ENCLOSURE (B) 6

DESIGN OF CATALYTIC CRACKING PLANT FOR PINE ROOT OIL

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Research Period: 1945

Prepared for and Reviewed with Authors by
the U. S. Naval Technical Mission to Japan

December 1945

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LIST OF TABLES AND ILLUSTRATIONS

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This plant was designed to produce 2,000 lit/day of aviation gasoline by catalytic cracking 10,000 lit/day of the heavy overhead cut from the simplified pine-root oil distillation and coking units.

The design was based on data from the catalytic cracking pilot plant in the research department of this depot. An effort has been made to make the process flow simpler, however, and especially to conserve on the use of special steels, the plant was designed to use carbon steels in the reactors and heating pipes.

Basic design calculations are given in Appendix I and the process flow diagram is given in Plate I(B)6.

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APPENDIX I

1. Object of the Plant

This plant is designed to obtain aviation gasoline by the catalytic cracking for which pine oil is used as the crude oil.

2. Plant Capacity

New Charge .... 10,000 lit/day

3. Property of Pine Heavy Oil (Crude)

Specific Gravity	0.896
I.B.P.	122.0°C
10% Point	160.5
20% Point	170.5
30% Point	180.0
40% Point	189.0
50% Point	200.0
60% Point	217.0
70% Point	241.0
80% Point	272.0
90% Point	348.0
E.P.	-

4. Crude Oil Feed Pump

10,000 lit/day = 10,000 x 0.896 = 8,960 kg/day
10,000 lit/day = 417 lit/hr = 6.95 lit/min

This pumping unit shall deliver a normal capacity of 6.95 lit/min at normal and shall be delivered against a discharge pressure of 10 kg/cm^2 with atmospheric suction.

5. Recycle Oil Pump

Basis: Recycle Ratio = 3

6.95 lit/min x 3 = 20.85 lit/min = 1,250 lit/hr

Discharge Pressure .... 10 kg/cm^2
Suction Temperature .... 250°C

6. Cracking Oil (Combined Feed)

Recycle stock (10,000 x 3) x 0.832 = 24,950 kg/day

New Charge	8,960 kg/day (+
Total cracking oil	33,910 kg/day

Specific Gravity .... 33,910 ÷ 4000 = 0.848
U.O.P. Characterization Factor 11.4
Mean Molecular Weight 170

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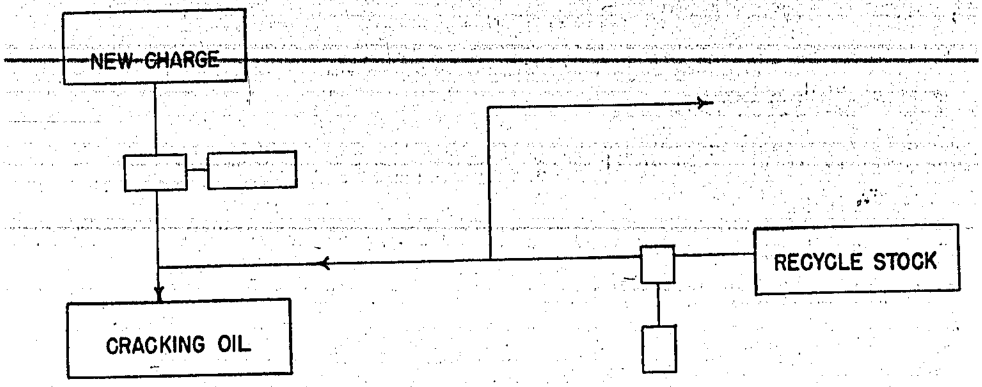

7. <u>Determination of the Temperature of Cracking Combined Feed Oil.</u>

New Charge .... 417 x 0.896 = 373.6 kg/hr
Recycle stock .... 1,250 x 0.832 = 1,040 kg/hr
Combined feed .... 373.6 + 1,040 = 1,414.6 kg/hr
= 1,667 lit/hr

Therefore Specific Gravity 0.848

Mean specific heat of recycle stock 0.572

Then $0.572 \times 1{,}040 \times (250 - 37) = 126{,}709$ Kcal/hr
$Cp' \times 1{,}413.6 \times (T_2' - 37) = 126{,}709$ ....(1)

