CH2404 Process Economics

Unit – V

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Economic Balance

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Contents

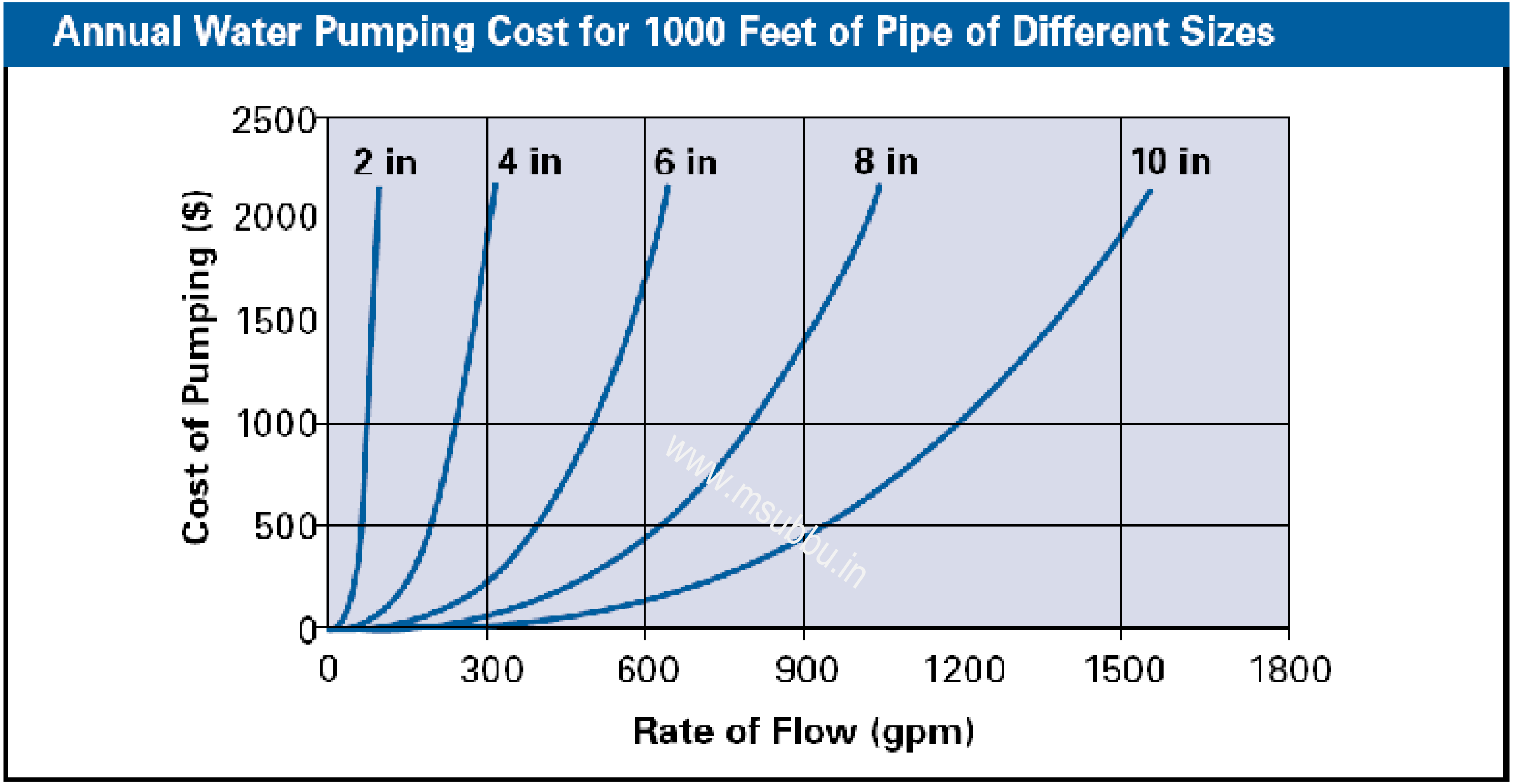
- Essentials of economic balance – Economic balance approach, economic balance for insulation, evaporation, heat transfer.

Economic balance approach

- Changes in design variables cause some costs to increase while others decrease. Total cost is the sum of fixed costs and variable costs. There is always a set of values at which the total costs are a minimum.

- Fixed costs are practically constant throughout time and independent of production rate. Examples of fixed costs are: interest, rent, insurance, taxes, and depreciation. Variable costs are tied to production rate. Typical variable costs include those for raw materials, labor and energy utilities.

Economic Pipe Diameter



Based on 1000 ft. for clean iron and steel pipes (schedule 40) for pumping 70°F water. Electricity rate—0.05 $/kWh and 8,760 operating hours annually. Combined pump and motor efficiency—70%.

