Steaming ahead with MVR

Mechanical vapour recompression (MVR) can improve energy efficiency in process plants and offers possibilities for integrating renewable electricity and demand side management, writes **Egbert Klop**

Steam recompression is an economically and energetically attractive technique. Steam is still a major energy carrier in all branches of the chemical industry. It can be used at several pressure and temperature levels. High-pressure steam is used to drive turbines while low-pressure steam delivers process heating.

As soon as the steam pressure drops below 5 bar, it hardly has any value since the corresponding temperature of approximately 150°C is too low. However, efficient recompressing of this steam yields a valuable energy carrier: a waste product becomes useful. The process is called Mechanical Vapour Recompression (MVR).

The thermodynamic principle

MVR is an open heat pump system. Through compression, both pressure and temperature increase, together with the corresponding saturation temperature. The required compression energy is very small compared to the amount of latent heat present in the recycled steam.

In the example in Figure 1, the added compressor energy is only 310 kJ per kg steam, whereas the latent heat of the compressed steam is 3060 kJ/kg. The process is illustrated by the solid red line. The system operates as a heat transformer that upgrades the quality of the heat in the steam.

It is primarily the isentropic efficiency (approximately 75%) of the compression process that causes superheating of the steam. This superheating can be compensated by injecting boiler feed water so that the desired steam

Efficient steam recompression yields a valuable energy carrier: a waste product becomes useful Credit: Atlas Copco

temperature is created. One might state that the overheating of the steam is transformed into additional steam production. In the example shown in Figure 1, an additional 11% of steam is produced by injecting boiler feed water of 70°C. The trick of the process is avoiding condensation of the steam and retaining the latent heat.

Figure 2 shows the schematic representation of steam recompression and water injection (de-superheating) based on two-stage compression. The knock-out drums and the demisters prevent erosive damage to the compressor blades caused by water drops. The recycle valve is needed for the startup process: the steam will be recycled until the desired condition has been reached.

Energetic performance

The energetic performance of MVR is commonly expressed in the coefficient of performance (COP), as is the case with standard heat pumps. The COP gives the ratio of the net recovered heat and the energy used by the compressor. In this case, the net heat is the steam production including the additional steam yield by water injection.

Typical economical and energy-efficient applications have a minimum COP of 3.5. Some applications of MVR prove that a COP of 10 or even higher is achievable.

Key elements for a high COP are:

- A low ratio of the absolute steam pressures. A guideline for the maximum ratio is 6; in daily practice the ratio is about 3;
- A minimum capacity. A guideline is a minimum of one tonne of steam per hour;
- Water injection after compression.

MVR is very effective in comparison with other techniques. Simple electrical heating yields a COP of only 1. Systems that turn hot water into steam by means of a heat pump are also being developed, but such systems are hardly available on the market yet. An interesting development in this context is the Radiax compressor from Bronswerk Heat Transfer.

Available compressor technology

For MVR, a wide range of compressors is available. The compressor type depends on the pressure and temperature ratios, the absolute pressure and the volume flow. Figure 3 gives an overview of the operating range of the available compressors, using atmospheric steam as the starting point.

Benefits of steam recompression

The technical and financial investment risks of MVR are low. MVR is primarily interesting for processes with a surplus of low-pressure or flash steam. Examples of the benefits are:

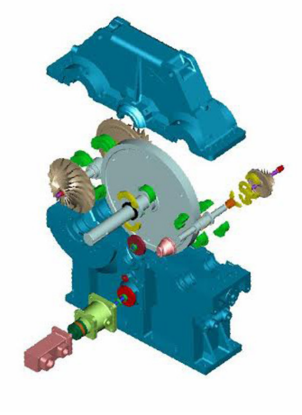
- Payback periods between one and three years;
- Reduced waste of energy;
- Higher energy efficiency and less use of fossil fuel;
- Flexibility in steam production;
- High compressor capacity: up to 200 tonnes per hour;
- Flexibility can be created by putting compression units in parallel;
- Control of the power/heat ratio in case of combined heat and power;
- Demand-Side Management depending on the electricity price. Systems are generally switched off at an electricity price exceeding €100 ($113)/MWh;
- The possibility of using renewable electricity for the compression process;
- Proven technology.

