Steam humidification:

Reducing energy use, airstream heat gain, and condensate production

Updated!
Includes analysis of stainless-steel-shielded dispersion tubes.

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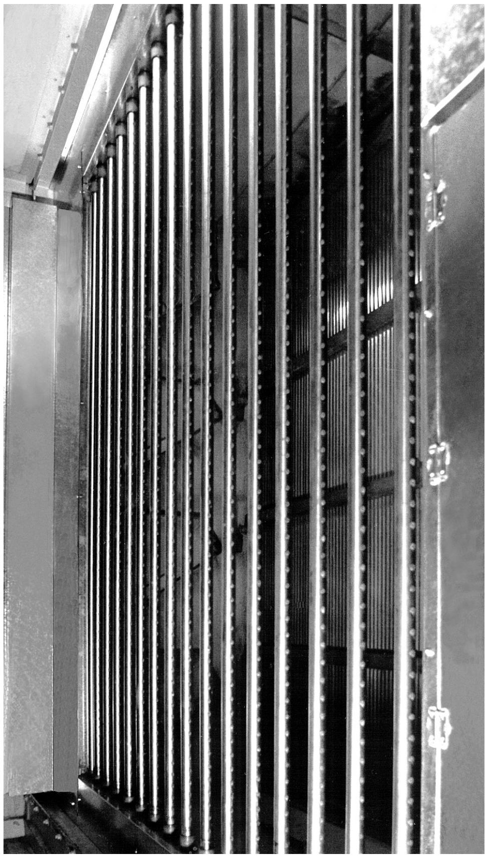
Enlightened building owners demand accountability for every resource consumed in the construction and operation of new or renovated buildings. Meeting conservation benchmark standards requires measurable building performance, for it is commonly understood that if you can't measure it you can't improve it.

Commercial and industrial steam humidification is considered essential for most process, preservation, and health applications such as semiconductor manufacturing, printing plants, museums, schools, and health care facilities. Given the significant number of large buildings requiring steam humidification, it is time to make strides toward measuring and improving the energy efficiency and water consumption of these building systems. Recent advances in materials and manufacturing techniques are bringing attention to this issue, specifically the energy and water wasted when dispersing steam into cool airstreams. This article describes these materials and includes data about their performance.

FIGURE 1-1:
TYPICAL DISPERSION ASSEMBLY



Shown here is a typical steam dispersion tube panel with uninsulated stainless steel tubes installed to span the full height and width of an air handling unit. These dispersion tubes discharge steam from both sides, perpendicular to airflow.

Steam dispersion basics

Humidifying with steam requires two essential functions: steam generation and steam dispersion.

Direct steam injection humidification systems disperse steam into duct or AHU airstreams from on-site boilers or unfired gas or electric steam generators. Unique to direct steam injection applications is the dispersion of pressurized steam.

Humidification steam can also be generated in a nonpressurized gas or electric steam generator connected to a dispersion assembly. This type of steam is often called "evaporative" steam because the steam chamber operates at or near atmospheric pressure.

Whether dispersing pressurized or nonpressurized steam, the function of a dispersion assembly doesn't vary: receive steam from the steam generator, discharge steam into the airstream

The only variable that can be changed to reduce heat transfer is the thermal conductance of the dispersion tubes. This can be accomplished with insulation.

through calibrated openings in stainless steel dispersion tubes, and drain condensate to a floor drain or pipe it back to the steam generator. (Note that some steam generators are not designed to accept returned condensate.)

Steam dispersion assemblies are available in a multitude of configurations designed to meet a variety of absorption and load requirements. Whether it's a 12-inch tube or a 12-foot panel, the purpose of a dispersion assembly remains essentially the same: distribute steam into the airstream.

This appears to be a simple process, but substantial thought goes into effective dispersion assembly design, primarily to accommodate the complex properties of steam while discharging it into a cool airstream.

