

UOP ENGINEERING DESIGN SEMINAR

FALL 1991

VACUUM UNITS

VACUUM UNITS

In the petroleum industry when we speak of a Vacuum Unit, we almost always mean a unit charging reduced crude, operating at a pressure of 0.5-1.0 PSIA (25-50 mm Hg abs) and producing flashed gas oils and asphalt bottoms.

Usually the gas oils as well as the asphalt have to meet certain specifications. In the past, the main criterion for the unit's operation was that the charge not suffer any thermal decomposition and that the gas oil products and residual bottoms be relatively free of cracked (unsaturated) material. As a result, specifications were written that limited the amount of olefinic material in the Vacuum Unit products.

With present day operation, less emphasis is placed on product olefinicity and more stress is put on maximum yield of premium products. The vacuum gas oils (VGO), except for FCC feed stock, are now almost universally treated in various catalytic process units where the bad effects of impurities are compounded to such an extent that they become of prime importance. Asphalt bottoms is either routed to fuel oil or processed as road oil with a smaller percentage going into specialty products such as roofing tars, fillers and paints. Therefore, in modern day operations, thermal decomposition is of minimal importance from a product quality standpoint.

However, even though product olefinicity is no longer a chief concern, cracking still affects the way a Vacuum Unit operates. The ability to maintain a vacuum in the tower and to operate without excessive coke formation dictate temperatures just below the point of thermal decomposition.

When asphalt bottoms material must meet rigid specifications that are sometimes still encountered in road oil and specialty product applications, it is processed further in a blowing or oxidation unit. In the oxidation step, air rate, time and temperature are variables used to produce products with desired properties, the most important being penetration and ductility.

The basic principle upon which a Vacuum Unit operates is - the boiling point of a material decreases as the system pressure is lowered. For example, water at sea level, where the barometric pressure is 14.7 PSIA (760 mm Hg abs), boils at 212°F (100°C). At an elevation of 5000 feet (1525 m) above sea level water boils at 203°F (95°C). If the pressure is further reduced to 1 PSIA (50 mm Hg abs), which is a typical vacuum column flash zone pressure, water boils at 102°F (39°C).

In a similar way, at atmospheric pressure, reduced crude containing gas oils which boil in the range of 650-1050°F (345-565°C) would be subjected to cracking temperatures long before significant quantities could be flashed off. By reducing the pressure, much greater quantities of specification gas oil can be flashed off before cracking temperatures are reached.

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Therefore, we can say that the best performance of a Vacuum Unit or its ability to yield maximum gas oil products depends on the lowest absolute pressure that can be maintained in the flash zone consistent with maximum, non-cracking, temperatures at the heater outlet.

Experience has shown that, for most charge stocks, a flash zone temperature of 750°F (400°C) is about right. However, some materials, usually those with a high UOP characterization factor, require lower temperatures and other stocks, usually having a low K, can tolerate temperatures as high as 800°F (425°C). Laboratory data is required for determining yields and cracking temperatures on charge stocks for which there is no commercial operating data available.

So far we have only dealt with processing generalities. Let us now look at specifics such as the internals of the vacuum column itself. For discussion purposes the tower can be divided into five sections.

1. Flash Zone - De-entrainment
2. Slop Wax Section - Washing
3. HVG0 Section - Heat Recovery
4. LVGO Section - Condensation
5. Resid Section - Stripping

Flash Zone

The feed enters the column at the flash zone through a feed distributor - either a tangential nozzle or box type distributor. In either case, the intention is to enhance vapor-liquid separation by dissipating some of the energy in the feed stream which often enters at sonic velocity.

The flash zone should be a minimum of 20'-0" (6100 mm) in height or preferably 20'-0" between the slop wax accumulator tray and feed nozzle. The reason for a long flash zone is to minimize liquid entrainment.

Slop Wax Section

A slop wax or slop oil section is provided to remove approximately 5-10 LV% of the total gas oil. Experience has shown that the higher boiling fractions of the vacuum gas oil contain more metals and associated asphaltenes than the lower boiling range gas oils. The slop wax draw provides some measure of control of these troublesome metals and at the same time provides a wash zone for heavy entrained material.

Hot slop wax is usually pumped as a wash oil to the packed section immediately above the draw while net slop wax can be blended into fuel oil or recycled back to the vacuum heater inlet.

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Directly above the slop wax wash area is another section of packing. This section is washed by hot heavy vacuum gas oil (internal reflux) from above and provides the heat removal necessary for condensing the slop wax cut.

In most older designs, either bubble cap trays or side to side pans were used in this section of the tower. Newer designs generally use ~~2-3~~ feet ^{4'-6'} (600-900 mm) of packing or grid for each service. The use of packing reduces the column length and, more importantly, lowers pressure drop. Modern UOP designs may utilize four, low pressure drop, valve trays in this section if the VGO feeds a hydrotreating or hydrocracking unit. *GURGEN*

HVGO Section

The heavy vacuum gas oil (HVGO) section can be considered the main heat removal section. It is here where the major portion of the VGO is condensed by circulating HVGO through heat recovery exchangers and coolers and then returning a portion as reflux to the top of the packing. In most designs, the HVGO draw is 70-75 LV% of the total gas oil. By drawing both a light and heavy vacuum gas oil the HVGO draw temperature is considerably higher than the corresponding draw temperature of a single VGO cut. As a result, we obtain a more efficient heat recovery scheme with two draws.

The internals currently used for this section of the tower consist of 5-6 feet (1500-1800 mm) of grid and/or rings. Fractionating trays result in higher pressure drops and are used only in cases where some degree of fractionation is required. Side to side pans are seldom used in modern designs.

LVGO Section

The light vacuum gas oil (LVGO) section can be described as the top or final condensing section. Here is where the LVGO is condensed and separated from the non-condensibles (air leakage and cracked gases) going to the ejectors. Usually, the LVGO draw is 20-25 LV% of the total gas oil. LVGO is normally not heat exchanged but only cooled and a portion returned as reflux to the top of the column.

Since the quantity of vapor rising to this section is considerably less than below, the tower diameter can usually be reduced at this point. The LVGO accumulator is usually located in the swaged section. On large diameter towers the cone height is such that part or all of the LVGO packing may fit in the swaged portion.

The internals used for this section consist of 5-7 feet (1500-2100 mm) of grid and/or rings.

Resid Section

The resid or bottom section is usually the narrowest part of the column and has no internals except in those cases where specification asphalt is to be produced. In this case, stripping steam (4-6 lb steam/bbl resid) is used along with side to side pans.

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Since time as well as temperature promotes cracking, every attempt must be made to keep the residence time low and not give the bottoms a chance to crack and deposit troublesome coke. As a result, we would like to provide only one minute of residence time but in most cases equipment and control requirements dictate a much greater time. Means should be provided to circulate partially cooled bottoms liquid back to the bottoms boot to serve as quench.

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VACUUM TOWER SIZING

VACUUM TOWER SIZING

For this presentation a flash curve has been constructed and from it we have determined that a flash zone temperature of 750°F (400°C) is required to yield the specified products at a pressure of 40 mm Hg abs. (See Figure I.). In addition, the reduced crude feed to the Vacuum Unit will come hot, directly from a Crude Unit charging Light Arabian Crude. The Vacuum Unit feed rate will be 10000 BPSD with an API gravity of 17.1.

As in any design, the first step is to break-up the reduced crude feed into the net products leaving the unit. All that is known about the reduced crude is what is published in the crude assay. Sometimes this information is sketchy and one must resort to empirical methods or "tricks of the trade" in order to arrive at a good material balance or yield statement. If good and complete crude assay information is available the break-up becomes routine. When good plant operational and laboratory data is available on the feed stock it provides, perhaps, the most reliable information from a designer's viewpoint. To say the least, commercial data serves as good backup information for the design.

The material balance for our problem is presented in the table below. The material balance was arrived at in the following manner:

Given the quantity of total vacuum gas oil (VGO) and the quantity and gravity of resid, we can calculate the gravity of the total VGO by difference. We also know that approximately 5 LV% of the VGO should be drawn as a slop wax cut with the remaining VGO being split into a light vacuum gas oil (LVGO) and heavy vacuum gas oil (HVG0). The LVGO is typically 20 LV% of the VGO with the remaining 75 LV% of the total VGO being HVG0.

The net gas rate is a somewhat arbitrary number arrived at from experience. In our example, this rate has been set at 0.33 wt% of the feed. We could also have used Chart PD-895 in setting this rate. In either case, we are trying to account for non-condensibles which may be present in the vacuum tower from the following sources:

- 1) Air leakage.
- 2) Gases produced in the heater and vacuum column due to thermal cracking.
- 3) Dissolved non-condensibles in the feed.
- 4) Water of saturation in the feed.

VACUUM TOWER SIZINGMATERIAL BALANCE

	°API	UOP K	MW	(10 ⁶ SCFD) BPSD	LB/HR	MOL/HR	LV%	WT%
Red. Crude	17.1	11.6	471.1	10000	138975	295.0	100.00	100.00
Est'd Yields								
Gas	—	—	30	(0.141)	465	15.5	—	* 0.33
LVGO	29.8	11.8	283	1356	17355	61.3	13.56	12.49
HVGO	21.0	11.85	460	5065	68575	149.1	50.65	49.34
Slop Wax	11.2	11.5	550	338	4890	8.9	3.38	3.52
Resid	7.2	11.35	630	3203	47690	75.7	32.03	34.32

* OBTENIDO DE LA EXPERIENCIA

FIG #1

In this problem four stripping pans (side to side pans) are provided for stripping the tower bottoms material. A conservative stripping rate of 5 lbs steam/bbl resid will be used. This results in a stripping steam rate of:

$$\frac{3203 \text{ bbl resid}}{24 \text{ hrs}} \times \frac{5 \text{ lb steam}}{\text{bbl resid}} = 667 \text{ lbs steam/hr}$$

$$= 37.0 \text{ mols steam/hr}$$

Now that all net flow rates have been established, we only need to fix certain temperatures in order to start writing the heat and weight balance. Temperatures used in Vacuum Unit design are usually set based on experience since there is no precise way to calculate them. Temperatures used in the lower portion of the tower are more or less directly related to the transfer line or flash zone temperature. The following table gives the temperatures that will be used in our presentation. (See Figure II.).

TYPICAL DESIGN TEMPERATURES

	°F	°C	Notes
Flash Zone	750	400	
Resid from tower bottom	710	375	1
Steam to tower bottom	413	210	2
Slop wax draw	675	355	
Vapors rising at HVGO draw	650	345	3
HVGO draw	545	285	
Circulating HVGO return	325	165	
Vapors rising at LVGO draw	375	190	
LVGO draw	300	150	
Circulating LVGO return	110	43	4
Vapors to ejectors	115	46	5
Resid from steam generator	450	230	
Blended bottoms from cooler	300	150	6
HVGO to air cooler	460	235	
HVGO from air cooler	325	165	7
HVGO from tempered water cooler	175	80	
BFW to unit	230	110	

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VACUUM TOWER SIZING

- NOTES:
- 1) Reflects the use of stripping steam.
 - 2) Saturated at 270 psig.
 - 3) Approximately (flash zone temp. ^{HEAVY} $\pm 100^{\circ}\text{F}$).
 - 4) Function of cooling media used.
 - 5) Function of circulating LVGO return temperature.
 - 6) Function of viscosity at pumping temperature.
 - 7) Function of viscosity at air cooler outlet.

Our presentation will focus on the heat and weight balance around the vacuum column only. This will provide enough information to size the tower.

VACUUM TOWER SIZINGSIZE THE COLUMN AT THE FLASH ZONE (See Figure III)

750°F at 40 mm Hg abs (0.774 PSIA)

<u>VAPORS RISING:</u>	<u>LB/HR</u>	<u>MOL/HR</u>
Gas	465	15.5
Steam	667	37.0
LVGO	17355	61.3
HVGO	68575	149.1
Slop Wax	4890	8.9
Total	91952	271.8

$$\text{MW of vapors rising: } \frac{91952 \text{ lb}}{\text{hr}} \times \frac{\text{hr}}{271.8 \text{ mol}} = 338.3$$

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DE UOP

The equation for permissible linear velocity in this service is:

$$PV = 2.5 \sqrt{\frac{760}{\text{mm Hg abs}}} = \text{ft/sec}$$

$$\text{Therefore, PV at this point in the tower is: } PV = 2.5 \sqrt{\frac{760}{40}} \\ = 10.90 \text{ FPS}$$

$$\text{Vapor density } (\rho_v) = \frac{(\text{MW}) (\text{PSIA})}{(10.73) (\text{OR})} = \text{lb/ft}^3$$

where: 10.73 = Gas Constant (R)

$$= \frac{(\text{PSIA}) (\text{ft}^3)}{(\text{lb mol}) (\text{OR})}$$

Therefore, ρ_v at this point in the tower is:

$$\rho_v = \frac{338.3 \text{ lb}}{\text{lb mol}} \times \frac{0.774 \text{ PSIA}}{10.73 \text{ PSIA} \cdot \text{ft}^3} \times \frac{1 \text{ lb mol} \cdot \text{OR}}{(750+460) \text{ OR}} \\ = 0.0202 \text{ lb/ft}^3$$

The cubic feet per second (CFS) of vapors rising is:

$$\text{CFS} = \frac{91952 \text{ lb}}{\text{hr}} \times \frac{\text{hr}}{3600 \text{ sec}} \times \frac{\text{ft}^3}{0.0202 \text{ lb}} \\ = 1267 \text{ CFS}$$

VACUUM TOWER SIZINGSIZE THE COLUMN AT THE FLASH ZONE

The required tower cross sectional area (CSA) is:

$$\text{CSA} = \frac{1267 \text{ ft}^3}{\text{sec}} \left| \frac{\text{sec}}{10.90 \text{ ft}} \right| = \frac{\text{EFS}}{\text{PV}}$$
$$= 116.2 \text{ ft}^2$$

This results in a tower diameter (ID) of:

$$\text{ID} = \sqrt{\frac{116.2 \text{ ft}^2}{\frac{4}{\pi}}}$$
$$= 12.16 \text{ ft (3710 mm)}$$

VACUUM TOWER SIZINGSIZE THE COLUMN AT THE HVGO DRAW (See Figure IV)

Let us now heat balance the lower portion of the tower by drawing an envelope around the whole section directly below the HVGO draw tray. This will enable us to calculate the quantity of hot HVGO reflux necessary to heat balance this section. As an alternate approach, one could set the HVGO reflux rate below the draw and then calculate the resultant temperature of the vapors rising. For our case, we will proceed on the basis of using 650°F (345°C) as the vapor temperature. Note that in this section of the column the circulating slop wax does not remove any heat from the tower and is, therefore, ignored in our heat balance.

