Process Technology and Economics-1
Module-4

Arnab Karmakar

BIT Mesra, Ranchi

Process / Project engineering & Economics for chemical Engineers. (1)

Module-3

Process design ; Chemical process considerations; Qualitative block type process flow sheet; selection of process equipment; plant layout: Planing layout and methods of layout planning.

Process Design Development

Process design can provide chemical engineers with probably the most ~~[illegible]~~ creative activity enjoyed by the engineering profession. Here, chemical engineers face challenges in creating ingenious and often complex flowsheets for new or revised processes. Such developments ~~[illegible]~~ involve innovative approaches to entirely new processes or revisions to existing processes that are more profitable, better controlled, operationally safe, aswell as environmentally sound.

Development of Design Databse.

~~Kind~~ Literature Survey: Development of solutions to a design need searching of literatures to obtain the latest data, flowsheets, equipment, and simulation models that may lead to a more profitable design.

Electronically access kineticsdata, thermophysical property Data, and related information about chemicals.

Chemical Abstracts (since 1907 it publishes comprehensive scientific indexing and abstracting services in Biochemistry, organic chemistry, physical and analytic chemistry, macromolecular chemistry, applied chemistry and chemical Engineering (electronically available now).

Engineering Index (with access to 4500 journals, technical reports, and books since 1985).

Applied science and technology index (350 journals since 1985)

Science Citation Index (with access to 3300 journals 1955 and electronically 1985).

Book: Perry's Chemical Engineers' Handbook (1997).
Chemical processing Handbook (1993).
Unit operations Handbook (1993).
~~JNAF~~ JANAF Thermochemical Tables (1985)
Handbook of reactive chemicals Hazards (1990).
Data for Process Design and Engineering Practice (1995).

Literature resources:
SRI (Standard research institute) → Design reports, and documentation of many chemical processes.

Encyclopedia:
kirk-othmer Encyclopedia of chemical Technology (1994), ~~Encycl~~
Encyclopedia of chemical processing and Design (1976).
Encyclopedia of industrial chemistry (1988).
Ullman's Encyclopedia

Software: ASPEN PLUS, HYSIS, CHEMCAD & PRO-II.
Database of 2000 compounds are provided by these simulators with ~~a~~ large libraries of programs that carry out material & Energy balances as well as equipment size and cost.

Thermodynamic data:
DECHEMA → Extensive phase equilibria data.
Determine interaction ~~coff~~ coefficients for the binary pairs to be used to estimate liquid phase activity coefficients from NRTL, UNIQUAC, Wilson etc. eqns.

Patent search :

Design engineers must aware patents to avoid duplication of designs protected by these patents.
Patents from US, Germany, Japan are available in ~~patent se~~ patentsearch ~~in~~ through internet.

Process creation

After surveying the literature for one or more practical solutions, design engineer encounters a major challenge in creating a new process or significantly improving an existing process to satisfy economic, technical, safety ~~and~~ goals.

It involves synthesis of various configurations of processing operations that will produce a product in a reliable, safe and economical ~~manner~~ manner with a high yield and minimum by-product or waste.

Earlier it was heuristics, or rule or thumb.
Nowadays it is more quantitative. and scientific with decision-tree analysis and mathematical programming aided by use of modern computers.

In process of synthesizing a flowsheet of process operations to convert raw material to desired product. ~~So~~ design engineer must select · various matters.

1) Batch or continuous operation.

~~contin~~ Continuous operation → reduced labor costs, improved process control and uniform product quality.

Batch operation → or semicontinuous process for small production rate, manufacture of special chemicals or pharmaceticals, elecrtronic material when product demand is intemittent.

Raw material and product/specification.

After determination operation mode, design engineer should establish a number of specification of raw material and ~~prd~~ product.

* Flow rate required for the product from market analysis.
* Composition (mol or mass fraction of each chemical species)
* Phase (liquid, gas or solid).
* Form (~~part~~ Particle size distribution and particle size).
* Temperature and pressure of each raw material and product stream.

4) Process Synthesis Steps.

It is selection of processing operatinos to convert the raw materials to products.

Synthesis step	Basic processing operation	Equipment.
Molecular change	Chemical reaction	Reactor
Composition "	Separation of mixture	Distillation column. absorber, stripper, evaporator, Leaching
phase elemination	Phase separation	Decanter, extraction column, leaching.
Temperatur difference	Change in temperature,	Heat exchanger, heater, reboiler.
pressure difference	Change in pressure	pump, valve, compressor.
phase difference	Change in phase.	condenser, boiler.
Distribution change	Mixing of stream	Mixer.

Process Design considerations

There are several entirely different processing flowsheets. for the manufacture of the same product. These processes must be compared in oredr to se select the one that is best suited for the existing condition, based on some considerations listed below.

1) Technical factor: Process flexibility; modeof operation; special control involved; commercial yield; Technical difficulties.; Energy requirement; special auxillaries. required.; possibility of future development; Health and safety hazards.

2) Raw material: Present and future availability, processing required; storage requirements; Material.

3) waste products & by-products: Amount produced; value; potential markets and uses; manner of discard, environmental aspects.

4) Equipment: Availability; MOC; initial costs, Maintenence & installation cost; Replacement requirements.; special design.

5) Plant location: Land required; Transportation; Market & Material sources; Service & power; Labor; climate; Legal restriction & Taxes.

6) Costs: Raw material, energy, Depreciation, fixed charges, Processing & overhead, labor cor; realestate, patent rights, environmental controls.

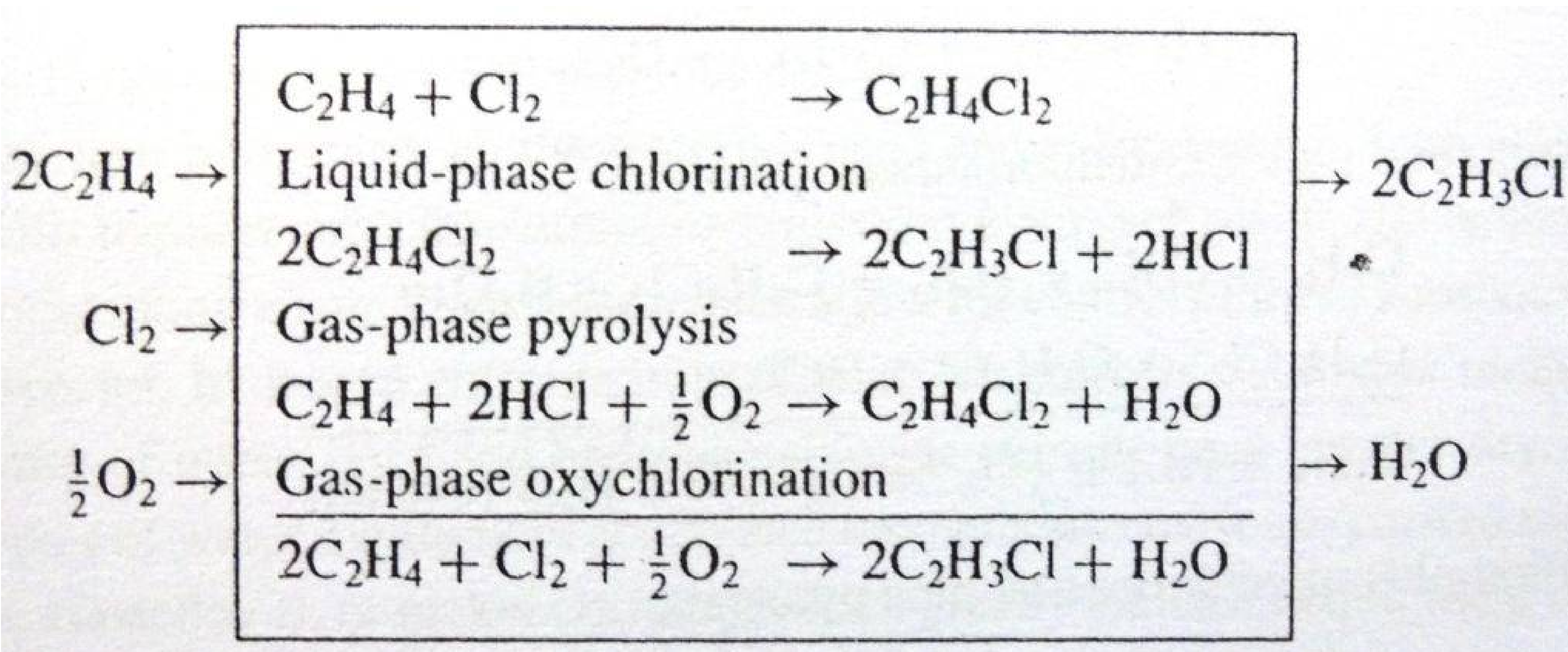
7) Time factor: Project completion dead line; process development required; Market timeliness; value of money.