FIGURE 2-1: DISPERSION PANEL WITH PVDF-INSULATED TUBES

Hot dispersion tubes heat the air and produce condensate

When operating, uninsulated stainless steel dispersion tubes are hot — they have a surface temperature just under 212 °F. Dispersion assemblies typically disperse steam into 50–55 °F airstreams. Cool air flowing across hot dispersion tubes causes some steam inside the tubes to condense, releasing latent heat. This heat passes directly through uninsulated stainless steel dispersion tubes into the airstream, increasing downstream air temperature. *Because of the relationship between latent heat and condensate, downstream heat gain from dispersion tubes is directly proportional to the amount of condensate produced within those dispersion tubes.*

Downstream heat gain wastes resources in the following ways:

- *Every pound of condensate produced wastes about 1000 Btus* — the energy originally used to change that pound of water into steam.
- *Every 8.33 pounds of condensate sent to a drain wastes a gallon of water.*
- *Heat added to downstream air increases the cooling load* in applications that humidify and cool simultaneously (such as hospitals, museums, schools), wasting energy cooling the unnecessarily heated air.
- *Unnecessary condensate production can cause a*

- *Every pound of condensate sent to a drain wastes water treatment chemicals* (e.g., softened water, deionized or reverse-osmosis treated water, water treated with boiler chemicals). Note that not all humidification systems return condensate to the steam generator.
- *Heating air with a humidification dispersion assembly is inefficient.* Dispersion assemblies are not designed to be heating appliances.

The heat transfer rate from dispersion tubes to an airstream is determined by airstream temperature, airstream velocity, dispersion tube quantity (surface area), and dispersion tube thermal conductance. In a typical application, air temperature and velocity are defined by HVAC system parameters; and steam pressure and dispersion tube quantity are functions of humidification requirements and cannot be reduced without a resulting drop in humidification performance. The only variable that can be changed to reduce heat transfer is the thermal conductance of the dispersion tubes. This can be accomplished with insulation.

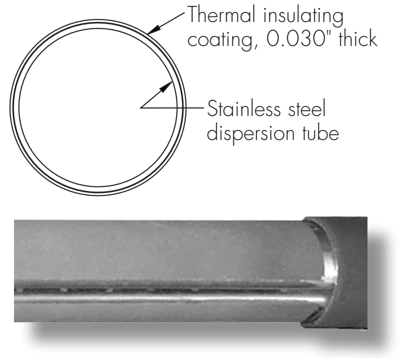
Insulate dispersion tubes to reduce downstream heat gain

Dispersion tube insulation must withstand the environmental extremes of steam humidification while meeting strict plenum requirements for smoke and flame. In addition, insulation thickness must not significantly obstruct airflow, which could cause an excessive pressure drop. There are three types of dispersion tube insulation that meet these requirements: thermal insulating coating, stainless-steel-shielded air gap, and PVDF insulation (Figure 3-1).

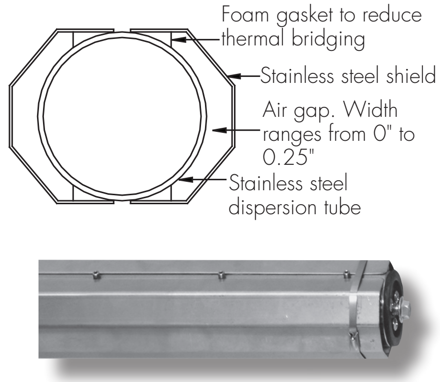
1. **Thermal insulating coating.** Commonly referred to as a “TIC” or as “ceramic insulation,” this coating is factory-applied to a dispersion tube as a liquid or semi-liquid that dries or cures to form a coating typically 0.030" thick (the maximum thickness of a single coating).
2. **Stainless-steel-shielded air gap.** A stainless steel shield, factory-applied or retrofitted to a dispersion tube, creates an air gap that provides insulating value. The air gap varies in thickness from 0" to 0.25" (1/4") thick.
3. **PVDF (polyvinylidene fluoride) insulation.** PVDF insulation is factory-applied or retrofitted to a dispersion tube. PVDF is dense, closed-cell insulation, 0.125" (1/8") thick.

FIGURE 3-1: DISPERSION TUBE INSULATION TYPES WITH DRAWINGS IN CROSS SECTION

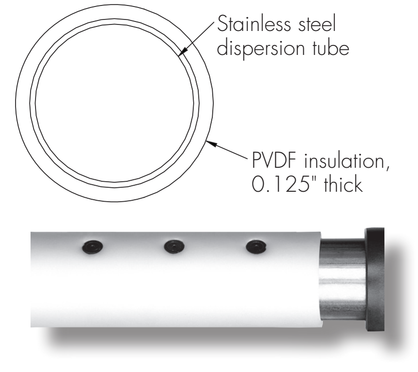
1. Thermal insulating coating



2. Stainless-steel-shielded air gap



3. PVDF insulation



Heat transfer basics and TICs

Heat transfer occurs in three ways: conduction, convection, and radiation.