For a given flow, cost of pumping increases with decrease of pipe diameter

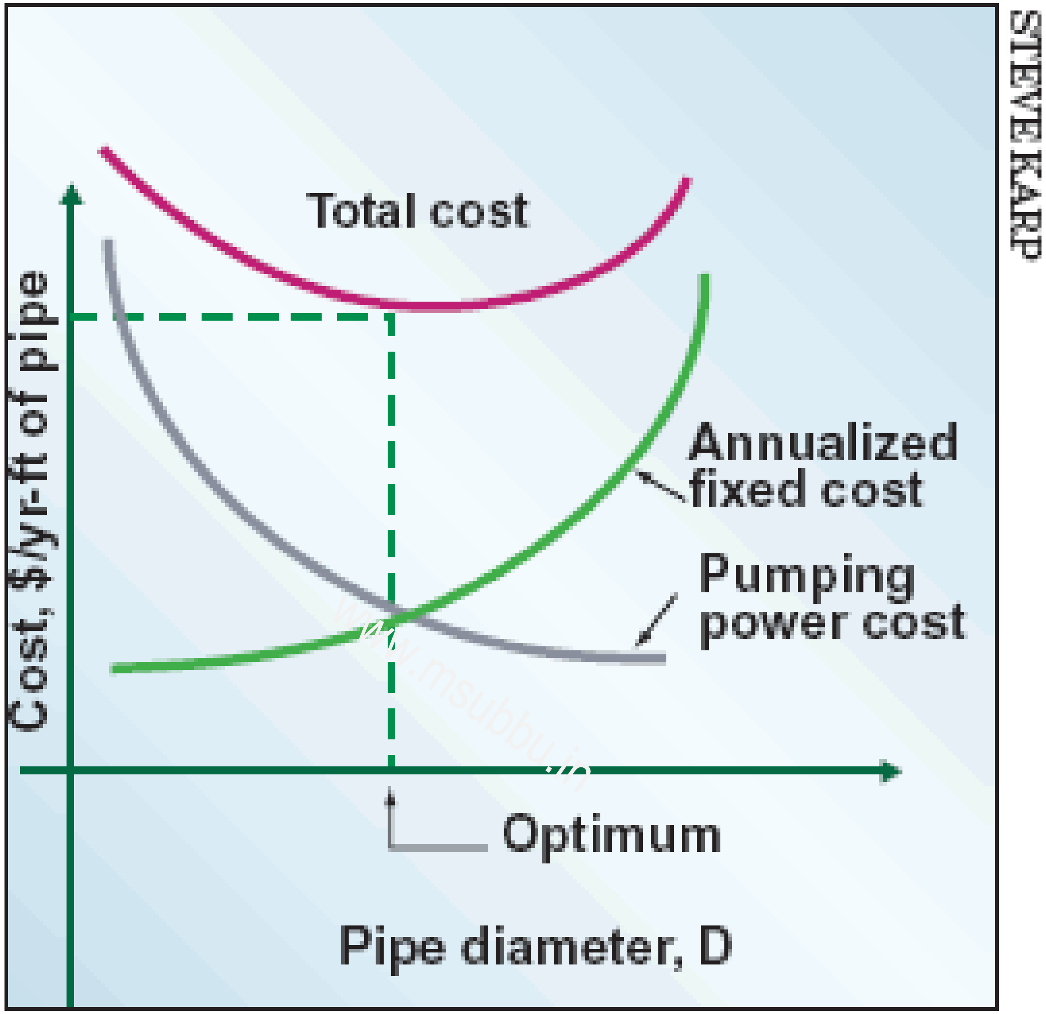
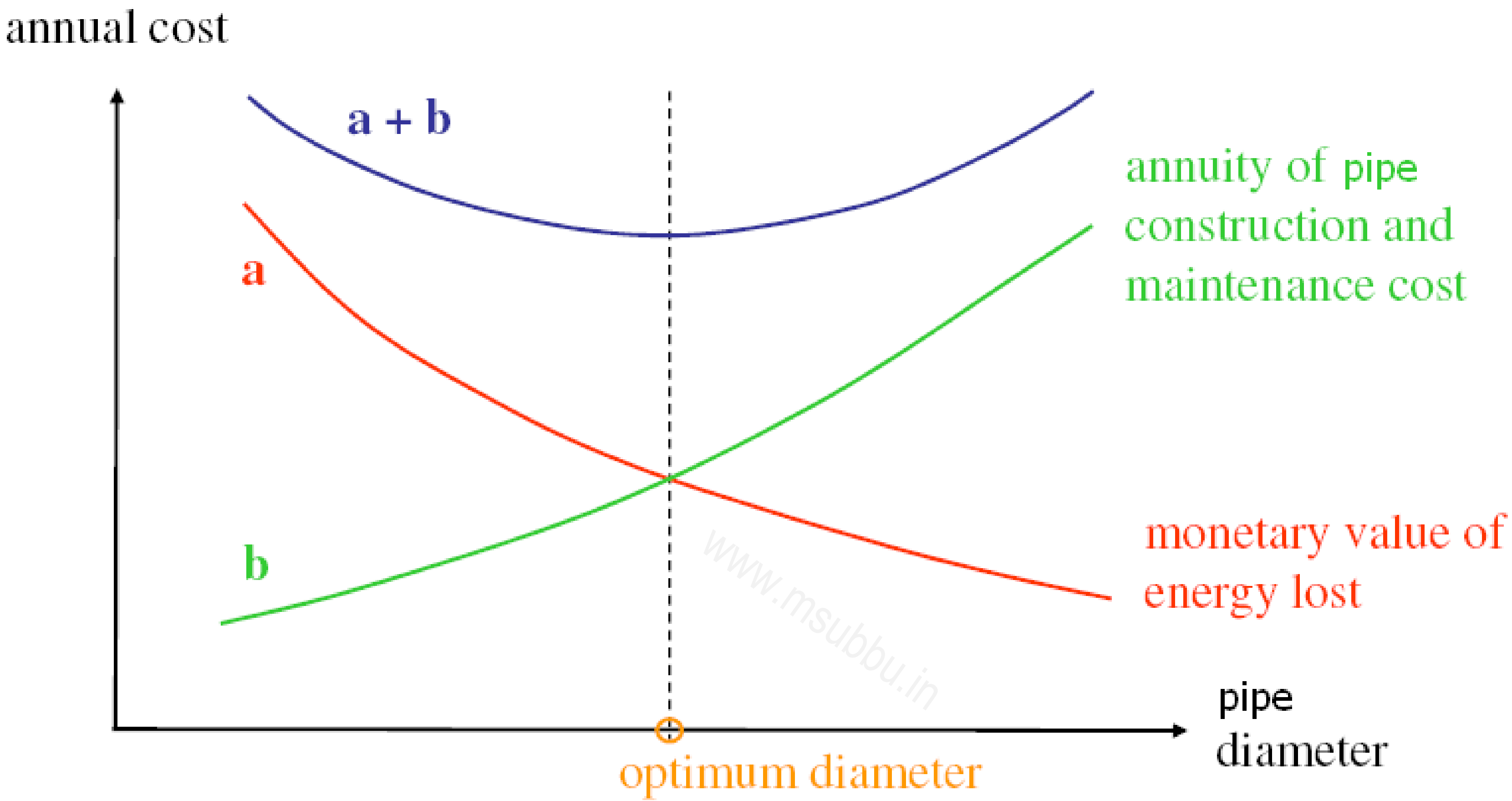
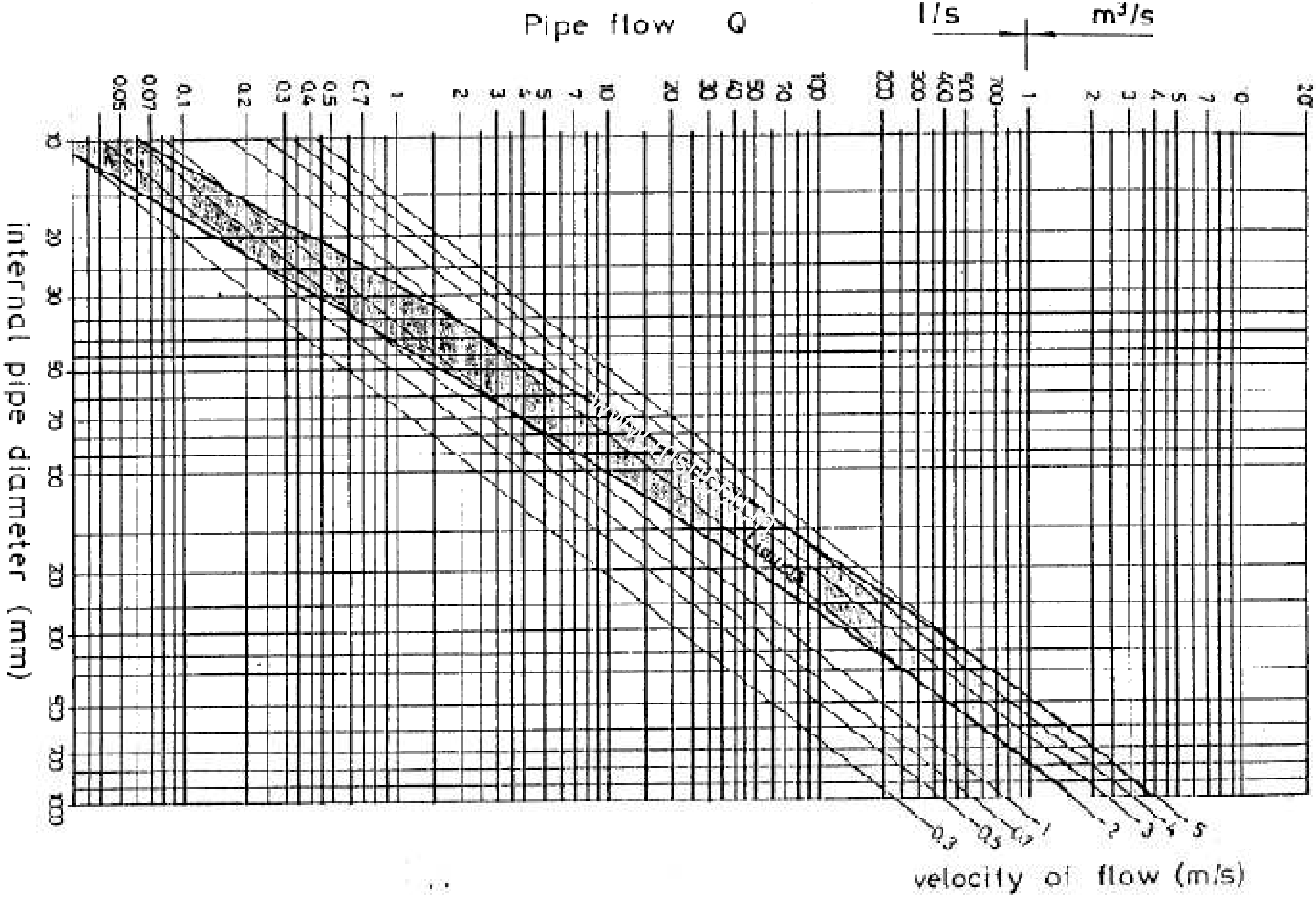


