**Plant Design and Economics**
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**Lecture - 60**
**Batch Process Scheduling**

Welcome to lecture 60 of Plant Design and Economics. This is the concluding lecture of this course. And in this lecture, we will talk about batch process scheduling.

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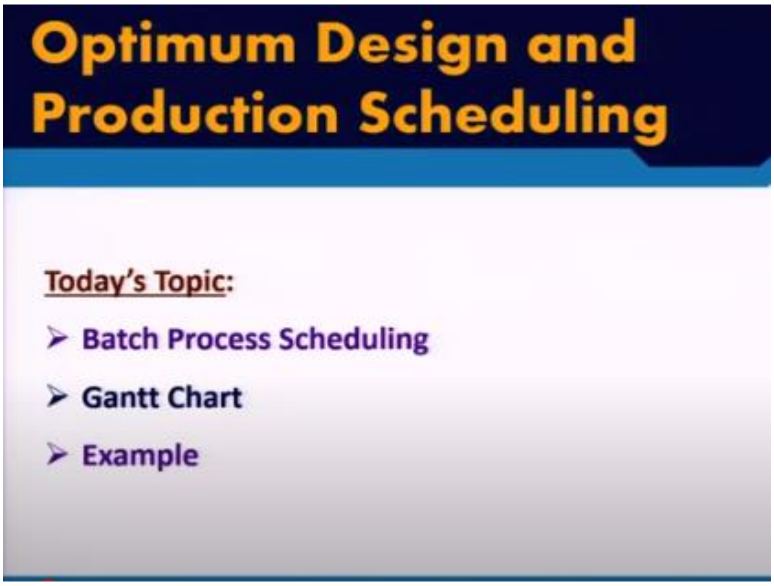


We will give a brief introduction to batch process scheduling. We will talk about the Gantt chart, its use for simple batch process scheduling because batch process scheduling itself is a very broad subject. But in this lecture, we will try to give you a flavor of batch process scheduling considering simple single product batch sequencing.

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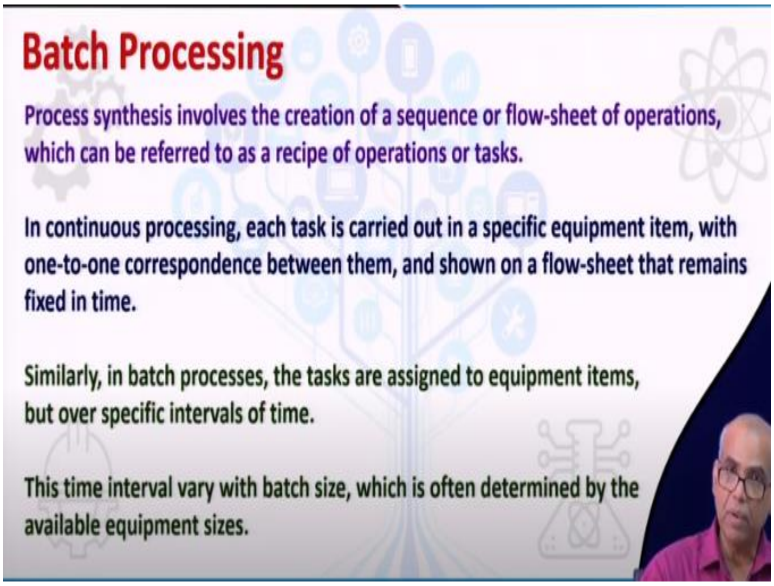


Process synthesis involves the creation of a sequence or flow sheet of operations, which can be referred to as the recipe of operations or task. In continuous processing, we know that each task is carried out in a specific equipment with one to one correspondence between them. And this piece of equipment is shown on a flow sheet that remains permanently fixed as long as the operation is on.

But for batch processes, the tasks are assigned to the equipment items, but that is not as permanent as in continuous processing. The tasks are assigned to equipment items in batch process as well, but that is over a specific period of time. Now for how long this assignment of tasks will be there depends on batch size, which is often determined by the available equipment sizes.

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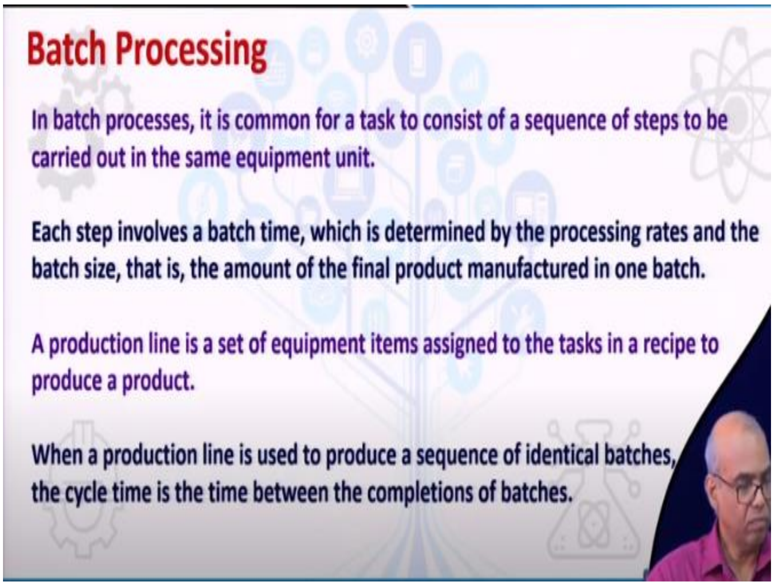

In batch processes, it is common for a task to consist of a sequence of steps to be carried out in the same equipment unit. Each step involves a batch time, which is determined by the processing rates and the batch size, which is the amount of the final product manufactured in one batch. A production line is a set of equipment items assigned to the task in a recipe to produce a product.

