Heat Pump Fluidised Bed Dryer with CO_2 as Refrigerant – Measurements of COP and SMER

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ABSTRACT

A prototype fluidised bed heat pump dryer with CO_2 as the working medium is constructed and build at the Dewatering R&D Laboratory at SINTEF and NTNU. The dryer is designed to use different inert gasses in the drying chamber, also included to run in under and over atmospheric pressure. This opens up for possibilities to test product under different conditions and investigate influence on the heat and mass transfer during the drying. The drying chamber can be changed and can operate in both fluid bed and static bed, and can be run in continues and batch operations. The options of the drying chamber gives possibilities to dry granulates or peaces/particles, foamed products, and liquids. It is also possible to coat, granulate particles and to agglomerate new particles.

To meet hygienic regulations the plant is build in stainless steel with CIP washing system, including 2.2 bar steam for sterilising.

The heat pump circuit is constructed to use CO_2 as working media with maximum working pressure of 130 bars. To operate in a wide range of temperatures (–20^oC to +90^oC) in the drying chamber the heat pump process will operate in a traditional way with evaporating and condensing mode, in a transcritical mode and also in a pure gas mode at high temperatures. These running conditions are depending of the product and its sensitivity of heat. In this paper tests of the plants are described and measured coefficient of performance and specific moisture extraction ratio are presented.

INTRODUCTION

Heat pump drying requires proper design of the size of the components of the refrigeration cycle. In reality the compressor capacity will control the efficiency of the plant together with the size of the heat exchangers, especially the evaporator. To large compressor capacity will give to low temperature in the evaporator and an inefficient energy use. It is therefore a challenge to make a laboratory heat pump dryer that shall operate at a wide range of temperatures. The size is optimal at only one temperature and that is at the lowest operation temperature level. At all other temperature levels the laboratory heat pump is out of design point due to the large compressor. At some extent this can be adjusted by installing a frequency controller. In a plant with CO_2 as refrigerant the thermodynamic process will operate at different operational modes such as; ordinary refrigeration cycle with condensation and evaporation; transcritical operation with cooling of the refrigerant at pressures above the critical point (cooling of a compressed gas without condensation) and evaporation; gas cycle where the refrigerant is totally above the critical point of the refrigerant. This is shown in figure 1.

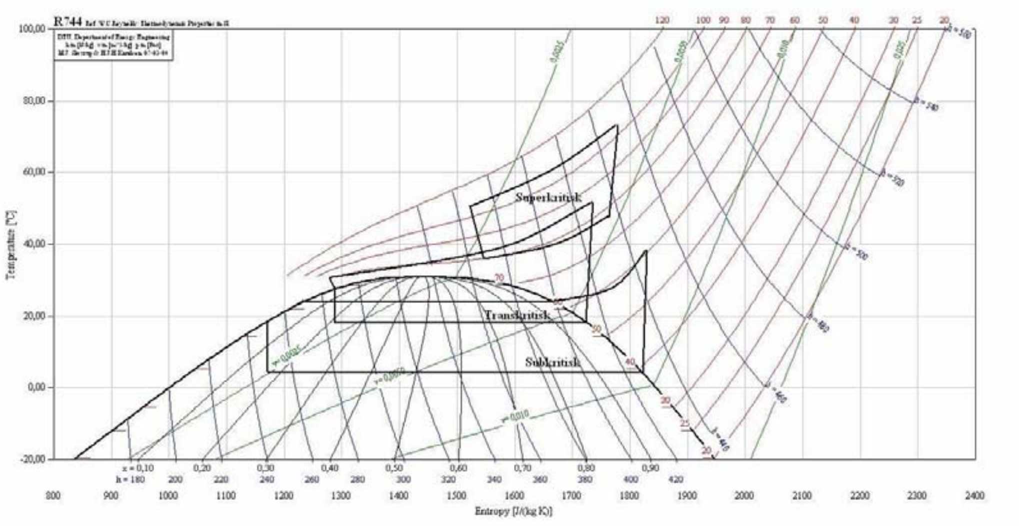

Figure 1 TS-diagram for the three different refrigeration cycles for the CO_2 process

The CO_2 process in the transcritical operation can be optimized bay increasing the pressure on the outlet of the compressor. The CO_2 gas temperature out from the air heater is kept constant and the pressure is increasing. As shown in the figure 2 the specific evaporation capacity will increase. At a given pressure the process will have the optimum COP. The optimized pressure level is controlled by the expansion valve with a high pressure sensor. It is then necessary to have a low pressure receiver at the outlet of the evaporator to accumulate the variation in the refrigeration charge at the high pressure side.

