Refinery Operations Optimization Integrated Production Process and Gasoline Blending

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Abstract. Operations optimization is key element of refinery production. The core production activities are operations of process units and product blenders. Operations Optimization of oil processing and product blending was researched in this paper. Using discrete time presentation, a MILP optimization model was built. By formulating operations of processing units and blending units, materials production and storage, energy generation and consumption, co-optimization of materials processing and product blending was realized. Utilizing the proposed model to optimize production operations of a refinery, simulation results show the formulation’s efficiency.

1. Introduction
Refineries are important energy suppliers of national economy development. Improved production efficiency and profit can be achieved via refinery-wide operations optimization. The key point of operations optimization is modelling production process based on refinery characteristics, which is an emphasis of production optimization research. The main modelling methods are mixed integer linear/nonlinear programming (MILP/ MINLP).
The refinery process is usually divided into three connecting sections, crude oil unloading process, production process and product blending process. Refineries with crude oil port need to conquer the crude oil operations optimization problem. An optimal crude oil scheduling contains optimized unloading operations, storage operations and delivery operations. In China, many refineries are inland. Crude oil is delivered by pipelines and stored in tanks to satisfy crude distillation units (CDU) charging requirements. Due to the guarantee of crude oil supply and large storage in plant, crude oil scheduling of inland refineries usually is omitted in normal production. Thus the key task of enterprise management and production control is the scheduling of oil processing and product blending operations.

Many researchers dealt with the processing and blending scheduling problems separately. Pinto [2] presented the common modelling approach for refinery production scheduling using mixed integer programming. Literature [3] built a MILP model combined heuristic rules to optimize operations of refinery processing units and logistics network. Considering scheduling optimization of processing system and utility system, Zhao H [4] introduced a MINLP model to meet the demand for higher profit and energy utilization. Otherwise many publications focus on the blending scheduling. Cerda [5] presented a MINLP formulation for the gasoline blend scheduling problem, and a two stage solution approach to conquer the nonlinear expression. Li [6] developed a continuous-time MINLP formulation for integrated scheduling of gasoline blending and order delivery operations. Literature [7] modified the previous published Li’s model, and introduced a reduced-size continuous-time model for
scheduling of gasoline blends. Although fine scheme can be got by scheduling processing and blending process separately, but it is hard to obtain global optimization for further profit improvement. Few publications focus on the combined scheduling of production and blending. Li [8] developed a multi-period MILP formulation for integrated scheduling, blending, and distribution of refinery products. Optimal scheme was generated by solving successive MILPs. Shah [9] presented an integrated optimization model by State Task Network (STN) representation for the scheduling problem of production units and end-product blending. Previous studies treated refinery scheduling problem as a whole. Some researches modelling refinery scheduling problem by bath process representation such as STN, while refinery is a typical example of continuous process. To acquire global optimization solution, the combined scheduling is usually big enough and hard to solve. Aim at the above problem of informed research, a concise multi-periodic discrete-time MILP model is proposed in this paper for integrated scheduling of production process and gasoline blending. The operations optimization problem of an inland refinery is stated in section 2. Section 3 demonstrates the formulation of the integrated scheduling. The model object is to maximize overall profit. In section 4, simulation study of the proposed operations optimization problem is presented. Finally, concluding remarks are given in section 5.

2. Problem Statement
The main objective of refinery is to convert crude oil into various petrochemicals. Figure 1 shows an inland refinery flow sheet. The refinery is consist of processing units, blending units and storage tanks which are omitted in Fig.1 for concise. Processing units include crude distillation unit (CDU), fluid catalytic cracking unit (FCC), continuous catalytic reforming unit (CCR) and diesel hydrogenation unit (DH). Crude oil is transported by pipelines to feed CDU. The amount and price of received crude oil is determined by delivery plan. The CDU outputs are feed to downstream units for further refining. Gasoline blending unit and diesel oil blending unit blend the input component oil to final oil products. The blending recipe is determined, and the product deliver is not considered, but the order and the price are known.

![Figure 1. Simplified flow sheet of an inland refinery.](image-url)

As a vital industry of national economy, efficient scheduling plays important role in refinery operations. The operations optimization task is to acquire production scheme to maximize enterprise profit and meet product orders.

