CHAPTER II

THEORIES AND LITERATURE REVIEWS

2.1. Theories

2.1.1 Suspension polyvinyl chloride kinetic reaction

Suspension polyvinyl chloride production is essentially a polymerization process carried out in millions of small "reactors" (droplets). Liquid vinyl chloride under its autogeneous vapor pressure is dispersed in water by vigorous stirring in a reactor (autoclave), fitted with a jacket and condenser for heat removal and baffles for optimum agitation. This results in the formation of droplets with an average diameter of 100 – 175 micron. These droplets are stabilized against coalescence by one or more protective colloids (granulating agent). The other essential ingredient is a monomer-soluble free radical initiator.

The formulations charged to the reactors are determined by the recipe. A basic recipe for suspension processes can be simply water, VCM, initiator, and suspension agent, for example;

1. VCM 100 parts
2. Water 100 – 130 parts
3. Protective colloid 0.05 – 0.15 parts
4. Initiator 0.03 – 0.08 parts

These quantities vary depending on the PVC grade, reactor size, plant type, etc. Optimum morphology is achieved by employing additives, such as oxygen, buffers, secondary or tertiary dispersing agents, chain-transfer or chain-extending agents, co-monomers, antioxidants, together with the right level of agitation and homogenization and the correct charging procedure and timing for each additive addition. A combination of just the right number and degree of the above parameters to achieve the optimum morphology determines the quality of a PVC grade.

After charging, the reactor content is heated to the reaction temperature of 45°–70 °C. Reactors are 80 – 95 % full at this stage. Heat causes some of the initiator to decompose into free radicals, and the monomer in the droplets begins to polymerize. The strongly exothermic reaction (1540 kJ/kg) is controlled by removing heat via the jacket and by boil-off into a condenser from which the condensed monomer is returned to the reactor.

Progress of the reaction in a jacketed reactor can be followed by continuously monitoring the water temperature in the jacket since flow rate is constant and a constant batch temperature is maintained by progressively reducing the cooling water temperature with injection of initiator or retardant.

Although PVC is insoluble in its monomer the polymer is swollen by ca. 27 wt % VCM to form a coherent gel. Therefore, as the conversion increases towards 70 %

and beyond, the pressure in the reactor starts to fall; slowly at first, but then much more rapidly as the last of the free liquid monomer is consumed. Polymerization continues in the gel phase, very rapidly at first since chain termination is hindered by lack of mobility of the growing chain, but, as conversion increases beyond 80 – 90 %, monomer starvation rapidly reduces the rate. The chemical reaction equation to converse Vinyl chloride to be Polyvinyl chloride is in Fig 2.1.

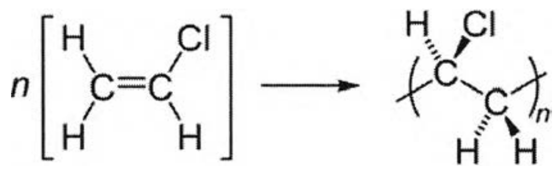

Figure 2.1 Polymerization from vinyl chloride to be polyvinyl chloride (Wikipedia, 2008)

The reaction is terminated at a predetermined pressure by either adding a chain terminator and/or venting off the un-reacted monomer to the recovery plant. After venting, the resin in the aqueous slurry can still contain 2 – 3 % un-reacted monomer, which is removed by stripping continuously in a column. The batch is discharged from reactor to a feed vessel and then fed continuously through a stripper column. The un-reacted monomer is recovered, liquefied, and reused in later polymerizations. After passing through a heat exchanger the slurry is fed to a continuous centrifuge to give a wet- cake with 20 – 30 % moisture content. The remaining water is then removed by conventional fluid-bed drying to give a dry free-flowing powder with a residual VCM content below 1 PPM. The chain symbol of polyvinyl chloride is in Fig 2.2.

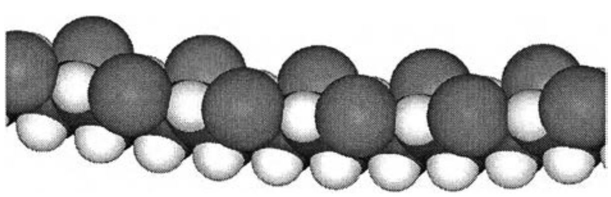

Figure 2.2 The chain symbol of polyvinyl chloride (Wikipedia, 2008)

2.1.2 Properties of polyvinyl chloride resin (Wikipedia, 2008)

Some interested properties of polyvinyl chloride are in table 3 below.

Table 2.1 Properties of polyvinyl chloride resin (A.K. vam der Vegt & L.E. Govaert, Polymeren, van keten tot kunstof, 2008)

Property	Data
Density	1380 kg/m3
Young's modulus (E)	2900-3300 MPa
Tensile strength(σt)	50-80 MPa
Elongation at break	20-40%
Notch test	2-5 kJ/m^2
Glass temperature	87 °C
Melting point	80 °C
Vicat B[1]	85 °C
Heat transfer coefficient (λ)	0.16 W/(m·K)
Effective heat of combustion	17.95 MJ/kg
Linear expansion coefficient (α)	8 10^{-5}/K
Specific heat (c)	0.9 kJ/(kg·K)
Water absorption (ASTM)	0.04-0.4
Price	0.5-1.25 €/kg

[1] Deformation temperature at 10 kN needle load.

2.2 Suspension Polyvinyl chloride process description

The process flow diagram of suspension polyvinyl chloride is followed Fig 2.3 here below.

