COMMERCIAL SIZED CO_2 HEAT PUMP WATER HEATER - NORTH AMERICAN FIELD TRIAL EXPERIENCE

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ABSTRACT

Eight commercially sized CO_2 heat pump water heaters have been developed for the North American market and installed into a diverse range of geographic and application sites. These units have been fitted with instrumentation to enable the tracking of performance and reliability in the field, and this data has been collected to give a true picture of the economic benefits of the units in their respective applications. The performance results show a considerable benefit over conventional water heating systems, with all of the units providing some $4,000 to $10,000 in annual energy cost savings compared to the pre-existing gas and propane heating systems. The units provide sanitary hot water at a temperature range of 60°C to 82°C at an hourly rate of 900 ltr/hr. The applications range from industrial aerospace facilities over food services to medical facilities. The units have accumulated a total of some 8000 operating hours and produced approximately 7.2 million liters of hot water. The availability of the units exceeds 85%. The field trial sites were selected to cover a wide range of geographic and climatic regions in the US and include locations on the east and west coast as well as the south of the States.

1. INTRODUCTION

The goal of the field trial effort has been to effectively reduce the barriers to broad application of heat pump water heaters in the US. Through market research, these barriers have been found to be (1) Reliability, (2) Customer Value, and (3) Infrastructure. Reliability is extremely important to the customer, and as heat pump systems are inherently more complex than the existing gas and electric systems, this has traditionally been very challenging. To address this, a reliability growth tracking model has been developed (Sadegh et al. 2004) and is being populated with field trial experience. These experiences, through the reliability model, will be used to improve the system design. The customer value proposition is a measure of how economically attractive the system is for a potential customer, and will vary from site to site. The fundamental issues to be addressed are the performance (both capacity and efficiency) and cost of system to the customer. The use of CO_2 as the working fluid allows the system to achieve higher efficiency levels than traditional HFC based heat pump systems as well as allowing the system capacity to remain high even under low ambient temperature operating conditions. Cost reduction is achieved by using a standard high volume small chiller platform as the basis of the heat pump design. The final barrier to be addressed is the infrastructure, which relates to the ability of a potential customer to get information on the system, find a dealer and installer, and provide for service and aftermarket support. For this, a large company with nationwide presence is needed, which UTC is in a good position to provide. The field trials are run in two phases, with three system designs developed over the life of the project. The first field trial (Phase I) commenced in the 4th quarter of 2004, and was developed from a CO_2 heat pump water heater currently in European field trials. There are three deployed units in this field trial, which will run to the 4th quarter of 2006. Modifications to the basic design achieved a functional system capable of running under 60Hz and relevant to UL requirements (UL tests and certifies equipment in the USA similar to CE in the EU). Phase II field trials have commenced in the 2nd quarter of 2005, and have included system improvements intended to optimize the unit for 60Hz operation as well as moving closer to full UL listing. There are an additional five deployed units in this phase of the field trial, which will also run to the fourth quarter of 2006. The final design will come after a full teardown analysis of the eight field trial units and will include all lessons learned from the field trial experience to improve reliability and cost effectiveness. In order to generate the most relevant information for reliability improvement, a broad selection of field trial sites is essential. This necessitates the selection of field trial sites which push the operational envelope of the unit. Examples of the type of variability desired in the field trial selection include duty cycle (continuous vs. cycling), temperature extremes (hot and cold), and building integration (indoor vs. outdoor). Every attempt has been made to select field trials with as broad a range of these parameters as possible, while also providing good operational economics to the field trial host.

2. CO_2 HEAT PUMP WATER HEATER

Together with the reinvention of CO_2 as refrigerant (Lorentzen 1994), heat pumps were identified as potential applications for transcritical vapor compression systems. The temperature glide of the refrigerant during the heat rejection process allows better matching of the refrigerant temperature with the secondary fluid compared to sub-critical cycles. The pinch point, the smallest temperature difference in the heat exchanger, which limits the efficiency of the cycle, occurs at the refrigerant outlet of the heat exchanger. Consequently, the refrigerant can be cooled to the lowest possible temperature before entering the expansion device, which benefits the cycle performance. In sub-critical cycles on the contrary, the refrigerant rejects heat during condensation at a constant temperature level, which results in a large average temperature difference between the refrigerant and the secondary fluid. The heat transfer across large temperature differences increases the irreversibility associated with the heat transfer. The pinch point in sub-critical cycles typically occurs at the onset of the two-phase region in the heat exchanger at much higher temperatures than the inlet temperature of the secondary fluid. The benefits of transcritical heat pumps have been analyzed by numerous authors (Lorentzen 1994, Rieberer et al. 1997, Saikawa et al. 1997, Hwang and Radermacher 1998, Neksa et al. 1998, Bullard et al. 2000, Rieberer et al. 2000, Neksa 2002, uca et al. 2003, Bullard and Rajan 2004).

