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Grassroot design of storageless batch plants

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Abstract

In this paper, a simultaneous design, synthesis and scheduling method for multipurpose storageless batch plants using the process intermediate storage (PIS) operational policy, is presented. The model is a time-point based mixed integer linear program (MILP) or mixed integer non-linear program (MINLP) formulation based on the State Sequence Network (SSN). The superstructure of all possible plant designs is constructed according to the potential availability of all possible process units. It is assumed that all units in a stage have the same capacity. The model is applied to a case study and gives good results.

Keywords: Batch scheduling, batch plant design, intermediate storage

1. Introduction

The production of low-volume high-value-added products such as pharmaceuticals and agrochemicals is the premise of batch plants. Due to the discrete nature of these processes, the scheduling of tasks is crucial to the operation. As with all facilities, the capital cost is significantly dependent on the size of the plant. It would, therefore, be advantageous to reduce plant size. In order to achieve this goal, the amount of intermediate storage is generally reduced.

Using the Gantt chart of a typical batch plant, as seen in Fig. 1., it can be noted that some units are idle and empty for large portions of the time horizon of interest. This unit availability affords the opportunity of using these units as intermediate storage. The use of process units in this way is known as the PIS operational policy. Although from this observation, the minimum amount of intermediate storage can be found, the capacity is rarely zero. However, this can be the case if there is an increase in the size of the process units.

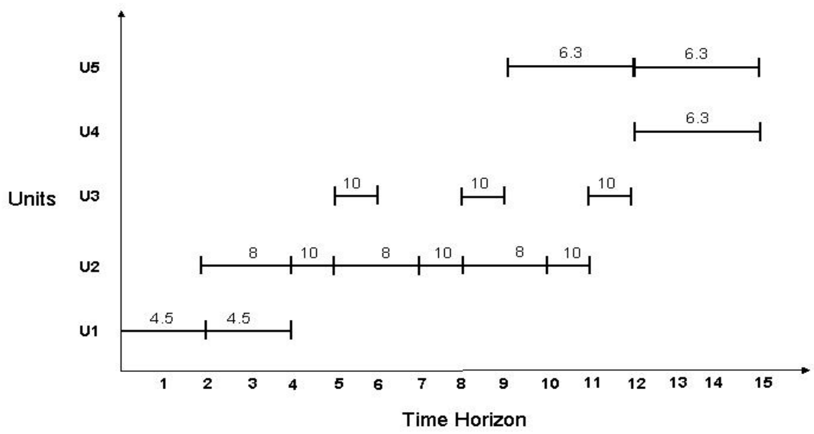

Figure 1: Schedule of a typical batch plant

Recently, a large amount of work has been done in the field of design of batch plants, as can be seen from the review by Barbosa-Povoa (2006) [1]. However, none of the methods reviewed take the PIS operational policy into account.

2. Problem statement

The problem considered in this investigation can be stated as follows,

Given:
- the production recipes, i.e. processing times for each task in a suitable unit as well as their sequence,
- the availability and suitability of process vessels,
- the potential number of process units in a stage, and range of capacity of potential process vessels,
- production requirement, and

- the time horizon of interest,

determine:

- the optimal sequence of tasks within the time horizon of interest, and
- the amount of material being processed at each time in each unit,

so as to minimize the capital cost.

3. Mathematical model

The model is based on the SSN and time-point based MILP model developed by Majozi and Zhu (2001) [2]. As such a number of the constraints are similar. Two of the more important constraints that were added are shown.

A unit can be used in two modes, that of processing or storing. However a unit cannot store and process at the same time. Neither can more than one state be stored in a unit at any given time point. This condition is ensured by Eq. 1.

$$\sum_{s} y'(s,i,p) + \sum_{s_{in}} y(s_{in},i,p) \le 1 \tag{1}$$

where,

$y(s_{in},i,p)$ is the binary variable associated with the processing of state s in unit i at time point p

$y'(s_{in},i,p)$ is the binary variable associated with the storage of state s in unit i at time point p

The mass balance over a process unit which is in storage mode is given by Eq. 2. It should be noted that the state does not change when entering or exiting the unit in storage mode. The only way a state can change is when it is processed.

$$\sum_{i' \in I} m_u^{ls}\left(s,i',i,p-1\right) = \sum_{i' \in I} m_p^{ls}\left(s,i,i',p\right) \tag{2}$$

where,

$m_u^{ls}\left(s,i',i,p\right)$ is the amount of state s to be stored in unit i from unit i' at time point p

$m_p^{ls}\left(s,i,i',p\right)$ is the amount of state s from unit i to unit i' at time point p

4. Case study

The case study is a modification of the example used by Ierapetritou & Floudas (1998) [3] and Majozi and Zhu (2001) [2]. The flow sheet of the plant is shown in Fig. 2. The data for the example is shown in Tables 1 and 2. The time horizon of interest is 24 hours.

