Within the scope of the demonstration projects of efficient electrotechnologies for industrial processes, CESI has identified Mechanical Vapour Recompression (MVR) as an advantageous system for use in the concentration and drying of food products. With MVR steam is compressed and delivered to the same process, or to another one, in such a way that it will be able to exchange heat with the process. Under these operating conditions primary, energy consumption reduces to less than 1/3 with respect to a traditional triple-effect evaporator.

In practice however major obstacles exist to MVR diffusion, because most potential users are concerned about the cost, complexity, and reliability of the compressors available. For this reason it was decided to initiate a demonstration project aimed to prove the suitability and effectiveness of MVR in evaporation processes. For the case study, reference was made to a plant converted from thermal energy to MVR installed at the SSICA (Experimental Center for the Food and Preserves Industry) in Parma (Italy). Such a plant is currently used for the concentration of tomato sauce, which is an extremely widespread process: think that about 1.8 million tons of water are evaporated to concentrate tomato juice in Italy alone every year.

The experimental tests have demonstrated that, when properly applied, MVR can provide for major energy and cost savings. Moreover, no marked problems have been detected concerning the dirtying of the compressor and heat exchanger, nor drawbacks arose tied to the acidity of the product to concentrate. For the execution of these tests, suitable components, but not specific to this purpose, have been used (for instance the compressor), nevertheless obtaining satisfactory results, it is expected that even better outcomes can be obtained when the proper equipment can be found. Therefore it is sought that this experience can feed a sufficient demand to induce manufacturers to develop and put on the market a sufficiently wide range of purposely made components.
FOREWORD

The Mechanical Vapour Recompression (MVR) is a very effective technique for heat recovery from the steam produced in liquid solution concentration and distillation processes. It consists in increasing the steam temperature through compression, which can thus be re-employed as heating fluid in the process itself, in which it is allowed to condense. In this way, in respect with a comparatively moderate contribution, in terms of electric power spent for the operation of the compressor (or fan), it is possible to recover the condensation latent heat. Being said heat equal to the one required for evaporation, the whole process is able to self-sustain without the supply of additional heat, but for the starting phase, and for the compensation of heat losses, for the amount possibly exceeding the thermal contribution of the demanded electric power.

The specific consumption of electric power is function of the temperature increase suffered by steam during compression and of the complexity (number of stages) of the evaporation plant, typically it ranges from 10 to 30 kWh per ton of evaporated water. Considering the electric power generation and distribution efficiency, these values correspond to primary energy consumption 50% lower than the demand of the more sophisticated alternative techniques, based on thermal evaporation. Figures 1 and 2 show two typical simplified diagrams, for an electrical MVR plant and for a 3-effect one supplied with boiler water, respectively. The literature relates of number of MVR applications, mainly encountered in the agricultural-food sector, where it is successfully employed for the concentration of skim milk, whey, fruit and vegetable juice (apple, beetroot, tomato, etc.), corn maceration water, etc. There are important installations also in the pharmaceutical (production of distilled water) and chemical industry (various concentration processes), as well as for the treatment of waste water in different industries (paper, textile, etc.).

The main advantages of the MVR, versus competitive technologies can be summarized as follows:

- Higher energy efficiency, resulting in important operation cost saving;
- Upgrade of evaporation plants without the need for adaptation of steam generators; more compact plants at equal performance, so that the same can be better housed in buildings;
- higher operation flexibility and reduced detergent consumption, thanks to the lower mass.