When you use a production line to produce a sequence of identical batches, then we define the cycle time as the time between the completion of batches. So the time when one batch is completed, and then the time when the next batch got completed. So the time between these completion of two batches we will call as cycle time.

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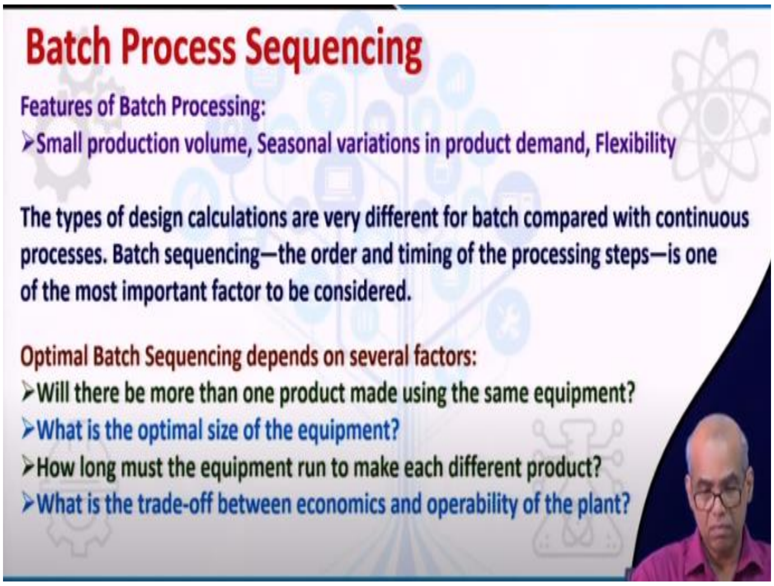


As we have talked about before, that there are several distinct features of batch processing or batch processes which makes it different from continuous processing. For example, for large volume processing we will always go for continuous processes, but for small production volume for example, small volume high value pharmaceutical products or specialty chemicals we will go for batch processing.

There are products whose demands are seasonal for example, fertilizer. So seasonal variations in product demand, also requires batch processing because it will be more advantageous it will be more cost effective. Also flexibility in operation is more in case of batch processes. We can have multipurpose batch plant, multi-product batch plant. The types of design calculations are very different for batch process compared with continuous process.

Batch sequencing, which is the order and timing of the processing steps is one of the most important factor for operation of a batch process. I repeat batch sequencing, which represents the order and timing of the processing steps is one of the most important factor for successful operation or profitable operation of a batch process. Optimal batch sequencing depends on several factors.

For example, will there be more than one product made using the same equipment or the equipment is dedicated for the production of only one product? What is the optimal size of the equipment? How long must the equipment run to make each different product? What is the trade-off between economics and operability of the plant? So there are several issues. There are several factors on which the optimal batch sequencing depends.

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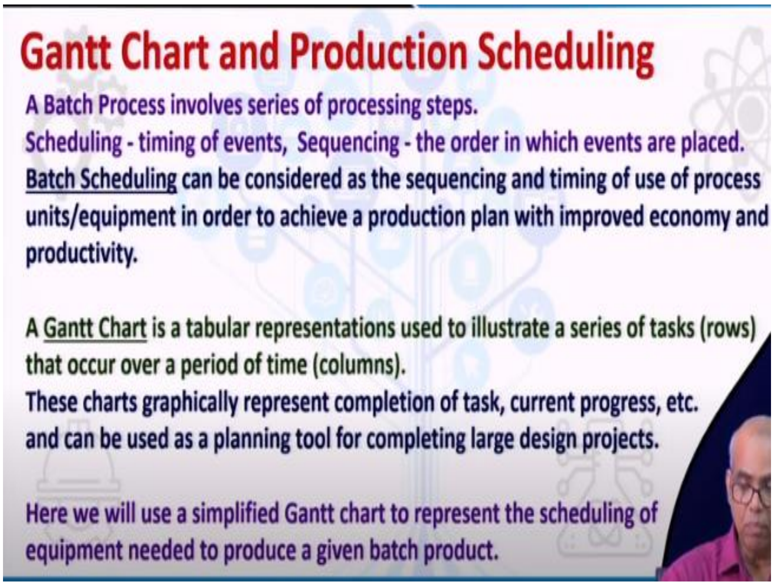


A batch process involves series of processing steps. It is like a recipe based operation. So there are series of events that will take place, a series of processing steps, well-defined series of processing steps. Scheduling means timing of these events and sequencing means, the order in which the events are placed or the order in which these events will occur. So scheduling means timing of events and sequencing means the order in which these events will occur.

So batch scheduling can be considered as the sequencing and timing of use or utilization of process units or equipment in order to achieve a production plan that gives us improved economy as well as improved productivity. So I repeat, batch scheduling can be considered as the sequencing and timing of use of process units or equipment in order to achieve a production plan with improved economy and productivity.

A Gantt chart is the tabular representation used to illustrate a series of tasks that occur over a period of time. So the Gantt chart is basically a table which represents a series of task as rows of the table. These tasks occur over a period of time, those times are represented as columns of the table. So rows represent task, column represent times. These charts graphically represent completion of task, current progress of the task, important milestones that have been achieved etc.

And thus this can be used as an efficient planning tool for accomplishing large design projects. So this is an important tool for project management. Here, we will use a simplified Gantt chart to represent the scheduling of equipment needed to produce a given batch product. So the task and the timings will represent using the Gantt chart. We will use a simplified Gantt chart to represent the scheduling of equipment needed to produce a given batch product.

