CHAPTER TWELVE

Refinery Stock Balancing

Before the advent of linear programming (LP) models, process-planning studies were done by hand with desktop calculators and usually large printed or duplicated worksheets. Little optimization was possible via trial and error, as this would involve calculating a stock balance over and over again until a satisfactory answer was arrived at.

Refinery LP models now do stock balancing. Many LP packages are available that facilitate plant yield calculations and optimize product blending.

However, stock balancing must be done by hand at times. A refinery operation planner may take an LP-optimized stock balance and redo it by hand, taking into account the conditions in the refinery that cannot be conveniently incorporated into the LP model,[1] for example, a critical pump-out of service, partially coked-up furnace, catalyst bed with high pressure drop or low activity, a delayed ship causing severe ullage constraints, or a change of specifications can upset the best-laid plans.

LP models are price driven and cannot handle nonlinear blending. LP models sometimes give complicated solutions to simple problems, which often need to be compromised for practical reasons. Also, LP solutions may require large number of changes to the model to realize small real benefits and tend to overoptimize, unless they are very sophisticated. For these reasons, they are not considered a good tool for producing a practical plan for the refinery operations.

Long-term process planning studies may also be done by hand when no LP model of the refinery in question is available; and putting together an LP model and testing it takes more time than a simple hand balance. Hand balancing is done on a personal computer (PC) with a spreadsheet program. The spreadsheet simulates a typical refinery flow diagram. Each box on the spreadsheet corresponds to a refinery unit. Each unit is represented by a performance equation that relates the output of the unit to change in the input or its operating conditions. The equations need not be linear.

DATA FOR MODEL BUILDING

Much of the data required for building a spreadsheet program are the same as required for building an LP model. As a matter of fact, a refinery's spreadsheet program and the matrix of an LP model have much in common. Both the models require data on the unit's possible operating modes, minimum and maximum capacities, operating factor, yields, stream qualities, and product specifications. Possible sources of these data are discussed next.

OPERATING MODES AND YIELDS

This information is available from refinery's stock balancing manual. This information is developed from crude oil assay and refinery test runs on the units. If no information is available, distillation yields can be estimated from crude assay and ASTM distillation of the cuts.

The process yields of secondary units such as cat reformers, FCCU, visbreakers, and hydrocracker units are available from the latest refinery test runs or the process licensor data. From whatever source the yield data is obtained, the feed composition and operating severity of the unit has to be decided on before a good estimate can be made. Therefore, for example, for a cat reformer, the feed PONA (paraffin, olefin, napthlene, and aromatic content of a feed) must be known and the severity has to be decided on before the unit yield can be estimated.

STREAM QUALITIES

Stream qualities, such as density, sulfur, octane number, smoke point, and pour point, can be obtained from the same source, such as crude assay data or results of the latest test runs on different units. To minimize the stock balancing calculations, experience and engineering judgment are required to decide which qualities would be most restrictive and control the stock balance. For example, if the diesel end point from a given crude is determined to meet the pour point specifications, the sulfur specification may not be a problem and need not be calculated. Often, a stock balance has to be calculated several times. The effort of laying out the calculations and including all necessary yields and stream qualities in a spreadsheet can save considerable time.

PRODUCT SPECIFICATIONS

All streams from different processing units are blended to produce saleable finished products at certain specifications. The major product groups are naphtha, gasoline, kerosene, diesel, and fuel oil. However, each product group may have a large number of product grades to meet the requirements of the product in different regions of the world. For example, a refinery may produce 10 or more grades of diesel with different pour points, sulfur, cetane indices, and the like to meet its client requirements, with different climatic conditions or different environmental regulations in force. The quality of the crude and processing unit capability decide the specifications a refinery can economically produce for each product group, to meet market demand. Information on the product grades a refinery can produce and sell are published in the form of product specification book, which is constantly updated.

UNIT CAPACITIES AND OPERATING FACTOR

All refinery units have a maximum and minimum operating capacity in terms of throughput in barrels per stream day. These data are available from the previous test run reports of the unit. However, the unit may not be available for a given period because of scheduled and unscheduled maintenance work. All refineries maintain a maintenance schedule for at least 1 year in advance. This schedule is constantly updated. Therefore, a unit operating factor can be worked out for every processing unit to estimate the available unit capacity in a given time period.

CALCULATION PROCEDURE

The objective of the calculations, otherwise known as problem statements, may have some control over the sequence of the steps. Typically, either the crude feed rate is known or the product requirements are given. For the latter case, the crude rate is estimated by totaling the product volume requirements. Next, to process the given crude rate, the various units capacity utilization are determined. Product blending calculations can be made once the blending volumes from various units are available. A good run ensures that the available unit capacities of all important units, such as distillation and key conversion units, are fully or nearly fully utilized. In the product blending part, there should be no unnecessary quality giveway. For example, if a fuel oil specification demands a product with 400 centistoke viscosity, any blend viscosity less than say 390 centistoke would constitute giveaway on viscosity and unnecessary loss of cutter stock, which could have been utilized for blending a higher-valued product.

If many different product grades are to be made, there are many ways to simplify the calculations. The different grades of same group (for example, all grades of fuel oils) can be pooled and pool specifications calculated, if product requirements are given. Stock balancing calculations may be carried out to determine what crude rate and downstream secondary unit feed rate will do the job. Conversely, if crude feed rate is known, only the balancing grade fuel oil production must be estimated.

The blending components of the pool must have diverse enough qualities to meet the demand for grades with extreme specifications. For example, if there is demand for equal volumes of two grades of gasoline at RON 90 and 100, a blend stock of RON 95 may satisfy the pool requirement for the two grades, assuming linear blending, but would be unsatisfactory for blending each of the individual grades. Although it could be used to blend RON 90 gasoline, there could be a lot of octane giveaway, and it could not used to blend RON 100 gasoline, without using another, much higher-octane blend stock.

As long as blending stocks are sufficiently diverse, blending individual grades may not even be required, depending on the problem statement; but if blends of individual product grades are required, these calculations should be done after pool specifications have been met.

Fixed blend "recipes" can be used for low-volume product grades. Ideally, this will decrease the unknowns down to one or two balancing grades for each product group.

Usually, one balancing grade is sufficient. Balancing grades tend to be those products that have the largest volume and are sold in the spot market. Any change that occurs in stock balance is absorbed on recalculation in the production of balancing grades only.

For example, if the fuel oil group has several grades with different viscosities and sulfur levels, blends of most of these grades can be fixed during the first calculation. The balancing grade may require one high-volume grade of cutter stock to meet viscosity plus another high-volume grade cutter to meet sulfur specs. Usually, one of these qualities controls the cutter requirement of each grade. Any changes to the volume of blend stocks available is reflected in these two grades. Each recalculation must include a recalculation of the volume of cutter stock required to meet controlling specification.

BLENDING MARGINS

Blending methods have always some level of uncertainty. It is necessary to incorporate a margin for error in critical specifications. The magnitude of this margin is decided on the basis of past experience. Some suggested blending margins used in actual practice follow. However, we emphasize that margins are, in fact, giveaways on quality and thus an economic penalty to refinery and it should be minimized. The magnitude of blending margins should be weighed against any economic penalty resulting from failure to meet a guaranteed specification.

QUALITY	BLENDING MARGIN
SPECIFIC GRAVITY	0.01
OCTANE NUMBER, RON/MON	1.0
VISCOSITY BLENDING INDEX	5.0 vol
SULFUR	0.05 Wt%
CETANE INDEX	2.0
POUR POINT INDEX	3.0
SMOKE POINT	2.0 mm
AROMATICS	0.50 vol%
REID VAPOR PRESSURE	3.5 kPa

REFINERY MATERIAL BALANCE SPREADSHEET PROGRAM

To run the program the following data in the spreadsheet are updated.