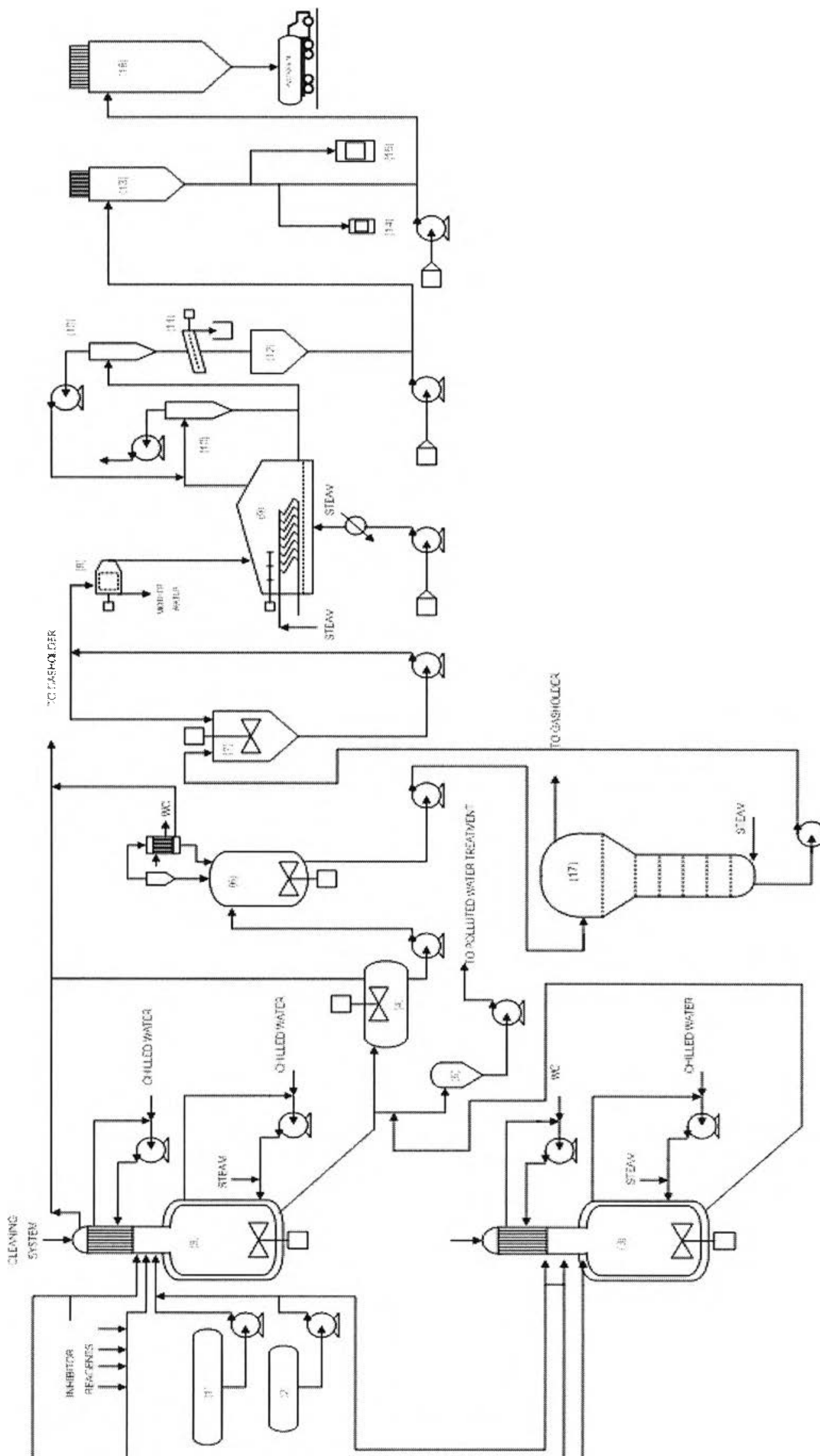

Figure 2.3 Process flow diagram of suspension polyvinyl chloride production line

The list of equipment is here below.

1. VCM storage tank
2. VCR storage tank
3. Autoclave
4. Degasser
5. Wash water drum
6. Column buffer feed tank
7. Dryer feed tank
8. Centrifugal decanter
9. Fluidized bed dryer
10. Cyclone
11. Vibrating screen
12. Intermediate hopper
13. Waiting silo or bagging silo
14. 25 kg bag packer
15. 500 kg bag packer
16. Product bulk silo
17. Stripping column

2.2.1 Suspension polyvinyl chloride polymerization

Autoclave is a 140 m^3 agitated pressure vessel (agitated by bottom agitator) provided with a jacket in which chilled water is circulated by pump. Autoclave is equipped with a top condenser fed by cooling water which is circulated by pump independently from the other autoclave.

Autoclave, agitator and condenser are treated through a proprietary surface treatment to avoid PVC build-up on walls.

VCM will be loaded from storage via filters. The existing VCM charge pumps will be used.

Initiator, necessary for one individual polymerization is prepared by batch, in the initiator synthesis sector. Initiator transfer from synthesis sector to polymerization is performed through lines that are cooled with refrigerant. An existing intermediate initiator storage drum equipped with an existing recirculation and charge pump.

Autoclave is equipped with high pressure cleaning valve. After empting of autoclave, autoclave will be cleaned. And the cleaning water of autoclave will be sent to existing waste water drum.

2.2.2. Degassing and stripping

After polymerization, autoclave is emptied in the existing agitated degasser. Degasser is a 180 m^3 pressure vessel intended to take the entire load of the new and the existing autoclave. During transfer of the slurry from the autoclave to the degasser both vessel are equilibrated via an equilibration line.

From degasser, slurry is transferred by pump to column feed tank over a slurry filter. Column feed tank is the buffer vessel between batch wise operated polymerization section and stripping section, which is operated continuously.

Column feed tank is a 65 m^3 agitated vessel kept at the gasholder pressure. Column feed tank is connected to degassing network via the existing cyclone. Most of the remaining VC gas will be degassed here.

Column feed tank will keep the batch stripping function in case of problems with the column. The crust and rinsing water of slurry filter will be sent to waste water drum. From column feed tank, the degassed slurry is sent to the stripping section by pump.

