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Large energy savings and reduction of CO_2 emissions with innovative heat pump technology

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Application of heat pumps at separation processes like distillation, absorption, and crystallization could result in large energy and economic savings. DSTI (Dutch Separation Technology Institute) recently announced the start of the project ‘Heat pumps in bulk separation processes’. This project will be executed together with Huntsman, Aker Kvaerner, DSM, Akzo Nobel, Lyondell, ECN, and Delft University. The objective is to increase the energy efficiency of bulk separation processes by integration of so called high temperature lift heat pumps. A fully integrated system consisting of traditional distillation and novel heat pump technology should be the end result.

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Background

About 40% of the energy use in the (petro)chemical and refining industry is used for the separation of products. This results in an energy use for separation of more than 100 PJ in the Netherlands. The main bulk separation processes within chemical and refining industry are distillation (Figure 1), absorption/desorption, and crystallization. The thermodynamic efficiency of these processes is usually very low. For instance, conventional distillation processes have a thermodynamic efficiency less than 10%. The process industry is facing rising energy costs and is therefore interested to increase energy efficiency by applying novel technologies.

DSTI project

Basis for the ‘Heat pump’ project lies in the Innovation Roadmap Separation Technology, made by more than 120 companies and knowledge institutes and supported by the Dutch Ministry of Economic Affairs. The roadmap forms the basis of the R&D program within DSTI. ‘Heat pumps in bulk separation processes’ is a typical DSTI project in which industry and knowledge institutes actively participate. Project partners for this DSTI project are Huntsman, Aker Kvaerner, DSM, Akzo Nobel, Lyondell, ECN, and Delft University. Project leader is Edwin Hamoen of Aker Kvaerner.

Objectives
Project objective is to increase the energy efficiency of bulk separation processes by integration of high temperature lift heat pumps. This is of benefit to operating companies (end users), technology providers and equipment manufacturers and leads to reduction of the national energy consumption and CO_2 emissions.

Scientific and technological know-how should be obtained about the design, the construction, and the operation of advanced heat pump concepts integrated with the separation process. Design issues relate to a design that is both energy-efficient and cost effective, and the availability of design tools for each concept. Constructional issues relate to the manufacturability of the design and the associated costs. The main issue with operation of the innovative heat pumps is the controllability of these systems. The research should lead to a fully integrated system consisting of traditional distillation and novel heat pump technology.

Figure 1: Ammonia column (Courtesy of Emerson Process Management)

About Heat pumps
Distillation requires high temperature heat as input (reboiler) and delivers low temperature heat as output (condenser); the column itself is adiabatic in principle. Significant reductions in energy consumption and consequently the related costs are expected to be achieved if the heat of the condenser can somehow be reused to heat the reboiler. This requires a device that is able to upgrade the temperature level of the condenser to the temperature level of the reboiler: a heat pump. Figure 2 depicts this in a schematic way. Work has to be applied to the heat pump, since heat does not flow spontaneously to a higher temperature. In principle, a heat pump should only be applied if the top and bottom temperature of the column are below and above the pinch temperature of the site. Even if this is not the case, logistic arguments can be used to apply a heat pump instead of using the heat of the condenser for heating another process at the site.

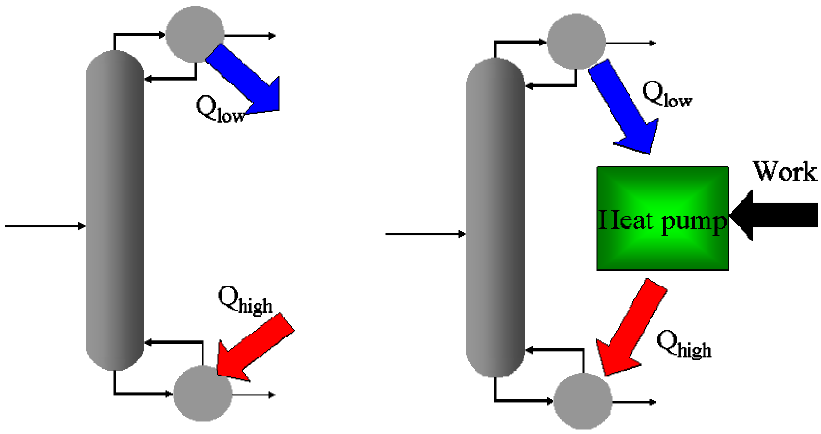

Figure 2: Distillation column without (left) and with (right) a heat pump

The heat pump concept is not new and is already applied by using mechanical vapor recompression heat pumps. In this case the overhead vapor is compressed to a higher pressure (and temperature) level. The vapor temperature gets high enough to heat the reboiler. This type of heat pump can only provide limited temperature lifts of 10-20°C in an energetically favorite way and application is therefore limited to distillation columns separating ‘close boilers’. There are only few applications of this type of heat pump in the Netherlands’ chemical and refining industry.

The application window of heat pumps at separations processes would be greatly enlarged if heat pumps would be available that can upgrade heat in an energetic efficient way with temperature lifts of more than 20°C, up to perhaps 80°C. These high-lift high-temperature heat pumps are presently not commercially available and therefore need to be developed. The requirements for these heat pumps can be defined as

- Operate at reboiler temperatures of 50 - 200°C
- Generate a temperature lift of 20 - 80°C

A prerequisite for the application of a heat pump is of course that the upgrading of the heat can be done in both an energetic and an economically favorite way. Investment in a heat pump has to be earned back by the energy savings achieved.

Depending on the efficiency of the heat pumps, the expected potential savings in The Netherlands are order of magnitude 10 – 20 PJ/y, equivalent to 100 – 200 M€/y (crude oil at 60 $/barrel). The related reduction of CO_2-emissions is estimated at 600-1200 kton each year. For distillation systems in general, the energy saving is expected in the range of 20-70% of present operations.

As yet three innovative heat pumps are identified:

- Thermo acoustic heat pumps (Figure 3)

Thermo acoustics relates to the physical phenomenon that a temperature difference can create and amplify a sound wave and vice versa. Thermal energy can be converted into acoustic energy via acoustic Stirling cycle. Within thermo acoustics this is referred to as a thermo acoustic (TA)-engine. In a TA-heat pump, the thermodynamic cycle is run in the reverse way and heat is pumped from a low-temperature level to a high-temperature level by the acoustic power. High temperature lifts are feasible this way.

Figure 3: Test installation for a thermo acoustic heat pump

- Thermo chemical heat pumps (Figure 4)

The operation principle of a thermo chemical heat pump is based on the reversible absorption and desorption of a vapor (water, alcohol, ammonia, hydrogen) in a solid substance (salt, ceramic, metal, etc.). The absorption of a vapor is an exothermic process which delivers heat, while desorption of vapor requires heat (endothermic). The specific solid/vapor couple determines the temperature range in which the heat pump operates. It is possible to construct a heat pump by using two different solid substances.

Figure 4: Test installation for a thermo chemical heat pump

- Compression-resorption heat pumps (Figure 5)

Compression resorption heat pumps are hybrid systems that combine an absorption heat pump with a compression heat pump. Compared to conventional compression heat pumps, higher operating temperatures and higher temperature lifts can be achieved. Due to the non-isothermal phase transition of the working medium, the temperature difference in heat exchangers is smaller which results in a higher efficiency.

Figure 5: Test installation for a compression resorption heat pump

The first results about possible applications will be available mid 2008.