Preparation for an actual application of mechanical vapor recompression evaporation in the sugar beet industry. POPE, JAMES D.[1]*, and JOHN K. MANNO[2], [1]PSI Process Systems, Inc., 1790 Kirby Parkway, Suite 300, Memphis, TN 38138, and [2]Dedert Corporation, 20000 Governors Drive, Olympia Fields, IL 60461-1074.

Introduction

Actual Application of Mechanical Vapor Recompression Evaporation. A molasses desugarization facility has the requirement to concentrate multiple water-based streams. As has been normal for these facilities, an evaporator is the preferred system for removal of the necessary amount of water. However, due to limits on available steam supply at a selected site for a molasses desugarization facility, a single or multiple-effect steam heated evaporator system alone was not adequate.

Many beet sugar factories have seen capacity expansions and process additions over the years. As a result of this growth, existing steam boilers have been pushed to maximum capacity limits. Some straight-forward responses to a need for additional steam would be to perform major modifications to existing boilers, install new boilers, or reschedule operating campaigns to prevent operation of all steam users simultaneously. However, if the purpose of the factory expansions and additions is to increase sugar production, shutting down facilities for an extended period of time is not acceptable. On the other hand, modifying existing or installing new boilers requires large capital expense, especially if the infrastructure of the fuel source for the boilers must also be constructed or expanded. In addition, steam generating options have become more complicated due to air emissions permitting requirements. By staying within existing boiler capacity limits, permits already in place for a factory may not be significantly impacted.

Obviously, increasing steam production is not always straight-forward. Therefore, use of energy saving techniques, such as mechanical vapor recompression evaporation, is considered a viable option for the basic case described in the first paragraph. A system of mechanical vapor recompression units for initial concentration to remove large quantities of water followed by multiple-effect, steam heated units to finish evaporate the process streams is an excellent solution for the processing and project requirements.

Typical Beet Sugar Factory Evaporation. Equipment used for concentration of juice streams in the beet sugar factory are well known.

- Horizontal-tube evaporator,
- Calandria-type evaporator (also known as Robert type),
- Long-tube, vertical type evaporator (both rising film and falling film),
- Plate-type evaporator.

Over the years, developments in equipment design have resulted in attempts to improve evaporator performance and reduce energy use. However, the basic design of a steam heated, multiple-effect system, likely the most popular in beet sugar, has remained very similar: arranging evaporator bodies in series with vapor and/or process streams for increased efficiency and reduced steam requirements.

The evaporator design within the traditional factory has consistently proven to be successful in operation and economically feasible compared to other alternatives. Some of the basic requirements of factory operation can be satisfied: evaporation of water without excessive destruction of sucrose by heat, economically reasonable consumption of steam, capable of being automated, availability of excess low pressure vapors to supply heat to other areas of the factory (such as juice heaters, other concentrators, and pans), and collection of condensate for return to the boiler(s) or to process users.

New Requirements for Molasses Desugarization (MDS). The typical MDS facility processes molasses from the factory sugar end into at least two streams, product and byproduct. The most important stream is the primary sugar carrier and product, often termed extract. The additional streams contain high amounts of non-sugars and smaller amounts of sugar. The main non-sugar stream and byproduct is often termed raffinate. These resulting streams from the molasses separator equipment contain large amounts of water. Consequently, to allow proper storage and further processing of the extract and economically feasible storage and transport of raffinate, concentration of these streams is required.

Recent installations of MDS facilities have introduced additional considerations to the evaporator evaluation.

- Multiple streams to concentrate,
- Low feed concentrations due to elution water requirements in separators,
- Recycle of clean process condensate for separator feed,
- Turn-down capability to allow operation of individual separator trains,
- Flexibility to change the number of streams feeding the evaporator,
- Year-round operation,
- Non-sugar stream with precipitation of salts during and after concentration,
- Stainless steel material of construction.

