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A planning model for multiple blending schemes ☆

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ABSTRACT

The key of production planning of refineries is to determine the production planning of units and blending schemes of blends in each period of the plan horizon, since they affect the effective utilization of components of refineries and hence profits. The optimization is difficult, because of many complicated product production–consumption relationships in production processes, which are closely related to the running modes of the units. Additionally, the blending products, such as gasoline and diesel, may use multiple blending schemes for their production that increase the complexity of the problem. This paper models the production planning problem as a mixed integer nonlinear programming. Computational experiments for a refinery show the effectiveness of the model. The optimal results give the effective utilization of the self-produced components and increase of the profit.

1. Introduction

Production planning of refineries is a hot academic area [1–8], since crude oil and its products, such as gasoline and diesel, are indispensable for modern production and life. The shortage of crude resources and the increase of quality specifications and environment regulations for petroleum products reduce the profit space of refineries. The refineries are facing a serious challenge to improve their production efficiency. Production planning optimization becomes an effective means for competition.

The production planning of a refinery is to determine what to produce, how much to produce and when to produce in each period of the plan horizon in order to implement the maximal profit or minimal cost with considerations of market demands, cost and utilization of components. The products include gasoline, diesel, naphtha, *etc.* In general the horizon of a plan is one year divided to 12 months or one month to 30 days, *etc.*, in a refinery.

The product blending in refinery is the key step for production of products. According to the blending schemes of products, the components are blended to produce blends. The blending schemes specify which and how much of components should be used to produce a specific blend. The product blending also takes place in other production processes, such as coal and food industries. In a refinery, a blended product can be produced from multiple blending schemes and the difference in cost with different schemes is quite large, and hence the profit.

The production planning problem considering these factors is important and difficult. Zhang and Zhu have proposed a two-phase optimization model for the overall refinery production planning [2]. It includes a site-level model and many process models. The site-level model uses linear programming (LP) to determine the allocation of resources and process-level optimization models return new solutions using special mechanism models. Gothe-Lundgren *et al.* proposed a mixed integer linear programming (MILP) model for a production scheduling problem of a refinery [3], in which the most important decision variables are the running modes of units. The model was solved with CPLEX and a Tabu search heuristic. Gao *et al.* proposed a MILP model for an overall refinery production planning problem, solved it with a column generation algorithm, and applied it to a practical refinery production planning problem with better results [4]. Moro *et al.* proposed a mixed integer nonlinear programming (MINLP) model for refinery diesel production [5]. A general refinery topology and nonlinear relations for process models and blending were considered. The model was solved with GAMS CONOPT based on a feasible path generalized reduced gradient method. The optimization model was applied to a refinery, increasing millions of dollars per year in profit. As an extension of the above model, Point *et al.* have considered production planning and scheduling simultaneously [6,7]. The overall model consists of two parts: a MILP model to optimize the production scheduling and a nonlinear model for the production planning, solved with GAMS CONOPT and OSL. The nonlinear production planning model considers a general refinery topology and allows nonlinear blending relation representations. The MILP model considers crude scheduling, component storage, inventory management and product blending. Zhang and Hua proposed a MILP model that integrates the production plan and the use of utility system, considering oil products, by-products, and effective utilization of utility [8]. The model was applied

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to a refinery including two crude distillation units (CDUs), two fluid catalytic cracking units (FCCs), two gas fractionation units (GFs), one methyl tert-butyl ether (MTBE) unit, a blending workshop, and a utility system with 6 boilers and 6 steamers, solved with GAMS CPLEX.

The blending or pooling problem is important in a refinery. A review article for blending problems is referred to [9]. The traditional blending problem is usually modeled as a bilinear programming model [10,11]. Other optimization models also exist, including mixed integer bilinear programming, non-convex nonlinear programming, and mixed integer non-convex nonlinear programming. The solution methods are mainly successive linear programming [12], Benders decomposition [13], Branch-and-Bound [14,15], *etc.* In 1980s, DeWitt *et al.* modeled the gasoline blending problem as a nonlinear programming (NLP), in which the quality specifications, availability of components and demands of products were considered [16]. The model was solved with a generalized reduced gradient algorithm and extensively applied to the refineries of TEXACO in USA. Adhya *et al.* proposed a Lagrangian relaxation approach for traditional pooling/blending problem [17]. The model can tackle multiple quality components problems. The computational results were compared with McCormick linearization approach and showed the advantages of the Lagrangian relaxation approach. They also emphasized the importance of global optimization approaches for NLP problems with 13 benchmark examples.

