ISSN 2229-5518

ADIABATIC HUMIDIFICATION OF AIR IN A DUCT

Aqib Iqbal and Ambar Srivastava

Abstract

We have derived a relation based on experiment giving dependence of relative humidity of air flowing through a duct, on the length covered by the flowing air in the duct, area of cross-section of the duct and velocity of air flowing through the duct. We have also discussed various factors controlling the constant of proportionality of the derived relation.

Index Terms- Adiabatic, By-pass, Humidity, Interface, Duct, Velocity, Vortex.

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1 INTRODUCTION

Finely atomized water is introduced into the air. The adiabatic process does not involve the contribution of thermal energy from an external source. There is no heat added.

Typical Types:

- High Pressure Atomizing
- Air/Water Atomizing

- Ultrasonic

- Wetted Media Evaporative

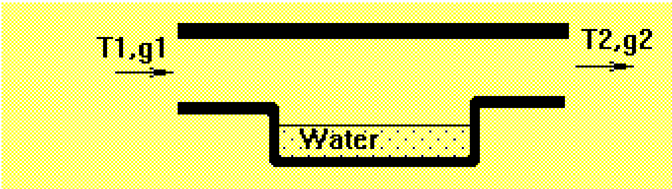
The biggest advantages of Adiabatic Humidifiers are:

- Significant Energy Savings.
- Helpful when Steam or Gas are not available
- Precise Humidity Control.
- Easy to Install and Retrofit.
- Proven and Simple Technology.
- Simple to Operate and Maintain.

Disadvantages seen in Adiabatic Humidifiers are:

- Longer Absorption Distances (more length need in an air handling unit)
- Requires Preheat of Supply air
- Typically Require RO Water
- Compressed Air required on Air/Water Systems

ISSN 2229-5518



In this process, air enters a duct (which is assumed to be perfectly insulated in order to satisfy the condition for an adiabatic process) at dry-bulb temperature T1 and moisture content g1 and leaves the duct at dry-bulb temperature T2 and moisture content g2.

The latent heat gained by the air is equal to the sensible heat loss by the air i.e. here h_{fg} is the latent heat of water. If the water tank is infinitely long, the air at the outlet will be 100% saturated. The temperature at this condition is known as adiabatic saturation temperature.

2 EXPERIMENTAL SETUP :

2.1 MATERIALS REQUIRED :

- Adiabatic PVC pipe.
- Blower with constant volume discharge.
- Digital thermometer.
- Water at wet bulb temperature of the air at inlet.

PROCEDURE -

A cylindrical PVC duct of 7ft. length and 10 cm. cross-section was taken.

- Half of the area at the cross-section was covered and filled with water at the wet-bulb temperature of the inlet air discharged by the blower at a particular velocity.
- a provision for make-up water was provided for keeping the water level constant and maintaining approximately the temperature of water at the wet-bulb temperature.
- Then digital thermometers were inserted at various points in the duct to measure the temperature of flowing air at different points in the duct.
- The temperatures at various points was calculated till the temperature of the flowing air was equal to the temperature of the stagnant water i.e. equal to the wet bulb temperature and the humidity was formulated at that point.
- Corresponding to this point of 100% humidity length was also measured from the starting point.
- Now the relative humidity at the points where thermometers were inserted was calculated by varying the velocity of inlet air and the area of air-water interface separately.

Using the experimental data we formulated an equation governing the variation of relative humidity with velocity of inlet air, area of interface between the water and air and the length of duct.

3 FACTORS GOVERNING HUMIDITY IN THE DUCT :

3.1 VELOCITY - lower is the velocity of inlet air, greater will be the chance of humidification as more time will be available for the mixing of water droplets at the interface. lesser is the velocity of air greater will be interaction at the water- air boundary and hence higher will be the diffusion of water molecule into the dry air and thus greater will be the rate of humidification.

MATHEMATICALLY IT CAN BE PROVED AS FOLLOWS -

Almost all the general evaporation rate based on Dalton's description on real gases is given by the formula-

$$E = (a + (b*V))*(P_w-P_a) / h_w$$

By this formula Dalton stated that evaporation is proportional to difference in vapor - pressure at the surface of water and in the air and that the velocity of wind affects this proportionality.

E = evaporation rate (kg /m^2 sec).

a = coefficient of empirical equation.

b = coefficient of empirical equation.

V = wind velocity (parallel to water surface)

P_w = saturated water vapor partial pressure at the water temperature.

ISSN 2229-5518

P_a = water vapor partial pressure at air temperature and humidity.

h_w = latent heat of vaporization of water

Φ (relative humidity) = P_a/P_w

$$E = (a + (b*V))* (P_w-P_a)/h_w$$

$$E = (a + (b*V))*P_a*((P_w/P_a)-1) / h_w$$

$$E = (a + (b*V))*P_a*((1/\Phi)-1) / h_w$$

thus ,

$$E \propto V$$

$$E \propto 1/\Phi$$

therefore,

$$\Phi \propto 1/V \qquad - \quad (1)$$

Therefore , relative humidity(Φ) at particular length of duct and particular area of interface varies inversely with linear power of wind velocity.