<u>Mechanical Vapor Recompression (MVR) Evaporators - General Description</u>

The vapor recompression evaporator system is similar to a conventional steam heated, single-effect evaporator, except the vapor released from the boiling solution is compressed in a mechanical compressor. Compression raises the pressure and saturation temperature of the vapor so that it may be returned to the evaporator steam chest to be used as heating steam. The latent heat of the vapor is used to evaporate more water instead of being rejected to cooling water in a condenser.

The compressor adds energy to the vapor to raise the saturation temperature of the vapor above the boiling temperature of the solution by the desired net temperature difference. The energy or driving force for pressure increase is provided through shaft horsepower. Two typical sources or compressor drives for the necessary shaft horsepower are electrical motors and steam turbines.

The most widely used drive applied to MVR systems is the constant speed motor. For high evaporative loads, like in an MDS facility, these motors may be large sizes requiring high voltage electric supply.

As implied earlier, the steam chest and vapor separator of an MVR evaporator are similar to a conventional steam heated, single-effect evaporator. The steam chest may have differing designs, including the vertical-tube and horizontal-tube configurations already often used in the beet sugar factory. In addition, the vapor separator will be a vessel designed with adequate volume and entrainment separator components to prevent carry-over.

Application of MVR evaporator technology is well proven in several industries including the food industries. The technique has been in use for over one hundred years and obtained wide acceptance in the 1930's and 1940's in fresh water evaporators. During the 1970's, extensive application in the process industries began in North America and Europe. MVR evaporation is definitely an accepted technology for industrial processing.

Advantages of MVR Evaporators

1) Steam and overall energy consumption is significantly reduced compared to conventional steam heated evaporator systems with the same capacity; the energy required for evaporation is approximately equivalent to a twelve to sixteen effect steam heated, multiple-effect evaporator.
2) Cooling water requirements are significantly reduced, if not eliminated; MVR evaporators have little or no requirement for the condensing of vapors.
3) Vacuum pumps or other non-condensable movers are greatly reduced in capacity and size or may be eliminated depending on operating pressure.
4) Where higher operating pressures and temperatures are acceptable, higher condensate temperatures will result that can be used in molasses heating or evaporator feed heating applications and for use in separator feed water.
5) Normally, floor space / layout area required is less than multiple-effect evaporator systems with the same capacity; this reduces real estate and building costs.
6) It is sometimes possible to retrofit existing evaporators to MVR or to expand existing capacity by incorporating an MVR preconcentrator ahead of an existing system.

Disadvantages of MVR Evaporators

A few possible disadvantages that should be considered are:

1) MVR systems, in general, have a higher capital cost than conventional steam heated systems.
2) Operation at pressures near one atmosphere result in boiling temperatures that may be too great for heat sensitive materials such as high purity and high concentration sugar solutions.
3) High boiling point elevation, such as at higher concentrations, are not feasible due to higher temperature and pressure rise needs and resulting increase in power and heat transfer surface; compressor power consumption will be prohibitively expensive.

4) Direct injection of steam to make up for heat losses can swing the overall balance of water in an MDS facility. (However, the quantity of steam used is typically small and insignificant compared to the larger quantity of condensate collected and used.)
5) High electrical consumption (in the case of motor driven compressors) is required with high voltage supply.
6) Compressors are normally a capital intensive and high speed item that require proper orientation and maintenance; however, the turbofan is a type of lower pressure recompressor that is not as intense as other compressors. In addition, compressors are normally long lead time items; the requirements for critical spare parts is a justified expense including a separate rotating element and bearing package.

<u>Specification and Design of the Evaporation System</u>

The evaporation system for an MDS facility currently being installed is used for the evaluation in this paper. The requirements of the evaporation must first be defined followed by evaluation of the system information, design decisions, and development of the system configuration.

Feed. Multiple feed streams are transferred from the MDS separators to the evaporator. The primary sugar product, extract, and primary non-sugar byproduct, raffinate, are two of these streams. Raffinate is the largest water carrier but has the lowest total D.S. compared to the other feed streams. It has the highest total feed rate and a concentration of approximately 5%DS. For all of the feed streams, the feed rate, concentration (%DS), and temperature are specified, or the equivalent evaporative rate necessary can be given.

