CHAPTER FIFTEEN

# Definitive Operating Plan

Before the start of an operating period, usually a month, the planner submits an operating plan, termed the *definitive operating plan* (DOP), to the refinery Operations Department, defining how the refinery is to be run during the month.

The DOP for a given month contains information on the following:

1. The crude oils to be processed during the month and their quantities.
2. Product grades and the quantities to be produced during the month.
3. Intermediate stocks to be drawn from the inventory to make the refinery's product slate.
4. Inventory of intermediate stocks to be built up during the month.
5. Process unit capacities available, based on the refinery's latest shutdown schedule and estimated process unit capacities utilized to make the product slate.
6. Composition of feed to all conversion units.
7. Product prices of the balancing-grade products and energy price used to optimize product blending.
8. Blending instructions for critical stocks, where alternate blending is possible.
9. Additives to be used for blending products and their estimated consumption. Only additives used for product blending (for example, dyes for gasoline, antistatic and anti-icing additives for jet fuels, pour point depressants for diesels) must be listed.
10. Expected production rate for all product groups during the month.

The DOP is prepared using a refinery linear programming model. Refinery material balance spreadsheet programs can also be used, but LP models are preferred as no product blending optimization is possible with spreadsheet programs. The first step in preparing the DOP for a given month is to update the refinery LP model by incorporating the following:

- *Refinery crude run.* The crude processing rate is estimated from the total crude to be run during the month.
- *Available processing units' capacity.* Every refinery processing unit has an agreed-on minimum and maximum nominal capacity in mb (thousand barrels) per stream day. The data are based on previous test runs on the unit. Also, the refinery maintains a unit shutdown schedule for the next 12 or more months to perform routine maintenance, major repairs, catalyst change or regeneration, and the like. This document is constantly updated. Thus, from the latest shutdown schedule, it is possible to find out as to how many days during the month a given unit would be available to process feedstock. From such data, two on-stream factors (OSF) are worked out:

$$\text{OSF1} = (\text{number of days unit is likely to be available})/(\text{total number of days in the month})$$

  Here, OSF is the on-stream factor for scheduled maintenance. To take into account unit unavailability due to possible unscheduled shutdowns, another factor (OSF2) is used. This is based on the past experience in operating the unit.

$$\text{Available (max) unit capacity} = \text{nominal max capacity} \times \text{OSF1} \times \text{OSF2}$$

  For example, if the nominal throughput of a unit is 50 mbpd, OSF1 is 0.70, and OSF2 is 0.985, available unit capacity $= 50 \times 0.7 \times 0.985$, or 34.475 mb per stream days during the month.
- *Product grades to be made during the month and their quantities.* This is based on the expected shipment of products during the month. The schedule of ships likely to arrive at the refinery marine terminal and the product to be loaded on them is known several weeks ahead of their actual arrival. Keeping in view the product

inventory likely to be available in refinery tanks, the production rates of all fixed product grades are worked out to meet the expected shipments. As the crude rate is already fixed, any blending stocks left after blending fixed grades is blended into balancing-grade products for spot sale by the refinery.

- *Product prices for all balancing-grade products.* The LP model optimize the production of balancing-grade products based on their prices. Prices are entered only for balancing-grade products whose production is not fixed. The LP optimizes the production of balancing-grade products based on their prices and maximizes refinery profit at the same time.
- *Updated specifications for all product to be made.* Although the LP model has built-in data on all product grades the refinery usually produces, updating may be necessary if the specifications for a product grade to be made are different.
- *Updated blend map.* Every LP model has a blend map that specifies which blend streams are to be allowed in blending a product grade. For example, if a refinery has a surplus heavy vacuum gas oil (HVGO) after meeting the requirements of conversion units, the model would dump all surplus HVGO in fuel oil. Disallowing HVGO in fuel oil in the blending map forces the LP to produce HVGO as an export stream.
- *Buildup or drawdown of intermediate and process stocks from inventory.* Inventories of all process stocks are closely monitored and regulated. Drawdown of intermediate or process stocks is done to ensure that processing units run to their full capacity or to meet given product demand. Buildup of stocks is sometimes done to ensure adequate stock ahead of a large shipment. For example, a refinery may build up reformate stock ahead of a large gasoline shipment or buildup HVGO ahead of a large export shipment of HVGO.

The format of an actual refinery DOP is shown in Table 15-1. The crude to be processed and product produced in the DOP become the refinery targets for the month (see Table 15-2). Also, feed rates and composition of all conversion units is kept close to DOP figures. If a product grade requires additives, such as military jet fuels, these are specified in the DOP and the refinery follows these directions while blending such products.

## Table 15-1
## Definitive Operating Plan of a Refinery

| | bpcd | mb |
|---|---|---|
| CRUDE RUN | | |
| ARAB LIGHT CRUDE | 201000 | 6030 |
| BAHRAIN CRUDE | 42000 | 1260 |
| CONDENSATE IMPORT | 3600 | 108 |
| TOTAL | 246600 | 7398 |
| INTERMEDIATE STOCK INVENTORY CHANGES | | |
| LIGHT CAT NAPHTHA | −2000 | −60 |
| POLYMER GASOLINE | −1000 | −30 |
| CAT REFORMATE 90R | −600 | −18 |
| CAT REFORMATE 95R | −2000 | −60 |
| TOTAL | −5600 | −168 |
| PRODUCTION GRADES | | |
| I-150 LPG | 600 | 18 |
| LIGHT NAPHTHA | 3600 | 108 |
| I-210 W.S.R.NAPHTHA | 39483 | 1184 |
| I-220 LIGHT NAPHTHA | 29 | 1 |
| I-390 GASOLINE 90R | 2560 | 77 |
| I-395 GAS 95 R | 0 | 0 |
| I-397L GAS 97 R | 19951 | 599 |
| I-398E GAS 98 R | 1470 | 44 |
| I-419 DUAL-PURPOSE KEROSENE | 14000 | 420 |
| JP-4 | 8000 | 240 |
| I-440 KEROSENE JET A-1 | 24301 | 729 |
| I-800 +6 POUR DIESEL | 14000 | 420 |
| I-876 −3 POUR DIESEL | 10000 | 300 |
| I-876ZP −18 POUR DIESEL | 8000 | 240 |
| I-885 −3 POUR, 0.5S DIESEL | 0 | 0 |
| I-888 −3 POUR 1%S DIESEL | 47098 | 1413 |
| I-928 2.8 %S 180 cst FO | 12000 | 360 |
| I-961 3.5 %S, 180 cst FO | 43513 | 1305 |
| I-1138 ASPHALT | 3553 | 107 |
| TOTAL | 252158 | 7565 |

NOTES:
MONTH = APRIL 2000
NEGATIVE ENTRY IN THE TABLE INDICATES A DRAWDOWN.
POSITIVE ENTRY INDICATES A BUILDUP OF STOCK.

