Energy Savings in Crude Vacuum Towers via Structured Packing

David A. Freed
Richard P. Hauser

Koch-Glitsch. LP

Presented in the Distillation Symposium of the 2003 Spring AIChE Meeting
New Orleans, LA
March 31 – April 3, 2003

Unpublished

Energy Savings in Crude Vacuum Towers via Structured Packing

David A. Freed
Richard P. Hauser
Koch-Glitsch. LP

AIChE Spring 2003 National Meeting

Distillation Symposium Session:
Refinery Distillation: Simple Modifications Yield Major Improvements

Introduction

Structured packing is considered the state-of-the art mass transfer internal to maximize capacity and gas oil recovery in crude vacuum towers by minimizing column pressure drop. In spite of this well-established practice, many towers still contain trays, random packing, or vapor distributors with high pressure drop.

The reluctance to upgrade the tower internals is often due to the capital cost to revamp the tower. When gas oil production is sufficient or constrained by downstream units, the perception is that there is little incentive to incur a revamp's cost for additional capacity that cannot be utilized. However, the lower pressure drop of structured packing can also reduce utility and energy costs if the feed and product rates are held constant. This energy cost reduction is often overlooked as a justification to revamp the tower. While the potential to reduce energy costs has been acknowledged for over 20 years[1,2], there is little literature outlining the magnitude of the savings. This paper attempts to fill that void.

Two methods to reduce energy costs by exploiting the lower pressure drop of structured packing are explored. Both methods assume feed rate and gas oil yield are held constant before and after a revamp. Method I is to hold a constant overhead pressure and reduce the flash zone pressure. This reduces the duty and corresponding fuel gas consumption in the furnaces. Method II is to hold a constant flash zone pressure and raise the overhead pressure. This reduces the steam requirement for the steam ejectors.

Method I: Reduce Furnace Fuel Gas Consumption (Constant Overhead Pressure)

The first case saves energy by reducing the furnace fuel gas consumption. For a constant overhead pressure and gas oil yield, less pressure drop across the tower packing results in a lower inlet pressure. Less fuel gas is required to achieve the furnace duty that results in the same gas oil yield (flash) at this lower inlet pressure. The lower furnace duty also results in a lower furnace coil outlet temperature, which reduces coking and increases run length.

Methodology

A vacuum tower simulation model using the Golden Topology[3] was developed to calculate the quantitative results. This topology provides a more accurate model of the non-equilibrium condition in the transfer line and flash zone. Refer to Figure 1 for a diagram of the topology.

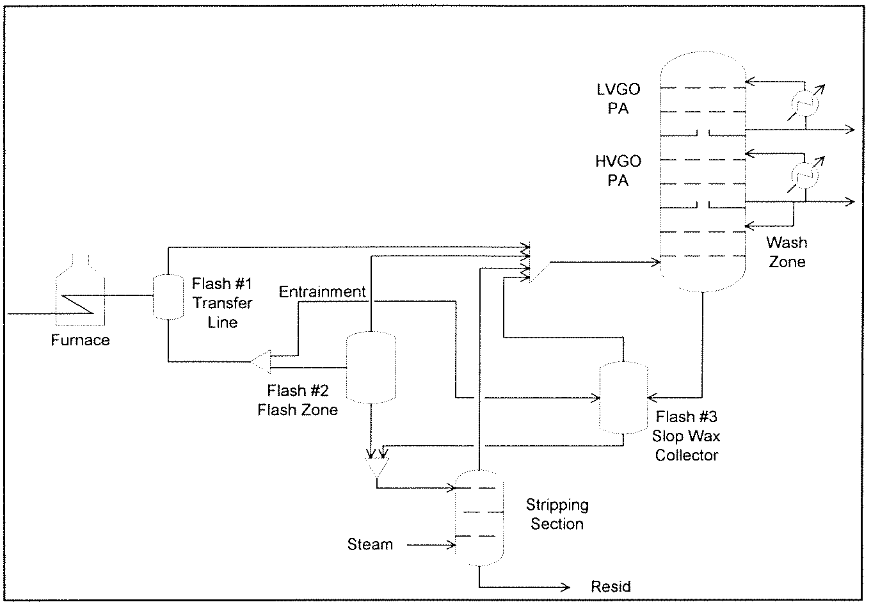

Figure 1: Golden Topology for Vacuum Tower Simulation

The methodology used to determine the furnace outlet temperature at various tower pressure drops is described as follows. A series of runs were performed at a constant overhead pressure and gas oil yield. Each run was at a different tower pressure drop. Vaporization in the furnace was allowed to vary to meet the specified gas oil yield given the flash zone pressure implied by the tower pressure drop and overhead pressure. This process was repeated for several gas oil yields. The resulting furnace outlet temperatures were plotted against the selected pressure drops.

