Options Analysis Of Vacuum Columns and Ejector systems

Desired increases in gas oil feed to FCCU's often drive reviews of atmospheric and vacuum column revamp options. Upgrading vacuum resid to VGO has financial attractions depending on operations downstream of the column. Gains are typically about $10/bbl with no downstream vacuum resid processing and $4/bbl where there are such operations. This paper analyses vacuum column revamp options targeted for cut point improvement from 1050° F to 1100° F to reduce vacuum resid.

Recently installed 1st stage ejectors included as part of a tour stage ejector system serving a CVDU in Asia.

For the purposes of the approach adopted herein the author has made the following process assumptions:

- that the vacuum column diameter and mass transfer capabilities do not restrict performance
- that column overhead discharge diameter is not limiting column effluent capacity
- that modern tower internals for low pressure drop are the basis for establishing flash zone and tower top pressure

Four revamp options are reviewed and the effect on an ejector system is discussed. A special case is examined, highlighting impact on an ejector system when an atmosphere tower has lost steam stripping capability. The basis for comparison is an 85 Mbbl/d refinery processing Venezuelan Bachaquero Field Blend (BCF-22). Information relates to an existing ejector system with the following characteristics:

a) 1050 °F cut point for vacuum column

b) 775 °F furnace outlet temperature

c) 20mm Hg abs column top pressure at 150 °F

d) 750 °F cut point is set for the atmospheric column

The effect on the ejector system is analyzed when:

a) vacuum tower cut point is increased to 1100 °F

b) atmospheric tower cut point is varied between 700 and 750°F

c) column top pressure is at 12 mm Hg abs or 20 mm Hg abs

Elevation of cut point from 1050 °F to 1100 °F increases VGO production by 1725 bbl/d. As a consequence of cut point improvements and vacuum resid upgrading, a yearly incremental gain of $2 million dollars is realisable by the refinery. This is based on $4/bbl benefit and 300 days of operations per year.

The analysis presented will describe effects of furnace outlet temperature, atmospheric column cut point and vacuum column pressure on an existing ejector system and necessary steps to revamp that ejector system so that it can handle new conditions. Furthermore, the impact on utility consumption, such as coil/stripping steam, motive steam for ejectors and cooling water, is also evaluated. The relevant schematic is shown at Figure 1 and overall comparisons are presented below.

EXISTING VACUUM COLUMN DESIGN

The refinery operates at 85 Mbbl/d with conventional fuels, atmospheric and vacuum columns. Atmospheric column bottoms charge to the vacuum column is based on 750 °F cut point for the atmospheric column. Vacuum column furnace outlet temperature is 775 °F and cut point for the vacuum column is at 1050 °F. Vacuum column top pressure is 20 mm Hg abs at 150 °F.

Recently installed 1st stage ejectors included as part of a four stage ejector system serving a CVDU in Asia.

Compositional break down of column overhead load to the ejector system is:

Steam	9839 pph	MW=18
Non -condensible	800 pph	MW=34
Condensible hydrocarbon	31.6 pph	MW=229.6

Utilities for the ejector system are:

Motive steam	20,155 pph	150 psig with slight superheat
Cooling water	3400 gpm	85°F to 105°F

The ejector system is a three-stage single element system with surface type inter and after condensers, model 10870A-66x20-380B-26x12-31C-22x10. Column overhead discharge connection diameter is 48 inches.

