GAS-DRIVEN SORPTION HEAT PUMPS; A POTENTIAL TREND-SETTING HEATING TECHNOLOGY

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Abstract: Increased efforts to reduce CO_2 emissions and continuous increases in fossil energy prices have led to stronger legislation concerning energy utilisation efficiency in the domestic heating sector. Accordingly, German gas utilities and the key European manufacturers of gas heating appliances have teamed up to form what is known as the “Gas Heat Pump Initiative” to introduce new heating technologies, which are capable of achieving an incremental improvement of gas utilisation efficiency compared to that delivered by gas condensing technology. This article provides a brief introduction to these innovative heating appliances and a presentation of the gas heat pump initiative.

Key Words: Gas heating, Sorption heat pumps, Zeolite-Water, Ammonia-Water, Initiative gas heat pumps

1 INTRODUCTION

According to the “EE-Wärmegesetz, 2008” (the Renewable Energy Heating Law) for increasing the share of renewable energy in household heating applications in Germany, a significant part of the heating demand shall be covered by renewable energy resources or shall be reduced by carrying out relevant building’s modernisation efforts. This means that more efficient and environmentally friendly gas heating appliances will have a significant market share compared with conventional technologies.

The spread of natural gas on the market was based, among other factors, on developments of low-pollution burners and later energy-efficient low-temperature boilers. The role of natural gas as a modern and ecologically compatible energy source was substantially extended by the introduction of gas condensing boiler technology in the 1990s. The heating market has subsequently become the largest consumption sector for natural gas. Since 2005, and particularly in the new buildings sector, the growth of the gas heating market has been clearly reduced, with a decline in service connection density from 80% to now less than 60%. In addition, expansion of the gas supply networks has reached the limits of economic feasibility.

The gas industry therefore needs to respond to customers’ increased environmental awareness and demands for autonomous solutions with innovative and modern heating technologies utilising renewable energy. Along with the established condensing boilers plus solar energy solutions, gas heat pumps, in particular, enable end users to meet the market’s political demands for high-efficiency heating systems in conjunction with renewable energy utilisation.

In addition, sorption heat pumps have attracted considerable attention due to their lower environmental impact than that of conventional vapour compression heat pumps using

HCFCs and HFCs, since sorption systems make use of natural refrigerants (ammonia and water), which have zero global warming potential. For these reasons, German gas utilities and the key European manufacturers of gas heating appliances established the Gas Heat Pump Initiative (www.igwp.de) in 2008 as a concerted action to carry out laboratory and field tests, prepare the market and work out the required standards framework for the introduction of gas heat pump-based heating appliances. This article presents a brief introduction to the sorption heat pump technologies involved, as well as to the Gas Heat Pump Initiative (IGWP) and its activities.

2 WORKING PRINCIPLES OF THE GAS-DRIVEN SORPTION HEAT PUMP HEATING PROCESSES

Heat pumps can in general be classified by the following technical principles:

- Vapour compression heat pumps (electrically-driven or gas-motor-driven heat pumps). In this type, the heat pump process is delivered solely by mechanical energy.
- Sorption heat pumps (absorption or adsorption heat pumps), in which heat is the main driving energy.

Common to both heat pump processes is that the liquid refrigerant leaving the condenser after transferring its heat of condensation to the heating system passes through an expansion valve in order to reduce its pressure, and therefore its temperature, below the temperature of the ambient heat source before entering the evaporator. In the evaporator, the expanded refrigerant vaporises as it picks up its heat of evaporation from the ambient heat source (air, ground, groundwater or solar collectors).

In a vapour compression heat pump, the gaseous refrigerant leaving the evaporator is induced by a mechanical compressor, where its pressure, and therefore temperature, is increased before entering the condenser to be liquefied again.

The duty of the mechanical compressor is tackled differently in a sorption heat pump, where heat becomes the main driving energy (thermal compression). There are several ways of realising what is known as the “thermal compressor” in a sorption heat pump. The main idea remains, however, to apply a sorbent for the refrigerant in the thermal compression process. If the sorbent remains in the solid state (silica gel, zeolite or active carbon are typical adsorbents for water, methanol or ammonia as refrigerants), we talk about an adsorption heat pump. Absorption heat pumps utilise liquid sorbents (LiBr-H_2O solution or diluted NH_3-H2O solutions for water or ammonia as refrigerants).