650°F at 30 mm Hg abs (0.580 PSIA)

	°F	LB/HR	BTU/LB	^{10⁶} BTU/HR
<u>Heat In</u>				
Feed to Column	750	138975	459	63.74
Stripping Steam	413	667	1174*	0.78
HVGO Reflux	545	W	271	271(W)
		<u>139642+W</u>		<u>64.52+(271W)</u>
<u>Heat Out</u>				
Resid from Column	710	47690	364	17.35
Net Slop Wax	675	4890	343	1.68
Radiation Loss	-	-	-	0.67
Vapors Rising to HVGO Draw:				
Steam	650	667	1331*	0.88
Gas	650	465	500	0.23
Net LVGO	650	17355	435	7.55
Net HVGO	650	68575	422	28.94
HVGO Reflux	650	W	422	422(W)
		<u>139642+W</u>		<u>57.30+(422W)</u>

*Corrected to liquid at 60°F.

$$\frac{64.52 \times 10^6 \text{ Btu}}{\text{hr}} + \left[\frac{271 \text{ Btu}}{1 \text{ lb}} \mid \frac{W \text{ lb}}{\text{hr}} \right] = \frac{57.30 \times 10^6 \text{ Btu}}{\text{hr}} + \left[\frac{422 \text{ Btu}}{1 \text{ lb}} \mid \frac{W \text{ lb}}{\text{hr}} \right]$$

$$W = 47815 \text{ lb/hr}$$

VACUUM TOWER SIZINGSIZE THE COLUMN AT THE HVGO DRAW

<u>VAPORS RISING:</u>	<u>LB/HR</u>	<u>MOL/HR</u>
Gas	465	15.5
Steam	667	37.0
Net LVGO	17355	61.3
Net HVGO	68575	149.1
<u>HVGO Reflux</u>	<u>47815</u>	<u>103.9</u>
Total	134877	366.8

$$\text{MW of vapors rising: } \frac{134877 \text{ lb}}{\text{hr}} \left| \frac{\text{hr}}{366.8 \text{ mol}} \right| = 367.7$$

PV at this point in the tower is:

$$PV = 2.5 \sqrt{\frac{760}{30}}$$

$$= 12.58 \text{ FPS}$$

f_v at this point in the tower is:

$$f_v = \frac{367.7 \text{ lb}}{1 \text{ b mol}} \left| \frac{0.580 \text{ PSIA}}{1 \text{ b mol} - ^\circ\text{R}} \right| \left| \frac{10.73 \text{ PSIA} - \text{ft}^3}{(650+460)^\circ\text{R}} \right|$$

$$= 0.01792 \text{ lb/ft}^3$$

The CFS of vapors rising is:

$$\text{CFS} = \frac{134877 \text{ lb}}{\text{hr}} \left| \frac{\text{hr}}{3600 \text{ sec}} \right| \left| \frac{\text{ft}^3}{0.01792 \text{ lb}} \right|$$

$$= 2091$$

The required tower cross sectional area is:

$$\text{CSA} = \frac{2091 \text{ ft}^3}{\text{sec}} \left| \frac{\text{sec}}{12.58 \text{ ft}} \right|$$

$$= 166.2 \text{ ft}^2$$

This results in a tower diameter of:

$$\text{ID} = \sqrt{\frac{166.2 \text{ ft}^2}{\pi}}$$

$$= 14.55 \text{ ft (4435 mm)}$$

CRITICAL DOWNDRAFT

VACUUM TOWER SIZINGCALCULATE THE HVGO CIRCULATION RATE (See Figure V)

Let us now analyze the tower directly below the LVGO draw by drawing an envelope around the whole section below this point. Since we have set the temperature of the vapors rising at this point at 375°F (190°C) and the temperature of the circulating HVGO returned to the tower at 325°F (165°C), a heat and weight balance can now be constructed. This will enable us to calculate the HVGO circulation rate. Note that the HVGO reflux returned below the HVGO draw does not remove heat from the envelope now considered.

	<u>°F</u>	<u>LB/HR</u>	<u>BTU/LB</u>	<u>10⁶ BTU/HR</u>
<u>Heat In</u>				
Feed to Column	750	138975	459	63.74
Stripping Steam	413	667	1174*	0.78
HVGO Circulation	325	W	132	132(W)
		<u>139642+W</u>		<u>64.52+(132W)</u>
<u>Heat Out</u>				
Resid from Column	710	47690	364	17.35
Net Slop Wax	675	4890	343	1.68
Radiation Loss	-	-	-	0.67
Net HVGO	545	68575	271	18.58
HVGO Circulation	545	W	271	271(W)
Vapors Rising to LVGO Draw:				
Steam	375	667	1200*	0.80
Gas	375	465	315	0.15
Net LVGO	375	17355	276	4.79
		<u>139642+W</u>		<u>44.02+(271W)</u>

*Corrected to liquid at 60°F.

$$\frac{64.52 \times 10^6 \text{ Btu}}{\text{hr}} + \left[\frac{132 \text{ Btu}}{\text{lb}} \mid \frac{W \text{ lb}}{\text{hr}} \right] = \frac{44.02 \times 10^6 \text{ Btu}}{\text{hr}} + \left[\frac{271 \text{ Btu}}{\text{lb}} \mid \frac{W \text{ lb}}{\text{hr}} \right]$$

$$W = 147480 \text{ lb/hr}$$

VACUUM TOWER SIZINGSIZE THE COLUMN ABOVE THE LVGO DRAW (See Figure VI)

We can now heat balance the top section of the tower by drawing an envelope around the upper part including the LVGO accumulator. We have already determined the heat content of the vapors rising to this section. Also, we have set the temperature of the net materials leaving this section along with the temperature of the circulating LVGO returned to the tower. As a result, a simple heat and weight balance can now be made to determine the LVGO circulation rate.

375°F at 15 mm Hg abs (0.290 PSIA)

	<u>OF</u>	<u>LB/HR</u>	<u>BTU/LB</u>	<u>^{10⁶} BTU/HR</u>
<u>Heat In</u>				
Vapors Rising to LVGO Draw:				
Steam	375	667	1200*	0.80
Gas	375	465	315	0.15
Net LVGO	375	17355	276	4.79
LVGO Circulation	110	W	23	23(W)
		<u>18487+W</u>		<u>5.74+(23W)</u>
<u>Heat Out</u>				
Net LVGO	300	17355	122	2.12
LVGO Circulation	300	W	122	122(W)
Vapors to Ejectors				
Steam	115	667	1083*	0.72
Gas	115	465	175	0.08
		<u>18487+W</u>		<u>2.92+(122W)</u>

*Corrected to liquid at 60°F.

$$\begin{array}{c} \text{IN} \\ \hline 5.74 \times 10^6 \text{ Btu} \\ \text{hr} \end{array} + \left[\begin{array}{c|c} 23 \text{ Btu} & W \text{ lb} \\ \hline 1 \text{ lb} & \text{hr} \end{array} \right] = \begin{array}{c} \text{OUT} \\ \hline 2.92 \times 10^6 \text{ Btu} \\ \text{hr} \end{array} + \left[\begin{array}{c|c} 122 \text{ Btu} & W \text{ lb} \\ \hline 1 \text{ lb} & \text{hr} \end{array} \right]$$

$$W = 28485 \text{ lb/hr}$$

<u>VAPORS RISING:</u>	<u>LB/HR</u>	<u>MOL/HR</u>
Gas	465	15.5
Steam	667	37.0
Net LVGO	17355	61.3
Total	18487	113.8

$$\text{MW of vapors rising is: } \frac{18487 \text{ lb}}{\text{hr}} \bigg| \frac{\text{hr}}{113.8 \text{ mol}} = 162.5$$

VACUUM TOWER SIZINGSIZE THE COLUMN ABOVE THE LVGO DRAW

PV at this point in the tower is:

$$PV = 2.5 \sqrt{\frac{760}{15}}$$

$$= 17.80 \text{ FPS}$$

f_v at this point in the tower is:

$$f_v = \frac{162.5 \text{ lb}}{\text{lb mol}} \left| \frac{0.290 \text{ PSIA}}{10.73 \text{ PSIA} - \text{ft}^3} \right| \frac{1 \text{ lb mol} - ^\circ\text{R}}{(375+460)^\circ\text{R}}$$

$$= 0.00526 \text{ lb/ft}^3$$

The CFS of vapors rising is:

$$\text{CFS} = \frac{18487 \text{ lb}}{\text{hr}} \left| \frac{\text{hr}}{3600 \text{ sec}} \right| \frac{\text{ft}^3}{0.00526 \text{ lb}}$$

$$= 976$$

The required tower cross sectional area is:

$$\text{CSA} = \frac{976 \text{ ft}^3}{\text{sec}} \left| \frac{\text{sec}}{17.80 \text{ ft}} \right|$$

$$= 54.8 \text{ ft}^2$$

This results in a tower diameter of:

$$\underline{\text{ID}} = \sqrt{\frac{54.8 \text{ ft}^2}{\frac{4}{\pi}}}$$

$$= \underline{8.36 \text{ ft}} \quad (2545 \text{ mm})$$

VACUUM TOWER SIZINGSIZE THE RESID STRIPPING SECTION

The resid stripping section is the only section remaining to be sized. Generally, the cross sectional area of this part of the column is set at 10 percent of the main tower area. In our example, we calculated that 14.55 ft (4435 mm) was required at the HVG0 draw. Ten percent of this area results in a diameter of approximately 4.5 ft (1370 mm). We can now check the 4.5 ft ID for the resultant residence time. The residence time should be in the range of 0.5 - 1.0 min/ft of length.

Given 4.5 ft ID, the resultant CSA is: $CROSS\ SECTIONAL\ AREA = \frac{\pi D^2}{4}$

$$\frac{(4.5\ ft)^2}{4} \times \pi = 15.90\ ft^2$$

The net resid leaving the bottom of the tower is 123 GPM (See HT & WT Bal.). As a result, the residence time in this section of the tower is:

$$GPM = \frac{Q_b/H}{300 \times SG} \quad \text{TO THE D T CONVERSION} \quad \frac{ft^3}{H} \rightarrow GPM$$

$$\frac{15.90\ ft^3}{ft} \times \frac{min}{123\ gal} \times \frac{7.48\ gal}{ft^3} = 0.967\ \frac{min}{ft}$$

Therefore, the 4.5 ft ID looks reasonable.

In this example the use of the PV equation resulted in a column diameter of 14.5 ft for the main portion of the tower and 8.4 ft for the top condensing section. We know from experience that the use of the PV relationship will result in a conservative design. Therefore, we can safely reduce the tower diameter to 14'-0" and 8'-0" (4265 mm and 2440 mm) in the main section and top section, respectively.