3.2 AREA OF INTERFACE - Humidification is directly proportional to area of interface between the air and water.

More is the area of contact between water and air surface , more will be mixing of water and air molecule and hence greater will be evaporation rate. Thus ,relative humidity increases with increase in area of contact at interface.

Experimentally we found that the variation of relative humidity (Φ) with area is linear.

$$\Phi \propto A \quad - \quad (2)$$

3.3 LENGTH OF DUCT - By performing the experiment we found that greater is the length of duct higher is the humidification of the air achieved .After a certain length for a given area of interface and velocity of wind supplied the humidity of air is constant as 100% humidification is achieved at an earlier length

Proportionality will be applicable till the length of 100% humidification. After that humidity will be constant and remain 100%.

$$\Phi \propto l \quad - \quad (3).$$

Now combining equations (1,2&3) -

$$\Phi \propto l * A / V$$

ISSN 2229-5518

$$\Phi = ((K*l*A) / V) + \Phi'$$

here Φ' is relative humidity at inlet and K is constant of proportionality.

Maximum attainable value of Φ is 1.If its value exceeds 1 according to the above formula then 100% humidity is achieved before only and thus take humidity equal to 100% .The formula gives correct result only to the point where 100% humidity is reached or Φ is equal to1.

Unit of K :-

As Φ is dimensionless, unit of K will be equal to unit of V / (l*A)

Therefore ,unit of K is **m/sec*m*m^2**

So, unit of K is **per sec *m^2**

4 GOVERNING FACTORS OF K :-

- **BY - PASS FACTOR** - It is the fraction of air which passes without coming in direct contact with water surface .Greater is the by-pass factor greater will be the time of humidification .Thus lesser will be evaporation rate.

Therefore the value of K will be lesser and thus higher will be the value of (l*A) / V.

4.1 BY - PASS FACTOR FOR VARIOUS DUCT GEOMETRIES :-

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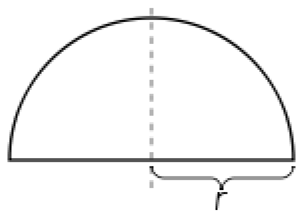
I. Duct with same area of wind flow but different contour curve - More is the average height above water surface more will be by- pass factor, thus ,lesser will be value of K.

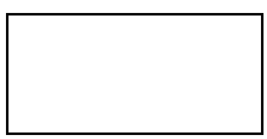


We find the average height , $y=(\sqrt{(r^2-x^2)})$ on the interval $-r \le x \le r$

Average height = $(1 / (2*r))*(\int (r^2-x^2))$

Here limit of integration varies from **– r to + r**Type equation here.

After calculation average height comes to be (∏*2*r)/8



Here, length of rectangle is 2r and area is $(\prod * r^2) / 2$

Therefore, average height = area / (2*r)

$= (\prod * r^2) / (2*(2*r))$

$= (\prod * r)/4$

ISSN 2229-5518

In this case average height of semi-circular section is same as the average height of rectangular section of same area .Thus, by-pass factor for semi-circular section will be same as the rectangular section. Hence, the value of K will be equal for both sections.

II. Duct with same maximum height of air flow -

Here we have height of rectangular section = maximum height of semi-circular section=r.

Length of rectangular section = 2*r

Here we can easily find that the average height of rectangular section is more than the average height of semi-circular section .So by-pass factor will be more for the rectangular section and hence value of K will be less for the

rectangular section . Hence, the value of (l*A) / V will be more for the

ISSN 2229-5518

rectangular section.

4.2 VORTEX FLOW VARIATION – Though the average height of rectangular section is equal or more than the semi-circular section in the above cases, still for small differences in average height vortex flow may be the deciding factor.

In rectangular-section , because of the presence of corner points there will be vortex formation while the flow will be uniform in semi-circular section. Because of vortex flow there will be turbulence leading to higher mixing of air and water molecules ,so by-pass factor will be lesser. Thus increasing the value of K and subsequently decreasing the value of (A*l) / V for the rectangular section.

However, excess of vortex formation is undesirable because of heat generation due to excess of turbulence leading to thermal losses.

5 APPLICATIONS :-

I. In processes where humidified air is required the formula can be used to cause humidification in a compact duct, thus ,saving the material cost.

II. In places where humidification after a certain limit is undesirable because of ill-effects like corrosion, this relation can be used to check the humidity of air flowing over the fluid approximately and provides measures to regulate the humidity within the limit by increasing the velocity or decreasing the area of interface (decreasing the by-pass factor).

III. Humidity measuring instruments for large scale are very costly .Thus leading to economic losses .This relation will help in approximate humidity analysis sufficient for jobs where higher accuracy is not required.