Steam stripping of PVC slurry is performed in stripping column. At the top of this column, there are two condensers connected in series (two stage condensation). The first condenser is a water condenser. The second condenser is operated on cooling water. The feed to the column is preheated in a spiral heat exchanger against the bottom stream of the column. The bottom stream of the stripper column is pumped to the slurry tank.

2.2.3 Drying unit

The slurry tank will be reused. The tanks are equipped with an agitator. The pump will pump slurry from slurry tank to centrifuge for mechanical drying.

PVC is dried in a heated fluidized bed dryer. The back-mix section of the fluid bed drier is equipped with two cake feeders and a cake distributor providing isolation between the centrifuge and the fluid bed. Inside the fluid bed the PVC slurry is dried against hot air. The hot air will be introduced in the drier by a directional bedplate. Heat input is realized via the fluidization air and via a set of heating bundles.

The dry air leaving bed is de-dusted in cyclone. Recovered PVC particles are recycled back to the dryer or to the outlet chute via a rotary valve. The PVC product leaves the fluidized bed via the discharge chute. A rotary valve is located under the discharge hood. From there the product falls into product distributor.

Dried PVC is screened to remove oversized particles and finally transferred pneumatically to the product bagging silos.

2.3 Design and scheduling of batch processes

While many chemicals products are manufacturing in large scale continuous process, it is also the case that chemicals are often manufactured in batch processes, especially if the production volumes are rather small. With the recent trend of building small flexible plants that are close to the markets of consumption, there has been renewed interest in batch processes (Reklaitis, 1990; Rippin, 1993).

2.3.1 Single product batch plant (Biegler, 1999)

Since it is manufacturer many batches or lots, one of the first decisions that need to make is weather we will use a non-overlapping or an overlapping operation as shows in Fig 2.4. In the non-overlapping operation, each batch is processed until the preceding one is completed. In this way no two batches are manufactured simultaneously. In the overlapping operation, one the other hand, we eliminate the idle times as much as possible which then leads to the simultaneous production of batches. For instance, after 7 hours the first batch has been completed in the third stage, while the second batch has been proceeded 75% of the time in stage 1.

From Fig 2.4, it is clear that the overlapping mode of operation is more efficient because the idle times are greatly reduced. In fact, stage 1 has no idle time, it operates without interruption. Also, what Fig 2.4b suggests is that stage 1 represents the bottle-neck for manufacturing successive batches.

The above observation can be quantified with the following definition of cycle time, CT.

$$CT = t_f - t_s$$

Where t_s and t_f are the initial and final times of each operating cycle. So, for instance in Fig 2.4a, we have for each stage:

$CT_1 = (8 + t_{s1}) - t_{s1} = 8$ hours
$CT_2 = (8 + t_{s2}) - t_{s2} = 8$ hours
$CT_3 = (8 + t_{s3}) - t_{s3} = 8$ hours
$CT_4 = (8 + t_{s4}) - t_{s4} = 8$ hours

Where t_{s1}, t_{s2}, t_{s3} and t_{s4} are the initial times at each stage. It is clear that all stages operate with identical cycle times of 8 hour.

For the case of Fig 2.4b, the cycle times for each stage are as follows:

$CT_1 = (4 + t_{s1}) - t_{s1} = 4$ hours
$CT_2 = (4 + t_{s2}) - t_{s2} = 4$ hours
$CT_3 = (4 + t_{s3}) - t_{s3} = 4$ hours
$CT_4 = (4 + t_{s4}) - t_{s4} = 4$ hours

Thus, the cycle time is 4 hours for all stages. In this way for Fig 2.4a $CT = 8$ hours implies every 8 hours a batch is manufactured, while for figure 9b with CT = 4 hours, a batch is completed every 4 hours.

From above example, it is clearly follows that the cycle times for a single product plant are given in the general as follows:

1. Cycle time non-overlapping operation

$$CT = \sum_{j=1}^{M} \tau_j \tag{2.1}$$

2. Cycle time overlapping operation

$$CT = \max_{j=1,M} \{\tau_j\} \tag{2.2}$$

Where τ_j is the processing time in stage j, the above equations can easily be verified with this example. It should also be mentioned that the scheduling term make span corresponds to the total time required to produce a given number of batches.

From figure 2.4a it can be seen that the make span for proceeding two batches is 16 hours; for figure 9b it is 12 hours.

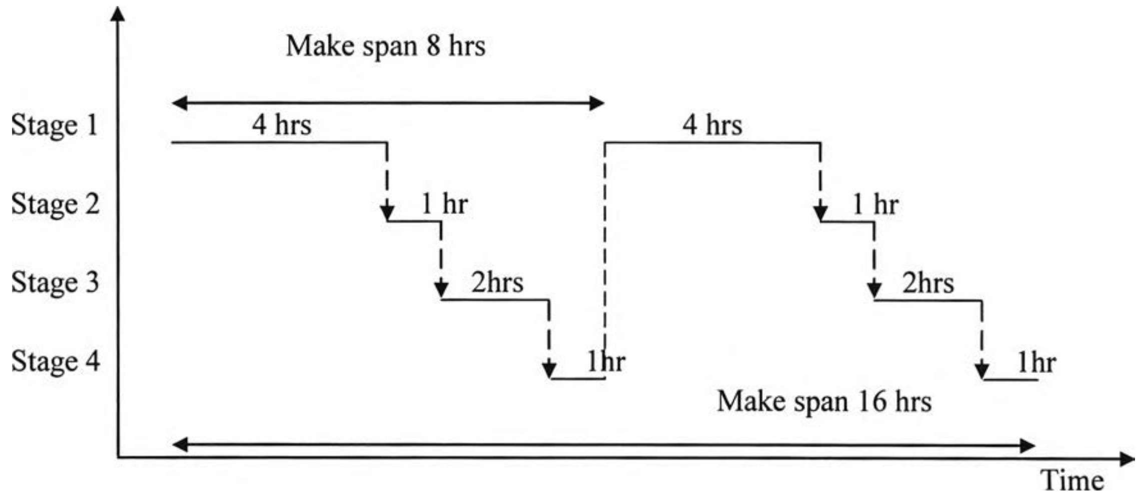

Figure 2.4a Non-overlapping mode operation (Biegler, 1999)