Figure 1 shows a simplified schematic of the gas-driven absorption heat pump process. The right-hand side of the diagram shows the components of the thermal compressor. Refrigerant vapour is first absorbed into the liquid sorbent after being expanded in the solution expansion valve, to form a refrigerant-rich solution. Both the heat of condensation of the refrigerant vapour and the binding energy of the refrigerant into the absorbent (the latent heat of absorption) are then transferred to the heating water in the form of useful heat. The pressure of the enriched solution is then raised to the condenser pressure by a solution pump, which requires only about 1 % of the mechanical energy required to raise the pressure of the refrigerant vapour in a mechanical compressor (mechanical work required for compression is proportional to the specific volume of the medium). The high-pressure enriched solution enters the generator, which is directly fired by natural gas. From here, refrigerant vapour at high pressure and temperature flow into the condenser, while the weakened refrigerant solution flows back to the absorber after being expanded to the absorber or evaporator pressure to absorb more refrigerant coming out of the evaporator. This is a simplified explanation: in fact, the real absorption heat pump process employs more units for internal heat recovery and therefore for further improvement of gas utilisation efficiency. The first gas-driven heat pump technology in the IGWP framework utilises ammonia-water as a working pair and is available in a heating power range of 40 kW (Dummer 2010). This type of heat pump technology can be used to cover the nominal heating demand or to cover the base load if integrated with a condensing boiler for peak loads.

