

<p><b>KLM Technology Group</b></p> <p>Practical Engineering Guidelines for Processing Plant Solutions</p>	 <p><b>ENGINEERING SOLUTIONS</b></p> <p><a href="http://www.klmtechgroup.com">www.klmtechgroup.com</a></p>	<p>Page: 1 of 145</p>
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<p>KLM Technology Group P. O. Box 281 Bandar Johor Bahru, 80000 Johor Bahru, Johor, West Malaysia</p>	<p><b>Kolmetz Handbook of Process Equipment Design</b></p> <p><b>REFINERY VACUUM TOWER SELECTION, SIZING AND TROUBLESHOOTING</b></p> <p><b>(ENGINEERING DESIGN GUIDELINES)</b></p>	<p>Co Author</p> <p>Rev 01 Reni Mutiara Sari</p> <p>Rev 02 Apriliana Dwijayanti</p> <hr/> <p>Editor / Author</p> <p>Karl Kolmetz</p>

## TABLE OF CONTENT

<b>INTRODUCTION</b>	<b>6</b>
Scope	6
General Consideration	8
A. Components for vacuum generation	9
B. Process in Vacuum Tower	11
C. Vacuum Ejectors and Pumps	19
D. Types of Operations in Vacuum Distillation	30
E. Classification of Oil Properties in Vacuum Tower	31
i. Pitch Operation	31
ii. Asphalt Operation	31
<b>DEFINITION</b>	<b>32</b>
<b>NOMENCLATURE</b>	<b>33</b>
<b>THEORY</b>	<b>36</b>
A. Unit for Processing	36
B. Vacuum Unit Charge Data	50
i. Lube-Asphalt Operation	50
ii. Fuels-Pitch Operation	54

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions  www.klmtechgroup.com	<b>Kolmetz Handbook of          Process Equipment Design</b>  <b>REFINERY VACUUM TOWER          SELECTION, SIZING AND          TROUBLESHOOTING</b>  <b>(ENGINEERING DESIGN GUIDELINES)</b>	Page 2 of 145
		Rev: 02
		December 2016

<b>C. The Vacuum Distillation Unit's Flash Zone</b>	<b>56</b>
<b>D. The tower overhead ejector system</b>	<b>62</b>
<b>E. Flash Zone and Tower Base Calculations</b>	<b>76</b>
a. Flash Zone Pressure	76
b. LVGO Losses in Overhead Gas	78
c. Steam Requirements	78
d. Heat Balance balance of flash zone	80
<b>F. Heat and Material Balance Calculations</b>	<b>81</b>
a. Mass balance across the Vacuum Distillation Unit (VDU)	81
b. Heat Balance for Lube-Type Towers	82
i. Steam to Product Strippers	82
ii. Tower Top Conditions	82
iii. Estimate of Tower Temperature Profile	83
iv. Overflash liquid (OI) Condensing Section	83
v. First Sidestream Product (D1) Draw Tray	87
vi. Second Sidestream Product (D2) Draw Tray	89
vii. Top Sidestream Product (D4) Draw Tray	91
c. Heat Balance for Fuel-Type Towers	93
<b>G. Draw-off temperatures</b>	<b>96</b>
<b>H. Pumpharound and internal flows for vacuum towers</b>	<b>97</b>
<b>I. Tower loading in the packed section of vacuum towers</b>	<b>97</b>
<b>J. Heater Transfer Line</b>	<b>103</b>
<b>K. Feed Distribution</b>	<b>104</b>

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		Rev: 02
		December 2016

## APPLICATION

<b>Example Case 1 : Vacuum Tower Mass Balance</b>	<b>109</b>
<b>Example Case 2 : Flash Zone Conditions</b>	<b>110</b>
<b>Example Case 3 : Heat balance at Flash Zone</b>	<b>115</b>
<b>Example Case 4 : Overflash Liquid (OL) Condensing Section Estimation</b>	<b>117</b>
<b>Example Case 5 : Heavy Vacuum Gas Oil (HVGO) Section Estimation</b>	<b>119</b>
<b>Example Case 6 : Light Vacuum Gas Oil (LVGO) Section Estimation</b>	<b>120</b>
<b>Example Case 7 : Verification of the Tower (Tower Diameter and Grid Volume)</b>	<b>123</b>
<b>Example Case 8 : Mass balances across the vacuum tower</b>	<b>127</b>
<b>Example Case 9: Vacuum Tower General Sizing</b>	<b>133</b>

<b>REFERENCES</b>	<b>147</b>
-------------------	------------

## LIST OF TABLE

<b>Table 1: Vacuum range and its application</b>	<b>9</b>
<b>Table 2 : Characteristic of vacuum distillation systems</b>	<b>13</b>
<b>Table 3: characteristic of various vacuum pumps</b>	<b>27</b>
<b>Table 4 : consideration of the vacuum operations types</b>	<b>30</b>
<b>Table 5: Grid de-entrainment efficiencies</b>	<b>37</b>
<b>Table 6: pressure drop values as recommended for design purposes</b>	<b>59</b>
<b>Table 7: relationship of diameter column and spray nozzle</b>	<b>108</b>

## LIST OF FIGURE

<b>Figure 1 : Vacuum ranges</b>	<b>8</b>
<b>Figure 2: Selection of vacuum equipment flow chart</b>	<b>10</b>
<b>Figure 3: Crude oil mixture</b>	<b>12</b>

These design guidelines are believed to be as accurate as possible, but are very general and not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

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		Rev: 02
		December 2016

<b>Figure 4: Vacuum Tower integrated with the Atmospheric Crude Distillation unit</b>	<b>15</b>
<b>Figure 5 : Vacuum distillation unit process schematic</b>	<b>17</b>
<b>Figure 6 : steam ejector</b>	<b>11</b>
<b>Figure 7: Typical steam jet ejector stage assemblies</b>	<b>20</b>
<b>Figure 8: Three-Stage Steam Jet Ejector Basis</b>	<b>22</b>
<b>Figure 9: Typical P&amp;I diagram for steam ejectors vacuum system</b>	<b>25</b>
<b>Figure 10: Typical ejector layout</b>	<b>26</b>
<b>Figure 11: Displacement vacuum pumps arrangement</b>	<b>28</b>
<b>Figure 12: Typical P&amp;I diagram for vacuum pump system</b>	<b>29</b>
<b>Figure 13 : fuel type vacuum tower</b>	<b>38</b>
<b>Figure 14 : lube type vacuum tower</b>	<b>39</b>
<b>Figure 15: Lube type vacuum tower with pump-back reflux heat removal</b>	<b>41</b>
<b>Figure 16: Lube type vacuum tower with pump-round reflux heat removal</b>	<b>42</b>
<b>Figure 17: Typical vacuum distillation unit no pre-condenser</b>	<b>44</b>
<b>Figure 18: Typical vacuum distillation unit with pre-condenser</b>	<b>45</b>
<b>Figure 19: Vapor and liquid flows in a. trays and b. structured packing</b>	<b>48</b>
<b>Figure 20: Typical vacuum column dimensions</b>	<b>49</b>
<b>Figure 21: whole crude TBP temperature-yield curve, lube-asphalt operation</b>	<b>51</b>
<b>Figure 22: crude assay data. Asphalt yield versus penetration</b>	<b>52</b>
<b>Figure 23: crude assay data, viscosities of vacuum gas oils</b>	<b>53</b>
<b>Figure 24: whole crude TBP temperature-yield curve, fuels-pitch operation</b>	<b>54</b>
<b>Figure 25: Shortcut of wash zone and flash zone</b>	<b>57</b>
<b>Figure 26: Shortcut of wash zone</b>	<b>58</b>
<b>Figure 27: Flash Zone Schematic</b>	<b>60</b>
<b>Figure 28: critical cracking zone</b>	<b>62</b>
<b>Figure 29: a. Vacuum producing equipment and b. Ejector condensate drum</b>	<b>64</b>