3. Operations Optimization Model
In this section, a multi-periodic discrete-time MILP model is formulated to optimize oil processing operations and product blending operations. To reduce variables and simplify model representation, only two elements that are unit and material are used to describe the refinery process. Model sets, parameters and decision variables are as follows:

Sets
\( T \): time period set  
\( PM \): processing unit set  
\( BM \): blending unit set  
\( J \): material set  
\( G(i) \): unit \( i \) processing mode set  
\( IT(i), OT(i) \): input and output materials of unit \( i \)  
\( UC(j), UP(j) \): set of units consuming and producing material \( j \)  
\( QM(j) \): specification of material \( j \)  

**Parameters**  
\( C_i^U, C_i^L \): maximum and minimum throughput of unit \( i \)  
\( I_j^U, I_j^L \): maximum and minimum storage of material \( j \)  
\( \beta_{jig} \): unit output material ratio  
\( rc_i \): running cost of unit \( i \)  
\( w_{ij}, m_{ij} \): price of raw material and final product during time period \( t \)  
\( p_{jq} \): quality \( q \) of material \( j \)  

**Decision variables**  
\( y_{igt} \): binary variable, value 1 denotes unit \( i \) running mode \( g \) during time period \( t \)  
\( xc_{igt} \): amount of material \( j \) consumed by unit \( i \) with run-mode \( g \) during time period \( t \)  
\( I_{jt} \): storage of material \( j \) during time period \( t \)  
\( B_{jt} \): purchase amount of material \( j \) during time period \( t \)  
\( S_{jt} \): sell amount of material \( j \) during time period \( t \)  

The operations of processing units are formulated as constraint (1) to constraint (5). The amount of materials feed to processing units are limited by unit production capacity, and only one run-mode are on at the same time, as shown by constraint (1) to constraint (3). Constraint (4) demonstrates the unit throughput must equal to its consumed volume. Constraint (5) calculates the unit output.

\[
y_{igt} \cdot C_i^L \leq x_{igt} \leq y_{igt} \cdot C_i^U, \quad i \in PM, \quad g \in G(i), \quad t \in T
\]

\[
y_{it} = \sum_{g \in G(i)} y_{igt}, \quad i \in PM, \quad t \in T
\]

\[
x_{igt} = \sum_{j \in G(i)} \sum_{j \in IT(i)} xc_{igt}, \quad i \in PM, \quad t \in T
\]

\[
\sum_{j \in IT(i)} xc_{igt} = \sum_{j \in OT(i)} xo_{igt}, \quad i \in PM, \quad g \in G(i), \quad t \in T
\]

\[
xo_{igt} = \beta_{jig} x_{igt}, \quad i \in PM, \quad g \in G(i), \quad t \in T
\]

Constraint (6) to constraint (9) describes operations of blending units. The blending recipe is determined. The blending amount is restricted, furthermore the input and output quantity must be equalled. The quality balance of the blending component is demonstrated by constraint (9) where function \( f_i(\cdot) \) is linearization of the blending component qualities.

\[
y_{it} \cdot C_i^L \leq x_{it} \leq y_{it} \cdot C_i^U, \quad i \in BM, \quad t \in T
\]

\[
x_{it} = \sum_{j \in IT(i)} xc_{ijt}, \quad i \in BM, \quad t \in T
\]

\[
\sum_{j \in OT(i)} xc_{ijt} = \sum_{j \in OT(i)} xo_{ijt}, \quad i \in BM, \quad t \in T
\]

\[
\sum_{j \in OT(i)} f_i(p_{jq}) \cdot xo_{ijt} = \sum_{j \in OT(i)} \sum_{q \in QM(j)} f_i(p_{jq}) \cdot xo_{ijt}, \quad i \in BM, \quad t \in T
\]
Material storage is computed by constraint (10). Constraint (11) limits the stock quantity. The purchase and sell volume of material $j$ is limited by production plan and market situation as constraint (12) and constraint (13) shown.

\[
I_j = \sum_{i\in\mathcal{P}_j} \sum_{g\in\mathcal{G}(i)} x_{ijg} + B_{ij} - \sum_{i\in\mathcal{U}_j} \sum_{g\in\mathcal{G}(i)} x_{ijg} - S_j, \quad j \in J, t \in T
\]  

\[
I_j^l \leq I_j \leq I_j^u, \quad j \in J, t \in T
\]  

\[
B_{ij}^l \leq B_{ij} \leq B_{ij}^u, \quad j \in R J, t \in T
\]  

\[
S_j^l \leq S_j \leq S_j^u, \quad j \in PJ, t \in T
\]

The model objective is to maximize production profit, as illustrated in expression (14) which is consisted of sell income, purchase outcome, processing unit running cost and material storage cost. The formulated constraints and object can be solved by B&B algorithm to get optimal solution.