Pressure specifications were set for the flash drums (with duties set to zero) in the Golden Topology unit operations of the simulation. The specified pressure below the bottom stage in the vacuum tower unit operation plus a constant pressure drop for the transfer line and flash zone defined the pressures of Flash Units #1, 2, and 3. These pressure drops were based on data obtained from an operating tower.

Table 1 presents the distillation of the atmospheric resid used as the feed to the vacuum tower.

Table 1: Atmospheric Resid TBP @ 760 mmHg Distillation

Volume % Distilled	Temperature (°F)
1%	276
5%	605
10%	668
30%	810
50%	916
70%	1053
90%	1282
95%	1407
98%	1679

Results

Figure 2a shows the relationship between vacuum tower pressure drop and furnace outlet temperature for several gas oil yields. Gas oil yield is defined as the mass ratio of vacuum tower products excluding resid to vacuum tower feed rate.

Figure 2a makes intuitive sense in that it shows that a lower furnace outlet temperature and duty is required to maintain a certain gas oil yield when flash zone pressure decreases. Flash zone pressure decreases because the overhead pressure is held constant as pressure drop is decreased. Figure 2b is included to clarify this point. It is the same as Figure 2a except that flash zone pressure is plotted on the x-axis. Figure 2b shows that as flash zone pressure increases the furnace duty increases to achieve the same gas oil yield.

Curves for several constant feed vaporizations in the furnace are also presented in Figures 2a & 2b. While feed vaporization has less practical value to refiners, it was studied as an exercise to determine which variables effect the slope of the pressure drop versus furnace outlet temperature curve.

