REDUCING ENERGY COSTS AND ENVIRONMENTAL FOOTPRINT.

Mechanical vapor recompression (MVR) solutions in evaporation processes.

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Contents

EVOLUTION OF ENERGY EFFICIENCY

Mechanical vapor recompression (MVR) reduces both energy costs and the carbon footprint and consequently, the environmental load.

Thermal separation processes, such as evaporation, are energy-intensive. In the course of its development, the aim to efficiently use this energy and reduce costs first led to single-effect plants heated by live steam, then to multiple-effect plants, then to thermal vapor recompression, and finally to the use of mechanical vapor recompression systems.

In conventional evaporation plants, the energy content of the vapor stream produced is either lost or only partially reused. In comparison, mechanical vapor recompression allows the continuous recycling of this energy stream by recompressing the vapor to a higher pressure and, therefore, a higher temperature. The compressed vapor can be used to heat the shell side of the evaporator. Instead of live steam, electric energy is used indirectly to heat the plant.

Advancements in thermal separation processes

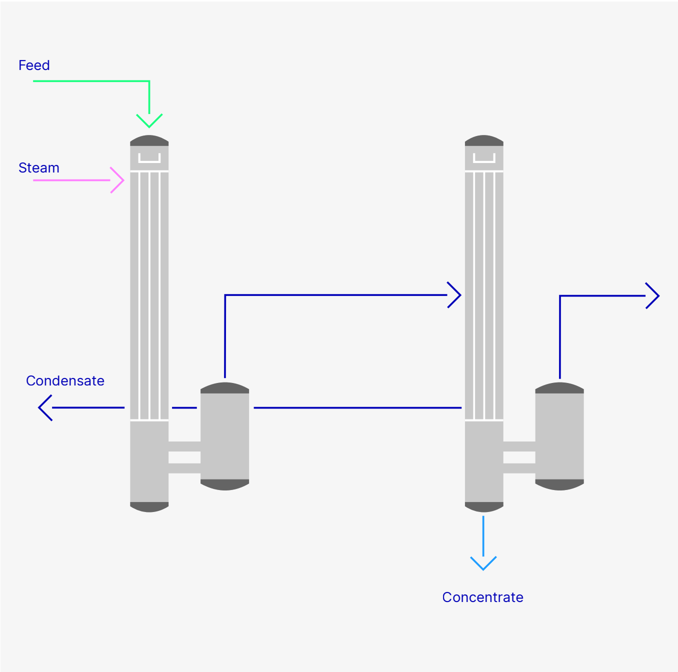


Fig. 1: Multi-effect evaporation plant, heated with direct steam

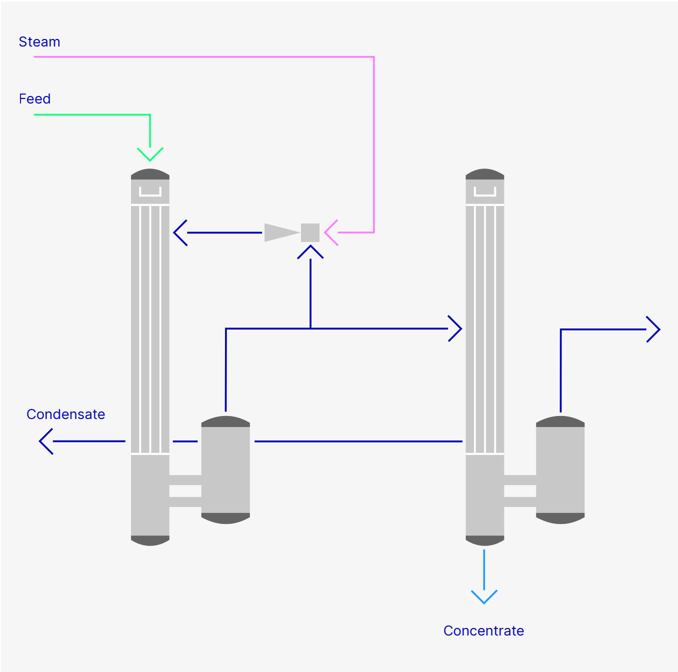


Fig. 2: Multi-effect evaporation plant, heated with direct steam and using TVR

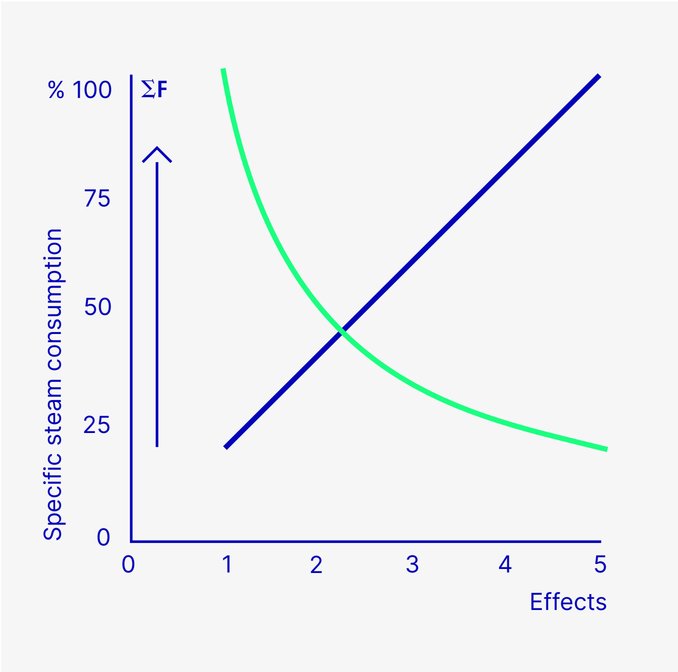


Fig. 3: Specific energy consumption vs No. of effects

In a single-effect evaporator, the heat content (enthalpy) of the evaporated vapor is approximately equal to the heat input on the heating side. In the case of water evaporation, about 1 kg/h of vapor will be produced by 1 kg/h of live steam, as the specific evaporation heat values on the heating and product sides are about the same. If the amount of vapor produced by primary energy is used as heating steam in a second effect, the energy consumption of the overall system is reduced by about 50%.

During vapor recompression, vapor from the separator is recompressed to a higher pressure on the heating side of the tube bundle. For thermal vapor recompression (TVR), steam jet compressors are used. These compressors operate according to the steam jet pump principle and require a certain amount of steam, known as ‘motive steam’, for their operation. Approximately half of the vapor produced by the evaporation process can be reused for heating, while the other half flows to the next effect to drive the process there.

This principle can be continued over several evaporation columns to further improve energy savings. The maximum permissible heating temperature of the first effect and the boiling temperature of the last effect result in a total temperature difference, which can be distributed to the individual evaporators. The more effects that are installed, the lower the energy requirement and the higher the investment.