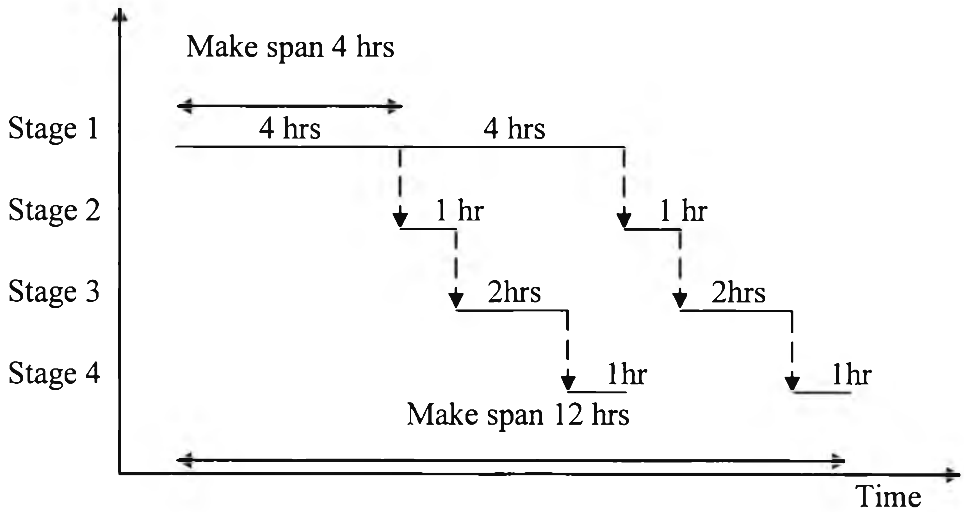

Figure 2.4b Overlapping mode operation (Biegler, 1999)

2.3.2 Parallel unit and intermediate storage (Biegler, 1999)

In the previous topic, the examples have dealt with simple sequential flow shop plants that involve one unit per stage. In this topic, adding intermediate storage tanks between stages or adding parallel units operating out of cycle can increase the efficiency of equipment utilization.

Biegler has shown the example for under standing following here below.

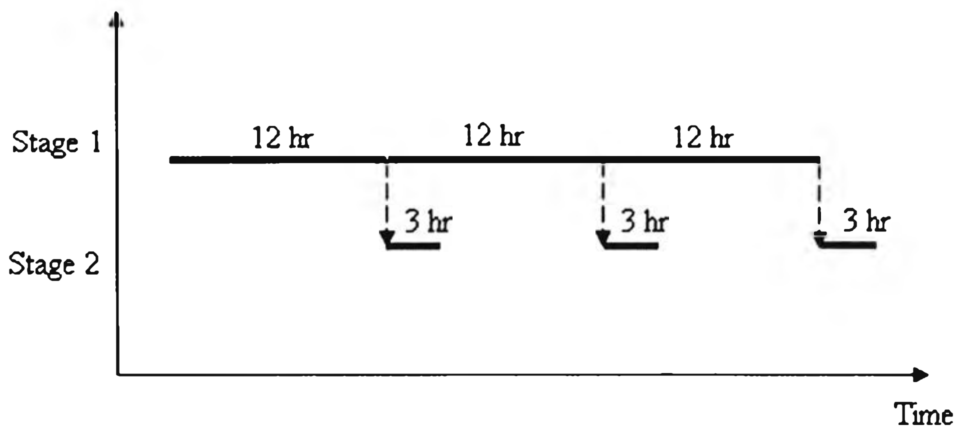

Figure 2.5 Gant chart for fermentation plant (Biegler, 1999)

As an example, consider the fermentation plant in Fig 2.5. in which stage 1 (fermentation) takes 12 hours compared to only 3 hours for stage 2 (separation). For simplicity, it is assumed zero-wait transfer and that the size of the batch in each stage is the same (1000 kg).

It is clear that the cycle time for each batch in Fig 2.5 is 12 hours applying equation 2.2. Since stage 1 is the bottle neck, we might consider adding a unit in parallel in that stage. With this additional unit the plant can be operated as shown in fig 10 in which the cycle time has been reduced to 6 hours the equation for cycle with ZW transfer and parallel units, NP_j, j = 1 … M is the following.

$$CT = \max_{j=1,M} \{\tau_{ij} / NP_j\} \qquad (2.3)$$

Apply to the example in Fig 2.6, this leads to CT =max {12/2, 3} = 6 hours. Note that if a large number of batches are to be produced, then to produce the same amount we can reduce the batch size to 500 kg since the cycle time has been halved.

The other alternative in Fig 2.5 is to introduce intermediate storage between stages. This has the effect of decoupling the two stages so that each stage can operate with different cycle times and batch sizes. As seen in Fig 2.7, stage 1 has a cycle time of 12 hours and handles batches of 1000 kg; stage 2 has a cycle time of 3 hours and handles batches of 250 kg. Thus, for every batch in stage j, four batches can be processed in stage 2. In this case it is also easy to verify that the intermediate storage must hold up to three batches (i.e. 750 kg) and that all the idle times have been eliminated.