Conduction is the transfer of thermal energy in solids and liquids at rest, such as through a stainless steel dispersion tube.

Convection describes thermal energy transferred between a solid surface and a fluid moving over the surface, such as cool air flowing over a hot dispersion tube.

Radiation is thermal energy transferred by electromagnetic waves and requires no medium; it will travel through a vacuum. Heat loss via radiation from a dispersion tube is only 1-2% of the total heat loss from convection. Heat loss via radiation is strongly dependent on the surface emissivity and temperature of that surface to the fourth power. For example, a 1' section of 1½" tubing with a surface emissivity of 0.3 and surface temperature of 211.5 °F radiates only about 27 Btus/hr. The surface temperature of the tube is too low to contribute any significant heat loss via radiation. However, for very hot surfaces, radiation can become the dominant heat transfer mechanism. For example, that same tube at 1,000 °F radiates about 1,835 Btus/hr — 68 times more than at 211.5 °F.

Because thermal insulating coatings (TICs) are most effective at reducing heat transfer via radiation, they are often used in applications such as on building roofs to reduce heat transfer due to solar radiation. This is an important benefit for this application. However, at 0.010" to 0.030" per coating, TICs cannot provide much resistance to heat transfer via conduction through a roof.

Take care when comparing effectiveness of insulating materials. First understand the difference between *R* value (thermal resistance), *k* factor (thermal conductance), and the type of heat transfer you wish to reduce (radiation, convection, conduction). Then, choose the appropriate insulating material.

Comparing thermal conductivity *(k)* and thermal resistance *(R)* values

Thermal conductivity is the property that indicates how well a material conducts or transfers thermal energy. A material with a high thermal conductivity, such as metal, conducts heat more readily than a material with a low thermal conductivity such as plastic. Materials that resist the conduction of heat have low thermal conductivities and are called insulators. A thermal conductivity value is also commonly called a *k* factor.

For example, a typical *k* factor for a thermal insulating coating is 0.0561 Btu/h•ft•°F. This means that heat will transfer through this material at a rate of 0.0561 Btu/h given a 1°F temperature difference (one side of the material is 1°F cooler than the other) over an area of 1 square foot through a thickness of 1 foot.

The thermal conductivity (*k*) factor of a material is independent of thickness. For example, an 8"-thick thermal insulating coating has the same k factor as an 0.030"-thick thermal insulating coating: 0.0561 Btu/h•ft•°F. However, the thermal resistance (*R*) value of a material, is dependent on thickness:

R = material thickness (in feet) / k

Therefore, the *R* value of a typical thermal insulating coating with a thickness of 0.030" (0.0025') is:

$R = 0.0025 / 0.0561 = 0.045\ \text{ft}^2\bullet\text{h}\bullet{}^\circ\text{F/Btu}$ or $R = 0.045$

The *R* value of PVDF insulation with a thickness of 0.125" (0.0104') is:

$R = 0.0104 / 0.0185 = 0.56$

Table 4-1:
Insulation *k* factors and *R* values

Insulation	Thickness	*k* factor	*R* value
	ft	Btu/h•ft•°F	thickness/*k*
Thermal insulating coating	0.0025 (0.030")	0.0561	0.045
Stainless-steel-shielded air gap	0 to 0.0208 (0" to 0.25")	0.108 (average)	0.16 (average)
PVDF insulation	0.0104 (0.125")	0.0185	0.56

Comparing TIC to PVDF insulation

For the thermal insulating coating to have the same R value as PVDF insulation it would need to have a thickness of 0.376" (0.0314'):

$$R = 0.0314 / 0.0561 = 0.56$$

Note that the thermal insulating coating would need to increase in thickness by a factor of 12.5 to have the same R value as 0.125" of PVDF insulation.

Comparing stainless-steel-shielded air gap to PVDF insulation

The R value of PVDF insulation (0.56) is 3.5 times higher than the R value of the stainless-steel-shielded air gap (0.16). While air can be an excellent insulator, open spaces between the stainless-steel shield and dispersion tube allow air circulation, which increases convective heat loss. Compare this to the most effective insulation types, which have numerous small air pockets that prevent air from circulating.