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		Rev: 02
		December 2016

<b>Figure 30: Ejector components and pressure profile.</b>	<b>65</b>
<b>Figure 31: Typical schematic of steam ejector 1</b>	<b>69</b>
<b>Figure 32: Typical schematic of steam ejector 2</b>	<b>70</b>
<b>Figure 33 : typical ejector set</b>	<b>71</b>
<b>Figure 34 : ratio factors for steam</b>	<b>72</b>
<b>Figure 35 : temperature entrainment ratios <math>R_{ti}</math>, <math>R_{ts}</math></b>	<b>73</b>
<b>Figure 36 : suction pressure <math>V</math>'s weight of motive steam</b>	<b>74</b>
<b>Figure 37 : motive steam usage correction factor</b>	<b>75</b>
<b>Figure 38 : correlation between TBP and ASTM end points</b>	<b>79</b>
<b>Figure 39 : flash zone heat and material balance</b>	<b>80</b>
<b>Figure 40 : heat and material balance summary, lube type vacuum tower with pumpback reflux heat removal</b>	<b>84</b>
<b>Figure 41 : heat and material balance-overflash liquid condensing section</b>	<b>85</b>
<b>Figure 42 : detail of first sidestream product draw</b>	<b>87</b>
<b>Figure 43 : detail of second sidestream product draw</b>	<b>89</b>
<b>Figure 44 : detail of top sidestream product draw</b>	<b>47</b>
<b>Figure 45 : heat and material balance summary for fuels type vacuum tower with pumparound heat removal</b>	<b>95</b>
<b>Figure 46 : capacity factor '<math>K</math>' <math>V</math>'s liquid rate</b>	<b>98</b>
<b>Figure 47 : transfer coefficient <math>H_o</math> <math>V</math>'s mass velocity for pumparound zones</b>	<b>100</b>
<b>Figure 48 : pressure drop through grid in inches of hot liquid per foot height</b>	<b>102</b>
<b>Figure 49: Heat transfer line</b>	<b>104</b>
<b>Figure 50: Tangential feed distributor</b>	<b>105</b>
<b>Figure 51: Box Feed Distributor</b>	<b>106</b>
<b>Figure 52: Spray nozzle assembly layout</b>	<b>107</b>
<b>Figure 53: Vacuum column spray nozzles</b>	<b>108</b>

These design guidelines are believed to be as accurate as possible, but are very general and not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

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		Rev: 02
		December 2016

## INTRODUCTION

### Scope

In an atmospheric tower operating at as low a pressure and as high a temperature as practical in the flash zone, the maximum amount of oils which will vaporize is described approximately by whole crude TBP cut points between distillates and residual liquid of 700 to 800 °F. At these operating conditions, the atmospheric residuum, commonly called reduced crude, still contains a large volume of distillable oils which can be recovered by vacuum processing. This is usually required to produce low cost feed to cracking units or to produce the basic stocks for lubricating oil production.

Originally vacuum units followed closely on design to the atmospheric unit except of course it operated under a vacuum condition. The vacuum was obtained by a two or three stage steam ejector and the internals of the tower were traditional trays, mostly bubble cap type. Under these conditions the vacuum obtained in the flash zone required the injection of steam to provide the required hydrocarbon partial pressure for adequate vaporization of the fuel oil feed<sup>[3]</sup>.

Vacuum distillates and residua can have several uses, depending upon the type of crude oil feed, the type of refinery and its downstream processing capabilities and, most important of all, the anticipated sales of products. Thus, the general function of the vacuum tower is to remove the maximum possible amount of distillate from the charge stock consistent with meeting product specifications on the residuum as well as the distillates.

This guideline is made to provide that fundamental knowledge and a step by step guideline; which is applicable to properly select and size vacuum tower in an independent manner.

There are two types of vacuum tower, such as lube-type and fuel-type towers. Fuel-type side distillates are processed in a conversion unit such as a fluid catalytic cracker (FCC) or hydrocracker. Whereas, lube-type product is used to generate base oils for lubricants.

Selection of vacuum tower is based on the method used for lube – asphalt operation and fuel – pitch operation. Whereas, in sizing the tower, there are several aspects that should be considered that are described in this guideline.

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		Rev: 02
		December 2016

The theory for the tower consists of vacuum distillation unit's flash zone, tower overhead ejector system, and the mass and heat balances. The procedures to design vacuum tower are also summarized in this guideline.

In the application section of this guideline, several case studies are shown and discussed in detail, highlighting the way to apply the theory for the calculation. Example Calculation Spreadsheets are part of this guideline. These Example Calculation Spreadsheets are based on case studies in the application section to make an engineer easy to follow the step by step calculation for different application industries.

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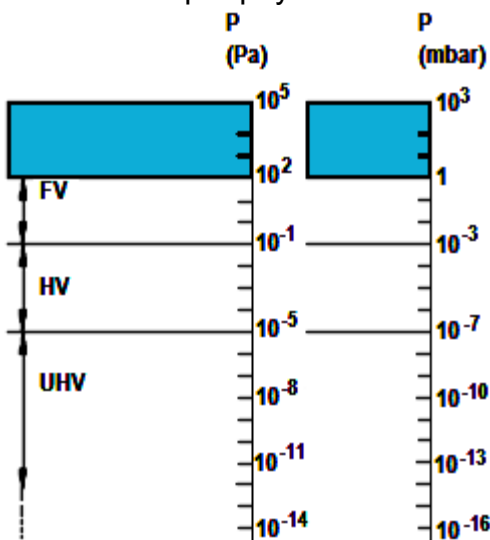
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		Rev: 02
		December 2016

## General Consideration

A vacuum is a space entirely devoid of matter “absolute vacuum”, when the air pressure in a space lies below atmospheric pressure. In physics, a vacuum is defined as “a state of emptiness that can be achieved by experiment” – in other words, nothing. This definition refers to the state of a space entirely devoid of matter (sometimes also referred to as an “absolute vacuum”). In practice, however, this state cannot be achieved. Therefore, talk instead about a vacuum when the air pressure in a space is lower than the atmospheric pressure or when the density of air molecules is reduced.

The vacuum plays a vital role in research in the fields of chemistry, biology and physics. It is also indispensable in many industrial processes. Noteworthy examples include semiconductor manufacture or mass spectroscopy. Vacuum technology has also plays a part in the development and implementation of new ideas in handling technology, i.e. lifting, holding, rotating and transporting all kinds of parts.

The vacuum ranges below are classified per physical attributes and technical requirements.