CRUDE AND VACUUM DISTILLATION UNITS

1. Time period or number of days in the month.
2. Crudes to be processed.
3. Total crude rate to each crude distillation unit, in thousands of barrels per day.
4. Operation mode of each crude and vacuum column.

5. Unit capacities available for each crude and vacuum column.
6. Disposition of atmospheric resids to various vacuum distillation columns.

The distribution of various crudes to crude distillation units (CDUs) and their operation mode is decided by the user; the spreadsheet program computes the flow rates and properties of various crude cuts on the basis of crude assays data and the unit test runs.

Disposition of atmospheric resids from CDUs to various vacuum distillation units (VDUs) is decided by the capacity of the VDU, its mode of operation, and sometimes the need to segregate certain feedstocks. For example, one VDU may be reserved to produce asphalt from certain heavy crude and another VDU may choose feedstocks to produce lubricating oil distillate only.

VACUUM RESID DISPOSITION

The disposition of vacuum resids is decided next. Vacuum resids from a VDU may have the following possible dispositions: to a visbreaker or other conversion unit, such as delayed coker, resid hydrocracker (H-oil etc.) or the asphalt converter; to fuel oil blending; or to inventory buildup for later processing or export.

Conversion units, such as resid hydrocracking, visbreaking, or asphalt converter, are filled up first, and the remaining stock goes to fuel oil blending or inventory buildup.

HEAVY DIESEL/HVGO DISPOSITION TO CONVERSION UNITS

Heavy-vacuum gas oils from vacuum distillation units and heavy diesels are pooled. Heavy-vacuum gas oil (HVGO) have the following possible dispositions: feed to the hydrocracker, feed to the fluid cat cracker (FCCU), use for fuel oil blending, or to inventory for later processing or export.

Conversion units are filled to capacity first. The operation mode of the processing unit is chosen by the user. The program computes the unit material balance and product streams qualities from the built in yield and quality data.

DISPOSITION OF STRAIGHT-RUN DIESELS AND LIGHT-CYCLE GAS OIL TO THE DIESEL DESULFURIZER

Material balance for the diesel desulfurizer is taken up next. The spreadsheet displays the volume and properties of various diesel streams from the CDU (light diesels), VDU (light-vacuum gas oil, LVGO), and FCCU (light-cycle gas oil, LCGO). Light cycle gas oil must be hydrotreated to send it to diesel pool because of product stability considerations.

The volume of the feedstream to the diesel desulfurizer is manually adjusted to fill the unit. The objective is to give priority to high-sulfur streams. A part of the LCGO from the FCCU is sent to diesel desulfurizer unit. The only other disposition for LCGO in fuel oil is as cutter, so there is every incentive to blend as much LCGO into diesel as possible. The primary purpose is to improve the stability of the LCGO rather than desulfurize it. The remaining capacity is utilized for desulfurizing straight-run diesel streams, starting with the highest-sulfur streams, until the unit is full.

DISPOSITION OF MEDIUM NAPHTHA TO THE PRETREATER/ CATALYTIC REFORMER UNIT

A cat reformer can have a number of medium naphtha feeds. Also, a unit may run on a number of different severities. The disposition of feed to different severites or modes must be decided before the unit material balance can be worked out.

FUEL OIL BLENDING

All available vacuum resids, visbroken resids, and atmospheric long resids are pooled to compute the available volumes and their properties. To these are added the available cutter stocks, such as light and heavy cycle oils and heavy cat naphtha from the FCCU. The resid and the cutter stock constitute the fuel oil pool. The program calculates the fuel pool volume and properties (viscosity, sulfur, Con carbon, etc.).

The volume and properties (specifications) of fixed fuel grades are known from the operating plan of the refinery for that month. These volumes and properties are pooled and deducted from the total fuel pool to arrive at the balancing grade fuel production and its qualities. The properties of the balancing grade (viscosity, sulfur, Con carbon, gravity) are adjusted by the addition of diesel oil to meet the specifications of the balancing grade fuel oil. The amount of diesel cutter is adjusted by trial and error until the properties of the balancing grade fuel oil are within its specification limits.

DIESEL BLENDING

All the remaining diesel blend streams, after feeding the diesel desulfurizer unit, and the desulfurized diesel stream from that unit are blended together to estimate the diesel pool volume and its properties. Next, fixed-grade diesel volumes and their properties are deducted from the pool to arrive at the balancing-grade diesel volume and its properties. The balancing-grade diesel pool properties are adjusted by the addition of kerosene until all the balancing-grade diesel properties (pour point, sulfur, diesel index, etc.) are within the limits required by the specifications of the balancing-grade diesel.

GASOLINE BLENDING

Gasoline blending is taken up next. Feed to the catalytic reformer is specified and so are the operation severities. The cat reformer material balance is computed by the program, on the basis of built-in yields of the cat reformer.

All the gasoline streams are pooled, and the average pool properties (RON, MON, Reid vapor pressure, specific gravity, etc.) determined. Next, fixed grades gasoline requirements are pooled and deducted from the gasoline pool to arrive at the balancing-grade gasoline production. If any property such as RON, MON, or Reid vapor pressure (RVP) of the balancing-grade gasoline fails to meet the specs, gasoline pool composition could be varied by changing the reformer severity or adjusting the butane or more volatile components of the blend.

NAPHTHA BLENDING

The only significant properties of naphtha blending are RVP and specific gravity (SG). Blending is done by adjusting the light straight-run, whole straight-run (WSR), and butane content of each grade to meet SG and RVP specs.

EXAMPLE 12-1

A refinery (Figure 12-1) has the following process units. The capacity of the major processing units indicated is nominal capacity, in barrels per stream day (bpsd):

PROCESS	NOMINAL CAPACITY
CRUDE DISTILLATION	260,000 bpsd
VACUUM DISTILLATION	115,000 bpsd
UNIFINER/CAT REFORMER	15,000 bpsd
DIESEL DESULFURIZER	20,000 bpsd
PARTIAL HYDROCRACKER	50,000 bpsd
FLUID CAT CRACKER	36,000 bpsd
POLYMER GASOLINE PLANT	2,400 bpsd
VISBREAKER	20,000 bpsd
KEROSENE TREATING	42,000 bpsd
HYDROGEN PLANT	27 mmscfd
SULFUR PLANT	150 (tons/day)

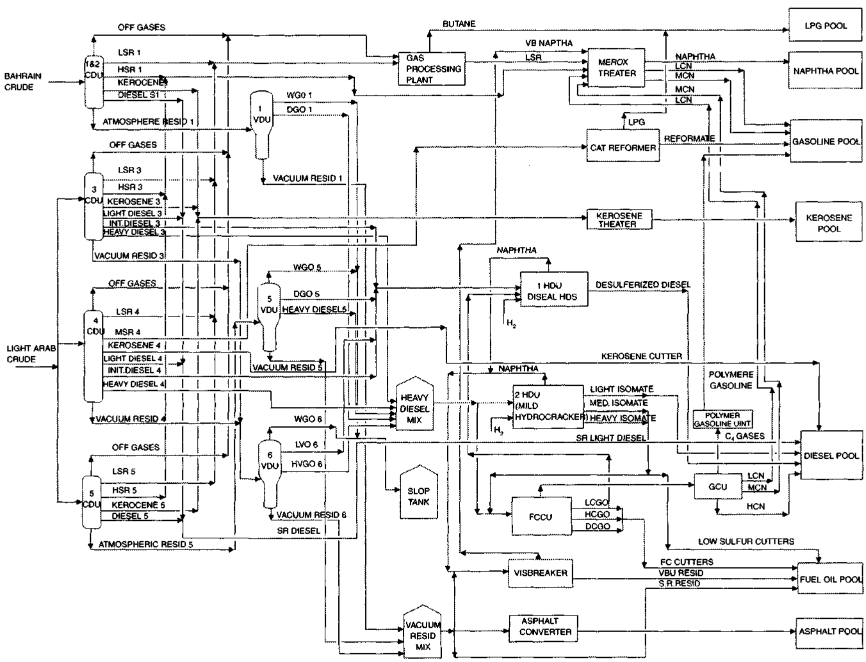

Figure 12-1. Refinery configuration for Example 12-1. LSR = light straight run; MSR = medium straight run; HSR = heavy straight run; INT. = intermediate; DGO = diesel gas oil; LVGO = light vacuum gas oil; HVGO = heavy vacuum gas oil; CDU = crude distillation unit; VDU = vacuum distillation unit; HDU = heavy diesel unit; LPG = liquefied petroleum gas; WGO = wet gas oil; VBU = visbreaker unit; LCGO = light cycle gas oil; HCGO = heavy cycle gas oil; GCU = gas concentration unit; LCN = light cat naphtha; MCN = medium cat naphtha; FC = FCCU cutters; DGCO = decant gas oil; HDS = hydrodesulfurization unit.

