

Mechanical Vapour Recompression applied to Alumina Spent Liquor Evaporation Plants

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Abstract

Mechanical Vapour Recompression (MVR) is a technology that has been widely used for many years in different processes where concentration by evaporation is required. This technology is based on the re-use of the vapour produced by evaporation as the heating medium, after having increased its temperature and pressure by mechanical compression. The main advantage given by MVR compared to classical evaporation is the use of electrical power instead of live steam, which gives lower operating expenses when electrical power is available. There is no need for cooling water and the operating temperature is lower than the one in conventional evaporation plants with Multiple Effects or Multiflash trains, which means lower scaling, higher availability and lower corrosion. While MVR evaporation is widely used in heavy industry such as the Salt industry or Pulp and Paper, it is quite rare to find this technology in an Alumina refinery. Based on a case study of an installed MVR evaporator in an Alumina refinery, we will show the advantages of this technical alternative. Considering its various advantages and the low operating costs, MVR evaporation technology should be really considered during the design of a new alumina refinery or during capacity expansion project of an existing plant.

Keywords: Mechanical Vapour Recompression, Concentration by evaporation.

1. Introduction

There are many evaporation technologies and some of them were developed before the Bayer process of the alumina industry. Evaporation process has always been a part of the Bayer process and development of evaporation technology was done in parallel of the Bayer process one. The improvements were in the equipment (for example Falling Films have replaced Climbing Films types of evaporators) but also in the process in order to obtain better efficiency and lower energy consumption. This explains the presence of many types of evaporation technologies in alumina refineries such as multiflash trains, falling film multiple effects, forced circulation multiple effects and other combined process.

One of the developed evaporation technology is called Mechanical Vapour Recompression. It consists of using the process vapour generated by the evaporation as the heating vapour on the service side of the evaporator heat exchanger(s). For that purpose a compressor machine is used to increase the pressure and saturated temperature of the process side vapour and use these recompressed vapours to exchange heat again with the boiling spent liquor. So live steam is not needed anymore in that case but only electrical power. This technology enables a reduction in energy when integrated at a correct place in the Bayer process.

2. Thermodynamic Principles

Evaporation is the change from liquid phase to gaseous phase of the solvent contained in a liquid solution (the solvent is water and the liquid is the spent liquor in the case of the alumina refineries). The gaseous phase (water vapours) of the solvent is separated by gravity from the liquid phase (Bayer process spent liquor).

2.1. Thermodynamics sequences

The thermodynamic sequence of an MVR evaporation is described in the below enthalpy and entropy diagrams. The sequence is composed of various energy transfers that can be split like described in Table 1.

Table 1. Thermodynamic sequences of MVR evaporation.

Difference of Enthalpy	Corresponding energy
$H_A - H_B$	Energy of solvent vaporisation
$H_R - H_A$	Polytropic work of compression
$H_E - H_R$	Energy of de-superheating
$H_F - H_E$	Heat released by condensation of the vapour

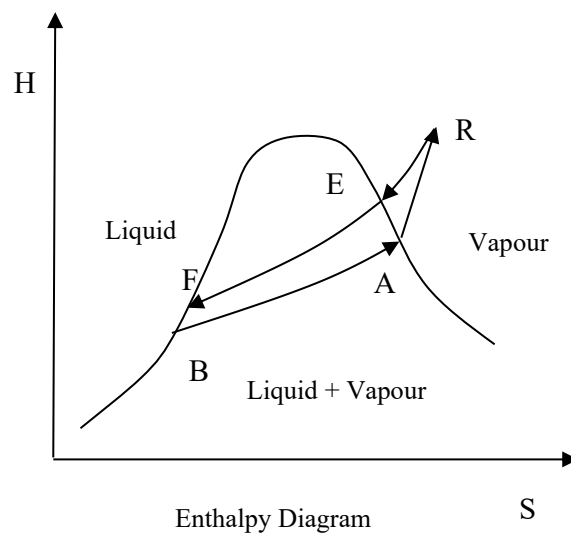


Figure 2. Enthalpy diagram for MVR Evaporation.

The energy needed for the evaporation of the water ($H_A - H_B$) corresponds approximately to the heat released by the condensation of the heating vapour ($H_F - H_E$). However a motive force is needed to allow this transfer of energy between the condensing vapours and the boiling liquor.

