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Altered Bi-Phase Flow Regime in Supermarket Evaporative Coils: Laboratory and Field Experiences

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ABSTRACT

Examining a typical pressure-enthalpy chart, it is generally believed that the evaporator benefits from a complete stream of liquid entering the coil. The conclusion from this is that maximum enthalpic capacity is achieved by subcooling or even super-subcooling the entering liquid and that anything less than a full column of liquid might limit the amount of heat transfer that the evaporator can accomplish.

The evolution in refrigerant flow testing and mapping is now providing support for a different view. This paper will examine the net effect of an altered bi-phase flow (ABF) regime in evaporative coils, with consideration of a high vapor fraction and turbulent refrigerant flow (HVFT). Furthermore, the pressure-enthalpy chart lends improving evaporator pressures, control during transient operation, refrigerant density at the compressor, and rate of heat transfer among other factors can combine to reduce energy consumption.

Two test and verification projects in supermarket medium- and low-temperature display cases and storage applications provide significant support for examining old rules-of-thumb. The first project involves a deli service case tested under laboratory conditions. This test demonstrates the effect of evaporator operation utilizing an ABF regime and compares this to the operation of a pulse-type electronic expansion valve system. The results demonstrated operation with the ABF regime permitted increased compressor suction pressure, improved product temperature, provided more stable refrigerant temperatures, and improved case humidity. The second test and verification project involves field retrofitting of existing direct expansion evaporators to the ABF regime and measuring the results. The resulting change in refrigerant flow regime demonstrated improved performance, resulting in consistent and reduced conditioned supply air and product temperatures, improved oil return, reduced compressor discharge temperatures, and increased evaporator pressure. Product quality and energy savings were also measurable.

INTRODUCTION

The industry has had a view that liquid at the entry of the evaporative coil is desirable and that superheated vapor at the exit of the evaporative coil is necessary. The common view has been that any improvement in Delta-h improves overall system capacity and is, therefore, the pinnacle. It is often commonly held that the heat transfer coefficient at the entry to the coil cannot be improved enough to profoundly impact capacity at the entry of the evaporator or to provide increased evaporator capacity. The superheated passes at the exit of the evaporator have been viewed as necessary due to the conventional liquid flow pattern that advances and recedes in the direct expansion (DX) coil, which, if regularly extended toward the refrigerant outlet from the evaporator coil, might extend toward the compressor inlet and then encroach the compressor inlet during periods of abnormal refrigerant flow. Although counterintuitive to this conventional thought and while enthalpic capacity is important, research in two-phase refrigerant flow regimes and heat transfer rates is supporting the position that improved flow regimes can make more dramatic system-wide performance increases.

PRIOR STATE OF THE ART

The supermarket industry is faced with challenges. Product quality, new Food and Drug Administration (FDA) product temperature mandates, product shelf-life and shrinkage, as well as product liability, all have brought new attention to

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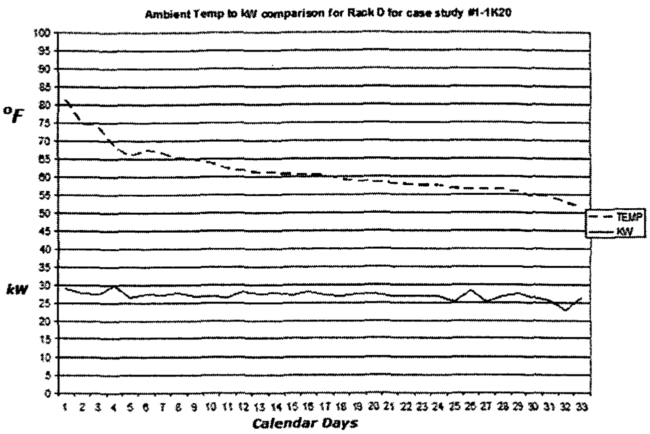