3. FIELD TRIAL EQUIPMENT

The design capacity of the unit is 60 kW at a rating point of 10ºC ambient temperature and a water inlet temperature of 10ºC. The capacity of the system is equivalent to approximately 1000 liters per hour of 60ºC sanitary water, at a design target efficiency of COP = 3.5. The unit provides 400 to over 1300 liters of hot water per hour at ambient temperatures between –20 ºC and 46 ºC. The design is based on Carrier's Aquasnap chiller series. The unit shares all components except for those in direct contact with the working fluid with the commercial product line. The utilization of high-volume production components allows a cost saving design and reduces the reliability risks associated with new component development. Figure 1 shows a picture and a schematic of the unit. The unit is approximately 1.30 m high, 1.06 m deep, and 2.08 m long. Designed for the US market, the unit runs on 480V, 60Hz power, which drives a two-piston single stage semi-hermetic compressor with roughly 51 cm^3 total displacement volume. The heat pump operates as once-through water heater with the storage tank as buffer between the unit and the water main line. The water is heated in a double-wall stainless steel plate heat exchanger to minimize the risk of contamination of the sanitary water in case of a heat exchanger failure. A single-speed fan draws air across a round-tube-plate-fin evaporator. A suction line accumulator provides storage volume for liquid refrigerant at low ambient temperature conditions. A microprocessor controls the electronic expansion valve and variable speed pump to accommodate an optimum discharge pressure and water flow rate depending on water inlet and ambient air temperature. The microprocessor also monitors the temperature of the water in the storage tank and in the inlet line of the pump to determine whether there is a demand for hot water. The control board is based on the design of a commercial chiller and is equipped with a communication board. The unit can be monitored and controlled remotely via Carrier Comfort Network, which also allows collecting and transferring data.

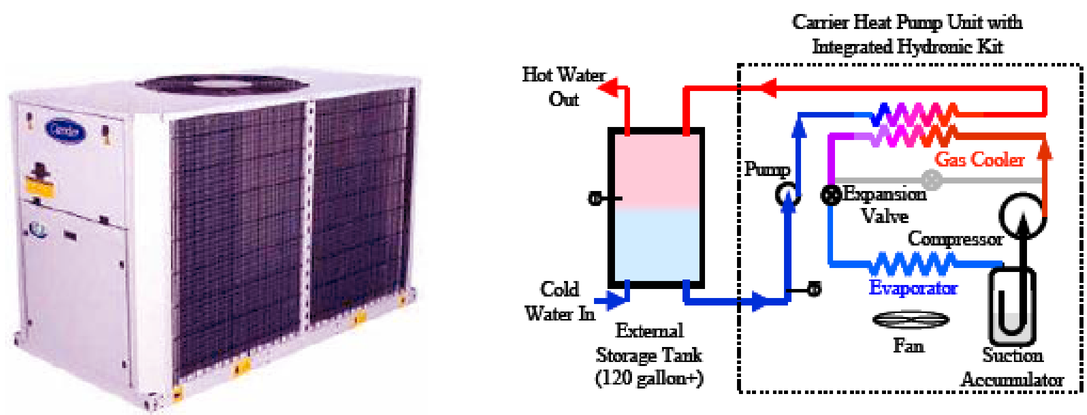

Figure 1: CO_2 Heat Pump Water Heater

3. FIELD TRIAL EXPERIENCE

3.1 Filed Trial Sites

The field trial sites were selected to represent a wide scope of potential commercial applications and geographical locations across the USA. Three of the eight units are installed outdoors with locations at the north eastern states and the north western states. In total 2 units are installed in the north eastern region, one in the north western region and five units are located in the southern states at the Golf Coast. The applications of the units at the various locations include commercial laundries, hotels, hospitals, food processing plants, industrial applications and food services. Figure 2 shows pictures of some of the installation sites.

The voice of the customer suggests a strong demand for commercial heat pump water heaters of this particular size. At indoor installations the heat pumps provide “free” cooling, which is especially welcome at locations where heat and humidity are frequently impede the working conditions for the employees. Several field trial hosts regard the potential for increased employee retention rates due to improved working conditions as significant benefit.

Figure 2: Installed CO_2 Heat Pump Water Heaters

3.2 Installation Costs

Market research indicates that customer value is one of the critical market barriers for heat pump water heaters. The customer value proposition depends on the performance and cost of the heat pump. While the installation costs are just a small fraction of the total cost of ownership of the heat pump, they can be a significant fraction of the first cost to the customer. This is especially important because investment decisions are often driven by payback time rather then by net present value. During the heat pump field trials we have seen a variation of the installation costs by a factor of five for comparable installation conditions. Analysis of the installation quotes suggests that the height of the installation costs strongly depends whether the pricing contractor views the heat pump as air conditioning/refrigeration equipment or as an electric water heater. Since the heat pumps are being delivered pre-charged with CO_2 and ready for operation, they should be regarded as highly efficient electric water heater and the installation costs should not significantly exceed those for conventional electric water heaters of the same size. With the market introduction of commercial CO_2 heat pumps water heaters contractors will certainly get accustomed to this technology, which will even the market place.

3.3 Field Trial Reliability

The last decade has seen tremendous progress in the development of CO_2 vapor compression systems. Today almost all manufacturer of vapor compression equipment have development programs for CO_2 components and systems. Together with increasing availability of CO_2 equipment, the reliability of critical components has increased to acceptable levels. However, compared to the mature technology of conventional sub-critical systems, the reliability of CO_2 components still offers room for improvement.

4. CONCLUSIONS

A series of commercially sized CO_2 heat pump water heaters have been installed into a diverse range of geographic and application sites across the USA. The installations include hospital, commercial laundry, food processing, food services, hotel, and industrial applications. The field trials have shown that the market place of contractors needs guidance on categorizing and appropriately pricing the installation of commercial heat pump water heater. It is important for the success and market acceptance of heat pump water heaters that these pre-packaged and pre-charged systems be regarded as electric heaters rather than as air-conditioning/refrigeration equipment. The continued effort of the refrigeration component manufacturer community in the development of CO_2 components is reflected in acceptable levels of component and system reliability.

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ACKNOWLEDGEMENT

The authors would like to thank the US Department of Energy (DOE) and the National Energy Technology Laboratory (NETL) for their support of this research effort. The authors would like to thank Alabama Power, the Southern Company, Portland General (PGE), and the Tennessee Valley Authority (TVA) for their support. The authors would also like to thank the United Technology Corporation (UTC) and Carrier for their support.