Note that stainless-steel shields are very effective for reducing and deflecting heat transfer via radiation; however, only 1-2% of dispersion tube heat loss is from radiation.

Note also from Table 5-1 that stainless-steel-shielded tubes weigh approximately 50 times more per linear foot than PVDF insulation.

A 0.030"-thick thermal insulating coating would need to increase in thickness by a factor of 12.6 to have the same R value as 0.125" of PVDF insulation.

The R value of PVDF insulation (0.56) is 3.5 times higher than the R value of the stainless-steel-shielded air gap 0.16).

Table 5-1:
Characteristics of dispersion tube insulating materials

Characteristic	Thermal insulating coating	Stainless-steel-shielded air gap	PVDF insulation
Flame/smoke rating	5/5*	0/0	0/0
Ultraviolet light ageing resistance	Good resistance to UV light UVC resistance data not available	Stainless steel not affected by any type of UV light; data not available on foam	Inherently resistant to UV light, including UVC; no additives required[1]
Microbial growth resistance	Data not available	Stainless steel does not support microbial growth; data not available on foam	Does not support microbial growth[2]
Material life	Expected to meet or exceed dispersion tube lifetime	Expected to meet or exceed dispersion tube lifetime	Expected to meet or exceed dispersion tube lifetime
Weight per linear foot	0.04 lbs	0.50 lbs	0.01 lbs
Typical air duct pressure loss[3]	0.09 in. wc	0.09 in. wc	0.12 in. wc
Peeling and particle shedding	Data not available	Stainless steel does not shed particles; data not available on foam	None[4]
Outgassing	Data not available	Stainless steel does not outgas; data not available on foam	None[5]

* Per manufacturer's literature
[1] Xenotest 1200, CEPAP, Ci3030, and other tests
[2] DO160 D, Section 13 Category F, and other tests
[3] 72" x 48" dispersion panel with 1½" dispersion tubes installed 3" o.c., duct air speed 1,000 fpm
[4] ASTM C 1071 Section 12.7 Erosion Resistance; and ASTM D 3330 Peel Adhesion
[5] ASTM D 5116, EPA Method IP-1B, ASTM D 6196

Charting performance

Figure 6-1 shows dispersion tube heat loss at various airflow speeds. Note from the graph that:

- At low air speeds there is little or no benefit from the thermal insulating coating.
- Tubes insulated with a stainless-steel-shielded air gap have two to three times more heat loss than tubes with PVDF insulation.
- Insulation efficiency increases with air speed for all types of insulation.
- Tubes with PVDF insulation reduce heat loss more than tubes with a thermal insulating coating or stainless-steel-shielded air gaps.

