KISR
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Industrial Pollution Control

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and

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Introduction

Environmental Challenges

- **Environmental quality is deteriorated due to increasing impacts of exponentially increasing population and industrialization.**
- **Environmental contamination of air, water, soil and food has become threat to many plants and animals communities of the ecosystem**
- **This ultimately threatens the very survival of the human race**
- **Civilization requires increase fuel, transportation, industrial chemicals, fertilizers, pesticides and countless other products.**
- **Total system approach is required by pooled talents of scientist, engineers, social scientists and medical professions focus on development of order and equilibrium in the presently desperate segment of human environment.**
- **Skills and tools are there that has created manifold environmental problem are capable of solving them through preventive technologies**

Source of Pollution

Our society all sectors generate waste: Industry, government, agriculture, mining, energy, transportation, construction and consumers pollution.

1. **Industrial waste: due to its quantity and toxicity is primary target, which is produced by industrial activities such as production, distribution, transport, storage, consumption of goods and services.**
2. **The most common pollutants are DDTE, CFCs, asbestos, leaded gasoline, plastic, medicines, cosmetics, fertilizers, pesticides and herbicides with addition of discarded by-products and used products**
3. **Environmentally services: governmental policies, regulations, implementation plan, consulting services in product and process design equipment, manufacturing and supply and education and training resulted negatively environmental quality**
4. **Currently emphasis is focussed on improving the quality of products and services through concept of design for environment and sustainability**

Industrial pollution problems

- **Toxic chemicals and hazardous wastes are urgent issues and must be solved by preventive modern technologies and proactive management skills**

Industrial growth: Inexorable increase resulted into destruction of habitats and eutrophication

- **Developing countries are catching up through industrialization of companies of developed world skipping environmental concerns but keeping democratic and economic rhetoric**
- **Evolution of fully global industrialized world, global market, global communication and global transportation and global prosperity.**
- **This growth is inadequate to sustain environmentally safe but it will not go unchecked and with mounting cost of pollution it will become increasingly difficult to argue for completely unregulated industrial growth**
- **Next slide presents estimates of pollution severity in some areas of the world**

Air Pollution Index 1990

Country	City	Index	Country	City	Index
China	Shenyang	100	USA	Birmingham	9
China	Beijing	82	Portugal	Lisbon	9
Indonesia	Jakarta	80	Malaysia	Kuala Lumpur	9
India	Delhi	59	Germany	Frankfurt	8
Italy	Milan	47	Israel	Tel Aviv	8
S. Korea	Seoul	34	Canada	Montreal	8
Thailand	Bangkok	30	Poland	Warsaw	6
Spain	Madrid	27	United Kingdom	London	6
Hong Kong	Hong Kong	22	USA	New York	5
Chile	Santiago	16	Australia	Sydney	5
Finland	Helsinki	12	USA	Chicago	2
Brazil	Rio de Janeiro	11	New Zealand	Christchurch	1
Brazil	Sao Paulo	10	Japan	Tokyo	1

Toxic Estimates US Inventory 1987

Industry	Lbs /$ooo of value added	Lbs /$ooo of gross output
Industrial chemicals	99.71	52.42
Primary metals	56.8	21.48
Paper products	56.46	25.87
Petroleum refining	41.43	5.79
Textile	13.45	5.47
Leather products	12.18	5.82
Plastic/rubber	6.26	3.2
Pottery, glass product	3.54	1.92
Furniture	2.95	1.6
Food product	2.35	0.87
Tobacco products	0.73	0.5
Wearing apparel	0.14	0.07

Industries producing hazardous waste

SIC	Category	Volume (Million of tons)
2869	Organic chemicals	60-80
2800	Chemical Manufacturing	40-50
2911	Petroleum refining	20-30
2892	Explosive	10-15
2821	Plastic	6-10
2879	Agricultural Chemical	5-8
2865	Cyclic crude, intermediates	5-8
2816	Inorganic Pigment	3-5
2812	Alkalis and chlorine	2.5-4.5

1987 statistics

Synthetic organic compounds in US 1969-90

Year	1969	1971	1973	1975	1977	1979	1981	1983	1985	1987	1989	1990
Coal Tar	MMm^3				2.24	2.23	1.76	1.07		0.72	0.59	0.6
Dye (MT)	109	111	129	93	120	121	104	111	101	116	140	117
Pigments	28	26	31	23	31	40	34	35	37	43	50	52
Medical	91	101	106	94	109	142	111	106	102	118	129	144
Flavour	53	44	53	46	68	88	75	79	69	57	64	60
Rubber	137	147	182	127	182	179	127	133	118	173	176	179
Plasticizers	635	680	862	635	816	953	862	771	771	907	976	891
Pesticide	499	499	590	726	635	635	649	463	562	472	572	557
Petroleum	32	37	41	35	57	55	50	50	47	54	50	52
cyclic	13	14	16	14	8	22	21	20	21	25	25	24
plastic	8	10	14	11	16	19	18	20	23	27	26	30
elastomer	2	2	3	2	3	3	2	2	2	2	2	2
Surface	2	2	2	2	2	2	2	2	2	3	3	4
Others	34	36	45	39	48	55	53	52	53	44	48	50

MMm^3 is billion of litres, MT is million kg, MMT is Billion of kg

C_2H_4, C_3H_6 & C_6H_6 grew

16.3 %, 12.3% and 13.4 % in South Korea

1980-1988: 14.1 14.0 14.2 % in India

9.8 12.2 11.7 % in China

10.5 7.5 5.6 % in Indonesia

US Pollution Abatement expanses

- **Growth was high since 1988 due to absence of regulations. Industrial pollution not only deplete resources and damage the environment but also hurt the economy.**
- **In 1991 US has spent over 10^{11} $ for pollution abatement**

Year	Air (10^9 $)		Water		Solid	
	Current	Constant	Current	Constant	Current	Constant
1981	26.3	28.5	20.8	25.2	10.2	13.4
1982	26.1	27.2	21.1	24.2	9.9	12.1
1983	27.6	28.5	22.5	24.7	10.3	12.0
1984	30.4	31.0	24.7	26.2	11.8	13.2
1985	30.1	32.0	26.7	27.4	12.7	13.7
1986	32.1	33.3	28.2	28.7	14.3	14.8
1987	30.7	30.7	30.6	30.6	15.9	15.9
1988	32.5	31.9	30.7	30.1	18.6	17.9
1989	30.9	29.2	33.4	31.6	21.7	19.8
1990	29.5	27.3	37.3	34.4	24.1	20.9

US Pollution abatement and control expenditure

Year	Pollution Abatement		Regulation & Monitoring		Research & Development		Total (10^9 US $)	
	Current	Constant	Current	Constant	Current	Constant	Current	Constant
1972	15.9	43.1	0.4	1.0	0.8	2.3	17.0	46.3
1973	18.0	46.3	0.5	1.2	0.9	2.3	19.4	49.8
1974	22.0	48.7	0.6	1.3	1.0	2.3	23.6	52.3
1975	26.7	53.7	0.7	1.3	1.1	2.3	28.4	57.3
1976	29.9	56.6	0.7	1.4	1.3	2.5	31.9	60.5
1977	32.8	57.8	0.8	1.5	1.5	2.7	35.1	62.0
1978	36.9	60.3	0.9	1.8	1.6	2.8	39.5	64.9
1979	42.8	62.4	1.1	1.6	1.8	2.7	45.6	66.8
1980	48.4	63.0	1.3	1.9	1.8	2.4	51.5	67.3
1981	53.4	62.6	1.4	1.8	1.7	2.2	56.5	66.5
1982	53.4	59.5	1.4	1.7	1.8	2.1	56.6	63.2
1983	56.3	60.9	1.4	1.6	2.3	2.6	60.0	65.1
1984	62.8	66.0	1.4	1.5	2.3	2.5	66.4	70.0
1985	67.3	67.3	1.3	1.4	2.4	2.5	70.9	72.7
1986	70.1	70.1	1.5	1.6	2.6	2.6	74.2	76.4
1987	72.5	72.5	1.5	1.5	2.6	2.6	76.7	76.7
1988	76.6	76.6	1.7	1.6	2.8	2.7	81.1	79.1
1989	80.6	80.6	1.8	1.7	3.0	2.7	85.4	80.1
1990	85.1	85.1	1.8	1.6	3.1	2.7	90.0	81.8

