

# NOVEL COMPACT SORPTION GENERATORS FOR HEAT PUMP APPLICATIONS

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**Abstract:** A new type of liquid-solid heat exchanger-reactor (carbon-ammonia) has been developed for use in adsorption cycles. It has the requirement to be of low thermal mass and also to have good heat transfer. The design solution chosen is a novel plate heat exchanger. It uses nickel brazed shims and spacers to create adsorbent layers only 4 mm thick between pairs of liquid flow channels of very low thermal mass. Prototype sorption generators have been manufactured and are being evaluated. The design is being used in a gas-fired heat pump, intended to replace a combi-boiler in the UK or similar climate. The heat pump uses two generators operating out of phase in a regenerative cycle. The system is described. Initial heat and mass transfer experiments on the generator are presented together with predictions of performance in the chosen application.

**Key Words:** *heat pumps, sorption, heat exchanger, reactor, COP, efficiency*

## 1 INTRODUCTION

Adsorption refrigeration and heat pumping machines have the potential to reduce harmful and greenhouse gas emissions (CO, CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub> ...) and to produce substantial fuel savings: about 20% with mobile air conditioning and 30% for a domestic gas fired heat pump. According to the UK's Department of Trade and Industry, 82% of domestic energy consumption and 64% of industrial energy consumption in the UK in 2001 could be attributed to space heating and hot water production (UK DTI, 2002). The domestic and industrial energy consumption represented 30% and 22%, respectively, of the UK's overall energy consumption and thus 39% of the UK's energy consumption can be attributed to space and hot water heating. Therefore improvements in the efficiency of space heating and hot water production could dramatically reduce the energy consumption and carbon emission footprint. However, the main challenges in the development of commercially viable adsorption cycle machines have long been the improvement of power density aimed to reduce capital cost and space requirements, and the improvement of the COP aimed to reduce running costs. The intensification of heat transfer within sorption generators has been the focal point of adsorption refrigeration R&D at Warwick University, aimed at high power density and COP for both cooling and heating systems. The concept of a plate heat exchanger applied to sorption generators for cooling and heat pump applications has been investigated initially through computational modelling and has proven to be interesting: a specific cooling power (SCP, the cooling power per unit mass of adsorbent) from 1 kW kg<sup>-1</sup> carbon up to 6.5 kW kg<sup>-1</sup> carbon with cooling COP varying between 0.5 and 1.2 are achievable (Critoph R.E. and Metcalf S.J., 2004; Metcalf S.J., 2006).

This paper describes a laboratory prototype gas-fired air-source adsorption heat pump that could replace a domestic gas combination boiler. For demonstration purposes, the heat input to the adsorption machine is to be simulated with electric cartridge heating elements. The