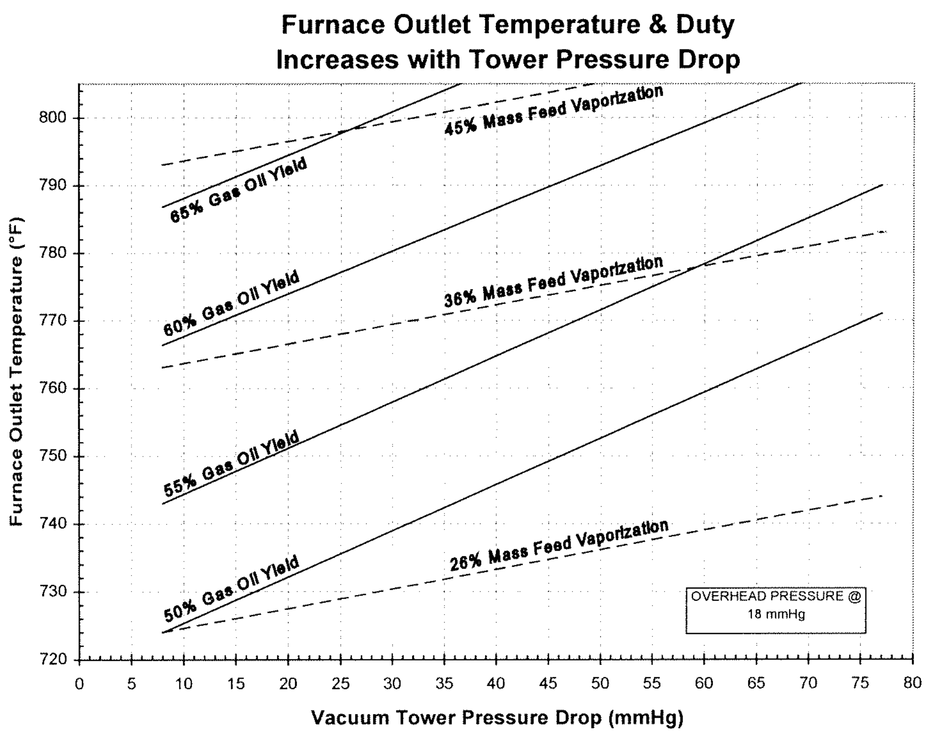

Figure 2a

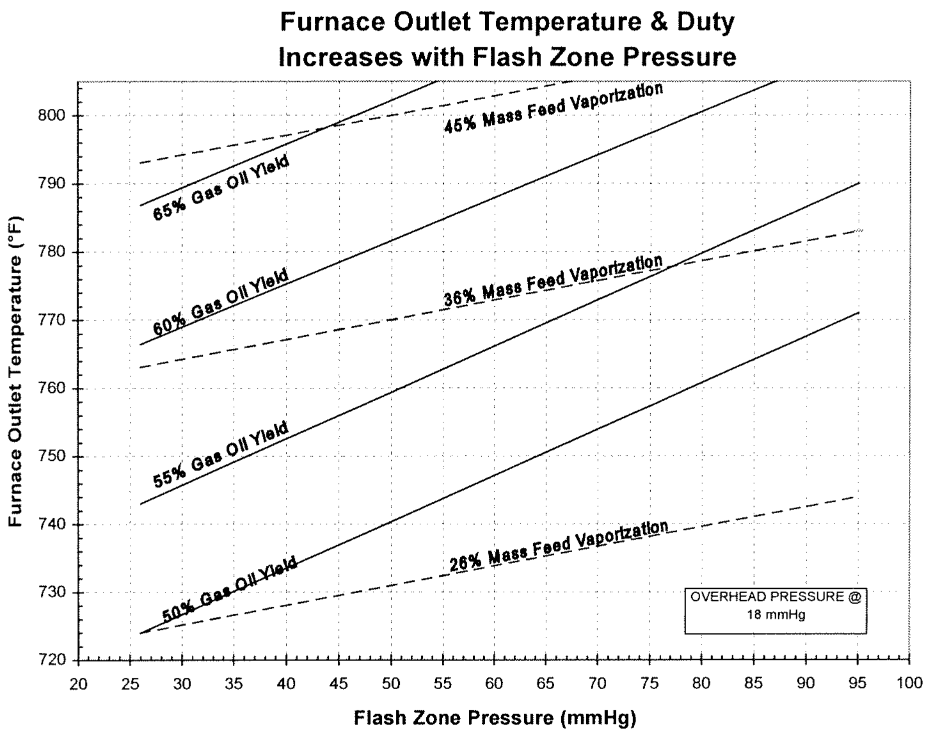

Figure 2b

It is interesting to note that the slopes of the various constant gas oil yield curves are nearly identical. This implies that each 1 mmHg reduction in tower pressure drop results in a certain constant reduction in furnace outlet temperature and corresponding duty regardless of the gas oil yield. While this ratio remained the same for specific tower and atmospheric resid simulated for this study, the absolute value of the ratio may vary with crude properties and product specifications.

There is a furnace outlet temperature boundary that constrains the combination of gas oil yield and furnace outlet temperature. Beyond this boundary, coking and cracked gas formation becomes problems. For this reason, the curves are truncated at furnace outlet temperature slightly greater than 800 F. This actual practical design limit will depend on the crude type and furnace design.

Case Study I

A sample case study illustrates the potential savings in fuel gas costs. A typical random packing used in pumparounds was the 3.5" Pall Ring. Bed heights of about 6 ft. were common to achieve the required surface transfer area for a given pumparound duty.

The structured packing that is currently used in many pumparounds has a 1" crimp height and a 60°-crimp angle (e.g., Koch-Glitsch FLEXIPAC® 3X). This structured packing has approximately twice the surface area of the 3.5" Pall Ring so the bed height can be reduced by half and still achieve the same heat transfer duty. Thus, the lower pressure drop that structured packing has compared to random packing (for a given bed height) is magnified by the shorter height of structured packing.

Table 2 lists the data for this case study. Note that the pressure drop per foot of packing cited is the arithmetic average of the pressure drop taken at the top and bottom of the bed. This accounts for large difference in process loads between the top and bottom of pumparound beds.