Where $Cp' = Cp37 \quad dCp\ (T_2' - 37)$
$Cp37 = 0.465 \quad dCp = 0.00097$

Therefore $Cp' = 0.465 + 0.00097\ (T_2' - 37)$ .... (2)

Combining equations (1) and (2)
$(T_2')^2 + 405{,}440T_2' - 108{,}791 = 0$

Therefore $T_2' \doteqdot 184°C$

8. <u>Temperature of the Flash Chamber.</u>

10% point of combined feed ...... 174°C (345.2°F
70% point of combined feed ...... 252°C (485.6°F
Slope of A.S.T.M. 2.34
Slope of flash, 10 - 70% 1.2
50% boiling point on A.S.T.M. .... 435°F
50% boiling point on flash .... 435°F

100 percent point on linear flash curve
$435 + 1.2 \times 50 = 495°F\ (257°C)$

As a check, at 0 percent.
$435 - 1.2 \times 50 = 375°F\ (190°C)$

The correction was made at the point where the operating pressure is 5 kg/cm^2 gauge.

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100% point 349°C (660°F) ≑ 350°C

~~Since, it must be the temperature of oil of the outlet.~~

9. <u>Cracking Oil Heater.</u>

If the condition is such that cracking oil does not pass through the exchanger, the heats required to be necessary to heat from 184°C to 350°C at liquid state, are as follows:

$$0.685 \times 1{,}413 \times (350 - 184) = 160{,}740 \text{ Kcal/hr}$$

Where Mean specific heat = 0.685

Assuming the cracking oils which pass through the pipe still are entirely vaporized on the score of the non-vaporized oils remained in the flash chamber are only 3 percent of all by data.

$$75.1 \times (1{,}413 + 2{,}2046) = 234{,}043 \text{ B.T.U./hr} = 59{,}283 \text{ Kcal/hr}$$

Accordingly the total heat is,

$$160{,}740 + 59{,}283 = 220{,}023 \text{ Kcal/hr}$$

Cracking oil (1667 lit/hr)	1413.6 kg/hr
Specific gravity	0.848
Mean M.W.	170
U.O.P. Characterization factor	11.4
Inlet temp.	184°C
Outlet temp.	350°C
Outlet pressure	5 kg/cm²
Heat required	220,023 Kcal/hr

In this case, the pressure drops of cracking oil throughout the pipe still and another are assumed 5 kg/cm² by the data of the pilot plant of the naval laboratory. The furnace capacity is taken as the above purposely, considering the conditions at the start and the allowance but the oils can get the large quantities of heats from the exchanger when operation becomes on stream.

10. <u>Flash Chamber</u>

Temp. of inlet	350°C
Temp. of top of the chamber	300°C
Operating pressure	5 kg/cm²(gauge)
Feed quantities	1413.6 kg/hr

To calculate the volume of oil vapors in the chamber,

$$1413.6/170 \times 22.4 \times 1/6 \times (273 + 300)/273 = 65.5 \text{ m}^3/\text{h}$$

Assuming the above vapors remain 90 seconds in the chamber.

$$(65.5/60) \times 90/60 = 1.64 \text{ m}^3$$

11. <u>Oil Vapor Heater</u>

Temp. of inlet	300°C
Temp. of outlet	500°C

Pressure of inlet 5 kg/cm2
Pressure of outlet 2 kg/cm2
Mean specific heat 0.695

$$0.695 \times 1413.6 \times (500 - 300) = 197,000 \text{ Kcal/hr}$$

With a 20 percent factor to allow more heating, the heat required is 235,000 Kcal/hr.

12. Reaction Chamber.

Charging quantities = 1,667 lit/hr = 1,413.6 kg/hr
Space velocity = 3

Therefore Catalyzer volume = 1,667 ÷ 3 = 555 lit.