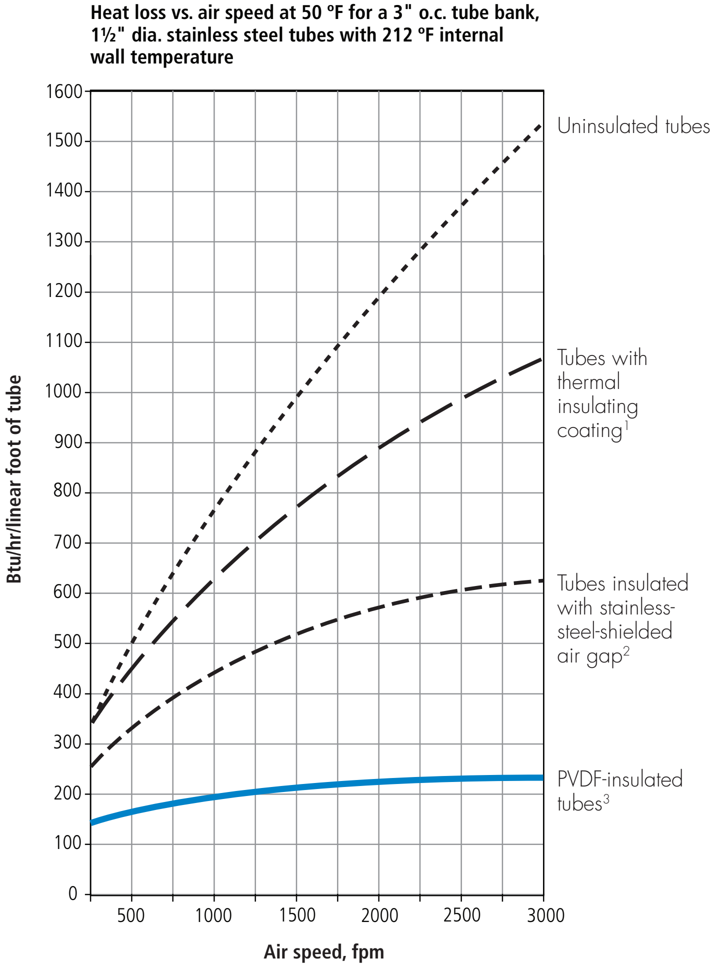
Downstream heat gain sources

Downstream heat gain from the sensible heat of steam injected into air cannot be reduced, as it is an inherent property of steam.

However, the convective transfer of heat from hot dispersion tubes to a cool airstream can be reduced significantly by using insulated dispersion tubes.

See the back cover for more information.

FIGURE 6-1: DISPERSION TUBE HEAT LOSS



Notes:

Heat loss calculations based on: Kakac, S., Shah, R.K., and Aung, W. (Eds.). (1987). Handbook of single-phase convective heat transfer (pp. 6.1-6.45). New York: John Wiley & Sons.

1 Tube with thermal insulating coating has a 0.030"-thick spray-on coating with a thermal conductivity of 0.0561 Btu/h•ft•°F and an R value of 0.045.

2 Stainless-steel-shielded air gap ranges from 0 to 0.25" (1/4") thick, has an average thermal conductivity of 0.108 Btu/h•ft•°F, and an average R value of 0.16.

3 PVDF insulation on tube is 0.125"(1/8") thick, has a thermal conductivity of 0.0185 Btu/h•ft•°F, and an R value of 0.56.

Conclusion

Dispersion tube heat loss is directly proportional to downstream heat gain and condensate loss in dispersion tubes. To reduce downstream heat gain and condensate loss, insulate dispersion tubes with one of the three methods discussed in this paper. To reduce wasted energy and water up to 85% (as demonstrated in Table 10:1), insulate dispersion tubes with PVDF insulation.

See the sample problem, starting on the next page, which compares energy and water savings per year for a typical dispersion tube installation using the three insulation methods described in this paper.

Use the tables at the end of this document to calculate savings for your particular application.

To reduce wasted energy and water up to 85%, insulate dispersion tubes with PVDF insulation.

What is "efficiency" measuring?

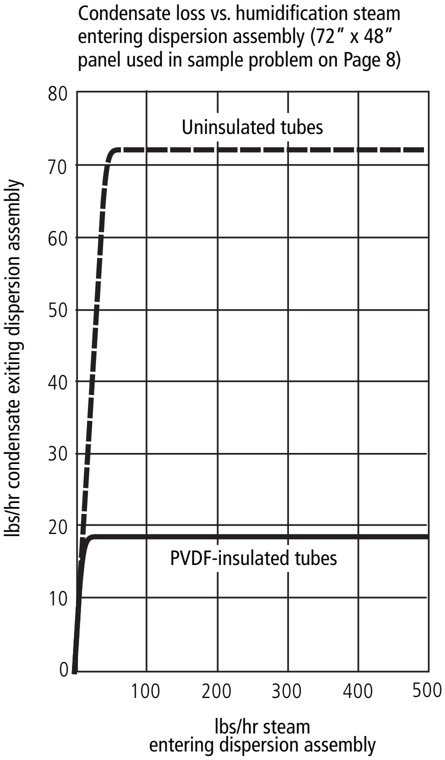
The "Efficiency" columns in Table 10-1 describe the efficiency of insulated dispersion tubes compared to an uninsulated dispersion tube, based on surface temperature, heat loss, and condensate production per linear foot of tube. Note that efficiency varies with airspeed; efficiency also varies with air temperature, but air temperature is constant in this table.

The efficiencies listed in Table 10-1 are for dispersion tubes only and do not include dispersion assembly headers.

These efficiencies do not change when the load changes. If a tube has hot steam running through it, it will produce condensate and give up heat at the rate listed in the table, regardless of load (Figure 7-1).