Stream Characteristics. With varying degrees, all of the process streams in the MDS evaporator have significant boiling point elevation (BPE) at the upper concentrations handled. These BPE must be properly specified. In addition, at the lower temperatures that are possible in an evaporator operated at vacuum pressures and at the higher concentrations that are required for the system products, viscosity of the streams begin to rise and may influence equipment sizing. Also, these streams have a slight tendency to foul the heat transfer surface over time, with raffinate having the added problem of precipitation of salts above approximately 42%DS. Finally, the streams high in sugar, such as extract, are heat sensitive since destruction of sugar occurs at high temperatures.

Product Requirements. As is typical with most MDS evaporators, the final concentrations required for the evaporator products are approximately 65% to 70%DS.

Steam Usage Restrictions. The MDS evaporator discussed in this paper is restricted to a maximum pounds per hour of steam due to boiler limits. This restriction is an overwhelming influence on the evaporator evaluation. The steam pressure and quality is specified.

Electric Power Limits. Supply of large electric loads are possible at the existing factory site. The cost for new electric feeder equipment is much lower than the costs associated with additional steam capacity.

Condensate Return Preferences. A large portion of the condensate from live steam should be returned to the boiler, whenever possible. In addition, the condensate from the evaporator vapors must have minimal contamination from carry-over.

Cooling Water Supply and Return Data. Cooling water is available in adequate amounts; however, new transfer equipment is required. Maximum supply temperature of 85°F and return temperature of 105°F is specified.

Material of Construction. The two grades of 316L and 304L stainless steel are the primary materials of construction for the evaporator parts in contact with liquid and vapors.

System Configuration and Design Decisions.

- Long-tube, vertical type, falling film, recirculated evaporators are used due to their efficiency with high viscosity, high density, and high boiling point elevation liquids. With these evaporators, the combination of a thin film undergoing boiling and viscous drag at the vapor liquid interface produces high heat transfer coefficients. In addition, a low liquid inventory inside the evaporator is beneficial when concentrating products which are heat sensitive and also reduces start-up and cleaning times. By use of the recirculated design on all of the bodies, the ability to turn down the capacity is greatly improved. Finally, tube lengths up to 40 feet allow conservation of floor space.

- Steam heated, multiple-effect evaporators are used for final concentration or as a "finisher". These evaporators provide very good steam savings from the use of vapors from preceding effects in series and an economical design, especially with the higher boiling point elevation present with higher concentrations. In addition, the pressure drop across the multiple-effect train results in evaporators operating at vacuum pressures and lower temperatures for heat sensitive streams like extract.