GV = Rough vacuum  
 FV = Medium vacuum  
 HV = High vacuum  
 UHV = Ultra-high vacuum

Figure 1: Vacuum ranges

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		Rev: 02
		December 2016

Table 1: Vacuum range and its application

Vacuum range	Pressure range (absolute)	Applications
Rough vacuum	Atmospheric pressure 1 mbar	Applications in industrial handling technology. In practice, the vacuum level is often specified as a percentage, i.e. the vacuum is defined in proportion to its ambient pressure. The material and the surface finish of workpieces play a major role in vacuum applications.
Medium vacuum	$10^{-3}$ ... 1mbar	Steel degassing, light bulb production, drying of plastics, freeze drying of foodstuffs, etc.
High vacuum	$10^{-3}$ ... $10^{-8}$ mbar	Smelting or annealing of metals, electron tube manufacture.
Ultra-high vacuum	$10^{-8}$ ... $10^{-11}$ mbar	Spraying of metals, vacuum metallizing (coating of metals) as well as electron beam melting.

### A. Components for vacuum generation

Vacuum equipment is defined as devices for creating, improving and/or maintaining a vacuum. Vacuum equipment can be roughly divided into "Steam Ejectors" and "Vacuum Pumps", Three major factors should be considered in the type selection stage for vacuum devices. These factors are operating requirements (i.e., suction pressure), suction gas properties and cost. As a general procedure for type selection, the flow chart shown in Figure 2 can be used.

Generally speaking, steam ejectors require less initial cost and have no moving parts, and hence they have high reliability. Their disadvantage is that their utility cost is high. Meanwhile, in the case of vacuum pumps, although they cost 5 to 20 times as much as steam ejectors and require high maintenance cost, their utility cost is lower. Regarding the operating costs, a general measure will be that, where the suction gas volume is large and the operating pressure is high, vacuum pumps will require less operating cost than steam ejectors.

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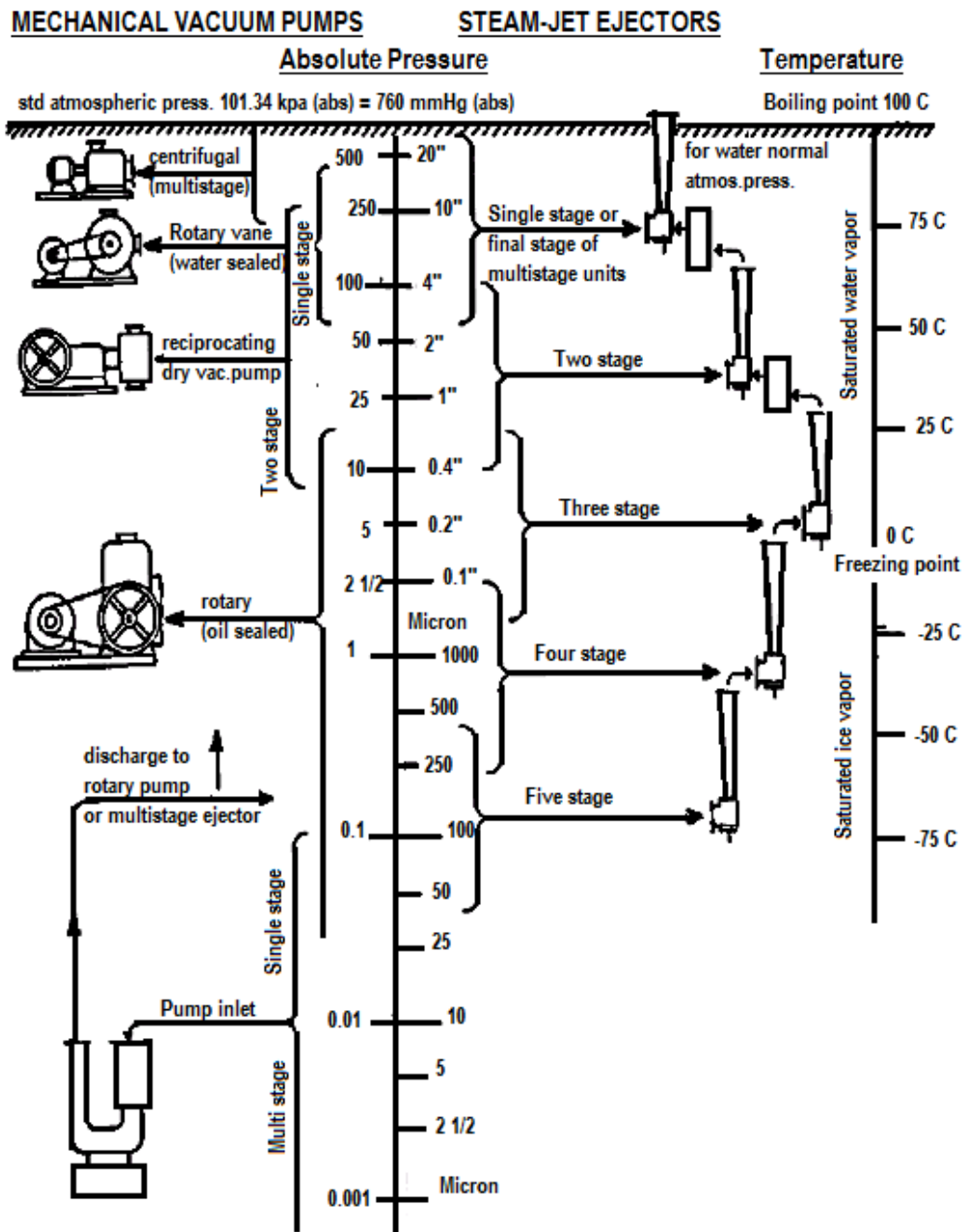


Figure 2: Selection of vacuum equipment flow chart

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		Rev: 02
		December 2016

The production of vacuum (subatmospheric pressure) is required for many chemical engineering processes, for example, vacuum distillation, drying, and filtration. The type of vacuum pump needed will depend on the degree of vacuum required, the capacity of the system, and the rate of air in-leakage. Reciprocating and rotary positive displacement pumps are commonly used where moderately low vacuum is required, about 10mmHg (0.013 bar), at moderate to high flow rates, such as in vacuum filtration. Steam-jet ejectors are versatile and economic vacuum pumps and are frequently used, particularly in vacuum distillation. They can handle high vapor flow rates and, when several ejectors are used in series, can produce low pressures, down to about 0.1mmHg (0.13 mbar).

Vacuum towers are one of the simpler refinery units since they are not a conversion unit like a hydro-cracker or FCCU. However, vacuum units are important because, along with crude units, they process a major portion of a refinery's incoming crude. Crude and vacuum unit performance affects all downstream operations.

Vacuum units have improved over the years. Originally, many vacuum units had trays for mass transfer. In fuels type vacuum towers where low pressures improve heavy vacuum gas oil (HVGO) recovery and profitability, trays gradually were replaced with random packing. The packing had lower pressure drops than trays, reducing flash zone pressures and overall column pressure drop, but had fouling issues. In the '70s end '80s, structured packings were successfully installed in many units. Structured packing has an even higher capacity than random packing and is now the dominant contacting device in vacuum service with less fouling than random packing.

## **B. Process in Vacuum Tower**

Vacuum distillates and residue can have several uses depending upon the type of crude oil feed, the type of refinery and its downstream processing capabilities. The general function of vacuum tower is to remove the maximum possible amount of distillate from the charge stock consistent with meeting product specification residuum as well as the distillates. Vacuum tower residuum properties can be set in various ways. When distillate production is to be maximized, the amount of gas oil allowed to remain in the bottoms stream must be minimized, this material usually 0 to 5 °API, is blended into residual fuels. In meeting product specification, the key to satisfactory operation is the maximum volume of clean gas oil, free from contamination by heavier materials.