UOP Process

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ENGINEERING DEPARTMENT

HEAT AND WL BALANCES

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PROJECT _____
BY RTV

Vacuum Tower Sizing

NOTE -

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Feed & Bottoms

STREAM	API LB/GAL	K	MW	FLOWING SP. GR. (LB/CF)	°F	PSIG (MM HG ABS)	BPSD @ 60°F (10" SCF/D)	FLOWING GPM (CFS)	MOLS PER HR.	LB/HR	BTU/ LB	10 ⁴ BTU/HR
REDUCED CRUDE TO HEATER	17.1	11.6	471.1	0.746	655	—	10 000	372		138975	337	46.82
VACUUM HEATER DUTY												16.92
MATERIAL FROM HEATER	—	—	447.6	—	771	(155)	—	—		138975	459	63.74
VAPOR	—	—	355.8	(0.081)	"	"	—	(213)		62616	517	32.36
LIQUID	12.0	11.6	567.8	0.734	"	"	—	208		76359	411	31.38
MATERIAL TO FLASH ZONE	—	—	447.6	—	750	(40)	—	—		138975	459	63.74
GAS	—	—	30	(2320.0)	"	"	—	—		465	575	0.27
LUGO	29.8	11.8	283	—	"	"	1356	—		17355	503	8.73
HVGO	21.0	11.85	460	—	"	"	5065	—		68575	490	33.60
SLOP WAX	11.2	11.5	550	—	"	"	338	—		4890	483	2.36
RESID	7.2	11.35	630	0.755	"	"	3203	127		47690	394	18.78
RADIATION LOSS												0.67
STRIPPING STEAM	—	—	18.0	(0.616)	413	270	(0.34)	(0.3)		667	1174	0.78
RESID TO STEAM GENERATOR	7.2	11.35	630	0.775	710	—	3203	123		47690	364	17.35
STEAM GENERATOR DUTY												8.05
RESID FROM STEAM GENERATOR	"	"	"	0.877	450	—	"	109		"	195	9.30
NET SLOP WAX	11.2	11.5	550	0.765	675	—	338	13		4890	343	1.68
TOTAL MAT'L TO BFW EXCH.	7.5	11.36	621.5	0.862	475	—	3541	122		52680	209	10.94
BFW EXCHANGE DUTY												1.98
TOTAL BOTTOMS TO COOLER	"	"	"	0.887	410	—	"	119		"	171	9.00
COOLER DUTY												3.16
BLENDED TEMS FROM COOLER	"	"	"	0.9	00	—	"	113		"	11	5.84

HEAT AND WEIGHT BALANCES

PAGE NO. 13
DATE 3-1
PROJECT RT
BY RT

Vacuum Tower Sizing

ENGINEERING DEPARTMENT

NOTE -

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[illegible]



ENGINEERING DEPARTMENT

Vacuum Tower Sizing

PAGE NO. 14
DATE 3-18-82
PROJECT _____
BY RJV

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[illegible]

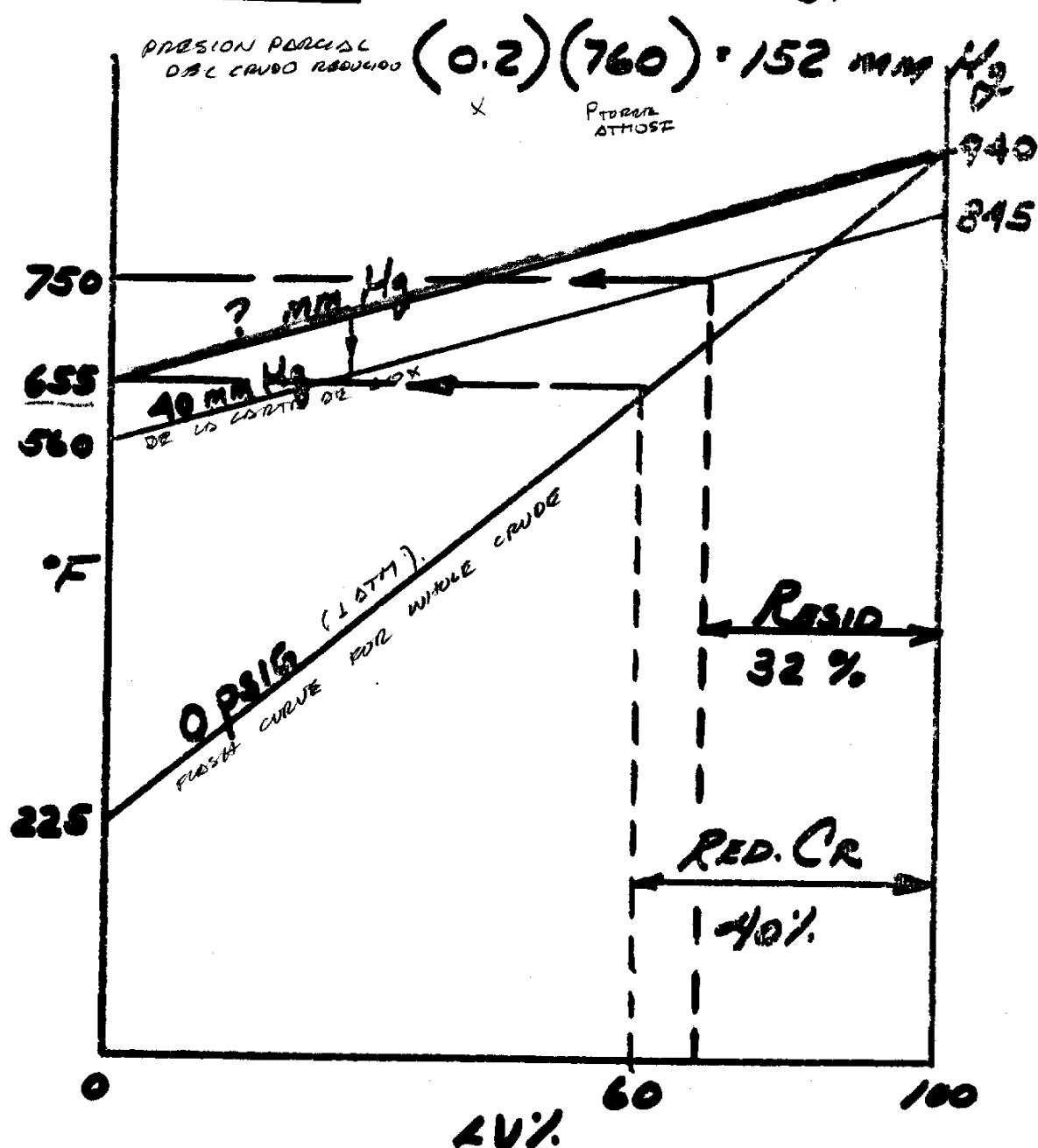
UOP17-1022B

FIG. I

FLASH CURVE

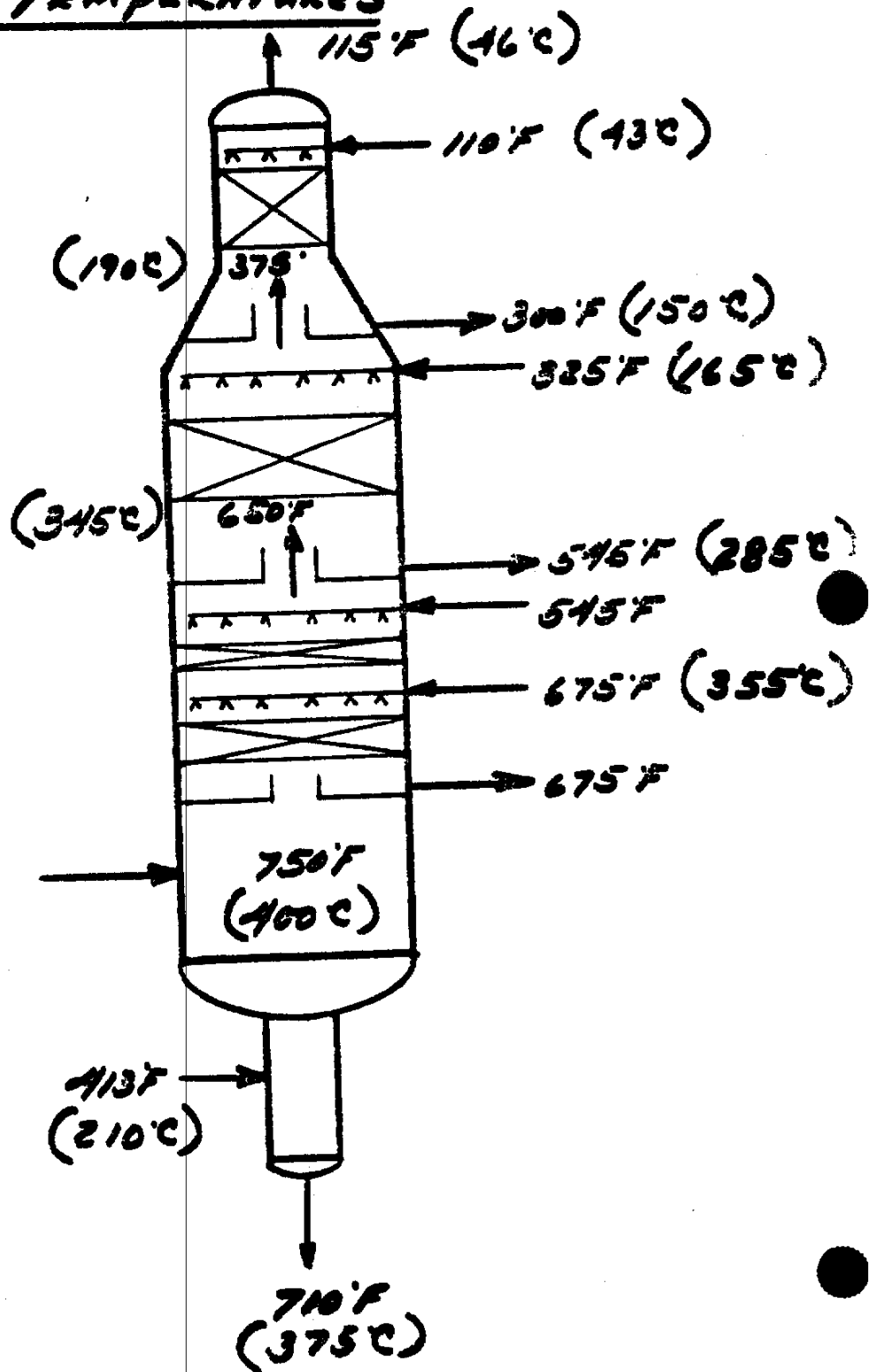
CRUDE

RED. CR. = 20 MOL% OF CRUDE



DESIGN TEMPERATURES

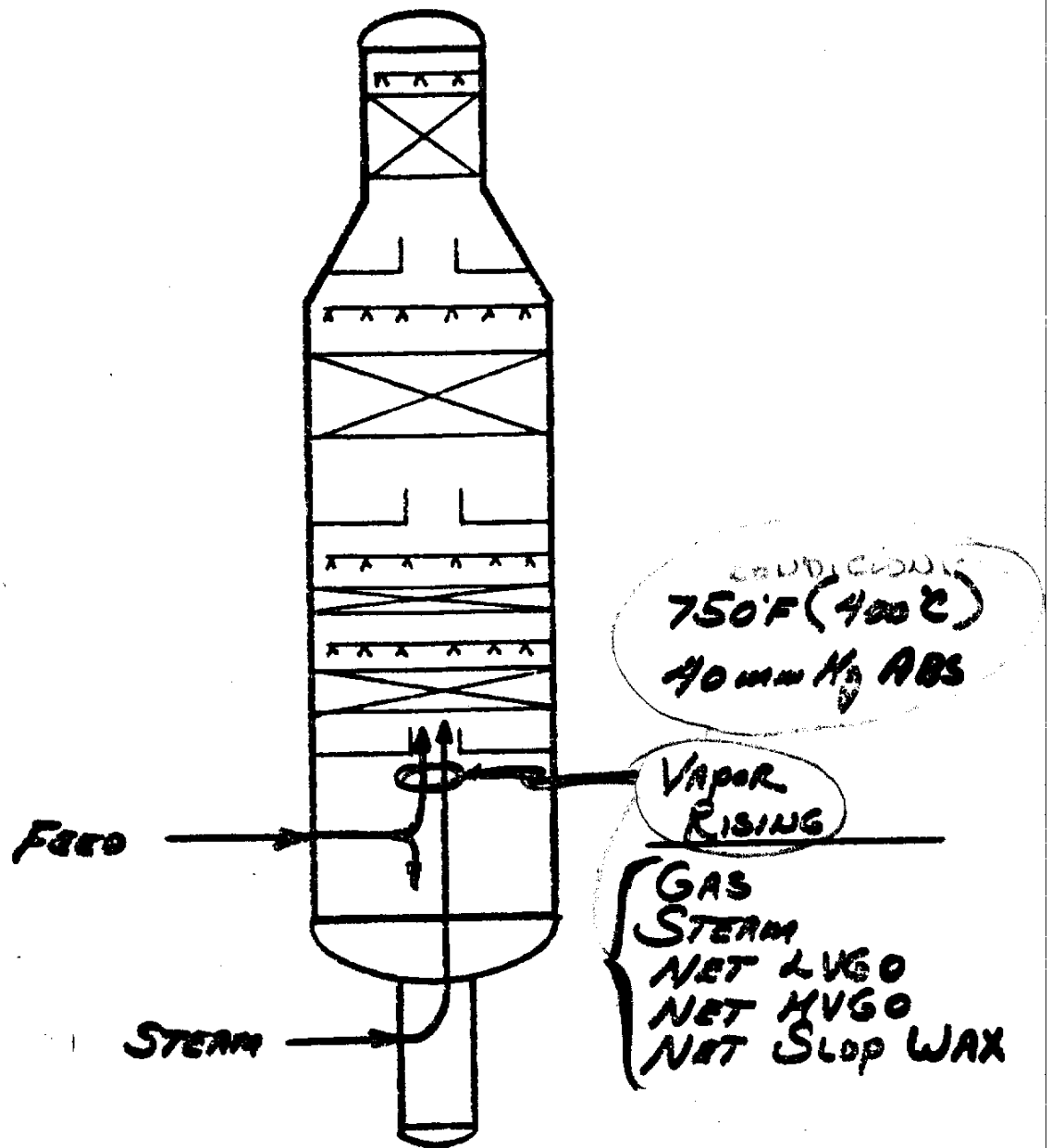
FIG. II



6' OF RMP GUTSCH
EQUIVALENT D UNK
FROM TROPICS.