FIGURE 1. Fixed costs rise as the pipe diameter increases. Power costs fall as the pipe diameter increases, because the pressure drop falls. The sum of these two has a minimum



The pumping cost is increased with decreased size of pipe diameter because of frictional effects, while the fixed charges for the pipeline become lower when smaller pipe diameters are used because of the reduced of capital investment. The optimum economic diameter is located where the sum of pumping cost and fixed cost for the pipeline become a minimum


Pipe flow Q
l/s
m³/s
internal pipe diameter (mm)
velocity of flow (m/s)

Capital cost of a pipeline of exotic material is estimated as 3 $D^{1.5}$ Rs/m. *where* D *is the pipe diameter in mm. The annual maintenance cost is estimated as 10% of the total capital cost. Annual operating cost of the pipe is given as follows:*

$$\text{Annual operating cost } = 3 \times 10^{15}/D^5 \text{ Rs/(m.year)}$$

Estimate the most economic pipe diameter based on the least annual cost approach to the nearest multiple of 10 mm. Estimated amortization period is 10 years. (GATE-1998-27)

Total cost per year =Investment cost per year+
operating and maintenance costs per year

Given: Investment cost $= 3D^{1.5}$, and useful life $= 10$ years. Therefore,

$$\text{Investment cost per year} = \frac{3D^{1.5}}{10}$$

Therefore, total annual cost C_T of pipeline is related to the pipe diameter as

$$\begin{aligned} C_T &= \frac{3D^{1.5}}{10} + 0.1 \times 3D^{1.5} + \frac{3 \times 10^{15}}{D^5} \\ &= 0.6D^{1.5} + \frac{3 \times 10^{15}}{D^5} \end{aligned}$$

Differentiating this expression with respect to D,

$$\frac{dC_T}{dD} = 0.9D^{0.5} - \frac{15 \times 10^{15}}{D^6}$$

Minimum total annual cost is obtained by equating dC_T/dD to zero. Therefore,

$$0.9D^{0.5} - \frac{15 \times 10^{15}}{D^6} = 0$$

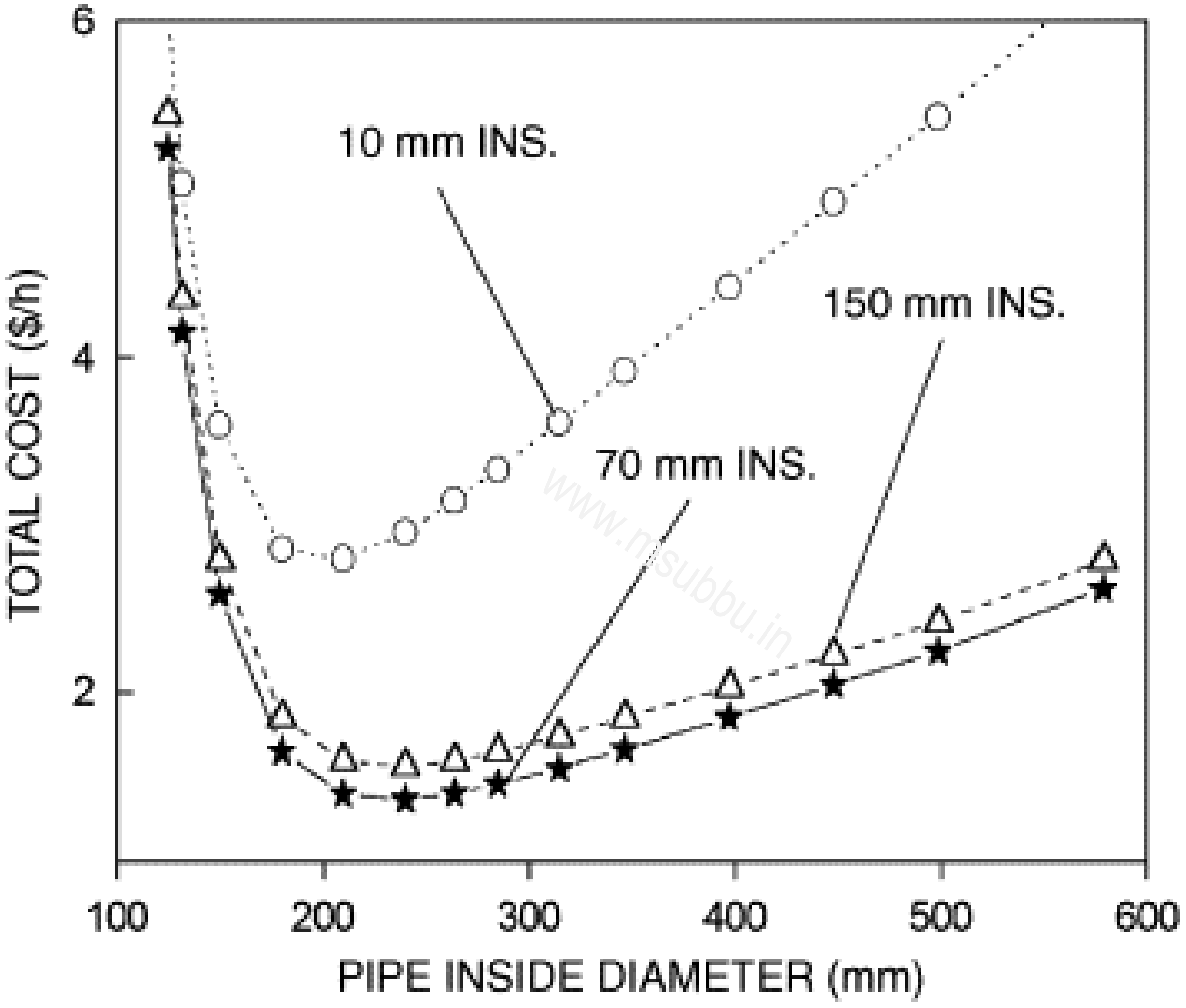
Solving, $D = 313$ mm.
Diameter to the nearest multiple of 10 mm:

$$\text{Total annual cost of pipeline of } D = 310 \text{ mm} \quad = \quad 0.6 \times 310^{1.5} + \frac{3 \times 10^{15}}{310^5} = \text{Rs. } 4323$$

$$\text{Total annual cost of pipeline of } D = 320 \text{ mm} \quad = \quad 0.6 \times 320^{1.5} + \frac{3 \times 10^{15}}{320^5} = \text{Rs. } 4329$$