8) Process considerations: Technology avaliability; Raw materials common with other processes, General company objectives.

Flow sheeting
of
Vinyl Chloride production

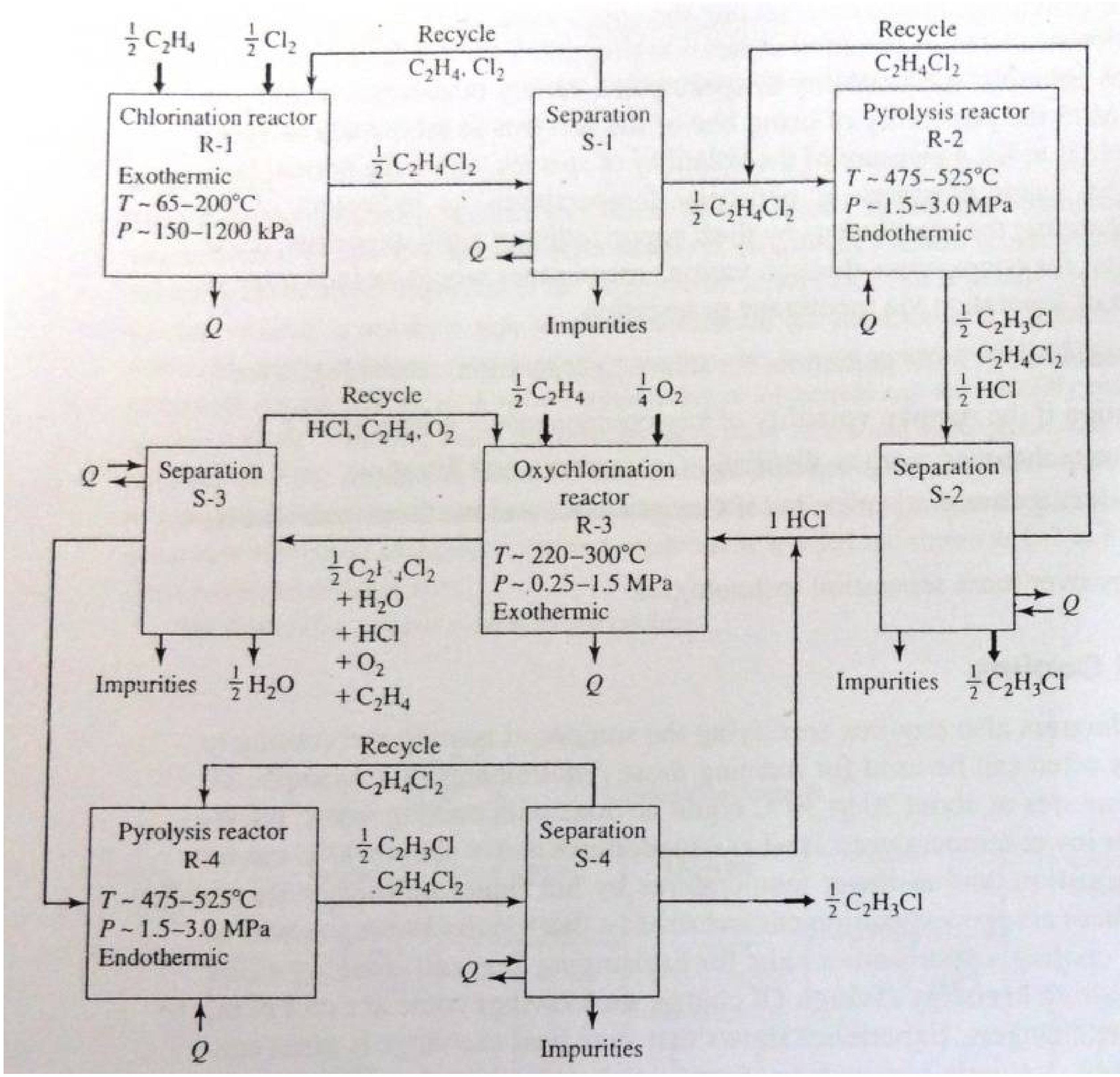
Hierarchical Flowsheet

Input output diagram



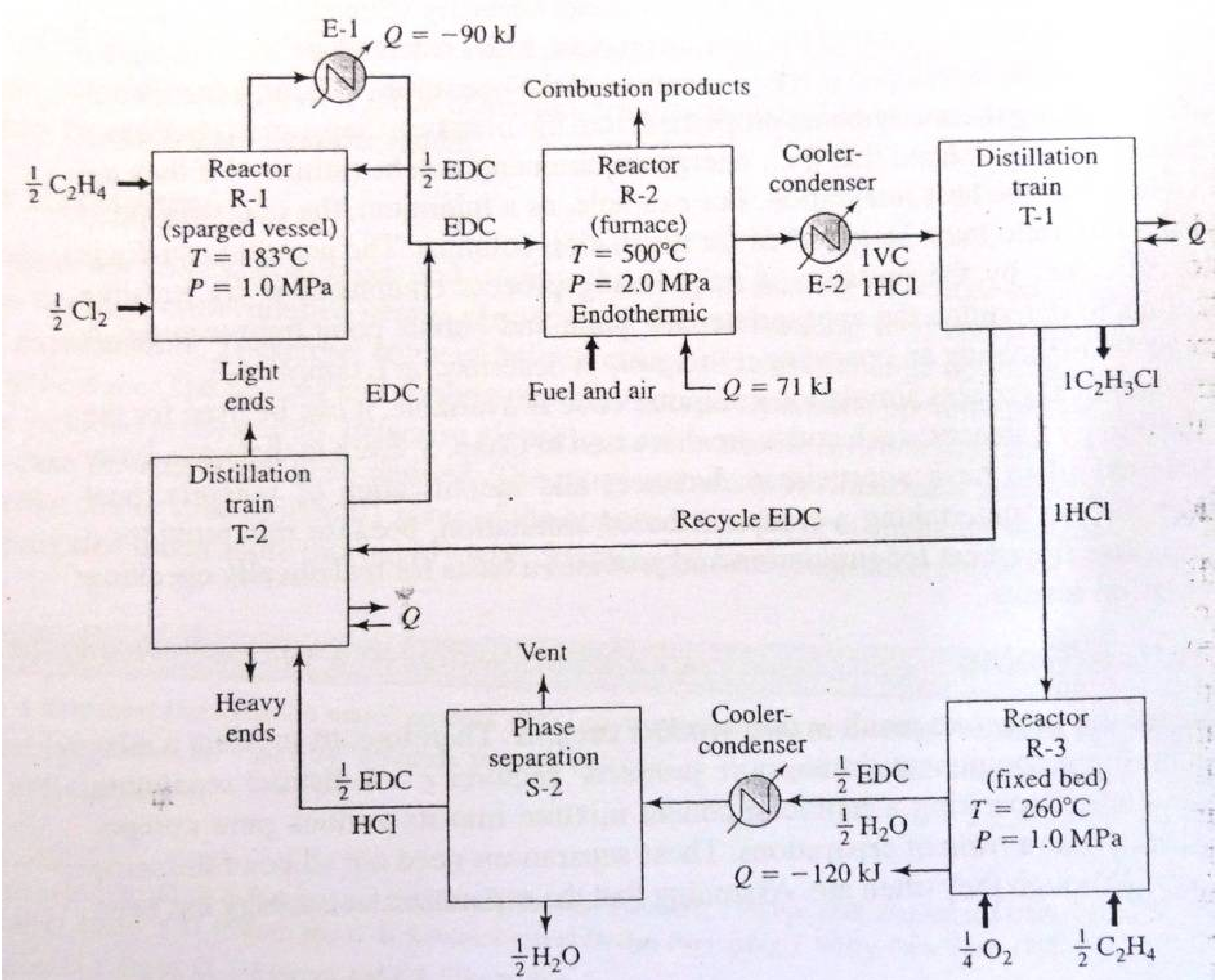
Picture from Peters and Timmerhaus

Function diagram



Picture from Peters and Timmerhaus

Operation diagram



Picture from Peters and Timmerhaus

Cont.

- Operation diagram involves types of processing equipment, unit operation necessary to accomplish the function previously identified by the function diagram .
- It specifies some key conditions such as T and P.
- **Furnace(R-2) :** i) EDC within the tubes flows essentially countercurrent to the combustion gases of the furnace. ii) Product gases leaving the furnace must be cooled very quickly to stop thermal decomposition of VC.