**(DOP continued)**

**Table 15-2**
**Unit Capacity Utilization**

| UNITS | TOTAL AVAILABLE CAPACITY, bpcd | TOTAL UTILIZED bpcd | %UTILIZED bpcd |
|---|---|---|---|
| CRUDE UNITS 1–5 | 243000 | 243000 | 100.00% |
| VACUUM UNITS 1, 5, 6 | 95000 | 92108 | 96.96% |
| KEROSENE RERUN UNIT | 15421 | 15421 | 100.00% |
| VISBREAKER | 20000 | 19173 | 95.87% |
| ASPHALT CONVERTER | 4800 | 2961 | 61.69% |
| KEROSENE TREATING UNIT | 45000 | 41987 | 93.30% |
| No. 1 HDU DIESEL HDS | 20000 | 19998 | 99.99% |
| No. 2 HDU, HYDROCRACKER | 50000 | 49005 | 98.01% |
| FCCU | 39000 | 37833 | 97.01% |
| CAT REFORMER | 15000 | 3625 | 24.17% |

NOTES:
THE MODEL BLENDS WSR (WHOLE STRAIGHT RUN) TO SG = 0.6918
DISPOSITION OF CRITICAL STOCKS:

| | | bpcd | mb |
|---|---|---|---|
| HEAVY CAT NAPTHA TO | MOGAS | 0 | 0 |
| | DIESEL | 863 | 25.89 |
| | FUEL | 1358 | 40.74 |
| | TOTAL | 2221 | 66.63 |
| KEROSENE TO | DIESEL | 2351 | 70.53 |
| | FUEL | 0 | 0 |
| LCGO TO | HDU 1 | 6463 | 193.89 |
| LIMITING SPECS | | DIESEL | DI/SULFUR |
| | | FUEL | VISCOSITY |
| FCCU FEED COMPOSITION | | | |
| | MEDIUM/HEAVY ISOMATE | | 91% |
| | FRESH FEED (HVGO) | | 9% |
| | VACUUM RESID | | 0% |
| | TOTAL | | 100% |

The refinery prepares its own estimates of production rates, based on a refinery spreadsheet model and revised every week on the basis of refinery operating conditions. At the end of the month, the total crude processed should be close to that stipulated in the DOP. The product produced would, of course, be different because of the following:

- Blending of products in the refinery is done to meet specific shipments and not to maximize profit, as in the LP.
- Production rates of blend stocks can be different from that in the LP due to unscheduled shutdown of a processing unit, or yields and properties may be different due to a change in the operating conditions of a processing unit.

## DOPS IN JOINT-OWNERSHIP REFINERIES

In joint-ownership refineries, the crude distillation unit (CDU) and downstream processing unit capacities are split between the two participants in the ratio of their equity in the refinery. Thus, the refinery is divided into two "virtual" refineries. Each participant is free to utilize its share of the refinery as it wishes.

In joint-ownership refineries, each participant prepares a DOP for its share of refinery capacity, stating the crude to be processed during the month and product to be produced. The DOP format is identical to that for single-ownership refineries.

To ensure that the participant DOPs are on a common basis, a reference LP model of the refinery is prepared by the refinery, reflecting the total CDU and process unit capacities likely to be available to the participants during the month, taking into account the refinery's shutdown schedule. Process yields and utilities, catalyst, and chemical consumption for all units; product qualities of all streams; and product specifications are updated, if required. The driving force behind the LP is product price for the agreed-on balancing grades, which are usually the mean of Platt published price (MOP) for each product prevailing during the previous month.

Two LP models are prepared from the reference refinery model by incorporating the unit capacity available to each participant as though these were independent refineries. Each participant updates its refinery model for preparation of its DOP by incorporating the following data:

1. The anticipated crude run during the month and any process stock drawn down or built up to meet its product slate.
2. The product grades and quantities it wishes to make during the month.
3. The maximum and minimum unit capacity of each processing unit available during the month, taking into account unit shutdowns, if any.

The LP model is run and the results of the LP feasible and optimum run are incorporated in the DOP.

## REFINERY DOP

The refinery combines the two DOPs to make a refinery DOP before the start of the month. Examples of participant DOPs and combined refinery DOP is shown in Tables 15-3 to 15-8. The combined DOP becomes the

**Table 15-3**
**DOP of Participant AOC**

| | bpcd | mb | % |
|---|---|---|---|
| FEED STOCKS | | | |
| ARABIAN LIGHT CRUDE | 161000 | 4,830.0 | |
| BAHRAIN CRUDE | 42000 | 1,260.0 | |
| TOTAL CRUDE | 203000 | 6,090.0 | |
| INTERMEDIATE STOCK INVENTORY CHANGES | | | |
| LIGHT CAT NAPHTHA | −2000 | | |
| POLYMER GASOLINE | −1000 | | |
| REFORMATE 95R | −2000 | | |
| REFORMATE 90R | −600 | | |
| TOTAL REFINERY FEED | 208600 | 6,258.0 | |
| FINISHED PRODUCTS | | | |
| I-150 LPG | 600 | 18.0 | 0.29 |
| I-201 LSR | 0 | 0.0 | 0.00 |
| I-210 WSR | 31845 | 955.4 | 15.26 |
| I-220 LSR | 0 | 0.0 | 0.00 |
| I-390 GASOLINE | 2560 | 76.8 | 1.23 |
| I-395 GASOLINE | 0 | 0.0 | 0.00 |
| I-397L GASOLINE | 17242 | 517.3 | 8.26 |
| I-398E GASOLINE | 1470 | 44.1 | 0.70 |
| I-419 DUAL KEROSENE | 14000 | 420.0 | 6.71 |
| I-434 JP-4 | 8000 | 240.0 | 3.83 |
| I-440 JET A-1 | 17401 | 522.0 | 8.34 |
| I-800 1.0%S +6 POUR | 14000 | 420.0 | 6.71 |
| I-876 1.0%S −6 POUR | 10000 | 300.0 | 4.79 |
| I-876ZP 0.4%S −18 POUR | 8000 | 240.0 | 3.83 |
| I-885 .5%S | 0 | 0.0 | 0.00 |
| I-888 1.0%S −3 POUR | 33348 | 1000.4 | 15.99 |
| I-928 2.8%S 180 CST | 12000 | 360.0 | 5.75 |
| I-961 3.5%S 180 CST | 36153 | 1084.6 | 17.33 |
| I-1138 BULK ASPHALT | 2000 | 60.0 | 0.96 |
| TOTAL PRODUCTS | 208619 | 6258.6 | 100.00 |
| LIQUID RECOVERY | 100.01% | | |

**(DOP of Participant AOC continued)**

**Table 15-4**
**Unit Capacity Utilization of Participant AOC**

| UNITS | AVAILABLE, bpcd | UTILIZED, bpcd | UTILIZED, mb | UTILIZED, % |
|---|---|---|---|---|
| CRUDE UNITS | 203000 | 203000 | 6,090.0 | 100.0% |
| VACUUM UNITS | 82086 | 76408 | 2,292.2 | 93.1% |
| NO.6 KEROSENE RERUN | 23809 | 10521 | 315.6 | 44.2% |
| VISBREAKER | 15873 | 15873 | 476.2 | 100.0% |
| ASPHALT CONVERTER | 3968 | 1265 | 38.0 | 31.9% |
| KEROSENE TREATING | 35087 | 35087 | 1,052.6 | 100.0% |
| HDU NO. 1 | 16708 | 16708 | 501.2 | 100.0% |
| HDU NO. 2 | 40935 | 40935 | 1,228.1 | 100.0% |
| FCCU | 31603 | 31603 | 948.1 | 100.0% |
| CAT REFORMER | 14285 | 2984 | 89.5 | 20.9% |