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		Rev: 02
		December 2016

Originally vacuum units followed closely on design to the atmospheric unit except of course it operated under a vacuum condition. To further distill high boiling point materials, reduced pressure is required to prevent thermal cracking. At atmospheric pressure hydrocarbons begin to crack between 660-725°F. If the pressure is reduced, it can still vaporize hydrocarbon compounds which can be separated from an even heavier residue thus it can separate Vacuum Gas Oil (VGO) from Vacuum Residue (VR) and process these 2 stream in separate units and increase the revenue for the refinery (see figure 3).

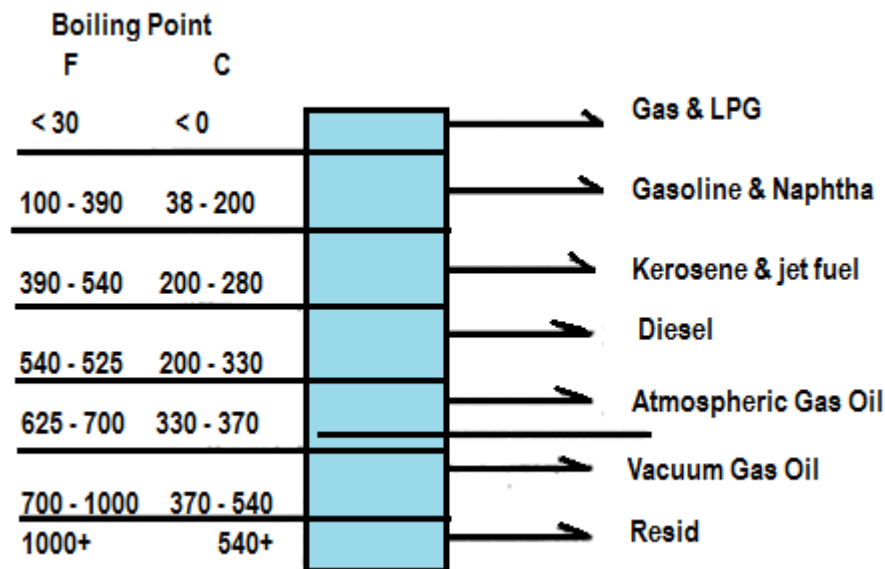


Figure 3: Crude oil mixture

Crude oil can be categorized as lube-bearing crude and non-lube bearing crude. The unit for processing of non lube bearing crude and lube-bearing crude are known as fuel-type and lube-type vacuum distillation column respectively. The fuel type is utilized when the vacuum distilled products are fed to cracking units. If the reduced crude is used for producing lubricating oils, the tower is said to be of lube type.

The process takes place in one or more vacuum distillation towers. The vacuum was obtained by a two or three stage steam ejectors and the internals of the tower were

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		Rev: 02
		December 2016

traditional trays, mostly bubble cap type. Under these conditions the vacuum obtained in the flash zone required the injection of steam to provide the required hydrocarbon partial pressure for adequate vaporization of the fuel oil feed. With the molecular weight of steam low at 18 the tower vapor traffic was extremely high in velocity requiring a large tower diameter to accommodate it.

The former produces vacuum gas oil (VGO) and later produces lubricating oil as the main distillate product. Atmospheric residuum is introduced into the vacuum distillation column after heat exchanging with distillation products, vacuum residue and pump-around reflux streams and finally heated in a furnace at required temperature.

Vacuum distillation furnace may be classified into two types, wet and dry. In wet type, steam is injected into the furnace coils and that helps to lower the partial pressure of feed as well as steam carries the feed vapours through the furnace tube more rapidly. In dry type, steam injection is not done in the furnace. Steam injection lowers the steam consumption in the vacuum ejector systems. The choice of the types depends on the overall economy of the refinery<sup>[7]</sup>.

In additional, vacuum distillation system is comprised into two types, dry system and deep cut system. The characteristics can be described in Table 2<sup>[2]</sup>.

Table 2 : characteristic of vacuum distillation systems

Dry system	Deep cut system
<ul style="list-style-type: none"> <li>- 1050°F+ cut temperature</li> <li>- No stripping steam</li> <li>- Smaller tower diameters</li> <li>- Reduced sour water production</li> <li>- Pressure profile : Flash zone : 20 – 25 mmHg abs at 750 – 770 °F Top of tower : 10 mmHg abs</li> </ul>	<ul style="list-style-type: none"> <li>- 1100°F+ cut temperature</li> <li>- Stripping steam</li> <li>- Steam reduces hydrocarbon partial pressures</li> <li>- Pressure profile : Flash zone : 30 mmHg abs HC partial pressure : 10 – 15 mmHg abs Top of tower : 10 mmHg abs</li> </ul>

The break-through to provide vacuum towers of much lower diameters came in with the use of high capacity steam injectors producing very low vacuum condition in the tower overhead. This coupled with the development of highly efficient expanded grid internals with very low pressure drop allowed the desired flash zone conditions to be met with out

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		Rev: 02
		December 2016

the injection of steam. This process became known as the 'Dry Vac' process and is the accepted process now for vacuum crude distillation<sup>[3]</sup>.

The principles of vacuum distillation resemble those of fractional distillation, except that:

- Larger-diameter columns are used to maintain comparable vapor velocities at the reduced pressures, the equipment is also similar
- The internal designs of some vacuum towers are different in that structured packing and demister pads are used instead of trays.

In petroleum industry vacuum distillation involves taking the residue produced in the crude distillation unit and further separating this fraction into lighter fractions:

- inerts/gas
- vacuum gas oil (light, medium and heavy)
- residue

The process of vacuum tower is often integrated with the Atmospheric Crude Distillation unit as far as heat transfer is concerned (see figure 4). Generally the atmospheric residue from the CDU is routed hot to the fired heater of the vacuum unit. In this unit, additional liquid is recovered from the residue of atmospheric distillation at a pressure of 4.8 to 10.3 kPa.

The vacuum, which is created by a vacuum pump or steam ejector, is pulled from the top of the tower. These ejectors remove inert and other vapor that may exist and pull a vacuum of about 5 mmHg absolute. Often, instead of trays, structured packing and demister pads are used. The tower internals are usually expanded grid type which offer low pressure drop such that the flash zone pressure is about 25–30 mmHg absolute. These materials are therefore distilled under vacuum because the boiling temperature decreases with a lowering of the pressure. The residue from the vacuum contains most of the crude contaminants such as metals, salts, sediments, sulphur, nitrogen, etc.