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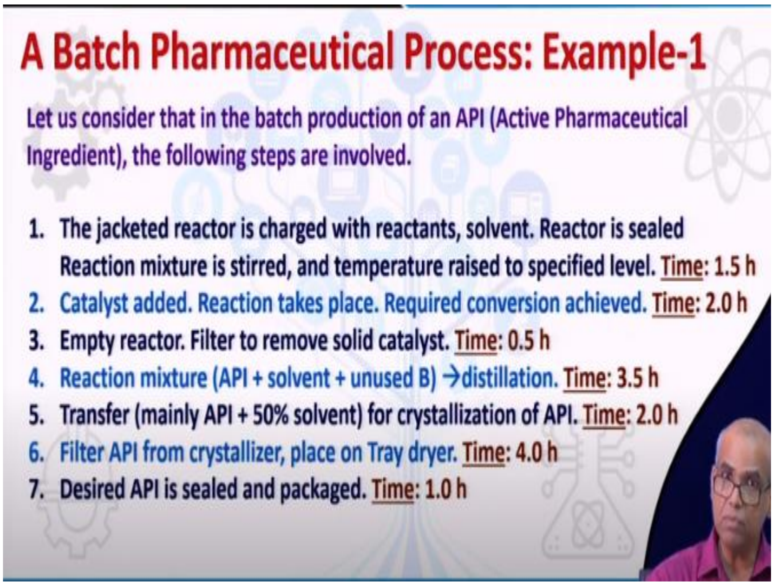


Let us take an example first. As a batch process, let us consider a pharmaceutical process, which is manufacturing an active pharmaceutical ingredient, which you call API. So active pharmaceutical ingredient is the key component is the main component of the drug or medicine. So let us consider that in the batch production of an API or active pharmaceutical ingredient, the following steps are involved.

So as I told you that a batch process involves a series of events, series of processing steps, so let us now list down the steps that are involved in a batch production of an active pharmaceutical ingredient. First, you take the jacketed reactor. The jacketed reactor is charged with reactants let us say I have reactant A, reactant B. Then you put solvent. You seal the reactor, the reaction mixture is stirred and the temperature is raised to the desired temperature level, less than 95 degrees Celsius.

I want to raise the temperature to 95 degrees Celsius. Let us note down that the time required for these activity is 1.5 hour. Next, I add catalyst to the reactor and then the reaction takes place. And I continue the reaction until I reach the required conversion. Let us say that this time taken is two hours. In the third step after the reaction is completed or the required conversion has been achieved, I should say after the required conversion has been achieved, I empty the reactor.

So I will take away the products and the reaction mixture from the reactor, filter it to remove the solid catalyst. Let us consider the time taken is 0.5 hour. Now I have removed the solid catalyst. So the reaction mixture is essentially the active pharmaceutical ingredient which has been formed due to the reaction, let us say between reactants A, reactants B etc.

So I have the active pharmaceutical ingredient, the solvent as well as also some unused reactant, let us say the unused reactant B. So I sent this reaction mixture to distillation for separation and this takes 3.5 hour and let us say this in the distillation state I removed say around 50% of the solvent and almost all reactant B or maybe very minute level of B is still present which is acceptable.

So now I transfer this mixture which is mainly the active pharmaceutical ingredient and 50% solvent for crystallization. Now crystallization in another purification step or separation and purification step this also for doing particular engineering in pharmaceutical processes. That means you can control a crystallization step to come up with crystals of desired size and size distribution, which are very important attributes for pharmaceutical products.

So the mixture from the distillation is transferred to the crystallizer and the API is crystallized. So now it is very pure form of API. Let us say this, the time for distillation was 3.5 hour and the time in the crystallizer is 2.5 hour. Then I filter API from the crystallizer and place on the tray dryer and this will be there for four hours. So this time is four hours.

After it is dried the desired API is sealed and packaged, which takes one hour. So this is my tasks and these are the timings. These are the times required. These are the times required for each processing step.

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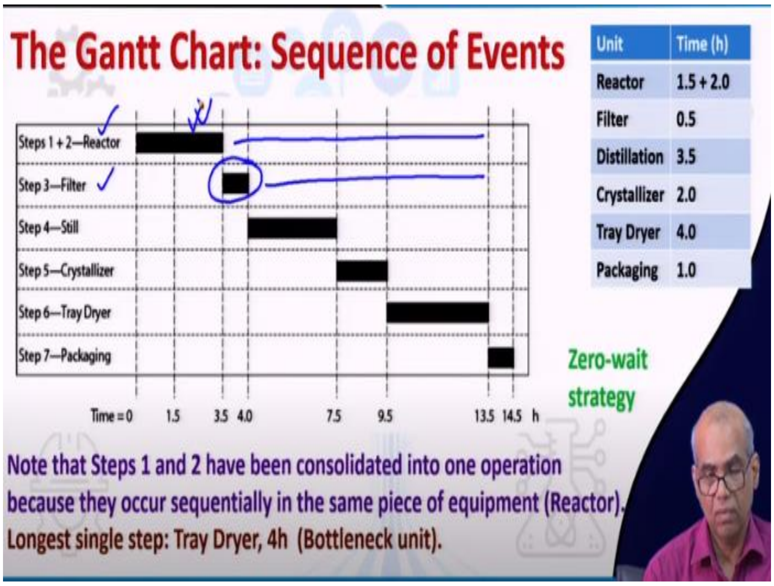


So these sequence of events can be placed on the Gantt chart. So if you look at this Gantt chart sorry Gantt chart we see that the steps 1 plus 2 both are placed here in the because in the reactor because both are taking place in the reactor. Step 3 is filter. Step 1 which is taking place in the reactor takes place 1.5 hour and then 2 hours. 1.5 hour was for the reaction, 2 hour sorry 1.5 hour was the, you know pretreatment and then heating, preheating and then 2 hours was the reaction.

