Heat Pipes For Terrestrial Applications In Dehumidification Systems

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HEAT PIPES FOR TERRESTRIAL APPLICATIONS
IN DEHUMIDIFICATION SYSTEMS

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ABSTRACT
A novel application of heat pipes which greatly enhances dehumidification performance of air-conditioning systems is presented. When an air-to-air heat pipe heat exchanger is placed between the warm return air and cold supply air streams of an air conditioner, heat is efficiently transferred from the return air to the supply air. As the warm return air precools during this process, it moves closer to its dew-point temperature. Therefore, the cooling system works less to remove moisture. This paper discusses the concept, its benefits, the challenges of incorporating heat pipes in an air-conditioning system, and the preliminary results from a field demonstration of an industrial application.

INTRODUCTION
Heat pipes are known for their extensive use in aerospace applications. Use in the heating, ventilating and air-conditioning (HVAC) industry is lesser known, yet not new. Perkins Tube, which contains only a small quantity of water and operates on a two-phase cycle just like a heat pipe, has been used in boiler applications (Jacob Perkins, U.K. Patent No. 7059, April 1936). Heat pipe heat exchangers have also been used recently in the HVAC industry to recover and transfer heat from the exhaust air to the make-up air. The use of air-to-air heat exchangers in conjunction with air-conditioning systems to improve their dehumidification performance has been mentioned in literature (Carrier, 1959). However, this technique has not been practiced due, perhaps, to abundant and cheap fuels available in the past.

An air conditioner performs two functions; temperature reduction, or sensible cooling, and moisture removal, or latent cooling. There is, however, a certain relationship between the available sensible and latent cooling which is generally expressed by a sensible heat ratio (SHR). The SHR is the ratio of the sensible to the total of sensible and latent cooling capacities. Alternatively, this relationship may be expressed as a dehumidification fraction (DF), a ratio of the latent to total cooling. The SHR, or DF, depends upon the entering air temperature, humidity, and the cooling coil temperature. When the cooling coil temperature is lowered, more moisture is removed and the DF improves. But the DF reaches a certain limit beyond which it does not improve by any further reduction of the coil temperature.

When a larger DF is required than what is available by the standard cooling and dehumidification process, air-reheat systems are commonly used. Air is first overcooled in order to remove moisture and then reheated to the desired temperature. Air-reheat systems are energy intensive; energy is first required to overcool the air and then additional energy is required to reheat the same. Reheat may be available cheaply or even free (e.g., by using the waste heat from the condenser), yet electric reheat is not uncommon. The requirement of overcooling also dictates larger equipment size. The increase in equipment size and energy requirement versus the required cooling and dehumidification load SHR for different air-conditioner SHRs are plotted in Figure 1. The solid lines represent an increase in cooling equipment size as well as cooling energy requirement. The dotted lines represent a total increase in energy requirement (cooling and reheating) if an electric resistance element is used for reheat. For any other practical source of reheat, the cost increase will lie within the bounds of solid and dotted lines.

HEAT PIPE APPLICATION
When a heat pipe air-to-air heat exchanger (HPHX) is placed between the warm air entering and cold air leaving the cooling coil, it provides two benefits; the cold supply air is
reheated, and the warm entering air is precooled, accomplishing both tasks without expending additional energy. The result of precooling the entering air is both a reduction in the cooling energy requirement and the cooling equipment size.

The schematic of a heat pipe application for cooling and dehumidification is shown in Figure 2. The DF improvement depends upon the size and effectiveness of the HPHX and the entering air conditions. Effectiveness is defined as the ratio of the entering air temperature drop across the HPHX to the maximum temperature difference between the air entering the HPHX and air leaving the cooling coil. The increase in DF for entering air at 78 F and relative humidities between 30% to 70% versus HPHX effectiveness are plotted in Figure 3. Due to the increased DF of the cooling and dehumidification system with HPHX, the equipment size is reduced as compared to an alternative air-reheat system. The reduction in equipment size vs. HPHX effectiveness is plotted in Figure 4. For example, to maintain a space temperature of 78 F and relative humidity of 40%, a HPHX of 0.45 effectiveness will enhance an air-conditioning system DF by 48%, and allow a 33% reduction in equipment size as compared to an air-reheat system. Note that at lower humidities, the use of a HPHX becomes even more effective.