In this paper, the production planning of a refinery is considered. The features of the planning problem are that it simultaneously plans the production of components and choice of blending schemes and allows using multiple blending schemes to produce a blend. These new features are not shared in the previous studies. A MINLP optimization model is formulated in this paper for the planning problem.

2. Problem Description

Consider a real refinery. It has 5 units, a product blending workshop and some auxiliary units. The 5 units are CDU, FCC, continuous catalytic reformer unit (CCR), hydro-treating (HC), and delayed coking (DC). The refinery has a capacity of processing 6 million tons of crude oil per year and produces fuel products, such as gasoline, diesel, and naphtha. A simplified production flowchart is shown in Fig. 1. The crude is first processed in CDU and some components, such as gas, light naphtha, kerosene, diesel, atmospheric gas oil (AGO), and residue, are produced. These components are stored in tanks or flow to other units for further processing or sold directly. Usually, light naphtha flows into CCR to produce reformate, and AGO and residue go to FCC to produce FCC gasoline and FCC diesel. CDU diesel and FCC diesel go to HC to produce refining diesel. The residue also flows into DC to produce coker gasoline and diesel. Finally, these components (products) are blended in the product blending workshop to produce a variety of blends.

From the flowchart, we see that the production of products in a refinery consists of two classes.

(1) Production of components
They are directly produced from processing units, such as naphtha, liquefied petroleum gas (LPG), and FCC diesel. At the same time, these components may be consumed in other units to produce other components. For example, the naphtha of CDU goes to CCR to produce reformate, the AGO and residue flow into FCC to produce FCC gasoline and FCC diesel.

(2) Production of blended products
Blend products are the final products in the blending workshop according to blending schemes. The blending scheme of a product is a constructing proportion relationship of components and additives for that blend to meet quality specifications. All blends are produced in the blending workshop.

The production plan is to determine the production quantities of all the components and blends in each period. From the refinery production technology, we know that the components are produced and consumed in production processes, and the production–consumption relation is closely related to running-modes of the units. A running-mode for a processing unit is specified by the combination of products produced and consumed and by the quantities of products. Usually, a processing unit has 5–10 or more running modes. In addition, the production of blends depends on the availability of the components produced or stored. The main task of the production plan of a refinery is making the production planning of its units. However, a unit must work in a running mode in any time period. Different running modes correspond to different product production–consumption relationships or product structure.

Fig. 2 shows an example of running modes of FCC, produced and consumed products for the special running-mode. The FCC consumes 1240 tons of AGO (80%) and 310 tons of residue (20%) and produces 70 tons of gas, 217 tons of LPG, 597 tons of gasoline, 510 tons of diesel, and 150 tons of coke, with 6 tons of loss.

Once the running mode of a unit is defined, the products and quantities are known as well. The production planning problem of the units is therefore transformed to determine the running modes of the units. In addition, running modes of units not only affect the structure of products but also their inventory. Long time use of a running mode increases inventories of corresponding products and hence the cost, while short work time of a running mode means frequent mode switch with higher switching cost, because stabilization time of 1–2 h is needed after switch, with products downgraded for sale. The profit is reduced by frequent switches. Therefore, there is a tradeoff for the use of running modes of processing units.

Commercial fuels, such as gasoline and diesel products, are blended according to blending schemes for meeting market demands. A blend product in general has many blending schemes. With different blending schemes, the cost difference is quite large.

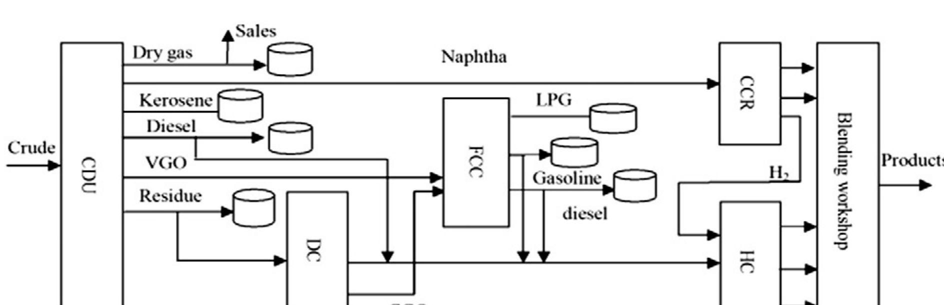

Fig. 1. Production flowchart for a refinery.