Evaluation of Mechanical Dehumidification Concepts (Part 1)

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ABSTRACT

In recent years, humidity concerns have gained increasing attention in the air conditioning industry. In part, this increased attention is the result of high indoor air quality standards and newly introduced legislation and industry regulations. Humidity concerns have become even more visible since the introduction of alternate refrigerants with superior thermo-physical properties that may adversely affect system dehumidification capability. Although various dehumidification concepts have found their way into standard equipment offerings, the choice of the system type and configuration is not obvious and entails detailed evaluation of multiple characteristics. This paper analyzes various mechanical reheat/dehumidification concepts and highlights their advantages and drawbacks. The conclusion reached is that the reheat method utilizing a two-phase refrigerant mixture may provide a viable alternative to existing concepts in terms of application coverage and operational flexibility while preserving system functionality and reliability.

1. INTRODUCTION

In recent years, humidity concerns have gained increasing attention in the air conditioning industry. In part, this increased attention is the result of high indoor air quality standards and newly introduced legislation and industry regulations. In addition, if certain conditions related to humidity exist, equipment applications can actually promote the growth of mold and bacteria. These conditions include: 1) High rates of internal humidity generation; 2) Buildings with insufficient insulation and poor construction; 3) Humid outdoor environments combined with high fresh air circulation requirements. These factors add another degree of complexity to the humidity issues, often resulting in lengthy and costly litigations for the original equipment manufacturers and consulting firms. Also, the introduction of alternate refrigerants with superior evaporation thermo-physical properties, such as R410A, (Lemmon et al., 2002) results in relatively high evaporation heat transfer coefficients and elevated saturation temperatures, which in turn may negatively impact system dehumidification ability at certain operating conditions.

It is not surprising that various dehumidification concepts and techniques have found their way into standard equipment offerings. Such methods have been classified by several authors (Harriman et al., 2001) and are based on the system type (mechanical, electrical, desiccant, etc.) or internal construction (integrated or add-on). Hybrid systems have been considered as well.

The selection of system type and configuration is not always obvious and entails detailed analysis of multiple characteristics, such as performance, life-cycle cost (partially defined by the system runtime and efficiency), reliability, control complexity, design flexibility, expandability, similarity to existing equipment currently in use, serviceability, etc. Mechanical dehumidification systems, especially the configurations utilizing the primary refrigerant circulating throughout the cycle, are often the category of first choice. The attractiveness of these systems is enhanced by relative application simplicity, solution flexibility with respect to treatment of both indoor and outdoor air streams, and elegant design options.
Although the category of mechanical dehumidification systems employing primary refrigerant is relatively narrow, numerous design schematics and arrangements are available within the class. In order to select a proper system type, the fundamental question of the application requirements must be addressed. The system conceptual design strongly depends upon a range of indoor and outdoor environments, or stated differently, upon the relative significance of sensible and latent load components over an array of operating conditions. Although a universal solution is desired, most of the systems are geared towards one end of the design spectrum or the other. The author of this paper makes an attempt to evaluate various mechanical reheat/dehumidification concepts introduced to the market for air conditioning and heat pump applications.

2. DESIGN CONCEPTS

2.1 Systems Utilizing Warm Liquid Refrigerant
Several mechanical reheat/dehumidification methods that have been developed for hot and humid environments and that deliver both sensible and latent components of the system capacity are well known in the industry. One of the most popular designs is the method employing warm liquid refrigerant exiting the condenser coil (Bussjager, et al., 1997) shown in Figure 1. While the system is in the dehumidification mode of operation, the refrigerant exiting the condenser is re-routed to a reheat coil connected serially with the condenser and located behind the evaporator in the indoor air stream. Thus, cooled and dehumidified air exiting the evaporator coil is reheated. During this heat interaction, the liquid refrigerant circulating through the reheat coil is subcooled. As a result, the refrigerant enthalpy difference in the evaporator and the evaporator capacity are increased (see Figure 2). The augmented subcooling results in evaporation temperature reduction and a boost to the system latent capacity. Since the system sensible capacity loss in the reheat coil is somewhat compensated for by the enhanced evaporator performance, the overall system cooling potential remains adequate. At the same time, a significant enhancement of the evaporator latent capacity is achieved. Since the system subcooling is limited only by the reheat coil size and temperature of the air leaving the evaporator (and not by usually much higher outdoor air temperatures, as in other systems), this process is one of the most efficient techniques for increasing system dehumidification capability without compromising cooling capacity.