US Pollution abatement and control expenditure by sectors

year	Pollution Abatement					Regulation & Monitoring		Research & Development		
	Private		Government							
	Pers’l	Bus	Fed	State	Others	Fed	State	Priv’t	Fed	State
1972	3.45	30.53	0.4	3.67	5.03	0.48	0.48	1.44	0.55	0.27
1973	4.54	32.14	0.54	3.69	5.34	0.63	0.56	1.49	0.68	0.17
1974	4.95	32.63	0.69	3.62	6.81	0.74	0.6	1.42	0.78	0.09
1975	6.17	33.11	0.94	3.74	9.72	0.74	0.61	1.28	0.93	0.1
1976	6.73	34.88	0.95	3.71	10.33	0.74	0.67	1.39	1.02	0.09
1977	7.15	37.1	0.92	3.73	8.9	0.74	0.78	1.56	1.04	0.1
1978	7.41	38.15	0.81	3.89	10.03	0.99	0.8	1.69	0.99	0.1
1979	7.16	40.22	0.84	3.93	10.27	0.91	0.72	1.76	0.87	0.12
1980	7.31	40.15	0.68	4.05	10.82	1.11	0.76	1.5	0.82	0.1
1981	8.49	40.47	0.63	3.98	8.98	1.04	0.77	1.33	0.81	0.04
1982	8.52	37.79	0.65	4.07	8.43	0.98	0.73	1.32	0.7	0.04
1983	10.02	38.04	0.91	4.2	7.7	0.92	0.69	1.82	0.71	0.04
1984	10.97	41.18	1.05	4.38	8.42	0.81	0.69	1.81	0.63	0.04
1985	11.78	42.41	1.3	4.65	8.67	0.61	0.75	1.86		0.02
1986	12.69	43.8	1.4	4.99	9.29	0.74	0.85	1.93	0.67	0.03
1987	10.88	44.5	1.24	5.36	10.54	0.7	0.82	1.99	0.63	0.03
1988	11.83	45.96	1.34	5.88	9.78	0.81	0.83	1.99	0.64	0.03
1989	10.13	47.76	1.27	6.5	10.04	0.78	0.88	1.99	0.72	0.03
1990	8.67	49.69	1.23	6.99	10.89	0.77	0.87	2.01	0.68	0.04

Knowledge of Pollution Prevention

i. Over seven Billion ($>7x10^9$) people live and some are concerned about pollution, waste, garbage or trash but others don't

ii. What happens to waste & pollution and what impacts on public health and environment

iii. Waste seems natural both biologically and socially and is inevitable and no one wants in his backyard

iv. Pollution exists because environment can absorb a limited amount of pollutants, hazardous and toxic cannot be assimilated and no one knows what to do?

v. Environmentalists provide cost effective govt. regulation of pollution but lacks management strategies

vi. Waste or pollution have multiple adverse effects, synergic interactions and cumulative exposures

vii. Waste management and pollution control is by end of pipe like pain relieving pill but pain occurs again

Human behaviour

1. People do not want to learn pollution prevention
2. Some resist change without thinking
3. We need new knowledge & education with creative & probing personalities
4. Future factories will consider the environmental implications of new product and services and will have pollution management strategy into its research experiment.
5. Acquisition of new components from other to minimize the waste generation in the life cycle of its products
6. Practicing prevention on daily basis require s commitment and discipline (practical and cost effective). To remain healthy one has to control diet, exercise and avoid addiction, least use of medication.
7. Preventive approach require more commitment & discipline as the benefits are likely to be more distant and uncertain to many people

Changing environmental Management concept

Dr. Royston promoted integrated approach based on six dimensions

1. **Technological :** Non-waste technology require financial & economic incentives
2. **Economical:** Economic benefits result from cleanup operations.
3. **Physical:** Basic principle is to work with eco-system
4. **Cultural: The critical element is education to work as community activity**
5. **Social: Every culture has a belief that economic growth is related to produce more waste and more Pouring raw-materials and energy getting products**
6. **Political: pollution problem is political and top down approach is no more required. Social changes have reformed the society and people are concerned about the future, they want to know the future of the world and that of their children and they want to have say in the decisions**

1. **Physical (geosphere) air, water and land**
2. **Biological (biosphere) animal, plants and micro-organisms**
3. **Social (Sociosphere) political, economical and cultural**
4. **Behavioral (behaviorsphere) perceptual and conceptual ability in living things.**

Pollution management requires at generation facility, distribution and use

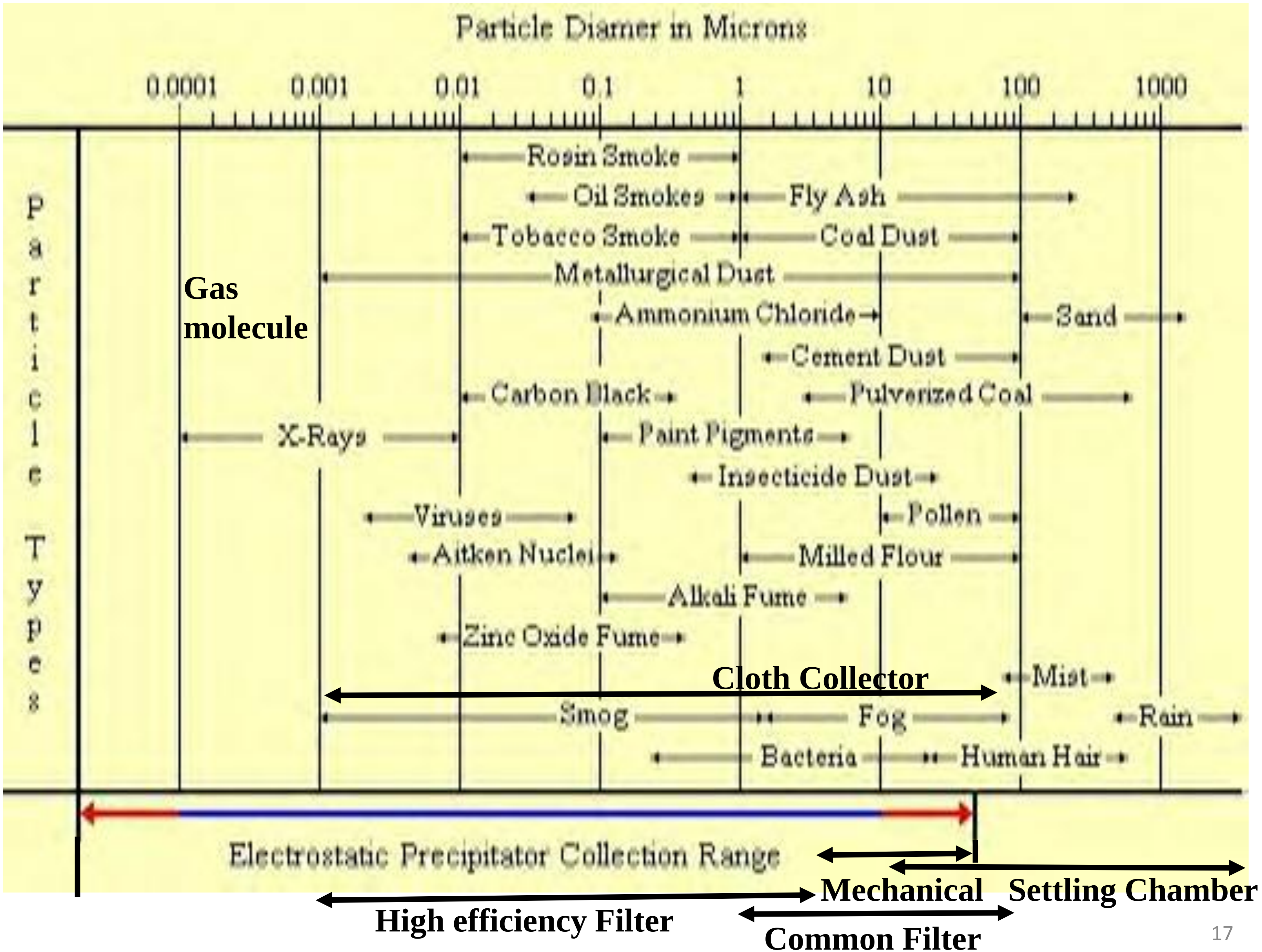
Factory, Storage, transport & products end of life