  Decision: i) Use an in line HE to quench the R-2 effluent and cool down to a temperature about 250ºC. ii) Use enriched oxygen in R-3 to reduce the chlorinated hydrocarbon in the effluent stream of the reactor hence purification cost of ethylene decreases.

Cont.

- **Chlorination reactor (R-1)**: Dispersion of gases in liquid EDC by sparger; It is a multiple hole pipe to obtain widespread distribution of gases in vertical cylindrical vessel.

  Decision: Use sparged vessel reactor.

- **Oxychlorination reactor (R-3)**: i) It resembles a shell and tube heat exchanger with catalyst particles and reactant gas in the tubes and cooling medium on shell side. ii) Flow in tube is plug flow hence temperature gradient and hot spot exist. iii) It is avoided by variable catalyst loading along the length of the tube- lowest catalyst at inlet and highest catalyst in outlet.

  Decision: Use packed bed reactor.

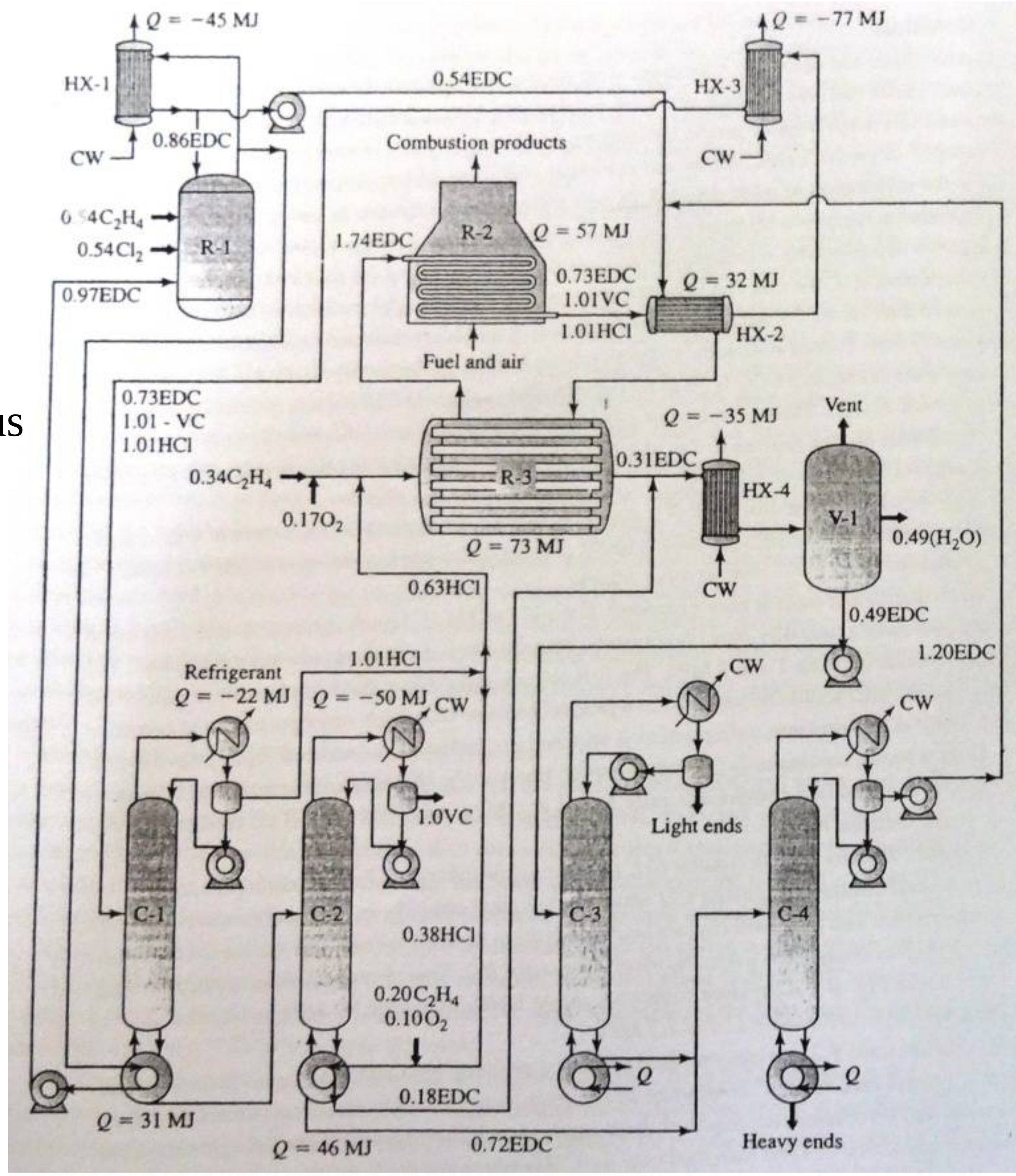
- Product stream of R-3 is a gas stream containing EDC+water+ small amount of ethylene and HCL.