Therefore, most economic pipe diameter = 310 mm

Economic Insulation Thickness



6
4
2
TOTAL COST ($/h)
10 mm INS.
150 mm INS.
70 mm INS.
100
200
300
400
500
600
PIPE INSIDE DIAMETER (mm)
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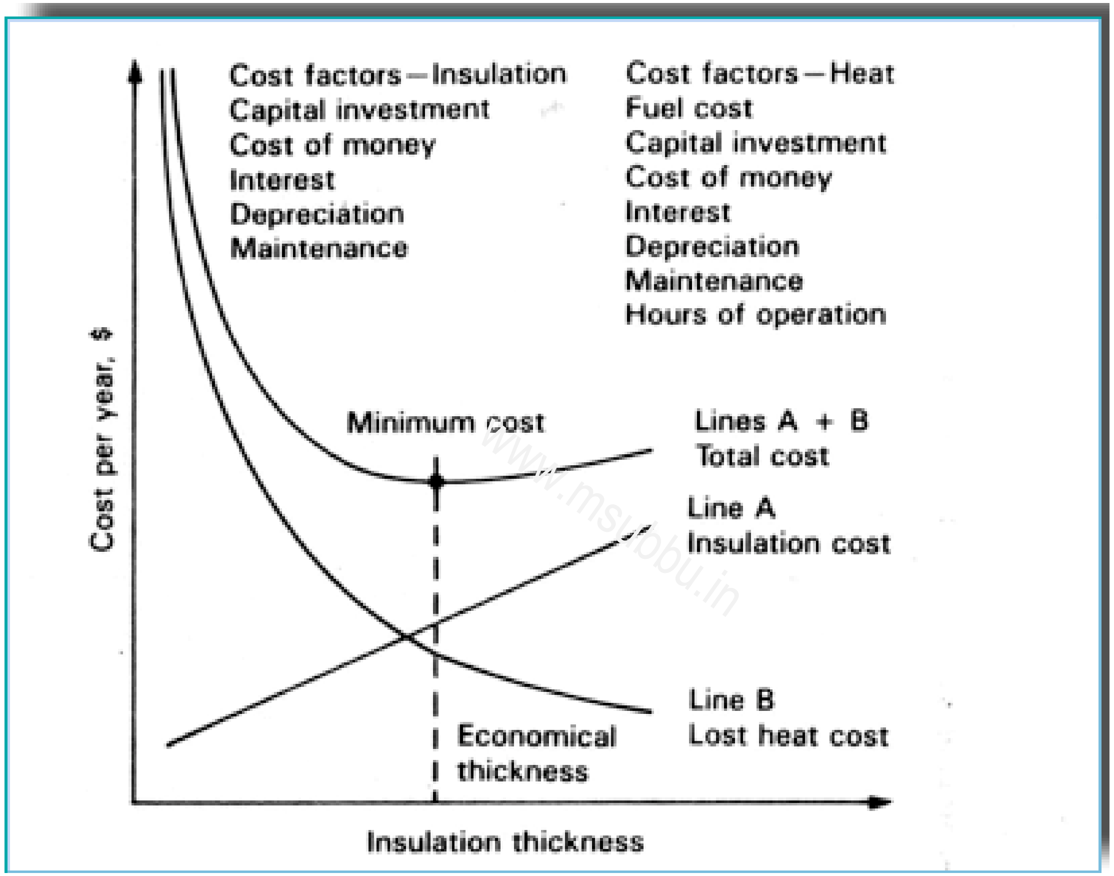
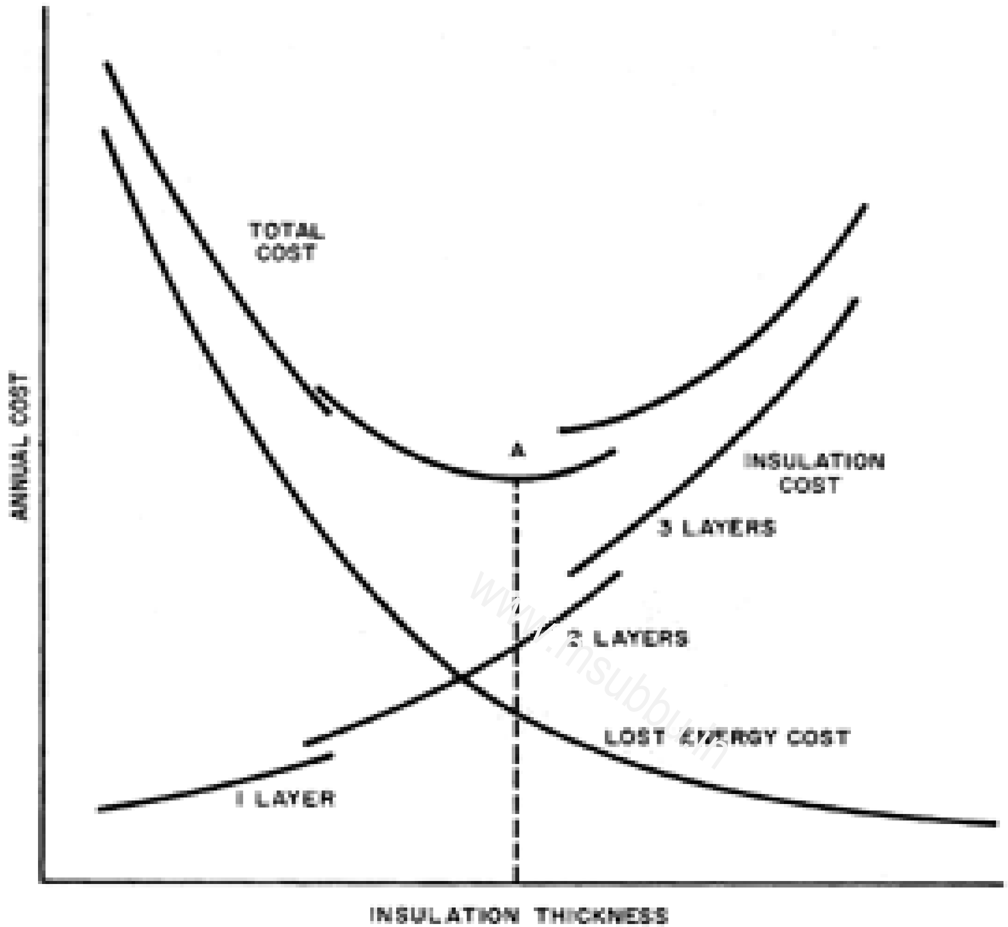

Cost factors—Insulation
Capital investment
Cost of money
Interest
Depreciation
Maintenance
Cost factors—Heat
Fuel cost
Capital investment
Cost of money
Interest
Depreciation
Maintenance
Hours of operation
Cost per year, $
Minimum cost
Lines A + B
Total cost
Line A
Insulation cost
Line B
Lost heat cost
Economical
thickness
Insulation thickness



Initially, as insulation is applied, the total annual cost decreases rapidly because the value of incremental energy savings is greater than the incremental cost of insulation. Additional insulation reduces total cost up to a thickness where the change in total cost is equal to zero. At this point, no further reduction can be obtained; beyond it, incremental insulation costs exceed the additional energy savings derived by adding another increment of insulation.