NOTES:
THE MODEL BLENDS WSR TO SG 0.6917
DISPOSITION OF CRITICAL STOCKS:

| | | bpcd | mb |
|---|---|---|---|
| HEAVY CAT NAPHTHA | MOGAS | 0 | 0.0 |
| | DIESEL | 793 | 23.8 |
| | FUEL | 1206 | 36.2 |
| | | 1999 | 60.0 |
| KEROSINE TO | DIESEL | 1981 | 59.4 |
| | FUEL | 0 | 0.0 |
| LCGO TO | 1HDU | 5255 | 157.7 |
| LIMITING SPECS | DIESEL | DI/SULFUR | |
| | FUEL | VISCOSITY | |

FCCU FEED COMPOSITION

| | |
|---|---|
| MEDIUM/HEAVY ISOMATE | 92.35% |
| FRESH FEED (HVGO) | 7.65% |
| 4 A VACUUM RESID | 0.00% |
| | 100.00% |

operating plan of the refinery, and the Joint Operating Committee (JOC) tries to run the refinery as close as possible to that plan. In case of any unscheduled shutdown of a major process unit or other emergency, like a major storage tank out of service or problem at marine or shipping terminal, the JOC can ask the participants to resubmit their DOPs after taking into consideration the latest situation.

In joint-ownership refineries, participants DOPs, apart from serving as a refinery operating plan, are used as the basis of product allocation, or establishing the ownership of stocks. The mechanism of product allocation is explained later on in the book. The concepts of fixed- and balancing-grade products, used both in the LP models for DOP and product allocation, is explained here. Fixed-grade product equivalencies are used later in the product allocation program.

**Table 15-5**
**DOP of Participant BOC**

| | bpcd | mb | % |
|---|---|---|---|
| FEED STOCKS | | | |
| ARABIAN LIGHT CRUDE | 40000 | 1,200.0 | |
| BAHRAIN CRUDE | 0 | 0.0 | |
| CONDENSATE IMPORT | 3600 | 108.0 | |
| TOTAL CRUDES | 43600 | 1,308.0 | |
| INITIAL STOCK INVENTORY CHANGES | | | |
| STOCK | | | |
| LIGHT CAT NAPHTHA | 0 | | |
| POLYMER GASOLINE | 0 | | |
| REFORMATE 95R | 0 | | |
| REFORMATE 90R | 0 | | |
| TOTAL REFINERY FEED | 43600 | 1,308.0 | |
| FINISHED PRODUCTS | | | |
| I-150 LPG | 0 | 0.0 | 0.00 |
| I-201 LSR | 3600 | 108.0 | 8.27 |
| I-210 WSR | 7638 | 229.1 | 17.54 |
| I-220 LSR | 29 | 0.9 | 0.07 |
| I-390 GASOLINE | 0 | 0.0 | 0.00 |
| I-395 GASOLINE | 0 | 0.0 | 0.00 |
| I-397L GASOLINE | 2709 | 81.3 | 6.22 |
| I-398E GASOLINE | 0 | 0.0 | 0.00 |
| I-419 DUAL KEROSENE | 0 | 0.0 | 0.00 |
| I-434 JP-4 | 0 | 0.0 | 0.00 |
| I-440 JET A-1 | 6900 | 207.0 | 15.85 |
| I-800 1.0%S +6 POUR | 0 | 0.0 | 0.00 |
| I-876 1.0%S −6 POUR | 0 | 0.0 | 0.00 |
| I-876ZP 0.4%S −18 POUR | 0 | 0.0 | 0.00 |
| I-885 .5% S | 0 | 0.0 | 0.00 |
| I-888 1.0%S −3 POUR | 13750 | 412.5 | 31.58 |
| I-928 2.8%S 180 CST | 0 | 0.0 | 0.00 |
| I-961 3.5%S 180 CST | 7360 | 220.8 | 16.90 |
| I-1138 BULK ASPHALT | 1553 | 46.6 | 3.57 |
| TOTAL PRODUCTS | 43539 | 1306.17 | 100.00 |
| LIQUID RECOVERY | 99.86% | | |

**(DOP of Participant BOC continued)**

**Table 15-6**
**Unit Capacity Utilization of Participant BOC**

| UNITS | AVAILABLE, bpcd | UTILIZED, bpcd | UTILIZED, mb | UTILIZED, % |
|---|---|---|---|---|
| CRUDE UNITS 1–5 | 40000 | 40000 | 1,200.0 | 100.0% |
| VACUUM UNITS 1, 5, 6 | 15700 | 15700 | 471.0 | 100.0% |
| KEROSENE RERUN NO. 6 | 4900 | 4900 | 147.0 | 100.0% |
| VISBREAKER | 3300 | 3300 | 99.0 | 100.0% |
| ASPHALT CONVERTER | 4800 | 1696 | 50.9 | 35.3% |
| KEROSENE TREATING | 6900 | 6900 | 207.0 | 100.0% |
| HDU NO. 1 | 3290 | 3290 | 98.7 | 100.0% |
| HDU NO. 2 | 8070 | 8070 | 242.1 | 100.0% |
| FCCU | 6230 | 6230 | 186.9 | 100.0% |
| CAT REFORMER | 2800 | 641 | 19.2 | 22.9% |

NOTES:
DISPOSITION OF CRITICAL STOCKS:

| | | | bpcd | mb |
|---|---|---|---|---|
| HEAVY CAT NAPHTHA TO | MOGAS | | 0 | 0.0 |
| | DIESEL | | 70 | 2.1 |
| | FUEL | | 152 | 4.6 |
| | | | 222 | 6.7 |
| KEROSINE TO | DIESEL | | 370 | 11.1 |
| | FUEL | | 0 | 0.0 |
| LIGHT CYCLE GAS OIL TO | 1HDU | | 1208 | 36.2 |
| LIMITING SPECS | DIESEL | D.I. | | |
| | FUEL | VISCOSITY | | |
| FCCU FEED COMPOSITION | | | V/V | |
| MEDIUM/HEAVY ISOMATE | | | 90.00% | |
| FRESH FEED (HVGO) | | | 10.00% | |
| VACUUM RESID | | | 0.00% | |
| | | | 100.00% | |

