CHEMICAL ENGINEERING (GATE & PSUs)

Postal Correspondence

STUDY MATERIAL (Handwritten Notes)

By Ajay Sir

PLANT DESIGN & ECONOMICS

GATE-2022 Syllabus: Chemical Engineering

Principles of process economics and cost estimation including depreciation and total annualized cost, cost indices, rate of return, payback period, discounted cash flow, optimization in process design and sizing of chemical engineering equipments such as compressors, heat exchangers, multistage contactors.

PLANT DESIGN & ECONOMICS COURSE CONTENT

Note for Student:

1. Full GATE Syllabus covers in Notes.

2. Total number of pages in PDE Notes = 115 Pages

3. No. of Questions solved in Notes = 110+ Questions

(GATE PYQs & other good quality question)

"Plant Design & Economics"

Depreciation :- The value of the equipment decrease with respect to time.

→ Time depreciation (value ↓ with time)
→ Technology depreciation (Technology dep. advance value ↓)
→ Physical depreciation (physical damage)
→ economical depreciation (change in policies level)

Method of Depreciation :-

I) Methods that does not depend on time value of money.

① straight line depreciation Method
② Declining balance method
③ Double declining balance method
④ sum of year digit method

II) Method that depends on time value of money.

① sinking fund depreciation method

✓ * Note→ only fixed capital depreciate, working capital doesn't depreciate.

* Important Defination:

1) Book value of the equipment (V_a): The value that will get actually after the sell of equipment.
It is calculated at the end of an year.

2) Service life (n): The life of the equipment up to which the use of the equipment is economic feasible. It is represent by n.

3) Salvage value (V_s): After the end of service life, if the equipment is not use and it is usefull for someone else, then the money obtained ~~by~~ after the selling of the equipment is known as "salvage value".

4) Scrap value: When the equipment is not in used and is not useful for someone else that it is sold as junk or scrap and the money obtain is neglegible in comparision to the initial value, that money is known as "scrap value".

→ Both of them represented by V_s

for salvage value $V_s \neq 0$

scrap value $V_s = 0$

1) Straight line depreciation method :- (SLM)

* Assumption :-

① Depreciation is same for all years

$$d_1 = d_2 = d_3 = \cdots = d_a$$

$$d_a = \frac{V_0 - V_s}{n}$$

Where d_a = Depreciation amount

V_0 = Initial cost of equipment

V_s = salvage value of equipment

n = service life of equipment

Book value $V_a = V_0 - ad$

$a = 1, 2, 3 \ldots \ldots n$

(GATE-1992)

Example 1) A chemical process plant has an initial investment of Rs 50 lakh and scrap value of Rs 2 lakh, at the end of service life of 8 year. Calculate the <u>net value</u> of the plant after 4 years & <u>depericiation</u> for the 4th year <u>using straight line method</u>.

Solution :- given data

$V_0 = 50$ lakh

$V_s = 2$ lakh

$n = 8$ years

formula for SLM

$$\boxed{d_0 = \frac{V_0 - V_s}{n}} = \frac{50-2}{8}$$

depericiation $d = 6$ lakh

Book value

$$\boxed{V_a = V_0 - ad}$$

$$V_4 = 50 - (4 \times 6)$$

$$V_4 = 26 \text{ lakh}$$ Answer

2) Declining balance method :-

* Assumption

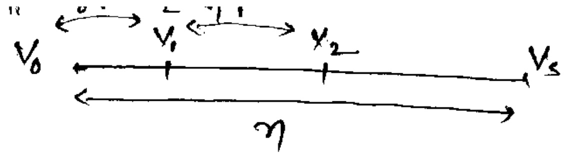
I) Depreciation is different for different year

$$d_1 \neq d_2 \neq d_3 \neq - - - \neq d_n \quad (d_1 > d_2 > d_3 \ldots)$$

II) Percentage of depreciation of capital is same ~~of~~ for all the year (f = fix percentage factor)

III) This method is also known as <u>fixed % method</u> or textbook decling balance method.