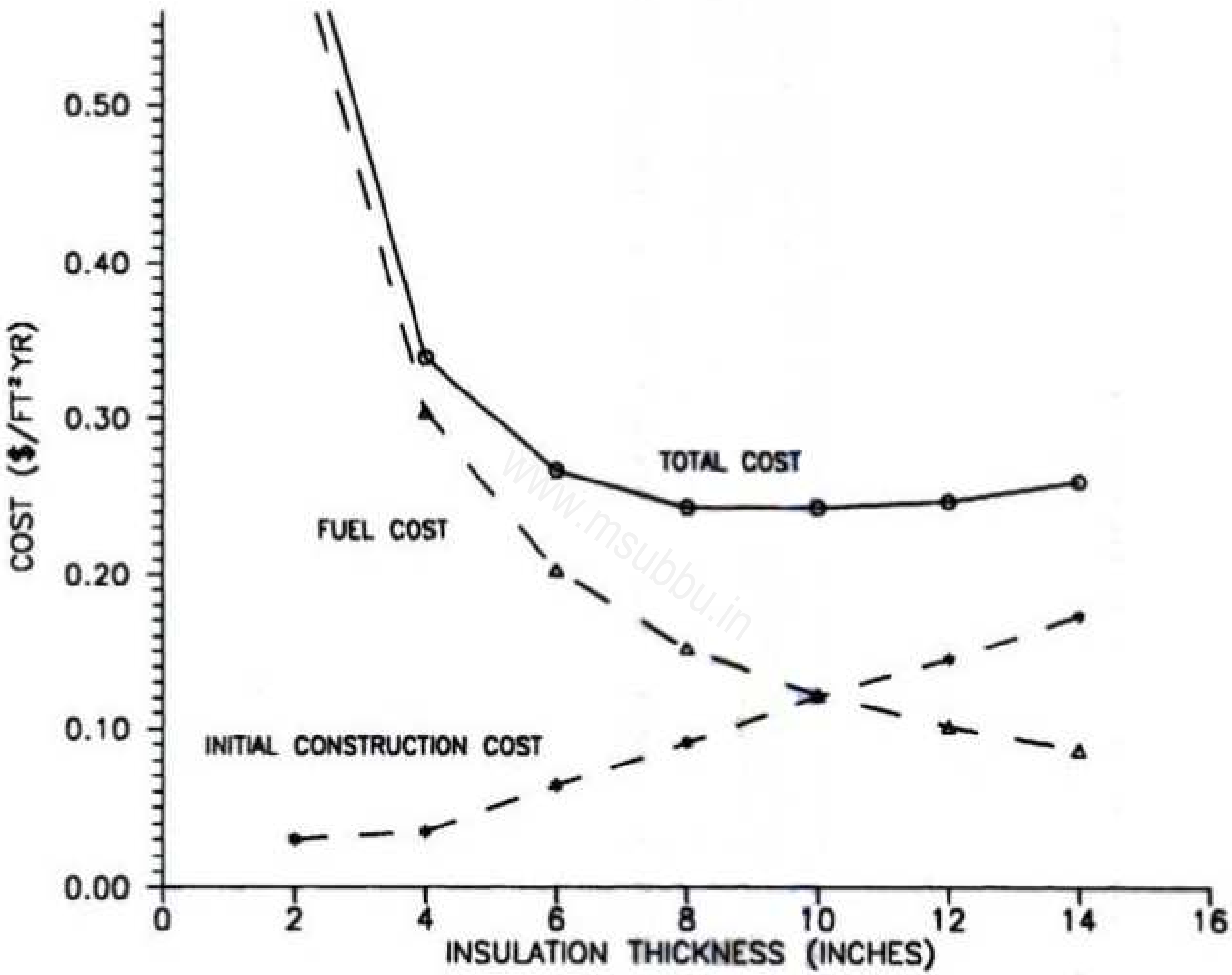
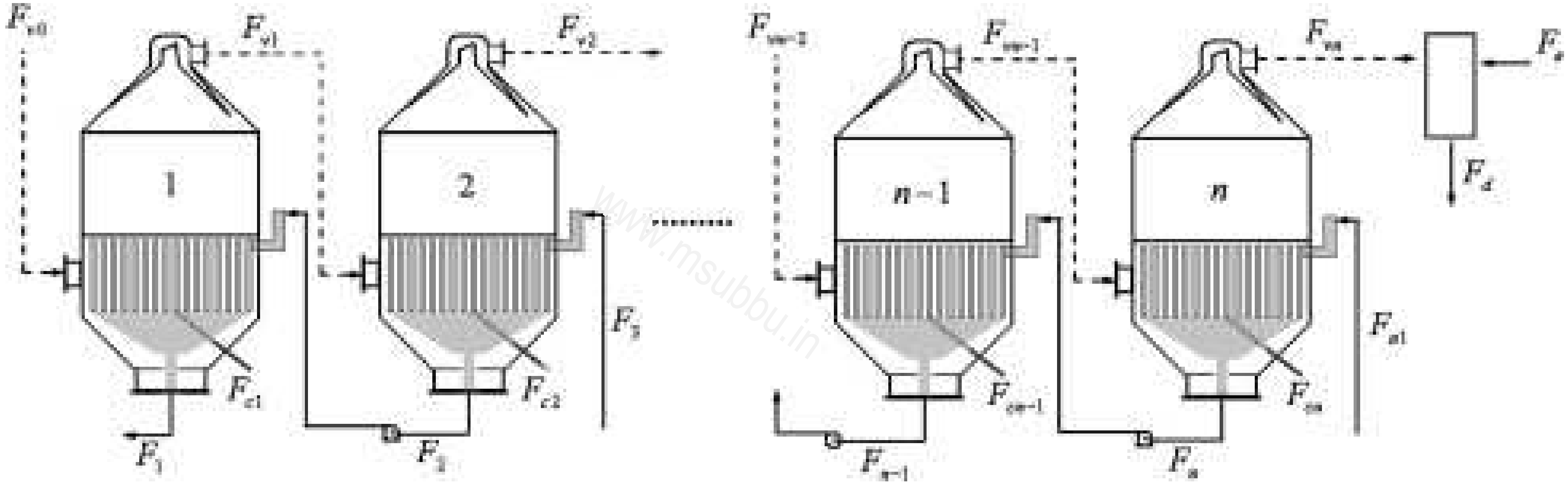
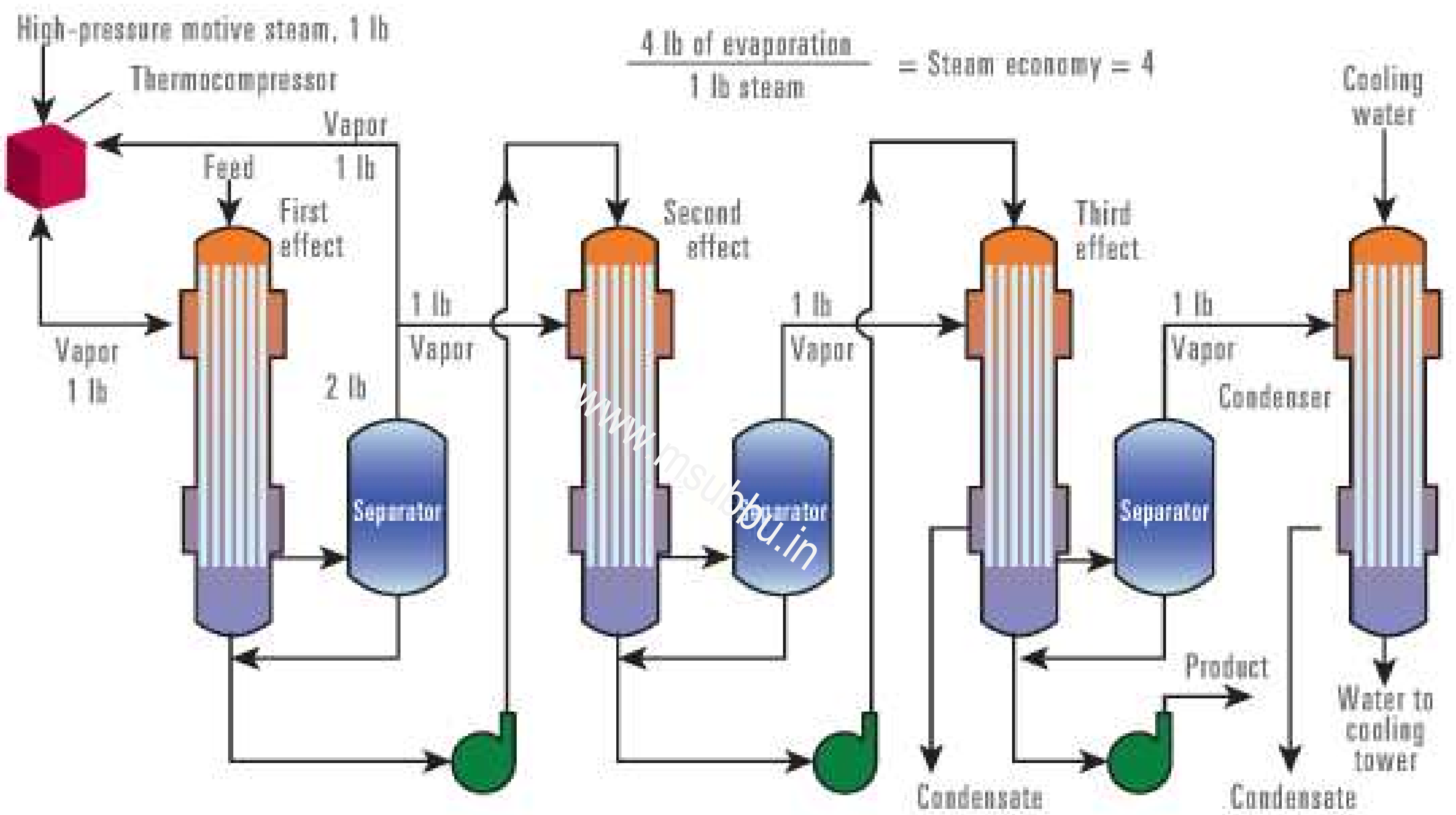