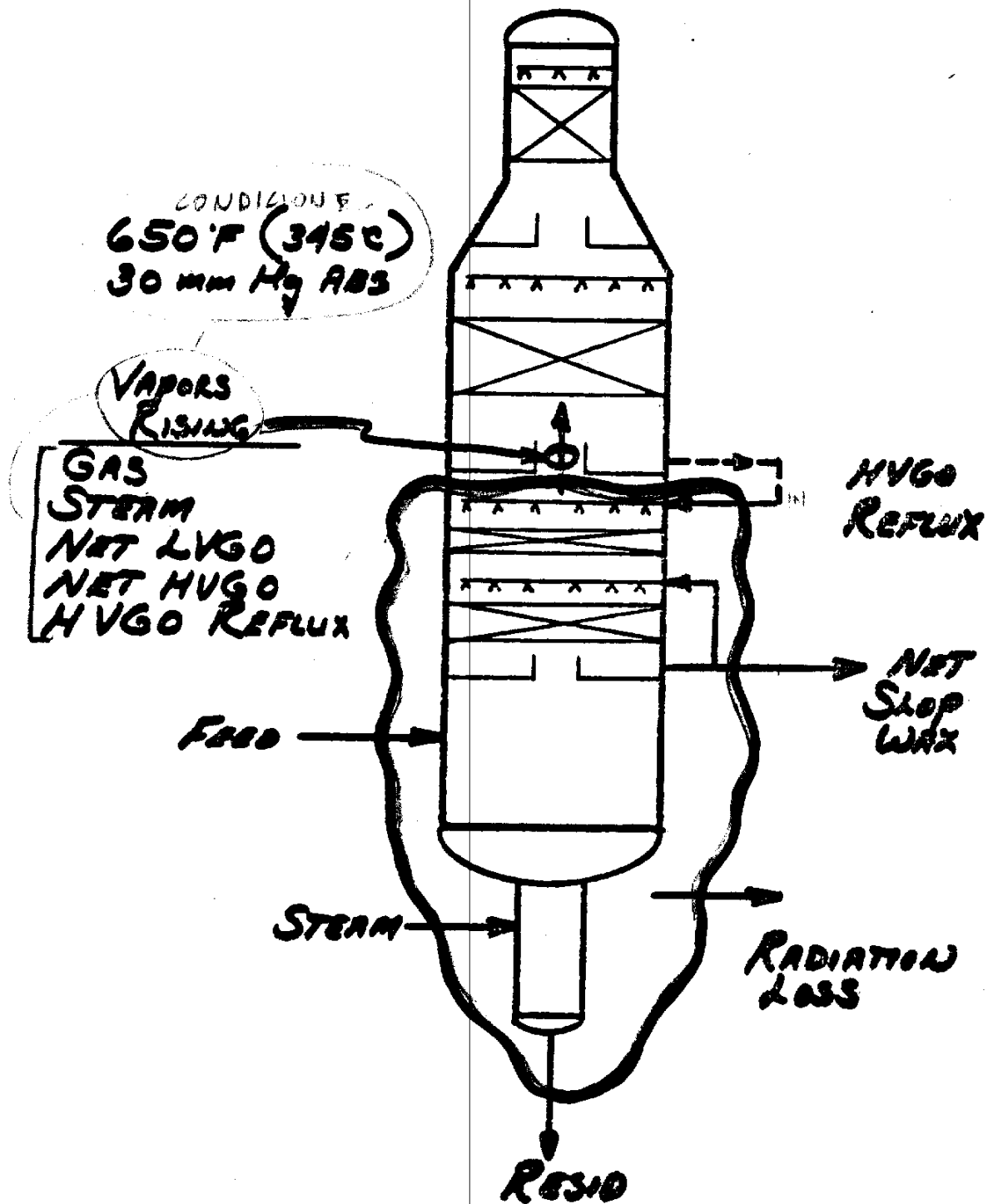
FIG. III

SIZE @ FLASH ZONE



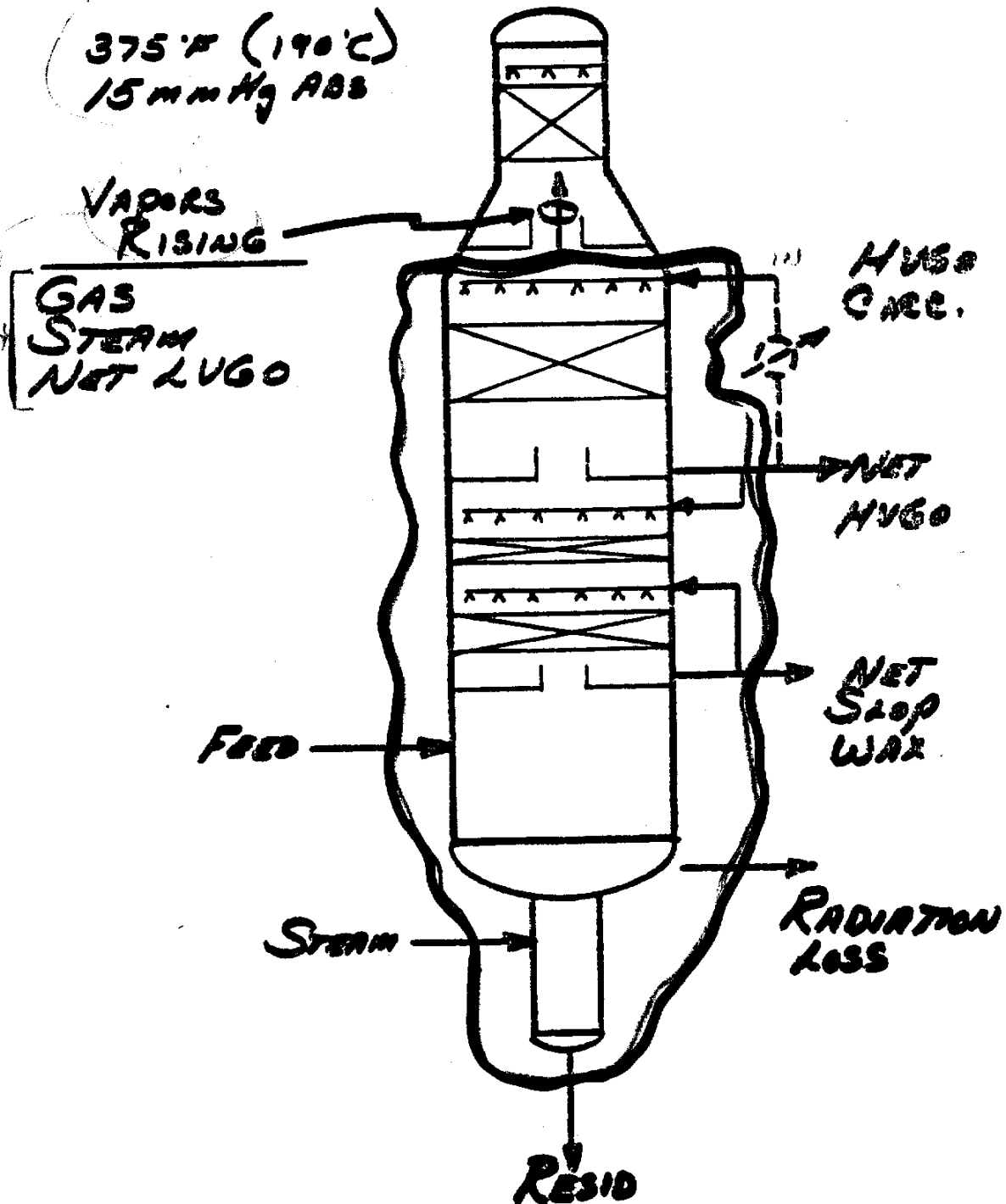
Size @ HVGO Draw

FIG. IV



CALC. HUGO CIRC.

FIG. I



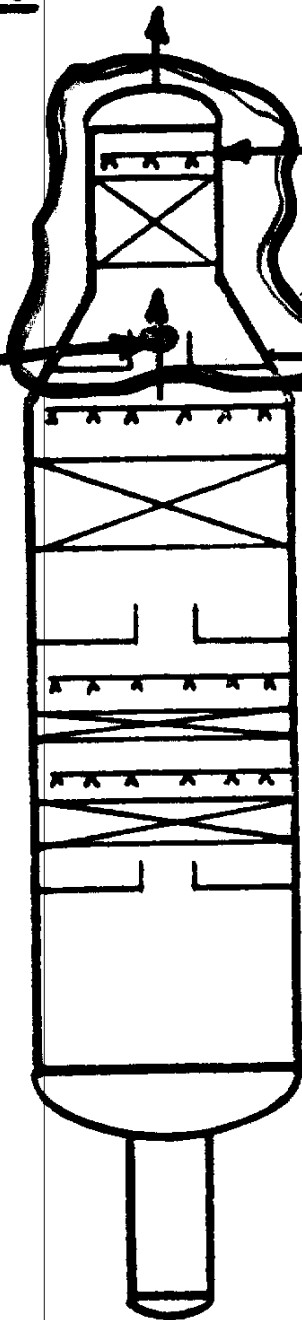
CALC. LVGO CIRC.

FIG. VI

CONDENSER
375°F (190°C)
15 mm Hg ABS

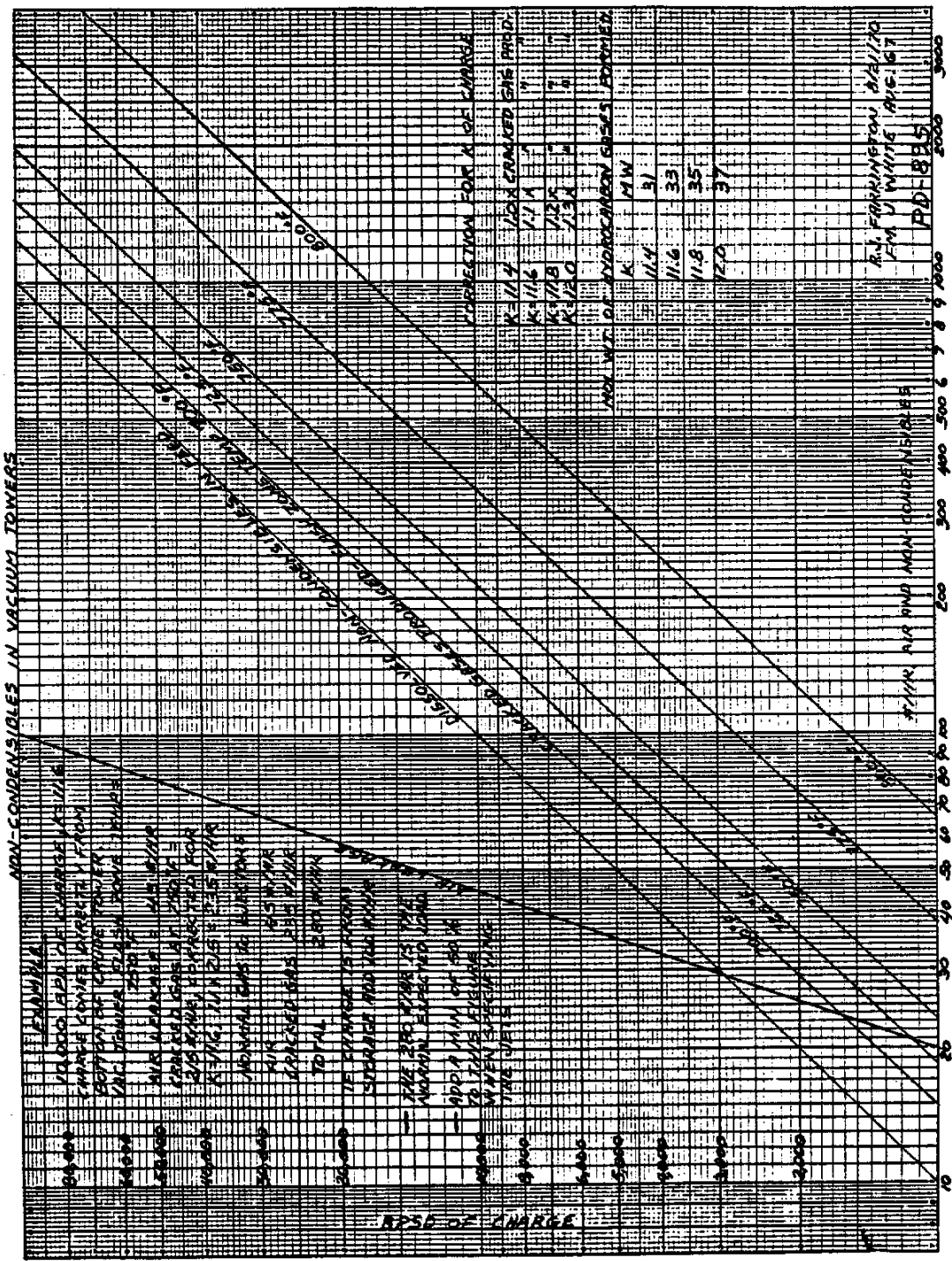
VAPORS
RISING

GAS
STEAM
NET LVGO



LVGO
CIRC.