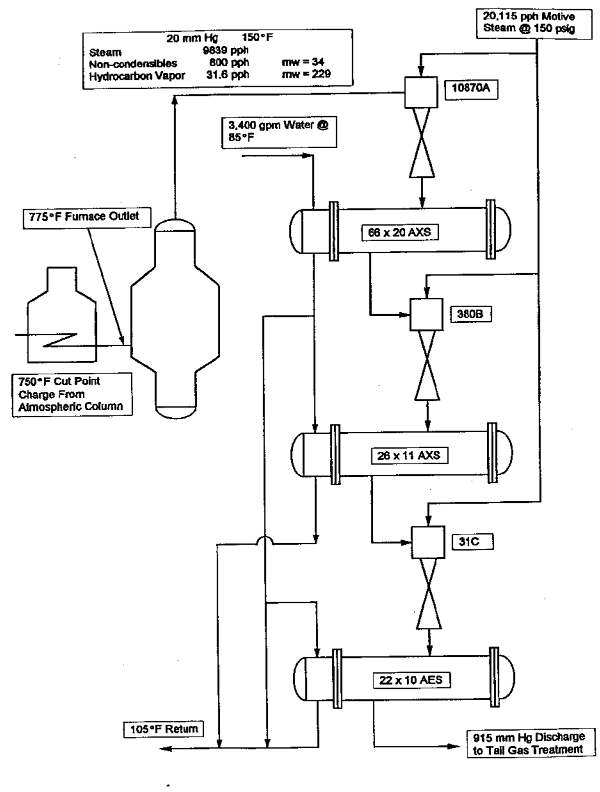
Ejectors:

	Model	Suction pressure	Discharge pressure
1st stage ejector	10870A	20 mm Hg	75mm Hg
2nd stage ejector	380B	70 mm Hg	270mm Hg
3rd stage ejector	31C	250 mm Hg	950mm Hg

Condensers

	Model	Water flow	In/outlet temp	Surface area
1st intercondenser	66x20 AXS	3400 gpm	85 to 102°F	9800 sq feet
2nd intercondenser	26x11 AXS	1000 gpm	102 to 108°F	700 sq feet
3rd intercondenser	22x10 AES	550 gpm	102 to 112°F	350 sq feet

FIGURE 1



EJECTOR PERFORMANCE CURVES

A set of certified ejector performance curves is required to permit analysis of system characteristics. Ejector performance curves depict suction pressure maintained by an ejector as a function of steam equivalent mass flowrate. Methods for converting crude tower overhead load to a steam equivalent load may be found in the HEI Standard for Steam Jet Ejectors. For the existing system, individual ejector performance curves follow.

FIGURE 2

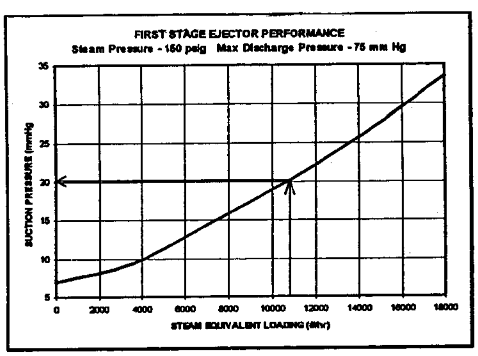
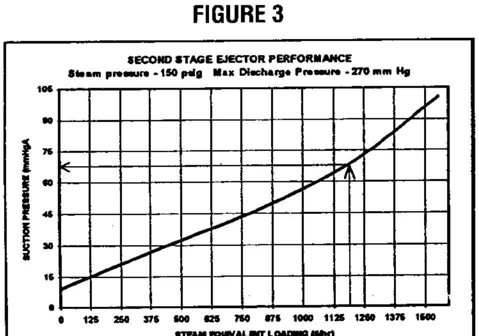


FIGURE 3



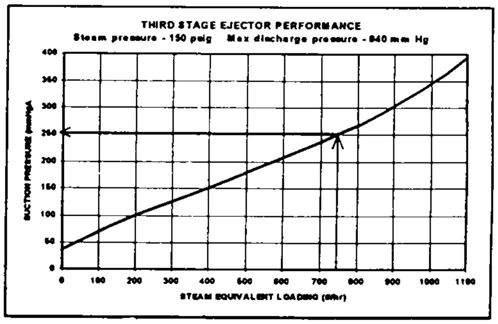
From the first stage ejector performance curve see (Figure 2), at 10.730pph of steam equivalent load, the ejector maintains a suction pressure of 20mm Hg. Similarly, if the loading is decreased to 7,500pph of steam equivalent the first stage ejector will maintain 15mm Hg suction pressure. Second and third stage ejector performance is conditional upon the noncondensible loading not exceeding 801pph MW=34. If non-condensible loading increases above 800 pph, new second and third stage ejectors are required. See Figures 3 and 4.