Evaluating heat pump efficiency: COP’s role

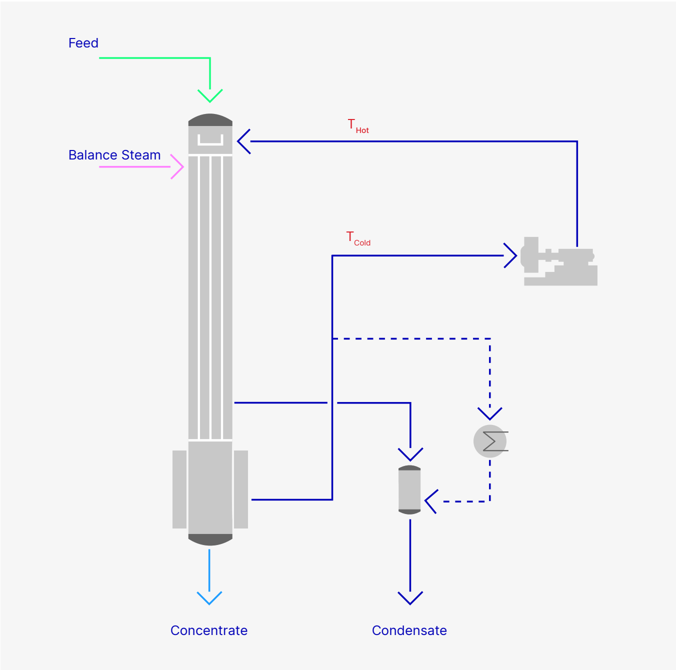


Fig. 1: 1-effect MVR evaporation plant

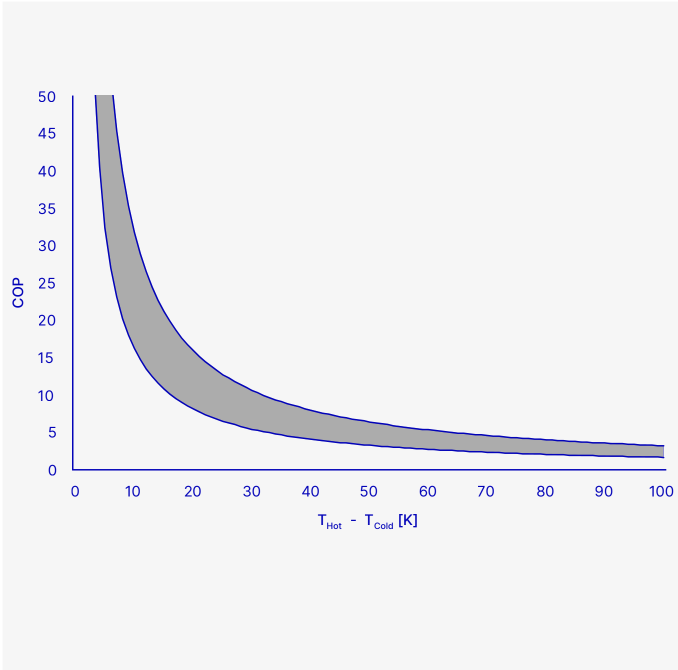


Fig. 2: COP of 1-effect MVR compared to thermal heating

Simplified calculation example:

- An evaporation plant is heated by 5 t/h of steam (at 1,2 bar(a)).
- The plant is revamped to MVR heating and the vapor temperature T_{Cold} is 65°C.