Fig. 1: MVR Evaporator

Fig. 2: Three-effect Evaporator

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THE POINT ON MVR IN ITALY

Industries counting important concentration processes are largely spread over Italy, food industry above all. The analysis of the more diffused applications in the different production sectors, has highlighted the evaporation needs summarized in the following Table I. In general, it is noticed the need for evaporation in the range of approximately 12 million tons/year of water, shared over about 11 different applications:

Though the MVR can in principle be employed in all the cases mentioned above, on the contrary, in practice it is detected that the more widely employed technology is that of multi-effect evaporators, fed with boiler produced steam. In fact, only occasional applications of the MVR are detected, mainly in the following sectors: milk-dairy for whey concentration, agricultural-food for the concentration of fruit juice and pharmaceutical for the production of distilled water. On the contrary, whenever the MVR should find systematic application, we would have a diffusion technical potential equivalent to a consumption of 240 GWh/year, to which a net reduction of 400000 t/year of CO\textsubscript{2} emissions would correspond. This hypothesis alone would enable to reach 6.7 % of the share of CO\textsubscript{2} emission abatement in the energy end-users pertaining to Italy for year 2006, on the basis of Kyoto undertakings.

From investigations recently made with some groups of potential users, it appeared that the limited diffusion of the MVR in our Country could be explained through the following reasons:

- Comparatively high cost of electric power, making this technology less attractive from the economical point of view than in other contexts;
- Technology requiring higher investments than the competitive technology;
- Reliability of compressors not completely satisfactory;
- Use of complex equipment, requiring more skilled personnel.

Answering to the first three issues, it can be affirmed that the cost of electric power is expected to decrease in time, following the opening of the market and the establishment of competition among the suppliers. The above, shortening the pay back time of investment, would make the recourse to the MVR more interesting, for the application of which, compressors with minimum unavailability rates at acceptable costs, are available on the market since long.

To disprove the last objection and prove the effectiveness of the MVR, a research and demonstration action was started, choosing as application the concentration of tomato juice that, as highlighted in the previous table, shows a particularly important diffusion potential, requiring each year the evaporation of approximately 1.8 million tons of water.

TABLE I: Quantity of yearly evaporated water in Italy in the main food processes

<table>
<thead>
<tr>
<th>Production Sector</th>
<th>Product</th>
<th>Evaporated Water (kton/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy</td>
<td>Powdered whey</td>
<td>1614</td>
</tr>
<tr>
<td></td>
<td>Concentrate whey</td>
<td>460.</td>
</tr>
<tr>
<td></td>
<td>Powdered milk</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Milk condensed</td>
<td>1</td>
</tr>
<tr>
<td>Fruit and Vegetable Juices</td>
<td>Tomato concentrate</td>
<td>1430</td>
</tr>
<tr>
<td></td>
<td>Peeled tomato, juice, mashed tomato</td>
<td>365</td>
</tr>
<tr>
<td></td>
<td>Citrus juice</td>
<td>384</td>
</tr>
<tr>
<td></td>
<td>Grape musts</td>
<td>480</td>
</tr>
<tr>
<td></td>
<td>Beetroot sugar juice</td>
<td>2700</td>
</tr>
<tr>
<td></td>
<td>Other sugar products</td>
<td>1669</td>
</tr>
<tr>
<td>Starch</td>
<td>Starch</td>
<td>2516</td>
</tr>
</tbody>
</table>

TRANSFORMATION TO MVR OF A PLANT FOR THE CONCENTRATION OF TOMATO JUICE

For the execution of demonstration tests on the effectiveness of the MVR in the concentration of tomato juice, a co-operation agreement has been signed by CESI and SSICA (Experimental Station for Food Conservation Industry), for the transformation to MVR of the present thermal evaporator existing at SSICA Canned Vegetables laboratory. This evaporator is a simple effect system, with a production capacity of 90 kg/h of evaporate, employing saturated steam at 0.6 MPa coming from the Laboratory boiler.

The main components of the plant under transformation are:

- Evaporator: is a vertical heat exchanger having concentric tubes with a thermal exchange surface of 0.9 m\textsuperscript{2}. The product in evaporation is pumped in the primary circuit, while the secondary one is fed with live steam coming from the boiler. The primary fluid is kept under vacuum at approximately 60°C temperature, while steam in the secondary condenses at approx. 100°C. An extraction pump with level regulation valve is tasked of condensate discharge.
- Separator: is an expansion tank, having the function to keep the steam phase from the liquid one separate. The separator is fed by the boiling liquid, coming from the evaporator, tangentially injected above the liquid surface, in order to avoid foam formation. A mixer keeps the liquid phase homogeneous.
- Feeding and pre-heating unit: the plant is continuously fed; the product to concentrate is heated with steam in a tank outside the plant. The product mass is weighed before starting feeding. The
The concentration process is vacuum made (18 kPa) with the aid of a liquid ring pump.