**Table 15-7**
**Combined DOP of Participants**

| | AOC, bpcd | BOC, bpcd | TOTAL, bpcd | TOTAL, mb |
|---|---|---|---|---|
| **PRODUCTION GRADE** | | | | |
| I-150 | 600 | 0 | 600 | 18.0 |
| I-201 | 0 | 3600 | 3600 | 108.0 |
| I-210 | 31845 | 7638 | 39483 | 1184.5 |
| I-220 | 0 | 29 | 29 | 0.9 |
| I-390 | 2560 | 0 | 2560 | 76.8 |
| I-395 | 0 | 0 | 0 | 0.0 |
| I-397L | 17242 | 2709 | 19951 | 598.5 |
| I-398E | 1470 | 0 | 1470 | 44.1 |
| I-419 | 14000 | 0 | 14000 | 420.0 |
| I-434 | 8000 | 0 | 8000 | 240.0 |
| I-440 | 17401 | 6900 | 24301 | 729.0 |
| I-800 | 14000 | 0 | 14000 | 420.0 |
| I-876 | 10000 | 0 | 10000 | 300.0 |
| I-876ZP | 8000 | 0 | 8000 | 240.0 |
| I-885 | 0 | 0 | 0 | 0.0 |
| I-888 | 33348 | 13750 | 47098 | 1412.9 |
| I-928 | 12000 | 0 | 12000 | 360.0 |
| I-961 | 36153 | 7360 | 43513 | 1305.4 |
| I-1138 | 2000 | 1553 | 3553 | 106.6 |
| TOTAL | 208619 | 43539 | 252158 | 7564.7 |
| **INTERMEDIATE STOCK CHANGES** | | | | |
| LCN | −2000 | 0 | −2000 | −60.0 |
| CPOR | −1000 | 0 | −1000 | −30.0 |
| CR90 | −600 | 0 | −600 | −18.0 |
| CR95 | −2000 | 0 | −2000 | −60.0 |
| TOTAL | −5600 | 0 | −5600 | −168.0 |

NOTES:
NEGATIVE ENTRY IN THE TABLE INDICATES A DRAWDOWN.
POSITIVE ENTRY INDICATES A BUILDUP OF STOCK.

| **CRUDE RUN** | **AOC bpcd** | **BOC bpcd** | **TOTAL bpcd** |
|---|---|---|---|
| ARABIAN LIGHT | 161000 | 40000 | 201000 |
| BAHRAIN | 42000 | 0 | 42000 |
| CONDENSATE IMPORT | 0 | 3600 | 3600 |
| TOTAL | 203000 | 43600 | 246600 |

**Table 15-8**
**Combined Unit Capacity Utilization**

| UNITS | TOTAL AVAILABLE, bpcd | UTILIZED AOC, bpcd | UTILIZED BOC, bpcd | TOTAL UTILIZED, bpcd | UTILIZED, bpcd% |
|---|---|---|---|---|---|
| CRUDE UNITS 1–5 | 243000 | 203000 | 40000 | 243000 | 100.0 |
| VACUUM UNITS 1, 5, 6 | 95000 | 76408 | 15700 | 92108 | 97.0 |
| NO. 6 KEROSENE RERUN | 15421 | 10521 | 4900 | 15421 | 100.0 |
| VISBREAKER | 20000 | 15873 | 3300 | 19173 | 95.9 |
| ASPHALT CONVERTER | 4800 | 1265 | 1696 | 2961 | 61.7 |
| KEROSENE TREATING | 45000 | 35087 | 6900 | 41987 | 93.3 |
| HDU NO. 1 | 20000 | 16708 | 3290 | 19998 | 100.0 |
| HDU NO. 2 | 50000 | 40935 | 8070 | 49005 | 98.0 |
| FCCU | 39000 | 31603 | 6230 | 37833 | 97.0 |
| CAT REFORMER | 15000 | 2984 | 641 | 3625 | 24.2 |

NOTES: THE MODEL BLENDS WSR to S.G. = 0.6918
DISPOSITION OF CRITICAL STOCKS:

| | | bpcd | mb |
|---|---|---|---|
| HEAVY CAT NAPTHA TO | MOGAS | 0 | 0 |
| | DIESEL | 863 | 25.89 |
| | FUEL | 1358 | 40.74 |
| | TOTAL | 2221 | 66.63 |
| KEROSENE TO | DIESEL | 2351 | 70.53 |
| | FUEL | 0 | 0 |
| LCGO TO | 1HDU | 6463 | 193.89 |
| LIMITING SPECS | | DIESEL | DI/SULFUR |
| | | FUEL | VISCOSITY |

| FCCU FEED COMPOSITION | |
|---|---|
| MEDIUM/HEAVY ISOMATE | 91% |
| FRESH FEED (HVGO) | 9% |
| VACUUM RESID | 0% |
| TOTAL | 100% |

## EXAMPLE 15-1

A joint ownership refinery has processing unit capacities as follows. Participant AOC has a 60% share of the refinery and Participant BOC has a 40% share of the refinery. Estimate the maximum crude the two participants can process within their capacity rights.

Crude distillation units = 200 mbpcd
Catalytic reformer = 20 mbpcd
FCCU = 40 mbpcd
Distillate hydrocracker = 50 mbpcd

The processing unit capacities available to each participant for processing their feed stock follows next:

| PROCESSING UNIT | REFINERY CAPACITY | AOC, 60% | BOC, 40% |
|---|---|---|---|
| CRUDE DISTILLATION UNITS | 200 mbpcd | 120 | 80 |
| CATALYTIC REFORMER | 20 mbpcd | 12 | 8 |
| FCCU | 40 mbpcd | 24 | 16 |
| DISTILLATE HYDROCRACKER | 50 mbpcd | 30 | 20 |

The maximum crude run of a participant is dictated by the crude unit capacity available to it. Therefore, the maximum crude run by participant company AOC is 120 mbpcd. Also, process unit capacities utilized for processing this crude must not exceed the capacities available to it.

## FIXED- AND BALANCING-GRADE PRODUCTS

Refinery products grades may be divided into two categories: fixed grades and balancing grades. Fixed grades are those products produced to meet a definite export commitment. The volumes required and product specifications are known before beforehand (see Table 15-9), and these are blended first. The balance of blending components in a product group, after meeting fixed grades demand, is blended to a balancing-grade specification. Balancing-grade production cannot be fixed. It depends on the volumes and specifications of fixed grades as well as its own product specification.

One grade in every product group (naphtha, gasoline, kerosene, diesel, fuel oil, etc.) is nominated as the balancing grade. In participants' DOPs, the production of balancing grades is optimized based on their price.

For the operation of the joint refinery, each participant can have different product specifications for its fixed grades that give it the flexibility to produce products to suit its market requirements. It is essential, however, that both participants have common balancing-grade products.