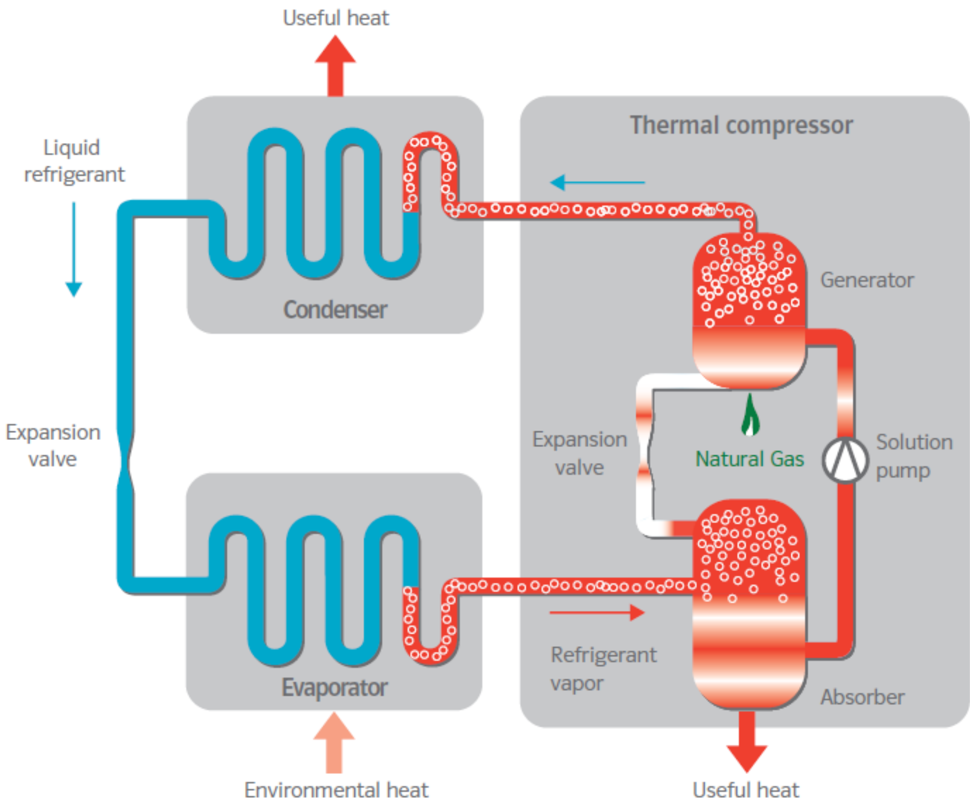

Figure 1: Schematic of the single-stage absorption heat pump process

The second type of gas-driven heat pump technology in the IGWP framework is shown in Figure 2. It is a hybrid heating appliance, comprising a gas condensing boiler to drive an intermittent adsorption heat pump module and to meet the peak load if the required heat demand exceeds the rated heat pump heating capacity (Lang and Marx 2010). This Vaillant zeolite heat pump module is referred to as a two- heat exchanger module, as it incorporates two heat exchangers. The top heat exchanger functions either as a desorber or an adsorber, while the lower heat exchanger works respectively as a condenser or evaporator. This technology utilises zeolite (as an adsorbent) in the form of loose pellets between the fins of a finned-tube adsorber heat exchanger, with water as a refrigerant. One important feature of this technology is the utilisation of solar collectors as an ambient heat source. Figure 2 left side depicts the heating appliance in the desorption phase, during which zeolite is heated up by a hot water loop connecting the adsorber heat exchanger with the gas burner heat exchanger. The water vapour from the zeolite pellets condenses on the lower heat exchanger (working as a condenser), delivering useful heat to the heating water through the lower plate heat exchanger. After reaching a certain desorption end temperature, the burner is switched off and the adsorber heat is transferred to the house heating system through the plate heat exchanger just below the zeolite module, resulting in reducing the temperature of the zeolite. The cold and dried zeolite then adsorbs water vapour from the condenser, progressively reducing its temperature until it is lower than the temperature of the brine flowing out of the solar collector panel. From then on, the lower heat exchanger works as an evaporator, feeding ambient heat into the process (Figure 2, right side).

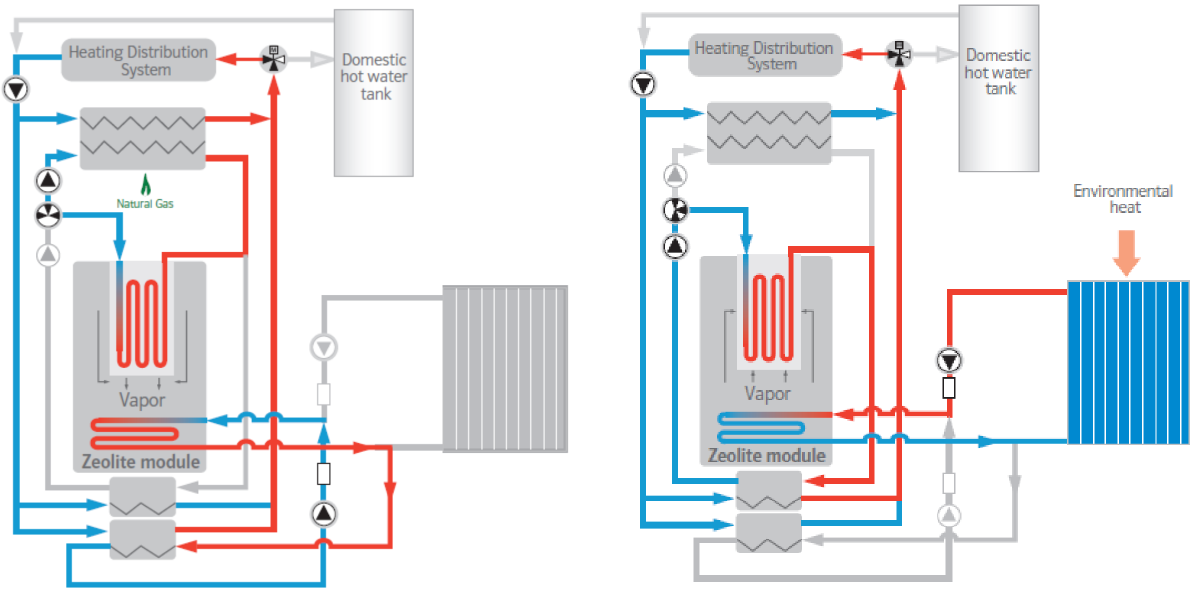

Figure 2: Vaillant gas-driven heat pump during the desorption phase (left) and the adsorption phase (right)

The third heating appliance based on a gas-driven heat pump process is from Viessmann and is shown in Figure 3.