- **Condenser**: it has an important role in the thermal process since it determines the vacuum in the plant primary side.
- **Vacuum Pump**: is of the liquid ring type, it has the function to remove non-condensable gases.

**Transformation Works**: the steam compressor represents the most important component in the transformation, whose acquisition required a particular research effort in a market, such as the Italian one, featuring for a poor offer of equipment and components that can be used in the electroheat domain. In fact, the already scarce availability of national and foreign manufacturers of steam compressors conflicted with the need to procure equipment having a capacity under the standard dimensions available on the market. After a careful evaluation of the compressors available on the market, we finally directed our choice to an air compressor, generally employed as vacuum pump. It is a roots type compressor. High vacuum version, having three-lobe rotary reels, with descending vertical flow.

The remaining transformations have been conditioned by the dimensions of the existing plant, which has been modified as for the following elements:

- **Evaporator**: completely replaced by a horizontal heat exchanger with concentric tubes, fit with motor operated scraper. The exchange surface is still 0.9 m².
- **Re-circulation unit**: completely modified.
- **The steam line** connecting the separator to the condenser has been modified with insertion of the steam compressor.
- **Condenser**: it has been cut off from its function of condenser, but it remained in the circuit as connection between the plant and the vacuum production unit.

The plant has finally been completed with the installation of measuring instruments for absolute and differential pressure, temperature, level, and flow rate. Fig. 3 shows the new plant configuration and highlights the position of measures acquired.

The main characteristics of the new plant are:

- **Rated capacity**: 152 Nm³/h
- **Fluid type**: saturated steam
- **Suction pressure Compressor**: 20 kPa
- **Suction Temperature Compressor**: 60 °C
- **Delivery pressure Compressor**: 40 kPa
- **Maximum temperature downstream Compressor**: 143 °C
- **Compressor Rated Power**: 3 kW
- **Suction Pressure drops**: 0.1-0.2 kPa
- **Rated thermal power**: 59 kW
- **Evaporated capacity**: 0.025 kg/s (90 kg/h, 152 N m³/h)
- **Re-circulation rated capacity**: 13.6 t/h

**Figure 3**: diagram of the evaporation plant transformed to MVR

[Diagram of the evaporation plant transformed to MVR]

**Legend**:
- CP: Steam Compressor
- SC1: Heat Exchanger
- SC0: Condenser
- SC3: Cooled Dripper
- SP: Steam Separator
- PV: Vacuum Pump
- PAC: Condensateaccumulator
- P1: Recycling Pump
- P2: Condensate Pump
- P: Feeding Pump
- TR-x: Temperature
- DPR-x, LR-x: Diff. Pressure
- PR-x: Aps. Pressure
- FR-x: Flow Rate
- V-x: Valves
- S: Solution Inlet
The plant transformed for operation with MVR has been commissioned on July 4, 2000. The tests have been divided into three groups, see Table II summarising the experimental matrix:

- Characterisation tests and plant testing, using pure water
- Concentration tests of simulating product, obtained from tomato concentrate diluted with water.
- Concentration tests of fresh tomato juice.

The testing of the plant enabled to perform the following inspections:

- Check the operation of the measurement and control instrumentation of the plant, evaluate air penetration in the circuit;
- Evaluate thermal losses;
- Set up the test procedure;
- Check the technical characteristics of the compressor.
- Evaluate the mass and energy balance.