IV) only valid for V_s (salvage value) $\neq 0$



$d_1 = V_0 f$

$d_2 = V_1 f$

$\vdots$

$$\boxed{d_a = V_{a-1} f}$$

f = fix percentage factor

$d_a = V_{a-1} - V_a$

$\Rightarrow \underline{d_1 = V_0 f}$

$d_1 = V_0 - V_1$

$V_1 = V_0 - d_1 \Rightarrow V_1 = V_0 - V_0 f$

$$\boxed{V_1 = V_0(1-f)}$$

$V_2 = V_1 - d_2$

$V_2 = V_1 - V_1 f$

$V_2 = V_1(1-f)$

$V_2 = V_0(1-f)(1-f) \Rightarrow \boxed{V_2 = V_0(1-f)^2}$

General formula for Book value $\boxed{V_a = V_0(1-f)^a}$

$$\Rightarrow \boxed{f = 1 - \left(\frac{V_s}{V_0}\right)^{1/n}}$$ Matheson formula

Que→2) for $V_0 = 50$ lakh, $V_s = 2$ lakh, $n = 8$ years. Calculate the Book value after 4 year & depreciation for the 4th year using declining balance method.

Sol:- formula: $\boxed{f = 1 - \left(\frac{V_s}{V_0}\right)^{1/n}} = 1 - \left(\frac{2}{50}\right)^{1/8} \Rightarrow \underline{f = 0.33}$

Book value for 4th year. $V_a = V_0(1-f)^a$

$V_4 = V_0(1-f)^4 \rightarrow 50(1-0.33)^4$

$\underline{V_4 = 10.07 \text{ lakh}}$

depreciation for 4th year

$d_4 = \underline{V_0(1-f)^3} \cdot f$

$d_4 = V_3 f$

$d_4 = 50(1-0.33)^3 \times 0.3 = \underline{4.96 \text{ lakh}}$ Ans

(GATE-2011)

Que→3) A process plant has a service life of 7 year & its salvage value is 30%. for what minimum fix percentage factor will be depreciation amount for the second year. calculated by declining balance method be equal that calculated by straight line method.

(A) 0.1 (B) 0.113 (C) 0.527 (d) 0.887

Sol:- given data $n = 7$ year

$V_s = 0.3\, V_0$

(a) by SLM: $\boxed{d_0 = \frac{V_0 - V_s}{n}}$ ⇒ $d_0 = \frac{V_0 - 0.3 V_0}{7}$

same for all year $\boxed{d = 0.1\, V_0}$ ——— (1)

$d_2 = 0.1\, V_0$

(b) by DBM $d_a = V_{a-1} f$

$\boxed{d_2 = V_1 f}$ ——— (2)

According to question $[d_2]_{DBM} = [d_2]_{SLM}$

$\underline{V_a = V_0 (1-f)^a}$

$V_1 f = 0.1\, V_0$

⇒ $V_0 (1-f)^1 f = 0.1\, V_0$

⇒ $(1-f) f = 0.1$

⇒ $f^2 - f + 0.1 = 0$

$\left(f = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \right)$ ⇒ $f = \frac{1 \pm \sqrt{0.6}}{2}$

$f = 0.113$ and $f = 0.887$

minimum percentage factor $\boxed{f = 0.113}$ Answer

* Double Declining balance method :-

→ generally we use this formula when ($V_s = 0$)

→ In this method the factor we use is double of the minimum factor in SLM (straight line depreciation method)

* suppose that salvage value is equal to zero

depreciation in the first year = $\frac{V_0}{n}$

* percentage depreciation in the first year = $\frac{V_0/n}{V_0}$

$= \frac{1}{n}$

* factor to be used in Double Declining method = $\frac{2}{n}$

(3) Double declining balance method :-

It is same as declining balance method but it is valid for scrap value $V_s = 0$.

* Assumption

I) complete capital will decline with in year.

$$V_a = V_0 (1-f)^a$$
$$D_a = V_{a-1} f$$

$$f = \frac{2}{n}$$

f = fix percentage factor
n = service life of equipment

(GATE-2009)

Que-4) A distillation column has a cost of rupees 5 lakh and a usefull life period of 10 years. using the double decling balance method calculate the value of equipment at the end of 6 year.