The reduction of catalyzer by means of the reactivation and high temperature is assumed about 15 percent by the data of the pilot plant of the naval laboratory.

$$555 \text{ lit} \times 1.15 = 638 \text{ lit} \doteqdot 640 \text{ lit}$$

Specific gravity of catalyzer 0.75

Weight of catalyzer = 0.75 x 640 = 480 kg per tower

Operating pressure 2 kg/cm2
Design pressure 5 kg/cm2
Operating temp. .... 450 to 500°C
Design temp. .... 550°C

Materials

Flanges .... Cast steel
Shell .... Class SB J.E.S.
Bolts and nuts ...... 4-6% Cr. steel

Note: It is really dangerous to use carbon steel plates at the high temperature such as 500°C, but daringly used carbon steel plates on account of the difficulties of getting special steel plates recently such as, Ni-Cr or Cr-Mo. Accordingly, the allowable working stresses must be taken not over 2 kg/mm2, considering the creep stresses.

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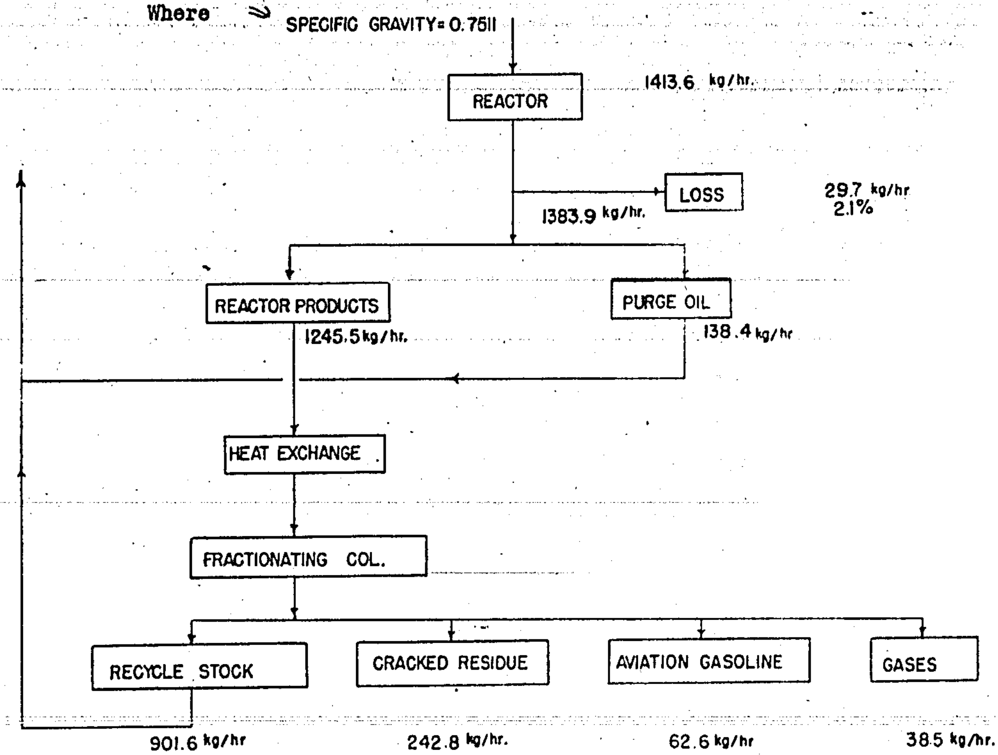
13. <u>Material Balance in and around the Fractionating Column.</u>

~~Assuming the aviation gasoline to be 20 percent (vol) of the new charge oil,~~

417 lit/hr x 0.20 = 83.4 lit/hr = 62.6 kg/hr

Where



Next, assuming the cracked residue is 70 percent (vol) of the new charge oil,

417 lit/hr x 0.70 = 291.9 lit/hr = 242.8 kg/hr.

