FALLING FILM TECHNOLOGY FOR LIQUOR CONCENTRATION, EXPERIENCES FROM A RECENT START-UP

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Abstract

Two principal evaporative techniques are used to concentrate aluminate liquor. In flash evaporation the liquor is preheated before it is flashed through a series of evaporators. In multiple effect evaporation the liquor receives heat in each evaporator separately. Multiple effect evaporation is carried out using a variety of evaporators such as, rising film, falling film or forced circulation.

The recent commissioning of an evaporation plant in India offers a good opportunity to look at the advantages that falling film evaporator technology offers the alumina refinery operator.

The plant consists of two evaporation trains each of which contains six effects. The plant is designed to accommodate various load requirements such as, economy (6 effects / 6 bodies), high capacity (5 effects / 6 bodies) and washing (5 effects / 5 bodies). To minimise downtime during configuration changes motorised isolation valves are provided in the liquor lines and vapour ducts.

Due to the high liquor velocity that prevails in the evaporator tubes the residence time is very short and the super-saturated liquor does not have sufficient time to reach equilibrium. Precipitation of solids is hindered and scaling minimised. As a result the frequency of the washing cycles is low and the plant has a high utilisation factor.

By installing high efficiency demisters in the vapour ducts condensate with a low conductivity is recovered and can be used as a source of make-up water for the boilers.

The extensive use of frequency controlled pumps in place of control valves not only reduces the electrical power requirements but also leads to very stable control of the level in the evaporators.

1. Introduction

In the production of alumina by the Bayer process the caustic liquor cycles between the unit operations in a closed loop. Due to the ingress of water into the loop, particularly in the washing stages, it becomes diluted and has to be re-concentrated before it can be recycled to the bauxite digestion.

In order to maintain the water balance an evaporation unit is installed in the spent liquor line to the digestion. To minimise the steam consumption the evaporation is performed in multiple evaporators. As the quantities of water that have to be removed are substantial, it is important that the most suitable equipment is chosen both from an investment as well as operating view point.

The recent commissioning of an evaporation plant based upon falling film technology offers a good opportunity to look at the advantages that this type of evaporator offers the refinery operator.

2. Criteria for Evaporator Selection

2.1 *Heat Transfer Coefficient*

In the selection of an evaporator the most import single factor is the heat transfer coefficient. The heat transfer coefficient determines the surface area and this represents the major part of the equipment costs. Other factors being equal the selection of the evaporator is based upon which type gives the highest heat transfer coefficient for a given cost.

If power is required to circulate the medium through the evaporator then this added cost has to be compensated for by an enhanced rate of heat transfer.

The maximum heat transfer coefficient is obtained when condensation or boiling occur at the heat transfer surface. In this case the temperature profile between the heat transfer surface and the liquid surface is minimal and a high heat flux is possible. The ideal situation occurs when there is condensation on one side of the heat transfer surface and evaporation on the other. In both rising and falling film evaporators this concept is utilised. For this reason these evaporators are always an early consideration whenever a new evaporation duty is being examined.

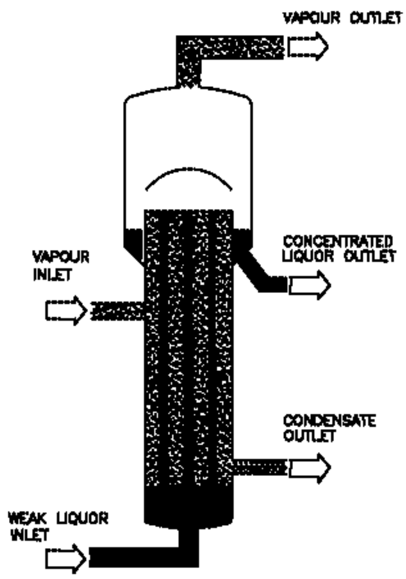

Figure 1 — Rising Film Evaporator

In rising film evaporators the thermal flux from the vapour condensing in the shell is the driving force for lifting the liquid film upwards through the tubes. Good heat transfer coefficients are obtained, provided the liquor enters the evaporator at close to its boiling point. If this is not the case then part of the surface area has to be used for preheating.

This type of evaporator has the advantage that no pump is required, however it does require a minimum

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temperature difference for hydraulic flow and this limits the number of effects and hence the steam economy.

The turn-down with this evaporator is also limited because the hydraulic flow is no longer provided at low heat fluxes.

This type of evaporator has found widespread application in alumina refineries, however it is being increasingly superseded by the falling film evaporator.

