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Winter 2021

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High-Temperature Heat Pumps Make Efficiency in Process Heating Come True

Industrial Energy Turnaround Leaves No More Room for Inefficient Processes

Steam is one of the most important heat sources in industrial processes. Its thermodynamic properties, (high thermal capacity, high heat of vaporization and high heat transfer coefficient) make it an ideal heat transfer medium. Whether it is used for heat supply, power generation in thermal power plants, as a propellant, for cleaning or a moistening agent, steam powers, in the fullest sense of the word, many industrial processes. Water is available almost everywhere and at low cost. And of course, water steam is not flammable and is not toxic. Steam-based technologies are very mature and have already been used for decades and in some cases even for more than 100 years.

Nevertheless, this technology is highly topical, especially during times when climate change, the energy transition and questions of energy efficiency are being discussed. The long-established German company, Spilling Technologies from Hamburg, became famous for the construction of the steam piston engine, whose operating principle still forms the basis of its many innovations today.

Piston steam compressors as high temperature heat pump (HTHP)

Most steam applications require steam with high pressures and high temperatures. By using high-pressure steam, for example, desired high reaction times and substance conversions in chemical processes or high drying rates can be realized. Excess low-pressure steam often results as a by-product of other production processes. For example, during product cooling or drying, in exothermal reactions (where heat is released) and in the combustion of residual material. Since it is often difficult to use low-pressure steam energetically, it is usually re-cooled and liquified using air-cooled condensers or cooling towers. The heat contained in the steam is emitted into the atmosphere and thus lost to the process.

At this point piston steam compressors as high temperature heat pump (HTHP), as developed by Spilling Technologies, come into play. At a relatively low cost, unusable low-pressure steam can be recycled by vapor compression. Low-pressure steam is directed into a piston compressor and compressed to the desired pressure level. In this way, it is possible to generate up to 15 times higher process steam power, compared to the electrical energy required for the compressor drive. The so-called COP (coefficient of performance) describes this correlation exactly (see figure 1 below). In contrast, generating steam of the same quality with conventional combustion requires considerable higher energy input. That is why steam recycling with piston steam compressors, compared to conventional steam generation, can achieve cost savings of up to 50 per cent or more in practice.

Photo: AdobeStock

Lower costs and lower CO2 emissions

The example shown in figure 2 illustrates these achievable savings. In the example, the pressure of the excess steam (its steam flow rate is six tons per hour) is raised by a factor of 2 (from 4.5 to 9.0 bar(abs)). This is done by the piston steam compressor, which consumes in 6,000 full load hours approximately 2,340 megawatt hours of electricity annually. If one were to generate this amount of 9 bar(abs) steam by burning natural gas in a gas fired boiler, one would need 25,200 megawatt hours of natural gas. This would be approximately eleven times as much compared to the electrical power demand.

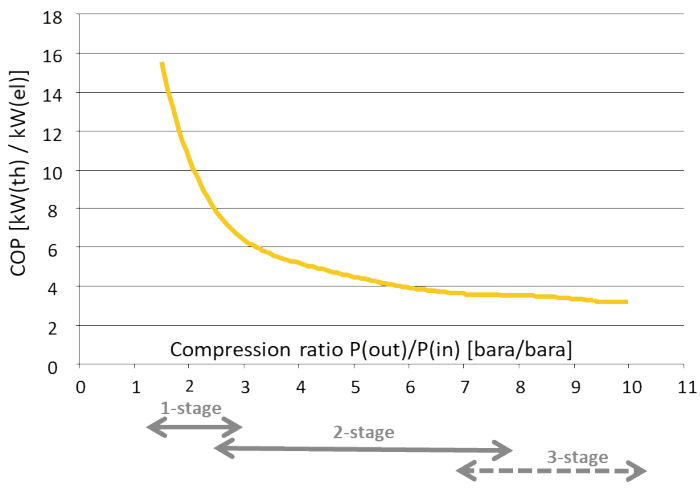

Figure 1: COP of piston steam compressors as function of the compression ratio.

Accordingly, a COP of factor 11 results from this. This high COP value is a key figure for the high efficiency of the process, with relating:

- High energy savings.
- High operation cost savings.
- And high CO2 emission savings.

Wide field of applications for high temperature heat pumps

Possibilities for the recycling of excess steam can be found in a wide range of industries: in the chemicals, petrochemicals, paper, food and beverage, pharmaceuticals and textiles industries. Here, steam recycling with high temperature heat pumps can make an important contribution to increasing the energy efficiency of the processes. In the case that piston steam compressors shall be used, the following conditions should be met to be effective:

- The low-pressure steam should have at least 1 bar(abs).
- The necessary discharge pressure should not be higher than 40 bar(abs), partly up to 65 bar(abs).
- The excess steam should be available on a relatively continuous basis - for at least a few hours in one piece. Meanwhile its flow rate can fluctuate, the piston steam compressors have a wide regulation range of 30 to 100 per cent.

Piston steam compressors: The technology behind high pressure steam recycling

Basically, the lower the required pressure ratio, the more economically attractive steam recycling is. The pressure ratio is also crucial for how many stages the steam compressor should have. Generally, with a pressure ratio of about 2 to 3, a single-staged design is sufficient. Higher pressure ratios require a multi-staged compressor (please compare figure 1). In high pressure steam recycling, the use of reciprocating compressors has proven itself.