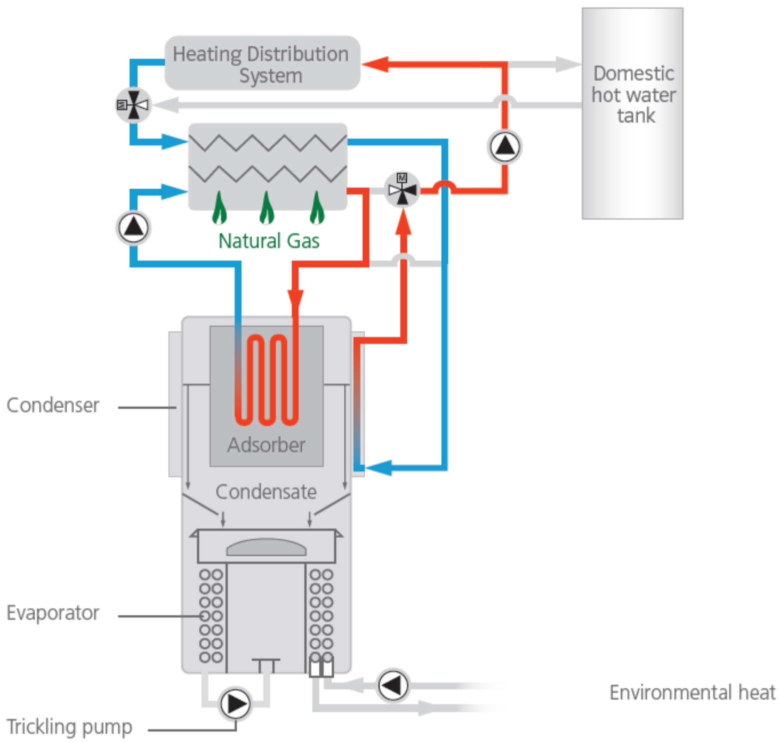

Figure 3.a: Viessmann compact heating appliance based on a gas-driven intermittent heat pump during the desorption phase

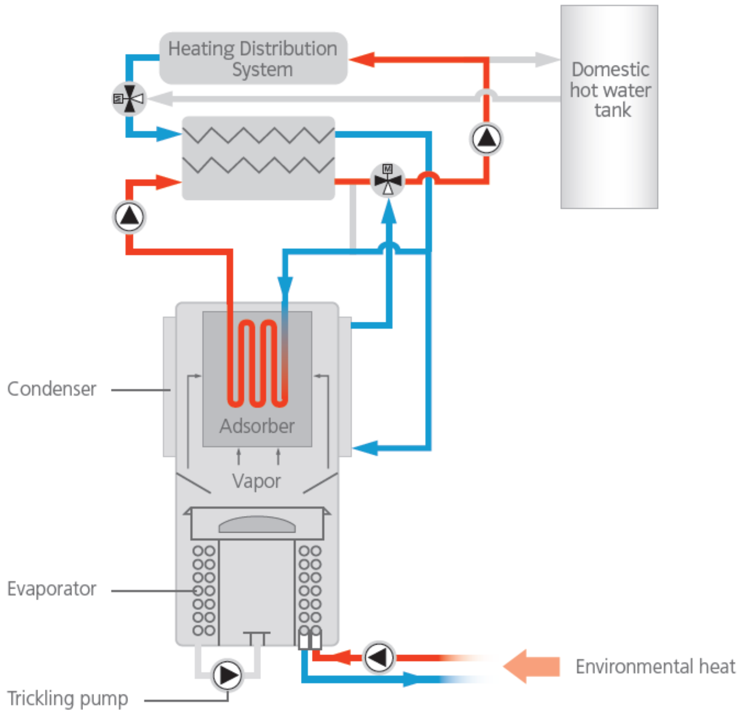

Figure 3.b: Viessmann compact heating appliance based on a gas-driven intermittent heat pump during the adsorption phase

