Dynamic Simulation of Segregation Tanks Connected to Optimally Scheduled Multiproduct Batch Plants

Jaydeep Jivani[1], Meka Srinivasarao[2] and Anand P. Dhanwani[3]

[1]*M. Tech student, Chemical Engineering Department,*
FOT, DD University, Nadiad, Gujarat (387001), India
[2]*Professor, Chemical Engineering Department,*
FOT, DD University, Nadiad, Gujarat (387001), India
[3]*Associate Professor, Chemical Engineering Department,*
FOT, DD University, Nadiad, Gujarat (387001), India

ABSTRACT

Batch plant is known for having better flexibility to meet customers demand which varies wildly. Batch operations used in many chemical industries such as Speciality chemicals, food, pharmaceuticals, cosmetics and certain type of polymer etc. Mostly production volumes are small in batch plant operations. To operate these Multi-product batch plants efficiently optimal production planning, scheduling and waste water handling are desirable. Hence, objectives of this work are optimal scheduling, to maximize production and minimize waste water generation and design of waste water handing system for batch flow-shop facility.We have formulated mixed integer linear programme (MILP) model to address the problem of environmental and economic objectives for flow-shop facility. In MILP model we consider different storage policies like no intermediate storage (NIS) and unlimited intermediate storage (UIS) for minimizing the make-span and to identify best sequence of products. Production schedule for each product is determined and represented in the form of Gantt chart. The waste water generated from each plant is connected to segregation tanks. Dynamic simulations are performed to identify time varying nature of the inlet flow rate and the height and concentration variation in segregation tanks are measured using MATLAB-GAMS interface.

Keywords:
Batch plant scheduling, Flow-shop facility, Waste water generation,Product optimization, Segregation tank.

1. INTRODUCTION

Chemical industries incorporate several batch operations (batch reactors, batch distillation, batch drying etc.). Flow-shop facility and Job-shop facility are the two types of production schemes are used for manufacturing several products in a batch process [1]. The arrangement of Manufacturing systems differs either physically or structurally. The physical arrangement consists of Job, Flown Project shop and Manufacturing systems of Continuous process where the most popular one amongst them is the Job-shop manufacturing system. Job shops cater maximum flexibility to manufacture wide variety of products in a concise volume [2]. In Job Shops the manufactured products need different operations thus having variable operation sequences. In job shop plant it is not mandatory for a product to pass through all stages or follow the same sequence of operation in a plant. Conversely, in a flow shop plant every product needs to follow the same sequence of operation and is required to strictly pass through all the stages. Conventionally, Multiproduct plants are also denoted as flow shop plants. The following figure represents the movement of product through different stages in a flow shop plant.

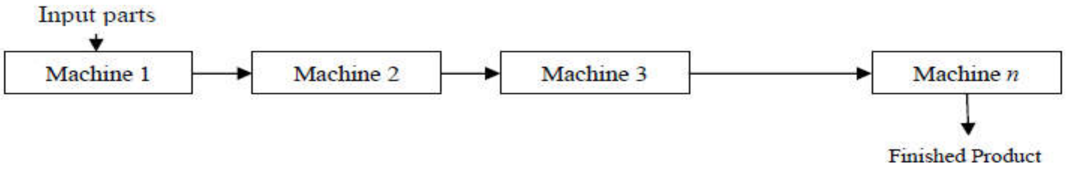

Fig. 1. Representation of Flow-Shop plant

Similar kind of products are required to follow identical processing paths and follow same sequence of manufacturing units. The make span time denotes the consolidated time needed for the manufacturing of all the products produced [2]. To maximize the profit of plant an optimum sequence of the flow of product is highly desirable. Hence, scheduling plays a vital role in maximizing the production and minimizing the make-span time [3]. Flow-shop batch plants schedule different product by sharing similar equipment. Therefore, for getting better quality of product, we require frequent washing of equipment at the changeover to avoid contamination. However, this generates huge amount of variable concentrated waste water which has a negative impact on the environment. So to overcome this major challenge of the multi product treatment plants the generated waste water from each plant is connected to segregation tanks. [4,5]

2. CASE STUDY OF FLOWSHOP PLANT

In current study, hypothetical case is considered to represent a mathematical methodology that addresses the issues of waste water generation from flow-shop plant based on scheduling of products. It also represents the dynamic simulation of height and concentration in segregation tank.

