BLACK LIQUOR EVAPORATORS: OPTIMIZING PERFORMANCE

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INTRODUCTION

Over the last decade, the Pulp & Paper Industry has entered a new era:

- New environmental regulations have been put in place resulting in a substantial tightening of the liquor cycle – to reduce color and BOD discharges – and also in the demand for higher firing solids in the recovery boiler to reduce air emissions.

- Rising energy costs have become a major concern for the financial viability of many mill operations resulting in special attention being paid to optimizing on-site energy production processes and usage to become more efficient and more competitive.

These factors have placed an increased emphasis on improving the performance and energy efficiency of the evaporator plant as it is among the biggest consumers of steam and cooling water within the mill. Many mills have responded by embarking on substantial programs to modernize and upgrade their facilities, in particular by:

- Gaining additional black liquor solids throughput and increasing final liquor concentration, often substantially above the original design capacity of the equipment.

- Reducing the generation of foul condensate though better segregation in order to minimize the operating cost associated with post-treatment of this condensate.

- Minimize liquor entrainment to reduce soda losses and allow for direct recycling within the mill of a large portion of the process condensate generated during liquor evaporation.

- Finally, more recently, look at the overall recovery island for opportunities to lower the overall energy consumption (steam and power) through better use of the evaporation process and of recent technological developments in concentrator designs.

Key to the success of these upgrades is understanding that each design parameter must be optimized individually, taking into account the unique features of each evaporator train, liquor characteristics, overall power and recovery configurations as well as the overall goals for the upgrades.

What worked well on one specific evaporator train at one location may not be appropriate at another mill and, whereas many such upgrades are successful, we all know several of these upgrades that turned into disappointments, with unmet performance guarantees or even outright failures.

The following are but a few of the performance problems encountered with multiple effect evaporators along with an overview of the typical upgrade programs that can be undertaken.

SURFACE CONDENSERS AND VACUUM SYSTEMS

Insufficient vacuum is by far the most common operating problem encountered with evaporators. Reduced vacuum lowers the available working Delta-T between the steam in the first effect and the vapors in the last effect – in other words the actual driving force for the evaporation process – resulting in a loss in evaporation capacity. To compensate for such loss, operators will run the first effect at higher steam pressure and temperature. Capacity is gained, however steam economy is lost.

The vacuum system must be designed to adequately remove the non-condensible gases that evolve from the liquor during evaporation. In this respect, many systems in service today are grossly underdesigned. Vacuum systems in a Kraft mill should be sized for 65 to 75 lbs/hr air removal (plus moisture of saturation) per 100,000 lbs/hr evaporation at the designed vacuum.

‘Moisture of saturation” is the water vapor present in the non-condensible gas. The ratio of water vapor to non-condensible gas increases greatly with a rise in the temperature of the mixture. For this reason, the gas must be cooled before it enters the vacuum system, either by a precooling section built into the surface condenser or by an external precooler.

Insufficient precooling is very common and is usually due to either an insufficient precooling surface or improper baffling for adequate gas contact.

The mechanical design of the piping and equipment between the last effect and the inlet to the vacuum system must be such that the pressure drop in this part of the system is minimal. A pressure drop higher than 1.0 to 1.5

in. Hg necessitates an unrealistically high vacuum at the vacuum system in order to achieve the design vacuum in the last effect.

Insufficient system vacuum may be caused by vacuum equipment malfunction or inadequate surface condenser performance, or both. Before condenser performance can be evaluated, proper operation of the vacuum equipment should be assured – i.e. an absolute pressure of approximately 3.0 to 3.5 in. Hg should be maintained at the vapor inlet to the vacuum system. If the absolute pressure is higher, then:

- The gases should be precooled to 100 °F or less (or 5 to 10 °F warmer than the cooling water inlet temperature)
- Vacuum reading at the inlet of the vacuum system should be approximately 26 to 27 in. Hg. Any lower reading, with proper gas temperatures, will indicate that repairs are necessary on the vacuum system itself.
- Insufficient vacuum could also indicate excessive air leakage or inadequate vacuum system sizing , or both. The entire system should be thoroughly checked for air leaks.