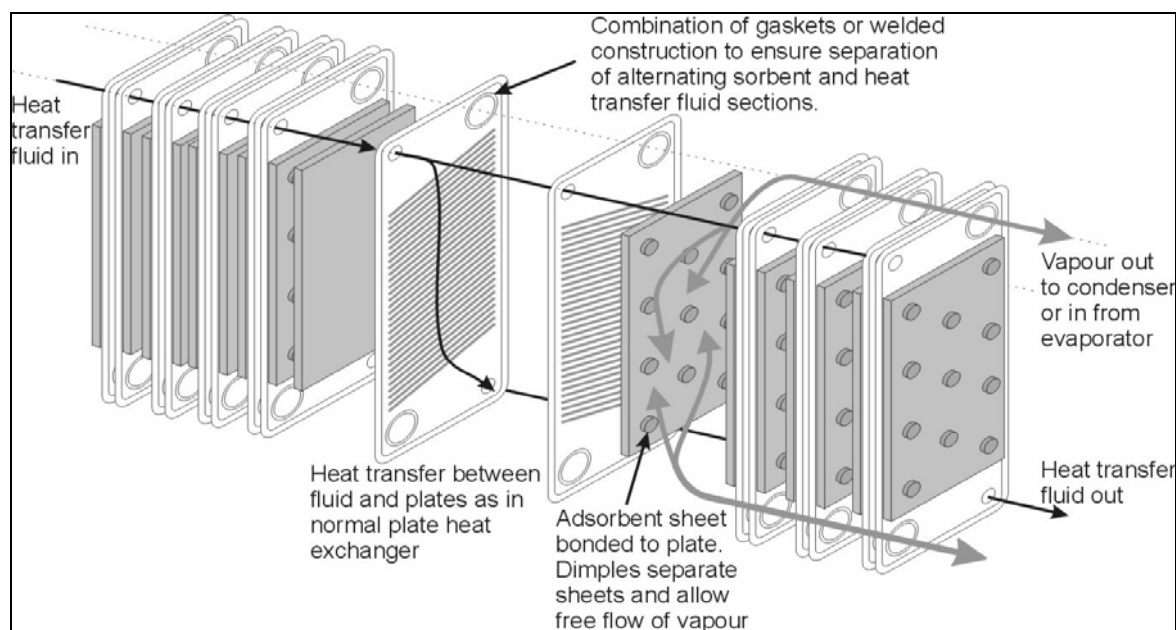
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heat pump is designed to provide a hot water flow rate of  $10 \text{ l min}^{-1}$  with a  $30^\circ\text{C}$  temperature rise and a nominal heating power of 7 kW.

## 2 SYSTEM DESIGN

The adsorption heat pump proposed in this paper employs a plate heat exchanger sorption generator in order to reduce cycle times and increase power density. The configuration of the generator is shown in **Figure 1**.



**Figure 1: Plate heat exchanger configuration of sorption generator**

The plate heat exchanger generators are currently under development as part of the EU project TOPMACS and is the subject of a patent (Critoph R.E., 2006). They are constructed from nickel-brazed stainless steel with a carbon layer thickness of 4-8 mm; water or oil may be used as a heat transfer fluid. The power density could be further enhanced with the addition of expanded natural graphite (ENG) to the active carbon adsorbent in order to increase its thermal conductivity. The COP of adsorption cycle heat pumps may be improved by using two principal heat recovery or 'regeneration' techniques: thermal wave cycles or multiple bed cycles. **Figure 2** shows the results of initial basic computational modelling which compared the COP-power density trade off for modular thermal wave and multiple bed cycle (two-bed and four-bed) adsorption air conditioners. Simulation results show that although a thermal wave cycle offers the possibility of achieving a higher COP than a four-bed cycle, it is at the expense of a reduced power density. It was concluded that a four-bed cycle could achieve an acceptable COP whilst maximising the power density in order to reduce the size and cost of the machine to a commercially viable level. Although multiple-bed cycles with a greater number of beds could give a higher COP, these were ruled out at this stage due to the complexity and the number of pumps and valves required. Thus a two-bed cycle was selected for the gas-fired adsorption heat pump (Metcalf, S.J., 2006).