In evaporation, as in any other heat transfer unit, this motive force is the temperature difference between the hot stream being cooled down or condensed and the cold stream being heated or evaporated ($T_E - T_B$). No heat transfer can happen without this temperature difference.

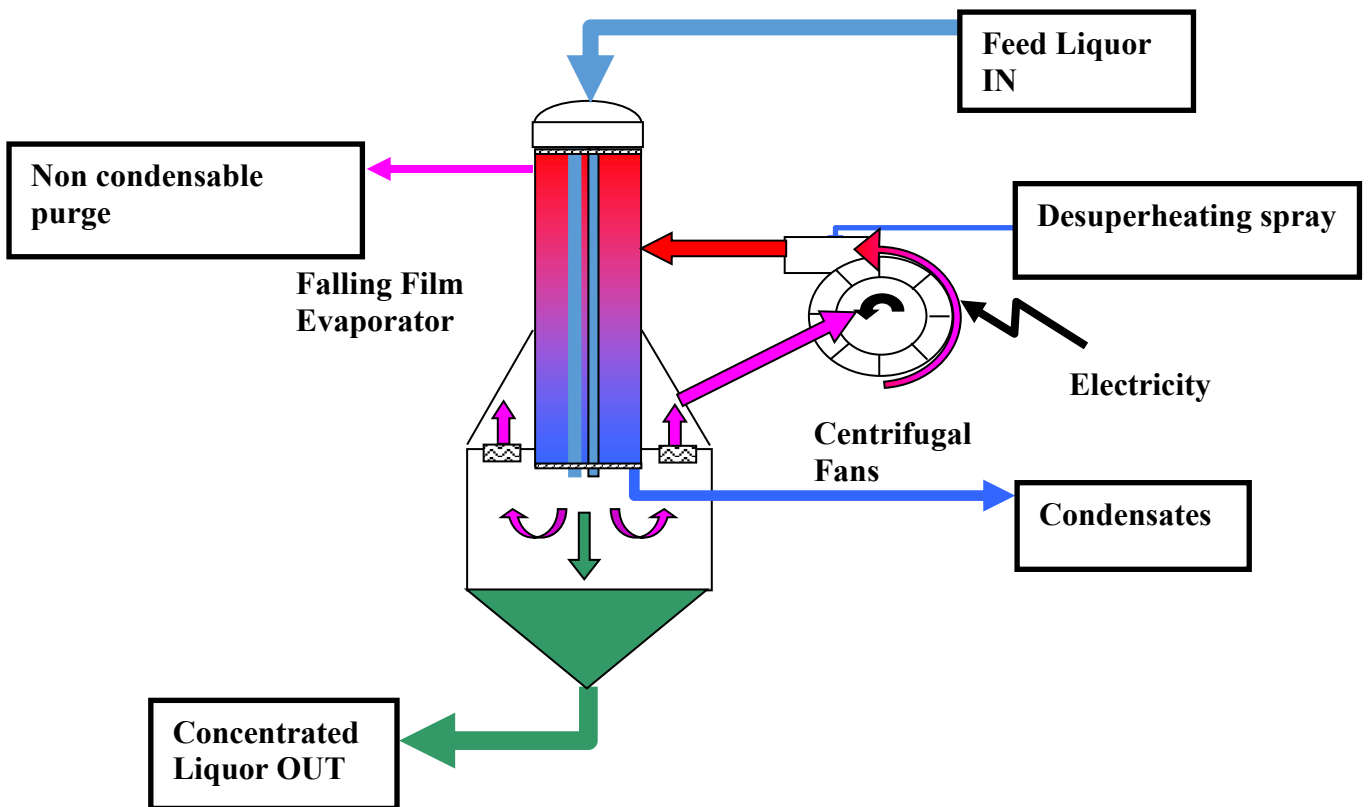


Figure 3. Falling Film Evaporator equipped with Mechanical Vapour Recompression.

This increase of the vapour temperature is the purpose of the compression work.