**Table 15-9**
**Refinery Product Grades**

| GRADE | PRODUCT GROUP | KEY SPECIFICATIONS |
|---|---|---|
| **I-150*** | **LPG** | **RVP** 275 – 690 **KPA** |
| I-151 | LPG | RVP 485 MAX |
| **I-201*** | **LSR NAPHTHA** | **LSR, RVP 95 KPA MAX., SG MIN 0.654** |
| I-220 | LSR NAPHTHA | LSR, RVP 95 KPA MAX., SG MIN 0.654-0.702 |
| I-222 | LSR NAPHTHA | LSR, RVP 95 KPA MAX., SG MIN 0.654-0.702 |
| I-206 | NAPHTHA | WSR, RVP 80 KPA, SG 0.702 MAX. |
| **I-210*** | **NAPHTHA** | **WSR, RVP 75 KPA, SG 0.69 – 0.735 MAX.** |
| I-211 | NAPHTHA | WSR, RVP 75 KPA, SG 0.70 – 0.735 MAX. |
| I-213 | NAPHTHA | WSR, RVP 65 KPA MAX. |
| I-253 | GASOLINE | FCCU LIGHT NAPHTHA, RON 88 MIN, RVP 70 MAX. |
| I-387 | GASOLINE | RON 87, RVP 75 MAX. |
| I-390 | GASOLINE | RON 90, RVP 70 MAX. |
| I-393 | GASOLINE | RON 93, RVP 75 MAX. |
| I-395 | GASOLINE | RON 95, RVP 65 MAX. |
| **I-397*** | **GASOLINE** | **RON 97, RVP 85 MAX.** |
| I-400 | KEROSENE | ILLUMINATING KERO, SMOKE 21, FLASH 35 0C MIN. |
| I-411 | KEROSENE | ILLUMINATING KERO, SMOKE 25, FLASH 35 MIN. |
| I-419 | KEROSENE | DPK, 38°C FLASH, −47°C FREEZE. |
| I-434 | KEROSENE | JP-4, −58°C FREEZE, 25 VOL % AROMATICS. |
| **I-440*** | **KEROSENE** | **JET FUEL, 25 SMOKE, −47°C FREEZE** |
| I-710 | HVGO | HEAVY LUBE DISTILLATE, VISCOSITY 14 CST AT 100°C |
| I-711 | HVGO | HVGO, VIS. 6–9 CST AT 100°C |
| I-725 | HVGO | FCCU CHARGE STOCK, SULFUR MAX 3.0% |
| I-800 | DIESEL | DIESEL INDEX 45, POUR + 6°C |
| I-803 | DIESEL | CETANE INDEX 45, CLOUD POINT 3°C |
| I-808 | DIESEL | CETANE INDEX 50, CLOUD POINT 2°C |
| I-875 | DIESEL | CETANE INDEX 47, CLOUD POINT −4°C |
| I-876 | DIESEL | CETANE INDEX 46, CLOUD POINT −1°C |
| I-876Z | DIESEL | CETANE INDEX 46, CLOUD POINT −12°C |
| I-884 | DIESEL | CETANE INDEX 47, CLOUD POINT −6°C |
| I-885 | DIESEL | CETANE INDEX 50, POUR −3°C, 0.5% SULFUR |
| **I-888*** | **DIESEL** | **CETANE INDEX 50, POUR** −3°C |
| I-890 | MARINE DSL | CETANE INDEX 45, POUR −9°C |

NOTE:
AN ASTERISK (*) DENOTES BALANCING GRADE PRODUCTS.

**Table 15-9**
**Continued**

| | | |
|---|---|---|
| I-892 | MARINE DSL | CETANE INDEX 43, POUR 3°C, 2% CON CARBON |
| I-893 | MARINE DSL | CETANE INDEX 45, POUR −9°C, 0.08% CON CARBON |
| I-903 | FUEL OIL | VISCOSITY 80 CST AT 50°C, 0.3% SULFUR |
| I-925 | FUEL OIL | VISCOSITY 180 CST AT 50°C, 2.5% SULFUR |
| I-928 | FUEL OIL | VISCOSITY 180 CST AT 50°C, 2.8% SULFUR |
| I-933 | FUEL OIL | VISCOSITY 80 CST AT 50°C, 3.5% SULFUR |
| I-934 | FUEL OIL | VISCOSITY 120 CST AT 50°C, 3.0% SULFUR |
| I-955 | FUEL OIL | VISCOSITY 75 CST AT 50°C, 3.5% SULFUR |
| I-957 | FUEL OIL | VISCOSITY 225 CST AT 50°C, 3.5% SULFUR |
| I-960 | FUEL OIL | VISCOSITY 120 CST AT 50°C, 3.5% SULFUR |
| **I-961*** | **FUEL OIL** | **VISCOSITY 180 CST AT 50°C, 3.5% SULFUR** |
| I-962 | FUEL OIL | VISCOSITY 280 CST AT 50°C, 3.5% SULFUR |
| I-963 | FUEL OIL | VISCOSITY 180 CST AT 50°C, 3.8% SULFUR |
| I-964 | FUEL OIL | VISCOSITY 140 CST AT 50°C, 3.5% SULFUR |
| I-965 | FUEL OIL | VISCOSITY 280 CST AT 50°C, 3.5% SULFUR |
| I-966 | FUEL OIL | VISCOSITY 280 CST AT 50°C, 4.0% SULFUR |
| I-967 | FUEL OIL | VISCOSITY 180 CST AT 50°C, 3.5% SULFUR |
| I-971 | FUEL OIL | VISCOSITY 380 CST AT 50°C, 4.0% SULFUR |
| I-975 | FUEL OIL | VISCOSITY 530 CST AT 50°C, 3.5% SULFUR |
| I-1110B | ASPHALT | BULK ASPHALT, PENETRATION 180–220 |
| I-1110D | ASPHALT | DRUMMED ASPHALT, PENETRATION 180–220 |
| I-1129B | ASPHALT | BULK ASPHALT, PENETRATION 85–100 |
| I-1129D | ASPHALT | DRUMMED ASPHALT, PENETRATION 85–100 |
| I-1138B | ASPHALT | BULK ASPHALT, PENETRATION 60–70 |
| I-1138D | ASPHALT | DRUMMED ASPHALT, PENETRATION 60–70 |
| I-1149B | ASPHALT | BULK ASPHALT, PENETRATION 40–50 |
| I-1149D | ASPHALT | DRUMMED ASPHALT, PENETRATION 40–50 |

| GRADE/CODE | PROCESS STOCK |
|---|---|
| PGAS | GASOLINE BASE STOCK |
| PLCGAS | TREATED LIGHT CAT NAPHTHA |
| PLLCN | UNTREATED LIGHT CAT NAPHTHA |
| PLSRBS | LSR UNTREATED |
| PMSR | UNTREATED MEDIUM ST. RUN NAPHTHA |
| PP90R | CAT REFORMATE, 90 RON |
| PP95R | CAT REFORMATE, 95 RON |
| PP97R | CAT REFORMATE, 97 RON |
| PSMCN | SWEET MEDIUM CAT NAPHTHA |
| PSWMSR | TREATED MSR NAPHTHA |
| PPOLY | RAW POLYMER GASOLINE |
| PUFCHG | UNIFINER CHARGE |
| PWCN | WHOLE CAT NAPHTHA |

**Table 15-9**
**Continued**

| GRADE/CODE | PROCESS STOCK |
|---|---|
| PSKERO | SWEET KEROSENE DISTILLATE |
| PDSDSL | DESULFURISED DIESEL STOCK |
| PDSL | UNTREATED DIESEL STOCK |
| PLTISO | LIGHT DIESEL EX HYDROCRACKER |
| PMIDSL | MEDIUM/INTER DIESEL STOCK |
| PBFUEL | BURNER FUEL OIL |
| PCTISO | DESULFURISED HVGO EX MILD HYDROCRACKER |
| PCTTR | FUEL OIL CUTTER STOCK |
| PFCCF | FCCU CHARGE, HVGO |
| PFCCO | FCCU CHARGE, DESULFURISED HVGO |
| PFDISO | HVGO FEED TO HYDROCRACKER |
| PLANTS | PLANTS AND LINE CONTENT |
| PMEISO | MEDIUM ISOMATE CUTTER |
| PRESID | ATM RESID/VDU FEED |
| PSLOPD | SLOP DISTILLATE |
| PSLOPO | SLOP OIL |