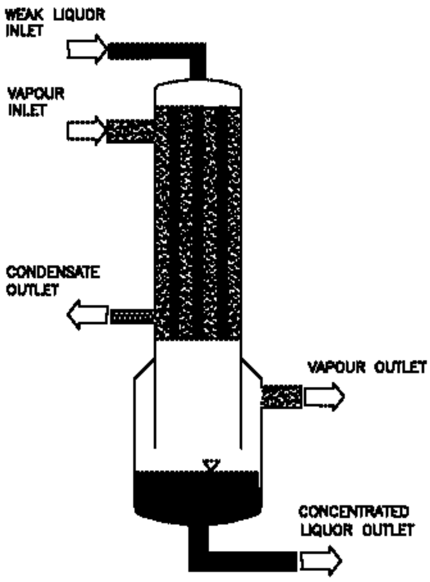


Figure 2 — Falling Film Evaporator

In falling film evaporators the liquid is pumped to the top and distributed to the tubes where it runs down as a film. Very high heat transfer coefficients are obtained with these evaporators because a film is ensured over its entire length.

As no temperature difference is required for hydraulic flow very small temperature differences are possible and this enables the number of effects to be increased, which boosts steam economy.

It is also feasible to operate this evaporator with a high turn down because the liquor is recycled over the evaporator by the pump irrespective of the actual load situation.

A further advantage of this type of evaporator is that as the hydraulic flow is independent of the heat flux a high concentration gain is possible. The concentration gain is the ratio between the product and feed concentrations.

For alumina refineries which require a high concentration gain the falling film evaporator is being increasingly chosen as the most suitable equipment.

A second group of evaporators is based upon the concept that on one side of the heat transfer surface there is condensation of the heating medium, for example steam, and on the other there is sensible heat transfer in the process medium. Typical examples of this type are flash evaporators, natural circulation or forced circulation evaporators.

In forced circulation evaporators good heat transfer coefficients are achieved however at the expense of very large circulation rates through the heat exchanger with the result is that the power consumption increases. The large circulation pump with corresponding piping also added to the plant costs.

This type of evaporator can however handle solids easily and for this reason finds application in some alumina plants.

In flash evaporators the liquid is firstly preheated in a series of heat exchangers against flash vapour before it is flashed through a series of flash vessels. Typically the heat transfer coefficients that are obtained in the heat exchangers are lower than with film evaporators because only sensible heat transfer is possible on the liquor side and as a result larger heat transfer surface areas are required. However they have the advantage of being simple and compact.

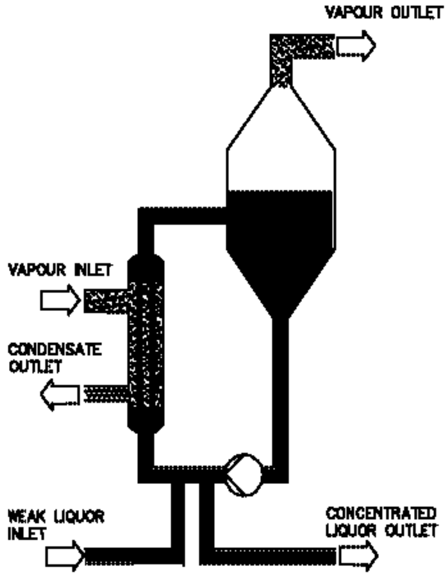


Figure 3 — Forced Circulation Evaporator

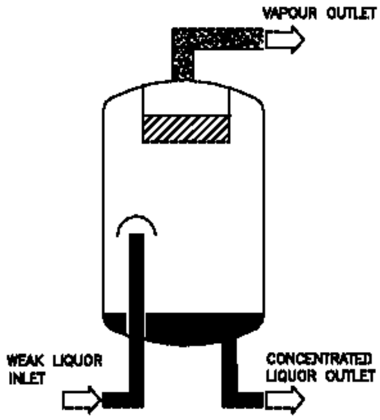


Figure 4 — Flash Evaporator

A limitation with this type of evaporator is that the temperature rise that can be achieved through preheating is restricted and hence the concentration gain is limited. This evaporator is therefore suited to alumina refineries where only a limited concentration gain is required.

2.2 *Tendency for Scale Formation*

An equally important criteria in selecting an evaporator is the tendency for the process medium to form scale. Scaling occurs when through a temperature or concentration change the saturation level is exceeded and a solid phase precipitates out of the solution. Precipitating solids have a tendency to grow onto the heat transfer surface as scale and this leads to a reduction in the heat transfer coefficient. As a result the heat transfer rate falls and either the capacity of the plant has to be reduced or the evaporator washed.

It is a well known phenomena that a certain degree of super-saturation is required before precipitation from a saturated solution starts. As a result there is a time lag between the moment when saturation is reached and when precipitation actually commences. If the contact time between the liquid and the heat transfer surface can be minimised then the potential for precipitation to occur whilst the liquid is in contact with the surface will be reduced and therefore the danger of scale forming on the heat transfer surface will be less.