One of the major concerns with multiple coil systems is refrigerant charge migration, which occurs when not all the coils are active during various modes of operation. Refrigerant naturally migrates to the coldest region in the system, which may vary based on the operating mode and environmental conditions. The process described above is free of charge migration problems, since the reheat coil is always filled with liquid refrigerant, regardless of the mode of operation.
2.2 Systems Employing Hot Refrigerant Vapor

Another category of systems has been developed for dehumidification applications where the requirement is that no sensible capacity be delivered by the system. In such cases, the sensible portion of the evaporator capacity must be significantly reduced by the reheating means.

2.2.1 Sequential arrangement: The most popular approach for these applications utilizes compressor discharge gas re-routed to a reheat coil located in the indoor section behind the evaporator and connected sequentially with the main condenser (Whinery and Chapin, 2002). This method allows reheating of the indoor air stream and considerable reduction of the system sensible capacity (see Figure 3). Note that the sensible capacity can be entirely eliminated only at a single design operating point; at all other conditions, the system will deliver some sensible cooling or heating to the conditioned space. Although the main condenser and the reheat coil jointly act as a much larger condenser coil in the dehumidification mode of operation, and the condensation temperature is noticeably reduced, the system subcooling is still limited by the outdoor air temperature. This constraint in turn limits the evaporator latent capacity, especially in cases when the main condenser coil is large and its temperature approach is small, in order to satisfy continually increasing system efficiency requirements (see Figure 4). As a result, the system latent capacity cannot be appreciably increased over the conventional evaporator performance.

As noted earlier, refrigerant migrates between the condenser and the reheat coil depending on the operating mode and environmental conditions. In the dehumidification mode of operation, the reheat coil primarily contains a two-phase refrigerant mixture, in comparison to the conventional cooling mode, during which the reheat coil is not operating and is filled with liquid refrigerant. On the other hand, the condenser coil holds predominantly a two-phase refrigerant mixture, but during the dehumidification mode of operation this refrigerant mixture is contained at lower pressure and density. As a result, the refrigerant charge rebalances, and alternating between the conventional cooling and dehumidification operating modes should not cause any major charge migration issues. Reheat coil isolation methods are incorporated into some design configurations, but such flow control devices tend to leak over time and cannot be relied upon to permanently solve the charge migration problems. Refrigerant bleed circuits also are commonly introduced to assist in charge migration prevention.
2.2.2 Parallel configuration: As shown in Figure 5, an alternate and relatively popular approach for these applications employs compressor discharge gas in a similar fashion, except that the reheat coil is positioned in a parallel arrangement with the main condenser and the condenser is taken out of the circuit in the dehumidification mode of operation (Sporlan Bulletin 30-20, 2001). Although the performance of this design is not thoroughly investigated in this paper, several features of the system operation are highlighted and discussed below. First, the reheat coil, which solely performs the condensing function in the dehumidification mode, is much smaller than the combined condenser/reheat coil in the sequential arrangement described above. Consequently, the system performance and life-cycle cost of the equipment may be affected. Additionally, when the reheat cycle is activated, the parallel configuration system will always produce heat (at least for a single-circuit system). The heat rejected into the conditioned space (comprised of the condenser heat flux and the evaporator fan power) exceeds the evaporator sensible capacity capability. As a result, the controls constantly alternate between the cooling and heating modes of operation in order to maintain the design point of the time-averaged neutral (zero) sensible capacity. Hence, additional instability, reliability and control issues may be undesirably introduced into the system design and operation.

![Figure 5: Parallel Hot Gas Refrigerant Cycle]

Another drawback of this type of system is that the airflow cannot be utilized as a head pressure control parameter, since the reheat coil and the evaporator are functionally coupled by the indoor air stream. Also, since the main condenser and the reheat coil are functionally separated, the parallel configuration design is more susceptible to refrigerant charge migration. Although flow control devices such as the conventional solenoid, the 3-way and the liquid line check valves may be introduced to isolate the reheat circuit, they leak over time, usually causing the refrigerant charge to migrate to the condenser in the dehumidification mode of operation. Thus, to protect against the charge imbalance and migration, a small bleed line with a solenoid valve and/or a hot gas bypass circuit is often integrated into the system design.