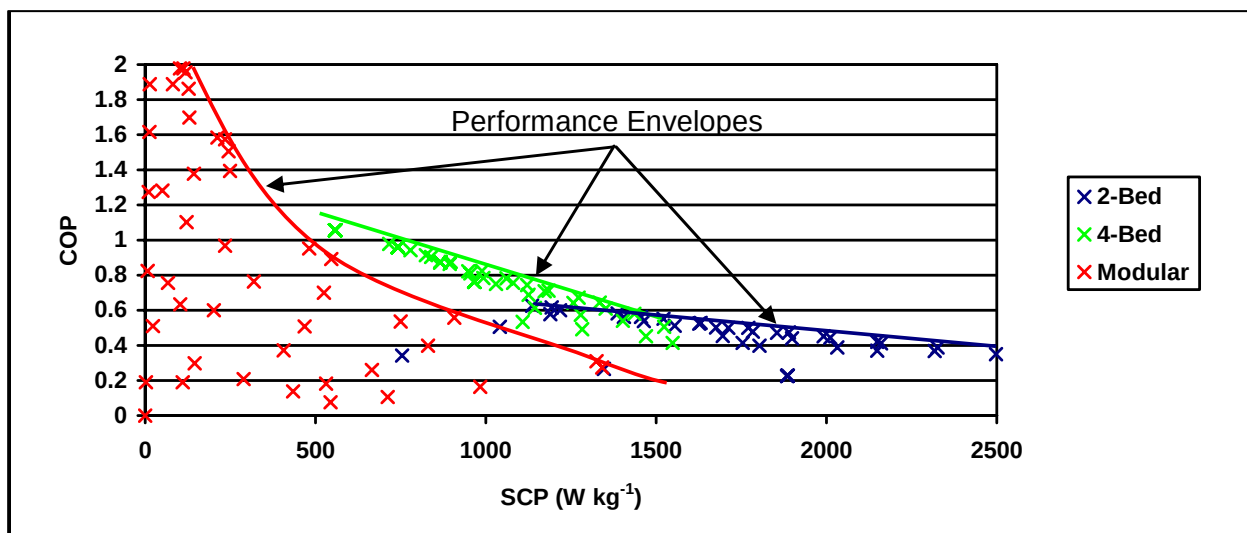


Figure 2: COP-SCP trade offs for multiple bed and modular thermal wave adsorption air conditioners