It is customary to consider reuse of only the first stage ejector when investigating revamp options. Performance curves for the second and third stage ejectors are shown for reference purposes. Additionally, it is important to note ejector flexibility is limited by discharge pressure. If an ejector has a compression ratio greater than 2 (discharge pressure/suction pressure), that ejector is unable to operate satisfactorily with a discharge pressure higher than the maximum discharge pressure indicated on the performance curve.

VACUUM CONDENSERS

Reuse of existing condensing equipment dramatically reduces capital cost in a revamped ejector system. The first intercondenser of a three stage system or precondenser of a two stage system is the

FIGURE 4



most expensive item of an ejector system. A thorough review of existing condenser design details is necessary in order to verify suitability of that equipment. Key variables to review include:

- surface area
- vapor space above tubefield
- tubefield penetration area
- outlet area
- connection sizes for both process and cooling water
- condition of existing equipment

Review of a condenser requires the assistance of the equipment supplier. Typical condenser designs for shellside condensing are either a TEMA 'E' or 'X' shell, as in Figures 5 and 6.

Vacuum condensers are integral components of a vacuum system and are critical to the proper performance of a vacuum distillation tower. Within a vacuum system, ejectors and condensers are interdependent. For proper performance, each must operate in accordance with its design requirements. Unlike a heat exchanger train, which loses efficiency when operated inadequately, a vacuum system will exhibit a dramatic performance loss when one of its components is not operating correctly.

It is important to bear in mind the inherent complexity of vacuum condenser design and that the proper matching of condenser performance to the capabilities of an ejector preceding and following a given condenser is essential for adequate system performance. For this reason, vacuum condenser simulation software was developed by vacuum equipment manufacturers. This software must effectively manage heat transfer requirements and be internally configured so as to minimize pressure drop. Another important aspect of design and internal configuration relates to ensuring an adequate non-condensible removal and the elimination of potential non-condensible blanketing or pockets.

REVAMP OPTIONS

Various possibilities are considered. A three year period is taken for determining best overall cost, including capital and operating cost. The cost of motive and stripping/coil steam is $6.00/1000# ($129.6/pph). The cost of cooling water is $0.15/1000 gallons ($194.4/gpm). Installed cost of the ejector system is 60% of the ejector system capital cost. The basis of operation is 300 days per year and 1725 bbl/d additional VGO production, valued at $6,210,000 net benefit over three years. Operating costs will be analyzed as incremental consumption over the existing unit, which utilizes 29,994 pph of steam (motive, coil and stripping steam) and 3400 gpm of cooling water.

Due to a higher vacuum column furnace outlet temperature, 795 °F rather than 775 °F, additional cracked gases are produced in the furnace and non-condensible loading increases from 800 pph to 1100 pph. With an increase in non-condensible loading, it is not possible to operate existing secondary ejectors for a revamped system, therefore, new second and third stage ejectors are required. The reason for this is that second and third stage ejectors are required to handle non-condensible loading and associated vapors of saturation exiting an intercondenser that precedes them. If non-condensible loading has increased from 800pph to 1100pph, the saturation load exiting an intercondenser is increased by 38% and existing ejectors will not handle such an increase.

FIGURE 5
TEMA "X" SHELL

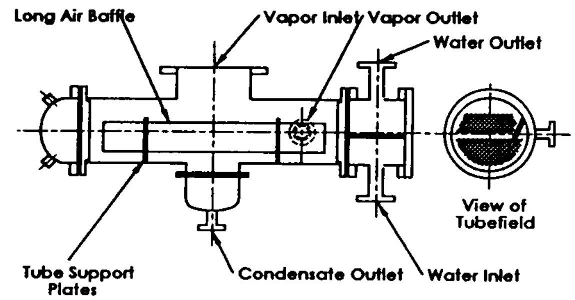
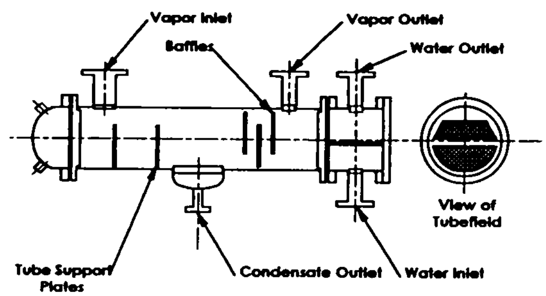