Where Specific gravity 0.832
Cracked gases and losses .... 38.5 kg/hr

14. <u>Fractionating Column.</u>

Operating pressure .... 1 kg/cm
Operating temp. .... @Top 120°C
Operating temp. .... @Bottom 250°C
Reflux ratio 5
M.W. of oil vapor at the top 120
M.W. of gases at the top 29

Therefore, distillates of Top

Gases .... 38.5 ÷ 29 = 1.33 Kgmol/hr
Vapors .. 62.6 x (5 1) ÷ 120 = 3.13 Kgmol/hr

However PV = ZnRT

Where $P = 2\ kg/cm^2$ (absolute)

$n_1 = 1.33$ (gases)

$n_2 = 3.13$ (vapor)

$R = 0.094786$

$T = 120 + 273 = 393°K$

$Z_1 = 0.99$ (gas)

$Z_2 = 0.95$ (vapor)

$T_c = 610°F\ (321°C) \quad (321 + 273)°$

Vapor: $TR = 393/594 \quad 0.662$

$P_c = 24\ kg/cm^2$ (absolute)

$Z_2 = 0.95$

Gas: $T_c = 305°K$

$TR = 393/305 = 1.29$

$P_c = 48\ kg/cm^2$ (absolute)

$PR = 2/48 = 0.0417$

$Z_2 = 0.99$

Therefore,

Oil Vapor $\frac{0.95 \times 3.13 \times 0.094786 \times 393}{2} = 55.3\ m^3/hr$

Gases $= \frac{0.99 \times 1.33 \times 0.094786 \times 393}{2} = 24.4\ m^3/hr$

Total $= 79.7$

The velocity of the vapors through the column are assumed 0.3 meters per second.

$$D^2 \times 3.1416/4 \times (0.3 \times 3600) = 79.7$$

$$D^2 \times 0.785 \times 1080 = 79.7$$

$$847D^2 = 79.7$$

$$D = 0.31$$

The actual tower diameter that is used for these conditions is taken 450mm ~~as a packed column.~~

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15. <u>Fractionating Column Condenser.</u>

~~Operating Pressure .... 1 kg/cm²~~
Operature temp.
Inlet .... 120°C
Outlet .... 37°C (100°F)

Heats to be removed from the gases,

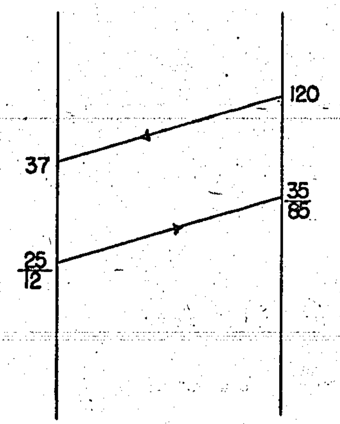
$$0.528 \times 38.5 \times (120 - 37) = 1,682.2 \text{ Kcal/hr}$$

Heats to be removed from the vapors,

$$0.553 \times 375.6 \times (120 - 37) = 17,239.7 \text{ Kcal/hr}$$

$$131 \text{ B.T.U./lb} \times (62.6 \times 6) \times 2,2046 = 108,500 \text{ B.T.U./hr} = 27,400 \text{ Kcal/hr}$$

Total = 46,326.9 Kcal/hr ≑ 46,500 Kcal/hr



$$\Delta Tm = \frac{85 - 12}{2.3 \log 85/12} \doteqdot 37^{o}C$$

$$K = 90 \text{ Kcal/m}^2, {}^{o}C, \text{ hr}$$

Therefore $A = 46,500/(37 \times 90) \doteqdot 14 \text{ m}^2$

Total surface 20 m²; Box condenser type.

Cooling water: $W = 46,500/(35-25) = 4,650$ kg/hr

16. <u>Fractionating Column Bottom Cooler.</u>

Cracked residues .. 291.9 lit/hr = 242.8 kg/hr
Specific gravity 0.832
Operating pressure .... 1 kg/cm²
Operating temp.
Inlet .... 250°C
Outlet .... 37°C

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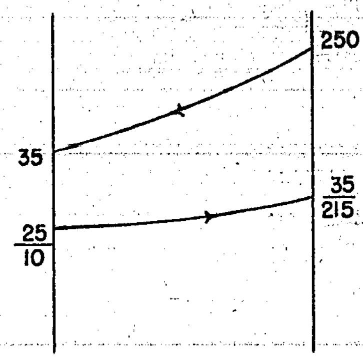
$$0.572 \times 242.8 \times (250 - 37) = 29{,}581 \text{ Kcal/hr} \doteq 30{,}000$$



$$dTm = \frac{215 - 10}{2.3 \log 215/10} = 67^{\circ}C$$

$K = 60$ Kcal/m^2, hr, $^{\circ}$C

Therefore. $A = 30{,}000/(67 \times 60) \doteq 7.5$ m^2

The actual cooling surface is taken 10 m^2.