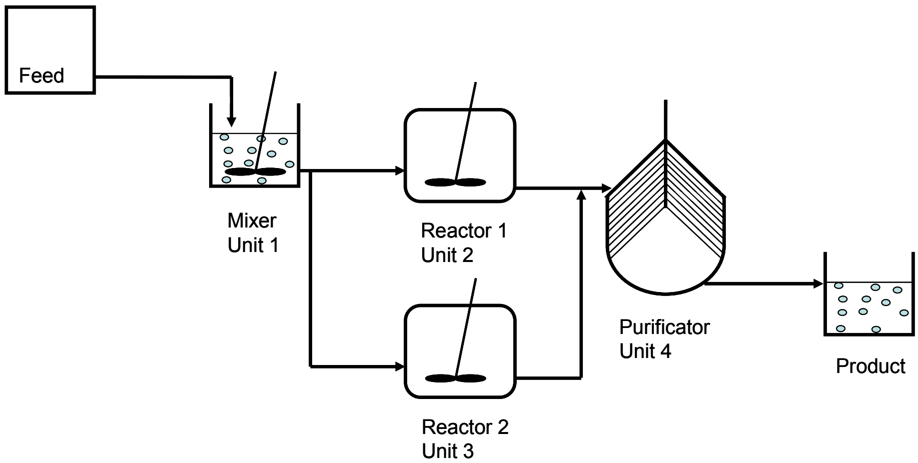

Figure 2: Plant superstructure for case study

Table 1. Unit data for case study

Unit	Capacity range	Suitability	Processing time (h)	Capital Cost
1	25 – 100	Mixing	4.5	$V^{0.68}$
2, 3	25 – 75	Reaction	3.0	$V^{0.6}$
4	25 – 50	Purification	1.5	$V^{0.7}$

Table 2. Data for case study

State	Storage capacity	Initial amount	Production requirement
1	Unlimited	Unlimited	0
2	100	0	0
3	100	0	0
4	Unlimited	0	300

5. Results & discussion

The model was solved using GAMS and the DICOPT solver, with CLPEX as the MIP solver and CONOPT as the NLP solver, on an Intel Pentium 4, 3.2GHz processor with 512 Mb of RAM. The computational results are shown in Table 3. The resulting plant requires only one reactor as shown in Fig. 3. The optimal volumes of the remaining units are 75 units for the mixer (U1), 75 units for the reactor (U2) and 37.5 units for the purificator (U3). The resulting schedule for the optimal plant is shown in Fig. 4, where the numbers above the bars are the amount of each state processed and the dotted lines represent the storage of a state in a process unit.

Table 3. Computational results for case study

Model property	Model results
Number of time points	10
Number of constraints	6,638
Number of variables	1,404
Number of binary variables	142
MINLP solution	44.82
CPU time (s)	47.656

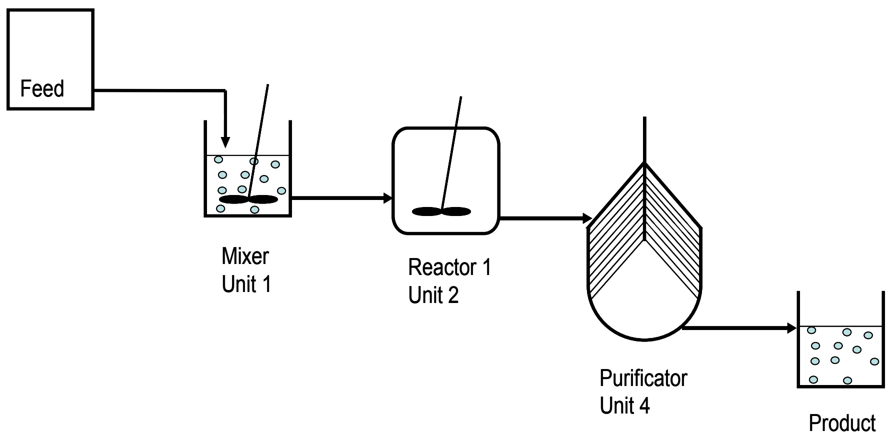

Figure 3: Optimal plant structure for the case study

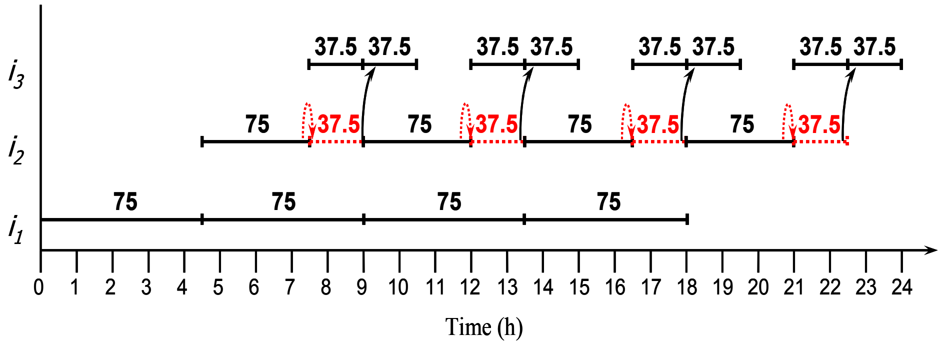

Figure 4: Optimal schedule for the case study

6. Conclusions

The model can be used to design storageless multipurpose batch plants using the PIS operational policy, as shown by the case study. The model takes the form of a MILP or MINLP depending on the objective function. For example, in the case study the model was non-linear due to the objective function which was the minimization of capital cost.

Acknowledgements

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