FIGURE 6
TEMA "E" SHELL



REVAMP OPTION 1

Vacuum column cut point increased to 1100 °F.
Furnace outlet temperature set at 795 °F.
Column top pressure is at 20 mm Hg and 150 °F.
Atmosphere tower cut point at 700 °F.

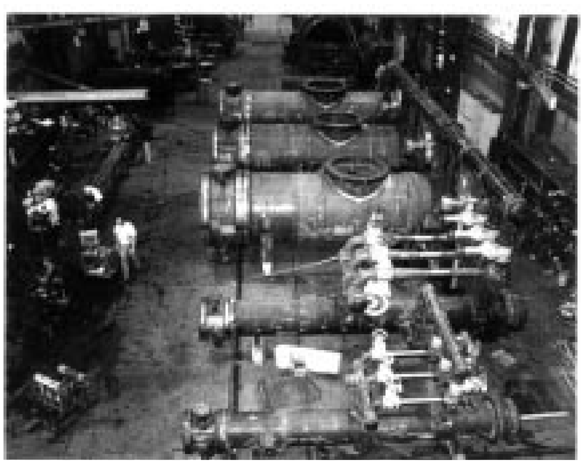
Column overhead load:

Steam	9858 pph	
Non-condensibles	1100 pph	MW = 34
Condensible hydrocarbons	124 pph	MW = 215

From HEI methods, the steam equivalent loading from the vacuum column is 11,022pph. The ejector performance curve for the existing first stage ejector indicates that at 11,022pph steam equivalent load, the ejector will maintain approximately 20.5mm Hg. This is close to the desired 20 mm Hg. At a similar overhead mass flowrate, the existing 48 inch connection is acceptable as the velocity is 227 ft/sec.

Next, it is important to review the first intercondenser to determine if it may be reused. From the performance curve for the existing first stage ejector, that ejector is capable of discharging to 75mm Hg, which is the maximum operating pressure of the first intercondenser. Knowing the non-condensible loading has increased from 800pph to 1100pph, it is unlikely that the existing 66x20 AXS first intercondenser will operate satisfactorily under revamped loading conditions at 75mm Hg. Additional non-condensibles reduce the shellside heat transfer coefficient, therefore, an investigation is undertaken to determine if there is a reasonable pressure at which the 66x20 AXS will operate adequately.

Using vacuum condenser simulation software, it is determined that the 66x20 AXS will operate at 79mm Hg. In simple terms, the operating pressure for the condenser was increased to provide a higher initial condensing temperature and corresponding LMTD. This increase in LMTD offset a reduction in overall heat transfer rate caused by greater noncondensible loading. Velocity checks of all connections confirmed 66x20 AXS was suitable. The software also verified the tubefield layout was acceptable and there was sufficient vapor space above the tubefield, as well as penetration and outlet area.



An ejector system assembly. Equipment is associated with CVDU revamp in Southeast Asia.

Due to an increase in operating pressure for the first intercondenser, the first stage ejector is no longer reusable because its discharge pressure had to be 79mm Hg and it was incapable of providing same.

For operating efficiency, it was determined that the remaining items of the system would be replaced, with the exception of the second intercondenser 26x11 AXS, which could be reused as an aftercondenser. The revamped system would be 11270A-66x20490B-30x 12-31C-26x11, with the following characteristics:

Ejectors

	Model	Suction pressure	Discharge pressure
1t stage ejector	I 1270A	20 mm Hg	79mm Hg
2nd stage ejector	490B	75mm Hg	330mm Hg
3rd stage ejector	31C	300mm Hg	950mm Hg