S-2 → **Gas phase (ethylene, HCL vented out)**

S-2 → **EDC phase (to distillation train T-2)**

S-2 → **Gas phase (Water phase is drawn off for treatment)**

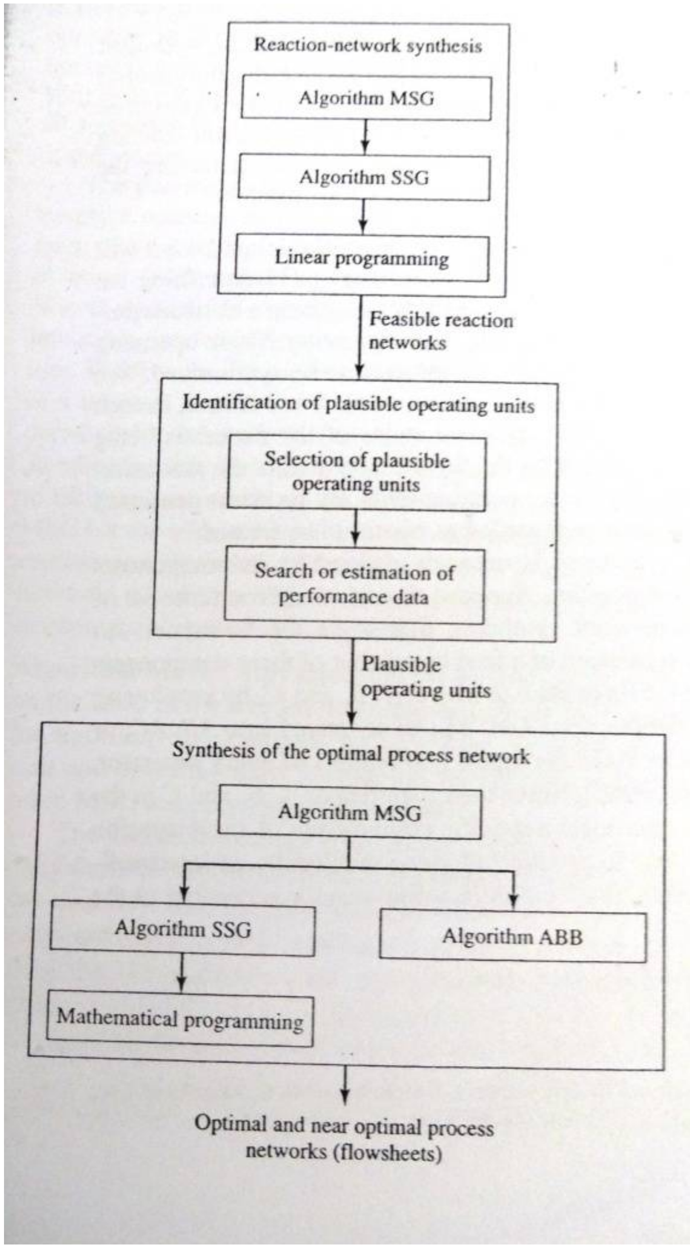
Flow sheet



Picture from
Peters and Timmerhaus

Algorithmic flow sheeting

Picture from
Peters and Timmerhaus



Methodology

- In ***algorithmic flowsheet***, a ***Process-Network*** is generated called ***Process-Network Synthesis*** (***PNS***) and it is subsequently ***optimized*** and ***analyzed***.
- A software framework called ***P-Graph*** was developed by Ferenc Friedler and L.T. Fan, (1993) to solve ***PNS*** problem.
- It is freely available in Web site www.p-graph.com .
- In P-graph framework, ***MSG* (maximal structure generation)** , ***SSG* (solution structure generatio*n***) and ***ABB*** (**accelerated branch bound**) are formulated to optimize a process.
- Steps include, i) Definition of a process synthesis with subsequent subprocess. ii) Creation of mathematical model of the subsequent process and their alternative solutions, through algorithmic ***MSG***, ***SSG*** and ***ABB***.
- The subsequent process are connected through logical ***AND gate*** or logical ***OR gate***.
- If any subprocess or unit has multiple inlet streams, and all the streams are required to carry out the operation then the unit is represented by ***AND constraint***.
- If any subprocess or unit has multiple inlet streams, and any combination of theses streams are sufficient to operate the subprocess, then it is represented by ***OR constraint***.

In P-Graph a process is presented in PNS studio.
At first a conventional process is prented.

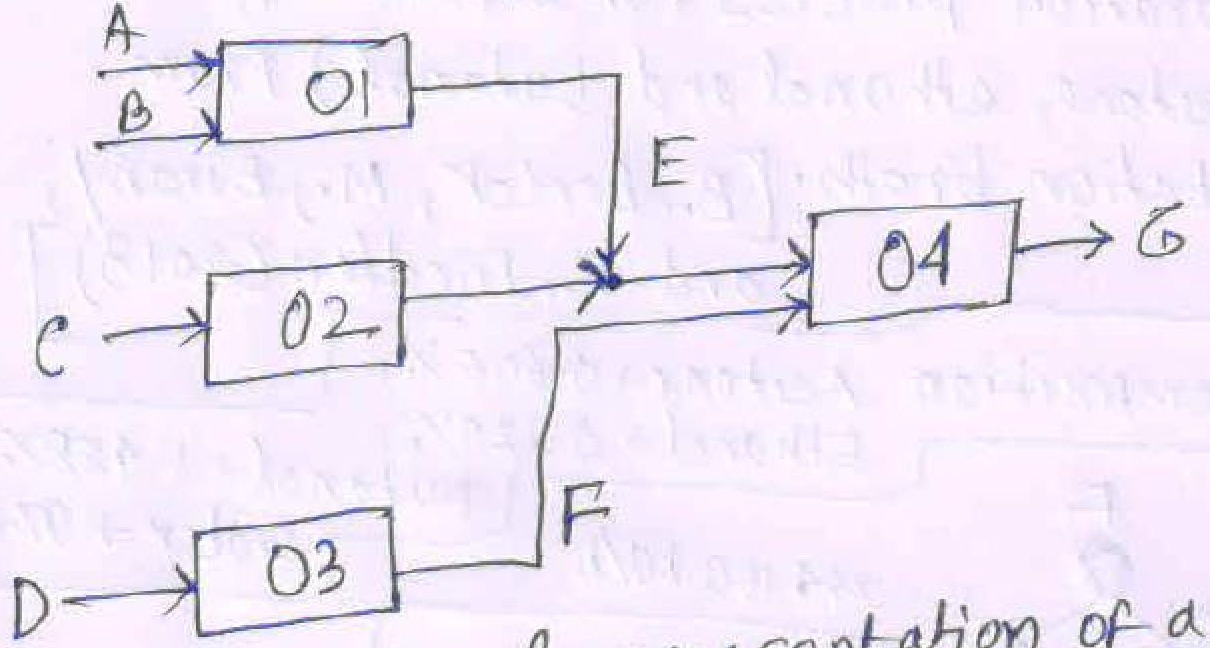


Fig: conventional representation of a process.

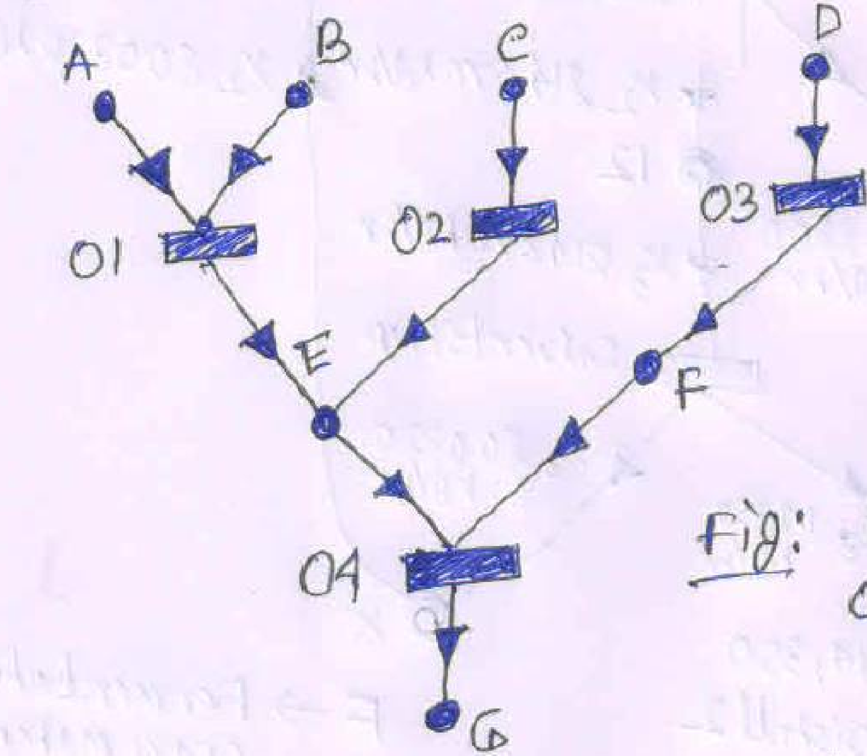
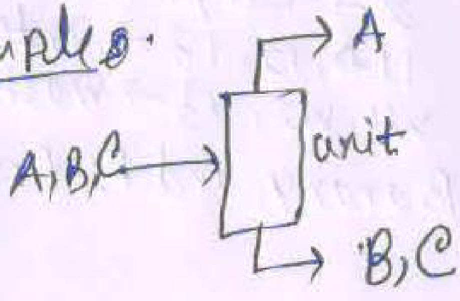
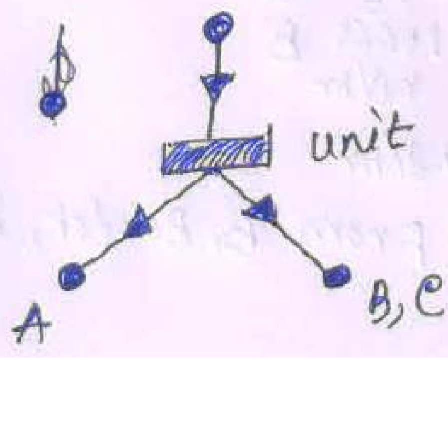


Fig: P-Graph representation of the conventional process.

