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Market-oriented scheduling and economic optimization of continuous multi-grade chemical processes

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Abstract

In this paper an approach for flexible production scheduling for continuous multi-grade chemical processes is proposed. The approach integrates the economics of production and of company–market interaction for single-machine multi-grade continuous processes. The operation of a continuous multi-grade plant is modeled utilizing the detailed inclusion of grade transitions and sales orders and opportunities. The added value of the operation, which is used as the criterion function, is modeled by analyzing the costs and benefits of plant operation. The model results in a mixed integer linear program which is solved to compute suitable short term production and sales decisions. The approach is demonstrated on a gas phase HDPE manufacturing plant.

Keywords: Process optimal operation; Continuous scheduling; Grade transitions; HDPE production

1. Introduction

During the past decades the chemical industry has been faced with a major change into a *globally competing* and *demand driven* mode of operation. Companies are required to respond quickly to changing market situations and must meet customer-specified product specifications. A main challenge and a key to demand-driven operation, is the allocation of production resources to comply with orders and physical constraints such as plant capacity and storage facilities. Such problems are generally referred to as *scheduling* problems, and their role in the internal supply chain of manufacturing companies is broadly acknowledged. An overview can be found in [11]. Although most of the scheduling literature focuses on *batch* operations, there is recent work on continuous process scheduling, see [8,4,9]. The approach here will consider continuous, single-stage, multi-grade chemical plants, and differs from the work cited in several aspects. Our way of including the effect of process transitions on the material flows appears new, although in a recent paper [12], a formal way of modeling the effect of grade transitions on product flows has been presented in relation to a continuous time formulation cyclic scheduling problem for hybrid flowshop facilities. In Giannelos and Georgiadis [4] sequence-dependent changeover tasks are modeled, however their effect on the material balance is not considered. Further, most scheduling studies assume the order base to be fixed in advance and strive for 'minimum makespan', 'minimum lateness', production maximization or cost minimization. In our approach, the negotiation of sales orders and purchases is an integral part of the decision making that is supported by the scheduler, and to this end the scheduler selects a set of appealing purchase and sales transactions from a larger set of possible transactions (denoted *opportunities*). Making the schedule responsive to varying market situations, implies that it will not exhibit simple structures like for example a cyclic

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Nomenclature

Symbols

C	raw material consumption (rate)
ES	end product storage
$E\$$	end product storage end-appreciation
g	grade
G	grade variable
H	horizon length
J	objective value
k	time index
n	number
P	purchase variable
$P\$$	purchase unit price
PA	purchase amount
PO	purchase order/opportunity variable
RS	raw material storage
$R\$$	raw material storage end-appreciation
S	sales variable
SA	sales amount
$S\$$	sales unit price
SO	sales order/opportunity variable
T	transition variable
TC	raw material consumption during transition
TM	transition mode
TY	end product yield during transition
V	intermediate objective value
Y	end product yield (rate)
γ	interest rate (per time span)
τ	(transition) time interval
Ω	set of time spans

Sub/superscripts

e	end product index
g,h	grade index
initial	initial value
k	time index
l	lower bound
m	transition mode
p	purchasing order/opportunity index
r	raw material index
s	sales order/opportunity index
u	upper bound

structure. The scheduling approach described in this paper is probably less general than formulation posed by Mockus and Reklaitis [9] and Lee and Lee [5], in the sense that for the moment, only single-machine chemical plants are considered. Nevertheless, with the detailed inclusion of grade transitions and sales orders and opportunities it is believed to capture some of the essential and distinguishing elements of the short term scheduling problem encountered in many high-volume chemical production plants.

The scheduling approach considered here includes a formulation of the grade change problem that includes a truly economic objective. This way, a feasible interconnection of the short-term scheduler and the process control and optimization functions that operate on a faster time scale is achieved. The paper presents a survey of work available in detail in Tousain [14].

2. Demand driven operation

The scheduling task concerns the timing of feedstock and grade changes. Most of today's multi-grade plants are still operated according to a predetermined sequence of product grades, called a *product slate* or a *product wheel*, see Fig. 1 [13]. The sequence is constructed such that the necessary grade changes are relatively easy, safe and well-known by the operating staff. Nowadays, the product slate mode of process operation is often considered inadequate by companies operating in competitive and fast changing markets. To maximize their responsiveness to the market, the restrictions and the potential of the processing plant have to be taken into account in a nonconservative manner, so that the limit in addressing the market is in the true plant limitations and not in the effects of ill-communication between sales managers and plant managers. Further, a responsive company does not require large stocks of its products to be able to cope with varying demands: it will handle those through operating *flexibility*, maintaining only the minimum required stock levels. Customer satisfaction is prioritized and this is put in practice by responding flexibly to specific quality demands and by guaranteeing short delivery times.

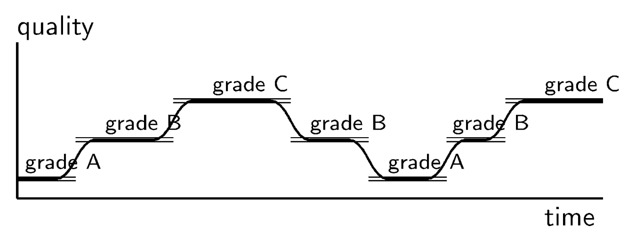

Fig. 1. A product grade slate A–B–C–B–A with on-spec-ranges.

One of the most important technological issues to be resolved to enable such a flexible operating mode is the development of decision support systems which enable to control the main decisions in the internal supply chain