Condensers

	Model	Water flow	In/outlet temp	Surface area
1st intercondenser	66x20 AXS (existing)	3560 gpm	85 to l02°F	9800 sq feet
2nd intercondenser	30x12 AXS	1200 gpm	102 to 109.4°F	950 sq feet
3rd intercondenser	26x1 l AXS (existing)	1000 gpm	102 to 107°F	700 sq feet

Utilities

Motive steam	22,575 pph
Cooling water	3560 gpm

Cost information:

Incremental steam cost	32433 - 29994 #/hr	<$316,000>
Incremental water cost	3560 - 3400 gpm	<$31,000>
New ejector system		<$110,000>
Equipment installation		<$66,000>
Total cost		<$523,000>
Incremental gain in VGO production		$6,210,000
Net evaluation		$5,687,.000

REVAMP OPTION 2

Vacuum column cut point increased to 1100 °F
Furnace outlet temperature set at 795 °F
Column top pressure at 20 mm Hg and 150 °F
Atmospheric tower cut point at 725 °F

Column overhead load:

Steam	11,566 pph
Non condensibles	1100 pph MW = 34
Condensible hydrocarbons	70.5 pph MW = 224

The steam equivalent loading from the vacuum column is 12,751pph. From the ejector performance curve for the existing first stage ejector, at 12,751 pph steam equivalent load, the ejector will maintain approximately 23.5mm Hg. It is determined that the existing first stage ejector must be replaced. The existing 48 inch connection is acceptable, as the velocity is 263 ft/sec.

It seems doubtful that the first intercondenser will be usable because the non-condensible loading is higher and coil/stripping steam load is 18% greater. This increased steam loading to the intercondenser results in far greater thermal duty and the existing unit will not handle it. With increased duty and a reduced heat transfer rate caused by increased non-condensibles, the 66x20 AXS does not have sufficient surface area.

An entirely new ejector is necessary but the second intercondenser is retained as an aftercondenser. The resultant system is 13030A-72x20-530B-28x13-40C-26x12, with the following characteristics:

Ejectors

	Model	Suction pressure	Discharge pressure
1st stage ejector	13030A	20mm Hg	75mm Hg
2nd stage ejector	530B	70mm Hg	270mm Hg
3rd stage ejector	40C	250mm Hg	950mm Hg

Condensers

	Model	Water flow	In/outlet temp	Surface area
1st intercondenser	72x20 AXS	4000gpm	85 to 102 °F	11781 sq feet
2nd intercondenser	28x13 AXS	I200gpm	102 to 108.8 °F	985 sq feet
3rd intercondenser	26x12 AXS (existing)	1000gpm	102 to 109.2 °F	700 sq feet

Utilities

Motive steam	24,728 pph
Cooling water	4000 gpm

Cost information:

Incremental steam cost	36,294 - 29994 #/hr	<$816,000>
Incremental water cost	4000 - 3400 gpm	<$117,000>
New ejector system		<$480,000>
Equipment installation		<$290,000>
Total cost		<$1,703,000>
Incremental gain in VGO production		$6,210,000
Net evaluation		$4,507,000

REVAMP OPTION 3

Vacuum column cut point increased to 1100 °F
Furnace outlet temperature set at 795 °F
Column top pressure at 20 mm Hg and 150 °F
Atmospheric tower cut point at 725 °F

Column overhead load:

Steam	12,9l3 pph
Non-condensibles	1100 pph MW = 34
Condensible hydrocarbons	40.0 pph MW = 230

The load to the first stage ejector is 14,120pph steam equivalent and a new first stage ejector is needed. Similar to Revamp Option 2, the loading to the first intercondenser is too great for the existing 66x20 AXS to handle satisfactorily. Vacuum column discharge connection of 48 inches is suitable as the velocity is 293 ft/sec.