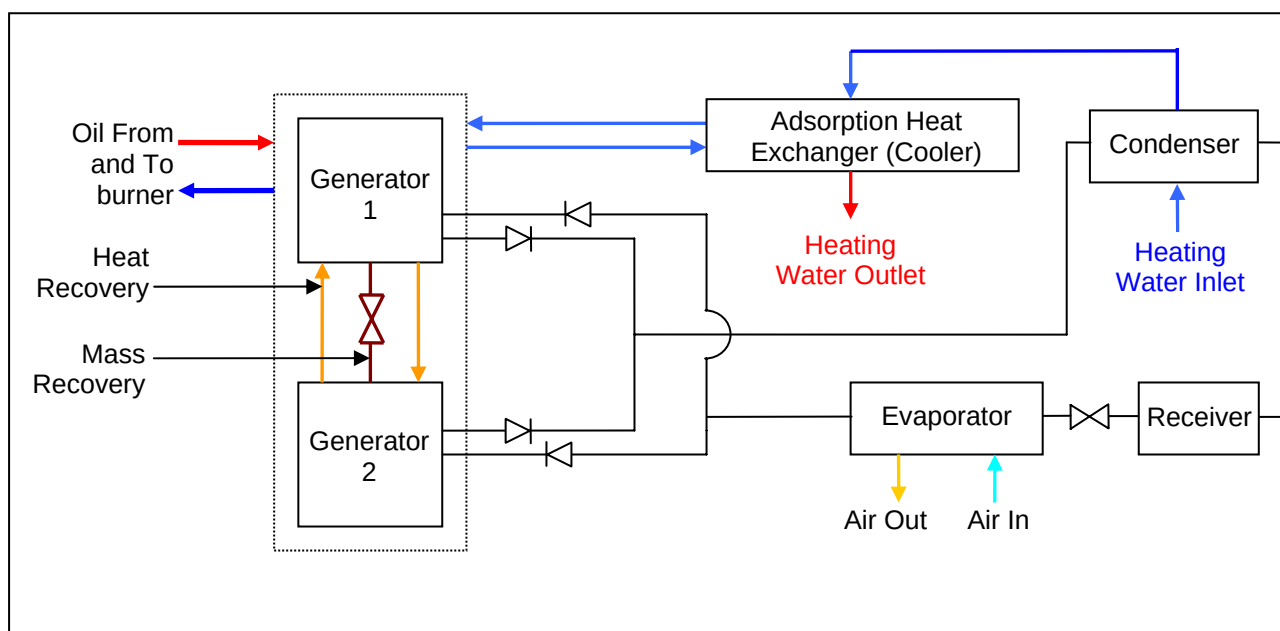
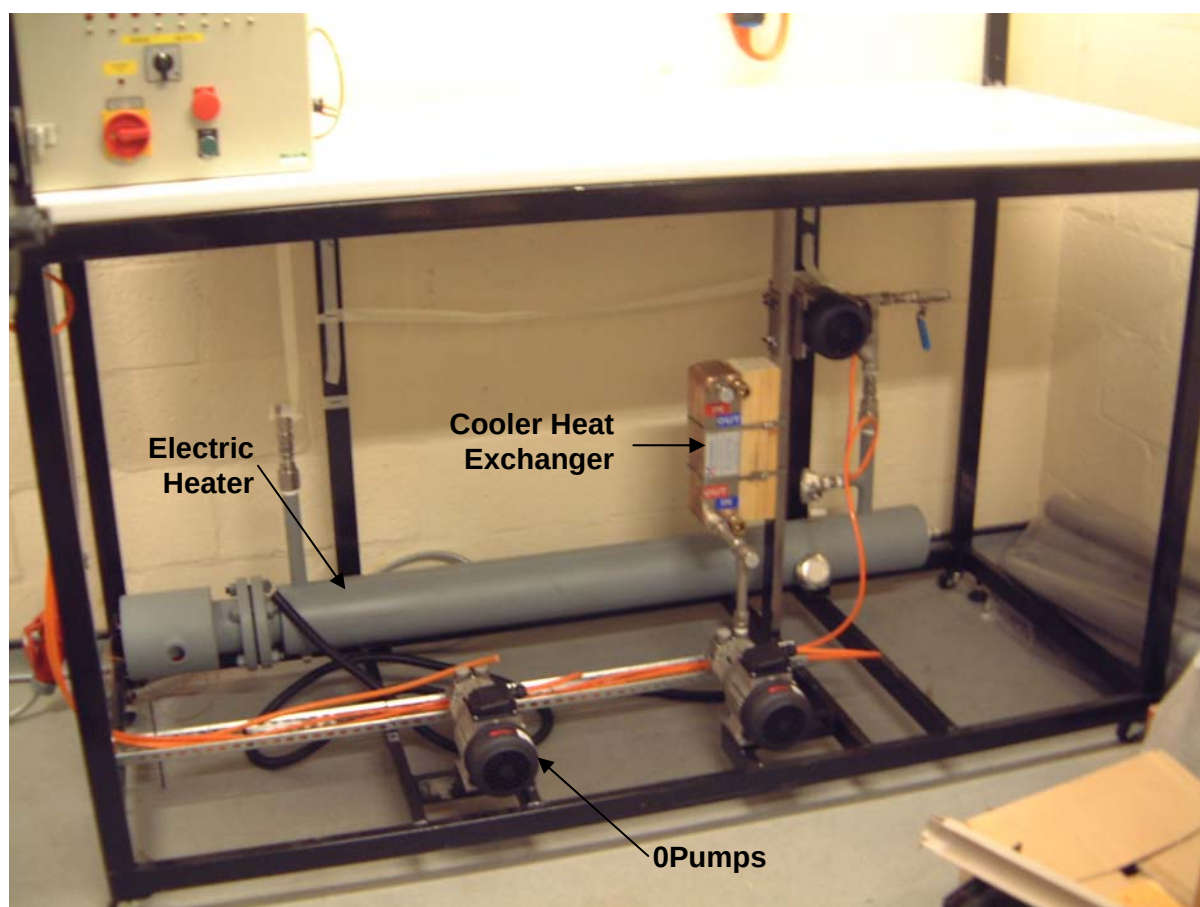