This is again a hybrid system comprising an intermittent heat pump module with a condensing boiler driving the heat pump process, assisting the heat pump in the mixed-operation mode, and working alone as a peak boiler in the direct heating mode (Dawoud et al. 2010a). The main differences between Viessmann and Vaillant technologies can be summarized as follows:

1) The Viessmann heat pump module comprises three heat exchangers; namely, adsorber-desorber, condenser, and evaporator, thus eliminating the internal heat losses from heating up and cooling down the same heat exchanger working periodically as an evaporator or condenser (Dawoud and Stricker 2008).
2) There is always a direct heat transfer between the heating water and either condenser or adsorber (Dawoud and Stricker 2008).
3) Zeolite is utilised in form of consolidated layers over the fins of the adsorber heat exchanger (Dawoud et al. 2010b).
4) The evaporator is constructed as a falling film evaporator (Dawoud et al. 2009).

For a vapour compression heat pump with a rated heating capacity of 8 kW, 2 kW of electrical energy and 6 kW of ambient energy are required to deliver a seasonal performance factor (SPF) of 4. With an assumed average power station efficiency of 38.5%, this SPF equals 1.54 based on primary energy consumption. With a gas-driven heat pump, the 8 kW are delivered from 5.2 kW of gas and 2.8 kW of ambient heat, to give a primary energy SPF of 1.54. This means that the ambient heat utilised by a gas-driven heat pump is less than 50% of that utilised by a vapour compression heat pump of the same heating capacity and same primary energy SPF. This gives a cost benefit concerning the ambient heat source in favour of gas-driven sorption heat pumps.

3 THE GAS HEAT PUMPS INITIATIVE (IGWP)

The IGWP was founded in February 2008 by the German gas utility companies EnBW, E.ON Ruhrgas, ESB, EWE, GASAG, MVV, RWE and VNG, together with key European appliance manufacturers Bosch Thermotechnik, Robur, Vaillant and Viessmann. The know-how of all these member companies is brought together to promote the market maturity of the previously described heating appliances. Appliance development remains with each manufacturer, but marketing and lobbying work is done cooperatively. So far, twelve gas heat pump heating appliances have been successfully tested in the E.ON Ruhrgas laboratory, and three more units are planned for tests this year. These units have been subjected to a comprehensive test program to ensure their durability and to evaluate their gas utilisation efficiencies under laboratory and real conditions. In addition, 39 units from the different manufacturers have been installed and are being field-tested by the gas utility customers, distributed over the entire country. A further 27 units are planned for installation before the beginning of the 2011-2012 winter season. The laboratory and field test results obtained so far confirm the high efficiency and durability of all the tested appliances. However, a good deal of development and optimisation work is still needed in connection with thorough investigation of the field test results, leading to more efficient control and hydraulics and better gas utilisation efficiencies in the field.

In parallel with this work, market analyses and an IGWP-sponsored marketing campaign have been started. Technical seminars and training programs for the installation sector have also been started. A guideline for evaluating the seasonal performance factor of gas-driven sorption heat pumps has also been worked out (VDI-4650-2), and is now being considered as a basis for the corresponding DIN and EN standards.

A study has been carried out to estimate the potential of gas-driven sorption heat pumps compared with different heating technologies (Oschatz and Kleemann 2010). Figure 4 illustrates the differences in primary energy consumption, CO_2 reduction, and the share of renewable energy for an existing German house having 150 m^2 floor area as delivered by seven different heating methods.