2.2. Compression Work

The compression is the increase of vapour's pressure and saturated temperature by the use of a mechanical machine. The compression work is linked with the difference of pressure produced by the compressor. It can be calculated with the following equation:

$$W_{comp} = \frac{nRT_1}{n-1} \left[\left(\frac{P_2}{P_1} \right)^{(n-1)/n} - 1 \right] \quad (1)$$

where:

W_{comp}	Polytropic work, J
R	Gas constant, J/mol/K
T_1	Inlet gas temperature, K
P_1	Suction pressure, Pa
P_2	Discharge pressure, Pa
n	Polytropic factor, nil

The compression work is generated by the compressor, which requires an energy input: this is the electrical power provided to the motor of the compressor (or, rarely, High-pressure steam on turbine and coupling between shaft of turbine and shaft of compressor). Despite the losses of the transmission, losses of the motors (efficiency) and losses of the compressor itself (hydraulic efficiency, like for a centrifugal pump), the energy consumption in terms of electrical power is clearly good in comparison with steam (from a boiler house) energy consumption.

2.3. Boiling Point Elevation

The Boiling Point Elevation (BPE) is the difference of temperature between the liquid temperature of a boiling spent liquor and the saturated temperature of the vapours generated during boiling at the same pressure. The higher the caustic concentration in the liquor is, the greater the BPE. This is a very important physical property to be taken into account during design of such MVR systems because the compressors can work only with low temperature difference.

This BPE can be also considered as the “dead” or “lost” compression for the MVR system. For example if the liquor’s boiling temperature under atmospheric pressure is 106 °C, the saturated vapour temperature will be 100 °C only and in order to be able to use this saturated vapour as a heating source for the shell and tube heat exchanger evaporator, its temperature needs to be increased by minimum 6 °C. This is the reason why multiple stages of recompression are generally needed in MVR evaporation units.

2.4. Typical Figures

The comparison is made in the following table 2 between MVR evaporation units with other types of evaporation technology used in the alumina refineries.

Table 2. Average energy consumptions for 1 ton/hour of evaporation.

Evaporation technology	Live Steam (ton/h)	Electricity (kW)	Cooling Water (m ³ /h)
6 effects FFE	0.22 to 0.25	6 to 8	10 to 12
M.V.R.	-	35 to 40	-
Multi Flash Train	0.22 to 0.25	10 to 12	10 to 12

3. Technology

Even if the theoretical laws and principles of the Mechanical Vapour Recompression are very old, it is only since reliable mechanical machines have been invented and developed and manufactured that MVR technology has been applied in the industry.

3.1. Centrifugal Fans (or Turbo-fans)

Centrifugal fans are made of a high efficiency impeller running at low speed (1700 to 6000 rpm max. depending on the machine size) inside a robust casing. The impeller is driven by an electrical motor associated with a Variable Frequency Drive which offers a wide and smooth range of operation. The bearings are in general of sleeve type and are equipped with a forced circulation of lubricating oil that provides a good power transmission of the electrical motor to the impeller of the fan. These bearings are protected from abnormal vibrations by the installation of vibration instruments. An example of such centrifugal fans is displayed in the Figure 4.

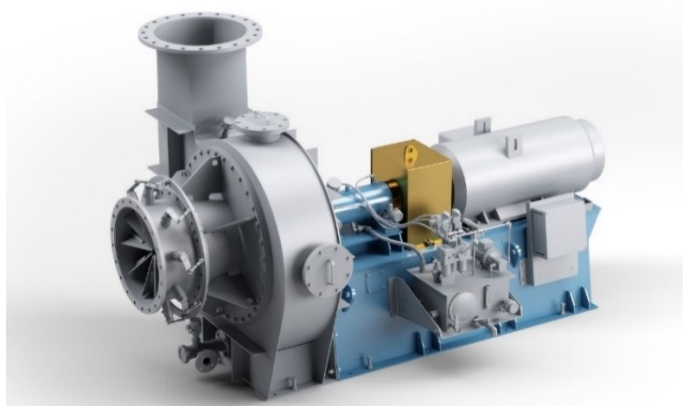


Figure 4. Front view of a centrifugal fan.

One of the main advantages of the centrifugal fan is the low running speed with limited tip speed which ensures a low maintenance cost and also a very good efficiency. The compression ratio for water vapour is equivalent to 9 – 11 °C for one single stage and 18 – 21 °C with a double stage.

Centrifugal fans are installed on a steel base-frame and are connected to vapour ducts with expansion bellows. This installation avoids any kind of vibration and permits a perfect stability of the machines.

In terms of maintenance, there is an annual check to be done by the manufacturer: during this check the shaft seal is in general replaced by a new one (carbon rings). The impellers replacement is depending on the production load but for a normal running with a good running of the vapour scrubber, impellers are in general changed after 5 years to 10 years of production.