Environmental Management Strategy

- **These strategies are gradually transforming as more and more people accept pollution prevention concepts.**
- **Waste management controls pollutants in the waste while Pollution management controls pollution but also seeks new alternative for manufacturing and consuming environmental friendly products and services**
- **Waste Management strategies deal with physical and biological spheres while pollution Management Strategies deal with all types of spheres in environmental system**
- **Industrial pollution prevention involve waste minimization, source reduction, cleaner production, design for environment & preventive service.**
- **Industrial ecology considers environmental management more than operation at single industry**

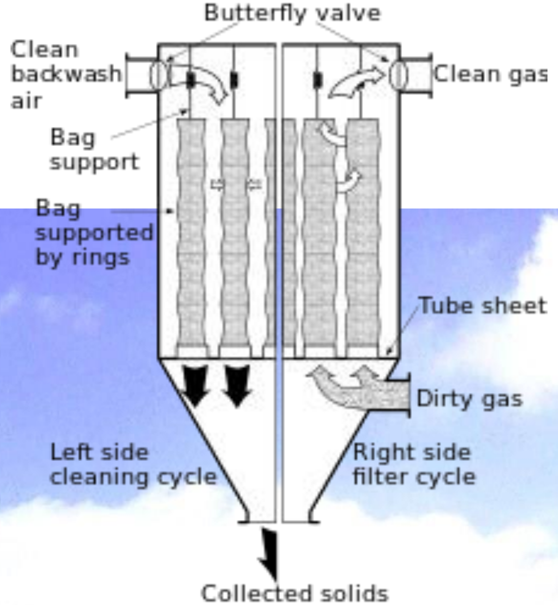
Industrial Pollution Prevention and Industrial Ecology

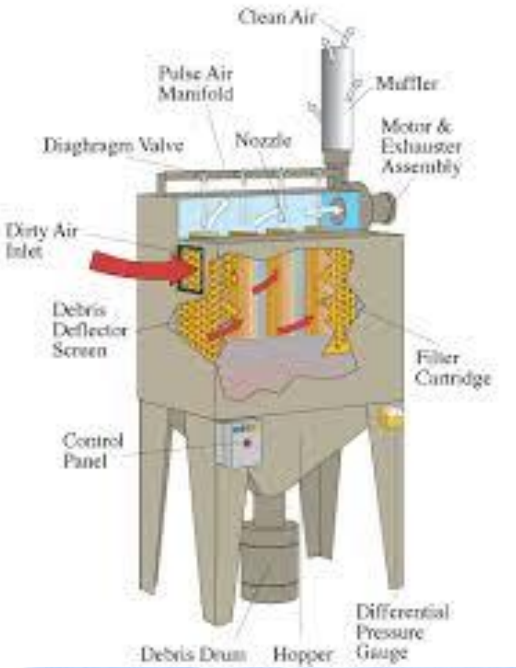
- Use less raw material, energy and natural resources
- Substitute non-toxic for the hazardous or toxic materials
- Redesign the manufacturing line to integrate new cleaner technologies and process equipment
- This applies beyond industrial sector to variety of economic sectors and institutional settings
- Considerable progress and success have been made in attaining pollution prevention in various sectors of our society

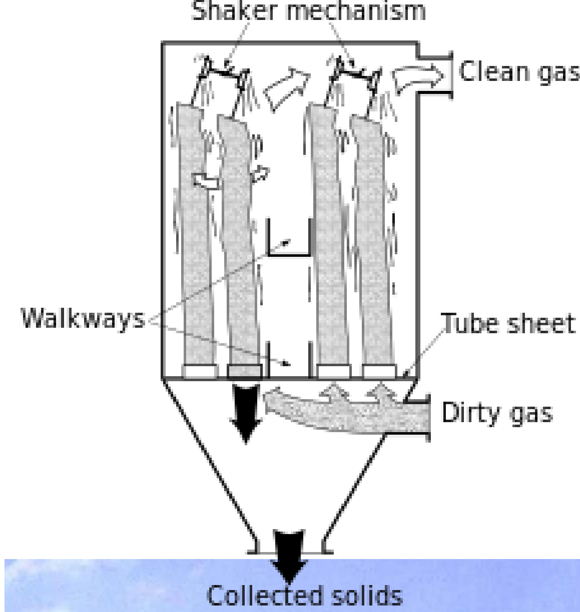

Particle Diamer in Microns
0.0001
0.001
0.01
0.1
1
10
100
1000
Particle Types
Rosin Smoke
Oil Smokes
Fly Ash
Tobacco Smoke
Coal Dust
Metallurgical Dust
Gas molecule
Ammonium Chloride
Sand
Cement Dust
Carbon Black
Pulverized Coal
X-Rays
Paint Pigments
Insecticide Dust
Viruses
Pollen
Aitken Nuclei
Milled Flour
Alkali Fume
Zinc Oxide Fume
Cloth Collector
Mist
Smog
Fog
Rain
Bacteria
Human Hair
Electrostatic Precipitator Collection Range
Mechanical
Settling Chamber
High efficiency Filter
Common Filter

Bag Filters

$$\text{Power} = \frac{1}{\eta}\frac{\gamma}{\gamma-1}P_1 Q_1\left(\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}-1\right)$$