## EXAMPLE 15-2

We want to estimate the production of balancing grade fuel oil (I-961). The production of fuel oil blending components in a refinery and their properties and its fixed-grade production are as follows:

| STREAM | VOL, mb | VBI* | SULFUR, wt% | SPECIFIC GRAVITY |
|---|---|---|---|---|
| VACUUM RESID | 1112 | 706 | 4.28 | 1.0170 |
| CUTTERS | 581 | 140 | 2.40 | 0.9684 |
| HEAVY CAT NAPHTHA | 95 | −250 | 0.40 | 0.8256 |
| TOTAL | 1788 | 471.2 | 3.46 | 0.9910 |

* VISCOSITY BLENDING INDEX

To estimate the production of balancing-grade fuel oil (I-961), the average properties of the fixed fuel oil grades is estimated, as shown next:

| FIXED GRADES | REQUIREMENTS, mb | VBI | SULFUR, wt% |
|---|---|---|---|
| I-928 | 250 | 460 | 2.0 |
| I-957 | 150 | 460 | 3.4 |
| I-971 | 300 | 516 | 4.0 |
| TOTAL | 700 | 470 | 3.2 |

Out of 1788 mb of available fuel oil components, 700 mb go to blending fixed fuel oil grades. The remaining 1088 mb have a viscosity blending index of 472.

For disposal of this material, we have two options: to blend off this material to the specifications of balancing grade fuel oil or to keep this material in inventory as process stock for product blending later.

In option 1, this material must be blended to fuel oil balancing-grade (BG) specifications I-961 by adding finished diesel (I-888) to the remaining fuel oil pool to lower its viscosity blending index to the I-961 specs of 458.

| STREAM | VOL, mb | VBI | SULFUR, wt% |
|---|---|---|---|
| FIXED GRADE | 700 | 469 | 3.2 |
| REMAINING POOL | 1088 | 472 | 3.4 |
| ADD DIESEL | 30 | −30 | 0.97 |
| TOTAL I-961 (BG) | 1118 | 458 | 3.50 |

Process stocks have no product specifications to meet. The product quality depends on the process conditions of the refinery units from which they originate. These are treated as fixed-grade products, even though they are not blended products.

From among the various product specifications for a product pool, we consider for possible nomination to balancing grade only those that can be met by average pool properties. For example, consider fuel oil pool (vacuum resids, cutter stocks, and the like) from a refinery with following properties:

| | |
|---|---|
| Sulfur | 3.50% |
| Viscosity | 400 cst |
| Con carbon | 15.0% |

A fuel oil balancing grade must have properties close to the pool properties. For example, if the fuel oil balancing grade has a viscosity of 100 cst, this product could be blended only by downgrading a large amount of diesel to the fuel oil pool to reduce the pool viscosity from 400 cst to 100 cst. Similarly, if a balancing-grade fuel oil had a sulfur content of 1.5% instead of 3.5%, the pool sulfur could be lowered only by inclusion of a large amount of diesel and a large economic penalty.

In the allocation program, balancing grades are required as reference grades, in terms of which all fixed grades and process stock equivalencies are expressed. All settlements between the participants for overlifting or underlifting is done by exchange of balancing-grade products, as these are produced by both participants.

In the final allocation LP models for each participant, production of balancing grades is optimized on the basis of their price after producing all the fixed stocks and inventory changes as per the actual productions and available unit capacities.

It is essential that both the allocation program and allocation LP models for both participants have identical balancing grades.

## PRODUCT EQUIVALENCIES

The concept of a fixed-grade product equivalencies makes it possible to express any fixed grade product into its balancing grade equivalent, in term of its volume. Note that each participant in a joint-ownership refinery may produce different product fixed grades within a product group, but both participants produce same balancing grade within the group. The concept of product equivalencies is fundamental to the mechanism of valuation and exchange of fixed-grade products with different specifications. In a joint-ownership refinery, all outstanding claims between the two participants are settled by exchanging balancing-grade products. The concept of equivalency allows participants to produce and ship products with the different specifications required for its sale domain without causing any accounting problems.

A joint-ownership refinery produces a large number of product grades and process stocks for its operations. Table 15-10 shows the product grades produced by one such refinery. Both participants are free to produce any number of fixed grades in a group, but they must also produce the balancing grade of the group. Fixed-grade volumes are converted into balancing-grade volumes by means of product equivalency. As balancing

## Table 15-10
## Fixed-Grade Product Equivalencies

| PRODUCT | CLASS | GROUP | I-150 | I-201 | I-210 | I-397 | I-440 | I-888 | I-961 |
|---|---|---|---|---|---|---|---|---|---|
| I-1110B | ASPHALT | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.7287 | 1.7287 |
| I-1110D | ASPHALT | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.7287 | 1.7287 |
| I-1129B | ASPHALT | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.7287 | 1.7287 |
| I-1129D | ASPHALT | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.7287 | 1.7287 |
| I-1138B | ASPHALT | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.7287 | 1.7287 |
| I-1138D | ASPHALT | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.7287 | 1.7287 |
| I-1149B | ASPHALT | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.7287 | 1.7287 |
| I-1149D | ASPHALT | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.7287 | 1.7287 |
| I-150 | LPG | 150 | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| I-151 | LPG | 150 | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| I-201 | LSR | 201 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| I-210 | WSR | 210 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| I-211 | WSR | 210 | 0.0245 | −0.3110 | 1.2865 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| I-213 | WSR | 210 | −0.0400 | −0.1680 | 1.2080 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| I-220 | WSR | 201 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| I-222 | WSR | 201 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| I-253 | CAT NAPHTHA | 397 | −0.0078 | 0.1634 | 0.0000 | 0.8444 | 0.0000 | 0.0000 | 0.0000 |
| I-387 | GASOLINE | 397 | 0.0054 | 0.6160 | 0.0000 | 0.3786 | 0.0000 | 0.0000 | 0.0000 |
| I-390 | GASOLINE | 397 | −0.0068 | 0.4543 | 0.0000 | 0.5525 | 0.0000 | 0.0000 | 0.0000 |
| I-393 | GASOLINE | 397 | 0.0103 | 0.2916 | 0.0000 | 0.6981 | 0.0000 | 0.0000 | 0.0000 |
| I-395 | GASOLINE | 397 | 0.0119 | 0.1834 | 0.0000 | 0.8047 | 0.0000 | 0.0000 | 0.0000 |
| I-397 | GASOLINE | 397 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.0000 |
| I-398 | GASOLINE | 397 | −0.0003 | 0.0216 | 0.0000 | 0.9787 | 0.0000 | 0.0000 | 0.0000 |
| I-400 | KEROSENE | 440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 |
| I-411 | KEROSENE | 440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 |
| I-419 | KEROSENE | 440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 |
| I-434 | JP-4 | 210 | −0.0350 | 0.0000 | 0.5230 | 0.0000 | 0.5120 | 0.0000 | 0.0000 |
| I-440 | KEROSENE | 440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 |
| I-710 | HVGO | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2500 | 0.7500 |
| I-711 | HVGO | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2500 | 0.7500 |
| I-725 | HVGO | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3468 | 0.6532 |
| I-800 | DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.5681 | 1.5681 | 0.0000 |