- The saturation temperature T_{Hot} downstream the MVR is 73°C.
- In this specific case, the MVR power consumption is 210 kW.

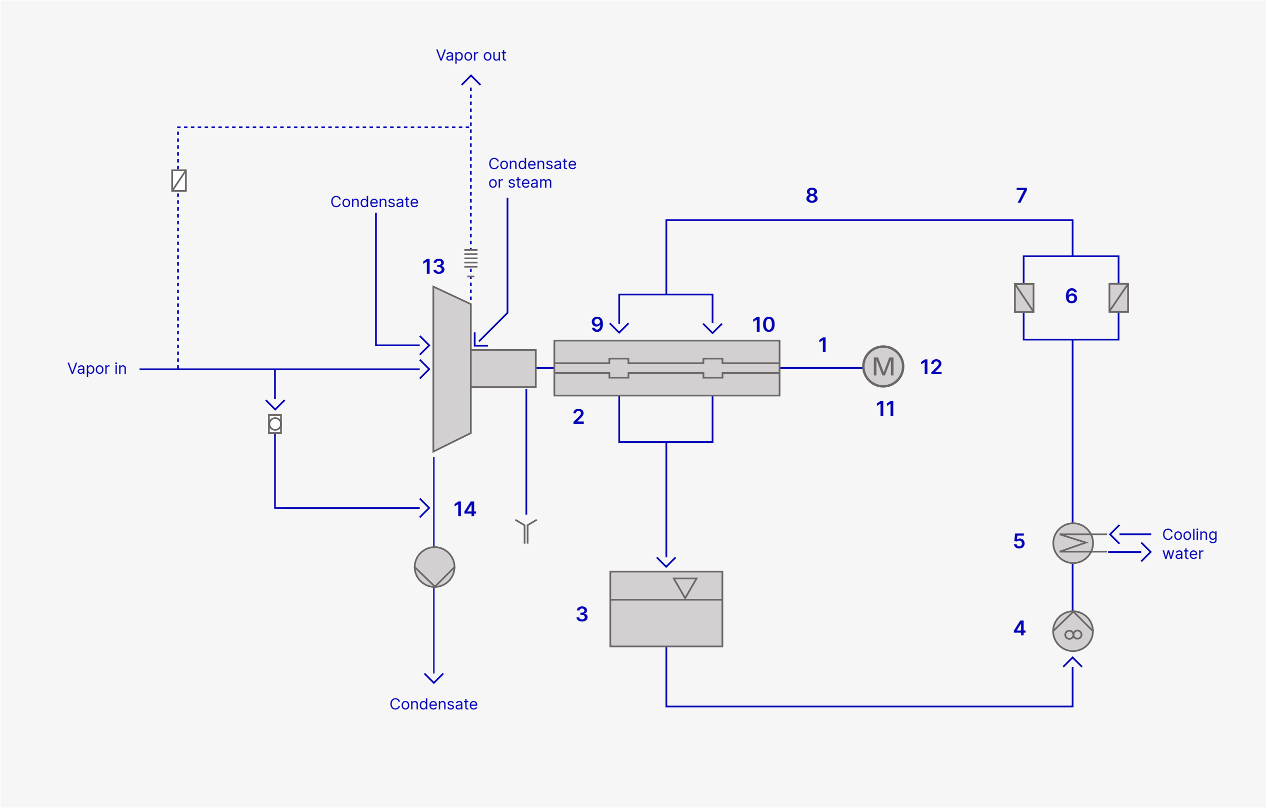
$$COP = \frac{Q_{thermal}}{Q_{electric}} = \frac{\dot{m} \cdot \Delta h_v}{E_{el}} = \frac{5.000\ \text{kg/h} \cdot 2.618\ \text{kJ/kg}}{210\ \text{kW} \cdot 3600\ \text{s/h}} = \frac{3.636\ \text{kW}_{th}}{210\ \text{kW}_{el}} = 17{,}3$$

