1 Heat pump technology

1.1 Criteria for possible heat pump applications

The first step in any possible IHP application is to identify technically feasible installation alternatives, and possibilities for their economic installation.

In simple operations, where the process in which the IHP will be used only consists of a few streams with obvious sink and source, the need for a thorough assessment is normally not necessary. In these cases, only the characteristics of the sink and source are of importance for the feasibility and selection of the IHP. The obvious parameters are:

- heat sink and source temperature;
- size (in terms of heat load) of the sink and source;
- physical parameters of the sink and source, such as phase and location

Industrial heat pumps are used in the power ranges of 50 – 150 kW and 150 to several MW.

The sink and source temperatures determine which IHP types can be used in a specific application. These types can be categorized in various ways, e.g. as mechanically- or heat-driven, compression or absorption, closed or open cycles.

1.2 Thermodynamic processes

The most important thermodynamic processes for industrial heat pumps are:

- closed compression cycle - electric driven or gas-engine driven
- mechanical (MVR) and thermal (TVR) vapour recompression
- sorption cycle
- absorption–compression cycle
- current developments, e. g. thermo-acoustic, injections

and will be described in the next chapters.

1.2.1 Mechanical compression cycles

The principle of the simple closed compression cycle is shown below.

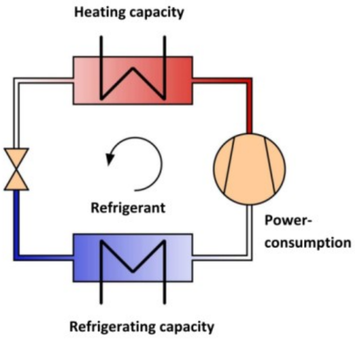

Figure 1-1: Closed compression cycle

Four different types of compressors are used in closed compression cycle heat pumps: Scroll, reciprocating, screw and turbo compressors.

Scroll compressors are used in small and medium heat pumps up to 100 kW heat output, reciprocating compressors in systems up to approximately 500 kW, screw compressors up to around 5 MW and turbo compressors in large systems above about 2 MW, as well as oil-free turbo compressors above 250 kW.

1.2.1.1 Vapour injection

In the economizer vapour injection (EVI) cycle, see figure below, a heat exchanger is used to provide additional sub-cooling to the refrigerant before it enters the evaporator. This sub-cooling process provides the increased capacity gain measured in the system. During the sub-cooling process, a certain amount of refrigerant is evaporated. This evaporated refrigerant is injected into the compressor and provides additional cooling at higher compression ratios, similar to liquid injection.

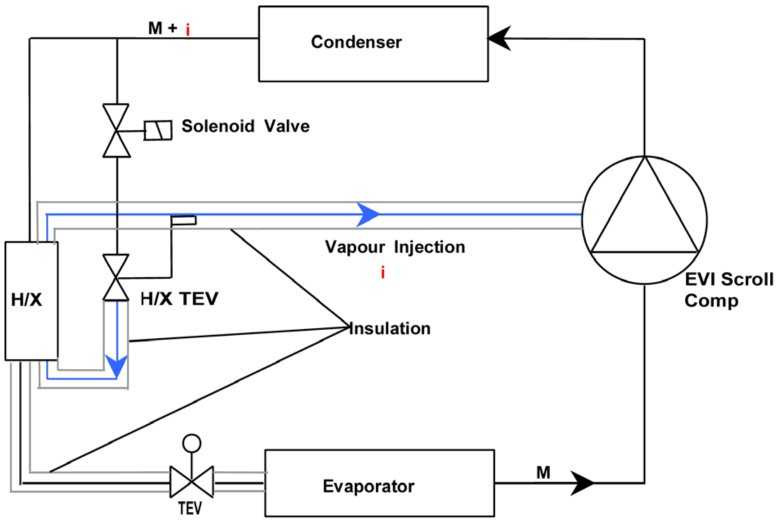

Figure 1-2: Vapour injection

1.2.2 Thermal compression cycles

1.2.2.1 Absorption heat pumps

Absorption heat pump cycles are based on the fact that the boiling point for a mixture is higher than the corresponding boiling point of a pure, volatile working fluid. Thus the working fluid must be a mixture consisting of a volatile component and a non-volatile one. The most common mixture in industrial applications is a lithium bromide solution in water ($LiBr/H_2O$) and ammonia water (NH_3/H_2O).

The fundamental absorption cycle has two possible configurations: absorption heat pump (AHP, Type I) and heat transformer (AHP, Type II), which are suitable for different purposes.

The difference between the cycles is the pressure level in the four main heat exchangers (evaporator, absorber, desorber and condenser), which influence the temperature levels of the heat flows.

The application of absorption cycles for high temperature heat recovery systems calls for the investigation of new working pairs. To qualify as a potential working pair, a mixture of two substances has to fulfil stringent requirements with respect to thermodynamic properties, corrosion and safety hazards like toxicity and inflammability.

