Petroleum & Coal
ISSN 1337-7027

Available online at www.vurup.sk/pc
Petroleum & Coal 49 (1), 61-66, 2007

LP MODELING OF OPERATION OF VDU, CDU AND VISBREAKER UNITS OF TEHRAN REFINERY FOR PROFIT MAXIMIZATION BY PROPLAN SIMULATOR

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Received May 2, 2007, accepted June 25, 2007

Abstract
Production planning is vital to modern refinery operation because of increasing crude prices and changing market demands. In this article LP/NLP is used to simulate the effect of change in crude types on the yields of CDU, VDU, visbreaker, feed and product blender units. Central Composite experimental Design (CCD)and Response Surface Methodology (RSM) are used to obtain a second-degree polynomial model for maximizing profitability of operation of these units.

Key Words: LP/NLP modeling, production planning, petroleum refinery

1. Introduction

Changing crude petroleum prices, fluctuation in production practices by the petroleum producing countries and changing market demands for different products are the reasons for refiners to resort to advanced decision-making strategies. Refinery production planning and scheduling are two such cases affected by market instabilities.

Optimization particularly Linear Programming (LP) has been traditionally used for such purposes. Other optimization algorithm such as Non Linear Programming (NLP) and Mixed Integer Non Linear Programming (MINLP) although often used but for refinery wide problems and complex nature of these algorithms still the preferred method is LP.

Additionally use of heavier feedstocks has become financially viable and consequently refinery units are continuously operated under more sever conditions. As a result blending of refinery feeds and products has become important processes.

Since the introduction of LP in the 1950’s the optimization of production planning has become possible. Symonds [1] and Manne [2] applied LP to long term supply and production planning of crude oil processing. Moreover availability of commercial software has increased use of this approach to real life problems

Due to complexity of NLP algorithms their use in plant wide problems is limited and consequently great deal of previous studies have dealt with application of Mixed Integer Linear Programming (MILP) algorithms to such problems Zhang et. al [3] consider a refinery as a combination of process systems and utility systems and develop a MILP algorithm for better energy utilization. The problem with this approach is that it can only be applied to a small or medium sized refinery complex.

Lundgren et. al. [4] used a MILP algorithm to optimization of scheduling and production planning of one distillation unit and two hydrotreatment units.

Reddy et. al.[6] used a MILP for short-term optimization of scheduling of refinery operations such as receiving crude from large crude carriers to the storage and CDU units.

In this article we report the results of LP optimization of operation of feed blender, CDU, VDU, visbreaker and product blender under changing feed specifications.

2. Validation of proplan simulator with existing operating data

Prior to optimization of units the validity of the LP model developed in this study was tested by simulating the existing operating conditions. For this purpose the properties of two types of crude used under normal practice were used as input to the model and the results were compared with actual plant data.

Table (1): Feed Condition

	Cheleken	Ahwaz
Flow (BPD/day)	55 000	55 000
Specific gravity	0.8381	0.8614
ASTM D1160 (IBP-FBP) (^{0}C)	65-645	15-625
Sufur (wt %)	0.15	1.46
Nitrogen (ppm)	810	1 200
Nickel (ppm)		12

Table (2): CDU Products

Product Name	Simulated flow rate(BPD)	Actual flow rate (BPD)
LPG	2 403	2 504
LSRG	4 768	4 310
HSRG	14 937	15 020
B. Naphtha	6 582	5 401
Kerosene	16 527	17 163
Gas oil	16 199	16 507
Resid	48 351	49 095

Table (3): VDU Products

Product Name	Simulated flow rate (BPD)	Actual flow rate (BPD)
H. Diesel	8 381	8 346
L.V.Gas Oil	5 482	5 302
H.V.Gas Oil	14 266	14 140
Slops Wax	2 090	1 949
Vac. Bottom	18 132	18 990

Table (4) :Visbreaker Products

Product Name	Simulated flow rate(BPD)	Actual flow rate (BPD)
VB Naphta	1 679	1 177
Tar	16 453	17 580

The properties of crudes used for model validation can be seen in Table (1). Tables (2), (3) and (4) show comparison between simulation and actual plant data.