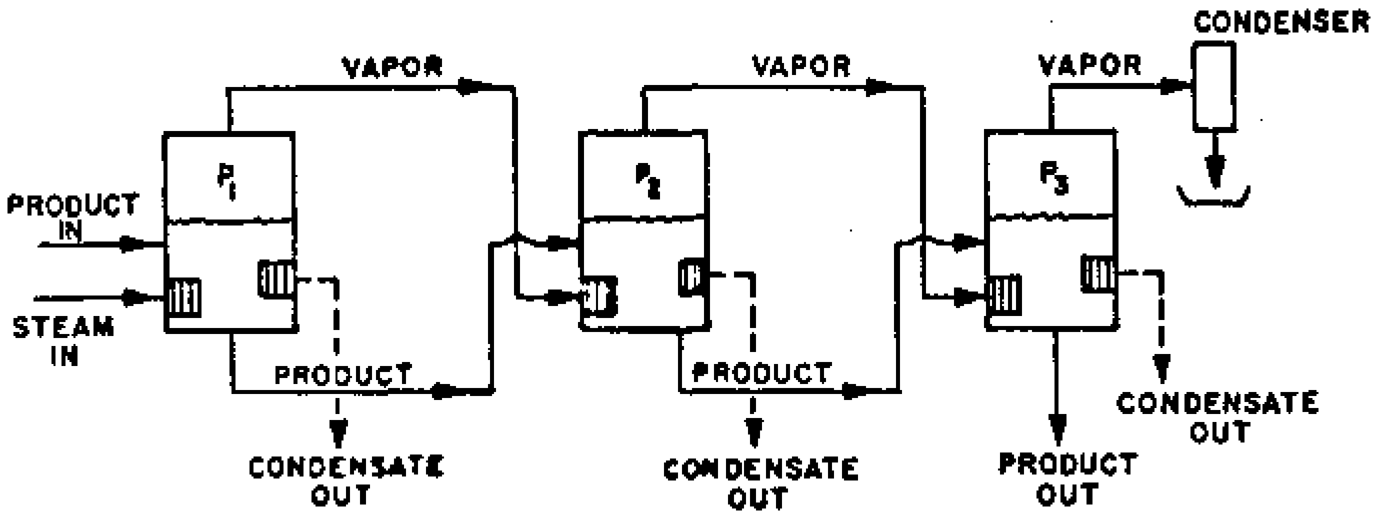
Figure 5.2.1. *Insulation thickness for lowest total cost.*

Optimum Number of Effects for Evaporation



1
2
n-1
n

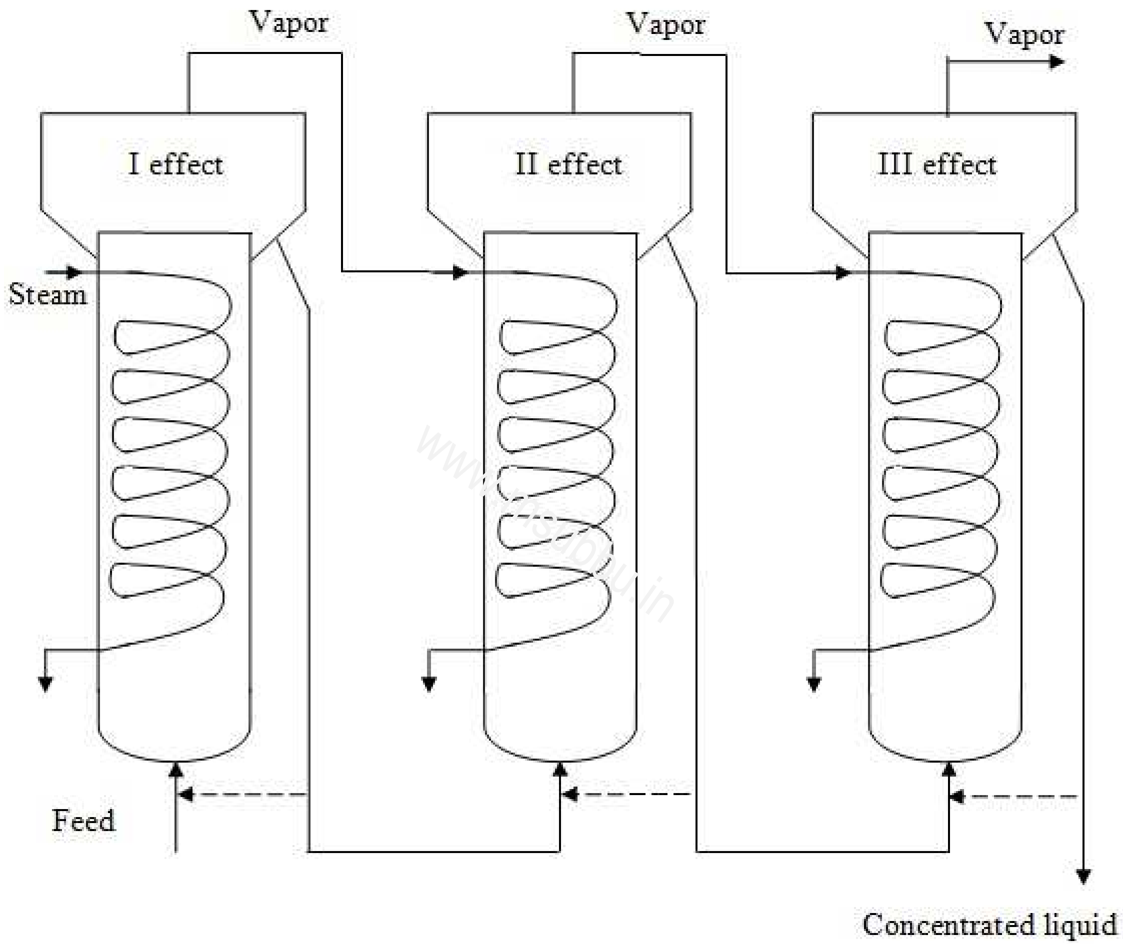

High-pressure motive steam, 1 lb
Thermocompressor
4 lb of evaporation / 1 lb steam = Steam economy = 4
Cooling water
Vapor 1 lb
Feed
First effect
Second effect
Third effect
Vapor 1 lb
1 lb Vapor
2 lb
1 lb Vapor
1 lb Vapor
Condenser
Separator
Separator
Separator
Product
Water to cooling tower
Condensate
Condensate