## Table 15-10
## Continued

| PRODUCT | CLASS | GROUP | I-150 | I-201 | I-210 | I-397 | I-440 | I-888 | I-961 |
|---|---|---|---|---|---|---|---|---|---|
| I-803 | DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1478 | 0.8522 | 0.0000 |
| I-808 | DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 |
| I-875 | DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1478 | 0.8522 | 0.0000 |
| I-876 | DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1478 | 0.8522 | 0.0000 |
| I-876ZP | DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.5768 | 0.4232 | 0.0000 |
| I-884 | DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2754 | 0.7246 | 0.0000 |
| I-885 | DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 |
| I-888 | DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 |
| I-892 | BULK DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.7320 | 0.2680 |
| I-893S | BULK DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0260 | 0.8800 | 0.0940 |
| I-893W | BULK DIESEL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.9963 | 0.0037 |
| I-903 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| I-925 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0015 | 0.9985 |
| I-928 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.0204 | 1.0204 |
| I-933 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1271 | 0.8729 |
| I-934 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0501 | 0.9499 |
| I-955 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1392 | 0.8608 |
| I-957 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2168 | 0.7832 |
| I-960 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0542 | 0.9458 |
| I-961 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| I-962 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.0548 | 1.0548 |
| I-964 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0360 | 0.9640 |
| I-966 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.0719 | 1.0719 |
| I-971 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.1042 | 1.1042 |
| I-975 | FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.1454 | 1.1454 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| PBFUEL | BURNER FUEL OIL | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| PCTISO | ISOMATE CUTTER | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3360 | 0.6640 |
| PCTTR | FCC CUTTER | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.6438 | 0.3562 |
| PDSDSL | DSL EX 1HDU | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 |
| PDSL | UNDESULF.DSL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 |
| PFCCF | HVGO | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2406 | 0.7594 |
| PFCOO | H.ISOM | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2697 | 0.7303 |
| PFDISO | HVGO FEED TO HCR. | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2406 | 0.7594 |
| PGABS | GASOLINE B.S | 397 | −0.0914 | 0.5571 | 0.0000 | 0.5343 | 0.0000 | 0.0000 | 0.0000 |
| PKERO | TKE/SOUR KEROSENE | 440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 |
| PLANTS | PLANT & LINE CONT. | 961 | 0.0103 | 0.1040 | 0.1105 | 0.1518 | 0.0886 | 0.1854 | 0.3494 |
| PLCGAS | LIGHT CAT NAPTHA, TREATED | 397 | −0.0075 | 0.0327 | 0.0000 | 0.9748 | 0.0000 | 0.0000 | 0.0000 |
| PLLCN | LIGHT CAT NAPTHA, UNTR. | 397 | −0.0075 | 0.0327 | 0.0000 | 0.9748 | 0.0000 | 0.0000 | 0.0000 |
| PLTISO | LIGHT ISOMATE | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 |
| PMEISO | MEDIUM ISOMATE | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3360 | 0.6640 |
| PMIDSL | 4A M/I DSL | 888 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | −0.4551 | 1.4551 | 0.0000 |
| PMSR | THN/SOUR MSR | 210 | −0.1140 | 0.4690 | 1.5830 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| PPOLY | POLY GASOLINE | 397 | −0.0154 | −0.1076 | 0.0000 | 1.1230 | 0.0000 | 0.0000 | 0.0000 |
| PP90R | REFORMATE 90 R | 397 | −0.0227 | −0.0263 | 0.0000 | 1.0490 | 0.0000 | 0.0000 | 0.0000 |
| PP95R | REFORMATE 95 R | 397 | −0.0206 | −0.1615 | 0.0000 | 1.1821 | 0.0000 | 0.0000 | 0.0000 |
| PRESID | 6VDU FEED | 961 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2218 | 0.7782 |
| PSKERO | SWEET KEROSENE | 440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 |
| PSLOPD | SLOP DISTILLATE | 961 | 0.0000 | 0.1000 | 0.1000 | 0.1400 | 0.1900 | 0.3700 | 0.1000 |
| PSLOPO | SLOP OIL | 961 | 0.0000 | 0.1000 | 0.1000 | 0.1400 | 0.1900 | 0.3700 | 0.1000 |
| PSLOPT | SLOP | 397 | −0.0123 | 0.1414 | 0.0000 | 0.4936 | 0.0488 | 0.3285 | 0.0000 |
| PSMCN | MCN | 397 | −0.1742 | 0.3624 | 0.0000 | 0.8118 | 0.0000 | 0.0000 | 0.0000 |
| PSWMSR | SWEET MSR | 210 | −0.1140 | −0.4690 | 1.5830 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| PUFCHG | UNIFINER CHG. | 210 | −0.1140 | −0.4690 | 1.5830 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| PWCN | NAPTHA FROM VISBREAKER | 397 | −0.1742 | 0.3624 | 0.0000 | 0.8118 | 0.0000 | 0.0000 | 0.0000 |

grades are produced by both participants, any overlifting by one participant is settled in terms of balancing grade products.

## PRODUCT EQUIVALENCY DETERMINATION

To work out the product equivalency of a fixed grade in any group, the basis of product equivalencies must be identified:

*Naphtha.* Calculations are based on density and Reid vapor pressure (RVP). The density and RVP of a fixed grade naphtha, whose equivalency is to be determined, must match those of a hypothetical blend of two balancing-grade products (LPG and naphtha).

*Gasoline.* The RVP and RON of the fixed-grade gasoline are matched with those of a blend of a balancing-grade naphtha, a balancing grade gasoline, and balancing grade LPG.

*Diesel.* The fixed-grade diesel equivalencies are based on pour point, cetane index, or the sulfur content of the grade.

*Vacuum gas oils.* VGO is an important intermediate stock. Its product equivalency is determined on the basis of its viscosity, in terms of diesel and fuel oil balancing grades.

*Fuel oils.* The key properties are the viscosity, sulfur, and Conradson carbon specs, which must be matched.

Representative values of the balancing-grade properties are used to determine the fixed-grade product equivalencies (see Table 15-11).

**Table 15-11**
**Balancing-Grade Properties**

| GRADE | GROUP | SPECIFIC GRAVITY | RVP, psia | RON | POUR INDEX | VBI | SULFUR, wt% | CON. CARBON |
|---|---|---|---|---|---|---|---|---|
| I-150 | LPG | 0.5740 | 60.00 | 98.0 | | | | |
| I-201 | LSR | 0.6698 | 13.97 | 55.2 | | | | |
| I-210 | WSR | 0.7052 | 8.80 | | | | | |
| I-397 | GASOLINE | 0.7279 | 10.29 | 97.2 | | | | |
| I-440 | KEROSENE | 0.7890 | 0 | | 38.7 | | 0.30 | |
| I-888 | DIESEL | | | | 250.0 | −45 | 0.97 | |
| I-961 | FUEL OIL | | | | | 463 | 3.35 | 13.4 |

## EXAMPLE 15-3

Calculate the product equivalency of I-434 (JP-4), a military jet fuel, blended from kerosene, naphtha, and LPG. The I-434 target blending specs follow:

Density = 0.7527 gm/cc
RVP = 2.50 psia

In the I-434 blend, let

I-150 = $x$
I-210 = $y$
I-440 = $z$

where $x$, $y$, and $z$ are the volume fraction of blend components required to blend grade I-434.