So note that it is placed accordingly. In the Gantt chart, it is placed accordingly 1.5 hour and then 2 hours. Then filter for half hour in the distillation 3.5 hours. So 4 to 7.5 and then 2 hours in the crystallizer. So 7.5 to 9.5 and then tray dryer for 4 hours. So

9.5 to 13.5 and then 1 hour packaging, so 13.5 to 14.5 hour. So the batch time is 14.5 hour.

Note that in this case, we are assuming that when I am done with the reactor I immediately pass on the mixture to the filter without any time delay. So we call this zero-wait strategy, zero-wait strategy. So in the Gantt chart you have placed the steps and the times. So these Gantt charts clearly shows me that 14.5 hours is the total batch time for this operation. And it also clearly shows the availability of the units.

For example, this is the reactor unit. This is the filtration unit. Now if you notice the reactor unit is not used anywhere here. The filtration is not used anywhere here. It is true that this filtration step can take place only after we are done with the reactor here at this stage. So these informations can be clearly visualized from this Gantt chart.

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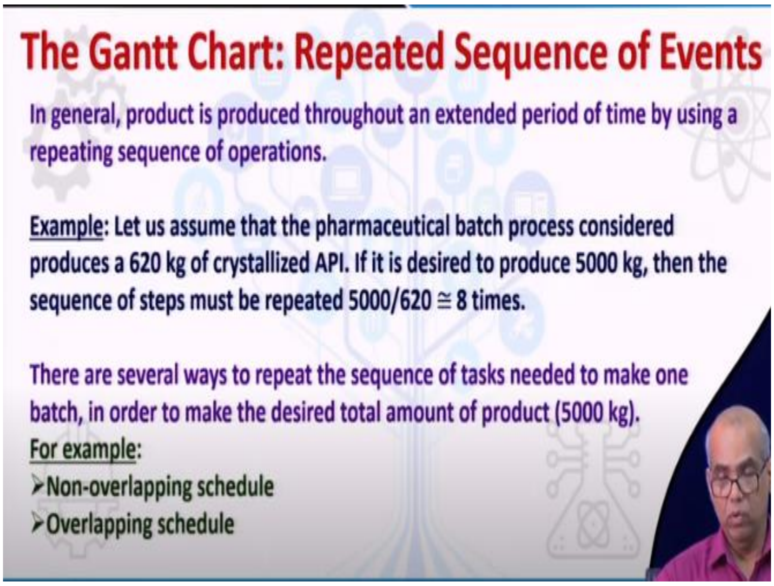


Now in general, a product is produced throughout an extended period of time by using a repeated sequence of operations. You are not going to use only one sequence of this process. Depending on how much of API you want to produce, you have to repeat this sequence of batch processes. For example, let us assume that the batch process that we are considering produces 620 kg of crystallized API in one batch and let us say my target is to produce 5000 kg of this API.

So how many batches are required? 5000 divided by 620, which is approximately 8. So 8 times such sequence must be repeated. Now how do I repeat these sequences?

We will talk about two different ways. One is non overlapping way of repeating the sequence, we call that non-overlapping schedule, another is overlapping schedule.

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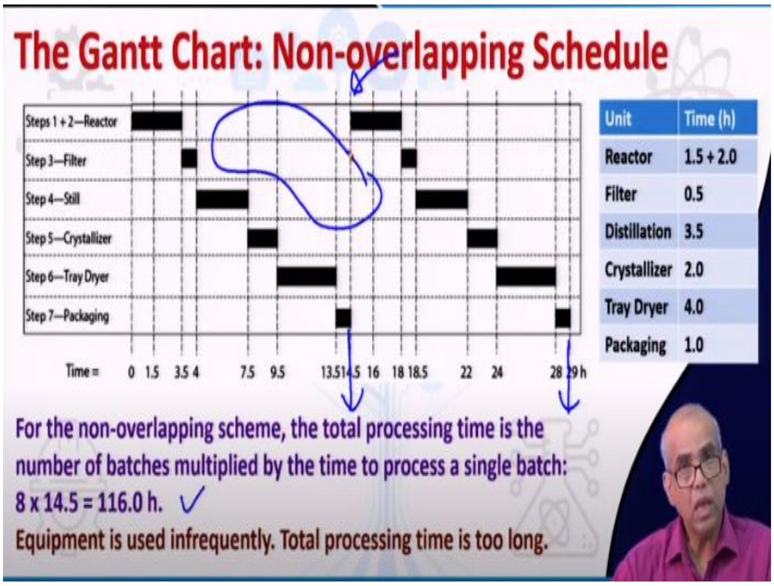


So let us first look at non-overlapping schedule. Note that this chart shows that I am done here with the first batch, 14.5 hours. So the Gantt chart shows that 14.5 hours my first batch is over and the second batch also starts at 14.5, which is again over after another 14.5 hours that means 29 hour. So it takes 29 hour to produce or complete two batches. So the non-overlapping schedule is represented on the Gantt chart by simply repeating the sequence one after another.

One batch is over, one sequence is over, then I start the next sequence and then I start the third sequence, so on and so forth. So the total processing time is the number of batches multiplied by the time required to process a single batch. Time required to process a single batch is 14.5 hour. And we just said that to produce 5000 kg of API and each batch produces 620 kg of API so you need 5000 by 620 equal to around 8 batches.