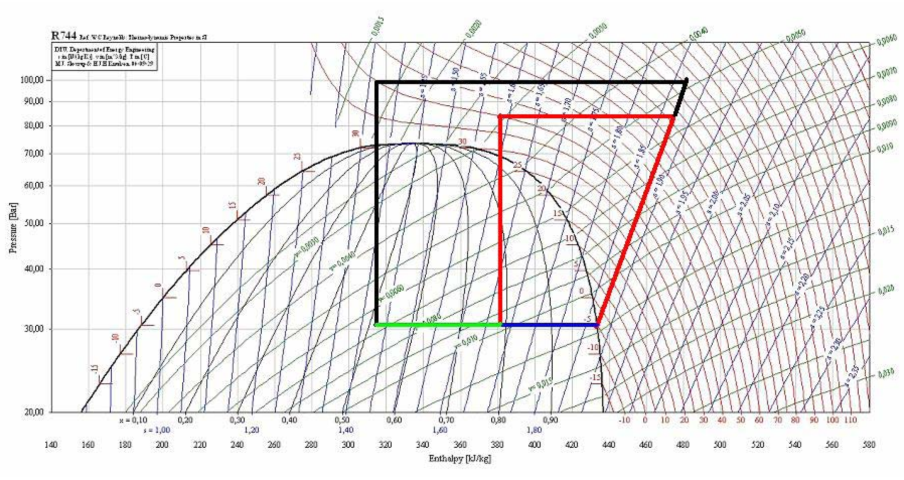

Figure 2 Log P-h diagram for the CO_2 process in transcritical operation

The refrigeration capacity needed over the operational temperature range of the dryer is relatively constant. In figure 3 this is shown for the temperature range from -20°C to +90°C and at a relative humidity of 30% at the inlet of the dryer and 70% at the outlet of the dryer. As shown the necessary cooling capacity varies from 2.5 kW to 3.2 kW. This is not possible to achieve with one compressor because of the thermodynamic properties of the refrigerant.

To meet this challenge it is necessary to have more than one compressor and in addition the compressor speed should be tuned by at frequency controller.

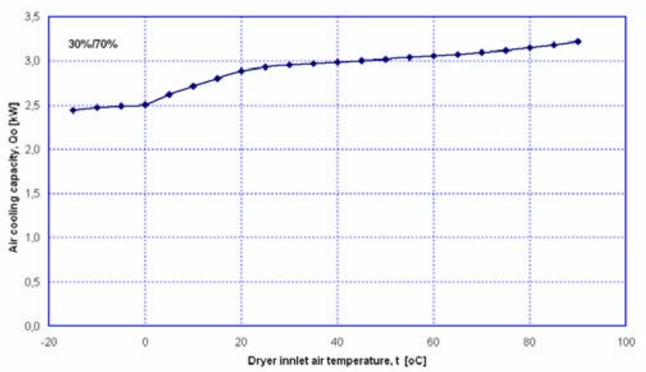

Figure 3   Air cooler capacity at different temperature levels at the inlet of the drying chamber

The laboratory plant (see figure 4) at the Dewatering R&D Laboratory at NTNU and SINTEF is designed to operate at the temperature range from -20°C to +90°C. The plant is build in stainless steel and is equipped with CIP washing system and with steam sterilizations system. The diameter of the fluid bed is possible to vary from 10cm to 35cm and the air flow can vary from 100 to 800m^3/h. The variation in air flow gives an oversized air fan with higher energy consumption than a normal plant is requiring.

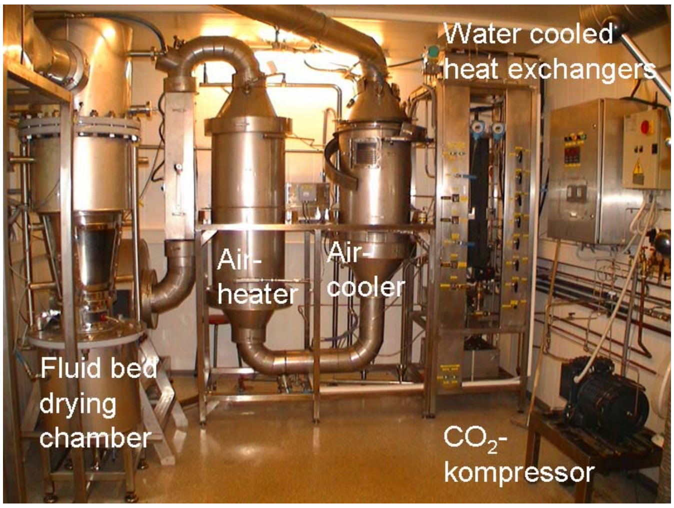

Figure 4   Photo of the laboratory fluid bed dryer with CO2 as refrigerant

Figure 5 shows the drawing of the laboratory plant. The plant has two external heat exchangers cooled with water to remove the excess heat form the plant. A heat pump dryer with closed loop will require energy to circulate the air in the drying system and to transport energy from the heat exchanger for cooling of the air and the heat exchanger for heating of the air to make the drying potential. This energy used to run the fan and the compressor has to be removed in the external heat exchanger.