Thus,

| | **x** | **y** | **z** | **= I − 434** |
|---|---|---|---|---|
| MATERIAL BALANCE | 1 | 1 | 1 | = 1 |
| DENSITY | 0.5740 | 0.7052 | 0.7890 | = 0.7527 |
| RVP | 60 | 8.8 | 0 | = 2.5 |

Solving for three equations for three unknowns gives the following result:

I-150 = −0.035
I-210 = 0.512
I-440 = 0.521

So, for accounting purposes, one barrel of JP-4 is equivalent to 0.521 bbl I-440 plus 0.512 bbl I-210 minus 0.033 bbl I-150. Therefore. the equivalency of JP-4 (I-434) is written as follows:

| | I-150 | I-210 | I-440 |
|---|---|---|---|
| I-434 | −0.0350 | 0.5120 | 0.5210 |

## EXAMPLE 15-4

Determine the equivalency of a diesel grade I-876Z blended from diesel and kerosene. The target blending specs of I-876Z are as follows:

Pour point = −0.4°F
Sulfur = 0.4 wt%

I-876 ZP could be considered a blend of kerosene and diesel to match the pour point −0.4°F. The limiting specification is the I-876Z pour point. As sulfur is not limiting, this property is not considered.

| GRADE | PRODUCT | VOLUME | POUR POINT, °F | POUR INDEX |
|---|---|---|---|---|
| I-440 | KEROSENE | 0.5768 | −50.0 | 45.68 |
| I-888 | DIESEL | 0.4232 | 26.60 | 388.70 |
| I-876ZP | DIESEL | 1.0000 | −0.40 | 190.42 |

Hence, the equivalency of I-876Zp becomes

1 bbl I-876ZP = 0.5768 bbl kerosene + 0.4232 bbl diesel

## EXAMPLE 15-5

Determine the equivalency of a marine diesel, grade I-892, blended from diesel and fuel oil. The target blending specs of I-892 are as follows:

Viscosity = 3.0 − 9.0 cst
Sulfur = 1.6 wt%
Con carbon = 2.0 wt%

Marine diesel grade I-892 could be considered a blend of diesel and fuel oil to achieve a Con carbon content of 2.0 wt%, as follows:

| GRADE | PRODUCT | VOLUME | CON CARBON, wt% | VBI |
|---|---|---|---|---|
| I-888 | DIESEL | 0.8582 | 0 | −45 |
| I-961 | FUEL OIL | 0.1418 | 13.4 | 458 |
| I-892 | MARINE DIESEL | 1.0000 | 1.90 | 26.3 |

We see that the viscosity index of the blend is 26.3, which corresponds to a viscosity of 4.1 cst, a value that falls within the specification range. Therefore, the equivalency of I-892 becomes

1 bbl I-892 = 0.8582 bbl I-888 + 0.14218 bbl I-961

## EXAMPLE 15-6

Determine the product equivalency of fuel oil grade I-971 (380 cst viscosity, 4% sulfur) in terms of balancing grades.

I-971 could be considered a hypothetical blend of fuel oil I-961 and diesel I-888. The viscosity of I-971 could be achieved by removing some diesel from the fuel oil grade, as follows:

| GRADE | PRODUCT | VOLUME | VBI | SULFUR, wt% |
|---|---|---|---|---|
| I-888 | DIESEL | −0.1044 | −45 | 0.97 |
| I-961 | FUEL OIL | 1.1044 | 458 | 3.35 |
| I-971 | FUEL OIL | 1.0000 | 511 | 3.76 |

Hence, the equivalency of I-971 becomes

1 bbl I-971 = −0.1044 bbl I-888 + 1.1044 bbl I-961

## EXAMPLE 15-7

Determine the equivalency of asphalt, I-1138 (viscosity blending index 814), in terms of balancing grade products.

I-1138 (asphalt) could be considered a hypothetical blend of fuel oil and diesel. The viscosity of I-1138 could be achieved by removing some diesel from the fuel oil grade, as follows:

| GRADE | PRODUCT | VOLUME | VBI | SULFUR, wt% |
|---|---|---|---|---|
| I-888 | DIESEL | −0.7287 | −45 | 0.97 |
| I-961 | FUEL OIL | 1.7287 | 458 | 3.35 |
| I-1138 | FUEL OIL | 1.0000 | 825 | 5.34 |

Hence the equivalency of I-1138 becomes

$$1\,\text{bbl I-1138} = -0.7287\,\text{bbl I-888} + 1.7287\,\text{bbl I-961}$$

## CRUDE OIL EQUIVALENCY

Crude oil equivalency is determined for a joint ownership refinery by conducting a series of test runs on the crude distillation unit by gradually increasing CDU feed from its nominal design capacity to the hydraulic limits of the crude distillation unit. The incremental crude yields are recorded and used to convert the incremental crude run to equivalent barrels of balancing-grade products (see Table 15-12). Crude oil equivalency is required for preliminary allocation and have virtually no effect on final allocation.

**Table 15-12**
**Incremental Yield of Balancing Grade from Crude**

| CRUDE RUN, mbpcd | I-201 | I-210 | I-440 | I-888 | I-961 | LOSS |
|---|---|---|---|---|---|---|
| 200 | 0.0010 | 0.1830 | 0.1000 | 0.3270 | 0.3740 | 0.0170 |
| 260 | −0.0100 | 0.1800 | 0.1000 | 0.3100 | 0.4030 | 0.0170 |
| 270 | −0.0150 | 0.2090 | 0.1000 | 0.2760 | 0.4110 | 0.0190 |
| 280 | −0.0290 | 0.2360 | 0.1000 | 0.2620 | 0.4150 | 0.0160 |
| 290 | −0.0400 | 0.2350 | 0.1000 | 0.1150 | 0.5740 | 0.0160 |

## EQUIVALENCY OF SLOP

Slop is the off-specification product produced by various processing units during start-up, shutdown, or emergency situations. This material is of variable composition and reprocessed either in the CDU or in product blending. The equivalency of the slop is determined from its ASTM distillation to determine the potential volumes of LPG, naphtha, kerosene, diesel, and fuel oil content likely to be obtained reprocessing it in a crude distillation unit. As the slop composition changes with time, the analysis is frequently updated for its use in determining the product equivalency. A typical slop equivalency is as follows:

$$\begin{aligned} 1\,\text{bbl slop} = {} & 0.0\,\text{bbl I-150} + 0.10\,\text{bbl I-201} + 0.1\,\text{bbl I-210} \\ & + 0.14\,\text{bbl I-397} + 0.19\,\text{bbl I-440} + 0.37\,\text{bbl I-888} \\ & + 0.10\,\text{bbl I-61} \end{aligned}$$

As product equivalencies are defined in terms of balancing-grade products, if either the balancing grades chosen or their properties undergoes a change, the equivalencies of fixed grades also change. Product equivalencies are not unique. These are refinery specific. It is sometimes possible to define a fixed-grade equivalency in more than one way. The equivalency adopted must be acceptable to both participants. For product allocation, the equivalency of every fixed grade and process stock, including slop, must be determined.