Economic aspects

MVR is always custom-made. The return on investment depends on the following factors:

- The capacity of the installation;
- The price of the output steam, which generally depends on the gas price;
- The pressure ratio;
- The value of the input 'waste' steam;
- The electricity price.

A number of business cases have shown that MVR is



'Bull gear' multi-stage compressor Credit: Atlas Copco

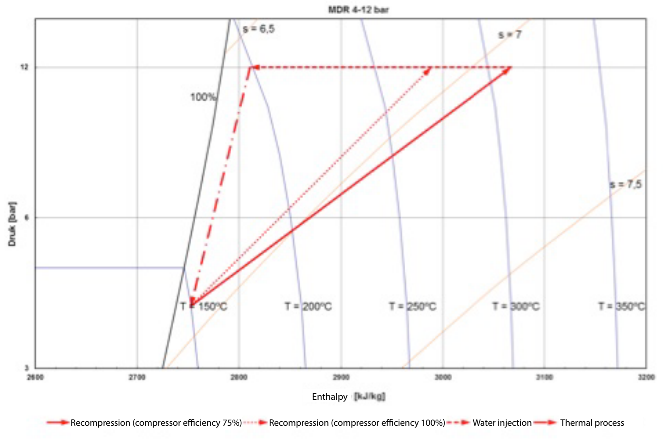


Figure 1. Pressure-enthalpy diagram for steam recompression with water injection *Source: Industrial Energy Experts*

economically quite robust. This is supported by extensive sensitivity analyses in which the electricity price, the value of the input steam, the value of the produced steam and the level of investment vary. At a ratio of three between the electricity price and the gas price per energy unit, the investment is still profitable, provided a good COP is present.

Typical electricity prices for large industrial users are €50/MWh. In practice, it is not the electricity price but the capital expenditure for MVR and the price of natural gas that determine its economic viability. If renewable electricity is used, the carbon footprint is even reduced.

Effect on the cogeneration sector

High gas prices and low electricity prices in Europe are drastically limiting the economic possibilities of CHP. Existing installations are often stopped or mothballed. The flexible application of MVR means that excess electricity does not have to be dumped at low prices, but can be used. This reduces the occurrence of excessively low electricity prices that hamper the profitability of CHP. A continued use of CHP will help reduce fossil fuel consumption as well as greenhouse gas emissions.

Social benefits of electrically-driven MVR

Beyond the direct economic benefits for the user of MVR, there are a number of synergetic effects.

The opportunity to use renewable electricity, especially in periods when production exceeds demand, is very welcome. Also, the combined heat and power (CHP) sector as well as the grid operator benefit from the possibilities of MVR.

Policy measures in the EU have resulted in a large increase in variable electricity production from renewables. This means there will be an increase in the volatility of electricity production, mainly caused by the subsidies for renewables. MVR is an excellent tool for balancing based on Demand-Side Management.

Co-operation between the different sectors is key to a more sustainable society. MVR is a major tool, provided it will be applied at a large scale in industry.

Dutch research organisation ECN has predicted the perspective for MVR at an electric power of 2000 MW in the Netherlands. This compares with a thermal energy flow of around 20 GW.

MVR case studies

In the following three case studies, the technical and economical feasibility of steam recompression are shown. Cases one and two show the upgrading of steam for different capacities, while case three shows the use and upgrading of flash steam from condensate.

The main conclusion from these cases is that steam recompression is a very economical way of improving energy efficiency, with a simple payback period between one and three years. It will be clear that a high number of annual running hours boosts profitability.

Looking at the effect of the annual running hours on the economics of cases one and two, it is obvious that the Capex dominates the economic viability.

Upgrading the steam

Two cases have been evaluated: first, the almost continuous (8000 hours/year) upgrading of 50 tonnes/hour of steam (saturated) at a gauge pressure of 3.5 bar to 12 bar; and second, the upgrading of 10 tonnes/hour steam at a gauge pressure of 1.5 bar to 9 bar during 6000 hours/year.

In both cases, there is no current application for low quality steam, and it therefore has no economic value at present. The steam is condensed, which even requires electric energy for the cooling fans of the condensers. This aspect has been neglected in the evaluation.

In both cases, the steam has been compressed to a level that can be used in the process. Two-stage compression is required because of the high pressure ratio. Water is injected between the two stages to reduce overheating, and consequently to improve the efficiency.