Do not state efficiencies based on load, for as you can see from Figure 7-1, when the humidification load is 100 lbs/hr, condensate exiting the PVDF-insulated tubes (from the sample problem on Page 8) is 17.9 lbs/hr (17.9% of load), and when the load is 1,000 lbs/hr, condensate exiting the PVDF-insulated tubes is still 17.9 lbs/hr (1.8% of load).

FIGURE 7-1:
CONDENSATE LOSS VS. LOAD



Sample problem demonstrates savings

For uninsulated steam dispersion tubes; and tubes insulated with a thermal insulating coating, a stainless-steel-shielded air gap, and PVDF insulation as described in this paper, calculate the following:

- Heat loss in Btus
- Condensate production in lbs/hr
- Total downstream air heat gain in °F
- Btus saved per year when using PVDF insulated tubes instead of uninsulated tubes.

System and conditions:

- Upstream RH: 20%
- Downstream RH: 60%
- Duct air speed: 1,000 fpm
- Humidification load: 435 lbs/hr
- Steam dispersion assembly: Face dimensions 72" wide × 48" high with 1½" diameter dispersion tubes on 3" centers; 23 tubes each 48" long
- Air temperature downstream from dispersion assembly: 55 °F
- Humidification steam pressure: Atmospheric, at sea level
- Humidification system operating hours: 2000 hrs/yr

Solution to sample problem

1. Using Table 10-1, determine heat loss per linear foot of tube:

a. Uninsulated dispersion tubes:
762 Btu/hr/linear ft
b. Dispersion tubes with the thermal insulating coating:
649 Btu/hr/linear ft
c. Dispersion tubes with stainless-steel-shielded air gap:
441 Btu/hr/linear ft
d. Dispersion tubes with PVDF insulation:
190 Btu/hr/linear ft

2. Determine total length of tubing.

The steam dispersion assembly has 23 tubes. Each tube is 48" long, for a total tube length of 92 feet. [(23 tubes × 48") / 12"/ft]

3. Determine total heat loss:

a. Uninsulated dispersion tubes:
92 feet of tube × 762 Btu/hr/linear ft
= 70,104 Btu/hr total heat loss
b. Dispersion tubes with the thermal insulating coating:
92 feet of tube × 649 Btu/hr/linear ft
= 59,708 Btu/hr total heat loss
c. Dispersion tubes with stainless-steel-shielded air gap:
92 feet of tube x 441 Btu/hr/linear ft
= 40,572 Btu/hr total heat loss
d. Dispersion tubes with PVDF insulation:
92 feet of tube × 190 Btu/hr/linear ft for PVDF insulated tubes
= 17,480 Btu/hr total heat loss

4. **Determine condensate production per hour:**
   (The latent heat of vaporization and condensation for water is 970 Btu/lb)
   a. Uninsulated dispersion tubes:
      (70,104 Btu/hr) / (970 Btu/lb) = 72.3 lbs/hr of condensate
   b. Dispersion tubes with thermal insulating coating:
      (59,708 Btu/hr) / (970 Btu/lb) = 61.6 lbs/hr of condensate
   c. Dispersion tubes with stainless-steel-shielded air gap:
      (40,572 Btu/hr) / (970 Btu/lb) = 41.8 lbs/hr of condensate

   d. Dispersion tubes with PVDF insulation:
      (17,480 Btu/hr) / (970 Btu/lb) = 17.9 lbs/hr of condensate

5. **Using Table 11-1, determine total downstream air heat gain:**
   Heat from steam + heat from dispersion tubes = total heat gain
   a. Uninsulated dispersion tubes: 1.07 + 2.58 = 3.65 °F
   b. Dispersion tubes with thermal insulating coating:
      1.07 + 2.20 = 3.27 °F
   c. Dispersion tubes with stainless-steel-shielded air gap:
      1.07 + 1.49 = 2.56 °F
   d. Dispersion tubes with PVDF insulation: 1.07 + 0.65 = 1.72 °F

6. **Determine annual energy savings in Btus using PVDF insulated tubes instead of uninsulated tubes.** Assume 2000 hours per year operation.
   Annual heat loss of uninsulated tubes per year – annual heat loss of insulated tubes = annual energy savings
   (70,104 Btu/hr × 2000 hr/yr) – (17,480 Btu/hr × 2000 hr/yr) = 105,248,000 Btu/yr