If the vacuum at the inlet to the vacuum system is adequate, but insufficient at the last effect vapor body, poor performance of the surface condenser is indicated. Typical problems encountered are

- The condensing surface may be insufficient. If a condenser has been designed with an unrealistically high heat transfer coefficient, the only solutions to the problem are to install an auxiliary condenser, increase the condenser water flow, or operate at higher condensing temperatures.
- Water flow may be insufficient, possibly due to such things as excessive usage elsewhere, a worn water pump, inadequate piping, flow restrictions, and high pressure drop across the condenser due to tube plugging.
- Condenser water boxes may be leaking. This condition would be indicated by poor condenser performance even though the water flow is adequate. Water partially or completely short-circuits one or more passes, effectively by-passing some of the condensing area.
- Condenser tubes may be fouled on the water side by slime or other materials. Hydroblasting of the tubes may be required.
- Condenser venting may be inadequate. Pockets of gas can accumulate in some areas of the condenser shell due to improper set-up of internal baffles. Additional vent nozzles may have to be installed in the condenser shell.
- Finally, the condenser tubes may be fouled on the shell side with dried up liquor or other organic material. Removal is difficult and may best be accomplished by boiling with special chemicals sold for that purpose. This condition is usually caused by excessive, even if infrequent, entrainment or foaming from the last effect during operational upsets.

LIQUOR PREHEATING

In any evaporator design, but more evident in older rising film evaporators, the entering liquor velocity and preheat requirement play a major role in determining the heat transfer coefficient at each effect. Liquor normally enters the tubes at the bottom tubesheet at a velocity of only 2 to 3 inches per second, far too low for good heat transfer to occur. In a rising film unit, good heat transfer is not achieved until the liquor begins to boil and the escaping vapors accelerate a thin film of liquor up the tube wall.

In a multiple effect train, the typical liquor scheme results in substantial liquor preheat loads on effects 1 through 4. Internal liquor heaters are normally provided to handle this sensible heat in an efficient manner. However, in time, the internal liquor boxes will start leaking or even fail altogether and the typical response to such occurrence will be to by-pass the internal heater. Such loss of an internal liquor heater is a common cause for a low heat transfer coefficient determination.

Operation and economy can be greatly improved with the conversion of internal liquor preheaters to evaporation tubes and the addition of an external heater in its place. This will effectively both increase the heating surface and increase the heat transfer coefficient in the offending effects

Liquor heater additions should always be designed correctly to maximize the benefits to the evaporators while avoiding the possibility of fiber plugging. Liquor heaters should be engineered to minimize pressure drop on the

liquor side and using a high Delta T to drive any heater should be avoided.

CONDENSATE SEGREGATION

It takes an amazing amount of energy and chemical cost to use and throw away water. As a result, the black liquor evaporators have become the major "water – treatment" plant to produce condensate suitable for re-use within the mill.

A large portion of a pulp mill's contaminated condensate comes from the multiple effect evaporator system. These condensates are contaminated with both BOD (mostly methanol) and TRS compounds which affect their reuse within the pulping process. About 75% of the volatile BOD and a much larger fraction of the TRS are stripped from the weak liquor in the first two stages of evaporation. In a six effect evaporator system, with the weak liquor feeding the fifth effect, the condensate resulting from the vapor generated in the fifth and sixth effects will be the highest in contamination.