So 8 repetitions of this sequence. One sequence takes 14.5 hours. So 8 sequence takes 8 into 14.5 hours, which is 116 hours. So 116 hours for completion of 8 sequences, which is required to produce my 5000 kg of API which is my target. Now if you look at the Gantt chart again, we see that there is lot of idle time. The equipment is not being used frequently. There is lot of idle time from the equipment.

So the equipments are not properly utilized. And that keeps us very long processing time. So you have to improve on this.

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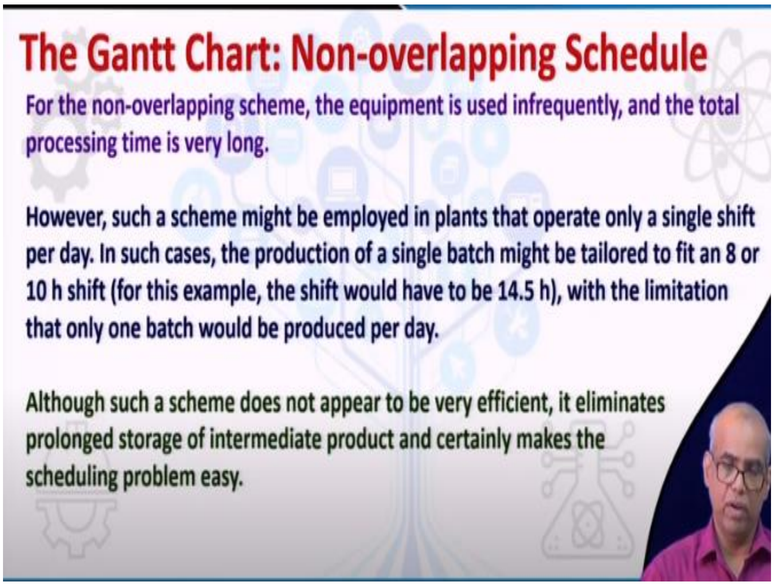


Now this non-overlapping schedule, which of course is not very efficient in the sense that the equipment is used infrequently and the total processing time is unnecessarily long. But it has certain advantages as well. Such a scheme might be employed in plants that operate only a single shift per day. In such case, what we will do is the production of a single batch can be tailored to fit an 8 hours or 10 hour shift.

In this particular case, the shift must be of 14.5 hours because one batch one sequence takes 14.5 hours. So limitation here will be that will produce only one batch a day. The advantage is that it eliminates any storage of intermediate product and the scheduling problem is very easy. However, is very inefficient in terms of uses of the equipment, because equipment are being used very infrequently.

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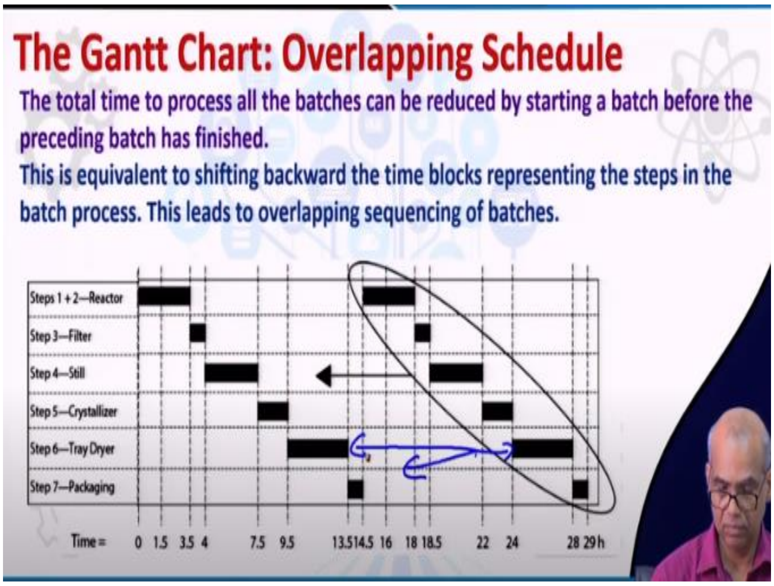


So we will talk about so we think of overlapping schedule. In overlapping schedule the total time of the processes, the total time to process all the batches can be reduced by starting a batch before the preceding batch has finished. That means, we do not have to wait up to this point all the time to start the next batch. We can start a batch before the preceding batch has finished.

So this is basically equivalent to shifting backward the time blocks representing the steps in the batch process. So you simply you simply move this in this direction. We are shifting this backward in time. So this will lead to overlapping sequencing of batches. How this will look like? So that depends on how much overlapping is allowed. That means, how far I can bring this backward. So what is the limiting case?

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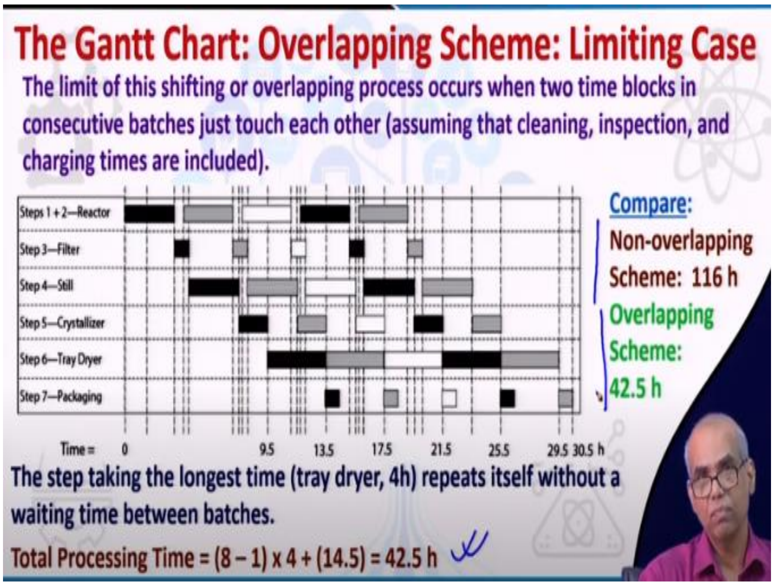

See, the limit of the shifting or overlapping process occurs when two time blocks in consecutive batches just touch each other. Beyond that it is not possible, right. So you bring this, you bring this block, this entire blog represents the next batch. You bring this block backward and you can come only up to the point when two time blocks just touch each other. Let us say this and this touch each other.