Table 2: Case Study of a HVGO Pumparound Bed

	EXISTING DESIGN	NEW DESIGN
Packing Style	3.5" Pall Rings	1" Crimp / 60° Structured
Specific Heat Transfer Area	17 ft^2 / ft^3	33 ft^2 / ft^3
Liquid Load	10 gpm / ft^2	10 gpm / ft^2
Vapor Load (C_s)	0.35 ft/s	0.35 ft/s
Flood Rating @ Bottom	90%	63%
Bed Height	6 ft.	3 ft.
Avg. Pressure Drop	1.26 mmHg / ft	0.18 mmHg / ft
Total Bed Pressure Drop	7.56 mmHg	0.54 mmHg

Table 3: Case Study Results

	EXISTING DESIGN	NEW DESIGN
Gas Oil Yield	60%	60%
Overhead Pressure	18 mmHg	18 mmHg
Furnace Outlet Temperature	786 °F	781 °F
Fuel Gas Cost	$4 / MM Btu	$4 / MM Btu
Yearly Fuel Gas Savings	-	$171,700 / yr

This case study results in a random packed bed rating moving from the marginal allowable flood (90% for heat transfer service versus 80% for fractionation service) and reduces the flood to 63% with structured packing. Pressure drop is reduced by about 7.0 mmHg (7.56 mmHg – 0.54 mmHg). Refer to Table 3 for a summary of the results.

The reduction in total pressure drop is converted into a specific reduction in furnace outlet temperature and duty using the slope of the curves in Figure 2a. For the given case study, the 7 mmHg reduction in pressure drop results in annual fuel gas savings of $171,700. It should be recognized that this is the savings for revamping only one bed. Revamping additional beds can increase the dollar savings by a multiple of this amount. The payback period on the equipment cost at this rate should be less than a year.

This analysis assumes a fuel gas cost of $4/MMBtu. However, the cost of fuel gas is known to spike to over $10/MMBtu for brief periods of time. This greatly increases the yearly savings and reduces the payback period. A two-month spike at $10/MMBtu would increase the annual savings to over $216,000.

This example illustrates how the pressure drop advantages of structured packing can be utilized not for capacity or yield but for energy savings.

Method II: Reduction of Ejector Steam Requirements (Constant Flash Zone Pressure)

The second case saves energy by reducing the motive steam required to operate the vacuum ejector system. If it is assumed that the flash zone pressure and temperature are held constant to maintain the same product split (via the flash inside the tower), less pressure drop across the tower packing results in a higher pressure in the tower overhead. Less steam is needed for the ejector system to achieve this higher pressure for the implied product split. Since ejectors are designed for a point load, either one of several parallel ejectors could be shut down or the motive nozzle could be replaced with one designed for a lower steam rate.

Methodology

The same simulation was used as for Method I. (Refer to Figure 1). However, the opposite specification was used – overhead pressure was allowed to vary. For a certain flash zone pressure and temperature (Flash Unit #2), a series of runs with different tower pressure drops were performed. Each run had a different overhead pressure since the flash zone pressure was the same but the tower pressure drop varied. For each pressure drop at a given flash zone pressure, temperature, and gas oil yield, the overhead dry air equivalent was calculated using methodology from the Heat Exchange Institute "Standards for Steam Jet Vacuum Systems"[4].

A three stage ejector system with two inter-condensers was assumed. This configuration allowed a value for the pounds of steam required per pound of dry air equivalent (DAE) to be determined for each overhead pressure. This value was determined from the Figure 7.31 in *Chemical Process Equipment Selection and Design*[5].

Results

Figure 3a shows the relationship between vacuum tower pressure drop and ejector steam requirement for several flash zone temperatures and corresponding inlet pressures. These curves indicate that steam consumption is nearly linear over a range of tower pressure drops but rises quickly as pressure drop exceeds a certain point. The reduction in steam required will vary depending on what part of the curve at which a given ejector is operating because the slope does change.

The ejector steam requirement in Figure 3a is cited in pounds of steam required per pound of dry air equivalent (DAE) to the first stage ejectors. Steam is cited in these units because the calculation method[5] is based on those units. This method makes the required steam depend only on the suction pressure of the first stage ejector and the ejector system arrangement. It will not vary with gas oil yield. However, the *total* dry air equivalent of gas to the first stage ejector will vary with gas oil yield. Thus a plot of *total* steam required (rather than steam per pound of DAE) would change with gas oil yield.