2.3 Systems Using a Two-Phase Refrigerant Mixture
As shown in Figure 6, this approach utilizes a mixture of hot compressor discharge gas and warm liquid exiting the condenser (Bussjager, 2004). In this process, the refrigerant flow at the compressor exit splits into two streams; one stream completes the conventional path through the condenser and the other stream is re-routed around the condenser coil. These refrigerant streams rejoin at the condenser exit, forming a two-phase mixture. As in the warm liquid dehumidification approach, the refrigerant subsequently enters the reheat coil, but in a two-phase state, where it is further condensed and then subcooled. During this heat transfer interaction, the air stream exiting the evaporator is reheated. Assuming that all other parameters are remain the same, the amount of flow bypassing the condenser will determine the vapor quality in the refrigerant mixture at the joint point and will define the reheat coil capacity. The bypass refrigerant flow
consequently establishes the evaporator performance (based on the amount of subcooling gained). If the bypass refrigerant flow is increased, the mixing point shifts into the higher vapor quality region inside the two-phase “dome,” which in turn enhances the reheat coil capacity (see Figure 7). Since the system subcooling is concurrently reduced, the evaporator performance diminishes accordingly. Obviously, the bypass flow reduction causes just the opposite effect. This design makes it possible to meet market requirements of both evaporator latent performance and system sensible capacity by means of modulating or pulsating the condenser bypass flow, without changing any of the system components.

![Figure 6: Two-Phase Mixture Refrigerant Cycle](image)

![Figure 7: P-h Diagram for Figure 6](image)

Note that if the conventional refrigerant path through the condenser is closed, the two-phase mixture system turns into the parallel hot gas schematic. If the bypass around the condenser is closed, the system develops into the warm liquid design method. This discussion demonstrates that some flexibility could be achieved for the hot gas or warm liquid systems as well, if regulating or pulsating flow control devices were substituted for the shutoff valves. Unfortunately, these methods offer significantly lower agility in system design and may encounter more complex system control and reliability issues. However, the two-phase refrigerant mixture system offers at least three distinct modes of operation to satisfy a wide range of environmental conditions and load demands. The system provides adequate operation for conventional cooling applications, for hot and humid environments, and for low sensible load cases, by alternating between these operating modes. Finally, although implementation of the considered design may require a slightly larger reheat coil than in the sequential hot gas approach, the original evaporator airflow distribution is not likely to be compromised, preventing a potential flooding problem in some of the evaporator circuits.

3. CONCLUSIONS

As stated above, a dehumidification system design concept should be selected based on the requirements of a particular application in terms of the cooling and heating needs and the moisture removal criterion. Reheat methods utilizing primary refrigerant circulating throughout the system have been evaluated and the two-phase mixture approach was found to possess several appealing features and to provide adequate coverage for a wide spectrum of potential applications. At first glance, this design may seem to present some operational concerns and performance deviation issues at off-design conditions. However, these concerns can be resolved easily by the control logic (e.g. activation of the head pressure control) and careful component design (e.g. reheat coil size adjustment and condenser circuiting). Also, it must be understood that, with any dehumidification system, the reheat coil size is selected for a particular operating point of the neutral total sensible system performance that will deviate from zero at any off-design
conditions. The advantage of the two-phase mixture dehumidification system is that these undesirable tendencies can be minimized or reversed in the vast majority of cases.

To further improve system flexibility, all the fixed-position 2-way and 3-way valves can be replaced with controllable devices to regulate the amount of refrigerant flowing through every branch of the dehumidification cycle. Additionally, all the considered schematics can be utilized in multi-circuit systems, in which each circuit is controlled independently to perform the desired function. Hybrid concepts satisfying even a wider range of cooling, heating and dehumidification requirements have been developed as well (Taras and Lifson, 2004). These systems can operate in a variety of the dehumidification modes discussed above, by opening and closing the appropriate flow control devices to reroute the refrigerant through a particular branch of the cycle. One of such schematics is displayed in Figure 8, where the two three-way valves and two shutoff valves (replacing typical check valves) manage an appropriate refrigerant flow path in response to external sensible and latent load demands. Obviously, the complexity in design and control logic for such systems increases proportionally but any subsystem of the hybrid design can be implemented and executed independently. Lastly, additional benefits in system heating performance can be obtained by utilizing a reheat coil as a section of an indoor heat exchanger (a condenser in this case) in heat pump applications (Taras and Lifson, 2004). One of such schematics is presented in Figure 9 where the reheat coil is arranged sequentially and located upstream of either outdoor or indoor heat exchanger in the dehumidification or heating mode of operation respectively.

REFERENCES