The Concentration Tests of the Juice obtained from tomato concentrate diluted with water had the following two targets:

- Demonstrate the feasibility of the concentration process with the MVR technique;
- Set up a procedure of industrial interest, enabling a reduction of energy costs and of the environmental impact, protecting the product quality.

From the operational point of view, the tests have been conducted as follows: the plant has been filled with the product to concentrate, appropriately heated at 70°C out of line. On the moment of filling starting, the recirculation pump is started, keeping it operating during the whole test, while the heat exchanger is supplied with live steam until the whole apparatus reaches 60°C temperature. In this phase the compressor is in off mode. When steady conditions are reached, the vacuum pump is started, taking the plant at 18 kPa absolute pressure. The opening of the bypass valve of the compressor facilitates a homogeneous heating of steam ducts. After a consistent steady period, the steam compressor is started closing the bypass valve and commencing the actual concentration phase.

This procedure is repeated three times, starting from different concentrations of tomato juice, as indicated in Table II, (tests C1807, C1907 and C2407). The tests on the fresh tomato juice had the target to confirm the validity of this concentration technique without impairing the quality of the product. To this purpose, two tests have been conducted: the first one (P1209) to confirm the power consumption and the process operation; the second one (P2109), to be compared with the test (PT2109), made with the traditional thermal process, starting from the same initial product, has been made to evaluate the quality of the final product.

Table III shows the main characteristic results of the tests, which have been successful under different viewpoints. They, in fact, have proved that the concentration of tomato juice with the MVR can be quality, if not better than that obtained with the thermal conventional system. In this specific case it has been possible to reduce the consumption of primary energy and CO\textsubscript{2} emissions to one seventh.

Table II: Experimental Matrix

<table>
<thead>
<tr>
<th>Test N°(*)</th>
<th>Concentration [brix]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Starting</td>
</tr>
<tr>
<td>A0407</td>
<td>0</td>
</tr>
<tr>
<td>C1807</td>
<td>4.7</td>
</tr>
<tr>
<td>C1907</td>
<td>8.3</td>
</tr>
<tr>
<td>C2407</td>
<td>11.8</td>
</tr>
<tr>
<td>P1209</td>
<td>6</td>
</tr>
<tr>
<td>P2109</td>
<td>6</td>
</tr>
<tr>
<td>PT2109</td>
<td>6</td>
</tr>
</tbody>
</table>

(*)Note: A: testing with pure water; 
C: tests starting from the tomato concentrate opportunely diluted at the pre-set starting concentration 
P: tests with fresh tomato; 
PT: comparison tests made with the standard process (thermal)

As far as the plant operation and specific consumption are concerned, no significant difference has been appreciated in the concentration of fresh tomato juice and of that obtained through concentrate dilution.
The global ebullioscopic increase ¹ does not exceed one and a half centigrade, almost enabling to completely employ the temperature boost offered by the compressor.

From the quality point of view, the tests have also enabled to check the possibility to operate with temperature differences of approx. 10°C, both at medium concentrations (10 to 20% of dry matter). Moreover, no marked problems have been detected concerning the dirtying of the compressor and heat exchanger, nor drawbacks arose tied to the acidity of the product to concentrate.

CONCLUSIONS

The Mechanical Vapour Compression shows in Italy an important potential for saving energy in a lot of concentration processes. Among these, particularly important is the tomato juice concentration, whose feasibility has been demonstrated transforming an experimental thermal plant to MVR. Test results have been successful and have demonstrated not only the energy advantages, but also the economic – production ones of this technology.

For the execution of these tests, suitable components, but not specific to this purpose, have been used (for instance the compressor), nevertheless obtaining satisfactory results, it is expected that even better outcomes can be obtained when the proper equipment can be found. Therefore it is sought that our experience can feed a sufficient demand to induce manufacturers to put on the market a sufficiently wide range of purposely made components. In Fig. 4 a picture is shown of the evaporator equipped with MVR.

Fig.4: Plant transformed to MVR

¹ The ebullioscopic increase represents the boiling temperature increase depending on the concentration of solids dissolved in the solution.