A process structure represented in the P-Graph studio can be composed of series, parallel and alternative event or subprocesses.

Examples.





- **Algorithmic MSG (maximal structure generation)**

  It is the mathematical representation of a laborious and modest superstructure that composed of all combinatorically feasible structures resulting the desired product from a given number of raw materials through several sequential subsystems.

  One must choose the optimal structure among these feasible structures I the MSG. The optimal structure is subjected to various objective functions like, cost, safety, environmental factors etc.

- **Algorithmic SSG (solution structure generation)**

It is the generation of feasible solution structure of MSG that reveals the feasible structures or flowshhets for computational purpose.

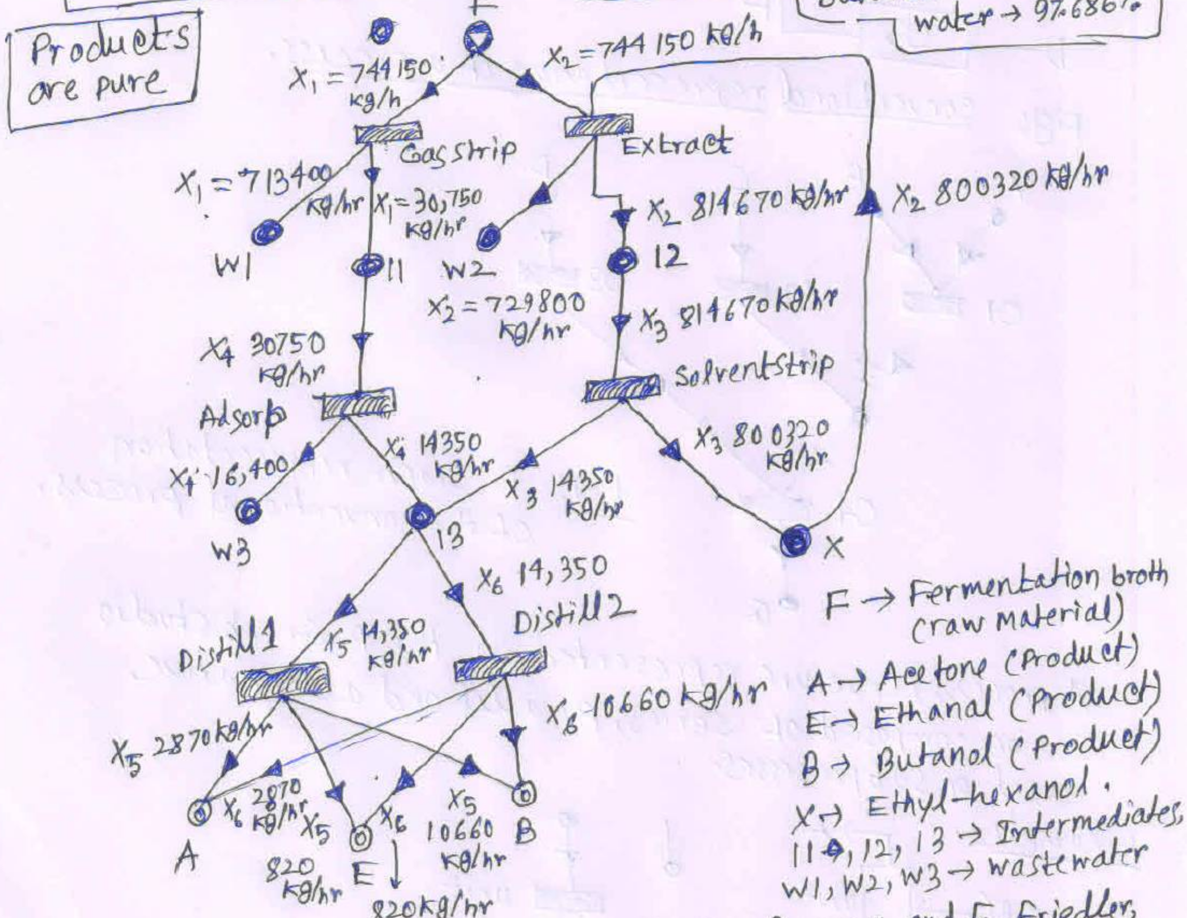
- **Algorithmic ABB (Accelerated branch and bound)**

In case of number of SSG is large, the optimization all feasible solution structures is time consuming. Generally, finite number of the optimal solution structures is chosen by the process engineer and these are ranked based on the priorities of objective functions. It eases the way of computation through the optimization.

MSG (Maximal Structure generation)

Consider a hybrid separation process for separating various products (acetone, ethanol and butanol) from a specified fermentation broth. [B., Bertok, M., Barany, and F., Friedler (2013)]

Fermentation broth composition Acetone → 0.606 %, Ethanol → 0.220 %, butanol → 1.488 %, water → 97.686 %



MSG Represented from B, Bertok, M., Barany, and F., Friedler (2013)

Figure MSG represented from Botond Bertok, Mate Barany, and Ferenc Friedler (2013)

- F → fermentation broth (raw material)
- A → acetone (product)
- E → ethanol (product)
- B → butanol (product)
- X → ethyl-hexanol
- 11 → intermediate
- 12 → intermediate
- 13 → intermediate
- W1 → wastewater
- W2 → wastewater
- W3 → wastewater

Table of operating units with streams specification and cost by Botond Bertok, Mate Barany, and Ferenc Friedler (2013)