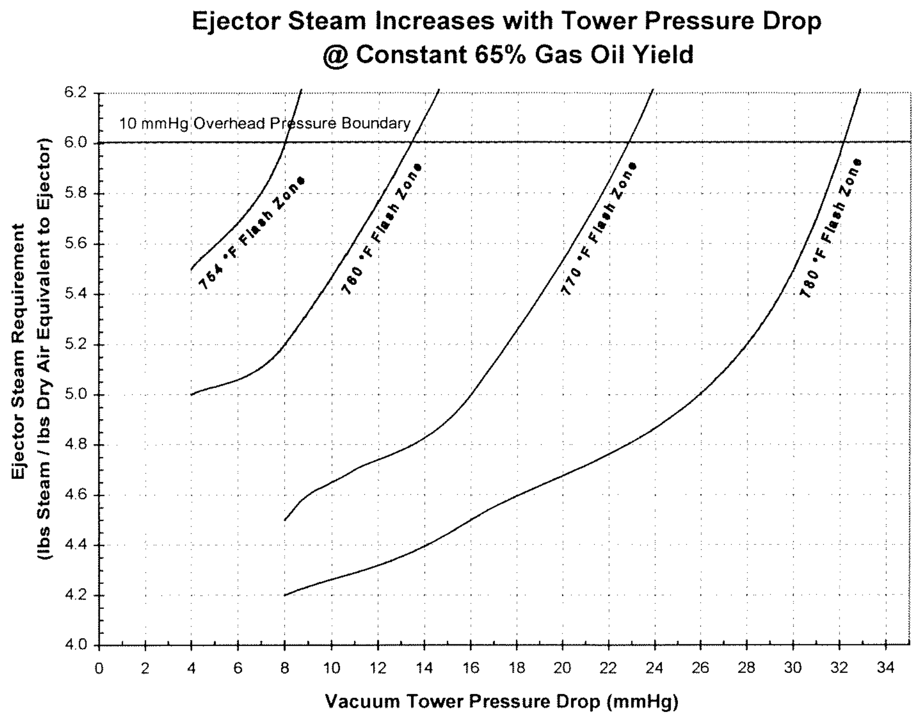

Figure 3a

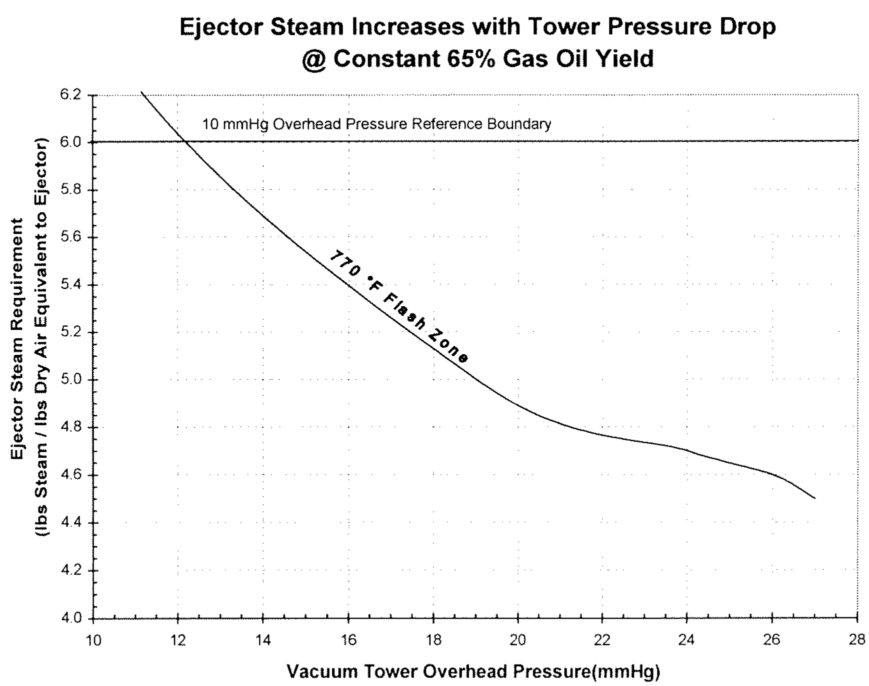

Figure 3b

Figure 3b presents the one 770 °F Flash Zone curve from Figure 3a in a different manner to illustrate a point (other curves are removed for clarity). Figure 3b shows that raising the overhead pressure in the vacuum tower reduces steam consumption. While raising pressure in a vacuum tower may seem counter intuitive, it must be remembered that the overhead pressure is raised with a simultaneous reduction in overall tower pressure drop. The flash zone pressure and temperature remain the same so gas oil yield is not affected.

Case Study II

A sample case study illustrates the potential savings from reducing ejector motive steam requirement.