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	<p><b>REFINERY VACUUM TOWER SELECTION, SIZING AND TROUBLESHOOTING</b></p>	<p>Rev: 02</p>
	<p><b>(ENGINEERING DESIGN GUIDELINES)</b></p>	<p>December 2016</p>

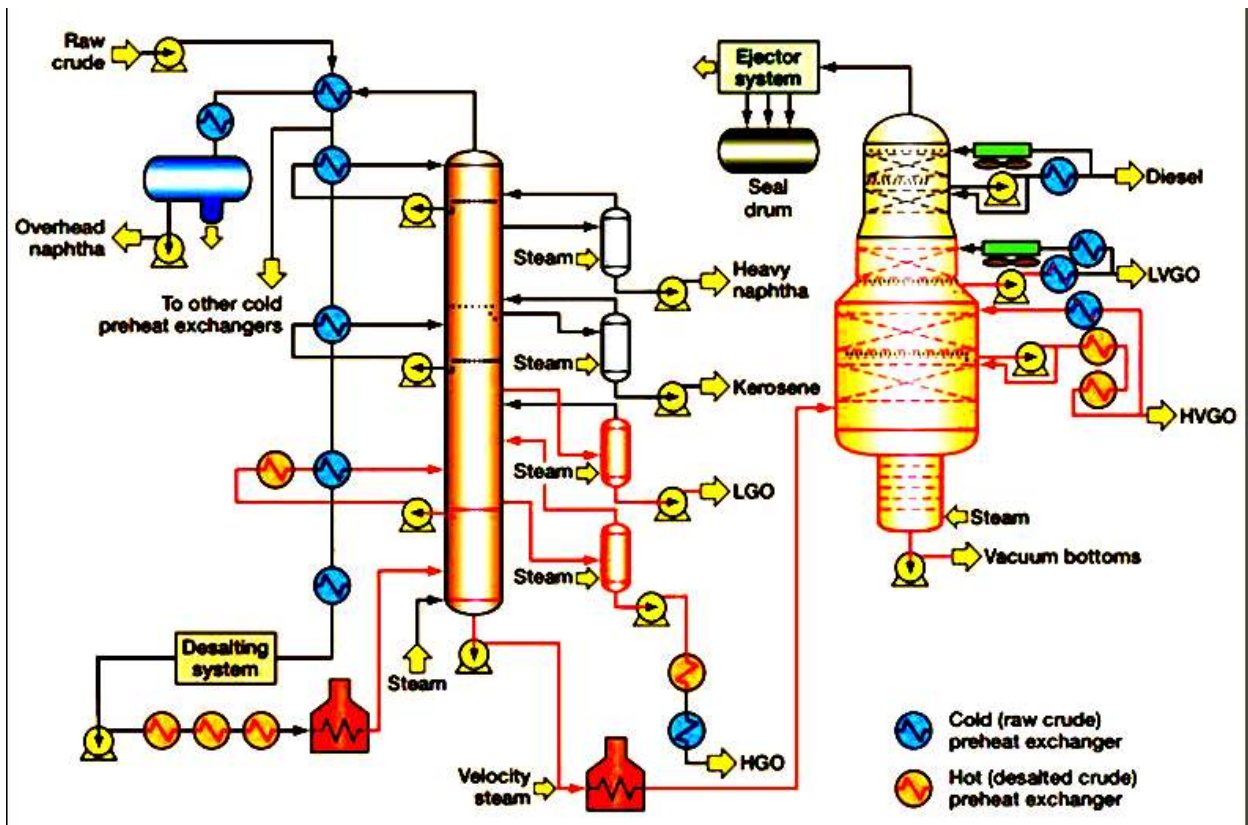


Figure 4: Vacuum Tower integrated with the Atmospheric Crude Distillation unit

The atmospheric residue is further distilled to provide the heavy distillate streams used for producing lube oil or as feed to conversion units. This distillation however has to be conducted under sub atmospheric pressure conditions. The temperature required for vaporising the residue at atmospheric pressure would be too high and the crude would crack.

To achieve this, the residue from the atmospheric unit is distilled under sub atmospheric conditions in the crude vacuum distillation unit. This unit operates similar to the atmospheric unit in so much as the feed is heated by heat exchange with hot products and then in a fired heater before entering the distillation tower. In this case, however, the tower

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		Rev: 02
		December 2016

operates under reduced pressure (vacuum) conditions. These units operate at overhead pressures as low as 10 mmHg. Under these conditions the hot residue feed is partially vaporized on entering the tower. To improve vaporization, the effective pressure is lowered even further by the addition of steam to the furnace inlet and at the bottom of the vacuum tower.

Addition of steam to the furnace inlet increases the furnace tube velocity and minimizes coke formation in the furnace as well as decreasing the total hydrocarbon partial pressure in the vacuum tower. The amount of stripping steam used is a function of the boiling range of the feed and the fraction vaporized, but generally ranges from 10 to 50 lb/bbl feed.

Should the cold feed be pumped from storage, it is heat exchanged against hot product and pumparound streams before being vaporized in the distillation unit heater. The feed is pre-heated in heat exchanger train and fed to fired heater, the heater outlet temperature is controlled to produce the required quality of distillate and residu. The hot vapors rise up the tower to be successively condensed by cooled internal reflux, stream moving down the tower as was the case in the atmospheric distillation unit. The condensed distillate streams are taken off as side stream distillates.

Structured packings are typically used as tower internals to achieve low flash-zone pressure and hence to maximize distillates yield. Circulating reflux stream enable maximum heat recovery and reduced column diameter. Vacuum distillation unit process can be given in figure 5.

A wash section immediately above the flash-zone ensures that the metal content in the lowest side draw is minimized. Heavy distillate from the wash trays is recycled to the heater inlet or withdrawn as metal cut. The operating pressure of the column is about 0.7 to 1.5kPa, at a lower temperature than that of the atmospheric tower. The overhead stream light vacuum gas oil can be used as a lube base stock, heavy fuel oil, or as feed to a conversion unit. Heavy vacuum gas oil is pulled from a side draw. The vacuum residence can be use to make asphalt, or it can be sent to a coker or visbreaker unit for further processing.

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	<p><b>REFINERY VACUUM TOWER SELECTION, SIZING AND TROUBLESHOOTING</b></p>	<p>Rev: 02</p>
	<p><b>(ENGINEERING DESIGN GUIDELINES)</b></p>	<p>December 2016</p>