We want to process the following crudes during the month:

Light Arabian, 201 thousands bpsd
Bahrain, 42 thousands bpsd

The processing scheme of the refinery is shown in Figure 12-1. The maximum available unit capacities and estimated operating factor for the crude and other processing units, per month (30 days), are shown in Tables 12-1 to 12-3.

Bahrain crude is processed on crude units 1 and 2, and light Arabian crude is processed on crude units 3–5. Atmospheric resid is further distilled in vacuum distillation units 1, 5, and 6. A part of the vacuum resid is visbroken in the visbreaker unit. Both visbroken and straight-run vacuum resid are blended with FCCU cutters to fuel oil grades. Vacuum gas oils from vacuum distillation units are pooled and sent to the mild hydrocracker unit (with approximately 30% conversion) and FCCU. Unconverted, desulfurized vacuum gas oil (medium and heavy isomate) is used as feed to the FCCU or low-sulfur cutter stock for fuel oil.

We want to make an estimate of the product slate in barrels per month, assuming 30 days operation, unit capacity utilization, and the inventory changes required to sustain this operation.

The format of the spreadsheets is shown in Tables 12-1 to 12-35. Most of the data on unit yield and stream qualities for blending are built into the spreadsheet model and need not be revised for most routine estimates.

Table 12-1 lists data on the number of processing days and individual crudes processed. Tables 12-2 and 12-3 list the maximum unit capacities, operating factor, and available unit capacities. Tables 12-4 and 12-5 compute the overall yield of various products from crude units. Tables

Table 12-1
Crude Processed

CRUDE	mbpcd*	TOTAL mb**
ARABIAN	201.00	6030.00
BAHRAIN	42.00	1260.00
MURBAN	0.00	0.00
DUBAI	0.00	0.00
TOTAL	243.00	7290.00

*mbpcd = 1000 barrels per calender day.
**mb = 1000 of barrels.

Table 12-2
Crude Distillation Unit (CDU) Capacities

UNIT	NAME	CAPX, mbpcd	OPFACT	CAPACITY, mbl
CRUDE UNIT 1	CDU1	20.00	1.000	600.00
CRUDE UNIT 2	CDU2	20.00	1.000	600.00
CRUDE UNIT 3	CDU3	64.00	1.000	1920.00
CRUDE UNIT 4	CDU4	93.00	1.000	2790.00
CRUDE UNIT 5	CDU5	46.00	1.000	1380.00
TOTAL CDU		243.00		7290.00

CAPX = MAXIMUM CAPACITY
CAPACITY = AVAILABE CAPACITY
OPFACT = UNIT OPERATING FACTOR

Table 12-3
Other Processing Unit Capacities

UNIT	NAME	CAPX, mbpcd	OPFACT	CAPACITY, mb
VACUUM DISTILLATION UNIT 1	VC1	9.60	0.843	242.78
VACUUM DISTILLATION UNIT 5	VC5	33.00	0.843	834.57
VACUUM DISTILLATION UNIT 6	VC6	70.00	0.843	1770.30
KEROSENE TREATING UNIT	KTU	45.00	0.843	1138.05
VISBREAKER	VB	20.00	0.843	505.80
FLUID CAT CRACKER	FCCU	44.00	0.818	1079.38
DIESEL HYDRODESULFURIZER	HD1	22.00	0.843	556.38
PARTIAL HYDROCRACKER	HD2	52.00	0.843	1315.08
CAT REFORMER	CR	18.00	0.750	405.00

12-6 to 12-12 calculate the material balance of vacuum distillation units no 1, 5, and 6. Table 12-13 shows pooling of vacuum resids from various vacuum distillation unit and its disposition to visbreaker, asphalt converter and fuel oil blending. Tables 12-14 and 12-15 show material balance and stream qualities for asphalt converter and visbreaker unit. Table 12-16 shows the composite volumes of vacuum resid and their estimated properties for blending into fuel oil. Table 12-17 show all the blend components

Table 12-4
Crude Unit Yields

CDU NO.	FEED RATE, mbpcd	CRUDE	VOLUME, mb	BUTANE YIELD %VOL	mb	LSR YIELD	mb	MSR YIELD	mb	sg	KEROSENE YIELD	mb	LIGHT DIESEL YIELD	mb	MEDIUM DIESEL YIELD	mb	HEAVY DIESEL YIELD	mb	RESID YIELD	mb	LOSSES, % CRUDE	mb	TOTAL, %
1	0	A	0	1.7	0	7.9	0	10.50	0.00	0.7380	16.60	0.00	11.8	0.00	0.00	0.00	0.00	0.00	51.20	0.00	0.30	0.00	100.00
2	0	A	0	1.8	0	7.4	0	9.70	0.00	0.7346	20.00	0.00	10.3	0.00	0.00	0.00	0.00	0.00	50.50	0.00	0.30	0.00	100.00
3	62	A	1860	1.8	33.48	6.4	119.04	11.70	217.62	0.7331	16.90	314.34	21.9	407.34	0.00	0.00	1.30	24.18	39.70	738.42	0.30	5.58	100.00
4	93	A	2790	1.3	36.27	11.1	309.69	9.50	265.05	0.7458	17.50	488.25	7.4	206.46	12.70	354.33	12.90	359.91	27.30	761.67	0.30	8.37	100.00
5	46	A	1380	1.7	23.46	7.6	104.88	10.40	143.52	0.7356	16.00	220.80	13.5	186.30	0.00	0.00	0.00	0.00	50.50	696.90	0.30	4.14	100.00
1	20	B	600	0.6	3.6	5.1	30.6	10.50	63.00	0.7338	16.60	99.60	13.3	79.80	0.0	0.00	0.0	0.00	53.60	321.60	0.3	1.80	100.00
2	20	B	600	0.7	4.2	4.6	27.6	9.70	58.20	0.7310	20.00	120.00	11.8	70.80	0.0	0.00	0.0	0.00	52.90	317.40	0.3	1.80	100.00
3	2	B	60	0.7	0.42	3.9	2.34	11.40	6.84	0.7284	17.40	10.44	23.80	14.28	0.0	0.00	1.4	0.84	41.10	24.66	0.3	0.18	100.00
4	0	B	0	0.3	0	8.1	0	9.00	0.00	0.7460	18.60	0.00	8.00	0.00	14.1	0.00	13.9	0.00	27.70	0.00	0.3	0.00	100.00
5	0	B	0	0.7	0	4.8	0	10.10	0.00	0.7318	16.80	0.00	14.40	0.00	0.0	0.00	0.0	0.00	52.90	0.00	0.3	0.00	100.00
1	0	C	0	1.7	0	7.9	0	9.40	0.00	0.7380	17.70	0.00	11.8	0.00	0.0	0.00	0.0	0.00	51.20	0.00	0.3	0.00	100.00
2	0	C	0	1.8	0	7.4	0	9.60	0.00	0.7346	20.10	0.00	10.3	0.00	0.0	0.00	0.0	0.00	50.50	0.00	0.3	0.00	100.00
3	0	C	0	1.8	0	6.4	0	10.30	0.00	0.7331	18.30	0.00	21.90	0.00	0.0	0.00	1.3	0.00	39.70	0.00	0.3	0.00	100.00
4	0	C	0	1.3	0	11.1	0	7.50	0.00	0.7458	19.50	0.00	7.40	0.00	12.7	0.00	12.9	0.00	27.30	0.00	0.3	0.00	100.00
5	0	C	0	1.7	0	7.6	0	9.60	0.00	0.7356	16.80	0.00	13.50	0.00	0.0	0.00	0.0	0.00	50.50	0.00	0.3	0.00	100.00
1	0	D	0	0.6	0	5.1	0	9.40	0.00	0.7338	17.70	0.00	13.3	0.00	0.0	0.00	0.0	0.00	53.60	0.00	0.3	0.00	100.00
2	0	D	0	0.7	0	4.6	0	9.60	0.00	0.7310	20.10	0.00	11.8	0.00	0.0	0.00	0.0	0.00	52.90	0.00	0.3	0.00	100.00
3	0	D	0	0.7	0	3.9	0	10.00	0.00	0.7284	18.80	0.00	23.80	0.00	0.0	0.00	1.4	0.00	41.10	0.00	0.3	0.00	100.00
4	0	D	0	0.3	0	8.1	0	8.00	0.00	0.7460	19.60	0.00	8.00	0.00	14.1	0.00	13.9	0.00	27.70	0.00	0.3	0.00	100.00
5	0	D	0	0.7	0	4.8	0	9.50	0.00	0.7318	17.40	0.00	14.40	0.00	0.0	0.00	0.0	0.00	52.90	0.00	0.3	0.00	100.00
TOTAL	243		7290		101.43		594.15		754.23			1253.43		964.98		354.33		384.93		2860.65		21.87	