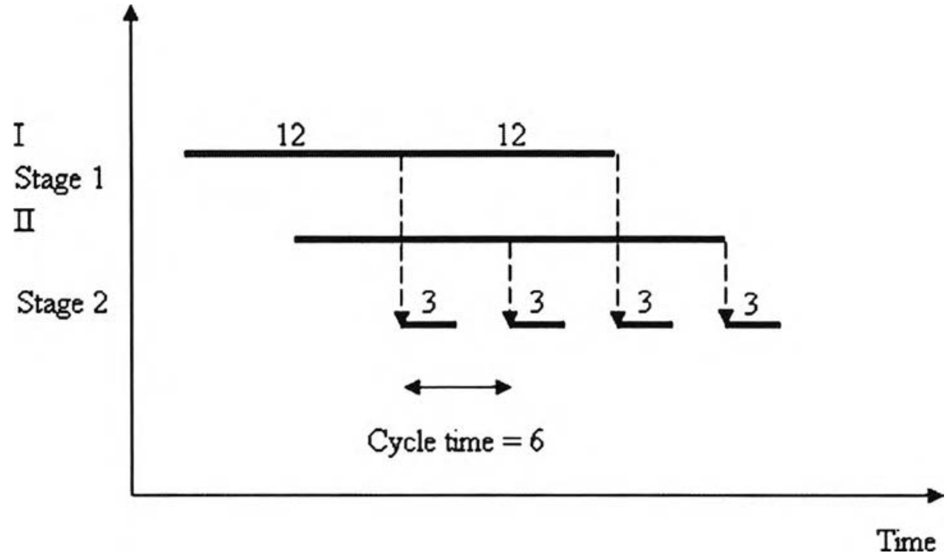

Figure 2.6 Plant with parallel units in fermenter (Biegler, 1999)

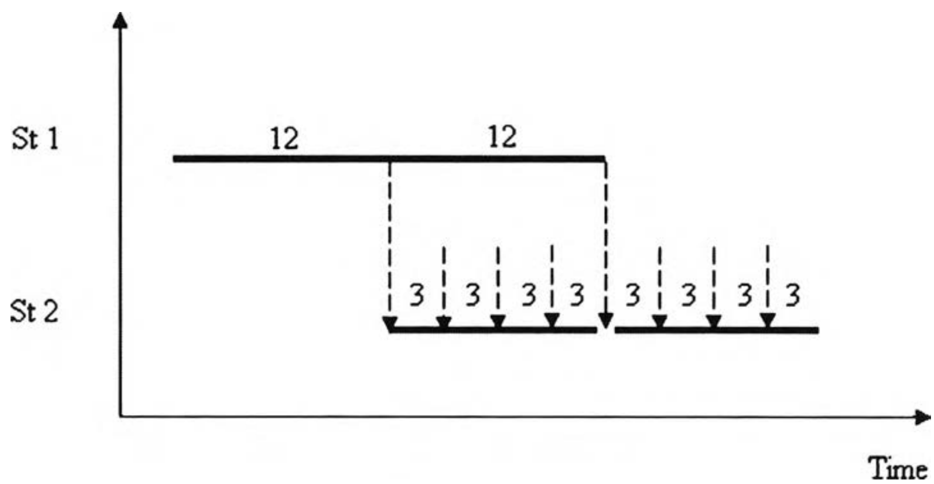

Figure 2.7 Fermentation plant with intermediate storage (Biegler, 1999)

2.3.3 Horizon constrains for flowshop plants-single product campaign (Biegler, 1999)

As Defined in 2.3.1, flow shop plants are those in which all products follow the same sequence through all the processing stages. It is considered in this section the case in which the plant is operated with single-product campaigns and when no intermediate storage is available (Grossmann and Sargent, 1978; Sparrow et al., 1975). This is a relatively simple case in the sense that the production scheduling is greatly simplified, thereby facilitating the considerations (or horizon constraints) at the design stage.

Let consider first the case of plant with one unit per stage for deriving the horizon constraints. We assume that the plant consists of M stage for manufacturing N different products. Giving H, the total horizon time (hrs) over which one production cycle will be considered, and given τ_{ij}, the processing time (hrs) of product i in stage j, $i = 1....N$, $j = 1, ... M$, the major variables to be determined are:

n_i = Number of batches of product i that are to be produced in horizon H
T_{Li} = Cycle time of product i
Θ_i = Time allocated to product I from time horizon H

As was shown in 2.3.1, the cycle time can be determined from the following equation:

$$T_{Li} = \max_{j=1,M} \{\tau_{ij}\} \qquad (2.4)$$

As an example, consider the Gantt chart in Fig 2.8 of a plant with three stages for manufacturing products A and B. Clearly the cycle time for product A is 20 hours.

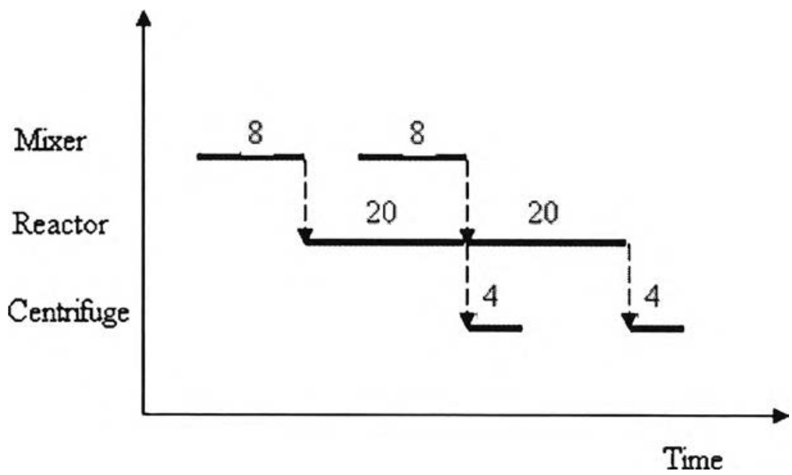

Figure 2.8a Gantt charts with one unit per stage of product A (Lorenz T. Biegler, 1999)