A new ejector system has to be designed and once more the second intercondenser will be retained as the aftercondenser. The resultant system is 14430A 78x20-570B-32x10-40C-26x11. with the following characteristics:

Ejectors

	Model	Suction pressure	Discharge pressure
1st stage ejector	14430A	20mm Hg	75mm Hg
2nd stage ejector	570B	65mm Hg	275mm Hg
3rd stage ejector	40C	250mm Hg	950mm Hg

Condensers

	Model	Water flow	In/outlet temp	Surface area
1st intercondenser	78x20 AXS	4400 gpm	85 to l02°F	13940 sq feet
2nd intercondenser	32x10 AXS	1600 gpm	102 to 107.7°F	1040 sq feet
3rd intercondenser	26x1 l AXS (existing)	1000 gpm	102 to 109°F	700 sq feet

Utilities

Motive steam	26,189 pph
Cooling water	4400 gpm

Cost information:

Incremental steam cost	39,102 - 29,994 #/hr	<$1,180,000>
Incremental water cost.	4400 - 3400 gpm	<$194,400>
New ejector system		<$575,000>
Equipment installation		<$345,000>
Total Cost		< $2,294,000>
Incremental gain in \'G0 production		$6,210,000
Net evaluation		$3,916,000

REVAMP OPTION 4

Vacuum column cut point increased to 1100 °F
Furnace outlet temperature set at 795 °F
Column top pressure at 12mm Hg and 150 °F
Atmospheric tower cut point at 750 °F

Column overhead load:

Steam	7110 pph
Non-condensibles	1100 pph MW = 34
Condensible hydrocarbons	40.0 pph MW = 230

The load to the first stage ejector is 8,160pph steam equivalent and the existing first stage ejector will maintain 16mm Hg at that loading. For that reason. a new first stage ejector is required. An optimization is undertaken to evaluate if the existing 66x20 AXS may be reused. That determines that at 76mm Hg the 66x20 AXS is usable. The column discharge velocity is 278 ft/sec which is satisfactory.

The revamped system is 12200A-66x20-520B-312x 9-40C-26x11 and again the second intercondenser is retained as an aftercondenser.

Ejectors

	Model	Suction pressure	Discharge pressure
1st stage ejector	12200A	12mm Hg	75mm Hg
2nd stage ejector	530B	70mm Hg	280mm Hg
3rd stage ejector	40C	260mm Hg	950mm Hg

Condensers

	Model	Water floss	In/outlet temp	Surface area
1st intercondenser	66x20 AXS (existing)	3400 gpm	85 to 112 °F	9800 sq feet
2nd intercondenser	32x9 AXS	1600 gpm	102 to 107.1 °F	950 sq feet
3rd intercondenser	26x1 l AXS (existing)	1000 gpm	102 to 109.4 °F	700 sq feet

Utilities

Motive steam	23,692 pph
Cooling water	3400 gpm

Cost information:

Incremental steam cost	30,802 - 29,994 #/hr	<$105,000>
Incremental water cost	4400 - 3400 gpm	$-0-
New ejector system		<$110,000>
Equipment installation		< $66,000>
Total cost		<$281,000>
Incremental gain in VGO production		$6,210,000
Net evaluation		$5,929,000

Summary of revamp options

	Existing	Option l	Option 2	Option 3	Option 4
Vacuum column cut point	1050 °F	1100 °F	1100 °F	l l00 °F	1100 °F
Furnace outlet	775 °F	795 °F	795 °F	795 °F	795 °F
Vacuum column top pressure	20 mm Hg	20 mm Hg	20 mm Hg	20 mm Hg	12 mm Hg
Atmospheric tower cut point	750 °F	700 °F	725 °F	750 °F	750 °F
Vacuum column and furnace steam consumption	9839 pph	9858 pph	11566 pph	12913 pph	7110 pph
Ejector system steam consumption	20155 pph	22575 pph	24728 pph	26189 pph	23692 pph
Total steam	29994 pph	32433 pph	36294 pph	39102 pph	30802 pph
Total water	3400 gpm	3560 gpm	4000 gpm	4400 gpm	3400 gpm
Ejector system revamp cost	-	$110,000	$480,000	$575,000	$110,000
Installation cost		$66,000	$290,000	$345,000	$66,000
Steam operating cost		$316,000	$816,000	$1,180,000	$105,000
Water operating cost	-	$31,000	$117,000	$194,400	$-0-
Total cost	-	$523,000	$1,703,000	$2,294,000	$281,000
Vacuum recid upgrade value		$6,2l0,000	$6,2l0,000	$6,2l0,000	$6,2l0,000
Net evaluation		$5,687,000	$4,507,000	$3,916,000	$5,929,000