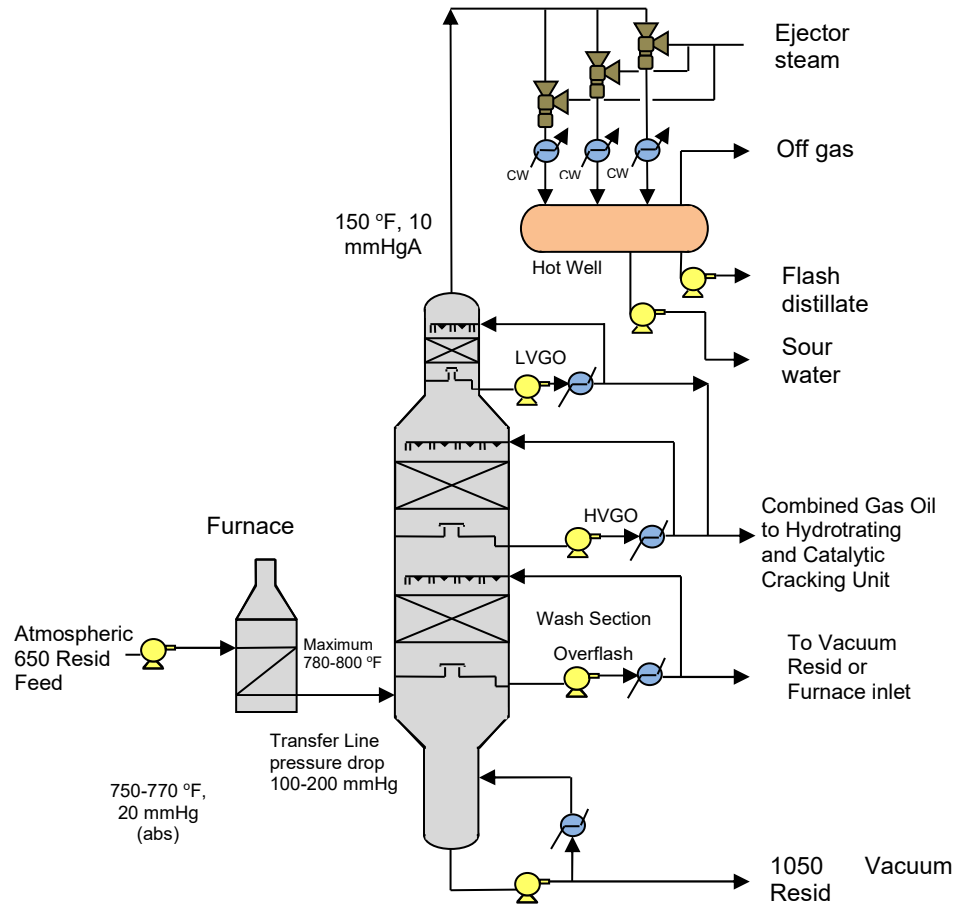


Figure 5 : vacuum distillation unit process schematic

Vacuum operation is used to reduce the column temperatures for the distillation of heat-sensitive materials and where very high temperatures would otherwise be needed to distill relatively nonvolatile materials.

When the stage and reflux requirements are calculated, it is usual to take the operating pressure as constant throughout the column. In vacuum columns, the column pressure drop will be a significant fraction of the total pressure, and the change in pressure up the

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		Rev: 02
		December 2016

column should be allowed for when calculating the stage temperatures. This may require a trial-and-error calculation, as clearly the pressure drop cannot be estimated before an estimate of the number of stages is made.

- For vacuum operation, lower weir heights are used to reduce the pressure drop; 6 to 12mm ( $\frac{1}{4}$  to  $\frac{1}{2}$  in.) is recommended.
- For vacuum distillations, the maximum allowable pressure drop will be determined by the process requirements, but for satisfactory liquid distribution, the pressure drop should not be less than 8mm water per m.
- If very low bottom pressures are required, special low pressure drop packings should be considered.

The vacuum tower can be divided into stripping section, wash oil section, HVGO section and LVGO section, from bottom to top, according to its product draw and working manner. Stripping section is the bottom part of the distillation tower below feed plate, where stripping steam is introduced. A mixture of the flashed vapour, stripped vapour from feed and steam flow up the column and enter into the wash oil section.

At this section, there are internal reflux is called wash oil. The wash zone removes entrained residue from the flash zone vapour and provides some fractionation of the heavy vacuum gas oil. The fractionation requirements depend on crude oil type, VGO yield target, and product quality. Typically, a wash zone consists of a packed bed, spray header or gravity flow trough type liquid distributors, and a collector tray below the packing<sup>[1]</sup>.

The washed vapour stream goes up to the HVGO section and then to LVGO section. HVGO and LVGO cuts are obtained from side draw trays by contacting with down-flow reflux liquid. The internal reflux liquid is achieved by condensing the ascending vapour by cooler pump-around reflux stream. HVGO and LVGO obtained after condensation from their respective trays and withdrawn as VGO product, either separately or together. A part of the wash oil from wash oil section is withdrawn as side stream.

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		Rev: 02
		December 2016

### C. Vacuum ejectors and pumps

The high vacuum condition needed in these units is produced by a series of steam ejectors attached to the unit's overhead system. These ejectors remove inert and other vapour that may exist and pull a vacuum of about 5 mmHG absolute. The tower internals are usually expanded grid type which offer low pressure drop such that the flash zone pressure is about 25–30 mmHg absolute. Following figure is steam ejector as shown in figure 6.

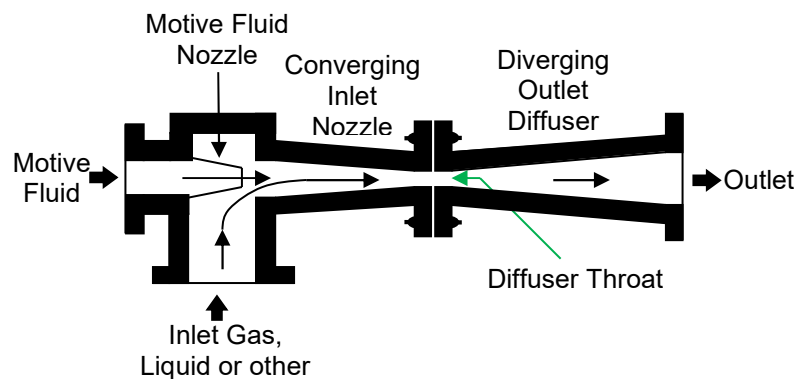


Figure 6 : steam ejector

The advantages of ejector:

- Simple, reliable means of producing vacuum
- They have low installed cost as well
- They are commonly found in process plants having available steam
- They provide many years of trouble-free operation

With the view of stablishing standard terminology, the sketches in figure 7 are shown of basic steam jet ejector stage assembly.

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	<p><b>REFINERY VACUUM TOWER SELECTION, SIZING AND TROUBLESHOOTING</b></p>	<p>Rev: 02</p>
	<p><b>(ENGINEERING DESIGN GUIDELINES)</b></p>	<p>December 2016</p>