Based on a thermodynamic analysis of an absorption heat pump cycle a systematic search for new working pairs has been required, e. g. investigation of organic compounds.

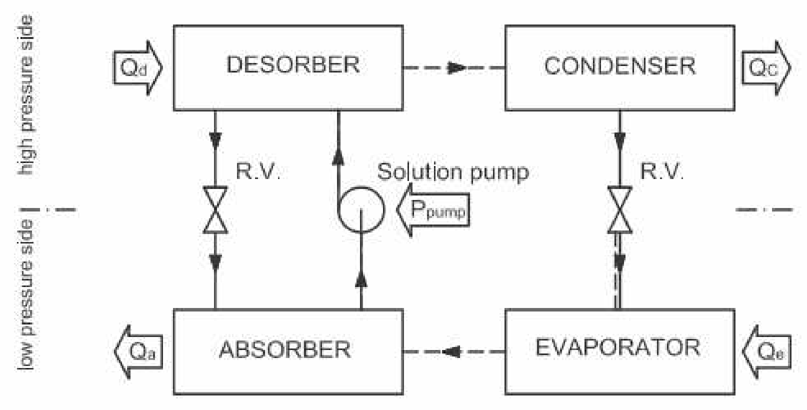

Figure 1-3: Absorption

1.2.2.2 Absorption-compression hybrid

The hybrid heat pump combines substantial parts of both absorption and compression machines - it utilizes a mixture of absorbent and refrigerant and a compressor as well. An important difference between hybrid and absorption cycle should be noticed - the absorber and desorber in the hybrid heat pump are placed in a reversed order than in the absorption machine, i.e. desorption in the hybrid cycle occurs under low temperatures and pressures and absorption under high temperatures and pressures.

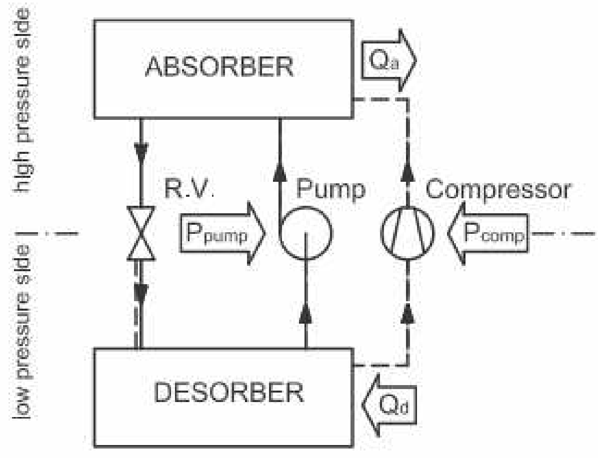

Figure 1-4: Absorption – compression hybrid

1.2.3 Mechanical vapour recompression (MVR)

Mechanical vapour recompression is the technique of increasing the pressure and thus also the temperature of waste gases, thereby allowing their heat to be re-used. The most common type of vapour compressed by MVR is steam, to which the figures below refer. There are several possible system configurations. The most common is a semi-open type in which the vapour is compressed directly (also referred to as a direct system). After compression, the vapour condenses in a heat exchanger where heat is delivered to the heat sink. This type of MVR system is very common in evaporation applications

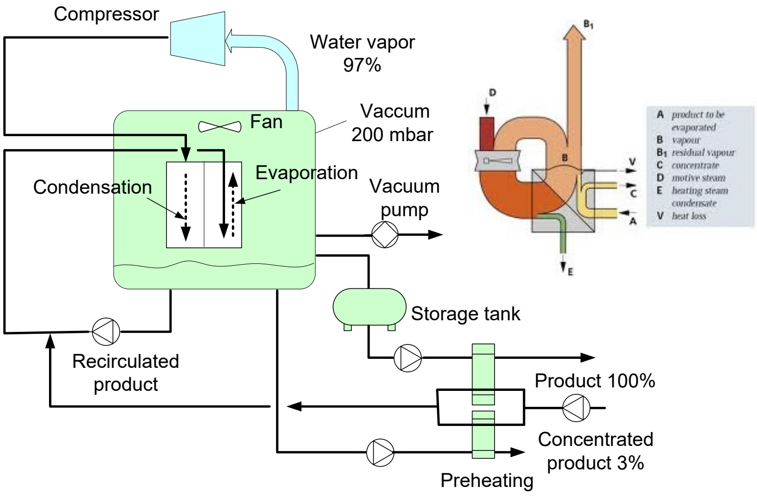

Figure 1-5: Mechanical vapor recompression [Bédard, 2002]

The other type of semi-open system lacks the condenser, but is equipped with an evaporator. This less usual configuration can be used to vaporize a process flow that is required at a higher temperature, with the aid of mechanical work and a heat source of lower temperature.

