

CONDENSATION PROTECTION

Roger Johnson

Overview

One of the most effective damage prevention strategies for stored products prone to condensation damage is the application of focused infrared heat. Our IRLens™ focuses and directs more radiant heat directly to the stored product than other heaters, which results in better condensation control.

Condensation is the result of a one way heat loss from a film of water vapor to a cooler adjacent surface. As the vapor is cooled below its dew point, water droplets form and adhere to the surface. As result, all condensation prevention strategies are successful to the extent they prevent the last layer of water vapor from cooling.

Our strategy maximizes the delivery of heat to these surfaces while preserving a more traditional dew point safety margin. In addition, the high intensity heat pattern reduces the time required to warm up cold material that is being introduced to the storage environment.

Strategies for Control

Traditional strategies of containing and heating a building's enclosed air mass to a safe level while controlling for infiltration were impractical. In addition, they suffered from stratification and inadequate air circulation near cold floors, which caused condensation. Low temperature tube heat systems improved on this by providing a heating means with less stratification and some radiant heat delivered to the floor. (See additional notes below concerning why eliminating the cold floor was helpful.)

Additional improvements came with better control strategies that were able to "stay ahead" of the dew point change. This required knowledge of local dew point fluctuation rates and experience with a heating system's ability to raise product temperatures. As a result, the onset of condensation could be anticipated within the heater systems response time.

Energy Engineering

An engineering approach to preventing condensation involves quantifying the heat flows between surfaces, the vapor film and environment. Since the thermodynamics for start-up and steady state are so different, separate evaluations are needed. This evaluation uses a dew point temperature buffer of 10 F°. This means that surfaces to be protected need to be continually maintained 10 degrees above ambient.

Steady State

Under steady state conditions the primary heat losses are described in the chart (pg 2). The heat loss consists of a radiant and convective component (since conduction for stored materials is low). Notice that the radiant losses are three times the convective ones and very sensitive to both the emissivity of the surface and the surroundings.

The advantage of warmed floors in reducing condensation can be seen by increasing the floor temperature as in scenario A in the chart. (Changes in the calculation conditions are boxed.) The penalty for warming the floor with radiant from above is that the floor can more easily absorb heat from the metal. In contrast, scenario B shows the effect of an aluminum pan underneath the metal while still unheated.

Steady State Heat Losses						
Radiant Loss = StephBoltz*(T1e^4-T2^4) / (1/Emiss1 + 1/Emiss2 - 1)						
<i>This is for parallel plates of equal area where the rolls of metal approximate a slab suspended off the floor. The Ceiling and Floor contributions have been separated to demonstrate the value of warming the floor. Emmissivities have been approximated. Only vertical losses are represented here since horizontal losses are assumed to eventually hit a ceiling or floor. T1 and T2 are absolute Temps.</i>						
Item	Value	Units	A	B	C	D
Temp Building Ceiling	50	F°	50	50	30	52
Temp Building Floor	50	F°	55	50	50	55
Temp Surface	60	F°	60	60	60	60
Emissivity Building Ceiling	0.8	na	0.8	0.8	0.8	0.8
Emissivity Building Floor	0.8	na	0.8	0.1	0.8	0.1
Emissivity Surface	0.8	na	0.8	0.8	0.8	0.8
IR Loss to Ceiling	-6.2	BT U/s qft-hr	-6.2	-6.2	-17.6	-5.0
IR Loss to Floor	-6.2	BT U/s qft-hr	-3.2	-0.9	-6.2	-0.5
Total IR Loss	-12.5	BT U/s qft-hr	-9.4	-7.1	-23.9	-5.5
*Steph-Boltz Constant 1.71E-09 BTU/sqft-hr-R° ^4						
Convective Loss = (Heat Transfer Rate of.22) (dT)^1/3						
<i>This formula is for air at ordinary pressures and temperature. If the Ralieg numbers indicate laminar flow, the constand changes to .19. The formula is for horizontal surfaces, vertical surfaces can increase losses up to 3 times this amount.</i>						
Item	Value	Units	A	B	C	D
Temperature Air	50	F°	30	40	55	
Temperature Surface	60	F°	60	60	60	
Conv. Heat Loss (Horiz)	-0.47	BT U/s qft-hr	-0.7	-0.6	-0.4	
Conv. Heat Loss (Vert)	-1.42	BT U/s qft-hr	-2.1	-1.8	-1.1	
Total Convective Loss	-2.84	BT U/s qft-hr	-4.1	-3.6	-2.3	

