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Hot Water Supply Using a Transcritical Carbon Dioxide Heat Pump

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Abstract

In New Zealand (NZ) a typical household uses between 160-330 l of hot water per day at 50 to 60°C. Most hot water systems are electrically heated. Heat pumps using carbon dioxide (CO_2) in the transcritical heat pump cycle offer high potential for energy savings. The use of CO_2 also offers further benefits such high volumetric heating capacity, reduced environmental impact, good availability and low costs.

The objective of this project was to design, build and test a hot water supply system (HWSS) using a CO_2 heat pump.

The main components of the HWSS were the heat pump, a stratified hot water storage cylinder (HWC), a water pump and a control system. The heat pump design was based on a prototype Dorin CO_2 compressor which was available. Key features were use of a vented spiral tube-in-tube heat exchanger for the gas cooler, use of a low pressure receiver incorporating an internal heat exchanger after the evaporator and the use of a back-pressure regulator as the expansion valve. The heat pump had a nominal design heating capacity of 8.1 kW with a COP of 3.9 at 0°C/34.8 bar.a evaporation temperature/pressure and 100 bar.a discharge pressure when heating water from 15°C to 60°C.

The prototype heat pump performance was measured for a range of operating conditions including 0°C/33.8 bar.g to 15°C/49.8 bar.g evaporation temperatures/pressures, 18 to 30°C cold water inlet temperature, 40 to 60°C hot water outlet temperature and 90 to 120 bar.g discharge pressures. Liquid refrigerant and/or oil carry over caused by limited LPR separation capacity and/or oil foaming in the LPR was apparent for some trials but could not be completely eliminated. The compressor isentropic and volumetric efficiencies were about 30% lower than stated by the manufacturer. Possible reasons were mechanical and/or compressor oil related problems. The gas cooler was marginal in capacity especially when the heat pump operated at high evaporation pressure conditions.

The measured heat pump heating capacity at the design conditions was 5.3 kW at a COP of 2.6. The heat pump COP was not sensitive to the discharge pressure across a wide range of operating conditions, so constant discharge pressure control was adopted. Overall best heat pump efficiency for 60°C hot water was achieved at 105 bar.g discharge pressure. At these discharge conditions the heating capacity and COP ranged from 4.8 kW and 2.2 at 0°C/33.8 bar.g evaporation temperature/pressure and

30°C cold water inlet temperature to 8.7 kW and 3.9 at 15°C/49.8 bar.g evaporation and 18°C water inlet respectively.

A mathematical model of the HWSS was developed. The model parameters were determined from a small set of separate trials. The overall agreement between measured and the predicted HWSS performance was good. The HWSS performance was predicted for conditions likely to occur in a one or two family home. The biggest efficiency losses were HWC standing losses to the ambient air. The heat pump operated with close to the maximum COP of 2.75 because the water inlet temperature seldom rose above 25°C. There was potential for efficiency improvements if the short on/off intervals caused by the relatively small HWC relative to the heating capacity of the heat pump could be avoided.

Overall, the investigation has shown that the CO_2 heat pump combined with a stratified HWC can provide a very efficient HWSS. The heat pump prototype performance was competitive with conventional heat pumps but there was significant potential for efficiency improvements due to the poor compressor performance. However, the availability and costs of heat pump components and the poor compressor performance constrain the commercial implementation.

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1 Introduction

New Zealand (NZ) is about to ratify the Kyoto protocol, a global convention to reduce the global greenhouse gas emissions. Fundamental to the convention is the development of more energy efficient technologies and greater use of renewable energies.

New Zealand's energy production is predominantly fossil fuel based (72% of the total), followed by hydro-powered electricity (23%), geothermal electrical power (5%) and other renewable energies (less than 1%) (Ministry of Economic Development, 2000). The production of sanitary hot water in domestic household accounts for 8.7% of the total energy use and represents 38% of the domestic energy consumption (4000 kWh/year for the average household).

Water heating technology in domestic and commercial applications is dominated by electric (69%) and gas-fired (19%) storage units (Williamson and Clark, 2001). Alternative systems, such as solar thermal, wet-backs and heat pumps represent less than 1% of the market. Even though the gas instantaneous water heaters dominate many world markets, the technology has only 8% of the market in NZ.

World-wide about 90 million heat pumps were installed in the year 1997, predominately for residential space heating, air conditioning and cooling applications (Runacres, 2002). The heat pump market has grown at an average of 15% per year since 1992. The biggest markets are China, Japan and the USA.

Heat pumps have the potential for high-energy efficiency but the high heating temperature required for the domestic hot water production limits their efficiency and use in domestic water heating applications. Therefore the use of heat pumps for water heating has not been as widespread as the use of heat pumps for space heating and air conditioning.

The recent concerns of ozone depletion and global warming caused by the emission of fluorocarbon refrigerants, has increased the research on more sustainable heat pump technology. One alternative is the natural refrigerant carbon dioxide (CO_2), which has high potential for water heating applications when used in a transcritical heat pump cycle (Lorentzen, 1994a).

The overall aim of this research was to develop and test the performance of a water heating heat pump using the transcritical CO_2 cycle based on a prototype CO_2 compressor produced by Dorin SA an Italien compressor manufacturer.