CH0401 Process Engineering Economics

Lecture 4c

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(Under section 3 of UGC Act 1956)

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Process Engineering Economics

1. Economic Analysis
2. Economic Balance in Cyclic Operation

1 Economic Analysis

2 Economic Balance in Cyclic Operation

Optimum conditions in cyclic operations

Many processes are carried out by the use of cyclic operations, which involve periodic shutdowns for discharging, cleanout, or reactivation.

This type of operation occurs when the product is produced by a batch process or when the rate of production decreases with time, as in the operation of a plate-and-frame filtration unit.

Optimum conditions in cyclic operations

In a true batch operation, no product is obtained until the unit is shut down for discharging.

In semi-continuous cyclic operations, product is delivered continuously while the unit is in operation, but the rate of delivery decreases with time.

Optimum conditions in cyclic operations

Analyses of cyclic operations can be carried out conveniently by using the time for one cycle as a basis.

When this is done, relationships similar to the following can be developed to express overall factors, such as total annual cost or annual rate of production:

$$\text{Total annual cost} = \left(\frac{\text{Operating costs} + \text{shut down costs}}{\text{cycle}}\right) \times \left(\frac{x \text{ cycles}}{\text{year}}\right) + \text{Annual Fixed Costs}$$

Process Engineering Economics – *Cyclic Process*

Optimum conditions in cyclic operations

$$\text{Annual production rate} = \frac{\dfrac{\text{total production}}{\text{cycle}}}{\dfrac{\text{Number of cycles}}{\text{year}}}$$

$$\frac{\text{Cycles}}{\text{year}} = \frac{\text{operating cost + shutdown time used/year}}{\text{Operating time + shutdown time/Cycle}}$$

Problem 1 Determination of conditions for minimum total cost in a batch operation

An organic chemical is being produced by a batch operation in which no product is obtained until the batch is finished. Each cycle consists of the operating time necessary to complete the reaction plus a total time of 1.4 h for discharging and charging. The operating time per cycle is equal to $1.5P_b^{0.25}$ h, where P_b is the kilograms of product produced per batch. The operating costs during the operating period are \$20 per hour, and the costs during the discharge-charge period are \$15 per hour. The annual fixed costs for the equipment vary with the size of the batch as follows:

$$C_F = 340\ P_b^{0.8} \text{ dollars per batch}$$

Inventory and storage charges may be neglected. If necessary, the plant can be operated 24 h per day for 300 days per year. The annual production is 1 million kg of product. At this capacity, raw material and miscellaneous costs, other than those already mentioned, amount to \$260,000 per year.

Determine the cycle time for conditions of minimum total cost per year.

Solution

$$\text{Cycles/year} = \frac{\text{annual production}}{\text{production/cycle}} = \frac{1{,}000{,}000}{P_b}$$

$$\text{Cycle time} = \text{operating} + \text{shutdown time} = 1.5P_b^{0.25} + 1.4 \text{ h}$$

$$\text{Operating} + \text{shutdown costs/cycle} = (20)\left(1.5P_b^{0.25}\right) + (15)(1.4) \text{ dollars}$$

$$\text{Annual fixed costs} = 340P_b^{0.8} + 260{,}000 \text{ dollars}$$

$$\text{Total annual costs} = \left(30P_b^{0.25} + 21\right)(1{,}000{,}000/P_b) + 340P_b^{0.8} + 260{,}000 \text{ dollars}$$

The total annual cost is a minimum where $d(\text{total annual cost})/dP_b = 0$.

Solution

Performing the differentiation, setting the result equal to zero, and solving for P_b gives

$$P_{b,\ \text{optimum cost}} = 1630 \text{ kg per batch}$$

This same result could have been obtained by plotting total annual cost versus P_b and determining the value of P_b at the point of minimum annual cost.

For conditions of minimum annual cost and 1 million kg/year production,

$$\text{Cycle time} = (1.5)(1630)^{0.25} + 1.4 = 11 \text{ h}$$

$$\textbf{Total time used per year} = (11)\left(\frac{1{,}000{,}000}{1630}\right) = 6750 \text{ h}$$

$$\text{Total time available per year} = (300)(24) = 7200 \text{ h}$$

Thus, for conditions of minimum annual cost and a production of 1 million kg/year, not all the available operating and shutdown time would be used.

Problem 2 Cycle time for maximum amount of production from a plate-and-frame filter press. Tests with a plate-and-frame filter press, operated at constant pressure, have shown that the relation between the volume of filtrate delivered and the time in operation can be represented as follows:

$$P_f^2 = 2.25 \times 10^4 (\theta_f + 0.11)$$

where P_f = cubic feet of filtrate delivered in filtering time θ_f h. The cake formed in each cycle must be washed with an amount of water equal to one-sixteenth times the volume of filtrate delivered per cycle. The washing rate remains constant and is equal to one-fourth of the filtrate delivery rate at the end of the filtration. The time required per cycle for dismantling, dumping, and reassembling is 6 h. Under the conditions where the preceding information applies, determine the total cycle time necessary to permit the maximum output of filtrate during each 24 h.

Solution

Let θ_f = hours of filtering time per cycle.

Filtrate delivered per cycle = $P_{f,\text{cycle}} = 150(\theta_f + 0.11)^{1/2}$ ft^3. Rate of filtrate delivery at end of cycle is

$$\text{Washing rate} \times 4 = \frac{dP_f}{d\theta_f} = \frac{150}{2}(\theta_f + 0.11)^{-1/2} \text{ ft}^3/\text{h}$$

$$\text{Time for washing} = \frac{\text{volume of wash water}}{\text{washing rate}}$$

$$= \frac{(4)(2)(150)(\theta_f + 0.11)^{1/2}}{(16)(150)(\theta_f + 0.11)^{-1/2}} = \frac{\theta_f + 0.11}{2} \text{ h}$$

$$\text{Total time per cycle} = \theta_f + \frac{\theta_f + 0.11}{2} + 6 = 1.5\theta_f + 6.06 \text{ h}$$

$$\text{Cycles per 24 h} = \frac{24}{1.5\theta_f + 6.06}$$

Filtrate in ft^3 delivered/24 h is $P_{f,\text{cycle}}(\text{cycles per 24 h}) = 150(\theta_f + 0.11)^{1/2} \dfrac{24}{1.5\theta_f + 6.06}$

Process Engineering Economics – *Cyclic Process*

At the optimum cycle time giving the maximum output of filtrate per 24 h,

$$\frac{d(\text{ ft}^3 \text{ filtrate delivered/24 h})}{d\theta_f} = 0$$

Performing the differentiation and solving for θ_f,

$$\theta_{f,\text{opt}} = 3.8 \text{ h}$$

Total cycle time necessary to permit the maximum output of filtrate = (1.5)(3.8) + 6.06 = 11.8 h.

Process Engineering Economics – ***References***

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