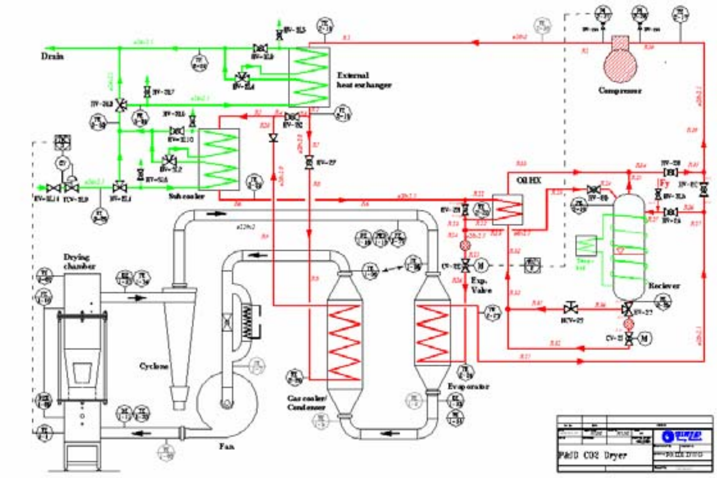

Figure 5 Schematic drawing of the fluid bed dryer with CO2 as refrigerant

The new fluid bed dryer with CO_2 as refrigerant has shown very stable drying conditions within ±0.5°C temperature variations at the inlet of the drying chamber. The relative humidity at the inlet of the drying chamber is given by the cooling capacity of the air cooler. To have the possibility to control the relative humidity at the inlet of the drying chamber there have been installed a spray nozzle for water after the air heater.

RESULTS

There have been run test of the heat pumping system at temperatures at +30°C, +40°C and +50°C. The product in the drying chamber has been plastic bids with a size of 3mm length and a diameter of 1.5mm. There has been added water in the fluid bed chamber with a water spray nozzle to simulate the drying process. The amount of water added has been controlled to meet 60% relative humidity at the outlet of the drying chamber. This is shown in figure 6. At this test the relative humidity at the inlet of the dryer was 20%. Figure 7 shows the CO_2 process in the Ts-diagram

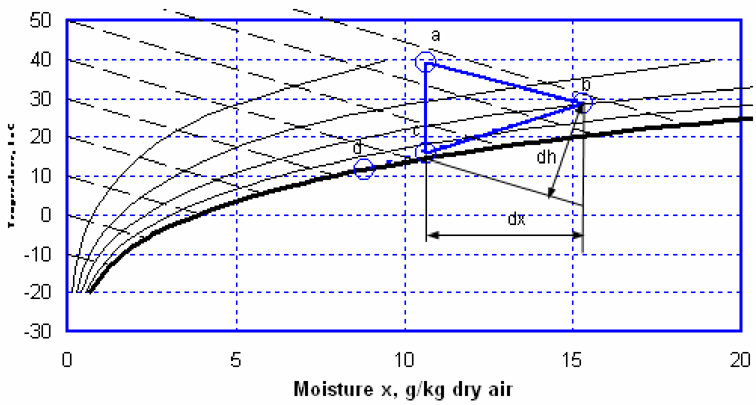

Figure 6 Mollier-diagram for drying process at air inlet temperature of 40°C

Due to the relative high capacity of the air blower the total energy consumption of the plant is higher than expected. This reduces the coefficient of performance for the plant. To reach the 20% relative humidity at the inlet of the dryer, the air is cooled to a lower temperature than the dew point. In figure 7 the yellow line (at high pressure) shows the heat removed in the external heat exchanger. The dark blue line is the air heating energy.

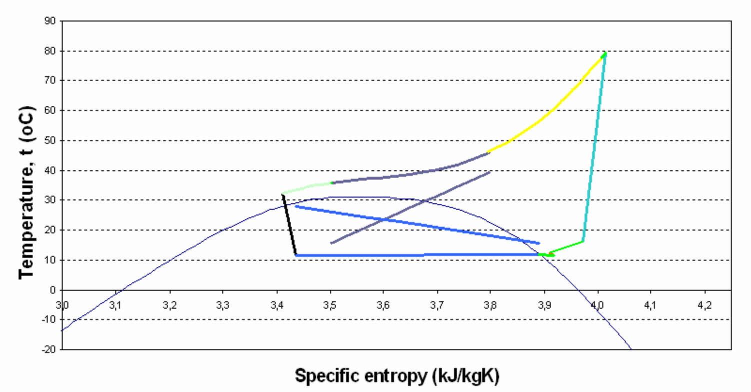

Figure 7 Ts-diagram for the CO2 process with drying process at 40^oC air inlet drying temperature

The following data have been measured for the three tests.

Table I. Results from the tests performed on the CO_2 heat pump

Air inlet temperature of drying chamber	30,3	40,6	50,7
Relative humidity inlet air	23,9	20,0	12,8
Air outlet temperature of drying chamber	22,3	28,6	32,5
Relative humidity outlet air	60,5	60,1	60,8
COP	2,71	2,31	4,18
SMER	1,73	1,65	3,73

CONCLUSIONS

There have been installed a new fluid bed dryer in the dewatering laboratory at NTNU and SINTEF with CO_2 as refrigerant. The plant is designed to operate at a wide range of temperatures. This gives operating conditions for the heat pump far out from the design point. The fan is oversized and reduces the COP for the process. The SMER values for the plan have been measured from 1.65 to 3.73 at different drying air temperatures.

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