3.2. Vapour Washer/Scrubber

The compressed vapours need to be free of any entrainments. The impeller shall not have any deposit of mineral dry mass or incrustation on its blades. Blades incrustation may result in unbalancing of the impeller creating possible strong damages at a rotation speed of 3000 rpm. This is the reason why MVR evaporators are designed with integrated vapour washer (also called scrubber) in order to capture any liquor droplets being carried over in the evaporated vapours. A principle sketch of this type of integrated scrubber is displayed in the figure 5 below, this scrubber is based on curtains of water condensates sprayed in counter-current of the process evaporated vapours leaving the separator.

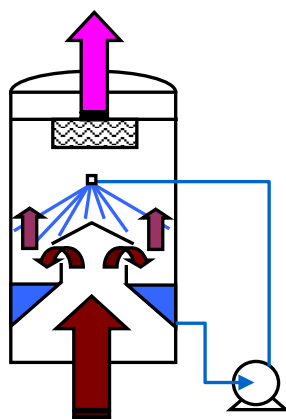


Figure 5. Vapour washer/scrubber.

With such design, the vapours from the evaporator separator crosses a continuous spray of water condensates that ensures the dilution of any droplets of liquor carried over and ensures the vapour is not superheated.

After this stage, the clean vapours cross a chevron type (also called V plates type) demister which captures the last condensates droplets. This demisting technology has been installed in many alumina refineries and has proven good results meaning low conductivity of process/regenerative condensates. Conductivity of condensates with such a scrubber can be expected to be lower than 60 $\mu\text{S}/\text{cm}$, whereas it is in general expected to be lower than 100 $\mu\text{S}/\text{cm}$ with other technologies of evaporation.

3.3. New Improvements:

There has been a major improvement in the last 15 years on the centrifugal fans machines which is the increase of the possible Delta T of recompression per machines. Back in 2005 the maximum Delta T per machines was 7.5 °C and 14 years later the fans manufacturers have been able to increase this value up to 11 °C. For a double stage train of recompression this means a Delta T of about 21 °C nowadays against 14 °C in 2005. It should also be noted that a train of 3 fans in serie is also possible if we need a Delta T higher than 25 °C.

There are some typical values of Boiling Point Elevation according the preferred choice of technology between an evaporation by multiflash and an evaporation by multiple effect Falling Film. Multiflash evaporation plants run in general with BPE between 8 °C and 9 °C, whereas multiple effect evaporation plants run in general with BPEs between 11 °C and 15 °C. With these ranges of BPE and a Delta T of 21 °C (or above if we think about a 3 fans train of compression), it makes it possible to think about a MVR evaporation unit.

There is also the possibility of recovery of filtration washing water with concentration of about 50 gpl of caustic concentration (expressed as Na₂O at 25 °C) and have this washing water concentrated up to 150 gpl of caustic (expressed as Na₂O at 25 °C) which can be an interesting concentration for an attack liquor in the refinery. With this scenario the BPE will be about 9 °C (depending on the carbonates concentration, sulphates and other organic impurities).

These new improvements developed by the fans manufacturers enable to re-think again on this MVR technology to be applied in alumina refineries. Apart from the offered Delta T of the machines another important point is the flow capacity. Improvements have been made and bigger machines in terms of flow capacity are available enabling the possibility to think with higher evaporation capacities that start to be comparable with the usual technologies in place in refineries. Of course the limitation of the capacity is related with the pressure in the system and the corresponding specific volume of the water vapour. Because these machines are limited by the volumetric flow, the lower the pressure, the higher the specific volume will be and the lower the allowable mass evaporation capacity will be. Table 3 shows typical values of specific volume of the water vapour and the corresponding available mass flow for a same volume flow:

Table 3. Correspondence between Volumetric flow and Mass flow for water vapours.

Volumetric Flow of vapours	m ³ /h	150 000	150 000	150 000	150 000
Pressure	bar abs.	0,124	0,250	0,600	1,013
Specific volume	m ³ /kg	12,0	6,20	2,73	1,67
Mass Flow of vapours	kg/h	12509	24176	54914	89645

Nowadays the fans manufacturers can offer machines with capacities up to 200 T/h on a single train of fans for a pressure of 1,20 bar abs. For a lower pressure the available mass capacity decreases. And if the required capacity of evaporation is higher, it is always possible to have two parallel trains of centrifugal fans having the same suction vapours and discharging to the same evaporator(s).