2.1 Problem statement

The industry has four products. Each product flows through three different units (mixer, reactor and separator). The processing times of each product is given in Table 1. Waste water generated from each stage of the production passes through the segregation tanks. Quantity and concentration of waste water generated from each stage shown in Table 3. The volume, height and area of these segregation tanks are considered as 4 kL, 1 m and 4 m^2 respectively.

Table 1. Processing time of products for each unit U_m in hr

Products	Units		
	U_1	U_2	U_3
P_1	12	6	3
P_2	20	8	5
P_3	26	12	3
P_4	16	7	2
Washing time	5	3	2

Table 2. Flow rate of waste water generated of products for each unit U_m in m^3/s

Products	Units		
	U_1	U_2	U_3
P_1	0.0022	0.00055	0.000278
P_2	0.00694	0.00194	0.0005
P_3	0.0033	0.00033	0.00044
P_4	0.00267	0.0022	0.00033

Table 3. Quantity and concentration of waste water generated

Unit	Quantity of Waste Water generated (Kg)				Concentration of Waste water generated (PPM)			
	P_1	P_2	P_3	P_4	P_1	P_2	P_3	P_4
U_1	8000	25000	12000	9600	1100	2400	1800	1000
U_2	2000	7000	1200	8000	800	1200	800	700
U_3	1000	1800	1600	1200	400	700	700	300

3. SOLUTION

The prime objective of this study is to develop an optimal scheduling methodology and formulate a mathematical model to determine the height and concentration of waste water in segregation tank.

Intermediate storages of varied operating types are studied for Multiproduct batch processes. Here, we have developed an optimal sequence algorithm and batch completion time for various storage strategies like UIS (Unlimited Intermediate Storage) and NIS (No Intermediate Storage).

3.1 Mathematical model

- HereP and U represent the no. of products and the no. of units respectively.
- CT_{km} (completion time) denotes the time for k^{th} product with allocation, which leaves unit U_m once it completes the processing.
- PT_{km} is required time to process of k^{th} product in U_m with proper allocation
- T_{km} is required time to process of k^{th} product in U_m
- C_{PU} is the make-span.

3.1.1 Sets

- P_k Product batches to be produced /p_1*p_4/
- U_m Batch processing units in the plant /u_1*u_3/
- j Slots for products in the sequence /1*4/

3.1.2 Variables

- $X_{(k,j)}$ Product k is in sequence slot j
- $CT_{(k,m)}$ Time needed to Complete the product k on unit U_m
- C_{PU} Make-span

Positive variables $CT_{(k,m)}$

Binary variables $X_{(k,j)}$

3.1.3 Specific Objective

The objective of this model is to achieve minimal make-span for given data. The time to complete the processing of all orders is denoted by make-span. The minimization of make-span of all tasks would lead to improvement in the productivity of batch plant.

$$C_{PU} = \sum_{k=1}^{P} \sum_{m=1}^{U} CT_{km}$$

(3.1)

3.1.4 Product Allocation

Binary variables handle only single product at a time of slot j in the sequence for making optimal decisions in optimization problems,

$$\sum_{k=1}^{P} X_{kj} = 1$$

j= 1, 2.... P. (3.2)

Similarly, only one slot should be occupied by product in the sequence,

$$\sum_{j=1}^{P} X_{kj} = 1$$

k = 1, 2… P (3.3)

3.1.5 Processing time of product

If product P_k is in slot j, then PT_{km} is determined as follows

$$PT_{km} = \sum_{j=1}^{P} X_{kj} * T_{km}$$

k, j = 1,2…P, m=1, 2…U (3.4)

3.2 No Intermediate Storage (NIS) Policy Model

NIS policy, It does not require the intermediate storage in the batch processes plant. Hence, in the case IfUnit$U_{(m+1)}$ is not free and a product completes on unit U_m, in that scenario the finished product must be storedin unit U_m till it finds unit $U_{(m+1)}$ to be free. [2,6]