Table 9-1: Results summary for sample problem: 72" × 48" dispersion panel; 1½" dia. dispersion tubes at 3" o.c.; 1000 fpm air speed, operating 2000 hrs/yr

	Uninsulated tubes	**PVDF insulated tubes**	**Savings**	**Percentage improvement**
Heat gain to downstream air from dispersion tubes	2.58 °F	0.65 °F	1.93 °F	75%
Heat loss per hour	70,104 Btu/hr	17,480 Btu/hr	52,624 Btu/hr	
Heat loss per year	140,208,000 Btu/yr	34,960,000 Btu/yr	105,248,000 Btu/yr	
Condensate production per hour	72.3 lbs/hr (8.68 gallons/hr)	17.9 lbs/hr (2.15 gallons/hr)	54.4 lbs/hr (6.53 gallons/hr)	
Condensate production per year	144,600 lbs/year (17,359 gallons/year)	35,800 lbs/year (4,298 gallons/year)	108,800 lbs/year (13,061 gallons/year)	

Table 10-1:
Heat loss from a 72" × 48" dispersion panel with 1½" dispersion tubes installed 3" o.c.

	Stainless steel tube (uninsulated)	Stainless steel tube with thermal insulating coating		Stainless steel tube with stainless-steel-shielded air gap		Stainless steel tube with PVDF insulation	
Air speed	Heat loss	Heat loss	Efficiency	Heat loss	Efficiency	Heat loss	Efficiency
fpm	Btu/hr/ linear ft of tube	Btu/hr/ linear ft of tube	%	Btu/hr/ linear ft of tube	%	Btu/hr/ linear ft of tube	%
250	316	332	-5	255	19	133	58
500	491	467	5	327	33	162	67
750	635	567	11	389	39	179	72
1000	762	649	15	441	42	190	75
1250	877	720	18	484	45	199	77
1500	984	782	21	520	47	205	79
1750	1085	837	23	550	49	211	81
2000	1181	887	25	573	51	215	82
2250	1272	933	27	592	53	219	83
2500	1360	975	28	607	55	222	84
2750	1444	1014	30	620	57	225	84
3000	1526	1051	31	630	59	227	85

Notes:
Heat loss calculations based on: Kakac, S., Shah, R.K., and Aung, W. (Eds.). (1987). Handbook of single-phase convective heat transfer (pp. 6.1-6.45). New York: John Wiley & Sons, with the following inputs:

- 1½" stainless steel tubes
- Internal wall temperature of tube = 212 °F
- Air temperature outside of tube = 50 °F
- Thermal insulating coating:
  Thermal conductivity = 0.0561 Btu/h•ft•°F
  R value = 0.045
  Thickness = 0.030"
- Stainless-steel-shielded air gap:
  Thermal conductivity (average) = 0.108 Btu/h•ft•°F
  R value (average) = 0.16
  Thickness = 0 to 0.25"
- PVDF insulation:
  Thermal conductivity = 0.0185 Btu/h•ft•°F
  R value = 0.56
  Thickness = 0.125"

Shaded cells refer to sample problem starting on Page 8.

Table 11-1:
Airstream heat gain from a 72" × 48" dispersion panel with 1½" dispersion tubes installed 3" o.c.
(55° downstream air temp, 20% upstream RH, 60% downstream RH)

Air speed	Humidification load	Heat gain from steam	Stainless steel tubes (uninsulated)		Stainless steel tubes with thermal insulating coating		Stainless steel tubes with stainless-steel-shielded air gap		Stain steel tubes with PVDF insulation	
			Upstream air temp.	Heat gain from tubes	Upstream air temp.	Heat gain from tubes	Upstream air temp.	Heat gain from tubes	Upstream air temp.	Heat gain from tubes
fpm	lbs/hr	°F	°F	°F	°F	°F	°F	°F	°F	°F
250	112	1.11	49.6	4.28	49.4	4.49	50.4	3.45	52.1	1.80
500	220	1.09	50.6	3.34	50.7	3.17	51.7	2.22	52.8	1.10
750	328	1.08	51.0	2.88	51.4	2.57	52.2	1.76	53.1	0.81
1000	435	1.07	51.3	2.58	51.7	2.20	52.4	1.49	53.3	0.65
1250	542	1.07	51.5	2.38	52.0	1.96	52.6	1.32	53.4	0.54
1500	648	1.06	51.7	2.22	52.2	1.76	52.8	1.17	53.5	0.46
1750	755	1.06	51.8	2.10	52.3	1.62	52.9	1.06	53.5	0.41
2000	861	1.06	51.9	2.00	52.4	1.50	53.0	0.97	53.6	0.36
2250	968	1.05	52.0	1.92	52.5	1.41	53.1	0.90	53.6	0.33
2500	1074	1.05	52.1	1.85	52.6	1.33	53.1	0.83	53.6	0.30
2750	1180	1.05	52.2	1.79	52.7	1.26	53.2	0.77	53.7	0.28
3000	1286	1.05	52.3	1.69	52.8	1.17	53.3	0.70	53.7	0.25