NET
LVGO



NORMAL

STEAM x 45

AIR 235

NO COND 200FX

DESIGN

STEAM x 1.5

AIR 45

NO COND 235x1.5

TURN DOWN

STEAM x 0.5

AIR 45

NO COND 235x0.5

AIR & WATER VAPOR OF CHARGE
FOR BRIDGES, TALLS, ETC.
% SO IN CONDENSER FOR OUR LEADERS
OR COLLECTED

A. J. FRANKINGTON, JR.
F. M. J. WHITE, JR.
P.D. 885

UOP ENGINEERING DESIGN SEMINAR

FALL 1991

VACUUM TOWER INTERNALS

VACUUM TOWER INTERNALS

Generally, modern day vacuum towers use some type of packing in the heat removal sections. We do not take any credit for this packing (grid and/or rings) furnishing any more fractionating capability than the side to side pans used on older designs.

For many years UOP used a heat transfer rate (U) of 350-400 Btu/hr-°F-ft³ when determining the volume of packing required. This was consistent with the 400 Btu/hr-°F-ft³ given in Glitsch Bulletin No. 7070 (dated 1963). Use of these U values usually resulted in packing depths as follows:

Section	Depth	
	Ft	mm
LVGO	5 → 7	1525 → 2135
HVGO	5 → 6	1525 → 1830

More recent design information supplied by Glitsch gave the following criteria for determining the volume of packed sections:

1. When the capacity factor (C)* fell between 0.2 and 0.4 FPS at any point within the packed section the recommended maximum U was 400 Btu/hr-°F-ft³ for Glitsch grid.
2. When a considerable part of the packing had a capacity factor (C) of less than 0.2 FPS the heat transfer efficiency decreased and the following U values were recommended:
 - a. 250 Btu/hr-°F-ft³ if the packed section consisted only of Glitsch grid.
 - b. 400 Btu/hr-°F-ft³ if the packed section used rings in that portion where C was less than 0.2 FPS and if Glitsch grid were used in the remaining part of the section where C was greater than 0.2 FPS.

$$\text{CAPACITY FACTOR} * C = V_s \sqrt{\frac{\rho_v}{\rho_L - \rho_v}}$$

where: V_s = superficial velocity, ft/sec(FPS)

ρ_L = liquid lb/ft³

ρ_v = vapor lb/ft³

The most recent design information furnished by Glitsch for calculating the volume of packed sections is given in their Bulletin No. 7070 (dated, Feb. 1981).

VACUUM TOWER INTERNALS

$$U = h_o = 421 C^{0.8} \times (GPM/A_T)^{0.58}$$

where: C = capacity factor
(defined above)

GPM = flowing liquid
gal/min

A_T = tower cross
sectional area, ft^2

Note that the capacity factor (C) used in the above equation is at the point of maximum loading (vapor rising to the packed section and liquid from the packed section).

Using the following dimensions and other necessary data given in Vacuum Tower Sizing, let us now calculate the heat transfer rate for the HVGO section.

<u>Section</u>	<u>Tower I.D., ft-in</u>	<u>Packing Depth, ft-in</u>
LVGO	8 - 0	5 - 6
HVGO	14 - 0	5 - 0

Calculate U for HVGO Section:

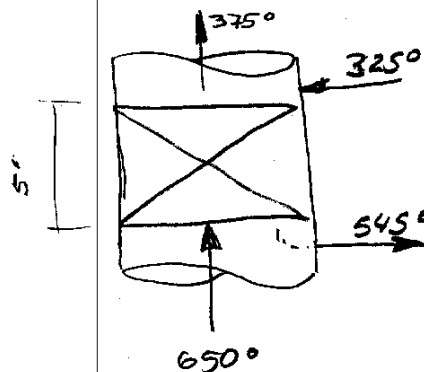
14'-0" ID = $153.94 ft^2$ tower cross sectional area (CSA)

Volume of packing is:

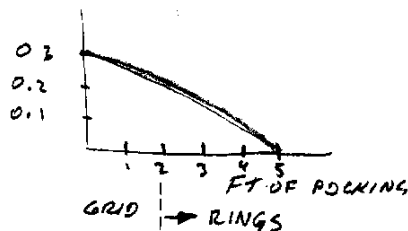
$$\frac{153.94 ft^3}{ft} \times 5 ft = 769.7 ft^3$$

LMTD is:

$$\begin{array}{r} 650 \rightarrow 375 \\ 545 \leftarrow 325 \\ \hline 105 \quad 50 \\ 74.10F \end{array}$$



EXISTING AND RELATION COOL
UNITAL BENTHE ACTUADORE
EMADUQTOAD Y BL TOCER
C



VACUUM TOWER INTERNALSDRL BALANCE
DR HCSS Y ENERGIN

$$\begin{aligned} 545^{\circ}\text{F} &\Rightarrow 271 \text{ BTU/LB} \\ 325^{\circ}\text{F} &\Rightarrow 132 \text{ BTU/LB} \end{aligned}$$

Resultant heat transfer rate (U) is: $147480 \text{ LB/hr} (271-132) \text{ BTU/LB} = 205 \times 10^6 \text{ BTU/hr}$

$$\frac{20.50 \times 10^6 \text{ Btu}}{\text{hr}} \bigg| \frac{74.10^{\circ}\text{F}}{769.7 \text{ ft}^3} = 359 \text{ Btu/hr-}^{\circ}\text{F-ft}^3$$

** The heat transferred in a given tower section is simply defined as the amount of sensible heat that is given up by the liquid stream returned to the top of the packing in going from its hot (draw) temperature to its cold (return) temperature.

Let us now check to see if the U value ($359 \text{ Btu/hr-}^{\circ}\text{F-ft}^3$) is reasonable in light of Glitsch's latest design criteria.

Calculate the capacity factor (C) below the packing: INFERIOR.

$$C = \frac{2091 \text{ ft}^3}{\text{sec}} \bigg| \frac{153.94 \text{ ft}^2}{45.74 - 0.01792} = 0.269 \text{ FPS}$$

Calculate the capacity factor (C) above the packing: SUPERIOR.

$$C = \frac{976 \text{ ft}^3}{\text{sec}} \bigg| \frac{153.94 \text{ ft}^2}{51.23 - 0.00526} = 0.0643 \text{ FPS}$$

Based on the above capacity factor calculations we see that, by today's criteria, a combination bed would be required in this section of the tower. As a result, let us check the predicted heat transfer rate using the Glitsch equation.

$$U = h_0 = 421(0.269)^{0.8} \left[\frac{720}{153.94} \right]^{0.58} = 360 \text{ Btu/hr-}^{\circ}\text{F-ft}^3$$

This U value is consistent with the heat transfer rate calculated earlier. Therefore, the 5'-0" of packing used in the HVGO section of the tower is sufficient assuming a combination grid/ring bed is used.

As a class exercise, calculate the heat transfer rate for the LVGO section based on information already furnished.

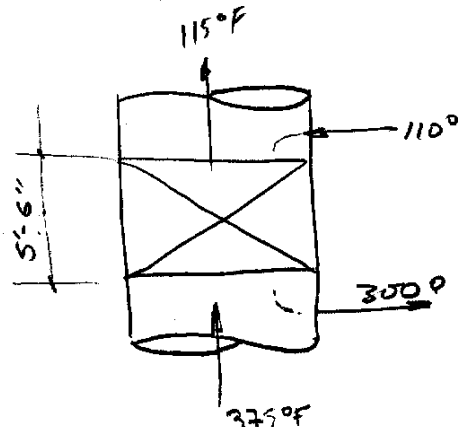
VACUUM TOWER INTERNALSCalculate U for LVGO Section:8'-0" ID = 50.27 ft² tower cross sectional area (CSA)

Volume of packing is:

$$\frac{50.27 \text{ ft}^3}{\text{ft}} \mid 5.5 \text{ ft} = 276.5 \text{ ft}^3$$

LMTD is:

$$\begin{array}{r} 375 \rightarrow 115 \\ 300 \leftarrow 110 \\ \hline 75 \quad \quad 5 \\ \hline 25.8^\circ\text{F} \end{array}$$



Resultant heat transfer rate (U) is:

$$\frac{2.82 \times 10^6 \text{ Btu}}{\text{hr}} \mid 25.8^\circ\text{F} \mid 276.5 \text{ ft}^3 = 395 \text{ Btu/hr-}^\circ\text{F-ft}^3$$

Let us now check to see if the U value (395 Btu/hr-°F-ft³) is reasonable in light of Glitsch's latest design criteria.

Calculate the capacity factor (C) below the packing:

$$C = \frac{976 \text{ ft}^3}{\text{sec}} \mid 50.27 \text{ ft}^2 \quad \sqrt{\frac{0.00526}{48.67 - 0.00526}}$$

$$= 0.202 \text{ FPS}$$

Calculate the capacity factor (C) above the packing:

$$C = \frac{465 \text{ ft}^3}{\text{sec}} \mid 50.27 \text{ ft}^2 \quad \sqrt{\frac{0.000676}{53.23 - 0.000676}}$$

$$= 0.0330 \text{ FPS}$$

Based on the above capacity factor calculations we see that, by today's criteria, a combination bed would be required in this section of the tower. As a result, let us check the predicted heat transfer rate using the Glitsch equation.

$$U = h_0 = 421(0.202)^{0.8} \left[\frac{118}{50.27} \right]^{0.58}$$

$$= 192 \text{ Btu/hr-}^\circ\text{F-ft}^3$$

VACUUM TOWER INTERNALS

This U value is low compared with the heat transfer rate ($395 \text{ Btu/hr-}^{\circ}\text{F-ft}^3$) calculated earlier. Therefore, the 5'-6" of packing used in the LVGO section of the tower may not be sufficient even if a combination grid/ring bed is used.

Based on the above findings, let's try making one design change and see how it affects the outcome of our evaluation of the LVGO section packing. Instead of using 300°F for the LVGO draw temperature, set this temperature at 200°F .

LVGO properties at 200°F are arrived at by interpolation.

<u>$^{\circ}\text{F}$</u>	<u>Btu/Lb</u>	<u>Flowing S.G.</u>
300	122	0.780
200	70	0.820
110	23	0.853

Heat balance the top section of the tower by drawing an envelope around the upper part including the LVGO accumulator (See Figure VI). We already know the heat content of the vapors rising to this section and have set the temperature of the net materials leaving along with the temperature of the circulating LVGO returned to the tower. As a result, a heat and weight balance can now be made to determine the LVGO circulation rate and the amount of heat that must be removed in this section of the tower.

375°F at 15 mm Hg abs (0.290 PSIA)

	<u>$^{\circ}\text{F}$</u>	<u>LB/HR</u>	<u>BTU/LB</u>	<u>10^6 BTU/HR</u>
<u>Heat In</u>				
Vapors Rising to LVGO Draw:				
Steam	375	667	1200*	0.80
Gas	375	465	315	0.15
Net LVGO	375	17355	276	4.79
LVGO Circulation	110	W	23	23(W)
		<u>18487+W</u>		<u>5.74(23W)</u>
<u>Heat Out</u>				
Net LVGO	200	17355	70	1.21
LVGO Circulation	200	W	70	70(W)
Vapors to Ejectors				
Steam	115	667	1083*	0.72
Gas	115	465	175	0.08
		<u>18487+W</u>		<u>2.01+(70W)</u>

* Corrected to liquid at 60°F .