1.2.4 Thermal vapour recompression (TVR)

With the TVR type of system, heat pumping is achieved with the aid of an ejector and high pressure vapour. It is therefore often simply called an ejector. The principle is shown in the figure below. Unlike MVR system, a TVR heat pump is driven by heat, not mechanical energy. Thus, compared to an MVR system, it opens up new application areas, especially in situations where there is a large difference between fuel and electricity prices.

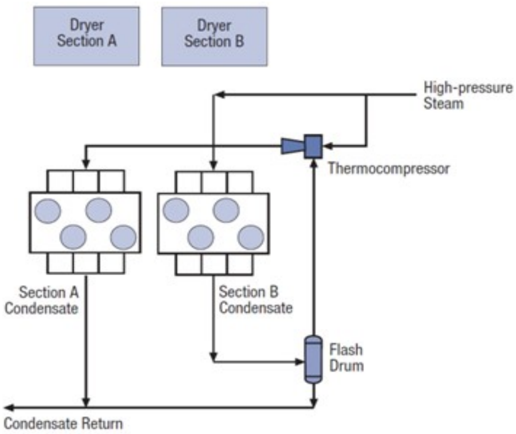

Figure 1-6: Thermal vapor recompression, Example from Japan

The TVR type is available in all industrial sizes. A common application area is evaporation units. The COP is defined as the relation between the heat of condensation of the vapour leaving the TVR and heat input with the motive vapour.

1.2.5 Thermo acoustic (TA)

The acoustic energy is subsequently being used in a TA-heat pump to upgrade waste heat to usable process heat at the required temperature. The picture below visualises the whole system. The TA-engine is located at the right side and generates acoustic power from a stream of waste heat stream at a temperature of 140 °C. The acoustic power flows through the resonator to the TA-heat pump.

Waste heat of 140 °C is upgraded to 180 °C in this component. The total system can be generally applied into the existing utility system at an industrial site.

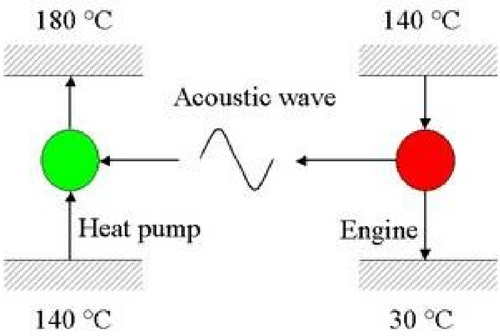

Figure 1-7: Thermo acoustic heat pump

1.3 Refrigerants suitable for high temperature heat pump

Many industrial processes have heating demands in the temperature range of 90-120 °C. At the same time, waste heat holding typically a temperature of 30-60 °C is available. Efficient heat pumping technologies are therefore attractive in order to reduce the specific energy consumption (kWh/product amount). The present, most common refrigerants, in particular HFCs are limited to heat distribution temperatures of around 80 °C. For temperature above 100 °C additional R&D is required.

Industrial heat pump using R-134a, R-245fa, R-717, R-744 and hydrocarbons (HC), etc. However, except for R-744 and the flammables R-717 and HCs, which are natural refrigerants with extremely low global warming potential (GWP.) HFCs such as R-134a and R-245fa have high GWP values, and the use of HFCs are likely to be regulated in the viewpoint of global warming prevention in the foreseeable future. Therefore, development of alternative refrigerants with low GWP has been required.

At present, as substitutes of R-134a, R-1234yf and R-1234ze (E) are considered to be promising, and R-1234ze (Z) is attractive as a substitute of R-245fa. R-365mfc is considered to be suitable as a refrigerant of heat pump for vapor generation using waste heat, but its GWP value is high. Therefore, it seems that development of a substitute of R-365mfc should be furthered. The table below shows basic characteristics of the present and future refrigerants for IHPs.

Table 1-1: Refrigerants, considered to be suitable for IHPs

Refrigerant	Chemical formula	GWP	Flammability	T_c °C	p_c M Pa	NBP °C
R-290	CH3CH2CH3	~20	yes	96.7	4.25	-42.1
R-601	CH3-CH2-CH2-CH2-CH3	~20	yes	196.6	3.37	36.1
R-717	NH3	0	yes	132.25	11.33	-33.33
R-744	CO2	1	none	30.98	7.3773	-78.40
R-1234yf	CF3CF=CH2	<1	weak	94.7	3.382	-29,48
R-134a	CF3CH2F	1,430	none	101.06	4.0593	-26.07
R-1234ze(E)	CFH=CHCF3	6	weak	109.37	3.636	-18.96
R-1234ze(Z)	CFH=CHCF3	<10	weak	153.7	3.97	9.76
R-245fa	CF3CH2CHF2	1,030	none	154.01	3.651	15.14
R-1233zd		6	none	165.6	3.5709	n. a.
R-1336mzz		9	none	171	n. a.	n. a.
R-365mfc	CF3CH2CF2CH3	794	weak	186,85	3.266	40.19

Source: IEA HPT Annex 35