To gain the highest steam economy within a set of evaporators, the contaminated condensate is flashed downhill in each succeeding effect to recover its heat content. Hence, the relatively clean condensates generated in the second through fourth effects of a six effect system are contaminated when they are flashed in the bodies of the fifth and sixth effects. The first step to minimize the amount of condensate to be handled is to remove the condensate from the fourth effect and flash it in external flash tanks with the vapors going to the shells of the fifth and sixth effects. This not only maintains the system's overall economy but further removes a portion of the volatile contaminants through flashing. This condensate fraction typically contains no more than a few ppm of TRS while methanol is at less than 150 ppm. This makes this condensate suitable for re-use on the brownstock washers in the pulp mill.

Condensate segregation technology follows the simple principle that volatile compounds present in the process vapors will tend to condense last compared to the less volatile water vapors. As such, two-stage condensing will effectively move or segregate most of the contaminants into the second condensing stage, thereby producing a fairly clean condensate fraction out of the first stage. On a new, modern falling film evaporator train, two-stage condensing is achieved internally to the heating element where a baffle divides the condensing area into two separate units in series.

The same thinking can be applied to an older evaporator system by adding additional heat exchangers and an auxiliary condenser to the system. Typically, condensate segregation will only take place on the fifth and sixth effects, and the surface condenser. The vapor enters each evaporator heating element in a typical fashion, however a large amount of vapors is then vented through a large nozzle on the heater shell into the external heaters and/or the auxiliary condenser. In other words, only partial condensation takes place in the heater shell while most contaminants are taken out with the large vapor vent. The amount of vapors that may be drawn into the liquor heaters is related to the heat and material balance of the set but can also be controlled for maximum contaminant removal.

The condensate fractions collected in the external heaters and secondary condenser are extremely fouled with methanol levels often over 6,000 ppm. This fraction requires external treatment, usually via stripping, before it can be re-used within the mill.

The condensate fraction collected in the shells of the fifth and sixth effects as well as from the main surface condenser is slightly contaminated with methanol levels typically around 400 ppm. This is still suitable for this condensate to be re-used in recausticizing operations.

MIST ELIMINATION

Implementing a process scheme for condensate segregation will all be for nothing if excessive liquor entrainment into the various condensate fractions prevents their optimum re-use within the facility.

The impact on recovery operations includes chemical (soda) losses, heaters and condenser fouling (reduced capacity), fouling of the stripper preheaters (boilout costs) and poor stripping efficiency.

Possible reasons for the excessive carry-over can be that the train is pushed too hard for capacity, but also fouled, damaged or dislodged mist eliminators.

Simply cleaning the existing mist eliminators or replacing them in kind only buys time until the units become fouled or plugged once again. It may instead make more economical sense to upgrade entrainment separation to high efficiency mist eliminators, available in either

vertical or horizontal flow patterns. Both options require some upgrades on the internals of the vapor domes but contamination levels in the condensate can be dropped to the 20-30 ppm Na_2O range for vertical flow units and as low as 5-20 ppm Na_2O for an horizontal flow configuration.

NON–CONDENSIBLE VENTING

Non–Condensible Gases (NCGs), primarily hydrogen sulfide and mercaptans are released from the liquor at each evaporation stage but the bulk of them comes out during the initial two stages of evaporation after the feed liquor enters the evaporator set. As these gases are all heavier than water vapors, they tend to accumulate toward the lower tubesheet area of the heating element where they effectively blanket the heating surfaces and do not allow access to the incoming vapors for condensing.

Effectively, less area is provided for condensing of the incoming vapors and the offending effect will end up operating at a higher Delta-T thus reducing the overall capacity of the set. A heat & material balance would typically reveal a low heat transfer coefficient in that effect. Operators would also notice that the set quickly returns to high pressure operation after a boilout.

NCGs removal is normally accomplished in an area of the heating element one to three feet above the bottom tubesheet. A nozzle on the side of the shell or a perforated tube extending from the top of the bundle is the common method of extraction. As the evaporator train is typically operated today at a capacity substantially above design, very often removal of NCGs is woefully insufficient. In addition, after years of operation, extensive amounts of scale (dried up liquor) will have accumulated enough to either impede or totally block off the NCG vent point.