3. Petroleum feedstock properties

Upon testing the validity of the LP model for simulating the yields using the existing crude mix, five different Iranian heavy crude were used for blending as feed. Table (5) shows various properties of these crudes and it can be seen that Bangestan and Chesmeh-Khosh field crudes are the heaviest crudes and Marun, AB-Teymour and Ahwaz Asmari field crudes are the lightest crudes. Additionally Bangestan and Chesmeh-khosh have the highest sulphur concentration.

Table (5): Specification of crude types used for blending

	Marun	Cheshmeh-Khosh	AB-Teymour	Bangestan	Ahvaz Asmari
Specific gravity	0.8556	0.8903	0.8977	0.9049	0.8621
Sulfur (wt %)	0.21	3.23	1.91	3.41	1.5
Nitrogen (wt %)	0.17	0.22	0.24	0.27	0.17
ASTM D1160 (IBP-FBP) ^{0}C Yields (vol%)	15-700 15-13.11	15-700 15-19.27	15-700 15-7.73	15-700 15-19.07	15-700 3.89-14.16
RVP (psia)	8.9	5.56	9.6	9.4	8.6
Nickel (ppm)	7.6	15	22	21	8.9

4. Experimental design for profit maximization

The flow rate of these crude as designated by the production planning office of the National Iranian Refining and Distribution Company (NIORDC) are shown in Table (6) and this in fact provide the base case in the study for profit maximization.

Table (6): Designated flow rate of crudes for feed blending

Crude Name	Current Case (BPD)
AB-Teymour	7 012
Cheshmeh-Khosh	109 756
Marun	85 365
Ahwaz Asmari	43 293
Bangestan	4 573
Total	250 000

Using the validated LP model two cases for blending these crudes were attempted. The first case involved a base case of five Iranian heavy crudes at specified BPD as designated by NIORDC. The second case involved optimized blending of these crudes with a view to maximize profit margin.

Tables (7) and (8) show the reparametrised factors used for the Central Composite Design for different blending strategies.

Table (7): Coded parameters for the optimization algorithm

Ratio 1	(Cheshmeh-Khosh + AB-Teymour)/Total
Ratio 2	AB-Teymour/(AB-Teymour + Cheshmeh-Khosh)
Ratio 3	Marun/(Marun+ Ahwaz Asmari + Bangestan)
Ratio 4	Ahwaz Asmari /(Marun+ Ahwaz Asmari + Bangestan)

Table (8): Five levels for optimization parameters in Central Composite Design of blending strategies

Coded parameters	-2	-1	0	1	2
Ratio1	0.373659095	0.420366	0.467074	0.513781	0.560489
Ratio2	0.048040559	0.054046	0.060051	0.066056	0.072061
Ratio3	0.512583408	0.576656	0.640729	0.704802	0.768875
Ratio4	0.259957517	0.292452	0.324947	0.357442	0.389936

Applying central composite design to the coded factors 25 different blending strategies were obtained. These strategies were implemented into the LP model. To estimate the expenditure and income for these blending strategies unit prices for the pooled component, utilities and product cuts were used as shown in Tables (9), (10) and (11). The profit is the difference between income and expenditure. Table (12) shows the simulation result of the LP model of the central composite designs.

A second-degree polynomial was fitted to these simulation results as follows:

$$
\begin{aligned}
P = {} & A_1 X_1^2 + A_2 X_2^2 + A_3 X_3^2 + A_4 X_4^2 + A_5 X_5^2 + A_6 X_1 X_2 + A_7 X_1 X_3 + A_8 X_1 X_4 + \\
& A_9 X_1 X_5 + A_{10} X_2 X_3 + A_{11} X_2 X_4 + A_{12} X_2 X_5 + A_{13} X_3 X_4 + A_{14} X_3 X_5 + A_{15} X_4 X_5 \\
& + A_{16} X_1 X_2 X_3 + A_{17} X_1 X_2 X_4 + A_{18} X_1 X_2 X_5 + A_{19} X_2 X_3 X_4 + A_{20} X_2 X_3 X_5 + \\
& A_{21} X_1 + A_{22} X_2 + A_{23} X_3 + A_{24} X_4 + A_{25} X_5
\end{aligned}
$$

In which X_1, X_2, X_3, X_4 *and* X_5 are the flow rate of different crude types and P is the profit obtained. The coefficients A_1 to A_{25} were obtained by a nonlinear regression fit of the LP model results to the polynomial.