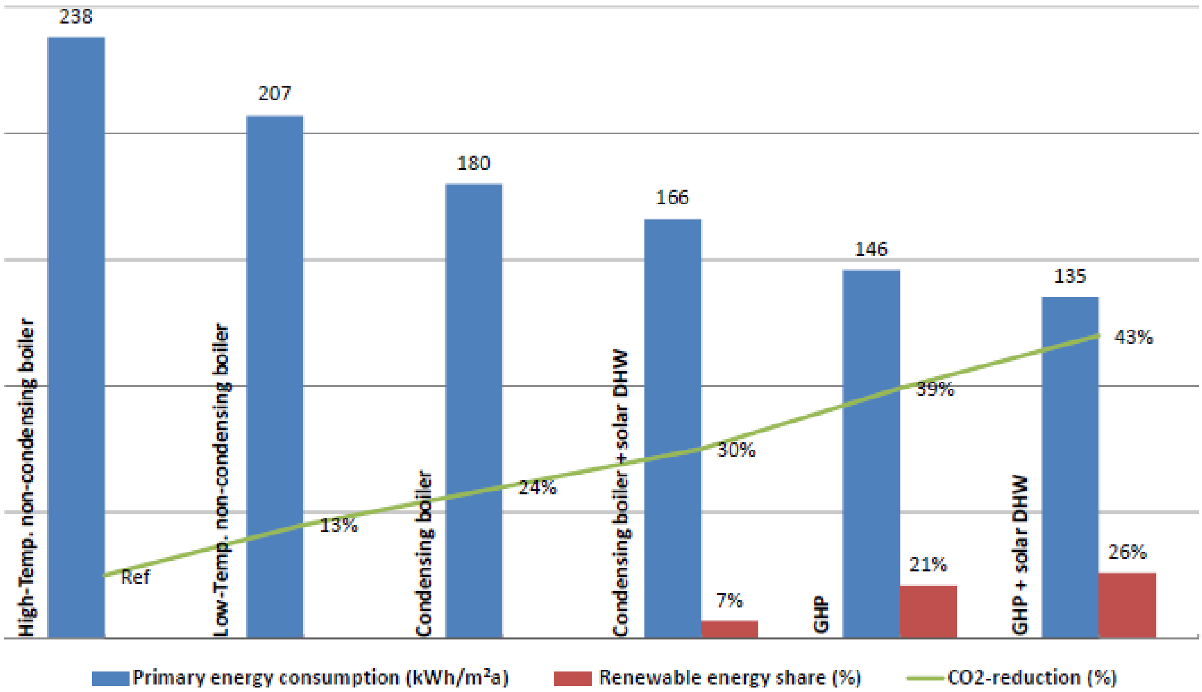

Figure 4: Potential of gas-driven sorption heat pumps for a typical 150 m^2 existing house in Germany (Oschatz and Kleemann 2010)

Compared with high-temperature non-condensing technology, which is the main heating technology in existing houses in Germany, the GHP technology offers 39% reduction in primary energy consumption, and therefore also in CO_2 emissions, and, at the same time, delivering 21% of the heating from renewable energy. Coupling solar energy for domestic hot water with a GHP results in 25% less primary energy consumption and CO_2 emissions, and utilises 26% renewable energy share compared with state-of-the-art gas-condensing boilers. This emphasises the need to promote GHPs as a possible trend-setting heating technology in the household sector.

As a result of the previous concerted actions within the framework of the IGWP, Robur could launch its E3 gas absorption heat pump model (Dummer 2010) at the ISH Fair 2009 in Frankfurt. In addition, Vaillant launched its zeolite heating appliance (Lang and Marx 2010) in April 2010. In addition, Viessmann is planning to launch its zeolite compact heating appliance in 2012.

4 CONCLUSIONS

The German gas utilities and the key European manufacturers of gas heating appliances have established an outstanding platform to support and stimulate the market introduction of a new heating technology based on small-scale gas-driven sorption heat pumps. The “Initiative Gas Heat Pump” was established in February 2008 and has since then comprehensively tested twelve heating appliances of this type in the E.ON Ruhrgas laboratory for durability and gas utilisation efficiency. In addition, 39 heating appliances have been installed in the field at customers of the German gas utilities. A further 27 units are planned for installation this year. Both laboratory and field test results have proved the durability of the new heating appliances and their clear efficiency enhancement over condensing boiler technology allowing at least compliance with the German Renewable Energy Act, 2008. An independent study of the potential of the new heating appliances in existing houses in Germany found that around 39% primary energy savings could be achieved compared with high-temperature non-condensing heating systems, which represent the state of the art of heating in existing houses, together with utilising a renewable energy share of 21%. Compared with condensing boilers, the GHP with solar collectors for domestic hot water production has the potential to save 25% of primary energy and deliver 26% from renewable energy. This indicates the need to promote the GHP as a possible trend-setting heating technology in the household sector.

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