A = ARABIAN CRUDE.
B = BAHRAIN CRUDE.
C = MURBAN CRUDE.
D = DUBAI CRUDE.

Table 12-5
Crude Unit Overall Material Balance

	mbpcd	mb	VOL %
INPUT			
ARABIAN	201	6030	82.72%
BAHRAIN	42	1260	17.28%
MURBAN	0	0	0.00%
DUBAI	0	0	0.00%
TOTAL	243	7290	100.00%
OUTPUT			
BUTANE	3.4	101.4	1.39%
LSR	19.8	594.2	8.15%
MSR	25.1	754.2	10.35%
KEROSENE	41.8	1253.4	17.19%
LIGHT DIESEL	32.2	965.0	13.24%
MEDIUM/INTER. DIESEL	11.8	354.3	4.86%
HEAVY DIESEL	12.8	384.9	5.28%
ATM RESID	95.4	2860.7	39.24%
LOSS	0.7	21.9	0.30%
TOTAL	243.0	7290.0	100.00%

Table 12-6
No. 1 Vacuum Distillation Unit (VDU), ASPHALT MODE

	YIELD, LV	mb	SG	SULFUR, wt%	SG*S	VBI, H
FEED	1.0000	267.30				
WGO	0.0740	19.78	0.8585	1.171	1.0050	−29
DGO	0.6230	166.53	0.9174	2.691	2.4690	280
BSGO	0.0460	12.30	0.9918	4.260	4.2250	638
VACUUM RESID	0.2570	68.70	1.0350	4.925	5.0970	827
TOTAL	1.0000	267.30				

VBI = VISCOSITY BLENDING INDEX (VOLUME BASIS).
WGO = WET GAS OIL.
DGO = DISTILLATE GAS OIL.
BSGO = HVGO.

of fuel oil pool, their volumes, properties and also overall pool volume and properties. The production of fixed-grade volumes is known or given (Table 12-18) and the production of balancing-grade fuel oil (I-961) is computed by

Table 12-7
Atmospheric Resid Distribution to Vacuum Units

RESID	AVAILABLE, mb/mol	TO 1 VDU FUEL	TO 1 VDU ASPHALT*	TO 5VDU (33 mb/day)**	TO 5 VDU ASPHALT	TO 6VDU (65 mb/day)***	TO FCCU	TO FUEL	TO INV.
1A RESID	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2A RESID	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3A RESID	738.42	0.00	0.00	287.40	0.00	451.02	0.00	0.00	0.00
4A RESID	761.67	0.00	0.00	287.00	0.00	474.67	0.00	0.00	0.00
5A RESID	696.90	0.00	0.00	250.60	0.00	446.30	0.00	0.00	0.00
1B RESID	321.60	0.00	267.30	18.40	0.00	35.90	0.00	0.00	0.00
2B RESID	317.40	0.00	0.00	116.70	0.00	200.70	0.00	0.00	0.00
3B RESID	24.66	0.00	0.00	0.00	0.00	24.66	0.00	0.00	0.00
4B RESID	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5B RESID	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1VDU WGO	19.78	0.00	0.00	0.00	0.00	19.78	0.00	0.00	0.00
TOTAL, mb	2860.65	0.00	267.30	960.10	0.00	1633.25	0.00	0.00	0.00
mbpcd	95.36	0.00	8.91	32.00	0.00	54.44	0.00	0.00	0.00

UNIT CAPACITY:
*270
**990
***1950

Table 12-8
No. 1 VDU, Fuel Oil Mode

	YIELD, LV	mb	SG	SULFUR, wt%	SG*S	VBI, H
FEED	1.0000	0.00				
WGO	0.1390	0.00	0.8713	1.795	1.5640	62
DGO	0.4790	0.00	0.9169	2.634	2.4151	281
BSGO	0.0000	0.00				
VACUUM RESID	0.3820	0.00	1.0247	4.722	4.8386	754
TOTAL	1.0000	0.00				

deducting from composite fuel oil pool (Table 12-17) the volumes and properties fixed-grade pool (Table 12-18). We see, however, that fuel oil thus produced does not meet the viscosity specification (180 cst, viscosity blend index = 480), so further cutting with diesel is done to reduce the VBI from 586 to 480, thus adding to fuel oil volume (Table 12-19).

Table 12-20 shows the pooling of all heavy diesels produced by crude or vacuum distillation units. Table 12-21 shows the disposition of these HVGO streams to processing units. Hydrocracker and cat cracker units are filled first, and anything left is either blended to fuel oil or sent to inventory for export or later use. Table 12-22 shows the material balance and product properties of a mild hydrocracker unit (2 HDU). Unconverted but desulfurized HVGO from mild hydrocracker, called *isomate*, is used as feed to the FCCU (Table 12-23), and any surplus isomate may be used as cutter to fuel oil. Light isomate, which is in fact desulfurized diesel, is sent to the diesel pool.

Tables 12-24 to 12-26 show yield from the FCCU and product properties. Light and medium cat naphtha are blended to gasoline, while heavy cat naphtha is routed to diesel. Light cycle gas oil is partly routed to diesel pool after hydrotreating in the diesel hydrotreating unit. All remaining LCO (light cycle oil), HCGO, and decant oil are used as cutter in fuel oil blending. Table 12-27 shows feed to the diesel desulfurizer unit. Knowing the available capacity of the unit enables computing the total feed to the unit. Light cycle gas oil from the FCCU is a feed that must be hydrotreated before it can be blended into diesel. A certain fraction of the unit capacity is used up for this stream. The rest of the unit capacity is used to desulfurize untreated diesel, starting with the stream of highest sulfur content.