3.2.1 Constraints of NIS policy

- kth product is not supposed to leave unit U_m if it is not processed
- Product can leave unit $U_{(m-1)}$. Once it gets processed on unit U_m

$CT_{km} \geq CT_{k(m-1)} + PT_{km}$ k= 1,2..P , m = 2,3…U (3.5)

- kth product cannot leave from unit U_m, without the removal of $(k-1)^{th}$ product, therefore

$CT_{km} \geq CT_{(k-1)m} + PT_{km}$ k= 1,2..P , m = 1,2…U (3.6)

- Lastly kth product cannot move from unit U_m, Without the free of $U_{(m+1)}$

$CT_{km} \geq CT_{(k-1)(m+1)}$ k= 1,2..P , m = 1,2…U-1 (3.7)

3.3 Unlimited Intermediate Storage (UIS) policy Model

Under UIS policy every pair of consecutive units has P-1 storages between them. This indicates that a product k finished at unit m should not necessarily occupy the same unit until it is ready to be processed at the next unit.

At any given point of time, if the next unit (i.e. m+1) isn't ready to process product k, then the product can be switched to any other available storage unit. [2]

3.3.1 Constraints of UIS policy

- If $CT_{k(m-1)}$ is minimum, then product k is stored in the unlimited storage tank
- If $CT_{(k-1)m}$ is minimum, then unit U_m is free until product k gets completed from $U_{(m-1)}$

$CT_{km} \geq \text{Max}\,[\,CT_{k(m-1)}, CT_{(k-1)m}\,] + PT_{km}$ k= 1,2..P , m = 1,2…U (3.8)

- k^{th} product cannot leave from unit U_m, without the removal of $(k-1)^{th}$ product, therefore

$CT_{km} \geq CT_{(k-1)m} + PT_{km}$ k= 1,2..P , m = 1,2…U (3.9)

4. RESULTS & DISCUSSION

Result of this case study for process and waste water generation details of products of single as well as multiple cycle is obtained using GAMS and MATLAB interface. The discharge waste water from each unit goes to the segregation tanks. Quantity of waste water intake in segregation tank is based on scheduling of products. The following figures reflect the height and concentration for the segregation tank.