\[
\max Z = \sum_{i\in\mathcal{P}_j} \sum_{j\in\mathcal{J}} m_{ij} \cdot S_j - \sum_{i\in\mathcal{P}_j} \sum_{j\in\mathcal{J}} w_{ij} \cdot B_{ij} - \sum_{i\in\mathcal{U}_j} \sum_{g\in\mathcal{G}(i)} r_{ijg} \cdot x_{ijg} - \sum_{i\in\mathcal{P}_j} \sum_{j\in\mathcal{J}} h_j \cdot I_j
\]

4. Case Study

Case study is based on the flow sheet illustrated in Figure 1. Annual production capacity and running cost of processing units are shown in Table 1. Table 2 illustrates specification of blending materials and products.

**Table 1.** Annual production capacity and running cost of processing units.

|            | CDU | FCC | CCR | DH |
|------------|-----|-----|-----|-----|
| Production | 4.8 | 2.5 | 0.7 | 0.9 |
| capacity   | (million tons per year) |
| Running    | 15  | 60  | 80  | 30  |
| cost       | (Yuan per ton) |

**Table 2.** Specification of blending materials and products.

| Gasoline blending | Octane value | Diesel blending | Freezing point |
|-------------------|--------------|-----------------|---------------|
| Reforming material| 66           | Kerosene        | 0.473         |
| Topped oil        | 80           | Diesel          | 1.6075        |
| Petrol            | 90.2         | Refined diesel  | 1.2075        |
| Ethanol           | 117          | -10# Diesel     | 1.2069        |
| 90# Gasoline      | 90           | 0# Diesel       | 1.6059        |
| 93# Gasoline      | 93           |                 |               |
| 97# Gasoline      | 97           |                 |               |

The blending operations are usually carried by blending tanks. As tank capacity is large enough, the blending units’ capacities are not limited. The scheduling time horizon was divided into ten discrete time periods. The above optimization model was solved by Lingo in sixteen seconds, and global
optimal solution was obtained. The optimal object value is 205.4206 million Yuan. The operations of processing units and diesel oil output were shown in Figure 2 and Figure 3.

Figure 2. Throughput of processing units.  
Figure 3. Diesel oil output.

5. Conclusion
The refinery operations optimization problem integrated production process and blending process is studied in this work. Based on discrete-time representation, a concise multi-periodic MILP optimization model is presented. The model formulates operations of processing units and blending units as well as activities of marital storage, bought and sells. The proposed formulation is easy to solve, and numerical results show that model is effective. Optimization problem combining refinery production process and energy network can be studied further.

Acknowledgments
This work is supported by Shandong Province Higher Educational Science and Technology Program, China (Grant No. J18KB153).

References
[1] Shah N K, Zukui Li and Ierapetritou M G 2011 Petroleum Refining Operations: Key Issues, Advances, and Opportunities Industrial & Engineering Chemistry Research vol 50 pp 1161–1170
[2] Pinto J M, Joly M and Moro L F L 2000 Planning and scheduling models for refinery operations Computers and Chemical Engineering vol 24 pp 2259–2276
[3] Li M 2015 Refinery production scheduling optimization research considering logistics priority of refining pipe network Computer Engineering and Design vol 36 pp 1115–1121
[4] Zhao H, Rong G and Feng Y 2015 Effective Solution Approach for Integrated Optimization Models of Refinery Production and Utility System Industrial & Engineering Chemistry Research vol 54 pp 9238–9250
[5] Cerda J, Pautasso P C and Cafaro D C 2016 Optimizing Gasoline Recipes and Blending Operations Using Nonlinear Blend Models Industrial & Engineering Chemistry Research vol 55 pp 7782–7800
[6] Li J and Karimi I A 2011 Scheduling Gasoline Blending Operations from Recipe Determination to Shipping Using Unit Slots Industrial & Engineering Chemistry Research vol 50 pp 9156–9174
[7] Castillo-Castillo P A and Mahalec V 2016 Improved continuous-time model for gasoline blend scheduling Computers & Chemical Engineering vol 84 pp 627–646
[8] Li J, Karimi I A and Srinivasan R 2009 Multi-period continuous-time formulation for integrated scheduling, blending, and distribution of refinery products Computer Aided Chemical Engineering vol 27 pp 1563–1568
[9] Shah N K and Ierapetritou M G 2011 Short-term scheduling of a large-scale oil-refinery operations: incorporating logistics details AIChE Journal vol 57 pp 1570–1584