In falling film evaporators the contact time between the liquid and the heat transfer surface is very short in comparison with the residence time of the liquid in the sump. This means that most of the precipitation places in the sump where there are no sensitive heat transfer surfaces and the evaporator tubes remain clean.

It has been found on some plants that the washing cycles of falling film evaporators are typically based upon a frequency of four to six months for the hotter effects and less for the colder. As a result high utilisation factors are achieved and only minimal operator attention is required.

3. Description of the Plant

The plant consists of two independent evaporation trains each of which contains six falling film evaporators. The process is based upon backward feed which means that the weak liquor enters at the cold end and flows countercurrently to the steam. As the temperature of the weak liquor feed is higher than that of the fifth effect the liquor is fed in parallel to both the fifth and sixth effects. In this manner heat can be re-utilised and the live steam consumption reduced.

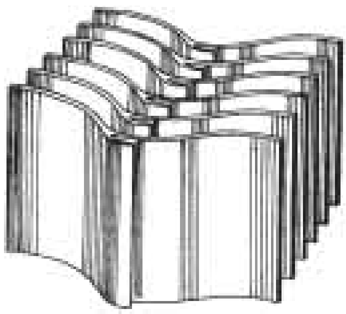
The liquor is pumped to the top of each evaporator where it is distributed uniformly over the cross section by the internal distributor. As the liquor flows down through the tubes it is heated by vapour which condenses in the shell and the liquid-vapour mixture enters the sump. In the sump the vapour is forced to change direction thereby discharging most of the entrained liquid droplets before it flows up through the annulus to the outlet duct. The concentrated liquor collects in the sump and is pumped to the next hotter effect, whereby provision is also made to recycle liquor as required.

The liquor becomes progressively more concentrated as it passes through the effects. Finally it is discharged from the first effect and cooled to the required return temperature by flashing it through two vessels. The flash vessels not only reduce the temperature but also boost the liquor concentration.

Live steam is used as a source of heat for the first effect only. The condensate is returned directly to the boiler house without flashing.

The vapour leaving the sump of each effect passes through an external demister to remove entrained droplets. The demister is equipped with lamella profiles and as the vapour passes between them it is forced to change direction. The liquid droplets impinge on the lamella surface where they collect in vertical channels and are returned to the evaporator sump. The vapour enters the shell side of the next colder effect where it is condensed.

As the recovery of high grade vapour condensate, for use as boiler make-up water, is one of the special requirements of the plant, the demister in the duct between the first and second effect is equipped with a two stage lamella system. The condensate that is recovered, known as the 2^{nd} effect condensate, is removed separately from the plant. To ensure that the conductivity satisfies the specification it is checked by a conductivity meter.



Mist eliminator profile, type series TXK

Figure 6 — Mist Eliminator Profile

The vapour from the other effects also passes through demisters but these are equipped with single stage lamellas. The condensate is flashed down through the effects and is discharged from the sixth effect as the sodic condensate. Its conductivity is also monitored before it leaves the plant.

Table 1 — Main feed and product data

Component	Units	Feed	Product
Na_2O Caustic	gpl	156	226
Na_2O Total	gpl	184	266
Al_2O_3	gpl	88	128
Temperature	°C	83	103

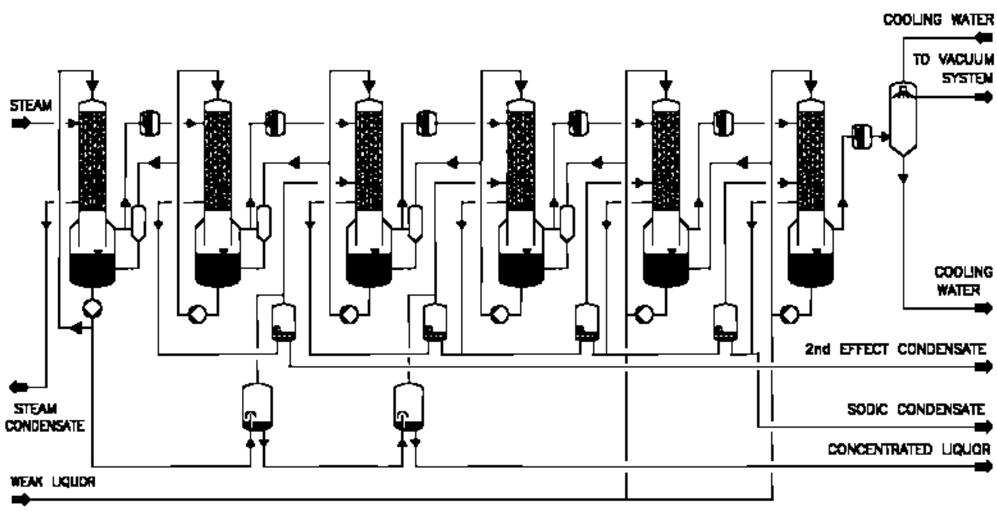


Figure 5 — Six Effect Falling Film Evaporation Plant

The plant is designed to operate at three different configurations:

Table 2 — Plant Configurations

Configuration	Economy	High Capacity	Washing
Effects	6	5	5
Evaporators	6	6	5
Evaporation, T/H	135	185	165
Steam, T/H	39.3	60.3	55.6

Economy (6 effects / 6 bodies), this is the standard configuration and gives the best steam economy.