3.4. Examples of Possible Process Flowsheets with MVR Technology

The diagrams below show the different possibilities of process flowsheets for a MVR evaporation plant that can be applied to alumina refineries projects.

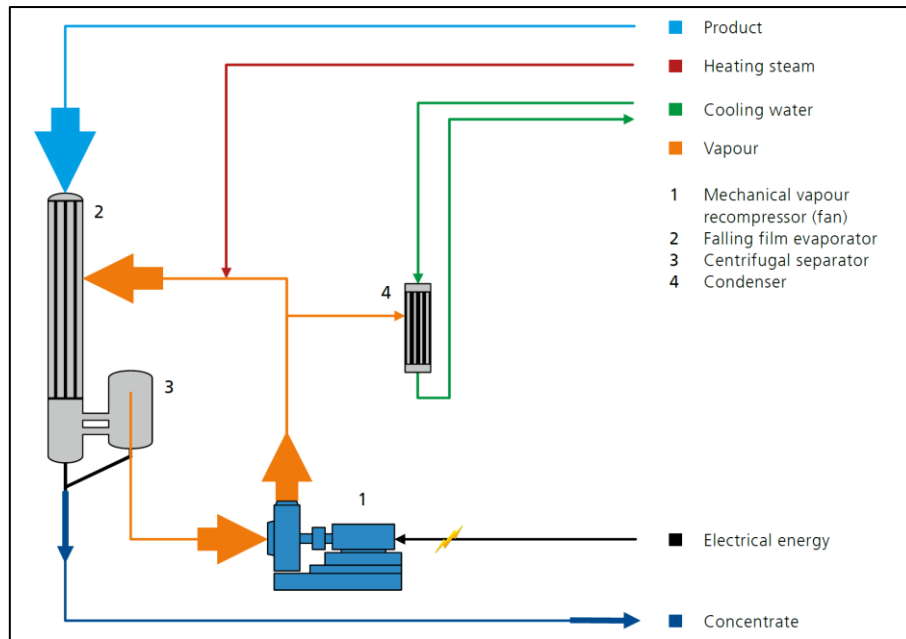


Figure 6. Single-effect falling film evaporator with centrifugal fan for mechanical vapour recompression.

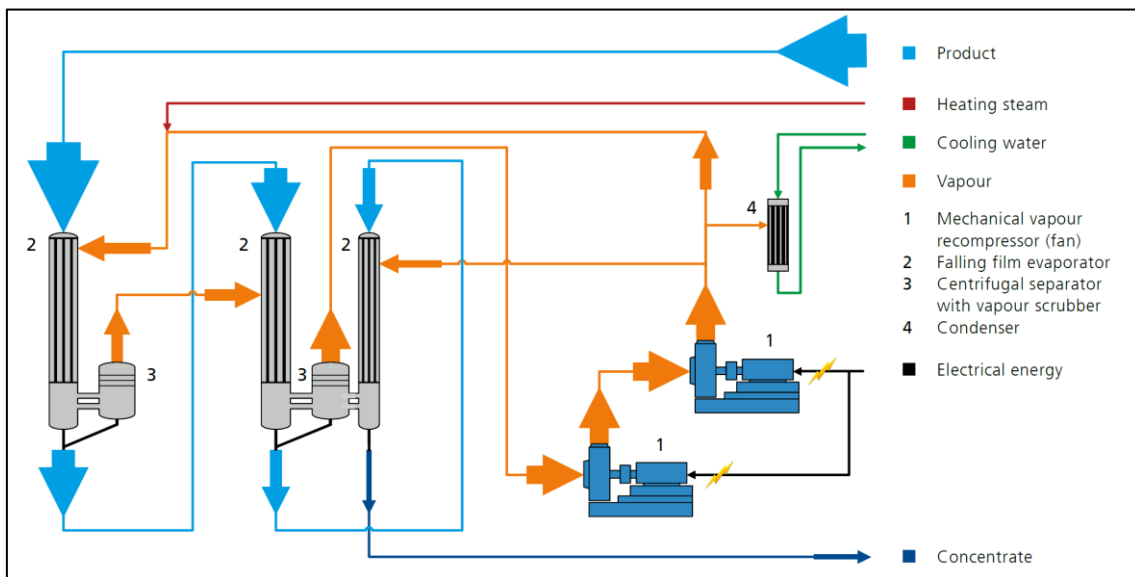


Figure 7. Two-effect falling film pre-evaporator and finisher arranged in parallel with two centrifugal vapour fans arranged in series.