4.1 No Intermediate Storage (NIS) policy results

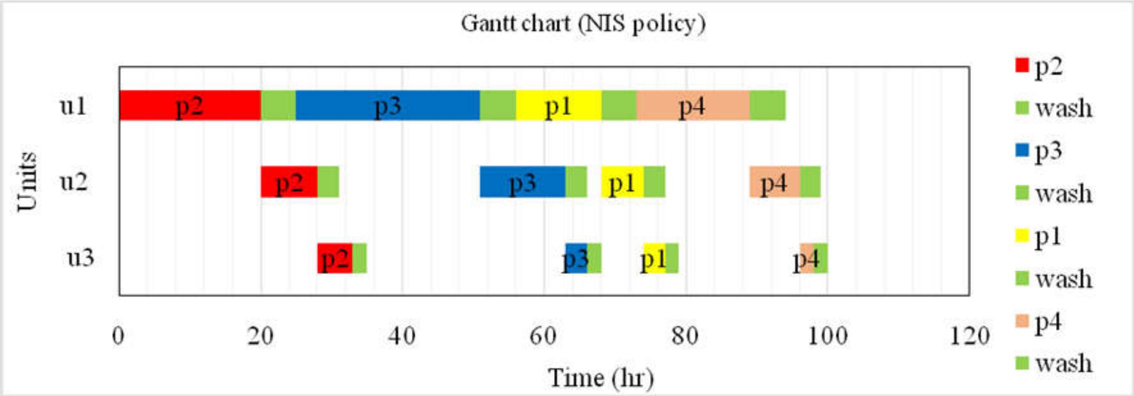

Fig. 2. Gantt chart of NIS policy model

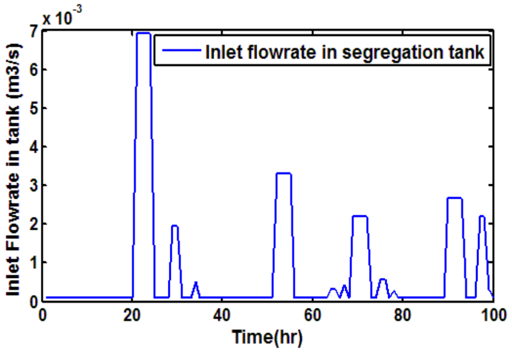

Fig. 3. Inlet waste water flowrate in tank

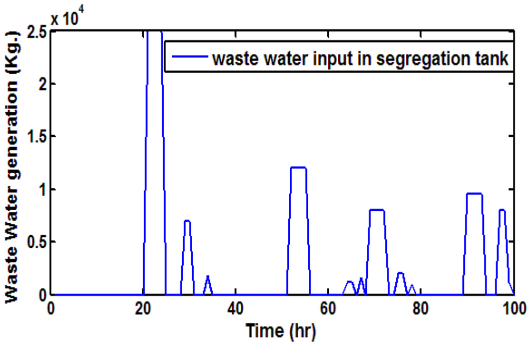

Fig. 4. Inlet waste water quantity in tank

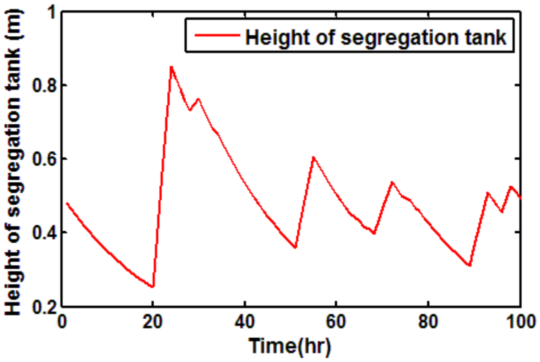

Fig. 5. Height in segregation tank

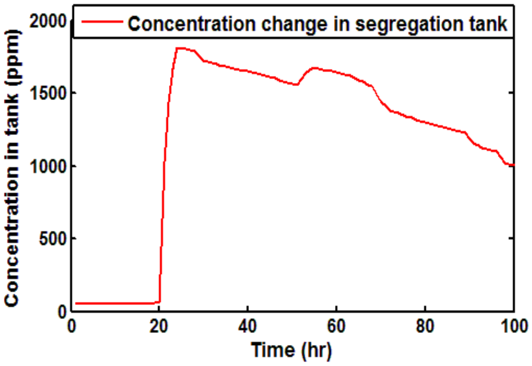

Fig. 6. Concentration in segregation tank

Waste water generation for four product forms a cycle after a fixed period of time which can be observed from Fig. 3 and Fig. 4. For NIS policy model, the observed maximum height and maximum concentration of tank are 0.85 m (Fig. 5) and 1800 ppm (Fig. 6) respectively. Here, GAMS result data represents only one cycle of all four products based on scheduling (P_2-P_3-P_1-P_4). Inlet waste water and its concentration into treatment plant from segregation tank based on its opening valve characteristic.