Cooling water: $W = 30{,}000/(35 - 25) = 3{,}000$ kg/hr @normal

17. Reflux Oil Accumulator.

Vapor condensed, $375.6 \div 0.7511 = 500$ lit/hr

Gases, $\frac{0.99 \times 1.327 \times 0.094786 \times 310}{2} = 19.3$ m^3/hr

Assuming the accumlator keeps reflux oil during 10 minutes in ½ volume of it.

$$500/60 \times 10 \times 2 = 167 \text{ lit}$$

Then the volume of the accumulator is necessary to occupy 167 lit or over.

18. Reflux Oil Pump.

This pumping unit shall deliver a normal capacity of 8.34 lit/min that volume at 37°C and shall be delivered against a discharge pressure of 5 kg/cm^2 suction.

19. Heat Exchanger.

Heat Balance

a. Heat contents of the vapors leaving the reactor system.

Basis: 100°F

Liquid: $0.61 \times 1{,}245.5 \times (300 - 100) = 152{,}000$ Kcal/hr

Vapor: $0.695 \times 1{,}245.5 \times (500 - 300) = 173{,}000$ Kcal/hr

Latent heat:

~~75 x 1,245.5 x 2.2046 = 205,500 B.T.U./hr~~
= 51,800 Kcal/hr (+

Total =376,800 Kcal/hr

b. Heats to be removed.

Top vapors and gases	46,500 Kcal/hr
Bottom cracked residues	30,000 Kcal/hr
Bottom recycle oils	111,000 Kcal/hr
Heat losses	56,500 Kcal/hr
Total	244,400 Kcal/hr

Heat loss is assumed about 15 percent of the total heat.

$$376,800 \times 0.15 = 56,500 \text{ Kcal/hr}$$

Heat to be exchanged

$$376,800 - 244,400 = 132,400 \text{ Kcal/hr}$$

a. Cold Fluid: (New charge and recycle oil)

1,413.6 kg/hr = 1,667 lit/hr

Specific gravity	0.848	35.5 A.P.I.
M.W.		170
Inlet temp.		180°C

If the outlet temperature is assumed nearly 300°C and not to be vaporized,

$$0.68 \times 1,413.6 \times (t_1 - 180) = 132,400$$

then $t_1 = 318°C$

In this case, taken 300°C

b. Hot Fluid: (Cracked oil and vapor)

If the outlet temperature assumed nearly 300°C and not to be condensed.

$$0.695 \times 1,245 \times (500 - t_2) = 132,000$$

then $t_2 = 345°C$

In this case, taken 320°C.

So that, the temperature of feed oil to the fraccionating column is about 320°C, but the temperature drops throughout the piping and other heat losses are obscure. However, it is assumed as follows, and taken a larger heating surface and should be regulated the feed temperature by adjusting the by-path valves.

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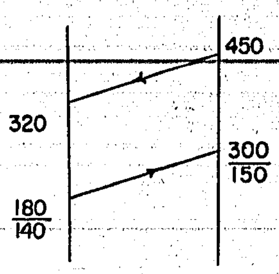


dTm $= 145^{o}C$

$K = 120$ Kcal/m^2, hr, ^oC

Therefore $A = 132{,}400 : (145 \times 120)$

$= 7.6$ m^2

With a safety factor, the surface is 15 m^2.

20. Reactivations of Catalyzer.

a. Carbon deposits are assumed 8 percent (wt) to the new charge oil depend upon the data of the naval laboratory.

$$6960/24 \times 0.08 = 29.9 \text{ kg/hr}$$
$$\doteqdot 2.49 \text{ kgmol/hr}$$

Oxygen is necessary 1 mol per mol of carbon theoretically, therefore necessary air amounts are as follows:

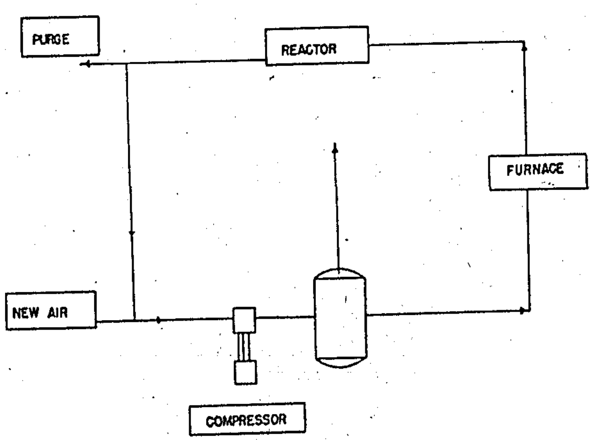
$$2.49/0.21 \times 22.4 = 265 \text{ m}^3\text{/hr}$$

With a 33 percent to allow the efficiency of combustion the necessary air amounts are 800 m^3 per hour.

b. The minimum air quantities to be necessary to keep uniformly the distribution of the temperature in the reactors is required about 600 600 m^3 per 1,000 kg of cracking stocks,

then $600 \times 33.910/24 \doteqdot 850$ m^3/hr

Having in mind (1) and (2), the capacity of the air compressor is determined 15 m per minute.



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Note: The reactors should be used three interchangeably.

21. Reactivating Gas Heater.

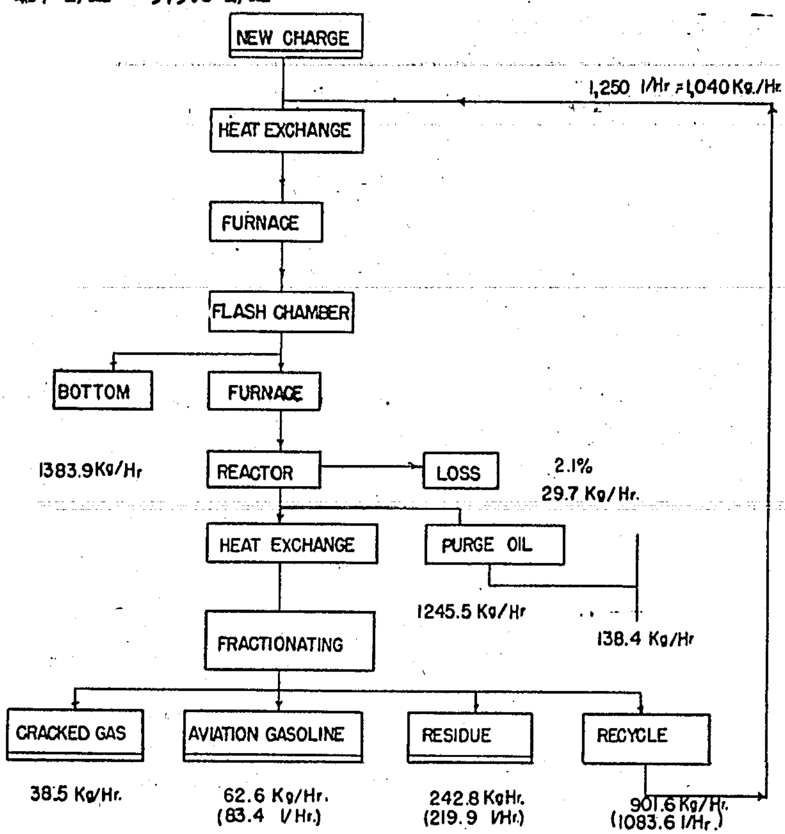
Quantities	850 m^3/hr
Operating pressure	5 kg/cm^2 to 2 kg/cm^2
Inlet temp.	25 °C
Outlet temp.	500°C

Heat required:

$$0.33 \times 850\ (500 - 25) = 133{,}000 \text{ Kcal/hr} \doteqdot 150{,}000 \text{ Kcal/hr}$$

Normal Operating Capacity 10,000 lit/day

417 l/Hr = 373.6 l/Hr



=10% =16.8%

Products	% to new charge
Aviation gas	20
Cracked gas	10
Residue	70

PLATE I (B) 6
FLOW DIAGRAM OF
CATALYTIC CRACKING PLANT