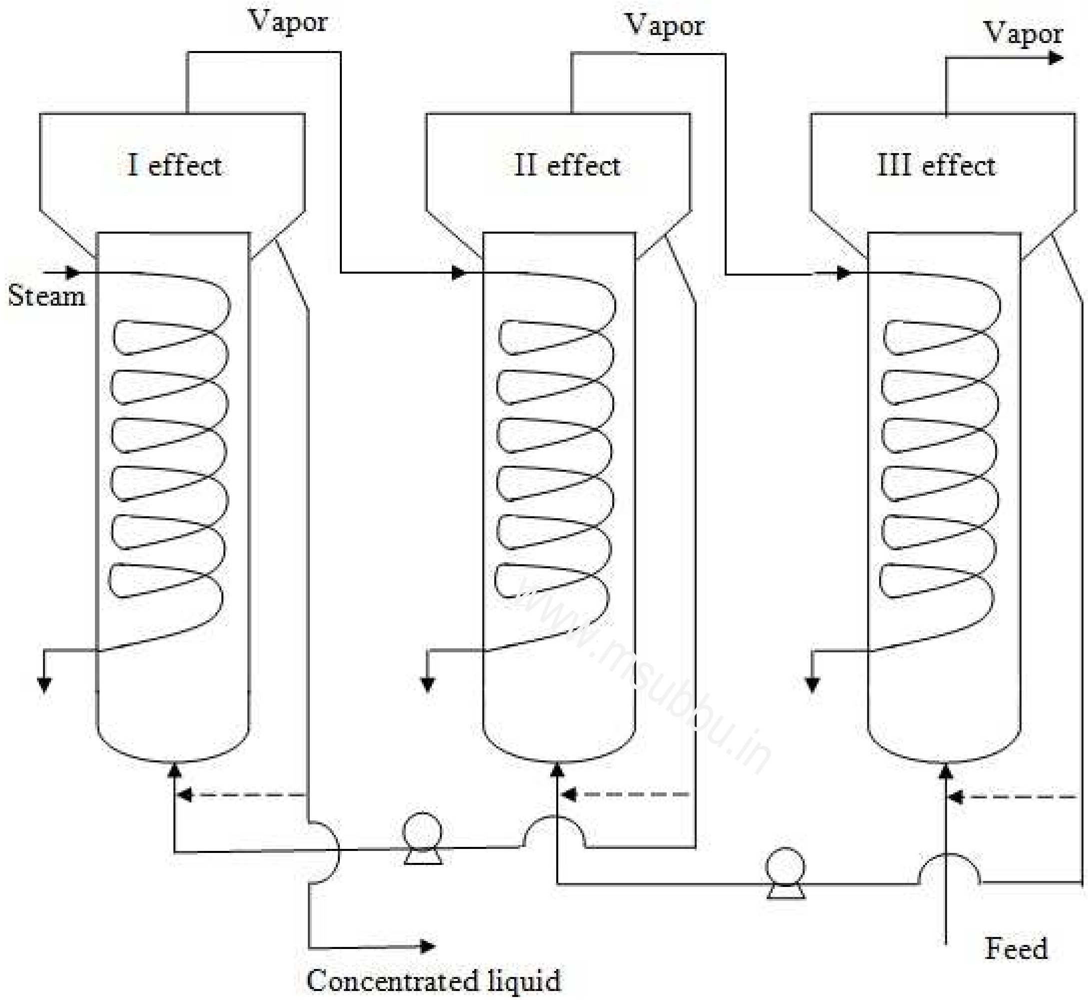
P = PRESSURE, psia

$P_1 > P_2 > P_3$

FORWARD FEED



Forward feed arrangement in triple-effect evaporator (dotted line: recycle stream)

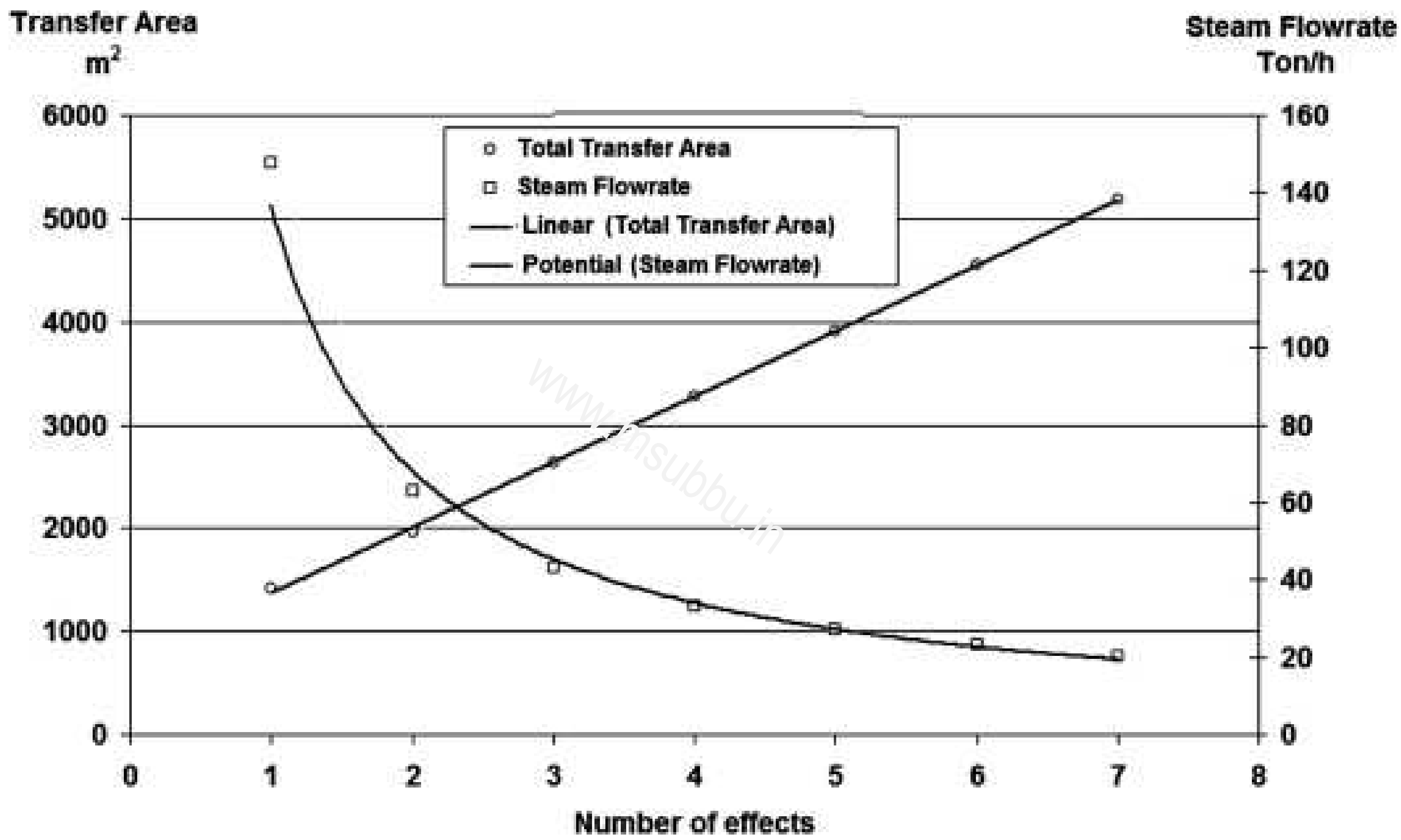


Backward feed arrangement in triple-effect evaporator (dotted line: recycle stream)