VACUUM TOWER INTERNALS

$$\begin{array}{c} \text{IN} \\ \hline \frac{5.74 \times 10^6 \text{ Btu}}{\text{hr}} + \left[\frac{23 \text{ Btu}}{\text{lb}} \mid \frac{W \text{ lb}}{\text{hr}} \right] = \frac{2.01 \times 10^6 \text{ Btu}}{\text{hr}} + \left[\frac{70 \text{ Btu}}{\text{lb}} \mid \frac{W \text{ lb}}{\text{hr}} \right] \\ \text{OUT} \end{array}$$

$$W = 79360 \text{ lb/hr}$$

The heat transferred (Q) is:

$$Q = \frac{79360 \text{ lb}}{\text{hr}} \mid \frac{(70 - 23) \text{ Btu}}{\text{lb}}$$

$$= 3.73 \times 10^6 \text{ Btu/hr}$$

Calculate the capacity factor (C) below the packing:

$$C = \frac{976 \text{ ft}^3}{\text{sec}} \mid \frac{50.27 \text{ ft}^2}{\sqrt{\frac{0.00526}{51.17 - 0.00526}}}$$

$$= 0.1969 \text{ FPS}$$

The total LVGO draw is:

	LB/HR
Net LVGO	17355
LVGO Circulation	79360
	96715

$$\frac{96715 \text{ lb LVGO}}{\text{hr}} \mid \frac{\text{hr}}{60 \text{ min}} \mid \frac{\text{gal}}{8.337 \text{ lb H}_2\text{O}} \mid \frac{\text{lb H}_2\text{O}}{0.820 \text{ lb LVGO}} = 236 \text{ GPM}$$

Calculate the predicted heat transfer rate using the Glitsch equation:

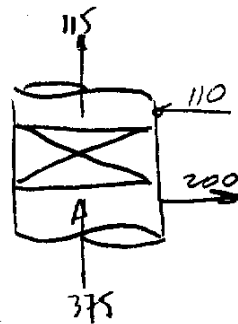
$$U = h_o = 421(0.1969)^{0.8} \left[\frac{236}{50.27} \right]^{0.58}$$

$$= 281 \text{ Btu/hr-}^\circ\text{F-ft}^3$$

LMTD is:

$$\begin{array}{rcl} 375 & \rightarrow & 115 \\ 200 & \leftarrow & 110 \\ \hline 175 & & 5 \end{array}$$

$$47.8^\circ\text{F}$$



VACUUM TOWER INTERNALS

Calculate amount of packing required:

$$\frac{3.73 \times 10^6 \text{ Btu}}{\text{hr}} \left| \frac{\text{hr-}^\circ\text{F-ft}^3}{281 \text{ Btu}} \right| \frac{1}{47.8^\circ\text{F}} = 277.4 \text{ ft}^3$$

$$\frac{277.4 \text{ ft}^3}{50.27 \text{ ft}^3} \left| \frac{\text{ft}}{1} \right| = 5.5 \text{ ft} \quad \underline{\underline{OK}}$$

OUTLINE

BASICS OF VACUUM UNITS

MECHANICAL DETAILS

TOWER HEAT & MAT'L BALANCE

TOWER SIZING

CONTACT CONDENSER CALC'S

CLASS PROBLEMS

OBJECTIVES

ESTABLISH A FEEL
FOR DESIGN

CONSIDER UNCERTAINTIES

3

WHAT IS A VACUUM UNIT?

REDUCED CRUDE CHARGE

FLASH Zone:

25-50 mm Hg ABS

750°F (400°C)

PRODUCTS:

FLASHED GAS OILS

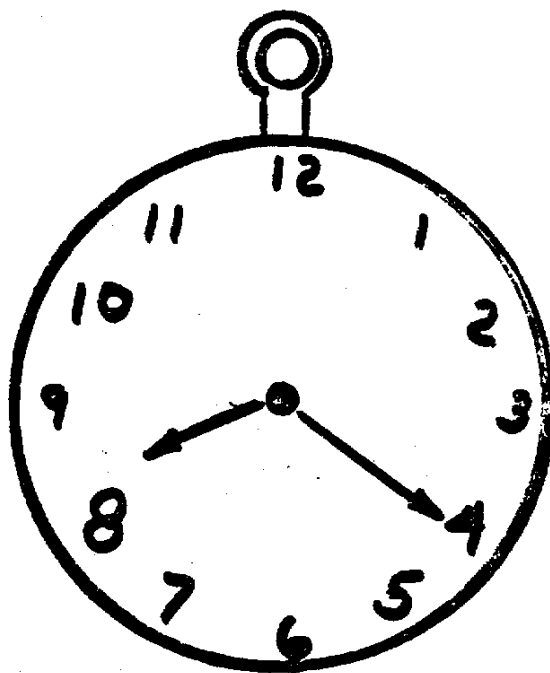
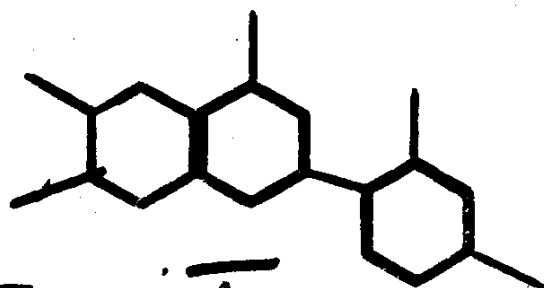
ASPHALT (RESID)

CRACKING Depends on:

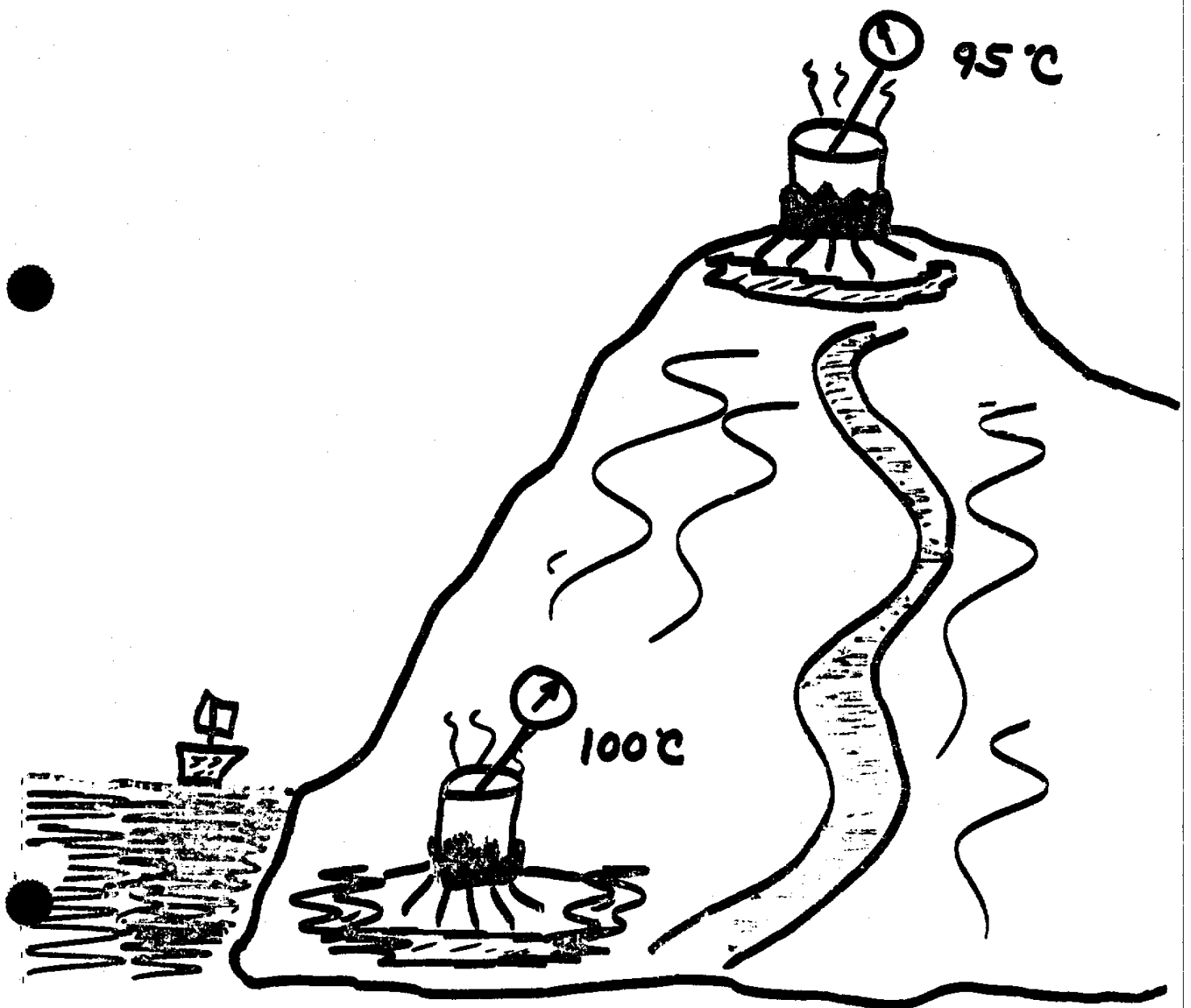
HCBN

PROPERTIES,

TEMPERATURE & TIME



WHAT MAKES IT WORK?



OPERATING CRITERION

PAST - NO PRODUCT THERMAL
DECOMPOSITION

PRESENT - HIGH GAS OIL YIELD
GOOD QUALITY

CRACKING CAN:

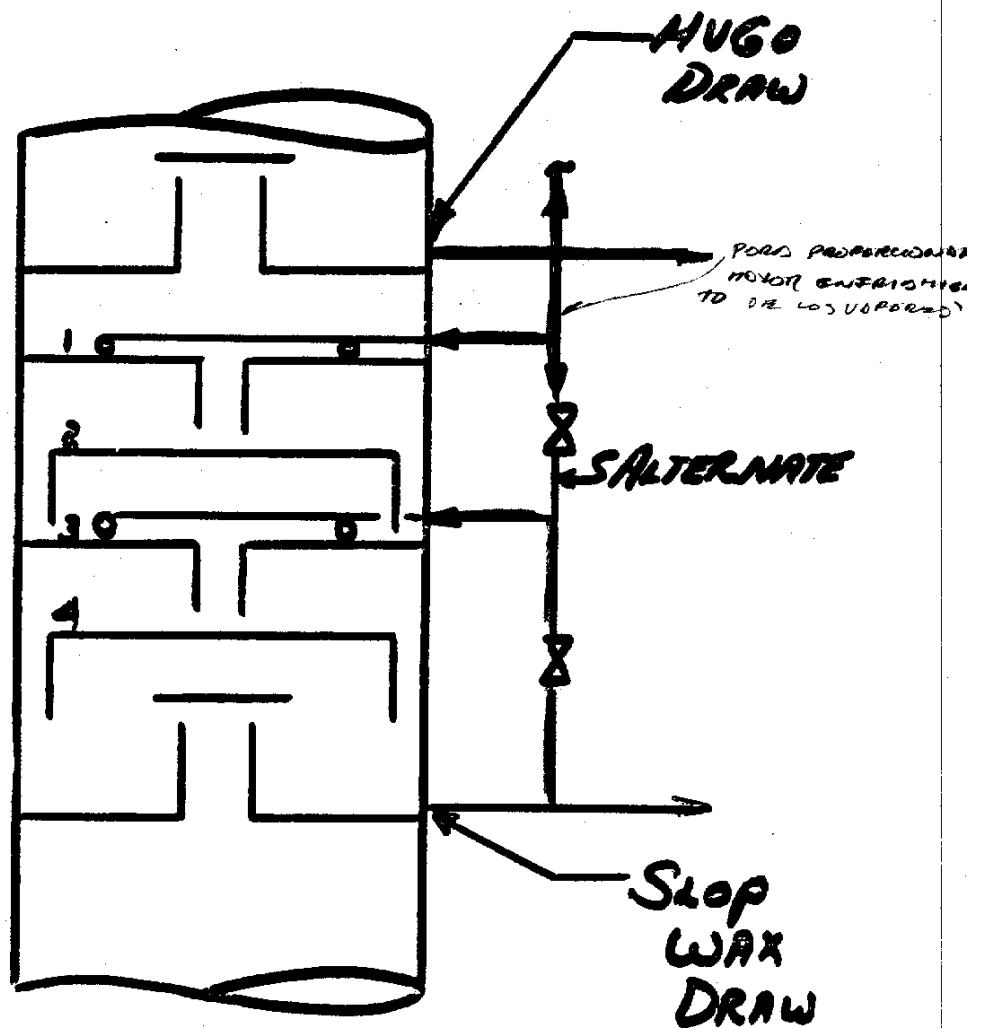
REDUCE VACUUM
(OVERLOAD EJECTORS)

LEAD TO COKING PROBLEMS

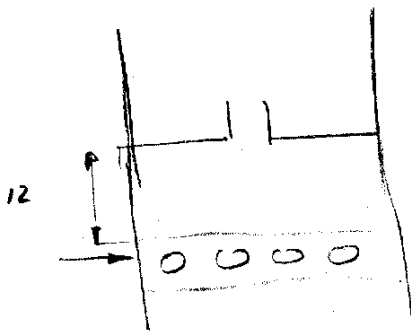
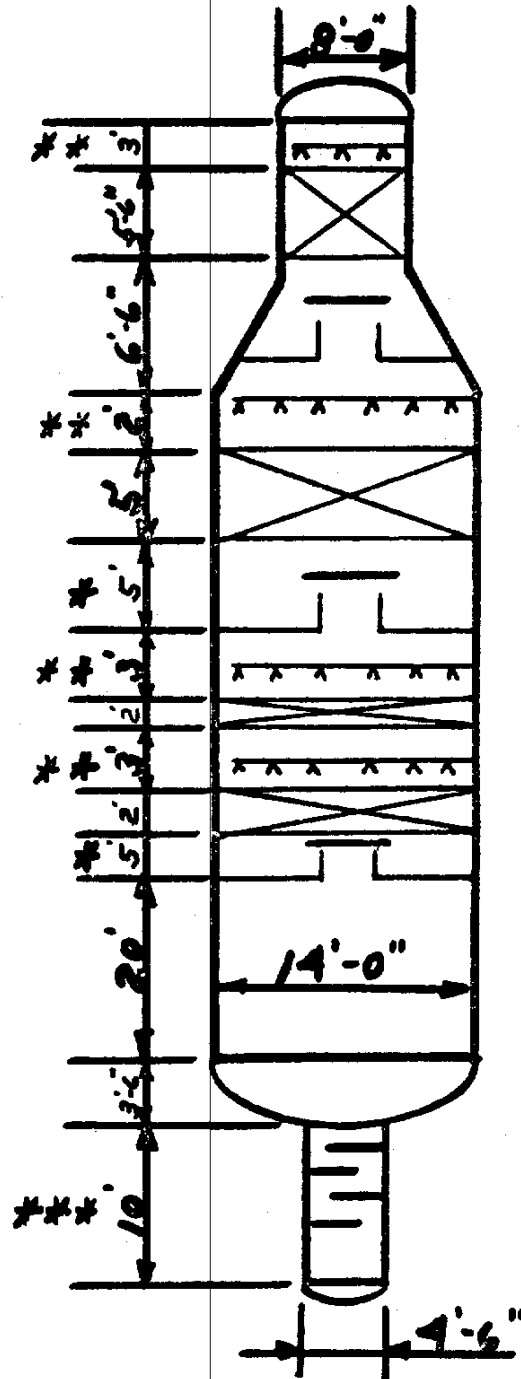
SLOP WAX SECTION