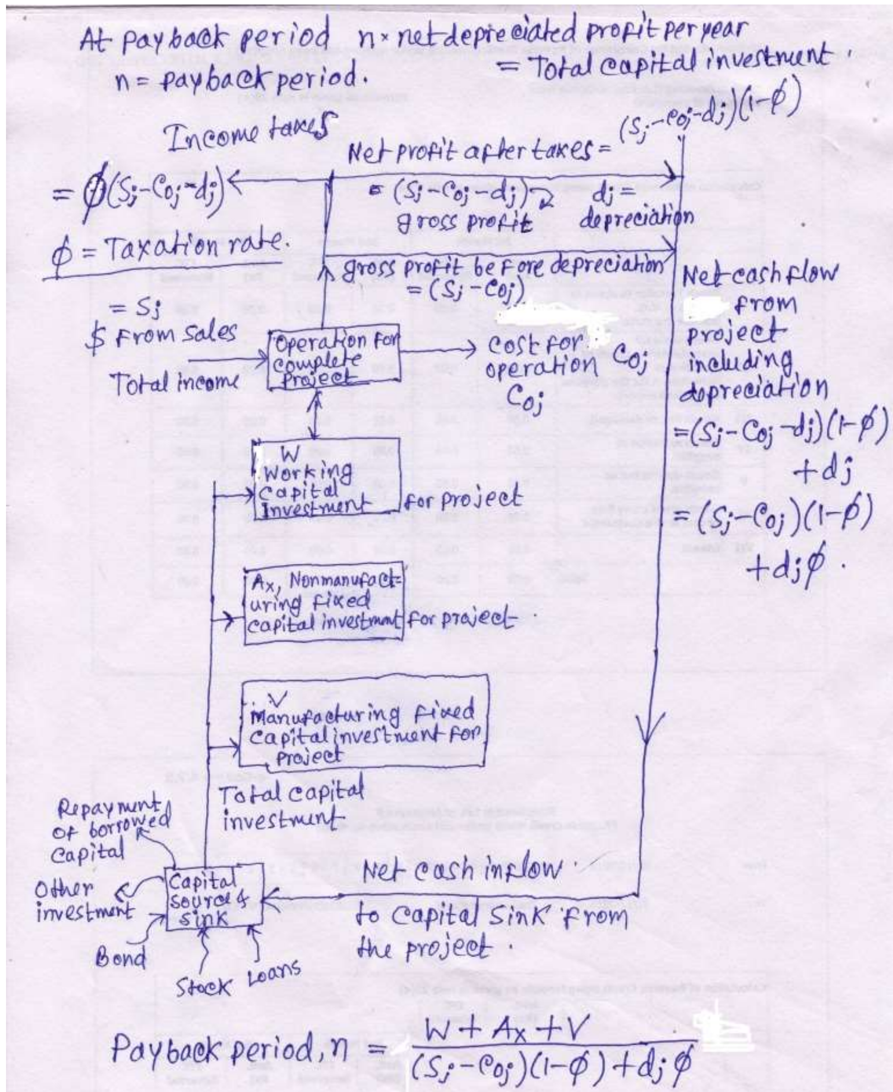
name	inlet streams [kg/h]	outlet streams [kg/h]	investment cost [US$]	operating cost [US$/year]
GasStrip	F (744 150)	W1 (713 400) I1 (30 750)	2 180 000	871 000
Extract	F (744 150) X (800 320)	W2 (729 800) I2 (814 670)	1 189 000	5 231 000
SolventStrip	I2 (814 670)	X (800 320) I3 (14 350)	1 914 000	864 000
Adsorp	I1 (30 750)	I3 (14 350) W3 (16 400)	3 806 000	132 000
Distill1	I3 (14 350)	A (2 870) E (820) B (10 660)	3 124 000	1 246 000
Distill2	I3 (14 350)	A (2 870) E (820) B (10 660)	4 156 000	1 658 000

References

- Plant Design and Economics for Chemical Engineers, Max S. Peters, K. D. Timmerhaus, 4th Edition, McGraw-Hill Inc.
- Friedler F., Tarjan K., Huang Y,, Fan L.T., (1993) Graph-theoretic approach to process synthesis: polynomial algorithm for maximal structure generation. Comput Chem Eng 17:929
- Botond Bertok, Mate Barany, and Ferenc Friedler, Generating and Analyzing Mathematical Programming Models of Conceptual Process Design by P-graph Software, Ind. Eng. Chem. Res. 2013, 52, 166−171
- Aniko Bartos, Botond Bertok, Parameter tuning for a cooperative parallel implementation of process-network synthesis algorithms, Central European Journal of Operations Research (2019) 27:551–572.
- Process Synthesis by the P-Graph Framework Involving Sustainability, B. Bertok, I. Heckl, in Sustainability in the Design, Synthesis and Analysis of Chemical Engineering Processes, 2016.
- Coulson & Richardson’s Chemical Engineering Design, R. K., Sinnott, Vol. 6., 4th Edition, Elsevier.

Thank You

Cash flow for industrial operations



Tree diagram for cash flow

Figure (Peters & Timmerhaus)

Cont.

- Total capital investment = working capital (W)+ fixed-capital investment (Ax+V)
- Working capital (1O-20% of total capital investment)

  Raw materials and supplies carried in stocks; raw material purchases; accounts receivable; operating expenses; salaries; wages; accounts payable; tax payable

- Fixed-capital investment = direct costs (V)+ indirect costs (Ax)
- Direct costs = material and labor involved in actual installation of complete facility (70-85% of fixed-capital investment)
  - Equipment + installation + instrumentation + piping + electrical + insulation + painting (50-60% of fixed-capital investment)
  - Buildings, process and auxiliary (10-70% of purchased-equipment cost)
  - Service facilities and yard improvements (40-100% of purchased-equipment cost)
  - Land (1-2% of fixed-capital investment or 4-8% of purchased-equipment cost)
- Indirect costs = expenses which are not directly involved with material and labor of actual installation of complete facility (15-30% of fixed-capital investment)
  - Engineering and supervision (5-30% of direct costs)
  - Construction expense and contractor’s fee (6-30% of direct costs)
  - Contingency (5-15% of fixed-capital investment)

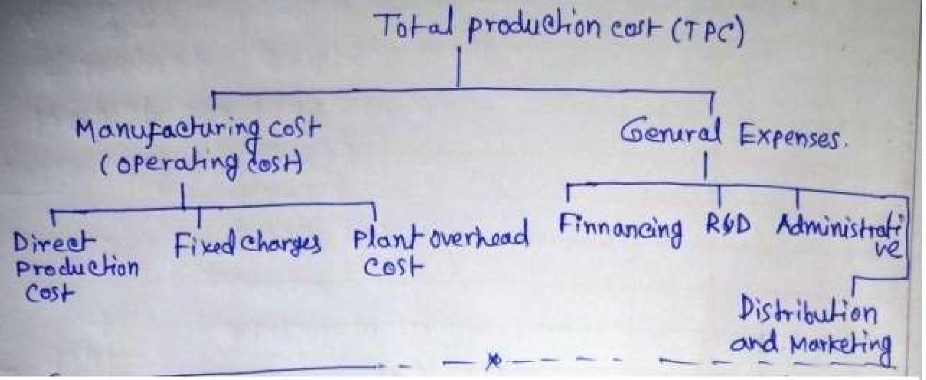
Estimation of total product cost

- **Gross earnings = Total income - Total product cost**
- **Total product cost = manufacturing cost + general expenses**
- **General expenses = administrative costs + distribution and selling costs + research and development costs**
  - Administrative costs (about 15% of costs for operating labor, supervision, and maintenance, or 2-6% of total product cost); includes costs for executive salaries, clerical wages, legal fees, office supplies, and communications
  - Distribution and selling costs (2-20% of total product cost); includes costs for sales offices, salesmen, shipping, and advertising
  - Research and development costs (2-5% of every sales dollar or about 5% of total product cost)
- **Manufacturing cost = direct production costs + fixed charges + plant overhead costs**
- **Direct production costs (about 60% of total product cost)**
  - Raw materials (1O-50% of total product cost)
  - Operating labor (10-20% of total product cost)
  - Direct supervisory and clerical labor (1O-25% of operating labor)
  - Utilities (10-20% of total product cost)
  - Maintenance and repairs (2-10% of fixed-capital investment)
  - Operating supplies (10-20% of cost for maintenance and repairs, or 0.5-1% of fixed-capital investment)
  - Laboratory charges (10-20% of operating labor)
  - Patents and royalties (0-6% of total product cost)

Cont.

- **Fixed charges (10-20% of total product cost)**
  - Depreciation (depends on life period, salvage value, and method of calculation-about 10% of fixed-capital investment for machinery and equipment and 2-3% of building value for buildings)
  - Local taxes (1-4% of fixed-capital investment)
  - Insurance (0.4-1% of fixed-capital investment)
  - Rent (8-12% of value of rented land and buildings)
- **Plant-overhead costs (6O-70% of cost for operating labor, supervision, and maintenance, or 5-15% of total product cost)**
  - Costs for the following: general plant upkeep and overhead, payroll overhead, packaging, medical services, safety and protection, restaurants, recreation, salvage, laboratories, and storage facilities.