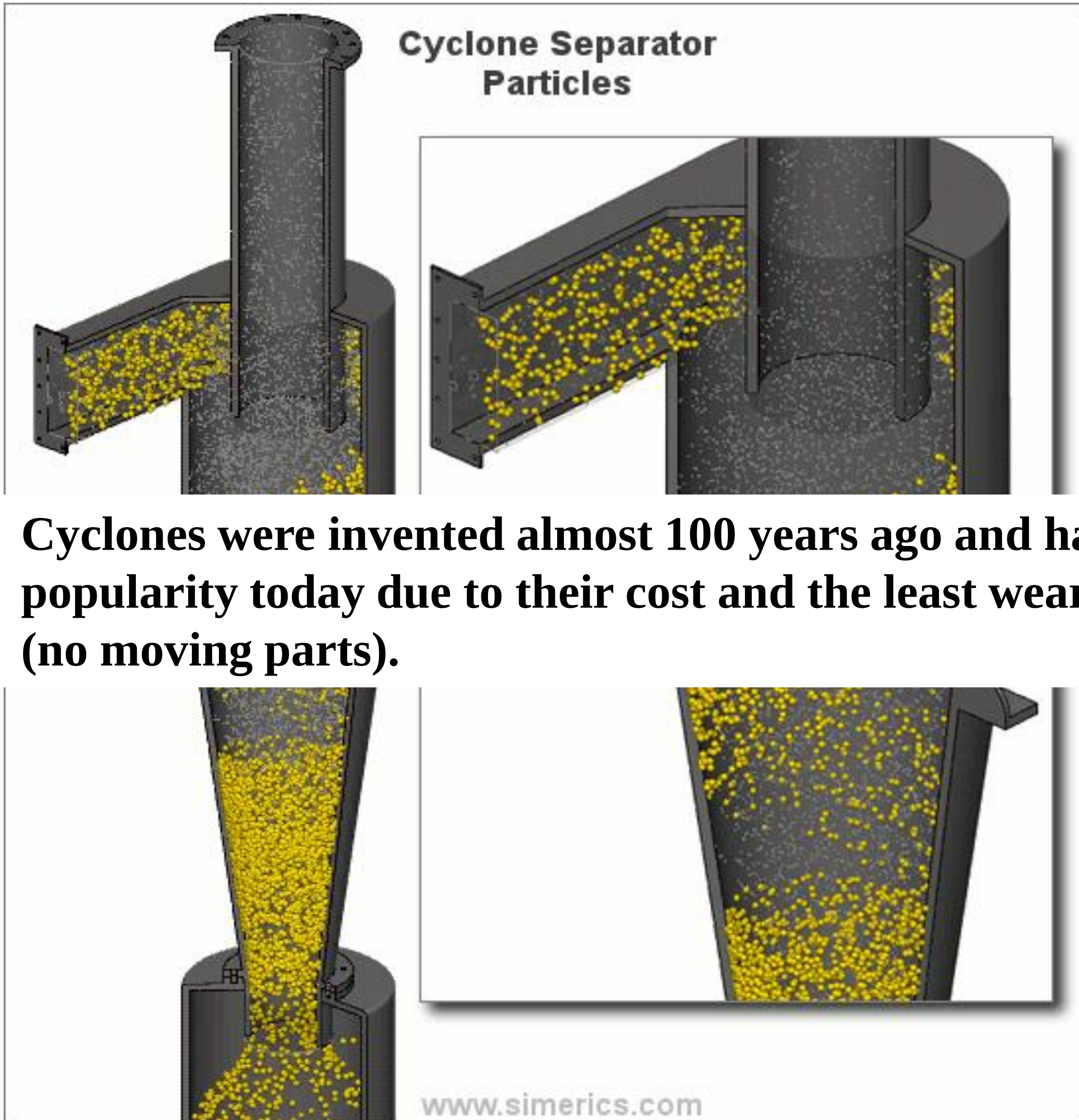






Cyclones

$$K_p = \frac{1}{9}\frac{d_a^2 . V_{p,d}}{\mu_G d_d}$$



Cyclones were invented almost 100 years ago and have same popularity today due to their cost and the least wear and tear (no moving parts).

Cyclone Application

Due to low cost and maintenance free operation, cyclones are used pre-cleaner for more expensive final control PM devices (bag filter and ESP).

Dried Powder products Food, (Coffee, milk, juices), Medicine

Catalyst recovery in petroleum and Petrochemical industries

With research, more efficient cyclones are designed but with increase cost (Capital and operation) due to required high pressure drop

1) High efficiency
2) Conventional
3) High throughput

Advantages of cyclones are:

Low capital cost

Ability to operate at high temperatures

Low maintenance requirements because there are no moving parts.

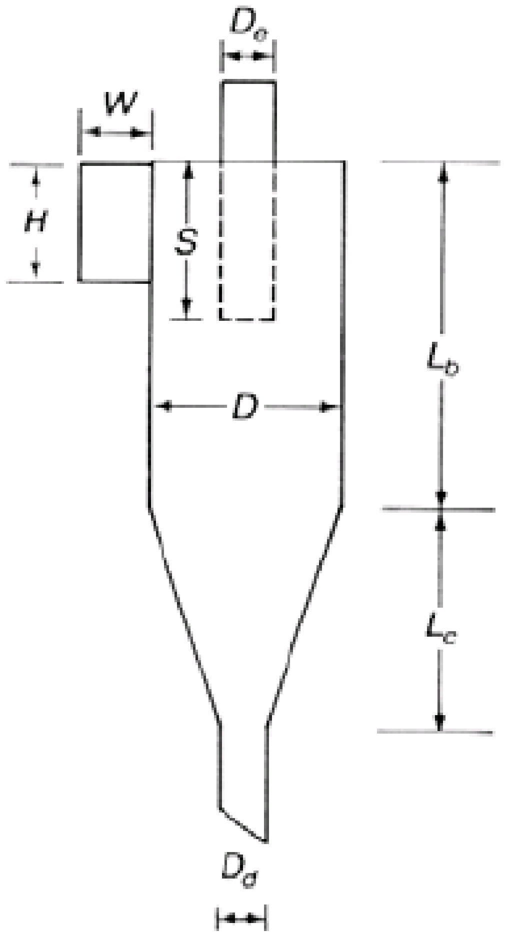
Disadvantages of cyclones are:

Low efficiencies (especially for very small particles)

High operating costs (owing to power required to overcome pressure drop).