Figure 3: Schematic diagram of the gas-fired heat pump

**Figure 3** contains a schematic diagram of the heat pump and the fluid flows to and from the system. It highlights five main components: a pair of sorption beds (carbon-ammonia), the cooler (water to water heat exchanger), the condenser (water to ammonia), the expansion valve and the evaporator (air to ammonia). There are two distinct loops: the ammonia loop and the oil loop. The hot oil is supplied by an electric heater (simulating the gas burner) in order to provide the driving heat for the cycle. The heat pump is an air-source machine with a finned tube fan coil as an evaporator over which ambient air is passed. The heating water and hot water are heated firstly in the condenser and then in an oil-to-water heat exchanger by the heat rejected from the beds during the adsorption phase. This strategy lowers the condensing temperature and increases the efficiency of the heat pump. Both the condenser and the oil-to-water heat exchanger would be compact heat exchangers such as spiral plate or plate heat exchangers. In order to prevent the heating water and hot water streams from mixing, four such heat exchangers would be required.

### 3 MAIN COMPONENTS SPECIFICATIONS

**Figure 4** shows a photograph of the demonstration heat pump under construction.



**Figure 4: Prototype heat pump test rig under construction**

#### 3.1 Heat exchanger generator (reactor)

The heat exchanger generator (reactor) was designed around heat driven car air conditioning system specifications: it must be light and compact as possible in order to be fitted within the vehicle engine compartment to accommodate two 8 litre cubes. The first complete prototype is shown in **Figure 5**.

It is a nickel brazed stainless steel design with 29 layers of active carbon adsorbent each 4 mm thick. By incorporating the carbon adsorbent in thin layers, conduction path lengths through the material are reduced and the area for fluid heat transfer is increased which enables rapid temperature cycling and thereby a high specific heating or cooling power. The separating stainless steel plates are constructed from chemically etched shims with 0.5 mm square water flow channels on a 1 mm pitch. These channels give a high heat transfer coefficient and a large heat transfer area, further improving heat transfer performance. The square design ensures equal flow path lengths in every channel and therefore even heating and cooling of the adsorbent. The internal pressure (up to 20 bar when condensing at 50°C) is withheld by the stainless steel shims that act as supporting webs to the outer wall, which only needs to be 3 mm thick despite being straight. **Figure 6** shows the complete first prototype with flanges but a second prototype to be used for this project will be fully welded. Its specifications, gathered from initial experimental testing of the first prototype are summarised in **Table 1** (Tamainot-Telto, Z. et al, 2007).