Sol:- $f = \frac{2}{n} = \frac{2}{10} = 0.2$

$V_a = V_0 (1-f)^a \Rightarrow V_6 = V_0 (1-f)^6$

$= 5(1-0.2)^6$

$V_6 = 1.31$ lakh

(4) Sum of year digit method

* Assumption :-

(i) $d_1 \neq d_2 \neq d_3 \neq \cdots \neq d_n$

(ii) It doesnot depend on value of V_s

$D_1 = V_0 - V_1$

$V_1 = V_0 - D_1$

$V_2 = V_0 - D_1 - D_2$

$$D_a = \frac{2(n-a+1)}{n(n+1)} (V_0 - V_s)$$

$$D_a = \frac{(n-a+1)}{\Sigma n} (V_0 - V_s)$$

$\because \Sigma n = \frac{n(n+1)}{2}$

(GATE-2010)

Que-5) P is the investment made on n- equipment. s is salvage, n is service life of the equipment. d is depreciation of the m^{th} year by the sum of year digit method.

ⓐ $\frac{P-s}{n}$ ⓑ $\frac{m}{n}(P-s)$ ⓒ $1-\frac{P^n}{s}$ ⓓ $\frac{2(n-m+1)}{n(n+1)}(P-s)$ ✓

Sol:
$$\left[d = \frac{(n-a+1)}{\Sigma n}(P-s)\right] \quad ; \quad \Sigma n = \frac{n(n+1)}{2}$$

$$d = \frac{2(n-a+1)(P-s)}{n(n+1)}$$

(5) sinking fund depreciation method :-

If the price of equipment remains the same at the end of service life we need an amount $= V_0 - V_s$,
To accumulate this amount depreciation fund is setup.
To calculate the depreciation with the help of annuity and is given by

$$V_0 - V_s = \frac{R}{i}\left[(1+i)^n - 1\right]$$

where R is the depreciation amount.

Book Value

$$V_a = V_0 - (V_0 - V_s)\left[\frac{(1+i)^a - 1}{(1+i)^n - 1}\right]$$

COST INDEX :-

cost index are just index values that relates the cost of an equipment that a particular time with the basic time or reference time.

* Estimation of cost of equipment :

I) It depends on capacity

II) It depends on time / cost

(I) Based on capacity :- (time is constant)

→ method $6^{th}/10^{th}$ Rule

$$\left[\frac{\text{Cost of equipment}|_{\text{capacity } C_1}}{\text{Cost of equipment}|_{\text{capacity } C_2}} = \left(\frac{\text{capacity } C_1}{\text{capacity } C_2}\right)^{6/10}\right]$$

Note:- In general way, for each equipment this power is different but if nothing is given we will use six-tenth ($6^{th}/10^{th}$) rule. which is default value.

(II) Based on time : (assume capacity constant)

Cost $\propto$ cost index of that year

$$\left[\frac{\text{cost of equipment}|_{\text{year}_1}}{\text{cost of equipment}|_{\text{year}_2}} = \frac{\text{cost Index}|_{y_1}}{\text{cost Index}|_{y_2}}\right]$$

<GATE-2011>

Que 11) An investment of rupees 1000 is carrying an interest of 10% compounded quarterly.

The value of the investment at the end of 5 years will be

(A) $1000\left(1+\frac{0.1}{4}\right)^{20}$ ✓ (B) $1000\left(1+\frac{0.1}{4}\right)^{5}$

(C) $1000\left(1+0.1\right)^{20}$ (D) $1000\left(1+\frac{0.1}{2}\right)^{5}$

Sol →

$$\boxed{S = P(1+i_{eff})^n} \quad \text{——— (1)}$$

$$\boxed{i_{eff} = \left(1+\frac{r}{m}\right)^m - 1} \quad \text{——— (2)}$$

$r = 10\% = 0.1$

$m =$ quaterly 4 time in a year $= 4$

$$\left[i_{eff} = \left(1+\frac{0.1}{4}\right)^4 - 1\right] \quad \text{——— (3)}$$

from eq^n (1) & (3)

$$S = P\left(1+\left(1+\frac{0.1}{4}\right)^4 - 1\right)^n$$

$P = 1000$ rupees

$n = 5$ year

$$S = 1000\left[1+\frac{0.1}{4}\right]^{4\times 5}$$

$$S = 1000\left(1+\frac{0.1}{4}\right)^{20}$$ Answer (a) option

Capitalized cost :- (C.C)

Capitalized cost is profitability analysis method and the purpose is just the compare the alternative and that why interest are withdrawn every year so that the calculation become simple.

→ for a fixed capital investment of V_0, the money that would need to deposit in the bank will be 1.5 time or 2 times the V_0. In reality we are short of money which makes this method

* Assumption :-

1) Capitalized cost consider the time value of money but doesn't consider the compounding.

