Design of a gas-fired carbon-ammonia adsorption heat pump
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INTRODUCTION/BACKGROUND

The University of Warwick is developing a very compact carbon-ammonia adsorption cycle gas fired heat pump so that it can be a box-for-box exchange for a conventional domestic gas boiler, with much reduced size and capital cost. Also for ease of retrofit, it is an air source machine. It would provide at least 10 kW of heat output, requirement for an average semi-detached UK household of three bedrooms. The working conditions of the machine are heating water to 50°C, for low temperature radiators, and typical ambient temperature range from -5 to 15°C.

The internal COP should be higher than 1.38 so that the gas utilisation efficiency is higher than 1.25. With this predicted COP, the machine will reduce the gas consumption by 30% compared to a conventional condensing boiler.

SORPTION MATERIAL

The material used in the generator is a carbon composite made with a mixture of lignin binder and active carbon type 208C in order to obtain enhanced thermal properties compared to loose carbon grains or pellets. The mass of refrigerant (ammonia) adsorbed and desorbed in the beds over a heat pump cycle is calculated with the modified Dubinin-ASTakhov equation presented by Critoph, 1999.

\[
x = x_0 e^{-\frac{m}{n}}
\]

where \( x \) is the heat pump cycle, \( x_0 \) is the adsorbed refrigerant concentration (kg/kg), \( m \) is the maximum (limiting) concentration (kg/kg) and \( n \) are air constants.

Adsortion and thermal conductivity characteristics of the carbon composite vary due to the addition of the binder, adsorption and thermal conductivity tests were carried out with a Rubotherm magnetic suspension balance and with Quickline-10 Anter machine respectively.

Figure 2 shows a sample of the carbon laminate used in the construction of the adsorption generators. The carbon is the monolithic type as described above. The laminate is made by compression in a die before pyrolysis in a furnace to bind the carbon composite into a monolithic layer between the fins. An (LTJ (transient technique) rig was designed, manufactured and constructed at the University of Warwick in order to determine the combined thermal conductivity and wall contact resistance of the carbon composites. The thermal performance of the heat exchangers was verified on a test section and comparing it to a transient model developed in MATLAB.

COMPUTATIONAL MODELLING & RESULTS

A two dimensional finite difference simulation model has been written in MATLAB to explore how varying the geometry of the generator, dimensions and control parameters affects the Coefficient of Performance (COP) and power output under specified conditions and sorption materials. The unit cell is a cylindrical section as shown in Figure 3. The lengthwise cell is split into radial sections and the carbon is split into radial sections. The pressurized water used to heat or cool steel has only one radial element.

Figure 3 shows an example of the different carbon pitches in the simulation model. The machine was tested with a system of electrical heating and cooling baths that provide up to 370°C of pressurised water, heat transfer fluid. It also allows 10 kW of heat rejection for the condenser and cooler and provides a glycol flow down to -10°C for the evaporator.

TESTING RESULTS

The machine was tested with a cooling inlet water temperature of 40°C, a heating water inlet temperature of 370°C and condensing temperature of 40°C. Although the temperature and pressure profiles of the machine seem correct and very repeatable, the COP and powers delivered were lower than the ones predicted by the simulation model. This was due to an unexpected low amount of refrigerant cycled during the testing, approximately a third lower than the adsorption characteristics of the sorption material predicted.

It is believed that some of the binder used in the carbon composite is causing blockage of the pores. Further work will be done to reevaluate the composite material and the design of the generator in order to avoid the pore blockage.

REFERENCES


ACKNOWLEDGEMENTS

This research was supported by the EPSRC grant to the University of Warwick (EP/K011847/1).