Figure 1 *Impact of ambient temperature on display case performance.*

refrigeration performance and its effect upon product and the bottom line of a business. Target food holding temperatures have been reduced. Energy awareness is high. The call for a reduction in energy consumption with simultaneous reduction in case temperature is an oxymoron. As the supermarket industry has moved away from energy-saving programs that adversely affect product, we have seen a movement toward use of electronic controllers to stage compressors and monitor system performance and toward the empowerment of positions in food safety or creation of positions with titles such as "Energy Czar." The more traditional approaches to energy reduction are now merely controlled electronically, as the commercial supermarket industry continues its focus on head pressure reduction and increased subcooling as the primary targets for improvement in system performance. Improving compressor COPs through floating head pressures does reduce overall power consumption. Figure 1 shows the effect that flooded condenser low-ambient controls have upon system power usage. The ambient temperature is shown dropping more than 11°C (19.8°F), and power consumption remains relatively constant because the compression ratio reduction is minimal.

TEST AND VERIFICATION PROJECTS

Two test and verification projects are presented. The first is a laboratory analysis that demonstrates evaporator efficiency increase in a controlled environment, resulting in energy reduction and product temperature improvement. The second project is a retrofit of an operational California supermarket, which showed that a dramatic improvement in evaporator efficiency can have a systemwide impact on energy and product quality improvement.

ABF Regime

Comparative testing was performed between before and after systems designs. The first system setup uses an optimized conventional direct expansion refrigerant feed, operated following all manufacturer-specified recommendations. The laboratory project used a substantial number of data points in accordance with European and ASHRAE standards, with extensive baseline verification of peak system performance. The field verification project conducted a full "re-commissioning" of each of 134 evaporators followed by a baseline period. The second setup combines the DX refrigerant feed in conjunction with the ABF regime and varies the vapor fraction of the refrigerant and creates turbulent flow through a mechanically induced fluid process. This process uses a device that separates liquid and vapor during the chaotic exit from the expansion valve through use of a two-stage expansion. The liquid is then entrained in the vapor fraction at a mass velocity enabling rapid transition to intermittent or annular flow. Theoretically, the reduced heat transfer of the slug, stratified, stratified-wavy, and wavy flow regimes are eliminated from the evaporator. Testing continues to validate the theoretical models.

Each test and verification project is monitored to measure the effect that this ABF flow regime can have on cooling rates, compressor work, temperature differences, evaporator efficiency, control of superheat, and in other significant observations.

The hypothesis being tested is that entering an evaporator coil with the ABF and a high vapor fraction enables a novel and highly efficient flow regime to be achieved throughout the evaporative coil. Furthermore, annular flow near the outlet and partial dry-out at the outlet of the evaporator coil in the ABF system communicates very efficiently with the superheat-sensing bulb, whereas the conventional vapor barrier of superheat in pre-ABF operation has extremely poor heat transfer and cannot communicate well.

The ABF-equipped system has been operated throughout the study in multiple and single pass circuiting, air/ventilated and gravity feed coils, and high, medium, and low temperature applications. Reduction in superheat exiting from the evaporator coil is accomplished with minimal liquid and is very tightly controlled with little fluctuation, as verified on the glass tube evaporator test stand. Lower superheat can mean greater surface exposure to the refrigerant and result in higher evaporator pressures. Lower superheat allows for a more dense refrigerant, boosting compressor capacity and lowering compressor superheat. Energy is reduced in each case.

Uniformity of evaporator temperatures allows for frost to build more uniformly across the coil and can therefore reduce defrost frequency or duration by not causing a restriction in air-side velocity.

Laboratory Test of One Deli Case

An independent laboratory in the United Kingdom conducted a performance analysis of a ventilated deli service case using electronic pulse-type valve technology to meter the refrigerant and compared that to performance of operation with the ABF flow regime in series relationship with the electronic pulse-type valve. While previous work had been done to determine a performance increase using the pulse-type technology in comparison to a conventional mechanical thermal expansion valve (TXV) in this refrigerated case, this test found results showing little change in system performance and that the ABF flow regime could not be sustained using the pulse-type valve technology. However, the test went on to compare the conventional electronic pulse operation with that of the mechanical valve in operation with the ABF flow regime.