Table (9): Unit price for utilities used in the LP model

Utilities		
Item	**Unit**	**Price ($)**
Fuel	MM Btu	2.7
HP Steam	MT / d	1.65
LP Steam	MT / d	1.17
BFW	MT / d	4.4
CW	1000 Gal	0.15
Power	KWh	0.06
Gas LHV	MM Btu	1.66

Table (10): Unit price for pooled components used in the LP model

Pooled Components		
Item	**Unit**	**Price ($)**
H_2	MT / d	635
Fuel gas	MT / d	76.06
H_2S	MT / d	5.43

Table (11): Unit price for product cuts used in the LP model

Cut name	Unit	Price ($)	Cut name	Unit	Price ($)
LPG	bbl	43.78	H. Diesel	bbl	89.006
L.SRG	bbl	57.46	L.V. Gas Oil	bbl	88.14
H.SRG	bbl	76.5	H.V. Gas Oil	bbl	102.3
B. Naphtha	bbl	78.66	Slops Wax	bbl	43.84
Kerosene	bbl	84.61	VB Naphtha	bbl	60.99
Gas Oil	bbl	81.49	Tar	bbl	55.44

Table (12): Results of LP modeling of different blending strategies as obtained by central composite design

No.	AB-Teymour (BPD)	Cheshmeh Khosh (BPD)	Marun (BPD)	Ahwaz Asmari (BPD)	Bangestan (BPD)	Profit (1000$)
1	5 452.6	95 435.4	80 219.8	40 683.6	18 208.6	7 068.5
2	5 452.6	95 435.4	80 219.8	49 724.4	9 167.8	7 051.5
3	5 452.6	95 435.4	98 046.5	40 683.6	381.9	8 131.3
4	5 452.6	95 435.4	92 301.3	46 810.8	1.0	7 777.1
5	6 664.2	94 223.7	80 219.8	40 683.6	18 208.6	7 066.9
6	6 664.2	94 223.7	80 219.8	49 724.4	9 167.8	7 050.0
7	6 664.2	94 223.7	98 046.5	40 683.6	381.9	8 129.7
8	6 664.2	94 223.7	92 301.3	46 810.8	1.0	7 775.7
9	6 664.2	116 643.3	67 291.5	34 127.0	15 274.1	6 296.1
10	6 664.2	116 643.3	67 291.5	41 710.8	7 690.3	6 281.9
11	6 664.2	116 643.3	82 245.1	34 127.0	320.4	7 188.0
12	6 664.2	116 643.3	77 425.9	39 266.6	1.0	6 890.8
13	8 145.2	115 162.3	67 291.5	34 127.0	15 274.1	6 294.2
14	8 145.2	115 162.3	67 291.5	41 710.8	7 690.3	6 279.9
15	8 145.2	115 162.3	82 245.1	34 127.0	320.4	7 185.9
16	8 145.2	115 162.3	77 425.9	39 266.6	1.0	6 888.8
17	5 385.2	84 292.9	96 315.6	48 846.6	5 159.6	8 019.1
18	8 077.9	126 439.4	67 585.9	34 276.3	3 620.6	6 305.5
19	41 886.3	70 211.4	81 950.7	41 561.4	4 390.1	7 120.8
20	8 077.9	104 019.9	81 950.7	41 561.4	4 390.1	7 116.7
21	6 731.5	105 366.2	65 560.6	41 561.4	20 780.2	6 184.8
22	6 731.5	105 366.2	89 905.7	37 996.5	1.0	7 643.5
23	6 731.5	105 366.2	81 950.7	33 249.2	12 702.4	7 178.3
24	6 731.5	105 366.2	79 512.4	48 389.8	1.0	7 004.1
25	6 731.5	105 366.2	81 950.7	41 561.4	4 390.1	7 162.6

The profit for different blending strategies was maximized by obtaining the maximum of the polynomial. The maximum of the profit was obtained for two different constrained and unconstrained cases. In the constrained case the flow rate of different crudes were allowed to vary only by 5% of the designated quota by the NIORDC, whereas in the unconstrained case no bound to this quota was implemented.