Table 12-9
Yield from Vacuum Unit No. 5

	YIELD 1A	mb	YIELD 2&5A	mb	YIELD 3A	mb	YIELD 4A	mb	YIELD 1B	mb	YIELD 2&5B	mb	YIELD 3B	mb	YIELD 4B	mb	TOTAL
FEED	1.0000	0.00	1.0000	250.60	1.0000	287.40	1.0000	287.00	1.0000	18.40	1.0000	116.70	1.0000	0.00	1.0000	0.00	960.10
WGO	0.0060	0.00	0.0060	1.50	0.0080	2.30	0.0000	0.00	0.0060	0.11	0.0060	0.70	0.0000	0.00	0.0000	0.00	4.61
DGO	0.2680	0.00	0.2600	65.16	0.0760	21.84	0.0000	0.00	0.2800	5.15	0.2730	31.86	0.1010	0.00	0.0000	0.00	124.01
HVGO	0.4410	0.00	0.4430	111.02	0.5330	153.18	0.3960	113.65	0.4400	8.10	0.4420	51.58	0.5240	0.00	0.3940	0.00	437.53
VACUUM RESID	0.2850	0.00	0.2910	72.92	0.3830	110.07	0.6040	173.35	0.2740	5.04	0.2790	32.56	0.3750	0.00	0.6060	0.00	393.95
TOTAL	1.0000	0.00	1.0000	250.6000	1.0000	287.4000	1.0000	287.0000	1.0000	18.4000	1.0000	116.7000	1.0000	0.0000	1.0000	0.0000	960.1000

NOTES:
FEED 1A = REDUCED CRUDE FROM CDU 1 PROCESSING ARABIAN CRUDE.
FEED 2A = REDUCED CRUDE FROM CDU 2 PROCESSING ARABIAN CRUDE.
FEED 3A = REDUCED CRUDE FROM CDU 1 PROCESSING ARABIAN CRUDE.
FEED 1B = REDUCED CRUDE FROM CDU 1 PROCESSING BAHRAIN CRUDE.

Table 12-10
Properties of Vacuum Distillates from VDU 5

	mb	SG	SULFUR	PI	VBI	SG*S
FEED	960.10					
WGO	4.61	0.8096	0.37	76	−197	0.30
DGO	124.01	0.8740	1.96	588	82	1.71
HVGO	437.53	0.9437	2.97	2919	413	2.80
VACUUM RESID	393.95	1.0177	4.26		765	4.34
TOTAL	960.1	0.9644	3.36	1406	512	3.236

NOTES:
VBI = VISCOSITY BLENDING INDEX (VOLUME BASIS).
PI = POUR POINT BLENDING INDEX.

Table 12-28 shows certain special blends, such as marine diesel. These are generally blended to specific formulas based on previous shipments. Table 12-29 show fixed grades diesel blending. Table 12-30 shows the total blend components, their volumes and blending properties, and the average pool properties. After deducting the properties of the fixed and special grades, the remaining volume of the pool and its blending properties are estimated. Kerosene is blended into it to meet the sulfur or pour properties of the balancing-grade diesel, whichever is limiting. Tables 12-31 to 12-33 show yields from the cat reformer unit and gasoline blending from LCN, cat reformate, light straight-run naphtha, and so forth. Tables 12-35 and 12-36 show the production estimates for kerosene. Some kerosene may be used up in special military blends such as JP-4 (a blend of kerosene, naphtha, and butane). The remaining kerosene pool is used first to meet fixed-grade requirements and next for balancing-grade production (Tables 12-35 and 12-36).

Blending naphthas, LSR and WSR, is taken up next. Most of the light and whole straight-run naphtha streams emanate from crude units. These are shown in Tables 12-37 to 12-39. The critical properties are the naphtha density and Ried vapor pressure. The RVP can be increased by blending butane, as there is generally economic incentive to blend the naphtha RVP close to specification.

If the refinery has facilities for liquefied petroleum gas recovery, it is recovered from crude, FCCU, and cat reformer units (Table 12-40). LPG is disposed of in gasoline, naphtha blending, and as LPG sale. The remaining LPG, if any, is spent as refinery fuel.

Table 12-11
Overall Yield from VDU 6

	YIELD 1A	mb	YIELD 2&5A	mb	YIELD 3A	mb	YIELD 4A	mb	YIELD 1B	mb	YIELD 2&5B	mb	YIELD 3B	mb	YIELD 4B	mb	YIELD 1VDU WGO	mb	TOTAL
FEED	1.0000	0.00	1.0000	446.30	1.0000	451.02	1.0000	474.67	1.0000	35.90	1.0000	200.70	1.0000	24.66	1.0000	0.00	1.0000	19.78	1653.03
WGO	0.0040	0.00	0.0050	2.23	0.0000	0.00	0.0000	0.00	0.0040	0.14	0.0050	1.00	0.0000	0.00	0.0000	0.00	0.0250	0.49	3.87
DGO	0.2590	0.00	0.2490	111.13	0.0650	29.32	0.0000	0.00	0.2710	9.73	0.2600	52.18	0.0700	1.73	0.0000	0.00	0.9530	18.85	222.93
HVGO	0.4400	0.00	0.4430	197.71	0.5090	229.57	0.3210	152.37	0.4420	15.87	0.4480	89.91	0.5220	12.87	0.3310	0.00	0.0220	0.44	698.74
VACUUM RESID	0.2970	0.00	0.3030	135.23	0.4260	192.13	0.6790	322.30	0.2830	10.16	0.2870	57.60	0.4080	10.06	0.6690	0.00	0.0000	0.00	727.49
TOTAL	1.0000	0.00	1.0000	446.30	1.0000	451.02	1.0000	474.6700	1.0000	35.9000	1.0000	200.70	1.0000	24.6600	1.0000	0.0000	1.0000	19.78	1653.03

Table 12-12
VDU 6 Stream Properties

	mb	SG	SULFUR	PI	VBI	SG*S
FEED	1653.03					
WGO	3.87	0.8127	0.51	71	−185	0.41
DGO	222.93	0.8439	1.87	537	67	1.58
HVGO	698.74	0.9375	2.89	2703	393	2.71
VACUUM RESID	727.49	1.0164	4.22		750	4.28
TOTAL	1653.03	0.95932	3.33		505	3.195

Table 12-13
Vacuum Resid Production and Disposition

UNIT	OPERATION MODE	PRODUCTION, mb	TO VISBREAKER	TO ASPHALT CONVERTER	ASPHALT VDU 1	TO FUEL OIL BLENDING
VDU 1	ASPHALT	68.70			68.70	0.00
VDU 1	FUEL OIL	0.00				0.00
VDU 5	FUEL OIL	393.95	393.95			0.00
VDU 6	FUEL OIL	727.49	200.05	23.26		504.18
TOTAL		1190.13	594.00	23.26	68.70	504.17

Table 12-14
Asphalt Converter Yield

STREAM	VOL% YIELD	mb
ASPHALT REQUIREMENTS		90
ASPHALT PRODUCTION FROM VDU 1		68.70
ASPHALT REQUIRED FROM CONVERTER		21.30
ASPHALT CONVERTER FEED		23.26
FEED	100.00	23.26
LOSS	1.00	0.23
FUEL OIL DURING REGULATION	7.40	1.72
ASPHALT	91.60	21.30
TOTAL	100.00	23.26

Table 12-15
Visbreaker Unit

	AVAILABLE mb	USED mb	SG	SG*S	H	YIELD LV %
FEED						
5VR	393.95	393.95	1.0177	4.337	764.71	
6VR	727.49	200.05	1.0164	4.285	749.73	
TOTAL	1121.43	594	1.0173	4.319	759.67	
PRODUCT						
LOSS		2.38				0.40
NAPHTHA		16.04				2.70
VISBREAKER RESID		575.59	1.03	4.653	669.67	96.90
TOTAL		594.00				100.00

NOTES:
H = VBI, VISCOSITY BLENDING INDEX.
VISBREAKER RESID = VISBROKEN RESID FROM VISBREAKER.
SG*S = PRODUCT OF SPECIFIC GRAVITY AND SULFUR WT%.
FEED RATE = 19.80 mbpcd.
VR = VACUUM RESID
LV = LIQUID VOLUME