The laboratory was equipped with a monitored and fully operational psychometric chamber and complied with ASHRAE method of test standards. The ambient conditions surrounding the refrigerated case were maintained throughout the test. Monitored points[1] included, but were not limited to, the following:

- Wet-bulb and dry-bulb temperature and CFM inside the chamber
- Wet-bulb and dry-bulb temperature of chamber supply and return air
- Instantaneous and totalized refrigerant mass flow (CH-51)
- Multiple product simulators in accordance with ASHRAE standards
- Multiple temperature and pressure sensors throughout the system.
- Outdoor DB and WB temperature
- Product surface temperature probe (CH-25, 27, 28, 30)
- Evaporator supply air temperature (CH-32), wet bulb and dry bulb
- Evaporator return air temperature, wet bulb and dry bulb
- Compressor suction pressure and temperature
- Liquid line pressure (CH-54) and temperature
- Evaporator inlet pressure (CH-53) and temperature
- Evaporator outlet pressure (CH-52) and temperature
- Evaporator tube surface temperature (CH-33)
- Evaporator tube fin temperature
- Additional product weight tests were conducted
- Defrost frequency and duration

Suction pressure was regulated by means of an electronic pressure regulating valve, and this was the only setpoint changed during the test in effort to maintain similar product temperatures.

Evaluation of the test results between the pulse-type electronic expansion valve (EEV) equipped evaporator and the evaporator in operation with the ABF flow regime demonstrated that the heat transfer of the ABF flow regime equipped evaporator was significantly better than the conventionally equipped evaporator. The average mass flow of the conventional system was 27.59 kg/h (60.82 lb/hr) and average mass flow of the ABF flow regime device equipped system was 27.83 kg/h (61.35 lb/hr)—see Figure 2 as compared to Figure 3.

However, the display case air temperatures as seen for the conventional pulse-type EEV system (shown in Figure 4) exhibited an average air supply temperature of –2.87°C (26.83°F)

Table 1. Equipment for Deli Case Test

Uneven parallel compressor rack system
R-404a
European design, ventilated service deli
Btu load of approximately 7,800 Btu per hour
Electronic smart controller
Electronic evaporator pressure regulating valve
Remote condenser, air-cooled

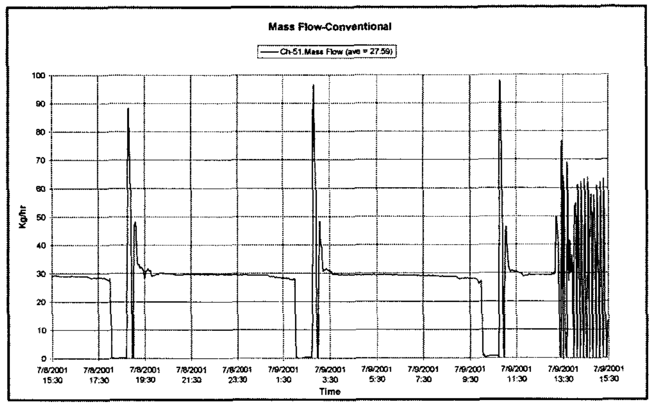

Figure 2 *Baseline EEV equipped evaporator mass flow rate.*

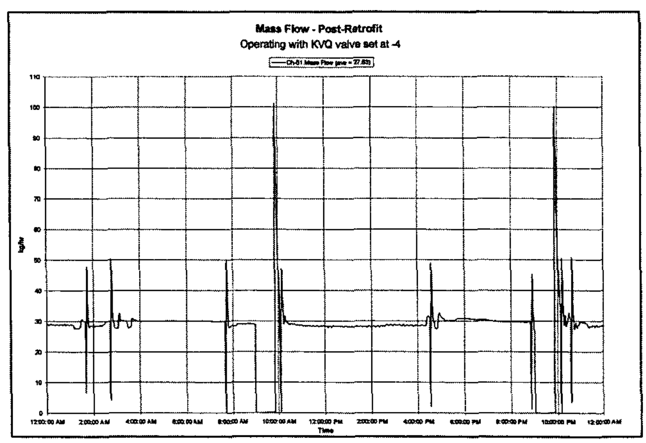

Figure 3 *ABF flow regime equipped evaporator mass flow rate.*

[1] Temperature and pressure data were sampled at a minimum of once per minute. Comparisons were made over a 24-hour period. All auxiliary thermocouples and sensors were manufactured in accordance with the guidelines set forth by ISO 9001 and were recently calibrated.