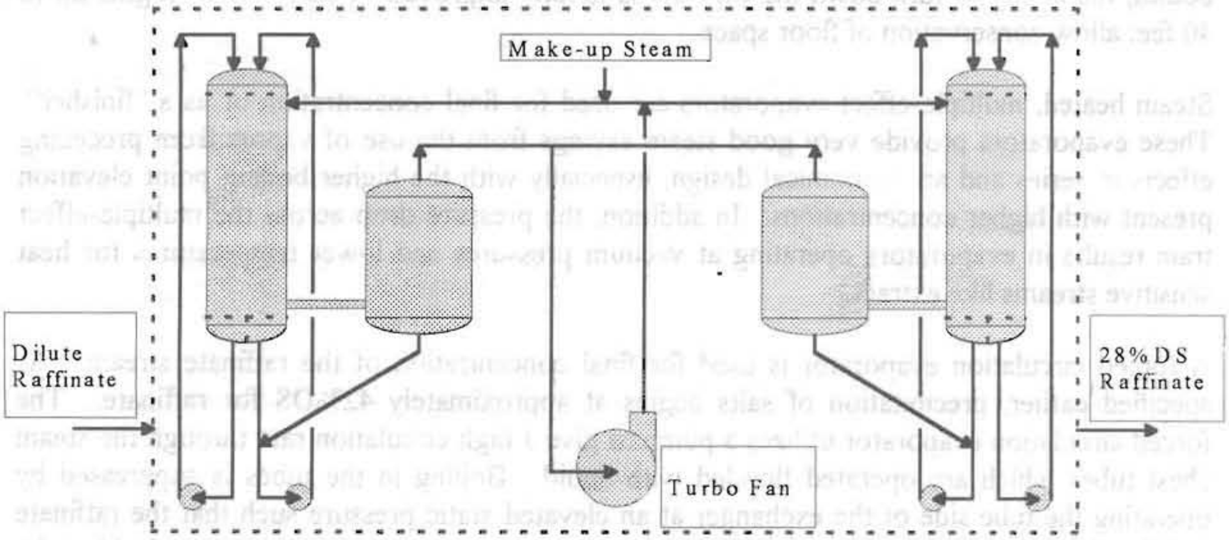
- A forced circulation evaporator is used for final concentration of the raffinate stream. As specified earlier, precipitation of salts begins at approximately 42%DS for raffinate. The forced circulation evaporator utilizes a pump to give a high circulation rate through the steam chest tubes which are operated flooded with liquid. Boiling in the tubes is suppressed by operating the tube side of the exchanger at an elevated static pressure such that the raffinate liquid will superheat rather than boil. Finally, evaporation is accomplished by flashing the liquid outside of the heat exchanger in a flash tank / vapor separator. These methods help prevent excessive fouling or precipitate buildup in the exchanger tubes.

- MVR evaporators become a necessary option because of the steam usage restriction. The necessary steam savings from a multiple-effect system alone become a costly method due to the high number of effects that would be required. Therefore, MVR evaporators are used on the streams with lower heat sensitivity, such as raffinate. By concentrating these streams in the MVR evaporator to a level where boiling point elevation is not unreasonably high, the largest portion of the water is removed before entering the multiple-effect finisher.

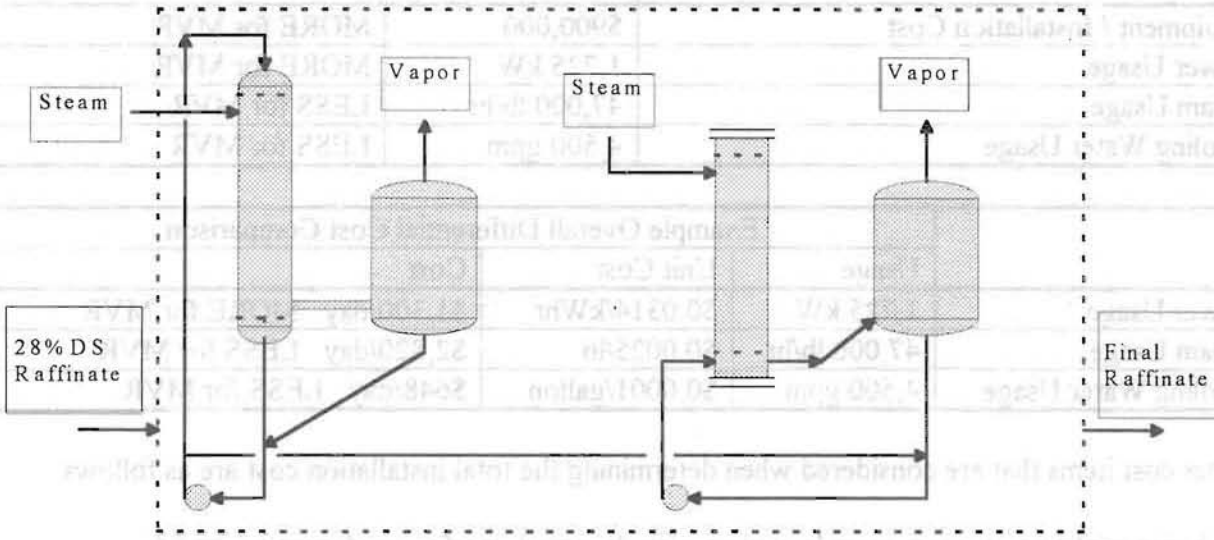
- Higher temperature condensate from the vapors produced in the evaporator may be used for preheating feed to the system. Especially with the MVR evaporator(s), the condensate is at a temperature near the boiling point of the liquid because of the energy supplied by the compressor. In addition, the collected condensate may be used for heating molasses, or if available, the higher temperature condensate recovered reduces the amount of further heating in the molasses separator area.