Table 12-16
Resid Pool

RESIDS	VOL	H	SG	SG*S	SULFUR WT %	CON CARBON
4A VR	0.00	646	0.9908	3.9400	3.98	13.7
5VDU VR	0.00	765	1.0177	4.3365	4.26	21.5
6VDU VR	504.18	750	1.0164	4.2846	4.22	21.1
VB RESID	575.59	760	1.0173	4.3191	4.25	23.1
ASPH 1/5	0.00	791	1.0350	5.0800	4.91	21.6
ASPHALT CONVERTER	1.72	832	1.0220	4.3500	4.26	26.9
3A VR	0.00	486	0.9643	3.2440	3.36	26.9
TOTAL RESID INCLUDING VB RESID	1081.48	755	1.0169	4.3031	4.23	22.2
TOTAL STRAIGHT-RUN RESID	505.89	750	1.0165	4.2849	4.22	21.1

Table 12-17
Fuel Oil Blending

FO BLEND STREAM	VOL	H	SG	SG*S	SULFUR	CON CARBON
TOTAL V.RESID	1081.48	755	1.0169	4.3031	4.23	22.17
TOTAL V.R w/O v.B	505.89	750	1.0165	4.2849	4.22	21.12
VBU RESID	575.59	760	1.0173	4.3191	4.25	23.10
FCC CUTTERS	316.92	173	0.9316	1.0736	1.15	0.80
MED ISOMATE	6.79	241	0.8844	0.0000	0.00	0.00
HEAVY ISOMATE	0.00	378	0.9018	0.0000	0.00	0.00
HEAVY CAT NAPHTHA	110.31	−250	0.7800	0.0780	0.10	0.00
4A M/I DIESEL	0.00	61	0.8709	1.6240	1.86	0.00
HVGO	74.49	364	0.9322	2.6200	2.81	0.00
TANKAGE	0.00	0	0.9602	2.5280	2.63	0.00
TOTAL	1590.00	549	0.9789	3.2690	3.25	15.24

Table 12-18
Fixed-Grade Fuel Oil Pool

FIXED FUEL GRADES	PROPERTIES					
	VOLUME	H	SG	SG*S	SUL	CON CARBON
I-925	0.00	458	0.9490	2.2300	2.35	15.00
I-928	360.00	458	0.9550	2.5800	2.70	15.00
I-934	0.00	427	0.9520	2.7100	2.85	15.00
I-933	0.00	394	0.9480	2.7200	2.87	15.00
I-957	0.00	349	0.9480	2.5900	2.73	15.00
I-957LS	0.00	338	0.9310	1.7800	1.91	15.00
I-960	0.00	430	0.9600	3.2100	3.35	15.00
I-962	0.00	484	0.9650	3.2300	3.35	15.00
I-964	0.00	439	0.9630	3.0700	3.19	15.00
I-971	135.00	488	0.9710	3.2900	3.39	15.00
I-961 (80 cst)	0.00	396	0.9480	2.7700	2.92	15.00
TOTAL FIXED GRADES	495.00	466.18	0.96	2.77	2.89	15.00

Table 12-19
Balancing-Grade Fuel Oil Blending

STREAM	AVAIL	H	SG	SG *S	SULFUR	CON CARBON
FUEL OIL POOL	1590.00	549	0.9789	3.2690	3.25	15.24
FIXED GRADES FUEL OIL	495.00	466	0.9594	2.7736	2.89	15.00
BALANCING GRADE FUEL OIL	1095.00	586	0.9878	3.4929	3.41	15.35
I-888 CUTTER (DIESEL)	210.00	−30	0.8530	0.8530	1.00	1.00
I-961 POOL (BALANCING GRADE)	1325.00	480	0.9515	3.0218	3.18	12.84
TO TANKS	0.00	480	0.9515	3.0218	3.18	12.84
I-961 POOL	1325.00	480	0.9515	3.0218	3.18	12.84

Table 12-20
Heavy Diesels Yield Summary

UNITS	STREAM	VOL	H	SG	SG*S
CDU 3	3A HDO	25.02	215	0.9020	2.170
CDU 4	4A HDO	359.91	290	0.9160	2.330
VDU 1	DGO (ASPHALT MODE)	178.82	299	0.9200	2.470
VDU 5	VDU 5 VHD	437.53	413	0.9437	2.802
VDU 6	VDU 6 VHD	698.74	393	0.9375	2.710
	TOTAL	1700.02	364	0.9322	2.620
	TO INVENTORY, +/−	−94.57			
	TOTAL, mb	1605.45			

Table 12-21
Heavy Diesel Disposition

STREAM	mb
TO I-725 (HVGO)	0.00
TO HYDROCRACKER, HDU 2	1315.08
TO FCCU	215.88
TO FUEL BLENDING	74.49
TOTAL	1605.45

Table 12-22
HDU 2 (Mild Hydrocracker) Unit Yield Summary

	VOLUME mb	DIESEL INDEX, DI	PI	SUL	H	SG
FEED	1315.08					
LIGHT DIESEL	18.72	64.0	46	0.030	−250	0.7950
WSR NAPHTHA	22.74					0.7034
LIGHT ISOMATE	393.21	38.0	450	0.120	25	0.8839
MEDIUM ISOMATE	316.30			0.240	241	0.8844
HEAVY ISOMATE	603.18			0.280	378	0.9018
TOTAL	1354.15					
VOLUME GAIN	39.07					

Table 12-23
Distribution of Isomates from HDU 2 Unit

	LIGHT ISOMATE	MEDIUM ISOMATE	HEAVY ISOMATE
PRODUCED	393.21	316.30	603.18
INVENTORY, +/−	0.00	−49.19	0.00
TOTAL	393.21	267.11	603.18
DISPOSITION			
TO DIESEL	393.21	0.00	0.00
TO FUEL	0.00	6.79	0.00
TO FCCU	0.00	260.32	603.18
TOTAL	393.21	267.11	603.18

Table 12-24
FCCU Feed Summary

	MODE 1, mb	MODE 2, mb
ISOMATE FEED	863.51	0.00
HVGO FEED	0.00	215.88
TOTAL	863.51	215.88
ISOMATE %	80.00	20.00
RUN DAYS	30.00	30.00
FEED RATE, mbpcd	28.78	7.20

Table 12-25
FCCU Yield Summary

PRODUCT	YIELDS LV% MODE 1	YIELDS LV% MODE 2	VOLUME, mb	SG	H	SG *S	DI
LIGHT CAT NAPHTHA	0.2950	0.2320	304.82				
MEDIUM CAT NAPHTHA	0.0613	0.1180	78.41				
POLYMER GASOLINE	0.0337	0.0336	36.35				
HEAVY CAT NAPHTHA	0.1060	0.0870	110.31	0.78	−250.00	0.08	
BUTANE	0.0295	0.0258	31.04				
LIGHT CYCLE GAS OIL	0.2810	0.2590	298.56	0.89	−82.80	0.65	33.00
HEAVY CYCLE + DECANT OIL	0.2140	0.2600	240.92	0.95	253.20	1.21	
TOTAL	1.0205	1.0154	1100.41				
GAIN			21.03				
CUTTERS			539.48	0.91	67.25	0.90	

Table 12-26
FCCU Cutter Quality

CUTTER BLEND	mb	H	SG	SG*S
STREAM				
TOTAL LCGO	298.56			
LCGO TO HDU 1	222.55			
LCGO TO FUEL OIL AS CUTTER	76.01			
LCGO	76.00	−82.80	0.89	0.65
HCGO + DECANT OIL	240.92	253.20	0.95	1.21
CUTTER QUALITY	316.92	172.62	0.9316	1.0736