2) Equipment cost is not change (or remain constant)

* capitalized cost is related to replacement of cost of equipment

* Gives alternative that has a least capitalized cost is the best.

$$\text{Capitalized cost} = C_1 + C_2$$

Where C_1 = cost of equipment (initial price)

C_2 = Cost for infinite replacement

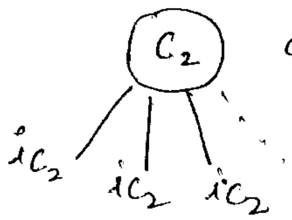
$$C_1 = C_V$$

Replacement cost

$$C_R = C_V - C_S$$

where C_S = salvage value of equipment

→ We are going to replace equipment with the help of interest only.



C_2 cost of infinite replacement

* C_2 is calculated in such a way that the interest on C_2 for a period of n years should accumulate to

$C_R = C_V - C_S$

future worth
$$\boxed{S_n = \frac{R}{i}\left[(1+i)^n - 1\right]}$$
; $R = iC_2$

, $S_n = C_V - C_S$

$$C_V - C_S = \frac{iC_2}{i}\left[(1+i)^n - 1\right]$$

$$\frac{C_V - C_S}{(1+i)^n - 1} = C_2$$

$$\boxed{C_2 = \frac{C_R}{(1+i)^n - 1}}$$

Capitalized cost $= C_1 + C_2$

✓
$$\boxed{C.C = C_V + \frac{C_R}{(1+i)^n - 1}}$$

Where C_V = original cost of equipment

C_R = Replacement cost of equipment

$$\boxed{C_R = C_V - C_S}$$

⟨GATE-2008⟩

Que→15⟩ A reactor has been installed at a cost of Rs 50,000 and is expected to have a working life of 10 years. with a scrap value of Rs 10,000. The capitalized cost of a reactor based on an annual compound interest rate of 5% is ______.

Sol→

$$C.C. = C_V + \frac{C_R}{[(1+i)^n - 1]}$$

$C_V = 50,000$

$C_s = 10,000$

$n = 10$

$i = 5\% = 0.05$

$$C_R = C_V - C_s$$

$C_R = 50,000 - 10,000$

$C_R = 40,000$

$$C.C = 50,000 + \frac{40,000}{(1+0.05)^{10} - 1}$$

$C.C = \text{Rs } 1,13,603.66$ Answer

* Application of capitalized cost :-

→ for vendor analysis

→ which project / equipment is more economical.

Note :→ which has least value of capitalized cost is more economical for us.

Example :- ①

Heat exchanger 1 $\quad C_{V_1} \quad C_{S_1} \quad n_1 \Rightarrow (C.C)_1$

Heat exchanger 2 $\quad C_{V_2} \quad C_{S_2} \quad n_2 \Rightarrow (C.C)_2$

Example ②

If V_1 & V_2 are equally economical $\boxed{(C.C)_I = (C.C)_{II}}$

→ C.C is used for comparing service life, replacement value etc.

⟨GATE → 2003⟩

Ques 16⟩ Two pump under consideration for install at a plant having the following capitalized cost or salvage value

	C_v	C_s
pump A	Rs 40,000	3900
pump B	Rs 50,000	20,000

using capitalized cost method determine what should be common life of the pump for both to be competetive (equally economical). Interest rate is 10% annully.

Sol →

$$C.C = C_v + \frac{C_R}{(1+i)^n - 1}$$

$\because C_R = C_v - C_s$

let $n_1 = n_2 = n$

$$C_{v_1} + \frac{C_{R1}}{(1+i)^n - 1} = C_{v_2} + \frac{C_{R2}}{(1+i)^n - 1}$$

$$40{,}000 + \frac{(40{,}000 - 3900)}{(1+0.1)^n - 1} = 50{,}000 + \frac{(50{,}000 - 20{,}000)}{(1+0.1)^n - 1}$$

$$\frac{6100}{(1+0.1)^n - 1} = 10{,}000$$

$$(1+0.1)^n - 1 = \frac{6100}{10{,}000} = 0.61$$

$$(1+0.1)^n = 1.61$$

$$(1.1)^n = 1.61$$

taking logarthmic on both side

$$n \ln(1.1) = \ln(1.61)$$

$$n = 4.99 \simeq 5$$

common service life: $n = 5$ years Answer