The efficiency of a heat pump is indicated by its Coefficient of Performance (COP). The COP is determined by the ratio between the amount of used thermal energy and the electrical energy consumption of the compressor. The COP is a suitable characteristic value to assess the energy-saving potential of an evaporation plant with mechanical vapor recompression compared to a thermally heated evaporation plant (Figure 2).

What does COP stand for?

A high COP value indicates high efficiency. Revamps from thermal to MVR heating with COP values of approximately ≥ 5 are profitable, depending on the energy costs and the expected amortization period, while MVR technology for new systems could be profitable at lower COP values.

Principle sketch of an MVR system



Reliable operation
Optimum operation of an evaporation plant requires reliable and sufficient heating. In plants with mechanical vapor recompression, the consistent and reliable operation of the compressor is crucial.

Typically, three-phase asynchronous motors with two poles are used. The motor speed is controlled by a frequency converter. There are distinctions between high-voltage and low-voltage motors.

Depending on the on-site conditions, the motor capacity in the low-voltage range can reach up to 630 kW at 400 V, and up to 2000 kW at 690 V. For capacities above 1.3 MW, medium voltage frequency converters and medium voltage motors, with voltages of 3 kV, 6.6 kV, or 10 kV, can also be considered.

Monitoring and safety devices in MVR systems:

- Impeller speed (1)
- Shaft vibrations (2)
- Bearing temperature (9, 10)
- Housing temperature (13)
- Fluid in the housing (14)
- Oil pump (4)
- Oil level and oil temperature in the tank (3)
- Oil pressure and oil flow (6, 7, 8)
- Oil cooler (5)
- Motor bearing temperature (12)
- Motor winding temperature (11)