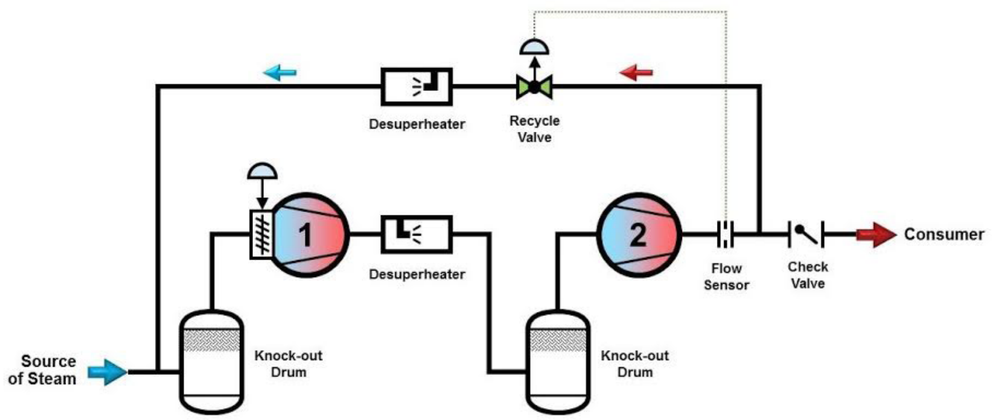


Figure 2. Steam recompression and water injection based on two-stage compression *Source: Atlas Copco*

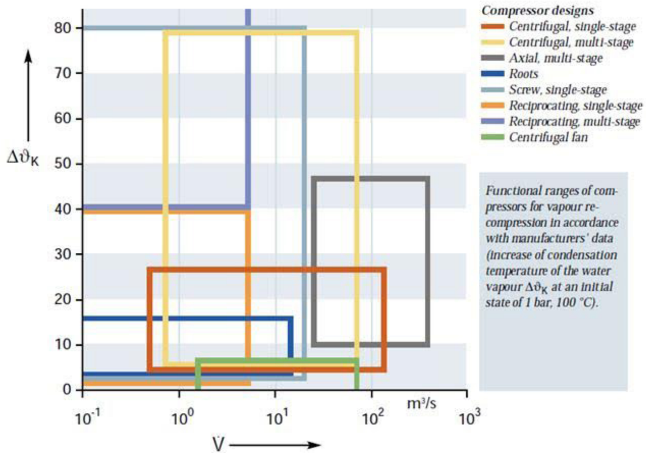


Figure 3. Functional ranges of compressors for vapour recompression
Source: GEA Wiegand

Case 1:

- Steam flow: 50 tonnes/hour
- Absolute input steam pressure: 4.5 bar
- Absolute output steam pressure: 13 bar
- Compressor power: 4.4 MW
- COP: 9.8
- Running hours: 8000 hours/year
- Reference energy costs: 7600 k€/year
- Energy costs MVR: 1760 k€/year
- Cost reduction: 5840 k€/year
- Capital investment: 5700 k€
- Simple payback period: one year

Case 2:

- Steam flow: 10 tonnes/hour
- Absolute input steam pressure: 2.5 bar
- Absolute output steam pressure: 10 bar
- Compressor power: 1.1 MW
- COP: 7.9
- Running hours: 6000 hours/year
- Reference energy costs: 1140 k€/year
- Energy costs MVR: 330 k€/year
- Cost reduction: 810 k€/year
- Capital investment: 2090 k€
- Simple payback period: 2.6 years

Case 3: flash steam

In this case, energy that is still available in intermediate- or high-pressure condensate is used. By reducing the condensate pressure, part of the condensate flashes to steam. In case 3, condensate of 8 bar is flashed at a pressure of 2.5 bar.This is then increased to 6 bar by MVR.

- Condensate flow (absolute pressure 8 bar): 50 tonnes/hour
- Absolute flash pressure: 2.5 bar
- Flash steam flow: 3.2 tonnes/hour
- Compressor power: 257 kW
- COP: 10.3
- Running hours: 8000 hours/year
- Reference energy costs: 486 k€/year
- Energy costs MVR: 103k€/year
- Cost reduction: 383 k€/year
- Capital investment: 800 k€
- Simple payback period: 2.1 years

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