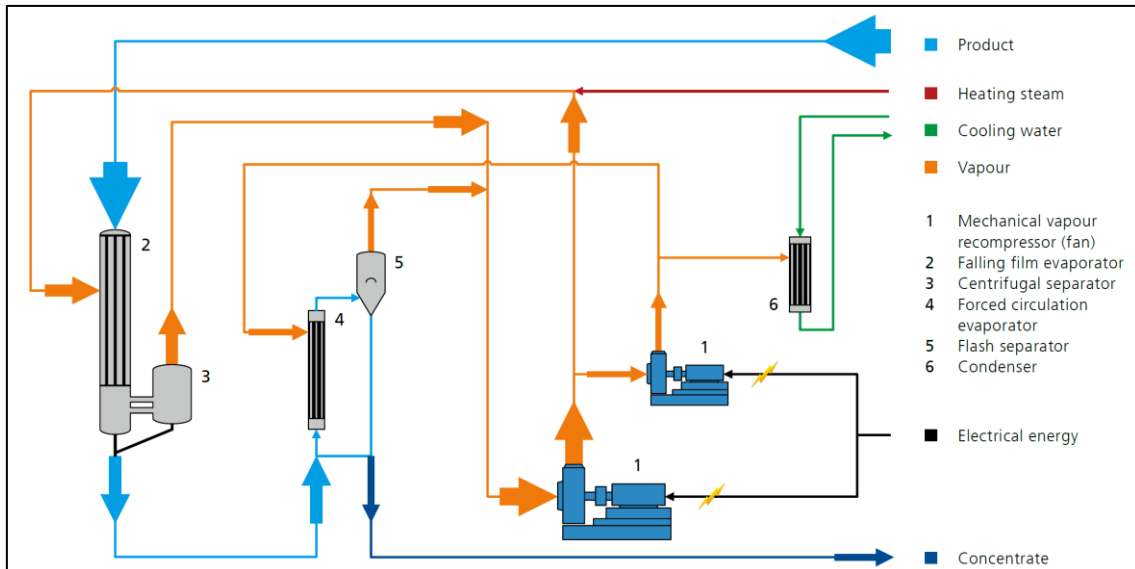


Figure 8. Two-effect falling film forced circulation evaporator with centrifugal vapour fan as main recompressor and a second smaller partial flow fan (booster).

3.5. Advantages of MVR

This Mechanical Vapour Recompression (MVR) offers many advantages:

- MVR units offer high capacity flexibility thanks to the use of variable frequency drive on the machines' motors
- Simple mechanical concept and robust and proven technology based on the centrifugal fan technology
- Live steam is not needed, the energy in the case of MVR is electrical power provided to the machines' motors.
- No condenser is required because almost all the evaporated vapours are re-used and condensed on the main shell and tube heat exchanger evaporator.
- The low operating temperature lead to lower rate of scaling on the heat exchange surfaces.
- During revamping projects or expansion projects, an independent evaporator unit can be installed on the side of the existing evaporation units and can offer very short production downtime during installation.

4. Case Study

This case study is about a MVR Falling Film Evaporator installed next to an existing spent liquor evaporation unit in order to boost the capacity of the unit and decrease the overall energy consumption. This case study is the only case of MVR application in an alumina refinery as far as we know but many producers of alumina are currently reviewing seriously this technology for potential expansion projects or new greenfield refineries.

4.1. Existing Spent Liquor evaporation unit

The existing unit was a 5 effect Falling Film evaporation unit and has been running successfully for 10 years and the owner wanted to increase the capacity of this unit.

4.2. Project Requirements

Here were the requirements for this project:

- Increase of the evaporation capacity by 30T/H
- Reduce the overall steam consumption
- Increase the overall efficiency
- Limit the downtime period of the running line during erection and start-up of the new one.

4.3. Proposed Evaporation Unit

The MVR Falling Film unit was offered as a pre-concentration unit in front of the existing line. This new falling film which was similar to the other falling films of the multiple effects line has been installed in front of this existing line, completely independently. This new falling film was a Monoblock type, the tube bundle was inserted in the vapours' separator enabling cost saving in terms of footprint and required steel structure. It was possible to make use of the existing steel structure without too many changes.