Notes:
Airstream heat gain calculations based on: Kakac, S., Shah, R.K., and Aung, W. (Eds.). (1987). Handbook of single-phase convective heat transfer (pp. 6.1-6.45). New York: John Wiley & Sons, with the following inputs:

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  R value = 0.045
  Thickness = 0.030"
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  Thermal conductivity (average) = 0.108 Btu/h•ft•°F
  R value (average) = 0.16
  Thickness = 0 to 0.25"
- PVDF insulation:
  Thermal conductivity = 0.0185 Btu/h•ft•°F
  R value = 0.56
  Thickness = 0.125"

Shaded cells refer to sample problem starting on Page 8.

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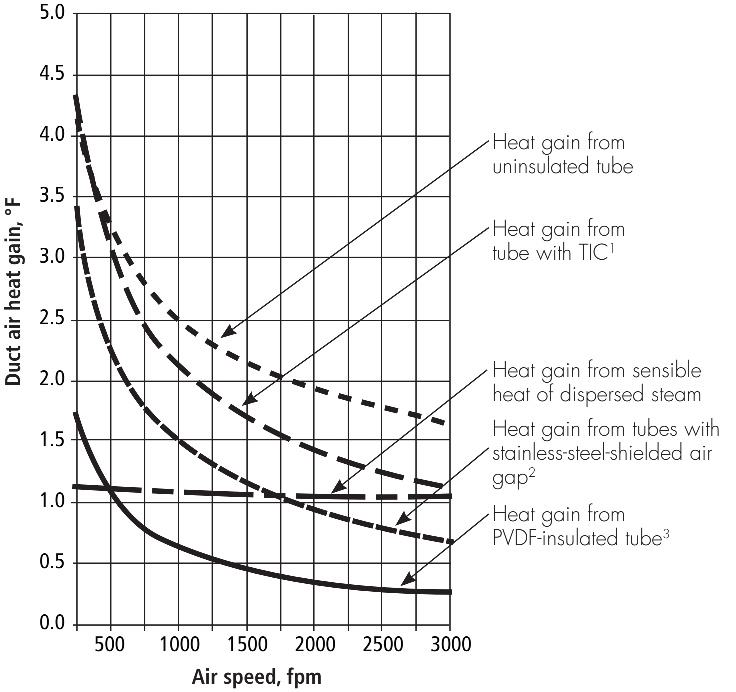
Form No. Heat gain paper-1016

FIGURE 12-1: DUCT AIR HEAT GAIN FROM STEAM AND FROM DISPERSION ASSEMBLY DESCRIBED IN SAMPLE PROBLEM ON PAGE 8



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1 Tube with thermal insulating coating has a 0.030”-thick spray-on coating with a thermal conductivity of 0.0561 Btu/h•ft•°F and an R value of 0.045.

2 Stainless-steel-shielded air gap ranges from 0 to 0.25” (1/4”) thick, has an average thermal conductivity of 0.108 Btu/h•ft•°F, and an average R value of 0.16.

3 PVDF insulation on tube is 0.125”(1/8”) thick, has a thermal conductivity of 0.0185 Btu/h•ft•°F, and an R value of 0.56.

Reducing downstream heat gain

Figure 12-1 illustrates how dispersed steam and dispersion tubes add heat to a duct or AHU airstream.

The first source of heat gain is from the sensible heat of steam injected into the air. This heat gain is due to the inherent properties of steam and cannot be reduced.

The second source of heat gain is from the convective transfer of heat from hot dispersion tubes to a cooler airstream. This heat gain can be reduced significantly by using insulated dispersion tubes.