If poor NCG venting is suspected, new vent points must be installed. Locating the new vent nozzle directly above the condensate outlet insures an unobstructed path for the NCGs as this area always remains clear of build-up due to the washing action of the exiting condensate.

Because the majority of the NCGs come out in the early stages of evaporation, it is advisable to vent the 5^{th} and 6^{th} effects directly to the condenser (to the secondary condenser on a set with condensate segregation) via a common header dedicated to these two sources alone. All the other effects can be vented to the next succeeding effect in line, a set-up commonly known as cascading the NCGs, which still allows good venting while optimizing energy recovery and steam economy.

HYBRID SYSTEMS FALLING FILM / RISING FILM

Mills wanting to increase capacity on an older rising film evaporator train or simply wanting to replace older bodies should consider integrating a new falling film unit with the existing rising film bodies.

Because the FF unit can be designed to accommodate a lower Delta-T, some driving force will effectively be freed and available to push the other effects harder, resulting in an overall capacity gain for the set. Obviously additional steam and cooling water will be required to sustain the new operating rate while, at the same time, other factors may limit the actual capacity gained.

Incorporating the new FF unit as the first effect will also provide the additional benefits of a better resistance to scale build-up and a greater turndown capability.

The same reasoning can be applied to increasing the capacity of an older quintuple or sextuple effect set via the addition of a new falling film body, converting the train to six or seven effect operation. Approximately 17% extra evaporation capacity can be gained by converting a five effect system to six effect operation in this fashion. With such conversion, each existing body is effectively maintained at the same evaporation load and therefore no additional steam or cooling water is necessary, only the new evaporator body is required. In fact, there has been many conversions of this kind driven solely by energy savings rather than increase in capacity.

Whether the new FF body is installed in the first or last effect position will depend on the actual characteristics of the existing train, not only from a heat transfer standpoint but also material of construction as the liquor concentration profile will change across the train as a result of the conversion. Falling film units can easily foam at low solids content and special attention has to be paid to the design when contemplating the addition of such unit as the last effect of a set.

FC CONCENTRATOR UPGRADE

Following the development and commercial demonstrations of enhanced heat transfer technology, and with energy costs rising, many existing conventional

Forced Circulation concentrators became ideal candidates for retrofit with turbulence enhancers. The technology is based on the use of spiral inserts within each tube of the concentrator heating element. Such inserts create very high levels of turbulence (high Reynolds number) thus greatly improving heat transfer conditions at the high liquor viscosities encountered in such concentrator service.

The main driving force for such retrofits is to significantly (about 45 to 50%) reduce the power consumption of the existing recirculation pumps. The power savings come from the lowering of the pumping rate, typically accomplished either by replacing the impellers or by reducing the rotating speed, or both. However, the addition of turbulence enhancers also results in a huge increase (about double) in heat transfer performance making such retrofits ideal for units operated near their maximum capacity. The retrofit allows the unit to run under much better conditions as the increase in heat transfer is matched by a corresponding decrease in Delta-T and therefore a reduction in the steam pressure used on the heating element.

Many State Authorities and Utilities are offering today some special financial incentives to help the mills finance such power savings upgrades. If your facility is still using a conventional, non-enhanced, FC concentrator, this type of retrofit can be a quick, easy and reliable source of savings for your operation.

CONCLUSIONS

Overall energy consumption for a multiple effect evaporator varies greatly from mill to mill based on the age of the facility, capital invested over the years, type of evaporator design used, configuration and integration of ancillary equipment (stripping systems, etc.), environmental limits, and other factors. Justification for the implementation of energy conservation projects at various mills will be different based on these factors. However it is critical to understand the performance of a particular evaporator train in terms of energy consumption and costs compared with a good operating train elsewhere.

The type of optimization projects as illustrated above can be undertaken in mills that have identified inefficiencies in operation and can improve the evaporator performance in terms of energy consumption, significantly improving the bottom line of the facility.