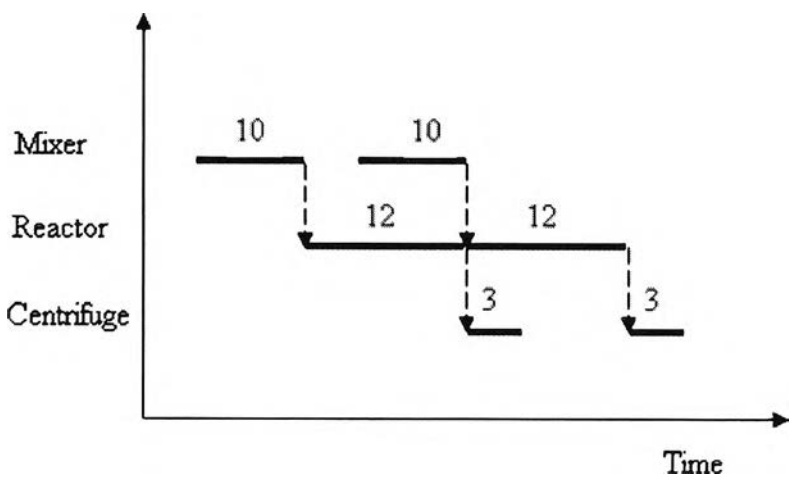

Figure 2.8b Gantt charts with one unit per stage of Product B (Lorenz T. Biegler, 1999)

While for product B it is 12 hours. Since the number of batches n_i is normally large, the "heads" and "tails"of the schedule can be neglected with which the production time Θ_i devoted to each product can be approximated by

$$\Theta_i = n_i\, T_{Li} \qquad i = 1 \ldots N \tag{2.5}$$

$$\sum_{i=1}^{N} \Theta_i \leq H \tag{2.6}$$

Substituting in equation 2.5, the horizon constraint for one unit per stage can be written in terms of number of batches n_i,

$$\sum_{i=1}^{N} n_i\, T_{Li} \leq H \tag{2.7}$$

Where the cycle time T_{Li} as given by above is a fixed parameter.

For the case when N_j parallel units might be use at each state of the flowshop plant, the cycle time T_{Li} is expressed as follows that,

$$T_{Li} = \max_{j = 1, M} \{ \tau_{ij}/N_j \} \tag{2.8}$$

Assume now that in our example we have $N_{\text{mixer}} = N_{\text{reactor}} = 2$, $N_{\text{centrifuge}} = 1$, From equation 5.8 and Figure 12, it follows that,

$T_{La} = \max \{8, 20/2, 4\} = 10$ hrs
$T_{La} = \max \{10, 12/2, 3\} = 10$ hrs

Figure 2.9 displays the operation of the plant with these cycle times.

Note that in this case for product A bottleneck is in the reactor. However, since we can process the batches twice as fast, the cycle time is 10 hours. For the case of product B, the bottleneck is now shifted to the mixer; hence, the cycle time is 10 hours.

The horizon constraints for flow shop plants with parallel units. we can then be expressed in general form as,

$$\sum_{i=1}^{N} n_i\, T_{Li} \leq H \tag{2.9}$$

$$T_{Li} = \max_{j = 1, M} \{\tau_{ij}/N_j\} \tag{2.10}$$

Which are clear generalizations of equation 2.7 and equation 2.4.

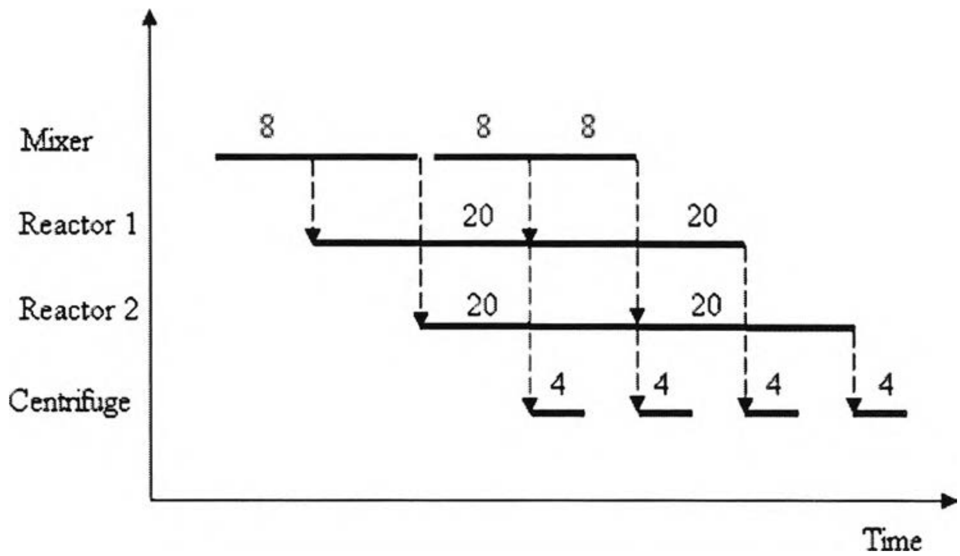

Figure 2.9a Gantt chart for two parallel reactors of product A (Biegler, 1999)

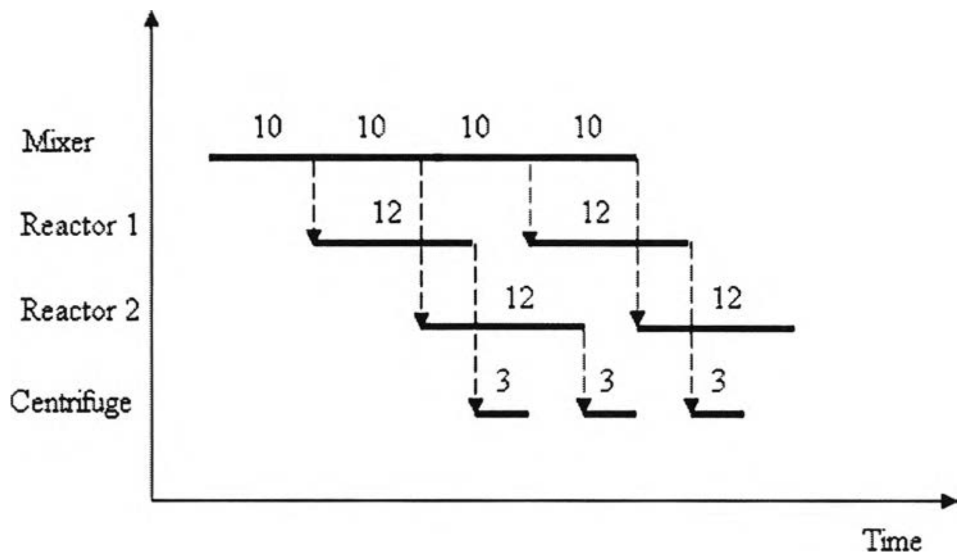

Figure 2.9b Gantt chart for two parallel reactors product B (Biegler, 1999)