4.2 Unlimited Intermediate Storage (UIS) results

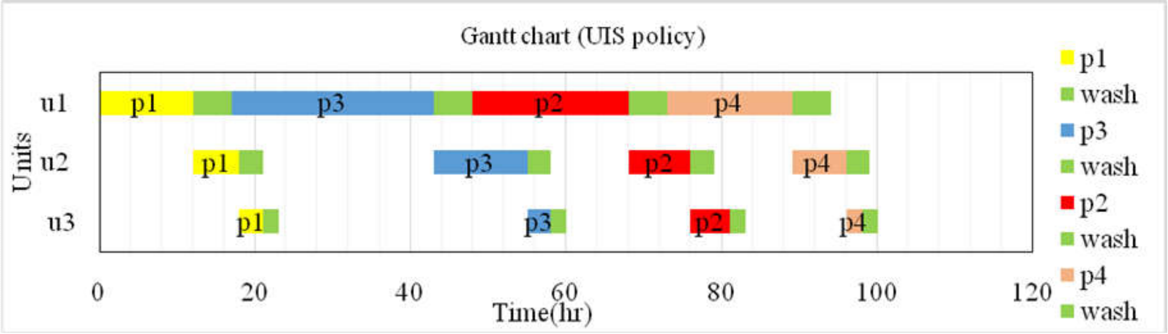

Fig. 7. Gantt chart of UIS policy model

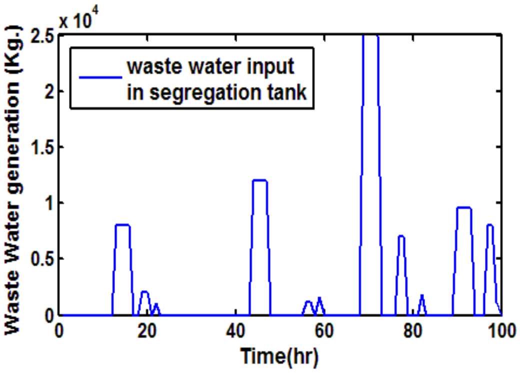

Fig. 8. Inlet waste water quantity in tank

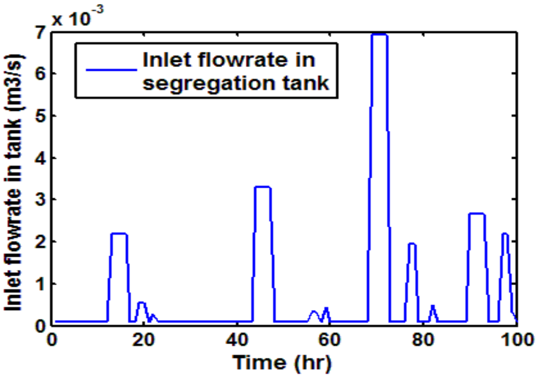

Fig. 9. Inlet waste water flowrate in tank

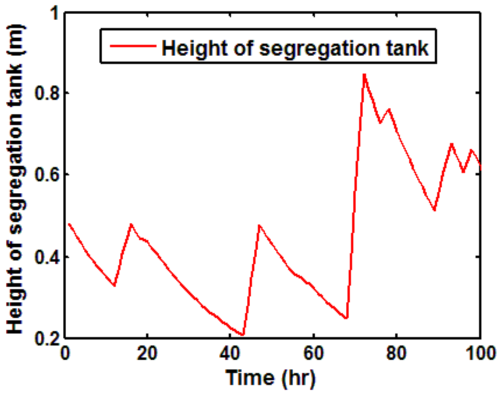

Fig. 10. Height in segregation tank

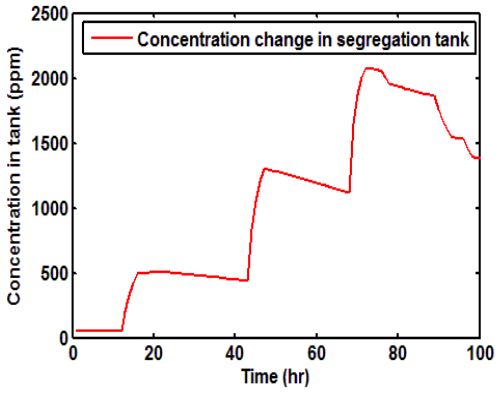

Fig.11.Concentration in segregation tank

Waste water generated for four product forms a cycle after a fixed period of time which can be observed from Fig. 8 and Fig. 9. For UIS policy model, the observed maximum height and maximum concentration of tank are 0.82 m (Fig. 10) and 2100 ppm (Fig. 11) respectively. Here, GAMS result data represents only one cycle of all four products based on scheduling (P_1-P_3-P_2-P_4). Inlet waste water and its concentration into treatment plant from segregation tank based on its opening valve characteristic.

5. CONCLUSIONS

Scheduling of products in flow-shop plant gives idea about waste water generation from each unit. Waste water generated from each unit is connected to the segregation tank. The GAMS – MATLAB interface is used to generate dynamic simulation which provides the basis for determining the variation in height and concentration of the segregation tank. The segregation tank in NIS policy model requires greater height than that of the UIS policy model. However, concentration of segregation tank is higher in UIS policy model as compared to the NIS policy model. The height of segregation tank gives an idea about overflow of the tank as well as the status of concentration of the waste water for the treatment plant. Therefore, based on the above results one can redesign or manipulate the desired parameters which are essential for the waste water handling system.

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