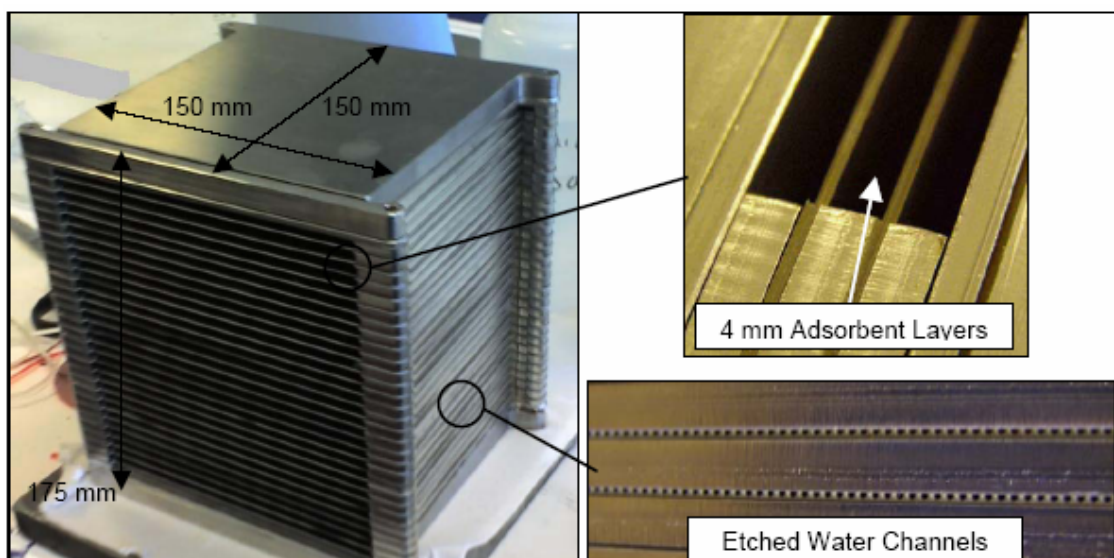


Figure 5: Plate heat exchanger generator design

Table 1: Heat exchanger generator specifications

|                                    |                                        |
|------------------------------------|----------------------------------------|
| Type of carbon                     | Chemviron SRD1352/3 (compacted)        |
| Filter                             | Stainless Steel Mesh (Mesh grade 180)  |
| Thermal enhancement additives      | None                                   |
| Sorbent density                    | 435 kg m <sup>-3</sup>                 |
| Mass of carbon                     | 1 kg                                   |
| Maximum ammonia concentration      | 0.37 kg ammonia/kg carbon              |
| Total weight of reactor)           | 9 kg                                   |
| Maximum operating temperature      | 200°C                                  |
| Maximum operating pressure         | 20 bar                                 |
| Operating cycle time               | 60 seconds                             |
| UA value in oil channels           | 920 W K <sup>-1</sup>                  |
| UA value in carbon-ammonia bed     | 420 W K <sup>-1</sup>                  |
| Effective bed thermal conductivity | 0.42 W m <sup>-1</sup> K <sup>-1</sup> |
| Overall bed UA value               | 290 W K <sup>-1</sup>                  |

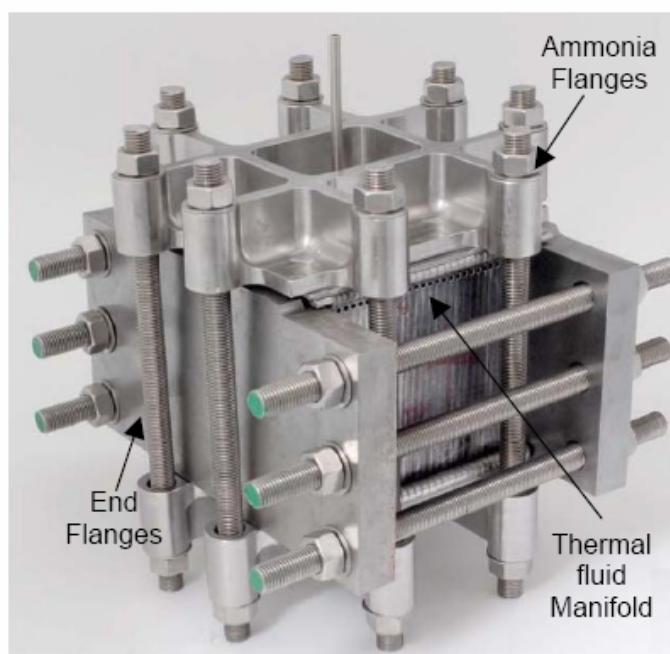


Figure 6: First laboratory prototype generator fitted with flanges and manifolds

### 3.2 Cooler

The cooler is a stainless steel copper-brazed plate heat exchanger 'SL23-BR25-40-TL-LIQUID' from UK Exchangers Ltd and can be seen in **Figure 4**.

### 3.3 Condenser

The condenser is an Alfa Laval AlfaNova HP52-20H fusion bonded plate heat exchanger.

### 3.4 Evaporator

The evaporator is a bespoke fan coil with aluminium finned stainless steel tubes and was designed and manufactured by Searle. It is shown in **Figure 7**.



**Figure 7: Bespoke evaporator fan coil from Searle**

### 3.5 Pumps

The oil circulation pumps are centrifugal pumps from Speck Pumps, model TOE/NPY2251.0007.

## 4. CONCLUSIONS

An adsorption heat pump using two innovative carbon-ammonia generators, operating out of phase in a regenerative cycle, has been presented. Initial heat and mass transfer experiments on the generator are given together with predictions of performance in the chosen application. The demonstration prototype of gas-fired heat pump that is still under construction is intended to replace a combi-boiler in the UK or similar climate. It has a nominal heating power of 7 kW.

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