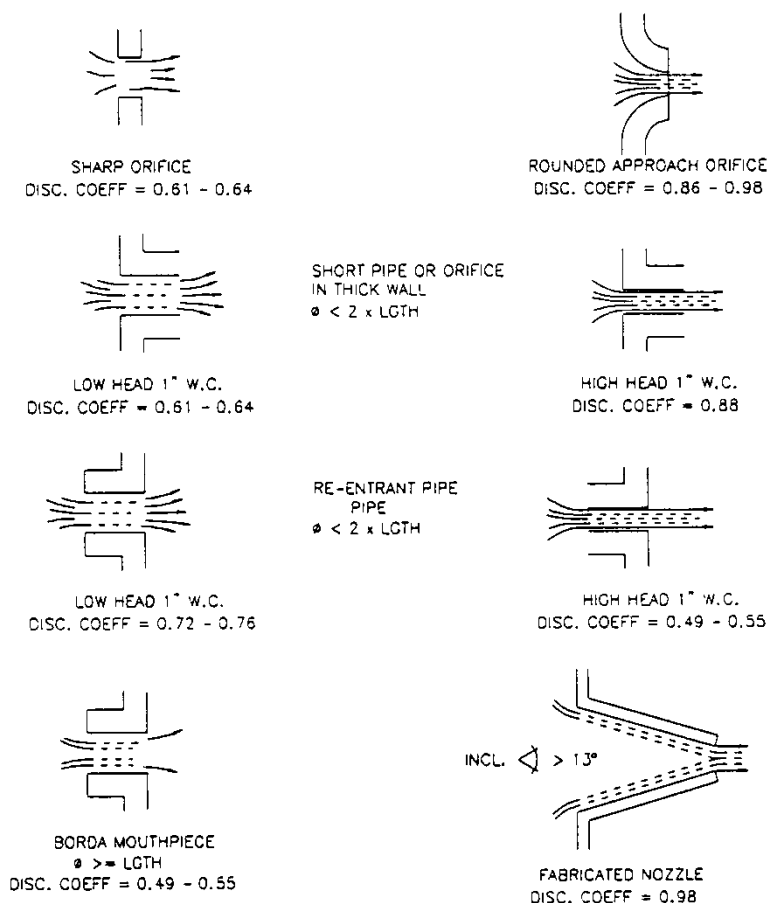


Fig. 2. Nozzle and orifice discharge coefficients