Total production cost (TPC)



Manufacturing cost.

* **Direct production cost:** Expences directly related to manufacturing. It is generally increases linearly with production.

Ex given → Raw materials, operating labor, operating supervision, power and utilities like, steam, electricity, fuel, refrigeration, heating, cooling, water etc, Maintenance and repairs, operating supplies, Laboratory charges, Royalities (Patents), catalyst, solvent etc.

* **Fixed charges:** Depreciation, Taxes, Insurance, Rent.

* **Plant overhead:** Medical, Safety & Protection, General plant overhead, payroll overhead, Packaging, Restaurant, Recreation, Salvage, control laboratories, Plant superintendence, storage facilities.

General expences

* **Administrative expences:** Executive salaries, clerical-wages, Engineering and legal costs, office maintenance, communications (phone, faxes, copies, mail).

* **Distribution and Marketing Expences:** Sales office, Salesman expenses, Shipping, Advertising, Technical sales services.

* **Research and development expences:**

* **Finnancing (interest):** Interest of borrowed capital.

Break even analysis

Relation between sales, costs and profit.

- Variable costs are proportional to the production rate – (0-100% of plant capacity).
- Fixed charges are independent of annual production rate.
- The finnancial costs are neglected for economic analysis.
- The income is from sales of ~~produced~~ g. products.

Annual gross profit, Rs/- or \$ per year

$= nS - (nV + F) = n(S - V) - F$

n = number of units produced per year.

S = price of one unit, \$/ Rs/- per unit.

V = variable cost per unit of product, \$ or Rs/- per unit product.

F = Fixed cost annual, \$ or Rs/- per year.

average cost per unit of product (\$ or Rs/- /unit)

$= \frac{nV + F}{n}$ (at Breakeven point).

$n \uparrow$, average cost of product $\downarrow$

Breakeven point: It is the plant operating point where gross profit is zero. The company just breaks even and annual sales of products equal to the annual production cost.

$\therefore n_{BE}(S - V) - F = 0$; $n_{BE} = \frac{F}{S - V}$

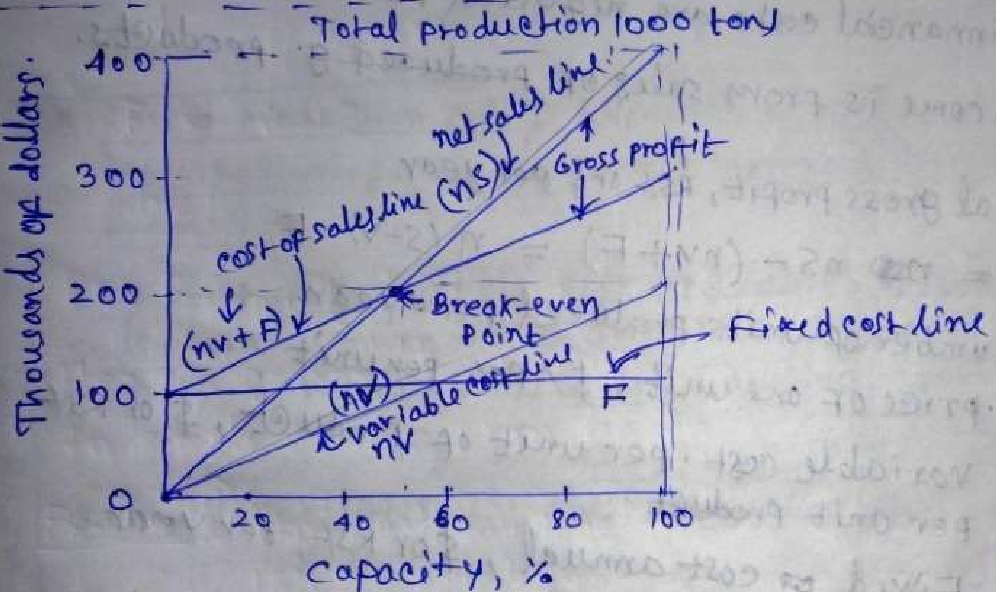
n_{BE} = number of units of product manufactured per year at breakeven point.

Example 1: For a company, F = \$ 100,000 per year. V = \$ 20 per ton of product, S = \$ 40 per ton of product. The plant produces 10,000 ton of product per year at 100% capacity.

Ans: $n_{BE} = \frac{100,000}{40-20}; \left[\left(\frac{F}{S-V}\right)\right]$

$= 5000$ ton per year

$= 50\%$ plant capacity.



COST INDEXES

- Prices changes considerably with time due to changes in economic conditions and cost data need to be updated.
- A cost index is merely an index value for a given point in time showing the cost at that time relative to a certain base time.
- Present cost = Original cost × (index value at present time/index value at time original cost was obtained)
- The most common of these indexes are the
  - ***Marshall and Swift all-industry and process-industry equipment indexes***
  - **The *Engineering News-Record construction index***
  - **The *Nelson-Farrar refinery construction index***
  - **The *Chemical Engineering plant cost index***

Estimating Equipment Costs by Scaling

- It is often necessary to estimate the cost of a piece of equipment when no cost data are available for the particular size of operational capacity involved.
- ***six-tenths-factor*** rule, if the cost of a given unit at one capacity is known, the cost of a similar unit with X times the capacity of the first is approximately $(X)^{0.6}$ times the cost of the initial unit.
- Cost of equip. ***a*** = cost of equip. ***b***×(Capac. Equip. ***a***/Capac. Equip. ***b***)$^{\mathbf{0.6}}$
- **Example: Estimating cost of equipment using scaling factors and cost index.**
- The purchased cost of a 50-gal glass-lined, jacketed reactor (without drive) was $8350 in 1981. Estimate the purchased cost of a similar 3OO-gal, glass-lined, jacketed reactor (without drive) in 1986. Use the annual average Marshall and Swift equipment-cost index (all industry) to update the purchase cost of the reactor.

TABLE 3
Cost indexes as annual averages

Year	Marshall and Swift installed-equipment indexes, 1926 = 100: All-industry	Process-industry	Eng. News-Record construction index: 1913 = 100	1949 = 100	1967 = 100	Nelson-Farrar refinery construction index, 1946 = 100	Chemical engineering plant cost index 1957-1959 = 100
1975	444	452	2412	464	207	576	182
1976	472	479	2401	503	224	616	192
1977	505	514	2576	540	241	653	204
1978	545	552	2776	582	259	701	219
1979	599	607	3003	630	281	757	239
1980	560	675	3237	679	303	823	261
1981	721	745	3535	741	330	904	297
1982	746	774	3825	802	357	977	314
1983	761	786	4066	852	380	1026	317
1984	780	806	4146	869	387	1061	323
1985	790	813	4195	879	392	1074	325
1986	798	817	4295	900	401	1090	318
1987	814	830	4406	924	412	1122	324
1988	852	870	4519	947	422	1165	343
1989	895	914	4606	965	429	1194	355
1990 (Jan.)	904†	924	4673	979	435	1203	356

† All costs presented in this text are based on this value of the Marshall and Swift index unless otherwise indicated.