SPECIAL CASE

Steam stripping within an atmosphere column is often questionable. There are numerous causes of inadequate steam stripping, such as trays blown out or water in the steam. The purpose of this case is to highlight how an ejector system must be designed to enable a vacuum to be maintained within the vacuum column when an ejector system is handling heavy hydrocarbon loading due to a loss of steam stripping in the atmospheric column. For comparison, this is the same as Revamp Option 1 but hydrocarbon vapor loading is much greater because of atmospheric column performance shortcomings. Note that a loss of steam stripping in an atmospheric column results in increased carryover of light hydrocarbons to the vacuum column. Condensible hydrocarbon load increases to 4990 pph MW 128 rather than Option 1 loading of 124 pph MW 215.

Vacuum column cut point increased to 1100 °F
Furnace outlet temperature set at 795 °F
Column top pressure at 20mm Hg and 150 °F
Atmospheric tower cut point at 700 °F

Column overhead load:

Steam	7010 pph
Non-condensibles	1253 pph MW = 34
Condensible hydrocarbons	4990 pph MW = 230

The load to the first stage ejector is 10702 pph steam equivalent and the existing first stage ejector will be suitable for maintaining 20 mm Hg. With considerably higher non-condensible loading, d5 well as additional hydrocarbon loading, all equipment downstream of the first ejector must be replaced. It is not possible to use the 66x20 AXS.

The revamped system is 10870A-74x20-1060B-36x 16-60C-26x12, with the following characteristics:

Ejectors

	Model	Suction pressure	Discharge pressure
1st stage ejector	10870A	20 mm Hg	75 mm Hg
2nd stage ejector	1060B	70 mm Hg	320 mm Hg
3rd stage ejector	60C	290 mm Hg	950 mm Hg

Condensers

	Model	Water flow	In/outlet temp	Surface area
1st intercondenser	74x20 AXS	3400 gpm	85 to l00 °F	1230 sq feet
2nd intercondenser	36xl6 AXS	1600 gpm	100 to 112.1 °F	2100 sq feet
3rd intercondenser	26x12 AES	750 gpm	100 to 113 °F	750 sq feet

Utilities

Motive steam	26,960 pp
Cooling water	3400 gpm

Cost information:

Incremental steam cost	33,969 - 29,994 #/ hr	< $515,000>
Incremental water cost		$-0-
New ejector system		< $560,000>
Equipment installation		< $335,000>
Total cost		< $1,410,000>
Incremental gain in VGO production		$6,210,000
Net evaluation		$4,800,000

SUMMARY

This paper attempts to show the effects on an ejector system when various operating parameters are modified in order to improve vacuum column cut point. Ejector system design is directly impacted by cut point set for the atmospheric column that precedes a vacuum column. It is noted that increasing cut point for the atmospheric column results in added stripping steam to the vacuum column, consequently, a larger ejector system is required. Additionally, vacuum column flash zone and column top pressure directly impacts ejector system design. It is shown that by decreasing flash zone pressure within the vacuum column, whereby the column top pressure is reduced, overall utility consumption and capital cost for a revamped ejector system are favorably reduced.

A special case was reviewed in which atmospheric column steam stripping efficiency was poor, as a consequence of which, lighter hydrocarbon loading to the vacuum column and ejector system increased substantially. This served to demonstrate how such a common condition affects ejector system design. It is important to recognize that it may be practical to design an ejector system based on poor atmospheric column steam stripping. By doing this, it is not anticipated that an ejector system would bottleneck column operations.

In conclusion, this was a simplified review of vacuum column revamp options for improved cut point. It highlighted the importance of integrating ejector system impact into the analysis. There is no commercially available software enabling a refiner to review various ejector system operating scenarios. For that reason, consulting ejector system manufacturers is important and will ensure revamp strategies are properly optimized.

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