Calculation Basis: Gas demand for conventional steam generation: 700 kWh/ton; electrical power demand for steam compression: 65 kWh/ton; natural gas costs: 0.03 Euro/kWh; electricity costs: 0.1 Euro/kWh; maintenance costs steam compressor: 30,000 Euro/year; CO2-emission natural gas: 0.2 kg/kWh, CO2-emission electricity: 0.48 kg/kWh; 6,000 full load operating hours per year.

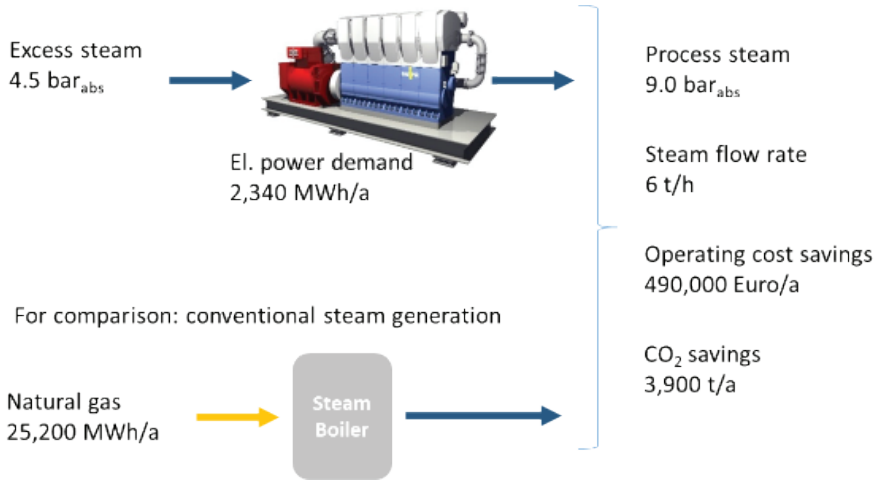

Figure 2: Example of steam recycling with high temperature heat pump (HTHP).

These are characterized by the following characteristics:

- Very good efficiencies, also in partial load mode.
- Capability of processing steam flow rates of about 1 to 20 tons hourly.
- Wide regulation range between 30 and 100 per cent steam flow rate by variable speed drive.
- Good controllability, also with quickly changing loads.
- High total compression ratios are possible.
- High discharge pressures possible – up to 65 bar(abs).

Building block for the energy transition

In the case that regenerative electricity (electricity from renewable energy sources) is used for operating the steam compressor, high-pressure steam can even be generated completely CO2-free. In this way, the steam compressor as HTHP is an enabler of sector coupling and thus contributes significantly to the energy transition. Sector coupling is the term used when regenerative electricity is used to reduce the use of fossil fuels in other sectors, and this is precisely what occurs with industrial process steam recycling.

The experts at Spilling Technologies develop with their customers individual solutions that are carefully tailored to the process in question so that maximum CO2 reduction and energy savings can be achieved. In order to counter climate change, the governments of many countries have provided extensive support measures for "green energies" and energy efficiency. Here, too, the experts are on hand to provide their customers with advice and support. •

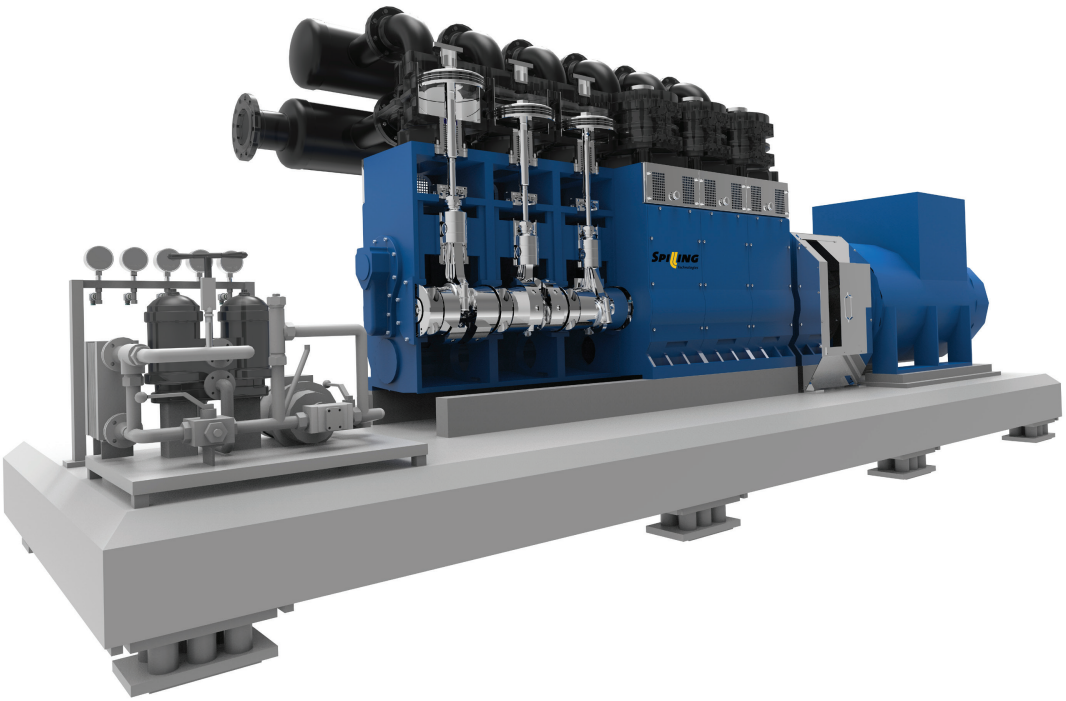

Figure 3: Piston steam compressors are high-efficient and extremely variable HTHP.

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