So that is the limit of shifting. So limit of this shifting or overlapping process occurs when two time blocks in consecutive batches just touch each other. Of course, we assume that cleaning, inspection and charging times are included. So this is what has been shown here.

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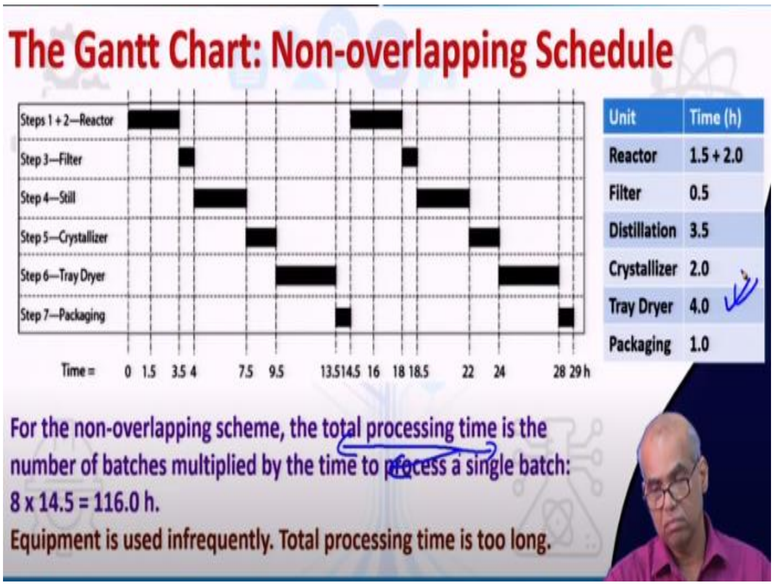


Note that the longest time for these steps is for tray dryer which is 4 hours. We call that as bottleneck unit. This takes the maximum time. Now if I come to this Gantt chart where I have done the maximum possible backwards shifting, I see that these are all touching each other. So this represents, this time block represents what? These time blocks are all of 4 hours duration corresponding to the tray dryer.

So the step taking the longest time, which is tray dryer here repeats itself without waiting between the batches. So this gives me the overlapping scheme where the maximum permissible overlapping has occurred. So we have gone we have done the maximum shifting backward. No more shifting is possible, because these time blocks which corresponds to tray dryer has just touched each other.

So what is the cycle time here now? This corresponds to the time for this tray dryer, which is 4 hours. Note that the step taking the longest time repeats itself without waiting time between the batches. So the cycle time is now reduced to 4 hours. So what will be the total processing time? Now there has to be a repetition of the sequence that is what we have learned, that we have seen before.

The first one of course, will take 14.5 hours to complete and the remaining 7 will take 4 hours each. So the time required for the total processing will be 8 - 1 into 4 + 14.5 which is 42.5 hours. So now compare this time of 116 hour for non-overlapping schedule with the 42.5 hour of overlapping schedule. So overlapping schedule is much more efficient scheduling compared to non-overlapping schedule.

Note that if your cycle time reduces it basically improves your economy, it saves time you can process more batches. You say you can you are completing your processing in much less time. So productivity increases.

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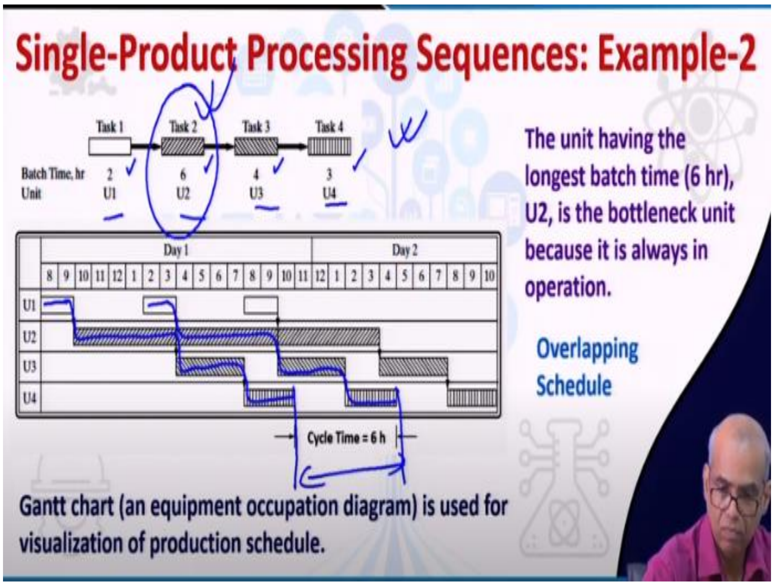


Now let us quickly take one more example. Again this represents an overlapping schedule on the Gantt chart. So we have a production line like this. There are 4 task, task 1, task 2, task 3, task 4 in 4 units U1, U2, U3, and U4. The batch time in hours are given for 2 hours for task 1, 6 hours for task 2, 4 hours for task 3 and 3 hours for task 4. So the Gantt chart has been prepared. Note the first batch U1, then U2, U3 and then U4. So here your first batch is completed. You also note the second batch, second batch got completed here.