- The final design is a combination of the configuration components and design decisions described. A generalized flow diagram is given labeled as "MVR Evaporator" and "Raffinate Finisher."

MVR Evaporator



Raffinate Finisher



Comparison of MVR Evaporator to Steam Heated, Multiple-Effect Evaporator

As a comparison between an MVR evaporator system and a steam heated, multiple-effect evaporator system, the raffinate initial concentration to 28%DS can be used. The initial concentration alone is used since an MVR evaporator is not preferred in high concentration applications as described earlier. Therefore, for either case in the comparison, the finisher evaporator is considered identical for increasing concentration from 28%DS to 70%DS.

The MVR Evaporator for raffinate is made up of two systems operated in parallel. Each system contains two bodies, a "body" being a steam chest and vapor separator, with one common turbofan for recompression. Each steam chest is a two-pass unit for a total of four passes and four circulation pumps per system. One common condenser is used for both raffinate MVR systems.

A Steam Heated, Six Effect Evaporator is an alternative design for comparison. The steam heated evaporator would be a "train" of six bodies and effects each containing a vertical tube, falling film steam chest, a vapor separator, and a circulation pump for recirculated, single pass evaporation. A single condenser would be used after the final effect. Steam would be supplied to the first effect with the vapor from each effect passing to the next.

	MVR Difference from Steam Heated	
Equipment / Installation Cost	$900,000	MORE for MVR
Power Usage	1,725 kW	MORE for MVR
Steam Usage	47,000 lb/hr	LESS for MVR
Cooling Water Usage	4,500 gpm	LESS for MVR

	Example Overall Differential Cost Comparison		
	Usage	Unit Cost	Cost
Power Usage	1,725 kW	$0.0314/kWhr	$1,300/day MORE for MVR
Steam Usage	47,000 lb/hr	$0.0025/lb	$2,820/day LESS for MVR
Cooling Water Usage	4,500 gpm	$0.0001/gallon	$648/day LESS for MVR

Other cost items that are considered when determining the total installation cost are as follows:

- More cooling water for steam heated requires larger piping for condenser supply.
- More steam for steam heated requires larger piping for steam supply.
- Large turbofan motors for MVR require larger starters and wiring.
- Turbofan motors for MVR require additional foundation requirements and special layout considerations for maintenance access.
- For piping, the MVR has more stages to transfer between (8 vs. 6) with stainless steel piping.
- Overall controls and instrumentation would be similar between the two types of systems; however, the MVR turbofan tends to require additional on/off drain valves and measurements to monitor equipment performance.
- Layout space would be similar; however, a six effect, steam heated evaporator with large condenser would tend to take more floor space than two MVR evaporators with a total of four bodies.

Based on the example unit costs and overall cost comparison, a simplified, one year (330 days) differential in operating cost would provide a savings of $715,000 using the MVR evaporator. However, as reviewed previously, there are several considerations that must be included in the evaluation with an operating and capital cost such as these simplified examples given.

Conclusion

The application of MVR evaporators requires an in depth analysis of the nature and volume of the evaporative loads as well as an understanding of the configuration alternatives available. Based on the system requirements, specifications, and limitations described, a system of mechanical vapor recompression units for initial concentration to remove large quantities of water followed by multiple-effect, steam heated units to finish evaporate the process streams is an excellent solution for the MDS application presented.