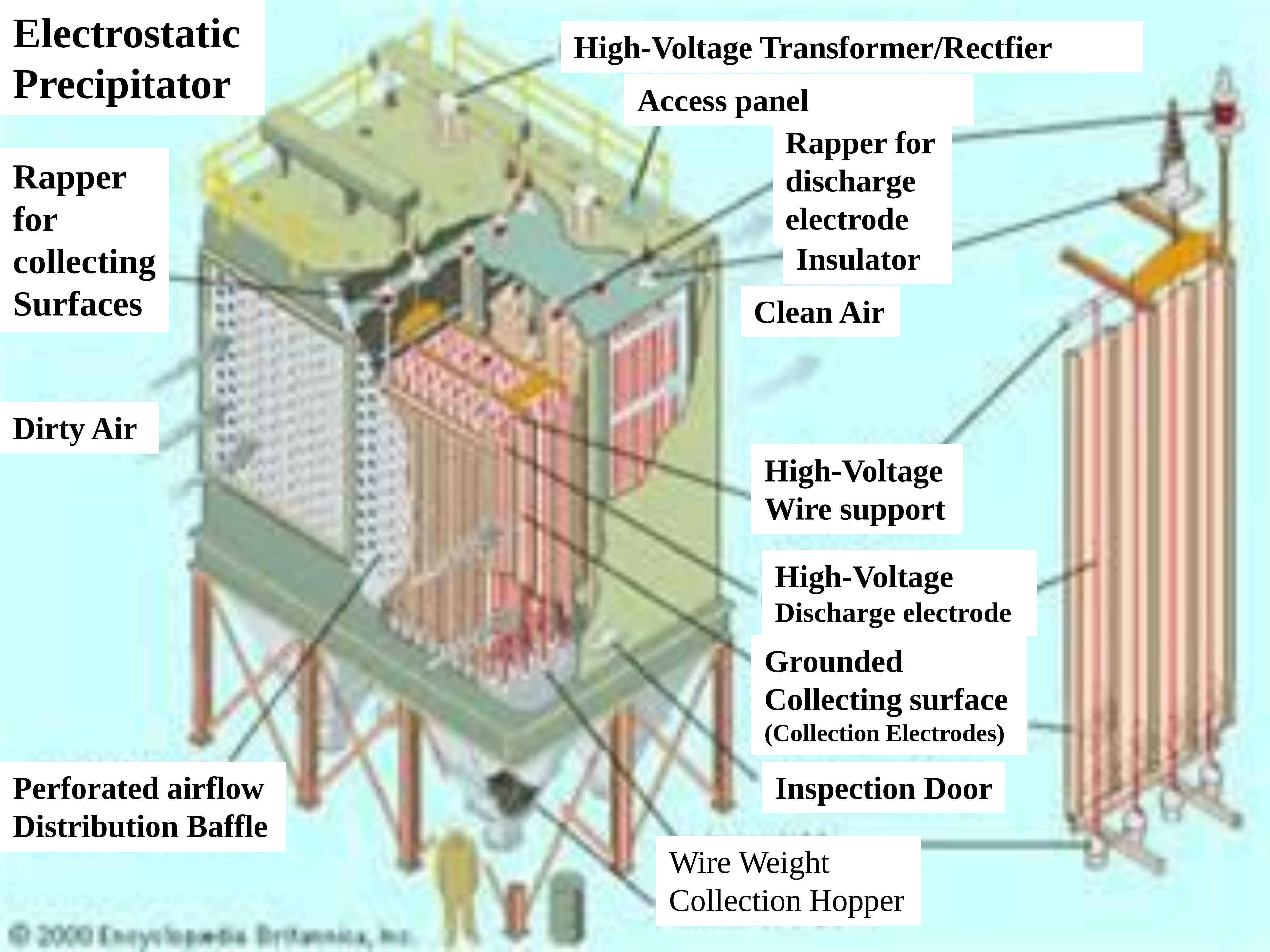
Standard Cyclone Dimensions

	Cyclone Type					
	High Efficiency		Conventional		High Throughput	
	(1)	(2)	(3)	(4)	(5)	(6)
Body Diameter, D/D	1.0	1.0	1.0	1.0	1.0	1.0
Height of Inlet, H/D	0.5	0.44	0.5	0.5	0.75	0.8
Width of Inlet, W/D	0.2	0.21	0.25	0.25	0.375	0.35
Diameter of Gas Exit, D_e/D	0.5	0.4	0.5	0.5	0.75	0.75
Length of Vortex Finder, S/D	0.5	0.5	0.625	0.6	0.875	0.85
Length of Body, L_b/D	1.5	1.4	2.0	1.75	1.5	1.7
Length of Cone, L_c/D	2.5	2.5	2.0	2.0	2.5	2.0
Diameter of Dust Outlet, D_d/D	0.375	0.4	0.25	0.4	0.375	0.4



SOURCES:
Columns (1) and (5) = Stairmand, 1951; columns (2), (4) and (6) = Swift, 1969; column (3) and sketch = Lapple, 1951.

Electrostatic Precipitator



VOCs, Incinerator, Absorption

One fire burns another fire

W. Shakspeare Romeo-Jullet 1696

VOC incinerators

VOCs are major class of air pollutants generated from petroleum activities, motor vehicles, heating, cooking, liquid, gas fuel sale, solvent industries, fires, forests etc.

These pollutants consists of hydrocarbon, aliphatic (alkane, alkenes and alkynes), aromatic (benzene ring compounds), oxygenated (Aldehyde, ketone, alcohol, acids, esters), hetro-cyclic compounds (furan, thiophene, pyridine), halogenated (Fluoro, Chloro, Bromo, Iodo derivatives) thousands of compounds

One of common methods applied broadly is VOCs incinerator also known as Thermal oxidizers or afterburners. In control of VOCS capturing is more important than burning. Relief valves are often fixed with compression cycle to capture, condense and recycle the VOCs.

Fugitive emissions are major source of VOCs in petroleum and petro-chemical industries Valve leak, rapture of transmission line, pump/compressor leak, relief valve opening add to directly exposed organics to the ambient air.

The vapor pressure or boiling point governs gas phase concentration of VOCs higher the vapor pressure, higher the evaporation and higher the concentration in the air

Gas and Liquid Properties

Experts were still unsure what caused the massive gas leak. A sharp change in temperature, impurities inside the tank or even a miniscule crack could have caused a rapid build-up in pressure…..The Chemical has very low boiling point so by the time it started leaking out, had turned from liquid to gas. The vapor cloud drifts slowly downwind over densely populated shanty town. The effect of chemical on human being resemble those of nerve gas

Bhopal 1984

Distinction between gas and vapor

From air pollution control point gas and vapors are sparsely spaced molecules like O_2, N_2, CO_2 in air, while water is referred as vapors. Similarly, NOx, CO, SO_2 are gases while VOC with the exception of very few (CH_4, C_2H_6) others are considered as vapor.

Vapor Pressure Every liquid exerts vapor pressure, n-decane in kerosene at 150^{o}F exerts 0.3 psi and iso-pentane about 44 psi

The vapor pressure is given as function of temperature

Known as **Antoine Equation**.

$$P_{vi} = e^{\left(Ai + \frac{Bi}{Ci+T}\right)}$$

Henry and Raoult's laws discribe the distribution

Among liquid and vapor phase

$$P_i = x_i H_i$$

$$\phi_i . y_i . P = \gamma_i . x_i . P^*$$

Absorption and stripping

There are four major factors to be established in the design of any plant involving the diffusional operation, the number of ideal stages or their equivalent, the length of required device, the cross-section area of the equipment and the energy requirement

Robert E. Treybal 1968

In Air pollution control, absorption refers to selective transfer of materiel from a gas to a contacting liquid. The separation principle involved is the preferential solubility of gases component in the liquid. If the contacting liquid is water, then the process is referred as Scrubbing or washing.

i. Application of gas absorption in pollution control include:
ii. Removal and recovery of ammonia in fertilizer manufacture
iii. Removal of hydrogen fluoride from glass furnace exhaust
iv. Control of sulpher dioxide from combustion sources
v. Recovery of water soluble solvent
vi. Control of odorous gases from rendering plants

Theory

Molecular diffusion and eddy diffusion are modes of transfer from gas phase to liquid phase through an interface. Eddy diffusion is many times faster than molecular diffusion and is maximized for designing absorption column

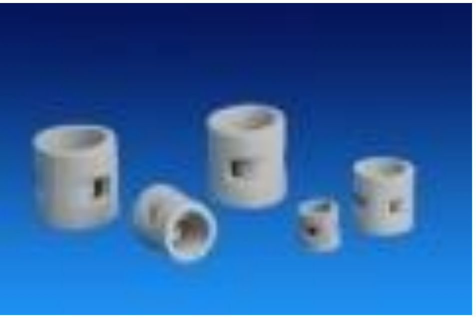
Gas Absorption Equipment:

This operation is usually carried out in packed towers, gas stream entering from the bottom of column and liquid stream from top of the column as counter-current uniformly distributed over the inert packing of different shapes to provide excellent contact with minimum pressure drop.