So the cycle time is the time between these two, which is 6 hours. And note that this corresponds to the task with the longest time. So that is what will always happen. The cycle time will correspond under such overlapping schemes will be equal to the longest time for this task and this U2 is the bottleneck unit. And you also note that in this overlap scheme, the U2 is always in use, this is this repeats, U2 repeats itself without any time gap between two batches.

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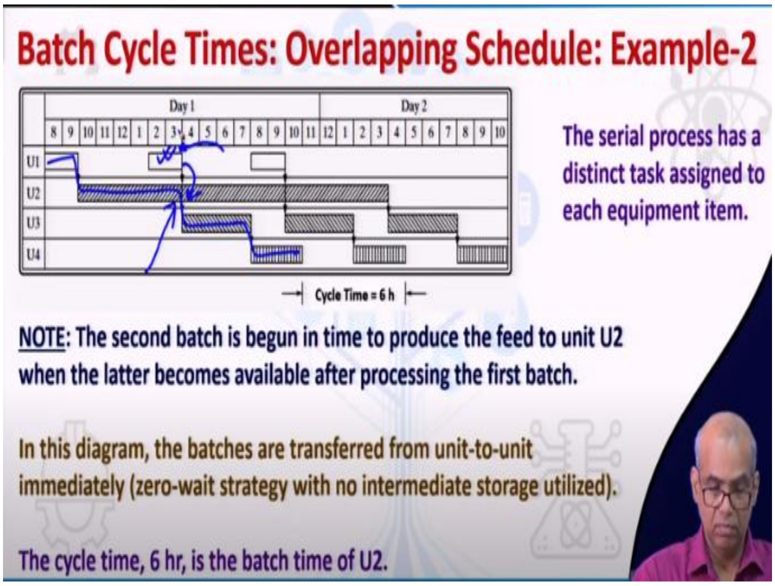


You notice that well, this represents the first batch. The second batch has begun in time to produce the feed to unit 2 when unit 2 is available after processing the first batch. So unit 2 is completed here. So U1 has started in time, so that it can give feed to U2 in time. Of course here again, we are assuming zero-wait strategy and also there is no intermediate storage. The cycle time is 6 hours.

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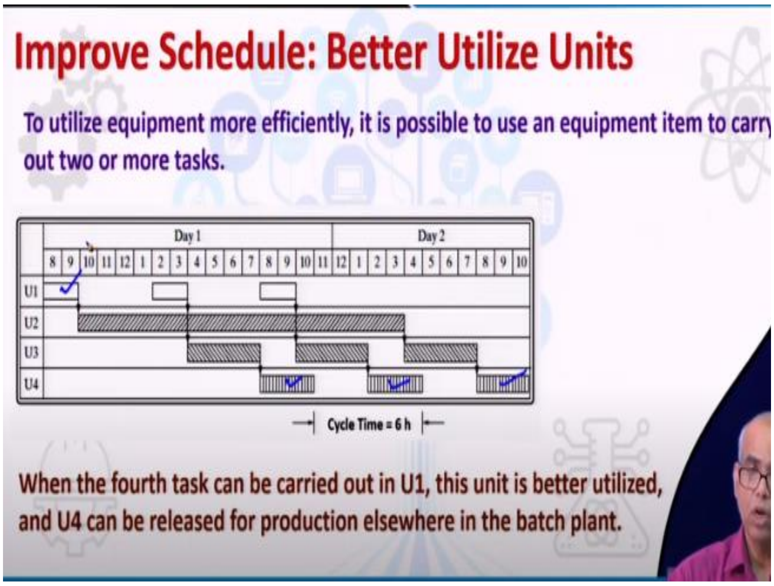


Now can I improve this schedule further? To utilize equipment more efficiently it is possible to use an equipment item to carry out two or more task. As of now we have been using each equipment for a dedicated task. Now if an equipment is available, if it is idle, and if it is possible to carry to carry out the task of another equipment in this particular equipment that is free, we should better do that and can release or can free up the other equipment.

For example, in this case, if the fourth task can be carried out in U1 then you should do that and release U4 for doing something else in the plant. So thereby we are using only 3 equipment items. We are releasing U4 for doing some other job in the plant.

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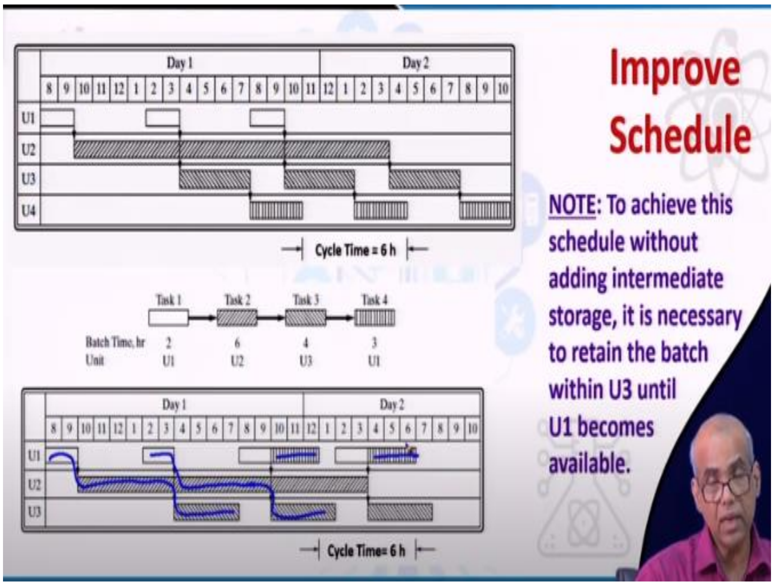

So this is how the task 4 will be done in U1. Note that this is the previous schedule where all the tasks are being done in the dedicated units U1, U2, U3, U4. Now I say that the task of U4 can be done in U1. So you first do U1 and then U2 and then U3 and then you do the task 4 in the U1 because U1 is available. U1 is available from this point.