Two centrifugal fans set-up have been proposed in order to get a compression factor high enough to exceed sufficiently the BPE of the spent liquor. A scrubber for the vapors has been integrated into the vapour's separator in order to protect the fans' impellers and also to ensure a good quality of the process regenerative condensates.

4.4. Economical comparison

In order to support the idea of an MVR unit, GEA has made an economical study and showed the advantages of this technology. The figure 8 below is presenting the economical comparison of the operating costs for this case study.

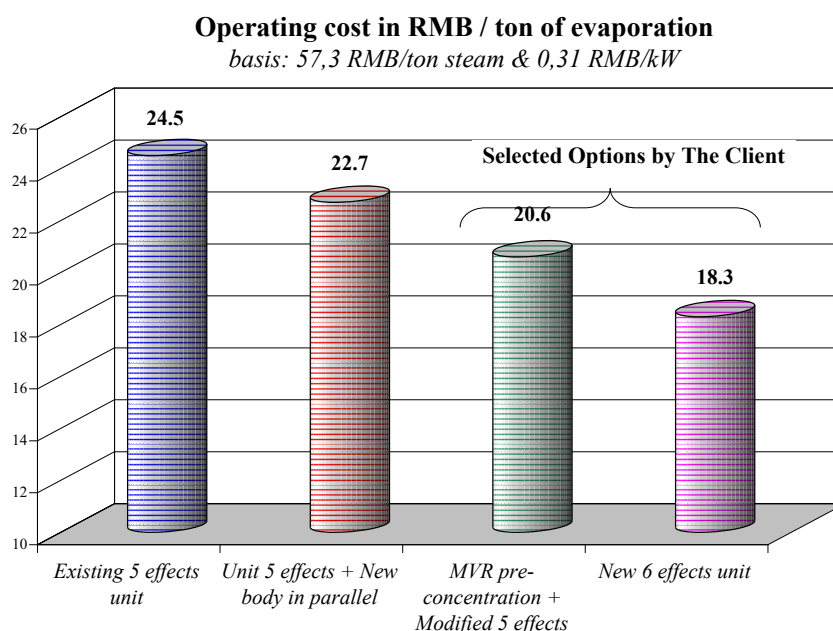


Figure 9. Operating costs comparison for this case study.

The installation of a complete new line of 6 effects was the most attractive one in terms of operating costs savings.

Two alternatives have been presented for the increase of the plant capacity:

- Having more surface area for the existing line of evaporation without changing the process flowsheet (this is the case called “Unit 5 effects + New body in parallel”).
- Offering a MVR pre-concentration in front of the existing evaporation line.

The above economical comparison of the operating costs enabled the end user to decide to choose the MVR option because this scenario was offering very good operating costs savings.

4.5. Records and Performances from this MVR Project

The new evaporator was erected independently to the existing one. The shutdown period for the existing line was only for the piping connection, and the production was re-started after only 24 hours.

In the following table we present the initial performances and the new performances after the MVR installation for this evaporation unit:

Table 3. Performances before and after MVR unit installation.

	Existing 5 effects	5 effects + MVR
Evaporation rate	150 tph	180 tph
Steam economy	0,375 t/t	0,260 t/t
Power	10 kW/t	15,8 kW/t
Cooling water	14 t/t	11,8 t/t
Inlet Na ₂ Oc	150 gpl	150 gpl
Outlet Na ₂ Oc	250 gpl	260 gpl

The two fans had a total electrical consumption of 1200 kW and an operating speed of 3200 rpm.

5. Conclusion

The Mechanical Vapour Recompression technology has proven its capabilities for energy savings in alumina refineries. The operating costs are minimized by replacing live steam and cooling water by electrical power, and moreover the reduced running temperature also limit significantly the scaling of the heat exchange surfaces. This means that maintenance and availability are improved in comparison with other designs.

If electrical power is available with steady conditions and a competitive price, MVR evaporation technology should be really assessed as a potential solution. It can be used as a booster for capacity with an existing unit during expansion programs; but it can also be the best solution for greenfield projects where the caustic concentration is limited leading to low boiling point elevation.

While MVR has been used for decades in other industries (i.e. Pulp & Paper industry or Salt industry), this technology is also a good fit for the Alumina refineries.