Energy optimization of existing evaporation plants by MVR

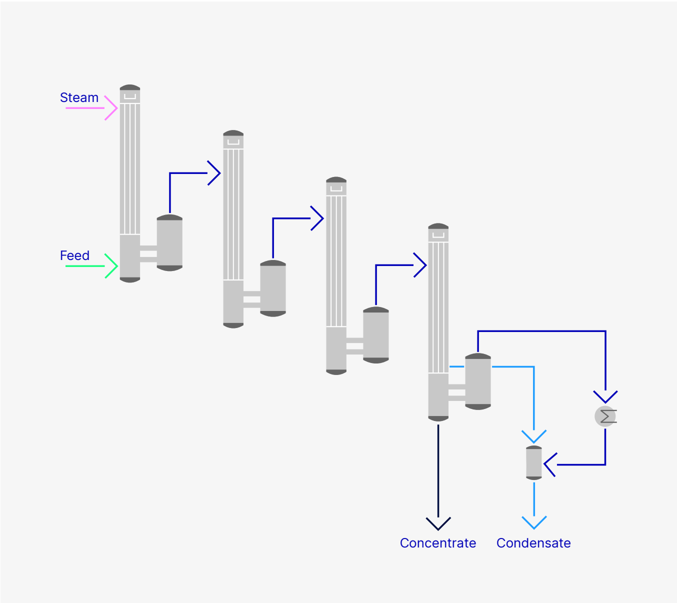


Fig. 1: Evaporation plant with live steam

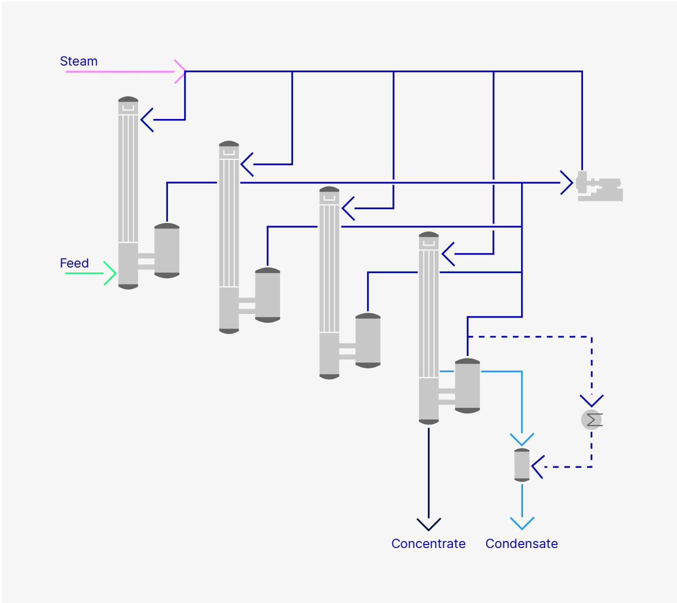


Fig. 2: MVR evaporation plant with compressed vapor

Example 1

A common conventional evaporation plant is usually heated by live steam in a multi-effect arrangement. Some plants are heated with steam or other media such as hot water, thermal oil, or dryer vapor. In the first effect, the product inside the tubes begins boiling, creating vapor that is used to heat the next effect, and so on. The final vapor from the last effect is condensed in a condenser with cooling water.

Example 2

The vapors from the boiling product inside the tubes of all evaporators are combined in downstream centrifugal separators into one suction line to the compressor. The compressed vapor is returned at a higher energy level and distributed for heating the shell side of all evaporators. The condensed vapor on the shell side is collected in a condensate vessel. If there is any surplus of vapor due to heat balance, this vapor is condensed in a balance condenser.