So to achieve this schedule without addition of any intermediate storage, it will be necessary to retain the batch within U3 until U1 becomes available at this point. So this is necessary that until my U1 becomes available for doing the task 4 the U3 will store the product. So the U3 will store the batch until U1 is available. So this is what is done. So you have the first batch and then you have the second batch. And this now continues. Note that the cycle time remains same.

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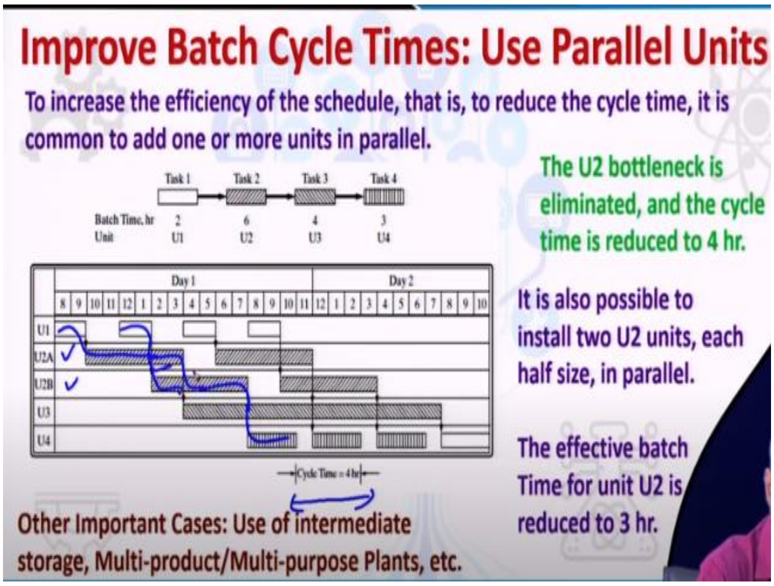


But here we improve the schedule by making use of fewer pieces of equipment. We could release U4. We can also improve the batch cycle times or the schedule by using parallel units. So in this particular case, where we use two parallel units of U2, U2A and U2B. And you notice that the cycle time has reduced from 6 hours to 4 hours. Note that this is my first batch and this is the second batch. **(FL)**.

We can also improve the schedule by improving the bad cycle time. We can do that by using parallel units. Look at this Gantt chart. What we have done is we are using two units of U2 in parallel, U2A and U2B. And that reduces the cycle time for 6 hours to 4 hours. There are several other important issues of batch scheduling such as intermediate storage. Here we have considered that the products are immediately transferred from one unit to the other without any waiting, zero-wait strategy.

Also there was no intermediate storage except for the case where I used U3. I used U1 to do the task of U4. In that case, U3 will be storing or holding the batch until U1 is released. But you can also use intermediate storage, additional intermediate storage can be used to improve the scheduling. Also there are important scheduling problems associated with multi-product batch plants as well as multipurpose batch plants.

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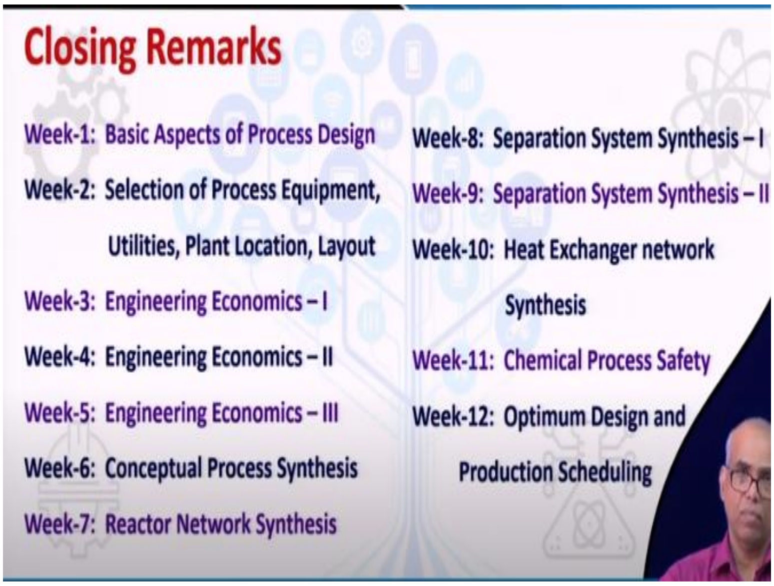


Now with this, we will come to the conclusion of this course. So over last 12 weeks, we tried to give you an exposure to various aspects of plant design and economics. We started with basic aspects of process design. We talked about selection of process equipment, utilities, plant location, layout. And then we talked about engineering economics over three weeks.

Then, we spent one week on conceptual process synthesis, where we took an example of hydrodealkylation of toluene and went through the steps of synthesizing the entire flow sheet. And then we talked about reactor network synthesis, where we introduced the theory of attainable region. Then, a reaction is followed by separation.

So we talked about separation system synthesis where we mainly emphasized on sequencing of distillation columns, azeotropic distillation. We tried to analyze results in terms of residue curve maps. And then we talked about pinch analysis for heat exchanger network synthesis. And then we talked about basic chemical process safety. Mainly we talked about fire explosion and the gas leaks.

And finally, we talked about role of optimization in engineering design and also tried to give you a flavor of batch process production scheduling. So with this, we come to the conclusion of this course. I wish you good luck for your career. And if you are writing exam for this course, good luck to you. Thank you for joining this course.