Table 3 (Peters & Timmerhaus)

TABLE 5
Typical exponents for equipment cost vs. capacity

Equipment	Size range	Exponent
Blender, double cone rotary, c.s.	50-250 ft^3	0.49
Blower, centrifugal	10^3–10^4 ft^3/min	0.59
Centrifuge, solid bowl, c.s.	10–10^2 hp drive	0.67
Crystallizer, vacuum batch, c.s.	500-7000 ft^3	0.37
Compressor, reciprocating, air cooled, two-stage, 150 psi discharge	10–400 ft^3/min	0.69
Compressor, rotary, single-stage, sliding vane, 150 psi discharge	10^2–10^3 ft^3/min	0.79
Dryer, drum, single vacuum	10–10^2 ft^2	0.76
Dryer, drum, single atmospheric	10–10^2 ft^2	0.40
Evaporator (installed), horizontal tank	10^2–10^4 ft^2	0.54
Fan, centrifugal	10^3–10^4 ft^3/min	0.44
Fan, centrifugal	2×10^4–7×10^4 ft^3/min	1.17
Heat exchanger, shell and tube, floating head, c.s.	100-400 ft^2	0.60
Heat exchanger, shell and tube, fixed sheet, c.s.	100-400 ft^2	0.44
Kettle, cast iron, jacketed	250-800 gal	0.27
Kettle, glass lined, jacketed	200-800 gal	0.31
Motor, squirrel cage, induction, 440 volts, explosion proof	5-20 hp	0.69
Motor, squirrel cage, induction, 440 volts, explosion proof	20-200 hp	0.99
Pump, reciprocating, horizontal cast iron (includes motor)	2–100 gpm	0.34
Pump, centrifugal, horizontal, cast steel (includes motor)	10^4–10^5 gpm × psi	0.33
Reactor, glass lined, jacketed (without drive)	50–600 gal	0.54
Reactor, s.s, 300 psi	10^2–10^3 gal	0.56
Separator, centrifugal, c.s.	50-250 ft^3	0.49
Tank, flat head, c.s.	10^2–10^4 gal	0.57
Tank, c.s., glass lined	10^2–10^3 gal	0.49
Tower, c.s.	10^3–2×10^6 lb	0.62
Tray, bubble cup, c.s.	3-10 ft diameter	1.20
Tray, sieve, c.s.	3-10 ft diameter	0.86

Table 5 (Peters & Timmerhaus)

Solution: Marshall and Swift equipment-cost index (all industry)
(From Table 3) For 1981: 721; (From Table 3) For 1986: 798
From Table 5, the equipment vs. capacity exponent is given as 0.54:

In 1986, cost of reactor = $(\$8350)\left(\frac{798}{721}\right)\left(\frac{300}{50}\right)^{0.54}$ **=$24,300**

METHODS FOR ESTIMATING CAPITAL INVESTMENT

- POWER FACTOR APPLIED TO PLANT-CAPACITY RATIO : This method for study relates the fixed-capital investment of a new process plant to the fixed-capital investment of similar previously constructed plants by an exponential power ratio.
- $$C_n = C f_e R^x$$
- Where C_n is the fixed-capital investment of the new facility; C is the fixed-capital investment of the constructed facility; R is the ratio of the capacity of the new facility divided by the capacity of the old; X is the power which has been found to average between 0.6 and 0.7 for many process facilities; f_e is the cost index ratio at the time of cost C_n to that at the time of cost C.
- A closer approximation for this relationship which involves the direct and indirect plant costs has been proposed as
- $$C_n = f[DR^x + I]$$
- Where f is a lumped cost-index factor relative to the original installation cost D is the direct cost and I is the total indirect cost for the previously installed facility of a similar unit on an equivalent site.

- **Example: Estimation of fixed-capital investment with power factor applied to plant-capacity ratio.** If the process plant, described in Example 1, was erected in the Dallas area for a fixed-capital investment of $436,000 in 1975, determine what the estimated fixed-capital investment would have been in 1980 for a similar process plant located near Los Angeles with twice the process capacity but with an equal number of process units? Use the power-factor method to evaluate the new fixed-capital investment and assume the factors given in Table 20.
- with a 0.6 power factor and the Marshall and Swift all-industry index (Table 3), the fixed-capital investment is

$$C_n = C f_e R^x = 436{,}000\left(\frac{660}{440}\right)(2)^{0.6} = \$982{,}000$$

- with a 0.6 power factor, the Marshall and Swift all-industry index (Table 3), and the relative labor and productivity indexes (Table 20), the fixed capital investment is

$$C_n = f[DR^x + I] = \left(\frac{660}{444}\right)\left(\frac{1.22}{0.88}\right)\left(\frac{1.04}{0.89}\right)\left[308{,}000(2)^{0.6} + 128{,}000\right] = \$1{,}432{,}000$$

- where $f = f_E f_L e_L$, f_L=Relative labor rates ratio, e_L=Relative productivity factor ratio.

TABLE 20
Relative labor rate and productivity indexes in the chemical and allied products industries for the United States (1989)†

Geographical area	Relative labor rate	Relative productivity factor
New England	1.14	0.95
Middle Atlantic	1.06	0.96
South Atlantic	0.84	0.91
Midwest	1.03	1.06
Gulf	0.95	1.22
Southwest	0.88	1.04
Mountain	0.88	0.97
Pacific Coast	1.22	0.89

Table 20 (Peters & Timmerhaus)

Components		Assumed % of total	Cost	Ratioed % of total
Purchased equipment	D=Direct capital investment	25	$100,000	23.0
Purchased-equipment installation		9	36,000	8.3
Instrumentation (installed)		7	28,000	6.4
Piping (installed)		8	32,000	7.3
Electrical (installed)		5	20,000	4.6
Buildings (including services)		5	20,000	4.6
Yard improvements		2	8,000	1.8
Service facilities (installed)		15	60,000	13.8
Land		1	4,000	0.9
Engineering and supervision	I=Indirect capital investment	10	40,000	9.2
Construction expense		12	48,000	11.0
Contractor's fee		2	8,000	1.8
Contingency		8	32,000	7.3
			$436,000	100.0

Range will vary from $371,000 to $501,000 for normal conditions; if economy is inflationary, it may vary from **$436,000–$566,000.**

- **Turnover ratio**=(gross annual sales/fixed-capital investment)
- The reciprocal of the turnover ratio is sometimes defined as the ***capital ratio or the investment ratio.*** Turnover ratios of up to 5 are common for some business establishments and some are as low as 0.2.
- **Example: Break-even point, gross earnings, and net profit for a process plant.**
- The annual direct production costs for a plant operating at 70 percent capacity are $280,000 while the sum of the annual fixed charges, overhead costs, and general expenses is $200,000. What is the break-even point in units of production per year if total annual sales are $560,000 and the product sells at $40 per unit? What were the annual gross earnings and net profit for this plant at 100 percent capacity in 1988 when corporate income taxes required a 15 percent tax on the first $50,000 of annual gross earnings, 25 percent on annual gross earnings of $50,000 to $75,000, 34 percent on annual gross earnings above $75,000, and 5 percent on gross earnings from $100,000 to $335,000?
- The break-even point occurs when the total annual product cost equals the total annual sales. The total annual product cost is the sum of the fixed costs (including fixed charges, overhead, and general expenses) and the direct production costs for n units per year. The total annual sales is the product of the number of units and the selling price per unit. Thus
- Direct production cost/unit =280,000/(560,000/40) = $20/unit,

Cont.

- At break-even point, Total product cost = Total income or all product sold
- 200,000 + 20n = 40n
- n = 200,000/20=10,000 units/year
- This is [(10,000)/(14,000/0.7)]100 = 50% of the present plant operating capacity.
- ***Total product cost = (direct production costs + fixed charges + plant overhead costs) + general expenses***
- ***Manufacturing cost = direct production costs + fixed charges + plant overhead costs***
- Gross annual earnings = total annual sales - total annual product cost

=(560,000/0.7)-[200,000 +(280,000/0.7)]

= 800,000 - 600,000

= $200,000

Cont.

- Net annual earnings = gross annual earnings - income taxes

=200,000 - [(0.15)(50,000) + (0.25)(25,000)+ (0.34)(200,000 - 75,000) + (0.05)(200,000 – 100,000)]

= 200,000 - 61,250

= $138,750

Reference

- Plant Design and Economics for Chemical Engineers, Max S. Peters, K. D. Timmerhaus, 4th Edition, McGraw-Hill Inc.

Thank You