- High wetted area per unit volume
- Minimal weight
- Sufficient chemical resistance
- Low liquid hold-up
- Low pressure drop
- Low cost

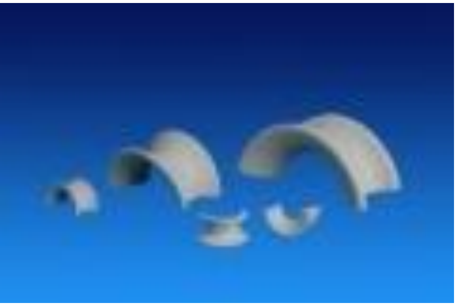
Several type of packings are A) Berl saddle b) intalox saddle c) Raschig rings d) Lessing ring e) pall ring f) Tellerwtte

Packing & Packing tower



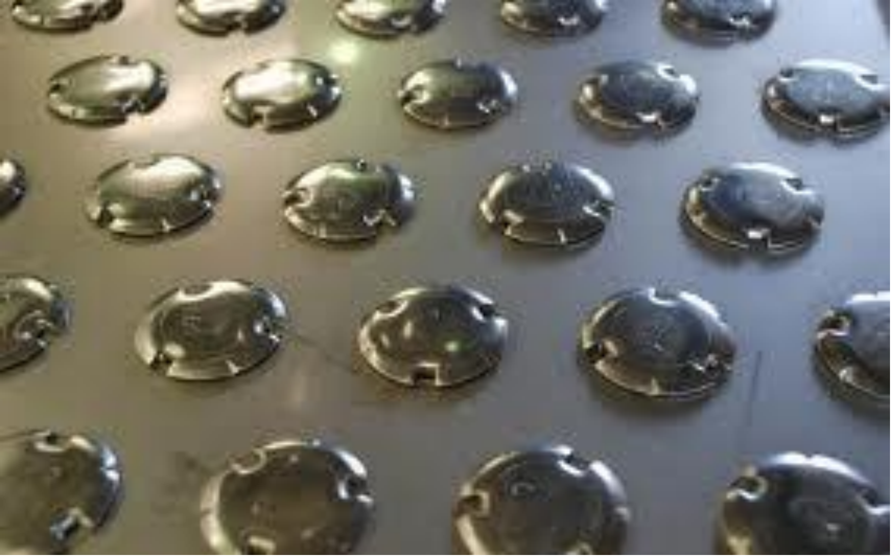
Raschig ring

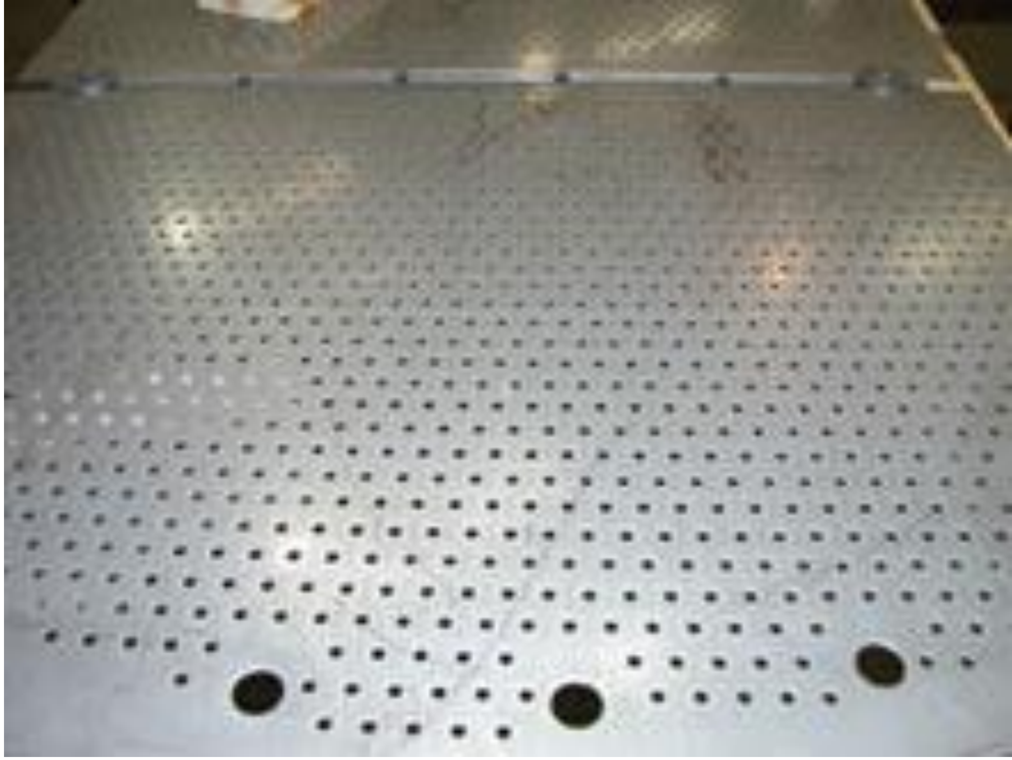
Pall Ring

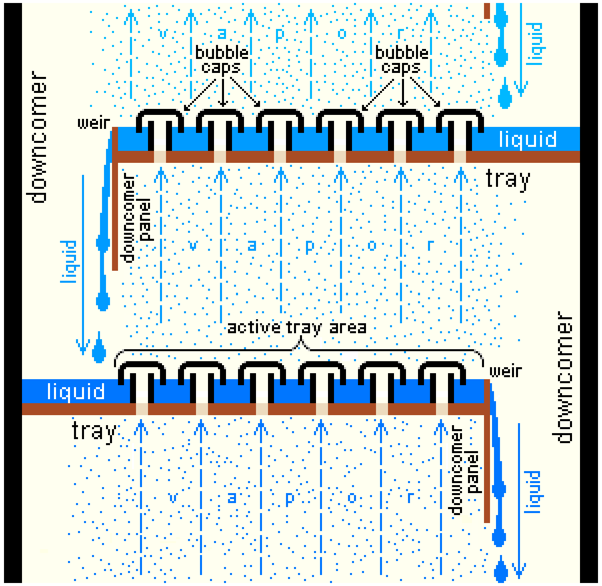


Saddle

Honey comb






vapor
bubble caps
bubble caps
liquid
downcomer
weir
liquid
tray
downcomer panel
liquid
vapor
active tray area
weir
liquid
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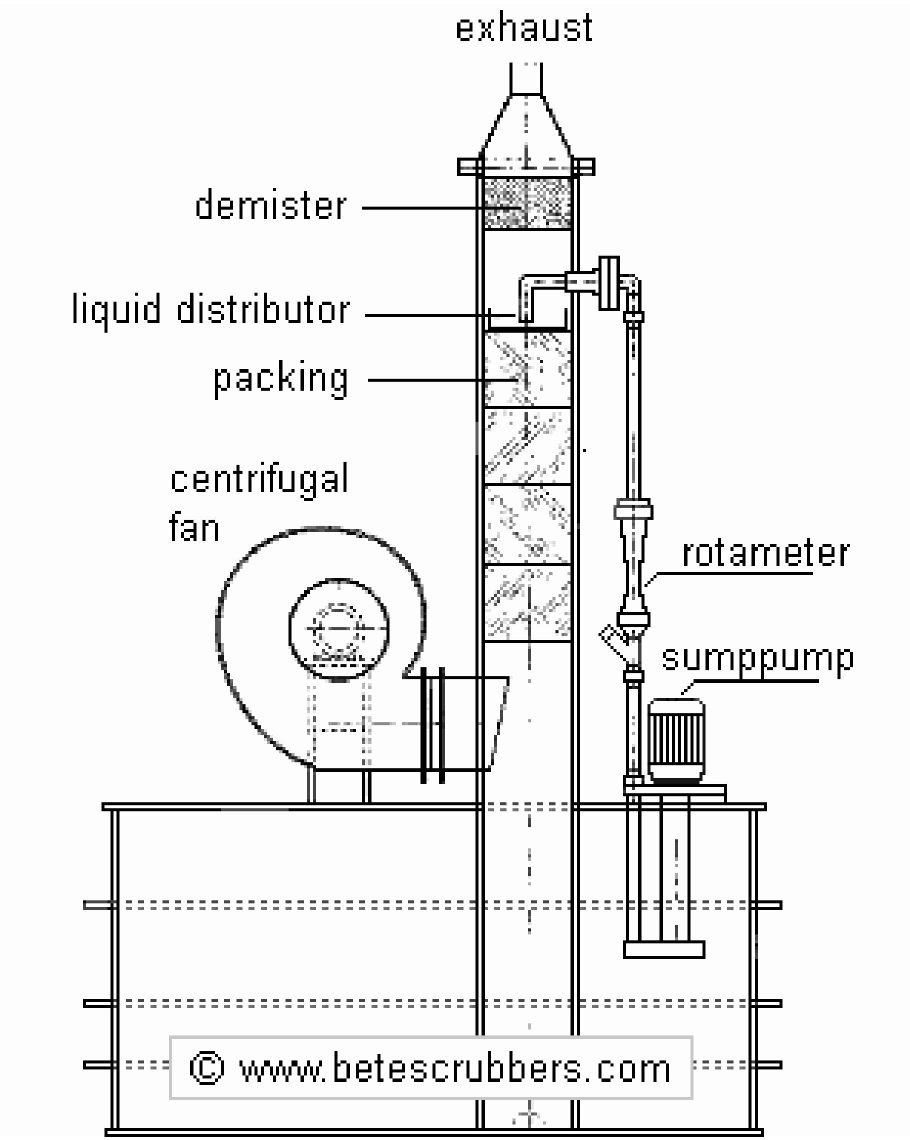
liquid
vapor

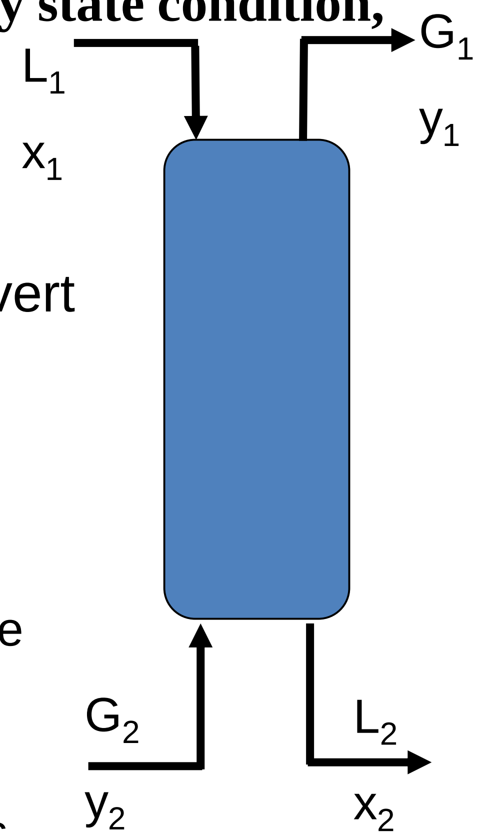
Plate & packed Towers



Materiel Balance:

Overall materiel balance is performed for steady state condition,

Input = Output



$G_2 + L_1 = G_1 + L_2$

all the units must be moles/time, for gases flow use Ideal Gas and for liquid use density to convert volumetric flow to mas and molar flow.

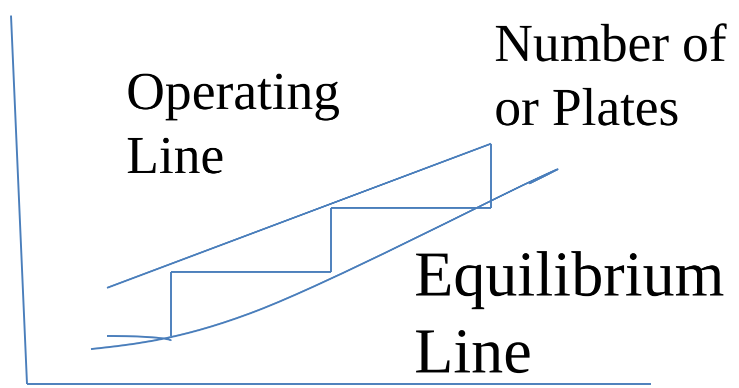
Materiel Balance w.r.t. Pollutant is