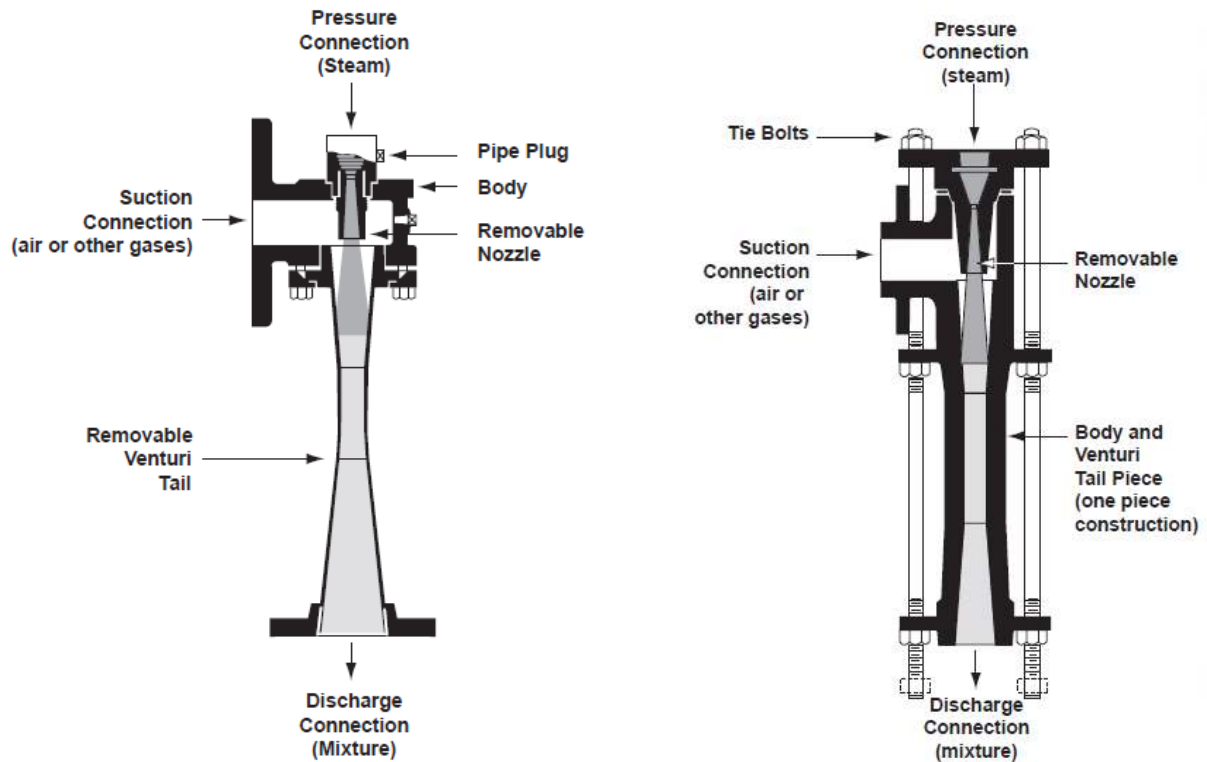


Figure 7: Typical steam jet ejector stage assemblies (Schutte)

These function according to the venturi principle, i.e. they are driven purely pneumatically and have a much simpler design compared with other vacuum generators.

Principle:

- The most important components are the jet nozzle (venturi nozzle) and at least one receiver nozzle.
- Accelerated compressed air generates a suction effect between both nozzles (vacuum).
- There are different design principles: single-stage and multistage ejectors.

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		Rev: 02
		December 2016

- ✓ Single-stage ejector: The design principle for a single-stage ejector includes a jet nozzle and only one receiver nozzle. After exiting the receiver nozzle, the exhaust air is generally discharged via a silencer or directly into the atmosphere.
- ✓ Multi-stage ejector: This design principle also includes a jet nozzle. Behind the first receiver nozzle there are additional nozzle stages, each of which has a bigger nozzle diameter in proportion to the falling air pressure. The drawn-in air from the first chamber, combined with the compressed air from the jet nozzle, is thus used as a propulsion jet for the other chambers.

#### Features:

- Low maintenance and low wear-resistant because there are no moving parts
- Low initial costs
- Compact design, smallest possible dimensions
- Suitable for pulsed applications
- Fast reacting
- Small line lengths between vacuum generation and application
- Easy to install, can assume any mounting position
- Low weight
- Multiple functions possible in a single device
- Supply port 4 - 6 bar optimal

#### Applications

- Part feeding systems in the automotive industry
- Packaging industry
- Industrial robot applications in all sectors
- Process engineering

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	<p><b>REFINERY VACUUM TOWER SELECTION, SIZING AND TROUBLESHOOTING</b></p>	<p>Rev: 02</p>
	<p><b>(ENGINEERING DESIGN GUIDELINES)</b></p>	<p>December 2016</p>

- Transport of liquids and bulk Material

In ejector basics, a three-stage ejector system with two surface-contact inter-condensers. motive force is provided by steam jets, which draw vapor from a vessel and through the system. The condensers act to reduce the load on the next ejector (see figure 8).

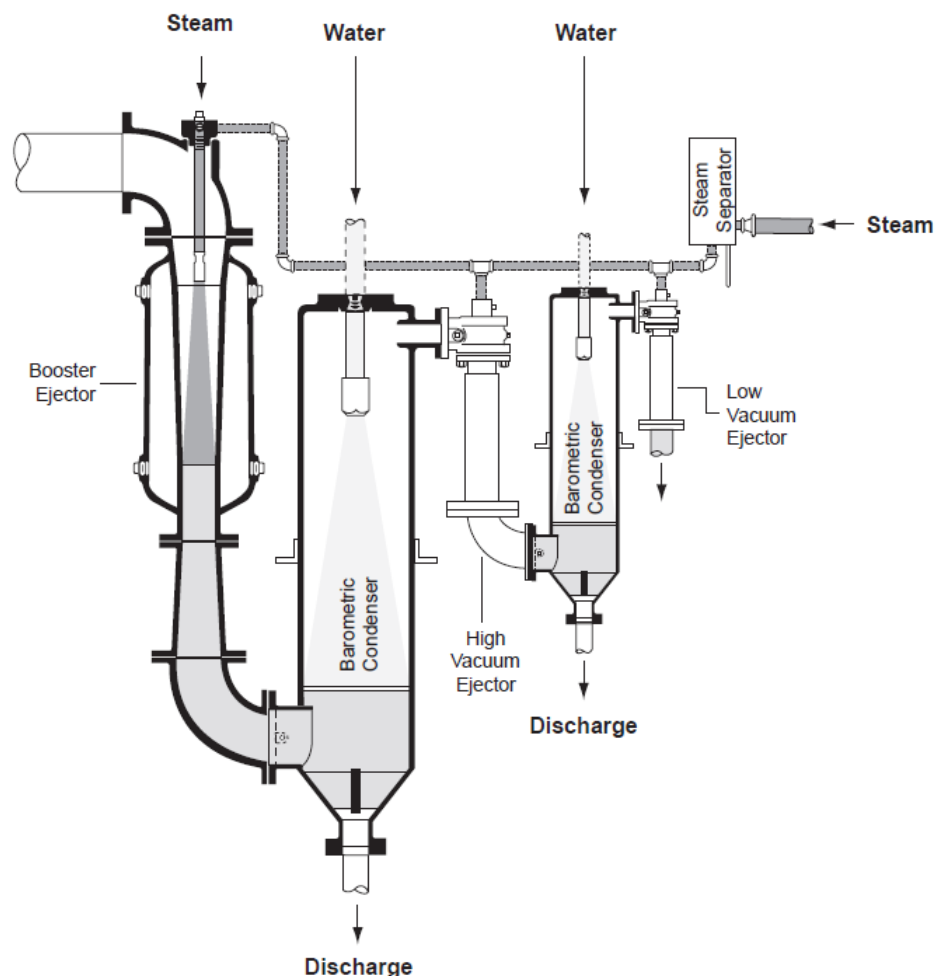


Figure 8: Three-Stage Steam Jet Ejector Basis (Schutte)

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		Rev: 02
		December 2016

## DEFINITION

**API gravity** - an arbitrary scale expressing the density of petroleum products.

**Asphalt** - a group of products produced from the vacuum distillation residue of crude oil. Asphalt is basically a colloidal dispersion of asphaltenes in oil with resins as the stabilizing agent. The quantities of these can vary widely with the type of crude.

**ASTM distillation** - standardized laboratory batch distillation for naphtha and middle distillate at atmospheric pressure.

**Bitumen** - a class of black or dark-colored (solid, semisolid, or viscous) cementitious substances, natural or manufactured, composed principally of high-molecular-weight hydrocarbons, of which asphalts, tars, pitches, and asphaltites are typical.

**Bottoms tower** - residues remaining in a distillation unit after the highest boiling point material to be distilled has been removed.

**Catalytic cracking** - the process of breaking up heavier hydrocarbon molecules into lighter hydrocarbon fractions by use of heat and catalysts.

**Coke** - a high carbon-content residue remaining from the destructive distillation of petroleum residue.

**Crude assay** - a procedure for determining the general distillation and quality characteristics of crude oil.

**Cut point** - temperature on the whole crude TBP curve that represents the limits (upper and lower) of a fraction to be produced (yield of a fraction).