Tables(13), (14) and (15) show a comparison of the designated case with the optimised blending strategies. Table (14) shows that 35% increase in profits would be obtained if the blending of crudes for feed were to be optimized.

Table (13) Comparison of designated case with optimised blending strategies

Crude Name	Designated Case	Constrained	Unconstrained
	BPD	BPD	BPD
AB-Teymour	7 012	6 661.4	10 518
Cheshmeh Khosh	10 9756	108 232.65	54 878
Marun	85 365	89 633.25	128 047.5
Ahwaz Asmari	43 293	4 1125.35	49 697
Bangestan	4 573	4 344.35	6 859.5
Total	250 000	250 000	250 000

Table (14): Comparison of profit made between the designated case and the optimised blending strategies

Profit	Designed	Constrained	Unconstrained
	$7.46*10^6$ $	$7.720*10^6$ $	$10.01*10^6$ $

Table (15): Comparison of the products distribution obtained between the designated case and the optimized blending strategies

Product Name	Designated Case	Constrained	Unconstrained
	BPD	BPD	BPD
LPG	5 699.9	5 709.4	6 232.4
LSRG	19 814.3	19 676.8	16 936.5
HSRG	29 731.3	29 777.9	31 883.9
B. Naphtha	9 501.3	9 485.5	8 763
Kerosene	36 212.6	36 393.6	36 422
Gas Oil	27 252.2	27 032.3	25 548.5
H. Diesel	7 551.6	7 671.6	8 436.5
L.V. Gas Oil	11 918.9	11 967.4	12 732.2
H.V. Gas Oil	53 260.1	53 325.7	55 537.1
Slops Wax	4 201.4	4 237.7	4 916.5
V.B. Naphtha	469.5	467.9	444.3
Tar	44 176.7	44 028.9	41 803.7

Depending on the requirement for different cuts and considering the economics this table provides guidelines for choosing a suitable blending strategy.

5. Conclusion

In this study using the commercial simulator PROPLAN, blending of petroleum crude as feed for Tehran refinery has been optimized by LP/NLP algorithms.

The equations used in the LP/NLP model and the whole simulator were tuned and validated against actual plant data and then using this model and Central Composite Design algorithm a statistical equation was obtained relating profit with variations in feed specification. The following feed blending strategies were simulated with a view to maximize profit:

1) Blending strategy as designated by the National Iranian Refining and Distribution Company (NIORDC).
2) Allowing a 5% variation on the NIORDC designated flow rate of different crudes .
3) No constraints on the flow rate of different crudes.

The simulation results show conclusively that blending strategy designated by the NIORDC produce the least profit and further study needs to be carried out to optimize yield of valuable products such as mid distillates.

Abbreviations

BFW	Boiling Feed Water	IBP	Initial Boiling Point
B.Naphtha	Blended Naphtha	LPG	Liquefied Petroleum Gases
BPD	Barrel Per Day	LP Steam	Low Pressure Steam
CW	Cooling Water	LSRG	Light Straight Run Gasoline
FBP	Final Boiling Point	L.V. Gas Oil	Light Vacuum Gas oil
Gas LHV	Gas Low Heating Value	ppm	Part per million
H.Diesel	Heavy Diesel	Resid	Residue
HP Steam	High Pressure Steam	RVP	Reid Vapor Pressure
HSRG	Heavy Straight Run Gasoline	Vac. Bottom	Vacuum Bottom
H.V.Gas Oil	Heavy Vacuum Gas oil		

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