ALTERNATE WITH TRAYS

MINIMIZAR
ESPACIO POR
CARGA CADA DE
CASA.
DEBIDO A QUE
CADA VEZ SON
MAYORES

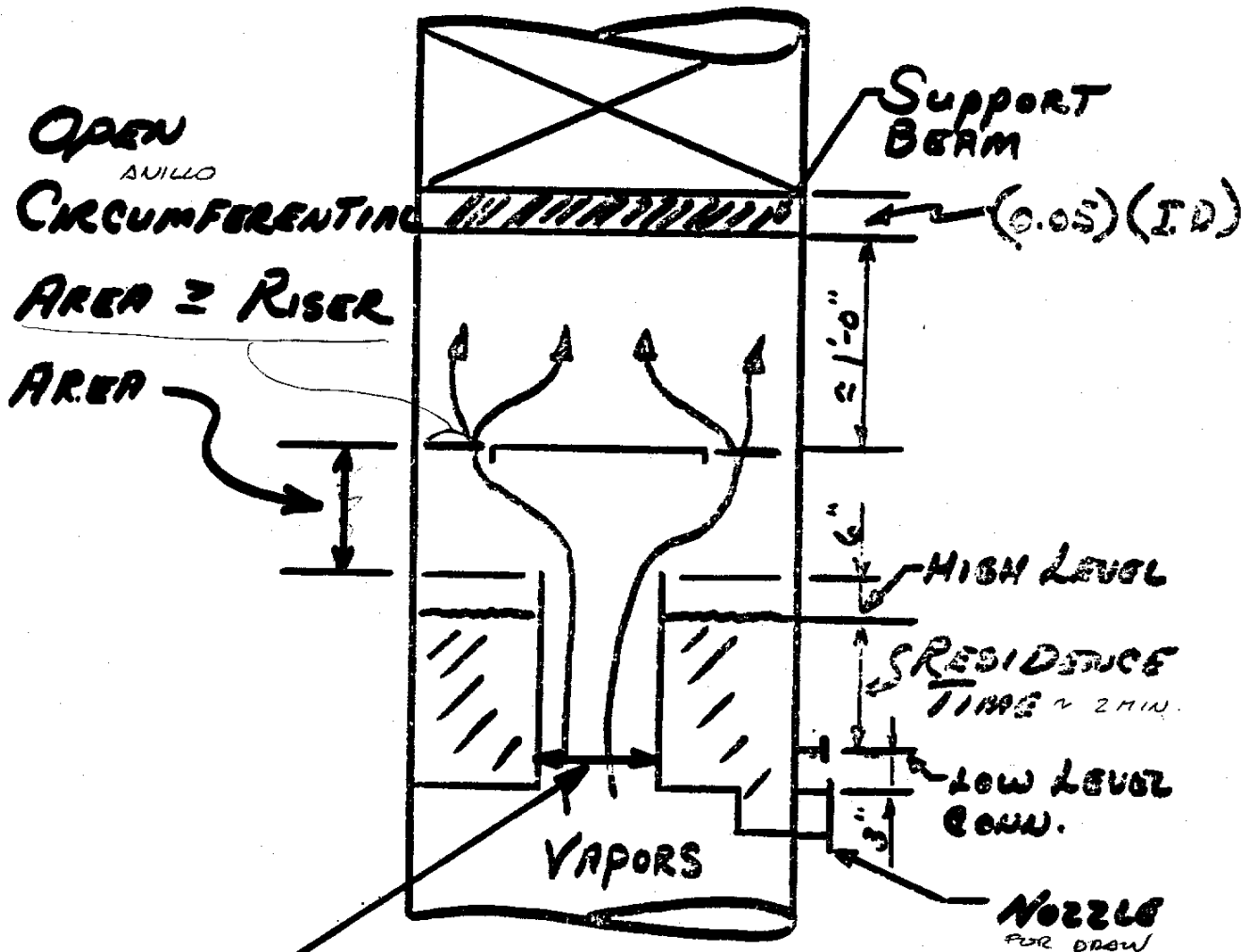


TYPICAL DIMENSIONS



- * FUNCTION OF NUMBER OF RISERS.
- ** FUNCTION OF SPRAY NOZZLE TYPE.
- *** FUNCTION OF S-S PAN SPRING.

ACCUMULATOR TRAY DETAILS



← RISER AREA IS 15-20%
OF TOWER CROSS SECTION AREA

ACTUAL 20%

LO FORMO DE LOS RISER NO IMPORTA SI NO
AL AREA ACUMULADO DE LOS RISER

SIDE TO SIDE PANS

SET SPACING:

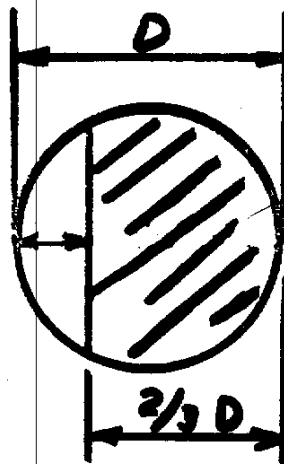
OPEN AREA
BETWEEN PANS

≥ OPEN

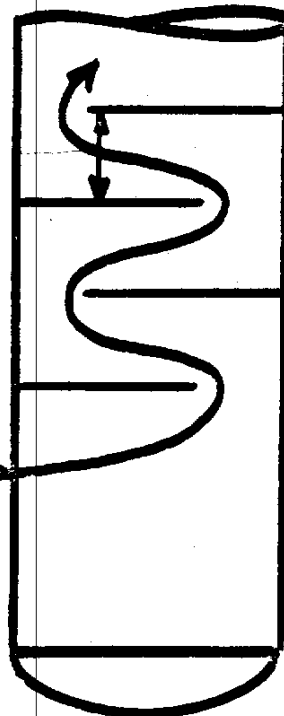
CHORDAL AREA

PARA NO RESTRINGIR EL
FLUIDO DE LOS CASOS.

STEAM



LOW PERFORMANCE



OPEN
AREA

VACUUM COLUMN
CLASS PROBLEM

8-4-53
RTV

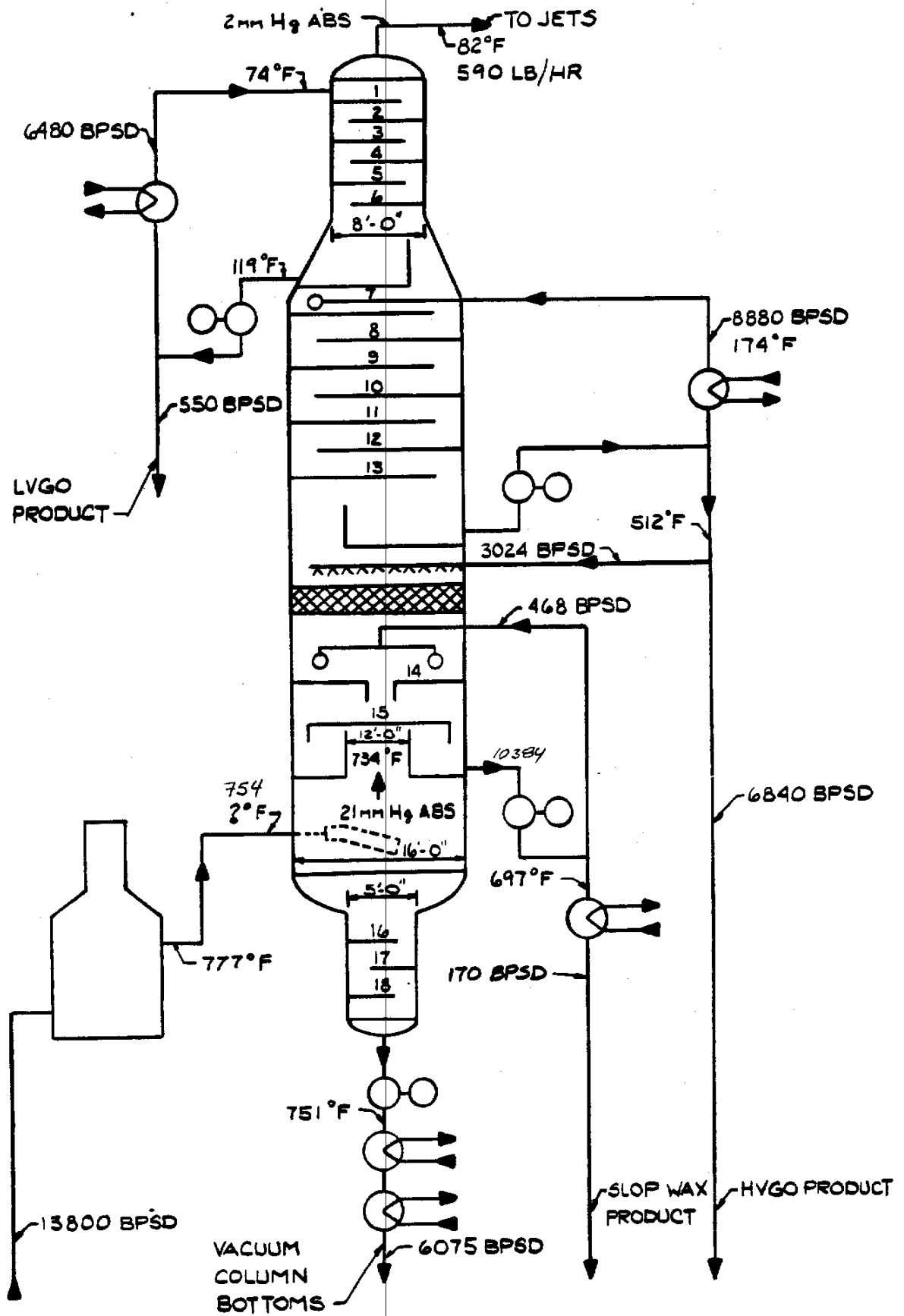
GIVEN THE OPERATING DATA SHOWN IN THE ATTACHED SKETCH,
THE LAB ANALYSIS OF THE TEST RUN SAMPLES AND THE
MATERIAL BALANCE STATED BELOW; DETERMINE THE FOLLOWING:

- 1) AMOUNT OF LEAKAGE (WEEPAGE) OF SLOP WAX LIQUID
THROUGH THE VAPOR RISER IN THE SLOP WAX
ACCUMULATOR.
- 2) HEAT AND WEIGHT BALANCE AROUND THE TOWER
ONLY. DO NOT CALCULATE DUTIES FOR EQUIPMENT
EXTERNAL TO THE VACUUM COLUMN.

NOTE - STRIPPING STEAM WAS NOT USED DURING THE TEST RUN.

MATERIAL BALANCE:

	API	K	MW	(10 ⁶ SCFD) BPSD	LB/HR	<u>MOL</u> HR	LV%	WT%
FEED	15.8	11.65	490	13800	193200	395	100.0	100.0
GAS	-	-	30	(0.179)	590	20	1.2	0.3
LUGO	32.8	11.68	225	550	6900	31	4.0	3.6
HUGO	20.9	11.85	449	6840	92550	206	49.6	47.9
SLOP WAX	15.7	11.96	650	170	2380	4	1.2	1.2
RESID	6.5	11.50	675	6075	90780	134	44.0	47.0



①

1) STRIPPING RATE $\approx 9 \text{ LB/BBL}$ ~~1000~~
 $6075 \text{ BPSD} \times 5 \text{ LB} = 17656 \text{ LB/H}$
 $24 \text{ H/D} \quad \text{BBL} \quad 70.3 \text{ MBL/H}$

Z	API	K	MW	°F	10° SCFO LB/H. BPSD	BTU/LB	10° BTU/H.
GAS			30	734 °F	590	558	0.3
LVGO	32.8	11.68	225		550	6900	500
HVGO	20.9	11.35	449		6040	92550	490
SLOP WAX	15.7	11.96	650		170	2380	485
						102420	491
							50.3

$50.3 \times 10^6 / 102420$

LVGO.

$$VABP = \frac{465 + 545 + 579 + 615 + 663}{5} = 573.4^\circ\text{F}$$

$$\text{SLOPE} = \frac{663 - 465}{80} = 2.5 \quad CF = -5.2$$

$$CDBP = 573.4 - 5.2 = 568.$$

ENTHALPID @ 734 °F $K = 11.68$

$$H = 500 \text{ BTU/LB} \quad \text{CARTS PD-189}$$

HVGO

$$VABP = \frac{761 + 838 + 886 + 948 + 1015}{5} = 889.6$$

$$\text{SLOPE} = \frac{1015 - 761}{80} = 3.2 \quad CF = -4.3$$

$$CDBP = 889.6 - 4.3 = 885.3^\circ\text{F}$$

ENTHALPID @ 734 °F $K = 11.35$

$$H = 490 \quad \text{CARTS PD-189}$$

(2)

SMP WLT

$$VABP = \frac{970 + 1038 + 1074 + 1104 + 1140}{5} = 1065.2$$

$$SWPB = \frac{1140 - 970}{80} = 2.1 \quad CF = -2.2$$

$$CDBP = 1063.0^\circ F$$

ENTHALPI @ 734 $\neq$ K = 11.96

H = 485 CORRT PD-129.