If the same HVGO Pumparound Bed is used from Case 1, the pressure drop across the bed is again reduced by about 7 mmHg. This corresponds to a 7 mmHg higher suction pressure to the first stage ejector. Assuming a 770 °F Flash Zone temperature held constant before and after the revamp, the steam requirement drops from 5 lbs_{Steam}/lbs_{DAE} to 4.55 lbs_{Steam}/lbs_{DAE}. This corresponds to a 206 lb/hr reduction in DAE and a 3,576 lbs/hr reduction in motive steam. If steam costs $5 per thousand pounds, this results in yearly savings of $156,650.

Table 4: Case Study II Results

	EXISTING DESIGN	NEW DESIGN
Flash Zone Temperature	770 F	770 F
Gas Oil Yield	65%	65%
Steam Cost	$5/ M lbs	$5 / M lbs
Overhead Pressure	19 mmHg	26 mmHg
Tower Pressure Drop	16 mmHg	9 mmHg
Motive Steam	32,860 lbs / hr	29,284 lbs / hr
Annual Motive Steam Savings	-	$156,630 / yr

It is recognized that existing steam ejectors do not necessarily have a lot of flexibility in the steam rate at which they can effectively operate. Modifications to motive nozzles or shutting down some of the ejectors may be necessary. This case is only a scoping study for the potential reductions in steam.

Flash Zone Internals

The results of this analysis have implications for the design of flash zone internals. It is well understood that proper vapor distribution is vital to the performance and reliability of the Wash Bed. Vapor maldistribution can cause localized areas of high vapor velocity, which promotes entrainment and coking.

There are two opposite design philosophies regarding the design of vapor distributors in vacuum tower flash zones. In one approach, the use on an enhanced primary vapor distributor enables the use of slop wax collectors with high open areas and low pressure drop (e.g., 30% open & 1.2 mmHg).

The other design philosophy uses an inlet device with coarser vapor distribution and a slop wax collector tray with much more pressure drop to achieve adequate vapor distribution (e.g., 15% open & 4.9 mmHg).

Ironically, the enhanced vapor distributor option has lower pressure drop than the device with only coarse vapor distribution[6]. This lower pressure drop is distinct from the lower pressure drop needed by the slop wax collector.

Utility costs can be minimized by using a feed inlet device that provides good initial distribution with less pressure drop than a collector. This analysis shows that collectors should be designed for minimal pressure drop for minimum energy and utility costs.

Conclusions

- There are economic incentives to use structured packing in crude vacuum towers even if additional capacity is not needed. For a constant feed rate and gas oil yield before and after revamp, structured packing can be used to substantially reduce either ejector motive steam or furnace fuel gas costs. Every reduction in pressure drop reduces utility and energy costs, which can help refining margins.
- Case study analysis shows that a lower pressure drop can yield savings with either approach of maintaining constant overhead or constant flash zone pressure.
- Figures 2a and 2b show that furnace duty and temperature is sensitive to flash zone pressure as well as total pressure drop. Lowering flash zone pressure while holding a constant overhead pressure reduces furnace duty for a constant gas oil yield.
- Figures 3a and 3b show that ejector motive steam consumption is sensitive to absolute flash zone pressure as well as total pressure drop. Raising overhead pressure will lower steam requirements at a constant gas oil yield.

Acknowledgements

Dana Laird of Koch-Glitsch is thanked for his invaluable assistance in the development of this paper.

References

[1]Gary, G.E., et al., *Petroleum Refining: Technology and Economics*, Chapter 4, Marcel Dekker, Inc., New York, 1984

[2]Martin, G. R., et al., "Understand Vacuum-System Fundamentals", *Hydrocarbon Processing*, October 1994, pp. 91-98.

[3]Golden, S. W., Shah, V. B., and Kovach III, J. W., "Improved Flow Sheet Topology for Petroleum Refinery Crude Vacuum Distillation Simulation", Canadian Chemical Engineering Conference, Calgary, Alberta, Canada, October 2-5, 1994.

[4]*Standards for Steam Jet Vacuum Systems*, Heat Exchange Institute Inc., 2000.

[5]Walas, S. M., *Chemical Process Equipment Selection and Design*, Chapter 7, Butterworth-Heinemann, 2002.

[6]Laird, D. G. "Vacuum Tower Design for Performance Reliability", National Petrochemical and Refiners Association Annual, San Antonio, Texas, March 23-25, 2003.