2.4 Literature review

2.4.1 Computer software tool for batch scheduling

Computer programming for optimal petrochemical plant was studied by Hua (2005). He has studied the modeling of a polyvinyl chloride (PVC) resins manufacturing process with computer programming, batch process simulator, Super-Pro Designer V6.0. The simulation has been developed base on the operating conditions of a local PVC manufacturing plant in Malaysia. As the polymerization process is carried out in the batch operation mode, efforts have been made to document in scheduling detail of each unit operation and the results are presented in Gantt chart. Cycle time for a complete polymerization process is determined to be 14.28 hours. The model also reveals that approximately 17 batches of polymerization can be processed per day, which tallies the real operation of the PVC manufacturing plant.

Almato, Espuna and Puigjaner (1999) have studied about the water management in the batch process industries. The water management has been optimized considering the reuse of water effluent in the same plant through storage tanks. For a given production plan, the characterization of the water streams associated to the different production tasks is established. The connections between the available tasks and the water streams have been determined targeting different aspects: fresh water demand, water cost, utility demands of water stream and water reuse network costs. The water reuse system has been modeled, simulated and optimized. A software tool has been developed that permits an easy application of the methodology.

Nait, Tahar, Yalaoui, Chu, and Amodeo (2005) have considered the problem of scheduling a set of independent jobs with sequence-dependent set up times and job splitting on a set of identical parallel machine such that maximum completion time (make span) is minimized. For this NP-hard problem, it is suggested a heuristic algorithm improving an existing one, using a linear programming modeling with setup times and job splitting considerations. The performance of new method is used tested on over 6000 instances with different size by comparing it with a lover bound.

2.4.2 Hand calculation for create algorithm model for batch scheduling

Bellanger and Oulamara (2008) have studied a two stage hybrid flow shop problem in tire industry in which the first stage contains several identical distance machines and the second stage contains several identical batching machines. Each discrete machine can process no more than one task at time, and each batching machine can process several task simultaneously in a batch with the additional feature that tasks of the same batch have to be compatible. A compatibility relation is defined between each pair of tasks, so that an undirected compatibility graph is obtained which turn out to be an interval graph. The batch processing time is equal to the maximal processing time of the tasks in the batch, and all tasks of the same batch start and finish together. The goal is to make batching and sequencing decisions in order to minimize the make span. Since the problem is NP-hard, they develop several heuristics along with their worst cases analysis. They also consider the case in which tasks have the same processing time on the first stage, for which a polynomial time approximation scheme (PTAS) algorithm is present.

Rizal, Tani, Nishiyama and Suzuki (2006) have studied about the safety and reliability analysis in a polyvinyl chloride batch process using dynamic simulator-case study: Loss of contaminant incident. The study about a novel methodology in batch plant safety and reliability analysis is proposed using a dynamic simulator. A batch processing involving several safety objects (e.g. sensor, controller, valves, etc.) is activated during the operational stage. The performance of the safety objects is evaluated by the dynamics simulation, and a fault propagation model is generated. By using the fault propagation model, an improved fault tree analysis (FTA) method using switching signal mode (SSM) is developed for estimating the probability of failures. The timely dependent failures can be considered as unavailability of safety objects that can cause the accidents in a plant. Finally, the rank of safety objects is formulated as performance index (PI) and can be estimated using the importance measures. PI shows the prioritization of safety objects that should be investigated for safety improvement program in plants. The output of this method can be used for optimal policy in safety object improvement and maintenance. The dynamic simulator was constructed using Visual Modeler (VM, the plant simulator, developed by Omega Simulation Corp., Japan). A case study is forced on the loss of containment (LOC) incident at polyvinyl chloride (PVC) batch process which is consumed the hazardous material, vinyl chloride monomer (VCM).

In this study, they apply dynamic analysis using simulator. A dynamic simulates time dependent of hazardous simulation. For the batch process, each task is activated base on the sequence. Time sequence is modeled by switching time the on (1) and off (0). The dynamic simulator generates the switching signal mode (SSM) to activate or deactivate the process. Therefore, SSM contributes to the system configuration changes. It reduced the complexity in analyzing the hazardous situation when SSM set to off (0 or false) condition, because the safety objects as time (t) are non-activated. The other advantage is PI rank can be managed timely dependent, since MCS depended on BE and SSM. The result gives the optimal policy for improvement and maintenance activities of safety objects.

Generally the batch process is conducted by activating the tasks. These tasks are implemented using SSM which naturally describes the process task execution base on time sequence. The SSM model for one batch is shown in Fig 2.10 here below.