1 HDU CAPACITY, 18.546 mbpcd, 30 DAYS

Table 12-27
Gas Oil (Diesel) Blending from HDU 1 Diesel Hydrodesulfurizer

STREAM	AVAILABLE	TO HDU 1	DI	PI	H	SULFUR	BALANCE
LCGO 1	222.55	222.55	33.1	107	−83	0.296	0.00
LCGO 2	0.00	0.00	33.1	107	−83	2.813	0.00
1A LD	0.00	0.00	63.0	197	−68	1.111	0.00
2A LD	0.00	0.00	61.3	235	−37	1.250	0.00
3A LD	407.34	0.00	61.2	308	−19	1.319	407.34
4A LD	206.46	0.00	57.4	190	−76	0.840	206.46
5A LD	186.30	0.00	62.5	240	−50	1.169	186.30
1B LD	79.80	0.00	55.0	197	−72	1.029	79.80
2B LD	70.80	0.00	56.3	220	−45	1.169	70.80
3B LD	14.28	0.00	54.2	300	−24	1.270	14.28
4B LD	0.00	0.00	0.0	127	−82	0.804	0.00
5B LD	0.00	0.00	61.4	240	−50	1.148	0.00
4A M/I D	354.33	0.00	57.2	524	65	1.677	354.33
5VDU HDO	437.53	334.03	56.5	588	0	1.955	103.50
6VDU HDO	222.93	0.00	56.5	537	0	1.873	222.93
TOTAL	2202.32	556.58	47.1	396	−33	1.292	1645.74
HDU 1 FEED		556.58	47.1	396	−33	1.292	

UNIT CAPACITY, 18.546 bpcd
TOTAL FEED, 556.38 mb
DAYS, 30

Table 12-28
Special Blends

STOCK	VOLUME	SG	H	CON CARBON	SG* SULFUR	SULFUR
VACUUM RESID 4A	0.00	0.9908	640	13.4	3.772	3.807
LD 3	0.00	0.8511	−19	0.0	1.123	1.319
HDU 1	6.00	0.8500	20	0.0	0.196	0.231
M/I 4A	4.00	0.8681	65	0.0	0.701	0.808
I-961	1.40	0.9795	461	15.0	3.411	3.482
TOTAL	11.40	0.87	89.95	1.84	0.77	0.832

I-892 MARINE DIESEL REQUIREMENTS, 11.15 mb
H = 90 MAX, CON CARB = 2.0 MAX, SULFUR = 1.6% MAX)

Table 12-29
Diesel Fixed Grades

GRADE	VOLUME	DI	PI	SG*SUL	SULFUR	FLASH INDEX
I-800	300	47.0	585	0.8300	0.9700	0.001
I-875	0	55.0	294	0.8200	0.9700	0.001
I-876	510	53.2	338	0.8230	0.9700	0.001
I-876ZP	0	53.2	190	0.3290	0.4000	0.001
I-885	584	51.9	365	0.4090	0.4800	0.001
I-88801	0	51.2	389	0.8280	0.9700	0.001
I-88802	0	45.6	389	0.8280	0.9700	0.001
I-88805	0	53.5	389	0.8280	0.9700	0.001
I-88803	0	51.2	446	0.8340	0.9700	0.001
I-88807	0	53.5	389	0.8280	0.9700	0.001
TOTAL	1394	51.3	402	0.6511	0.7647	0.0010

Table 12-30
Diesel Blend Pool

STREAM	AVAILABLE, mb	VOL, BLENDED, mb	DI	PI	SG* SUL	SUL	FI	H
LCGO 1	0.00	0.00	31.5	76	0.210	0.240	0.380	−83
LCGO 2	0.00	0.00	26.7	255	2.750	2.990	0.330	−50
1A LD	0.00	0.00	57.9	197	0.932	1.100	0.380	−68
2A LD	0.00	0.00	56.6	235	1.058	1.251	0.380	−37
3A LD	407.34	407.34	57.1	308	1.123	1.320	0.240	−19
4A LD	206.46	206.46	57.4	190	0.701	0.840	0.450	−76
5A LD	186.30	186.30	57.1	240	0.985	1.160	0.380	−50
1B LD	79.80	79.8	56.5	197	0.867	1.029	0.380	−72
2B LD	70.80	70.8	53.7	220	0.994	1.169	0.380	−45
3B LD	14.28	14.28	52.5	300	1.087	1.271	0.220	−24
4B LD	0.00	0	0.0	0	0.676	0.804	0.000	0
5B LD	0.00	0	61.4	240	0.974	1.148	0.380	−50
4A M/I D	354.33	354.33	51.9	524	1.456	1.677	0.000	57
VDU 5 DGO	103.50	103.5	48.7	569	1.618	1.856	0.350	0
VDU 6 DGO	222.93	222.93	50.1	531	1.579	1.817	0.350	0
LIGHT ISOMATE	393.21	393.21	38.8	450.0	0.062	0.070	0.170	25
HY CAT NAPHTHA	0.00	0	30.8	46	0.330	0.400	−1.910	−250
HDU 1 DIESEL	550.58	550.58	50.3	375	0.194	0.228	0.300	20
HDU 2 DIESEL	18.72	18.72	64	46	0.024	0.030	−1.910	−250
TOTAL	2608.25	2608.252	51.2	380	0.635	0.941	0.242	−2
FIXED GRADES		1394.00	51.32	402.47	0.65	0.76	0.00	0
I-888 POOL		1214.25	51.1	355.1	0.6	1.1	0.52	−4
KERO CUTTER		270.00	64.0	46	0.158	0.170	−1.91	−300
TOTAL I-888 POOL		1484.25	53.4	298.9	0.53	0.97	0.08	−58
SPECIFICATIONS, I-888			51.2	389	0.828	0.970	0.001	

NOTE:
FI = 144 °F FLASH INDEX

Table 12-31
Catalytic Reformer Feed

FEED	AVAILABLE, mb	VOLUME, mb	SG	BALANCE, mb
MEDIUM STRAIGHT RUN FROM CDU 4A	265.05	100.00	0.7400	165.05
HSR FROM CDU 3A	217.62	108.00	0.7331	109.62
MEDIUM CAT NAPHTHA	78.41	0.00	0.7750	78.41
OTHERS	0.00	0.00	0.0000	0.00
TOTAL CAT REFORMER FEED	561.08	208.00	0.7364	353.08

Table 12-32
Product from Cat Reformer

STREAM	FEED, mb	DAYS	TOTAL FEED, mb	YIELD, %	PRODUCT, mb	C4 VOLUME, mb	LOSS, mb
90R REFORMATE	8.00	0.00	0.00	86.10	0.00	0.00	0.00
95R REFORMATE	8.00	0.00	0.00	80.50	0.00	0.00	0.00
97R REFORMATE	8.00	26.00	208.00	76.50	159.12	0.00	48.88
TOTAL			208.00		159.12	0.00	48.88

Table 12-33
Gasoline Streams for Blending

STREAMS	AVAILABLE, mb	VOLUME BLENDED	RON	RVP	SENSITIVITY RON-MON	BALANCE
97R REFORMATE	159.12	159.12	97.20	9.00	10.10	0.00
95R REFORMATE	0.00	0.00	95.20	9.00	9.80	0.00
90R REFORMATE	0.00	0.00	90.20	9.00	8.30	0.00
LIGHT CAT NAPHTHA	304.82	304.82	89.60	9.10	11.50	0.00
MEDIUM CAT NAPHTHA	78.41	78.41	84.00	1.70	10.00	0.00
POLYMER GASOLINE	36.35	36.35	97.50	9.40	16.70	0.00
VBU NAPHTHA	16.04	16.04	63.40	8.20	7.00	0.00
LSR NAPHTHA	594.15	0.00	55.20	9.70	1.00	594.15
BUTANE	101.43	0.00	96.20	60.00	4.50	101.43
POOL	1131.20	594.74	90.67	9.71	11.12	695.58