GAS MW = 30

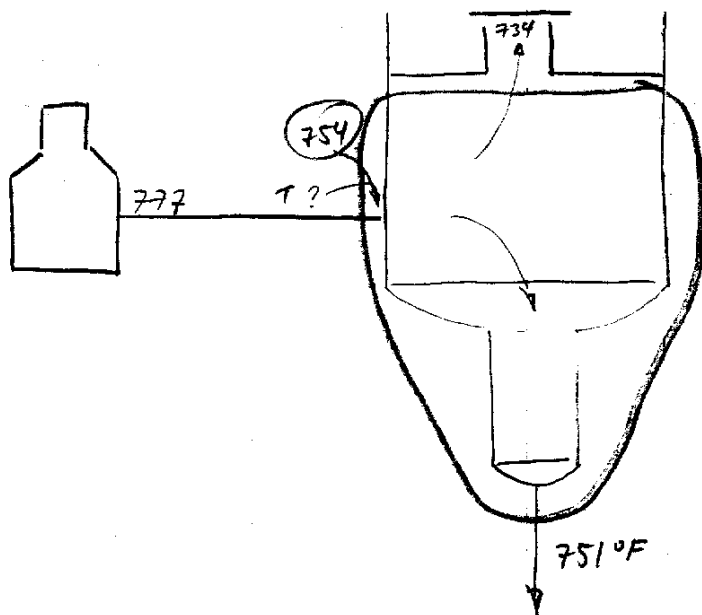
T = 734°F

H_v = 415 BTU/LB.

CORR MW = 143

H_g = 415 + 143 = 558 BTU/LB.

CORRT PD-293.



DETERMINAR CALOR ESPECIFICO DE LA CARGA.

CHART PD 855 $K = 11.65$
 $API = 15.8$ | 0.69 FL. 0.98.
 $T = 734^{\circ}F$

$$491 \text{ BTU/LB} + 0.67(754 - 734) = 503 \text{ BTU/LB} @ 754^{\circ}F$$

HEAT IN

	$^{\circ}F$	LB/H.	BTU/LB	10^6 BTU/H
FEED VAPOR	754	102420	503	51.5
FEED LIQUID.	754	90780	402	36.5
SWAP W/TA LEAKAGE	699	W	378	378 W
		193200+W		88.0+378W

* CHART PD 870 PARA RESID.

HEAT OUT

	$^{\circ}F$	LB/H	BTU/LB	
RESID	751	90780	400	36.3
GAS	734	590	560	0.3
NET LUGO		6900	500	3.5
" HUGO		91550	490	45.3
" SW		2380	485	1.2
SW LEAKAGE.		W	485	485 W
		193200+W		86.6+485W

$$W = 13084 \text{ LB/HR.}$$

PARA RESID $K = 11.5$ $API = 65 + SG = 1.025$
 $UOPIK = (COSP)^{1/3}$
 $(SG = 22^{\circ}F)$

$$COSP = (UOPIK \times SG_{60})^3$$

$$COSP = (11.5 \times 1.025)^3$$

$$= 1640^{\circ}R$$

$$CSPB = 1180^{\circ}F$$

DE CHART PD 870 $H_L = 402$

④

*

SUP WEA

K = 11.96

CSVP = 1064°F

TEMP = 697°F

PD 870 → 12 = 373

Sample Designation Sample Date	Vacuum Test Run			
	LVGO	HVGO	Slop Wax	Vacuum Bottoms
	< - - - - - November 12, 1974 - - - - - >			
Properties of Sample				
Gravity, °API at 60°F	32.8	20.9	15.7	6.5
Specific Gravity at 60°F	0.8612	0.9285	0.9613	1.0254
Sulfur, Total, Wt. %	1.79	2.87	3.51	
Heptane Insolubles, Wt. %		0.01	0.17	
Softening Point, B&R, °F				95.
Penetration @ 77°F, 100g/5 sec				217.
Ductility @ 77°F, 5 cm/min, cm				100+
Conradson Carbon Residue, Wt. %	0.007	0.67	5.71	
Viscosities				
Kinematic at 100°F., cSt.	3.639			
Kinematic at 122°F., cSt.		57.50		
Kinematic at 210°F., cSt.			50.76	
Universal at 100°F., secs.	38.0			
Universal at 122°F., secs.		267		
Universal at 210°F., secs.			237	
Distillation, Type				
I.B.P., °F	D1160	D1160	D1160	
5%	305	575	720	
10	420	726	925	
20	465	761	970	
30	512	805	1010	
40	545	838	1038	
50	562	861	1059	
60	579	886	1074	
70	596	911	1090	
80	615	948	1104	
90	638	979	1121	
95	663	1015	1140	
E.P., °F	688	1041		
% Recovered	730	1081		
% Bottoms	99.0	99.0	90.0	
	1.0	1.0	10.0	
Emission Spectrographic Analysis of Wet Ash				
Elements	Reported as ppm metal in the oil.			
Fe		0.4	1.3	
Ni		0.19	4.8	
V		0.05	13	
Pb		<0.05	0.07	
Cu		<0.02	<0.02	
Na		3.2	6.3	

VACUUM COLUMN SOLUTION TO CLASS PROBLEM

8-4-83
RTV

CALCULATE THE AMOUNT OF HEAT IN THE VAPORS RISING TO THE
SLOP WAX DRAW:

	API	K	MLW	°F	(10 ⁶ SCFD) APSD	10 ⁶ LB/HR	10 ⁶ Btu/LB	10 ⁶ Btu/HR
GAS	—	—	30	734	(0.179)	590	560	0.3
LUGO	32.8	11.68	225	"	550	6900	500	3.5
HUGO	20.9	11.85	119	"	6840	92550	190	45.3
Slop WAX	15.7	11.96	650	"	170	2380	185	1.2
						102420	491	50.3

SINCE THE FLASH ZONE INLET MUST BE AT LEAST 751°F
AND THE AMOUNT OF VAPORIZATION MUST BE AT LEAST
EQUIVALENT TO THE SLOP WAX AND LIGHTER MATERIAL IN
THE FEED AND SINCE THE BOTTOMS IS QUENCHED SOMEWHAT
BY THE WEEPAGE FROM ABOVE, WE CAN ASSUME THE
FOLLOWING:

- 1) VAPOR AT FLASH ZONE INLET IS EQUIVALENT TO
THE SLOP WAX AND LIGHTER MATERIAL IN THE FEED.
- 2) MATERIAL ENTERING THE FLASH ZONE IS AT 754°F.

BASED ON THE ABOVE, CALCULATE THE AMOUNT OF HEAT IN THE VAPORS PRESENT IN THE FEED AS IT ENTERS THE FLASH ZONE AT 754 °F:

$$\left[\frac{(1) \quad 491 \text{ BTU}}{\text{LB}} \right] + \left[\frac{(2) \quad 0.6 \text{ BTU}}{\text{LB} \cdot ^\circ\text{F}} \mid \frac{(3) \quad 20 \cdot ^\circ\text{F}}{\text{LB}} \right] = 503 \frac{\text{BTU}}{\text{LB}}$$

- NOTES: (1) ENTHALPY OF VAPOR AT 734 °F.
(2) TYPICAL SPECIFIC HEAT FOR MCBN VAPOR.
(3) ΔT BETWEEN FLASH ZONE INLET AND VAPOR RISING TO SLOP WAX DRAW.

LET US NOW HEAT BALANCE THE LOWER SECTION OF THE TOWER BY DRAWING AN ENVELOPE AROUND THE PORTION DIRECTLY BELOW THE SLOP WAX DRAW TRAY. THIS WILL ENABLE US TO CALCULATE THE QUANTITY OF SLOP WAX LEAKAGE RESULTING IN A HEAT BALANCE.

		^{10⁶} °F	LB/HR	BTU/LB	BTU/HR
<u>HEAT IN</u>					
FEED TO COLUMN:	Vapor	754	102420	503	51.5
	Liquid	754	90780	402	36.5
SLOP WAX LEAKAGE		697	W	378	378(W)
			193200+W		88.0+(378W)
<u>HEAT OUT</u>					
RESID FROM COLUMN		751	90780	400	36.3
VAPOR RISING TO DRAW:	GAS	734	590	560	0.3
	NET LVGO	734	6900	500	3.5
	NET HVGO	734	92550	490	45.3
	NET S. W.	734	2380	485	1.2
	S. W. LEAKAGE	734	W	485	485(W)
			193200+W		86.6+(485W)

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$$\begin{array}{c} \text{IN} \\ \hline \frac{88.0 \times 10^6 \text{ Btu}}{\text{HR}} + \left[\frac{378 \text{ Btu}}{\text{LB}} \mid \frac{W \text{ LB}}{\text{HR}} \right] = \frac{86.6 \times 10^6 \text{ Btu}}{\text{HR}} + \left[\frac{485 \text{ Btu}}{\text{LB}} \mid \frac{W \text{ LB}}{\text{HR}} \right] \end{array}$$

$$W = 13084 \text{ LB/HR}$$



Process Division

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HEAT AND WEIGHT BALANCES

Vacuum Column

Solution To Glass Problem

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DATE 8-4-83

PROJECT _____

BY RJV

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STREAM	°API (LB/GAL)	K	MM	FLOWING SP. GR. (LB/CF)	°F	PSIG (MM HG ABS)	BPSD @ 60°F (10° SCFD)	FLOWING GPM (CFS)	MOLES PER HR.	LB/HR	BTU/ LB	10° BTU/HR
FEED FROM HEATER	15.8	11.65	490		777	-	13800		395	193200	455	88.0
VAPOR RISING TO SLOP WAX DRAW					734	(21)						
GAS	-	-	30		"	"	(0.179)		20	590	560	0.3
NET LVGO	32.8	11.68	225		"	"	550		31	6900	500	3.5
NET HVGO	20.9	11.85	449		"	"	6840		206	92550	490	45.3
NET SLOP WAX	15.7	11.96	650		"	"	170		4	2380	485	1.2
SLOP WAX LEAKAGE	"	"	"		"	"	935		20	13080	"	6.3
RESID FROM COLUMN	6.5	11.50	675		751	-	6075		134	90780	400	36.3
LIQUID SLOP WAX LEAKAGE	15.7	11.96	650		697	-	935		20	13080	378	4.9
TOTAL SLOP WAX TO PUMP	"	"	"		"	-	638		14	8930	"	3.4
SLOP WAX CIRCULATION TO TOWER	"	"	"		"	-	468		10	6550	"	2.5
NET SLOP WAX FROM COLUMN	"	"	"		"	-	170		4	2380	"	0.9
TOTAL HVGO TO PUMP	20.9	11.85	449		512	-	18744		565	253610	251	63.7
HVGO REFLUX BELOW DRAW	"	"	"		"	-	3024		91	40910	"	10.3
HVGO CIRCULATION TO TOWER	"	"	"		174	-	8860		268	120150	55	6.6
NET HVGO FROM COLUMN	"	"	"		512	-	6840		206	92550	251	23.2
TOTAL LVGO TO PUMP	32.8	11.68	225		119	-	7030		392	88190	29	2.6
LVGO CIRCULATION TO TOWER	"	"	"		74	-	6480		361	81290	10	0.8
NET LVGO FROM COLUMN	"	"	"		119	-	550		31	6900	29	0.2
GAS TO JETS	-	-	30		82	(2)	(0.179)		20	590	160	0.1

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8-4-83
RTV

CHECK OVERALL HEAT & WEIGHT BALANCE

	<u>LB / HR</u>		<u>10⁶ BTU / HR</u>	
	<u>IN</u>	<u>OUT</u>	<u>IN</u>	<u>OUT</u>
FEED	193200		88.0	
RESID		90780		36.3
Slop WAX TO pump		8930		3.4
Slop WAX CIRC. TO TOWER	6550		2.5	
HUGO TO pump		253610		63.7
HUGO REFLUX BELOW DRAW	40910		10.3	
HUGO CIRC. TO TOWER	120150		6.6	
LUGO TO pump		88190		2.6
LUGO CIRC. TO TOWER	81290		0.8	
GAS		<u>590</u>		<u>0.1</u>
	442100	442100	108.2	106.1

RADIATION & UNACCOUNTED FOR

2.1 x 10⁶



HEAT AND WEIGHT BALANCES

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HEAT AND WEIGHT BALANCES

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HEAT AND WEIGHT BALANCES (SI UNITS)

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