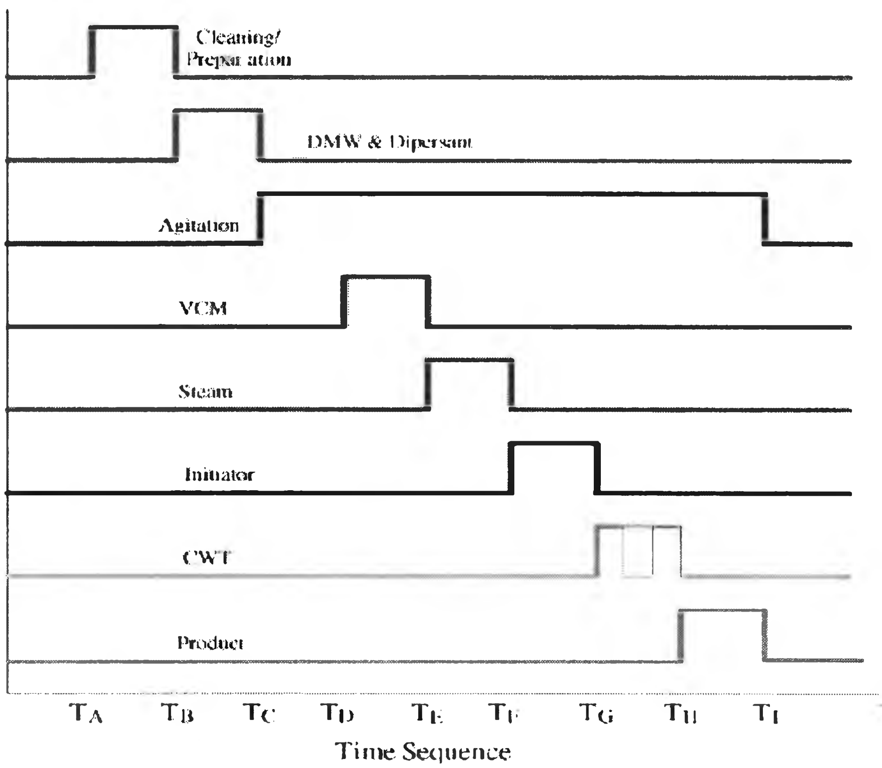

Figure 2.10 Switching signal mode for PVC batch process (Rizal, Tani, Nishiyama and Suzuki, 2006)

From Fig 2.10, they generate the characteristic of the processes which can be described by process matrix (PM). PM for a batch product may differ from other products. Thus, PM can be adaptively modeled and designed as a tool for safety and reliability analysis in a batch process. The example of PM can be seen as follows:

$$SSM_l = \begin{bmatrix} P_{Aa} & P_{Ab} & P_{Ac} & P_{Ad} & P_{Ae} & P_{Af} & P_{Ag} & P_{Ah} & P_{Ai} \\ P_{Ba} & P_{Bb} & P_{Bc} & P_{Bd} & P_{Be} & P_{Bf} & P_{Bg} & P_{Bh} & P_{Bi} \\ P_{Ca} & P_{Cb} & P_{Cc} & P_{Cd} & P_{Ce} & P_{Cf} & P_{Cg} & P_{Ch} & P_{Ci} \\ P_{Da} & P_{Db} & P_{Dc} & P_{Dd} & P_{De} & P_{Df} & P_{Dg} & P_{Dh} & P_{Di} \\ P_{Ea} & P_{Eb} & P_{Ec} & P_{Ed} & P_{Ee} & P_{Ef} & P_{Eg} & P_{Eh} & P_{Ei} \\ P_{Fa} & P_{Fb} & P_{Fc} & P_{Fd} & P_{Fe} & P_{Ff} & P_{Fg} & P_{Fh} & P_{Fi} \\ P_{Ga} & P_{Gb} & P_{Gc} & P_{Gd} & P_{Ge} & P_{Gf} & P_{Gg} & P_{Gh} & P_{Gi} \\ P_{Ha} & P_{Hb} & P_{Hc} & P_{Hd} & P_{He} & P_{Hf} & P_{Hg} & P_{Hh} & P_{Hi} \end{bmatrix}$$

And the PM for Fig 2.10 is

$$SSM_l = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

SSM_l is a representation of a batch switching mode through sequence of time. The horizontal part represents a number of time sequences for a batch process which determines the activation period of the systems. The vertical part contains a number of batch tasks (phase) for one batch cycle. For example, $\{P_{Aa}, P_{Ab},\ldots,P_{Ai}\}$ are the parameters of activation for preparation/cleaning task in time sequences $\{T_a, T_b,\ldots T_i\}$.SSM_l describes the behavior of the certain process as a function of time sequence.

The simulator performs the process based on SSM. Therefore, the complexity of the process and the hazards are managed by the matrix configuration. Since, the batch is a discontinuous process, SSM is important in order to obtain credible analysis of the batch process. In the other way, for a continuous process, SSM is not required due to all steps are steady state and relatively simple.

Barketau, Cheng and Kovalov (2007) have studied about the bearing manufacturing. The problem of scheduling, the production of new and recoverable defective items of the same product manufactured on the same facility is studied. Items are processed in batches. Each batch comprises of two sub-batches processed consecutively. In the first sub-batch, all the items are newly manufactured. Some of them are of the required good quality and some are defective. The defective items are manufactured in the second sub-batch. They deteriorate while waiting for rework.

This result is increased time and cost for their remanufacturing. All the items in the same sub-batch complete at the same time, which is completion time of the last items in the sub-batch. Each remanufactured defective item is of the required good quality. It is assumed that the percentage of defective items in each batch is the same. A setup time is required to start batch processing and to switch from manufacturing to remanufacturing. The demands for good quality items over time are given. The objective is to find batch sizes such that the total setup and inventory holding cost is minimized and all the demands are satisfied. Dynamic programming algorithms are presented for the general problem and some important special cases.

Galindez and Melas (2004) have studied and implemented the automatic and optimal scheduling of PVC production line at polyvinyl chloride manufacture in Argentina. The study is to find maximum flow rate out off discharge vessel from reactors in order to find the starting time of polymerization. The optimal production rate by quadratic program has been developed by calculation through distribution control system block (DCS). The time values of the scheduling scenario are ordered (by sort algorithm) and used in the quadratic program, which is solved every second. The benefit base on the first obtained, the economic benefit is between 5 to 10 percent of increase in production rate. It is also allowed the good functioning of the whole line maximizing the production pushing continuously the production facility constraints.