TESTS AND DEMONSTRATION

Experiments were conducted with a small air-conditioning unit at the Florida Solar Energy Center's HVAC Laboratory to verify the concept and system modeling. Six different HPHXs were tested, and DF improvement from 22% to 42% were observed for an entering air temperature of 80 F and relative humidity 50% (Khattar, 1986).

FSEC has begun a field demonstration at a candy storage warehouse in Albany, Georgia (Khattar, 1987). The 45,000 ft² warehouse requires a relative humidity below 42% and temperature below 80 F in order to maintain crisp candies. Its air-conditioning system consisted of two 30-ton direct-expansion cooling and dehumidification units with two 80 kW electric resistance reheating in two steps for each unit. Electrical energy consumption and billing data over the past 4 years for the HVAC system alone is available.

A heat pipe was selected and retrofitted to match the cooling and dehumidification requirements of the warehouse before the cooling season of 1987. Since heat pipes increase the dehumidification performance, only one of the 30-ton systems was required after the retrofit. Therefore, only one of the units was retrofitted with heat pipes and the other unit was shut down. The system performance was measured before and after the retrofit.

Early results were excellent. Substantial energy savings were recorded: an average of 75% over the 1985 and 1986 summer seasons. The billing savings were equally impressive: because of the resulting reduction in demand and kWh charges, the installation showed a simple payback period of less than three months. However, not all of these savings were due to the heat pipes alone. It is suspected that some of the savings are attributable to innovative control strategies. Data analysis is still in progress.

HEAT PIPE DESIGNS

There is one major disadvantage with currently available HPHXs: their design dictates that the air entering and leaving the cooling coil must flow side-by-side. A typical heat pipe application is shown schematically in Figure 5. In addition, space for ducting is required which causes additional air-side pressure losses. The availability of space for ducting is a constraint even in new installations.

Khattar (1986) conceptualized and investigated several innovative heat pipe configurations to overcome these fundamental limitations. A U-shape heat pipe shown schematically in Figure 6 seems to hold the most promise, and a patent is in process. The U-shaped heat pipe is placed around a cooling coil in such a manner that its evaporator section is on one side and condenser section on the other. The air passes sequentially over the heat pipe evaporator section, cooling coil and the heat pipe condenser section. The heat pipes are tilted slightly from the horizontal to take advantage of gravity. Raising the evaporator end above the condenser allows control of the HPHX performance. The air-side extended surface design may vary from an individually finned heat pipe tube to a design with plate fins on a group of heat pipe tubes. U-shape heat pipes were built and tested successfully with a residential size air-conditioning system. The major advantages of such a configuration are:

- they can be accommodated within conventional air handling units
- air-flow direction is not disturbed
- the performance can be controlled
CONCLUSIONS

An air-to-air heat pipe heat exchanger, if properly designed, installed and controlled, can improve the dehumidification performance of air-conditioning systems. Compared to an air-reheat system, HPHXs offer the following advantages:

- elimination or reduction of reheat energy requirements
- smaller air-conditioning equipment size
- reduced energy required to operate smaller air conditioning equipment
- reduced peak power demand
- reduced operation and maintenance costs

The heat pipes are passive devices and their maintenance requirements are low. Reduction in peak power demand is particularly attractive when the replaced reheating energy source is electricity.

FUTURE WORK

A methodology is being developed to properly select heat pipes for dehumidification applications with air-conditioning equipment. A U-shaped heat pipe will soon be installed in an industrial application for field demonstration. Calorimetric experiments need to be conducted on U-shaped heat pipes to study various parameters which affect its design and performance. Control strategies need to be developed not only for heat pipes but also for entire HVAC systems which include heat pipes.

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REFERENCES

Figure 1. Increase in Equipment Size and Energy Requirement vs. Load SHR in Air-Reheat Systems

Figure 2. Schematic of a Heat Pipe Application with Cooling System to Improve Dehumidification

Figure 3. Increase in Dehumidification Fraction vs. HPHX Effectiveness with use of Heat Pipes

Figure 4. Reduction in Air-Conditioning Equipment Size vs. HPHX Effectiveness as compared to a Air-Reheat System

Figure 5. Typical Layout of a Conventional HPHX with Air-Conditioning System

Figure 6. Layout of a U-Shape HPHX