$G_2.y_2 + L_1.x_1 = G_1.y_1 + L_2.x_2$

Where x is mole fraction in liquid phase and y is mole fraction in gas phase

Equilibrium and operating

Number of theoretical plates or Number of Transfer Units



$$y = mx$$

$$y = m'x + c$$

Absorption factor is:

$$A = \frac{L}{mG} = \frac{1}{m}\sqrt{\frac{L_1}{G_1}\frac{L_2}{G_2}}$$

value of A is between 1.5 and 2.05

$$\frac{y_{n+1} - y_1}{y_{n+1} - mx_0} = \frac{A^{n+1} - A}{A^{n+1} - 1}$$

A1 = 2.01, A_2=2.04 and A = 2.024

N= 3.97, that is 4 ideal stages, and actual stages are dependent on efficiency, if η = 40% then actual stages will be 10

$$N = \frac{\log\left(\frac{y_{N+1} - mx_0}{y_1 - mx_0}\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right)}{\log(A)}$$

Stripping or Desorption is inverse of Absorption:

$$S = \frac{mG}{L} = m\sqrt{\frac{G_1}{L_1}\frac{G_2}{L_2}}$$

value of S is between 0.5 and 1

$$\frac{x_{n+1} - x_1}{x_{n+1} - y_0 / m} = \frac{S^{n+1} - S}{S^{n+1} - 1}$$

ideal stages, and actual stages are dependent on efficiency

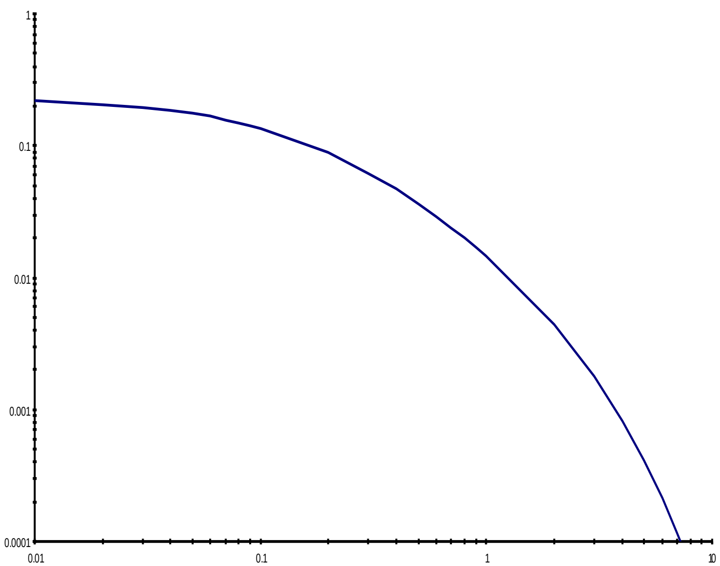
$$N = \frac{\log\left(\frac{y_{N+1} - y_0 / m}{y_1 - y_0 / m}\left(1 - \frac{1}{S}\right) + \frac{1}{S}\right)}{\log(S)}$$