High Capacity (5 effects / 6 bodies), this configuration is utilised when high evaporation rates are required.

Washing (5 effects / 5 bodies), this configuration is utilised when one of the first three effects is being washed.

To minimise downtime during configuration changes motorised isolation valves are provided in the liquor lines and vapour ducts. A typical change-over takes about 45 minutes.

The steam saving when operating in the six effect Economy configuration when compared with the five effect High Capacity or Washing configurations is approximately 11%. There is no appreciable difference in the steam economy of the High Capacity and Washing configurations because both are based upon a five effect arrangement.

For an absolute comparison between these figures and those on other plants the following points must be taken into consideration. The steam condensate is not flashed but is returned directly to the boiler from the first effect. The 2^{nd} effect vapour condensate is returned hot. The temperature of the liquor product is 20°C hotter than the feed temperature.

4. Operating Experiences on the Plant

The plant was subjected to an evaluation three months after it had been commissioned. During this period the plant had not been washed.

For the evaluation the train was operating in the Economy configuration. The guaranteed figures were as follows:

Table 3 — Guarantee Figures

Configuration	Economy
Evaporation, T/H	135
Steam Economy, T/T	3.44
2^{nd} Effect Condensate, Conductivity microSiemens/cm	6.0
Sodic Condensate, Alkalinity as mgpl Na_2O	20
Power kWh/T Evaporation	7

4.1 *Evaporation Capacity and Steam Economy*

The evaporation capacity and steam economy of the plant exceeded the guarantee figures. Furthermore the pressure and temperature profiles of the plant were well within the design figures indicating that the heat transfer coefficient was unchanged. This confirms that the tubes have not suffered any measurable scaling even though the plant has been in operation without washing for three months.

The lack of appreciable scaling confirms the good characteristics of the falling film evaporator, namely the short residence time in the tubes. It also confirms that the distribution of the liquor to the tubes is uniform and that full wetting is being achieved over their entire length without the formation of dry spots.

4.2 *2^{nd} Effect Condensate*

As the 2^{nd} effect condensate is to be used as make-up for boiler feed water its conductivity was restricted to maximum 6.0 microSiemens/cm.

The actual conductivity was found to be between 3–6 microSiemens/cm (equivalent to 0.55–1.10 ppm Na_2O) therefore fully satisfying the specification.

In order to achieve this very low value the efficiency of the demister has to be very high and was found to be over 99.8%.

The typical droplet load of the vapour from the first effect evaporator is 2'000 ppm. The maximum total caustic concentration of 266 g/l as Na_2O and the specific gravity is 1'274 kg/m^3 which gives a Na_2O concentration of 20.88%.

$$\frac{(2'000 \times 20.88\% - (0.55 + 1.10)/2)\ \text{ppm} \times 100}{2'000 \times 20.88\%} = 99.8\%$$

An important criteria for such a high efficiency of the demister is that the lamella surface remains clean and free from solid deposits. The demisters are therefore equipped with multiple spray nozzles which are installed directly in front of the lamella and operated intermittently with a timer.

4.3 *Sodic Condensate*

The alkalinity of the sodic condensate fulfilled the specification of 20 mgpl as Na_2O without any problem.

4.4 *Electrical Power Consumption*

The total electrical power consumption of the plant was measured over a 24 hour period and found to be well below the guaranteed figure.

The use of frequency controlled transfer pumps in place of control valves for regulating the flows between the evaporators enabled a significant reduction in the power consumption to be realised.

It was further observed that the use of frequency controlled transfer pumps led to very stable levels in the evaporators.

5. Conclusions

The commissioning confirmed that the plant was meeting all the guaranteed operating parameters.

An important advantage of falling film evaporators is their high heat transfer coefficient. The results have confirmed that this has been achieved.

Of significant importance is the fact that although the plant had been operating for a period of three months without any washing the temperature and pressure profile throughout the plant was well within the design limits. This confirms that the heat transfer coefficients were practically unchanged and the rate of scaling is very slow.

It has been shown that by installing high efficiency demisters it is possible to obtain a very pure process condensate that can be used as make-up for boiler feed water.

The power consumption of the plant has been minimised through the use of frequency controlled transfer pumps. It has also been found that this means of control also provides very stable levels in the evaporators.

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