**Distillation** - the act of vaporizing and condensing a liquid in sequential steps to effect separation from a liquid mixture.

**Ejector** – the act to remove inert and other vapour that may exist and pull a vacuum of about 5 mmHG absolute.

**Flash zone** - the area in these distillation towers where the distillate vapors are allowed to separate from the un-vaporized liquid. A flash zone is associated with the distillation of

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		Rev: 02
		December 2016

crude oil, both atmospheric and vacuum, the main fractionating towers of the fluid catalytic cracking unit, visbreaker or thermal cracking units

**Jet** - The stream of pump fluid issuing from a nozzle, in an ejector or diffusion pump.

**Lubricant** - any material interposed between two surfaces that reduces the friction or wear between them.

**Liquid ring vacuum pump** - A rotary positive displacement pump in which an eccentric rotor with fixed blades throws a liquid against the stator wall. The liquid takes the form of a ring concentric to the stator and combines with the rotor blades to define a varying volume.

**Overflash** - to provide additional heat (over and above that set by the product vaporization required) required by the process to generate the internal reflux required by the process.

**Partial pressure** - the contribution of one component of a system to the total pressure of its vapor at a specified temperature and gross composition.

**Pumparound** - the term given to any reflux stream which is created inside the distillation tower by taking off a hot liquid stream, cooling it, and returning the stream back into the tower two or three trays above the draw off tray. Pumparound systems are usually associated with complex distillation processes such as the atmospheric and vacuum crude oil distillation, where a single reflux stream (i.e., overhead condensate) would result in too low a reflux in the lower section of the tower. A single overhead reflux also would require a large tower diameter to cater for the increased tower vapor and liquid traffic. The pumparound concept does smooth out the liquid/vapor traffic in the whole tower.

**Residues** - In petroleum refining the term 'Residue' refers to the un-vaporized portion of the heated crude oil entering either the atmospheric crude oil distillation tower or vacuum tower that leaves these towers as their bottom product. The stream from the atmospheric column is often referred to as the 'long' residue while that from the vacuum unit is often called the 'short' residue or bitumen. Both residues are black in color the atmospheric residue has a specific gravity usually between 0.93 and 0.96, whilst the vacuum residue will be 0.99 and higher.

**Reflux** - the portion of the distillate returned to the fractionating column to assist in attaining better separation into desired fractions.

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		Rev: 02
		December 2016

**Stripping** - the removal (by steam-induced vaporization or flash evaporation) of the more volatile components from a cut or fraction.

**Wash zone** – zone that removes entrained residue from the flash zone vapour and provides some fractionation of the heavy vacuum gas oil

**Vacuum distillation unit** - the further distillation of the residue portion of atmospheric distillation of the crude. These units operate at overhead pressures as low as 10 mmHg.

**Vacuum pump** - A device for creating, improving and/or maintaining a vacuum. Two basically distinct categories may be considered: gas transfer pumps and entrapment or capture pumps

## NOMENCLATURE

A	= heat transfer area, ft <sup>2</sup>
API	= API gravity, (dimensionless)
A <sub>D</sub>	= design cross sectional area, ft <sup>2</sup>
A <sub>T</sub>	= tower area, ft <sup>2</sup>
D	= total hydrocarbon distillate products including the decomposition gas, moles/hr
e <sub>L</sub>	= liquid density, lbs/ft <sup>3</sup>
e <sub>R</sub>	= ratio, $\frac{\text{water density}}{\text{liquid density}}$ (dimensionless)
e <sub>v</sub>	= gas density, lbs/ft <sup>3</sup>
F	= reduced crude feed, lb/hr or bbl hr
F <sub>p</sub>	= packing factor $\approx a / \epsilon^2$
G	= hydrocarbon decomposition gas, lb/hr
G	= gas rate, lbs/sec. ft <sup>2</sup>
g <sub>c</sub>	= gravitational conversion factor = 32.2
h <sub>F</sub>	= enthalpy of feed, Btu/lb
H <sub>o</sub>	= overall heat transfer coefficient in Btu/sqft·hr· °F
L	= liquid rate, lbs/sec.ft <sup>2</sup>
L <sub>D1+1</sub>	= internal reflux required to absorb the excess heat at Tray D1, lb/hr
Lo	= overflash, lb/hr
Lp	= required pumpback reflux, lb/hr

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		Rev: 02
		December 2016

Mp	= steam usage multiplier, dimensionless
P	= pressure, psia
Q	= heat duty, Btu/hr
Q <sub>A</sub>	= heat of air leakage, btu/hr
Q <sub>F</sub>	= heat of feed, btu/hr
Q <sub>LO</sub>	= heat of overflow, btu/hr
Q <sub>LVS1</sub>	= heat removal from D1 product stripper to tray D1, btu/lb
Q <sub>SW</sub>	= heat of steam, btu/hr
Q <sub>VOFZ</sub>	= heat of flash zone vapour out, btu/hr
Q <sub>W</sub>	= heat of waste bottom, btu/hr
Q <sub>R</sub>	= reflux heat at the exit of the grid, Btu/hr
q' <sub>R</sub>	= heat removal capability of reflux, Btu/lb
R <sub>a</sub>	= ratio of lb motive steam/lb air equivalent, dimensionless
R <sub>mi</sub>	= molecular weight entrainment for component <i>i</i> from ejector, dimensionless
R <sub>ms</sub>	= molecular weight entrainment for steam, dimensionless
R <sub>ti</sub>	= temperature entrainment for component <i>i</i> from ejector, dimensionless
R <sub>ts</sub>	= temperature entrainment for steam, dimensionless
SG	= specific gravity, (dimensionless)
T	= temperature, °F
V <sub>a</sub>	= actual vapor velocity, ft/s
v <sub>f</sub>	= vapor velocity at flood, ft/s
V <sub>v</sub>	= vapor loads, ft <sup>3</sup> /s
W	= volume of total bottom products, lb/hr or bbl/hr
W <sub>a</sub>	= equivalent air flow, lbs/hr
W <sub>i</sub>	= actual of o/head (includes air, and light ends), lb/hr
W <sub>ms</sub>	= weight flow of motive steam, lbs/hr
W <sub>s</sub>	= weight flow of steam, lbs/hr
y <sub>HC</sub>	= ratio of hydrocarbon partial pressure to total pressure, mole fraction

These design guidelines are believed to be as accurate as possible, but are very general and not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

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<p><b>KLM Technology Group</b></p> <p>Practical Engineering Guidelines for Processing Plant Solutions</p> <p>www.klmtechgroup.com</p>	<p><b>Kolmetz Handbook of Process Equipment Design</b></p> <p><b>REFINERY VACUUM TOWER SELECTION, SIZING AND TROUBLESHOOTING</b></p> <p><b>(ENGINEERING DESIGN GUIDELINES)</b></p>	Page 27 of 145
		Rev: 02
		December 2016

## Greek Letter

$\Sigma D$  = total distillate products exclusive of overflash, gal/hr

$\frac{Q_R}{q' R}$  = required pumpback reflux, lb/hr

$\Delta t_m$  = Log mean temperature difference in °F

$\rho_{HL}$  = heavy liquid density, lb/ft<sup>3</sup>

$\rho_L$  = liquid density, lb/ft<sup>3</sup>

$\rho_V$  = vapor density, lb/ft<sup>3</sup>

$\mu_L$  = liquid viscosity, cp

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