Flooding and Dp for allowable Gas & Liquid rates

For flooding one uses the following equation

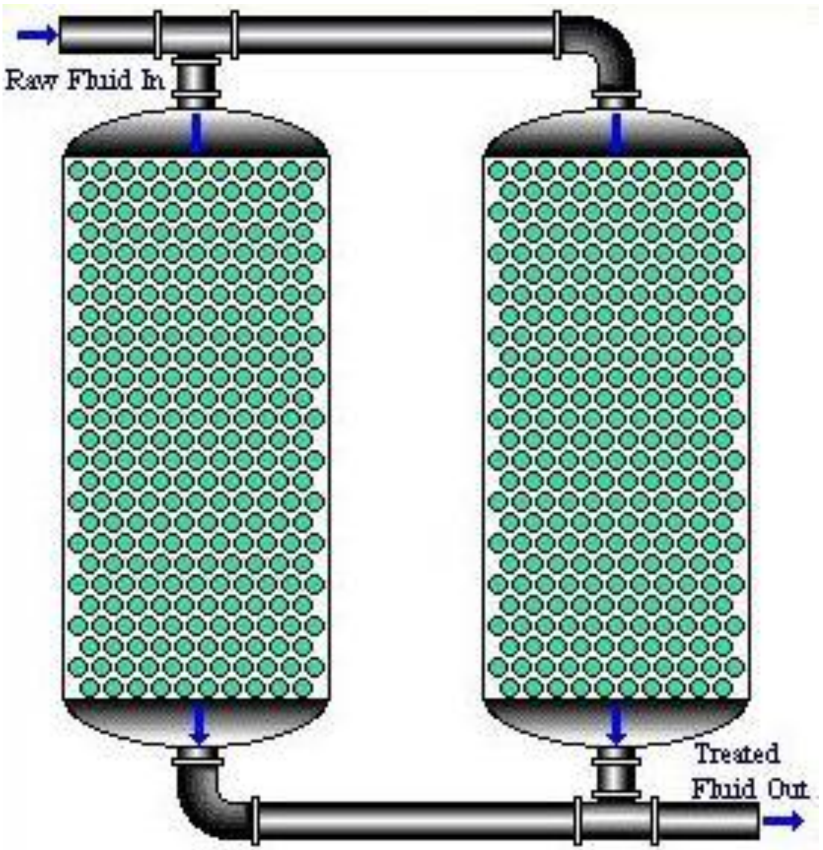
$$\frac{G^2 F_P \mu_L^{0.1}}{g_C\left(\rho_L - \rho_G\right)\rho_G} \text{ VS } \frac{L}{G}\sqrt{\frac{\rho_G}{\rho_L - \rho_G}}$$

$$\text{and } y = \frac{0.025e^{-0.438x}}{0.11 + x^{1.18}}$$



Type	Materiel	Size in	ρ	Area	ε	Packing Factor	
Berl Saddle	Ceramic	0.5	54	142	0.62	240	1.58
		1.0	45	76	0.68	110	1.36
		1.5	40	46	0.71	65	1.07
Intalox Saddle	Ceramic	0.5	46	190	0.71	200	2.27
		1.0	42	78	0.73	92	1.54
		1.5	39	59	0.76	52	1.18
		2.0	38	36	0.76	40	1.0
		3.0	36	28	0.79	22	0.64
Raschig ring	Ceramic	0.5	55	112	0.64	580	1.52
		1.0	42	58	0.74	155	1.36
		1.5	43	37	0.73	95	1.0
		2.0	41	28	0.74	65	0.92
Pall ring	Steel	1.0	30	63	0.94	48	1.54
		1.5	24	39	0.95	28	1.36
		2.0	22	31	0.96	20	1.09
	polypropene	1.0	5.5	63	0.90	52	1.36
		1.5	4.8	39	0.91	40	1.18

Adsorber and Regenerator



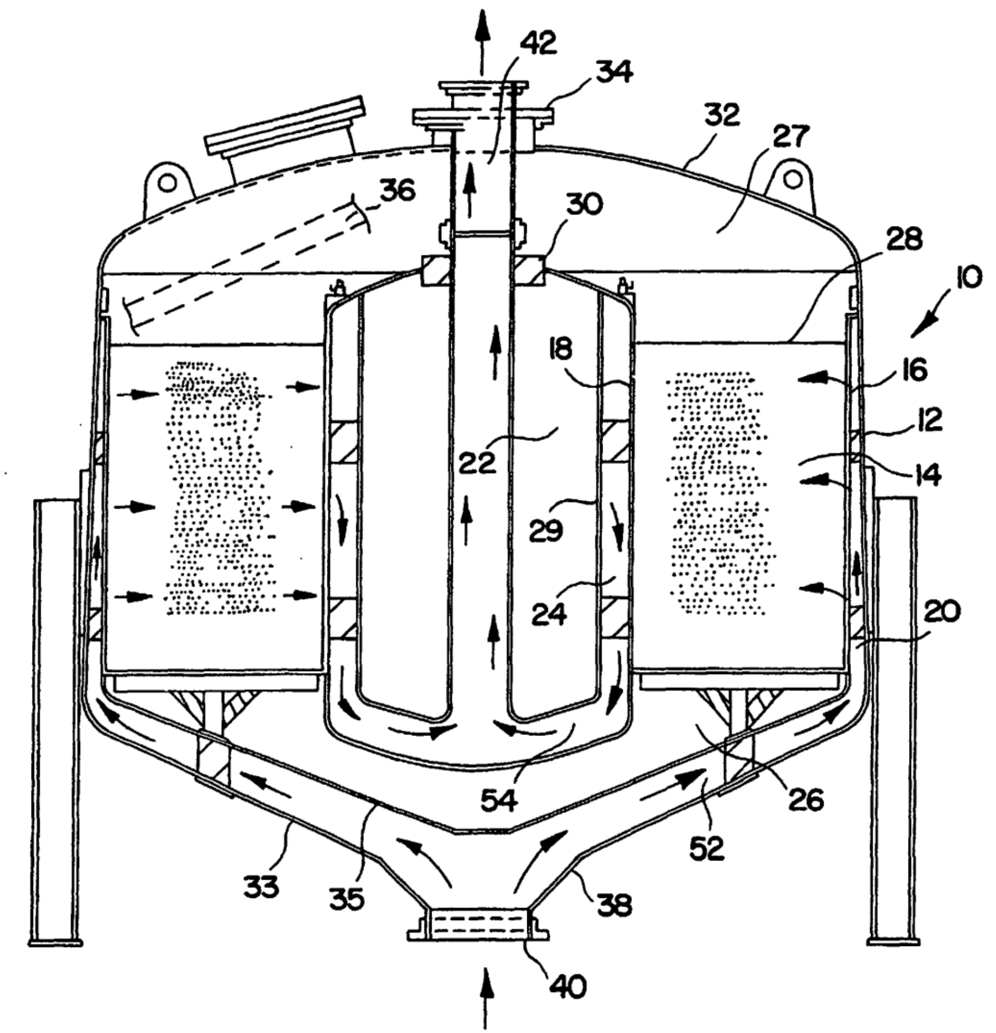


FIG. 1

Freundlich Isotherm $y = kx^n$

Langmuir Isotherm: $y = \dfrac{k_1 P_A}{1 + k_2 P_A}$

Thank You

Question Please