Energy optimization of existing evaporation plants by MVR

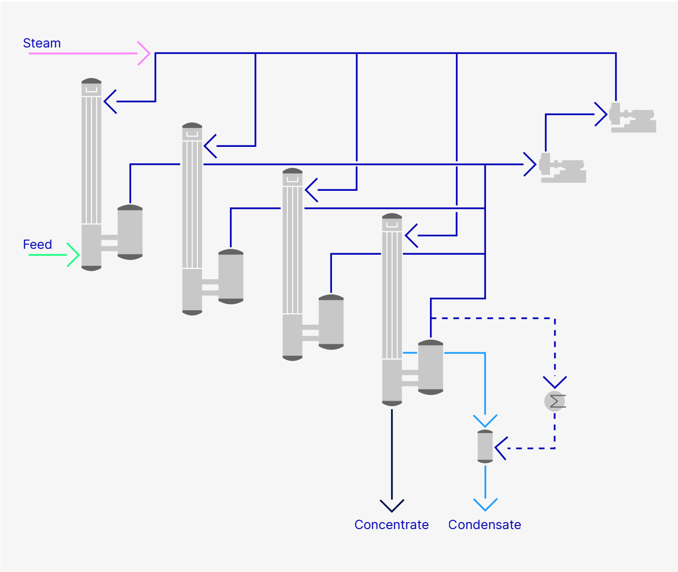


Fig. 3: MVR plant with vapor compression in parallel

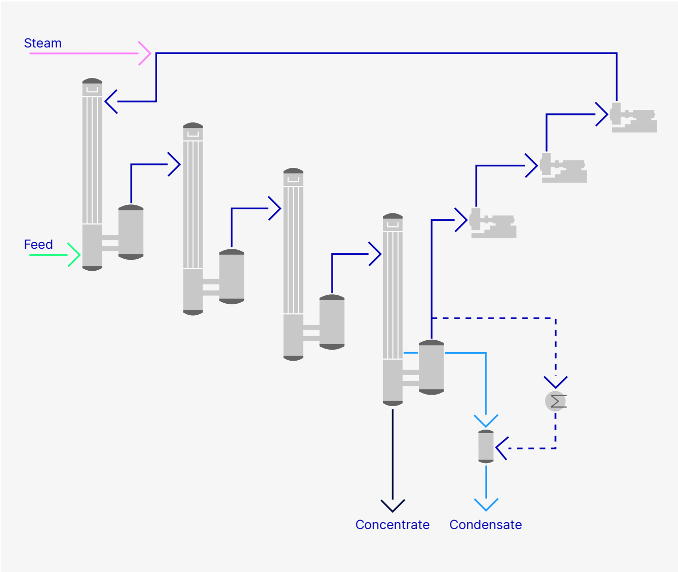


Fig. 4: MVR plant with vapor compression in serie

Example 3
The vapors from the boiling product in the tubes of all evaporators are collected from the separators in parallel, into a single suction line connected to compressors installed sequentially.

Advantages and disadvantages compared to Ex. 4:

+ Less energy consumption due to smaller temperatures differences, even with higher mass flow
+ Reduced fouling tendency inside the heating tubes
- Requires more space and less vapor line modification
- Longer downtime for tie-in

Example 4
The vapors from the boiling product in the individual tubes of the last evaporator are collected from the separators into a single suction line connected to compressors installed in series.

Advantages and disadvantages compared to Ex. 3:

+ Requires less space and vapor line modification
+ Reduced downtime for tie-in
- Higher energy consumption due to larger temperature differences, even with lower mass flow
- Increased fouling tendency inside the heating tubes

Enhancing efficiency with dual pressure levels

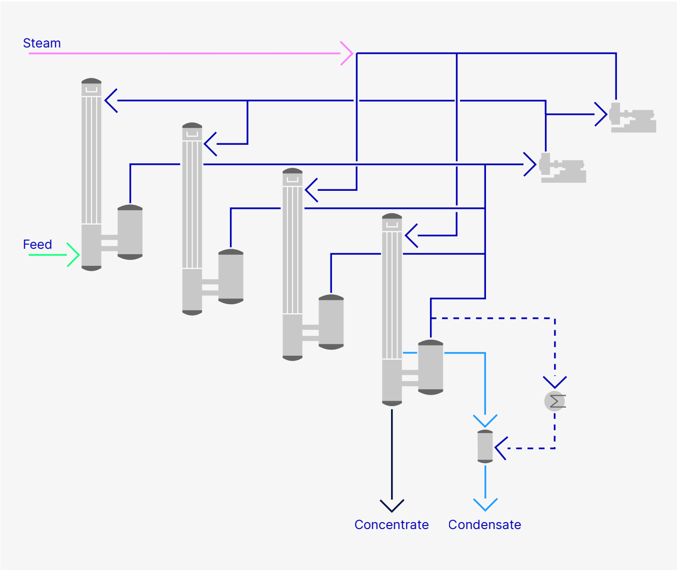


Fig. 1: MVR evaporation plants running on different heating pressures

The energy efficiency of an evaporation plant heated by mechanical vapor recompression can be further increased by heating at two different pressure levels.

Portions of the compressed vapors are used to heat the first two effects until the specific intermediate concentration of the product is reached. For final concentration in the last effect, the compressed vapor from the first compressor must be further boosted to a higher pressure by a second compressor in the last two effects.

The condensate from the higher pressure level of the last two effects will be flashed first on the shell side to recover energy within the system. The challenge is to determine, with the existing heating surface, which intermediate concentration can be achieved with one compressor and how many compressors are required to achieve the final concentration with the remaining heating surface.

Products with high boiling point elevation and high viscosity need a larger temperature difference ($T_{Hot} - T_{Cold}$) to maintain the evaporation process.

EVAPORATION – UNLIMITED APPLICATIONS

Chemical Industry
- Glycerin
- Caprolactam
- Industrial waste water
- White biotech

Food & Beverage
- Coffee, beer, wort, malt
- Corn / wheat stillage
- Pet food
- Plant based products
- New food

Starch, Sugar & Sweetener
- Glucose, fructose, dextrose
- Starch effluents
- Polyol, sorbitol, maltitol
- Maltodextrine

Fermentation products
- MSG
- Lysine, threonine
- Leucin, valin
- Citric / lactic / succinic acid
- Yeast extracts

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Constantly improving – Sharing our knowledge to safeguard your investment

Together with you – Enduring commitment to you and your business

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