The saturated water vapor on the other hand is easily heated as it is nearly completely absorptive of radiant heat. In addition, it has less total mass and good insulative qualities. In 6 minutes the vapor surface is warmer than 12 hours of heat on the metal surface. Direct heating of the vapor film can prevent condensation damage without requiring the entire mass of metal to be heated. This aspect of direct radiant heating can change the way material is heated up to storage temperature.

Conclusion

A net radiant intensity of 40 BTU/sq-ft-hr absorbed by the surface of stored steel to be protected provides condensation protection of 6 degrees within 6 minutes by adding heat directly to the vapor layer. (This requires even coverage.) As the material's surface warms up the heat loss approaches its final value of about 15 BTU/sq-ft-hr, resulting in a net heat gain by the stored metal of 25 BTU/sq-ft-hr.

The convective losses change with temperature to the 1/3 power and so are rather insensitive to temperature swings. Even mild increases in airflow do not have a great effect on the total heat loss as the last layer of air next to the surface is difficult to dislodge.

In total, approximately 15 BTU/sq-ft-hr will have to enter the metal to maintain the required 10 F° in a steady state mode. Additional heat will be required to change the initial temperature of the stored product as well as to keep pace with long term temperature swings.

Start-Up

Start-Up conditions present a time dependent heating analysis. A simple calculation of total heat required to raise the entire mass of material is excessive. Surface temperatures are affected immediately when radiant heat is added. The material raises in temperature as its mass is warmed which in turn provides a means to drive heat further into the material. The Surface Temperature chart below provides an evaluation of how quickly the outer most surface will warm. (The conductivity of the steel has been reduced due to the poor conductive ability of rolled metal coils vs solid ones.) The steel clearly heats up slowly due to its large mass and ability to conduct heat. The chart does not take into account the increased losses incurred as the temperature differential with ambient increases or the fact that the metal coil in not an infinite slab and will at some time warm the entire roll.

Surface and Film Temperatures after Specified Times						
Temp = Time + (2)(IR Flux)/ThermConductivity) *sqrt((Diffusivity)(Time)/Pi)						
<i>This is for nondimensional temperature variation through a semi-infinite slab simplified for surface temp after the specified time.</i>						
Item - Steel	Value	Units	A	B	C	D
Temp F° Initial	50	F°	50	50	50	50
IR Flux Input	40	BTU/sqft-hr	40	40	40	50
Emissivity	0.8		0.8	0.8	0.8	0.8
Conductivity	36	BTU/sqft-hr	36	36	36	36
Diffusivity	0.7	sqft/Hr	0.7	0.7	0.7	0.7
Time	24	Hr	0.5	5	12	24
Surface Temp F° *	8.2		1.2	3.8	5.8	10.3
*Layer Effect Applied 0.5 Values been adjusted due to coil vs solid.						
Item - Sat. Water Vapor	Value	Units	A	B	C	D
Temp F° Initial	50	F°	50	50	50	50
IR Flux Input	40	BTU/sqft-hr	40	40	20	40
Emissivity	0.98		1	0.98	0.98	0.98
Conductivity	0.332	BTU/hr-ft-F°	0.3	0.33	0.33	0.33
Diffusivity	0.0053	sqft/Hr	0	0.01	0.01	0.01
Time	1	Hr	0.1	0.5	1	1
Surface Temp F°	19.4		6.1	13.7	9.7	19.4