Table 12-34
Gasoline Grade Production

GRADE	VOLUME, mb	RON	RVP, psia	SENSIBILITY RON-MON
I-383	120.00	83.20	9.20	4.50
I-385	50.00	85.20	8.60	6.20
I-390	100.00	90.20	8.90	7.30
I-393	140.00	93.20	9.40	10.00
I-397	20.00	97.20	9.00	11.50
SUBTOTAL	430.00	88.97	9.12	7.47
TOTAL GASOLINE POOL	594.74	90.67	9.71	11.12
FIXED GRADES	430.00	88.97	9.12	7.47
BALANCING GRADE I-395	164.74	95.12		

Table 12-35
JP-4 (Jet Fuel) Blending

STREAM	AVAILABLE, mb	VOLUME, mb	RVP, psia	SG	FREEZE POINT, °F	FREEZE INDEX	FR.I* VOL
LSR NAPHTHA	594.15	0.00	10.3	0.6724	−105.0	7.548	0.00
MSR NAPHTHA	754.23	52.13	1.5	0.7313	−105.0	7.548	393.46
BUTANE	101.43	2.73	60.0	0.5692	−105.0	7.548	20.61
KEROSENE	1253.43	42.13	0.0	0.7911	−40.0	61.742	2601.17
MEDIUM CAT NAPHTHA TANKAGE	0.00	0.00	1.7	0.7750	−105.0	7.548	0.00
TOTAL	2703.24	96.99	2.5	0.7527	−62.4		31.09

SPECIFICATIONS I-434 (JP-4 FUEL) JET FUEL BLENDING:
SG MIN = 0.7525
FREEZE = −50°F

Table 12-36
Kerosene Grades Production

PRODUCTION FROM CRUDE UNITS, mb	1253.43
TO DIESEL BLENDING	270.00
TO FUEL OIL BLENDING	0.00
TO INVENTORY	0.00
NET AVAILABLE FOR BLENDING	983.43
TO KEROSENE TREATERS	983.43
KEROSENE TREATER FEED RATE, mbpcd	32.78
UNTREATED KEROSENE	0.00
KERO FIXED GRADES, mb	
I-400	200.10
I-411	8.10
I-434	42.13
I-419	238.00
TOTAL, FIXED GRADES	488.33
BALANCING-GRADE KEROSENE PRODUCTION, mb	495.10

Table 12-37
Naphtha Production

STREAM	AVAILABLE, mb	VOL BLENDED, mb	RVP, psia	SG
LSR	594.15	594.15	10.3	0.6732
MSR	494.10	494.10	1.5	0.7354
HDU 2 WSR	22.74	22.74	5.4	0.7034
TOTAL POOL	1110.99	1110.99	6.3	0.7015

Table 12-38
Light Naphtha Blending

	AVAILABLE, mb	VOL BLENDED, mb	RVP, psia	SG
LSR NAPHTHA	294.00	294.00	10.3	0.6732
BUTANE	0.00	0.00	60.0	0.5692
BLEND	294.00	294.00	10.3	0.6732

Table 12-39
Whole Straight-Run (WSR) Naphtha Blending

STREAM	AVAILABLE, mb	VOL. BLENDED, mb	RVP, psia	SG
LSR NAPHTHA	300.15	300.15	10.3	0.6689
MSR NAPHTHA	494.10	494.10	1.5	0.7250
HDU 2 WSR	22.74	22.74	5.4	0.7034
INVENTORY, +/−		0.00		
SUBTOTAL	816.99	816.99	4.8	0.7038
BUTANE		25.00	60.0	0.5692
TOTAL BLEND		841.99	6.5	0.6998

Table 12-40
LPG Production and Disposition

PRODUCTION	mb
LPG PRODUCTION FROM CRUDE UNITS	101.43
FROM FCCU	31.04
FROM CAT REFORMER	0.00
TOTAL PRODUCTION	132.47
DISPOSITION	
LPG PRODUCT	25.00
TO GASOLINE BLENDING	2.73
TO NAPHTHA BLENDING	25.00
TO SPECIAL JET FUEL (JP-4)	2.73
REMAINING LPG TO REFINERY FUEL	77.01
TOTAL DISPOSITION	132.47

Table 12-41
Unit Volume Losses and Gains

UNIT	mb
LOSSES	
CRUDE UNITS	21.87
ASPHALT CONVERTER	0.23
CAT REFORMER	48.88
VISBREAKER UNIT	2.38
TOTAL	73.36
UNIT GAINS	
FCCU	21.03
MILD HYDROCRACKER	39.07
TOTAL VOLUME GAIN	60.10
NET LOSSES	13.26

Table 12-42
Estimated Overall Material Balance

	mb	DOP* REQUIREMENT
FEED		
LIGHT ARABIAN CRUDE	6030.00	6030.00
BAHRAIN CRUDE	1260.00	1260.00
MURBAN CRUDE	0.00	0.00
DUBAI CRUDE	0.00	0.00
TOTAL CRUDE	7290.00	7290.00
PRODUCTS		
LPG	25.00	25.00
LIGHT NAPHTHA	294.00	
WSR NAPHTHA	841.99	
GASOLINES		
I-383	120.00	120.00
I-385	50.00	50.00
I-390	100.00	100.00
I-393	140.00	140.00
I-397	20.00	20.00
I-395 (BALANCING GRADE)	164.74	
TOTAL GASOLINES	594.74	430.00
KEROSENES		
I-400	200.10	200.10
I-411	8.10	8.10
I-434	96.99	96.99
I-419	238.00	238.00
I-440 (BALANCING GRADE)	495.10	
GROSS KEROSENE PRODUCTION	1038.29	
KEROSENE TO DIESEL BLENDING	270.00	
KEROSENE PRODUCTION	768.29	543.19
DIESELS		
I-800	300.00	300.00
I-875	0.00	
I-876	510.00	510.00
I-876ZP	0.00	
I-885	584.00	584.00
I-888 (BALANCING GRADE)	1484.25	
I-892	11.40	11.40
GROSS DIESEL	2889.65	
DIESEL TO FUEL OIL BLENDING	210.00	
DIESEL PRODUCTION	2679.65	1405.40
FUEL OILS		
I-925	0.00	
I-928	360.00	360.00
I-934	0.00	
I-933	0.00	
I-957	0.00	
I-957LS	0.00	
I-960	0.00	
I-962	0.00	
I-964	0.00	
I-971	135.00	135.00
I-961 (80 cst)	0.00	
I-961 (BALANCING GRADE)	1325.00	
TOTAL FUEL OIL	1820.00	495.00
ASPHALT	90.00	90.00
TOTAL PRODUCTS	7113.67	
INTERMEDIATE STOCKS, INVENTORY CHANGES**		
90R REFORMATE	0.00	
95R REFORMATE	0.00	
97R REFORMATE	0.00	
LIGHT CAT NAPHTHA	0.00	
MEDIUM CAT NAPHTHA	0.00	
HEAVY CAT NAPHTHA	0.00	
POLYMER GASOLINE	0.00	
HSR NAPHTHA	0.00	
KEROSENE BASE STOCK	0.00	
DIESEL	0.00	
LVGO (4 M/I DIESEL)	0.00	
HDU LIGHT DIESEL	0.00	
LIGHT ISOMATE	0.00	
MED ISOMATE	49.19	
HEAVY ISOMATE	0.00	
FCC CUTTER	0.00	
6VDU FEED/ATM RESID	0.00	
HVGO	94.57	
VACUUM RESID	0.00	
TOTAL	143.76	
TOTAL OUTPUT	7257.43	
LIQUID RECOVERY	99.55%	

*DOP REQUIREMENTS REFER TO CRUDE RUN AND FIXED GRADES ONLY.
*POSITIVE INVENTORY CHANGES INDICATE BUILDUP OF INVENTORY AND NEGATIVE INVENTORY CHANGES INDICATE DRAWDOWN FROM INVENTORY.

NOTES

1. J. R. White. "Use Spreadsheets for Better Refinery Operation." *Hydrocarbon Processing* (October 1986), p. 49. "Linear Programming Optimisation of Refinery Spreadsheets" *Hydrocarbon Processing* (November 1987), p. 90.