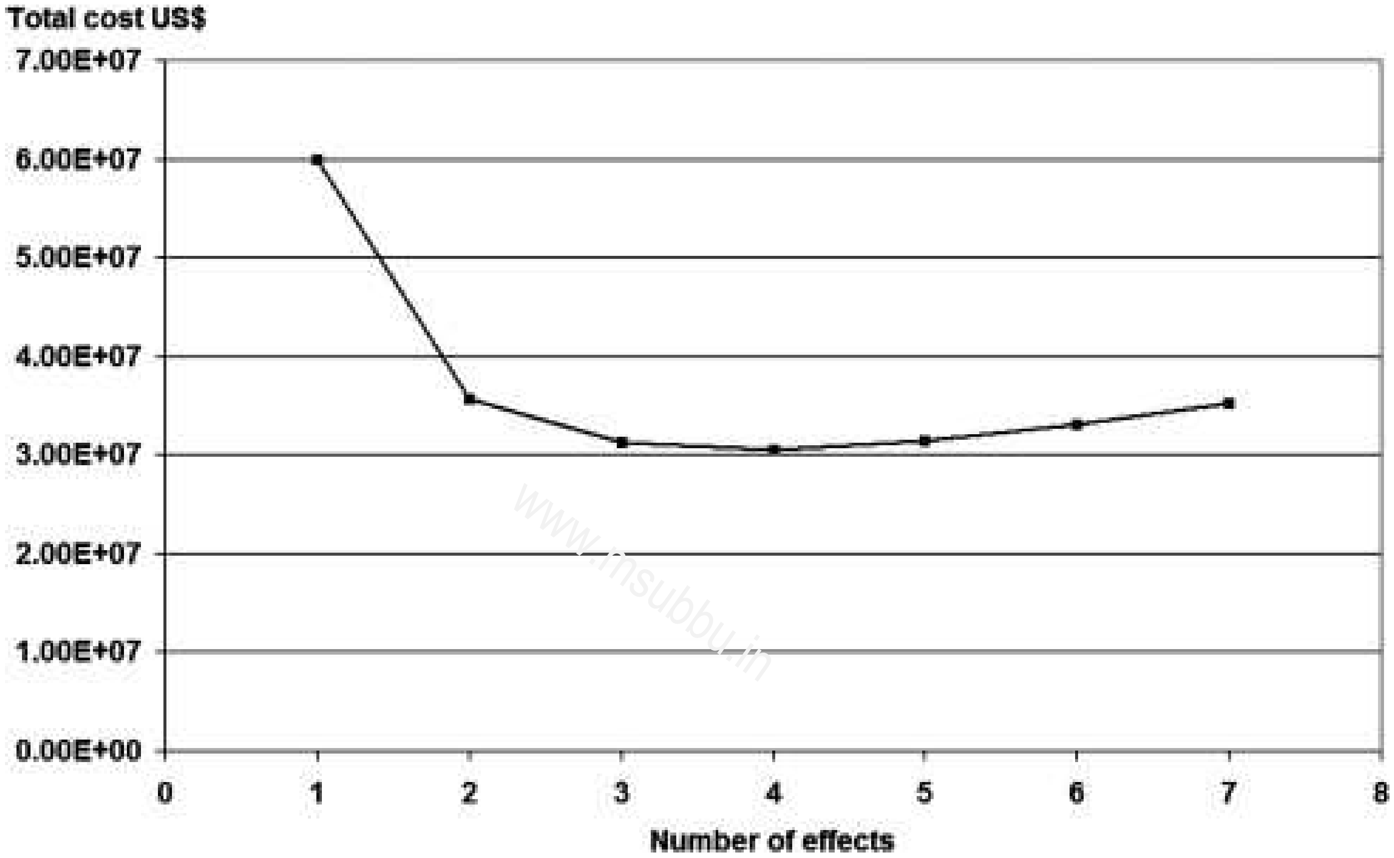
It may be noted that the first effect is that in which the fresh steam is fed, whereas the vapour generated in the first effect is fed to the next evaporator (connected in series with the first effect) is known as second effect and so on.

The forward feed requires a pump for feeding dilute solution to the first effect. The first effect is generally at atmospheric pressure and the subsequent effects are in decreasing pressure. Thus, the liquid may move without the pump from one effect to another effect in the direction of decreasing pressure. However, to take out the concentrated liquid from the last effect may need a pump.

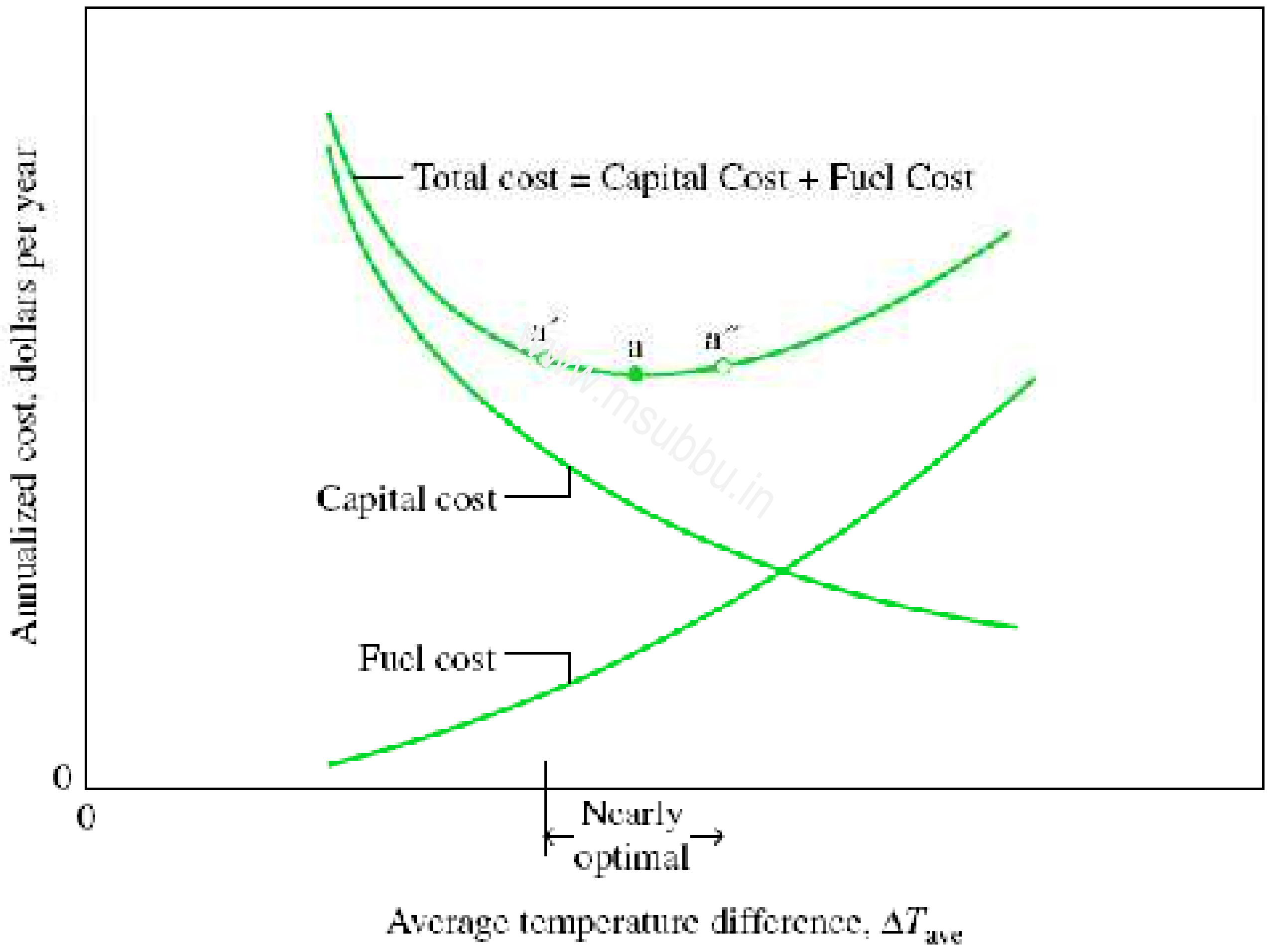
The backward feed arrangement is very common arrangement. A triple-effect evaporator in backward arrangement is shown in the fig.9.6. In this arrangement the dilute liquid is fed to the last effect and then pumped through the successive effects to the first effect. The method requires additional pumps (generally one pump in between two effects) as shown in the fig. 9.6. Backward feed is advantageous and gives higher capacity than the forward feed when the concentrated liquid is viscous, because the viscous fluid is at higher temperature being in the first effect. However, this arrangement provides lower economy as compared to forward feed arrangement.



Transfer Area
m²
Steam Flowrate
Ton/h
6000
5000
4000
3000
2000
1000
0
160
140
120
100
80
60
40
20
0
Total Transfer Area
Steam Flowrate
Linear (Total Transfer Area)
Potential (Steam Flowrate)
0
1
2
3
4
5
6
7
8
Number of effects


Total cost US$
7.00E+07
6.00E+07
5.00E+07
4.00E+07
3.00E+07
2.00E+07
1.00E+07
0.00E+00
0
1
2
3
4
5
6
7
8
Number of effects

Optimizing Heat Exchanger



Batch Processing Plants