**ENVIRONMENTAL ENGINEERING - I**

**(20A01404T)**

**LECTURE NOTES**

**II - B.TECH &II- SEM**

**Prepared by:**

# MrVinothkumar M, Assistant Professor

**Department of Civil Engineering**

****

**VEMU INSTITUTE OF TECHNOLOGY**

**(Approved By AICTE, New Delhi and Affiliated to JNTUA, Ananthapuramu)**

**Accredited By NAAC, NBA( EEE, ECE & CSE) & ISO: 9001-2015 Certified Institution**

**Near Pakala, P.Kothakota, Chittoor- Tirupathi Highway**

**Chittoor, Andhra Pradesh-517 112**

**Web Site:** [**www.vemu.org**](http://www.vemu.org)

****

**Department of Civil Engineering**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Course Code** | | **ENVIRONMENTAL ENGINEERING** | **L** | **T** | **P** | **C** |
| **20A01404T** | | **3** | **0** | **0** | **3** |
| **Pre-requisite** | | **ENVIRONMENTAL STUDIES** | **Semester** | | | **III** |
| **Course Objective:** | | | | | | |
| * To teach requirements of water and its treatment. | | | | | | |
| * To impart knowledge on sewage treatment methodologies. | | | | | | |
| * To provide facts on Air pollution and control. | | | | | | |
| * To enable with design concepts of wastewater treatment UNITs | | | | | | |
| * To throw light on importance of plumbing. | | | | | | |
| **Course Outcomes (CO):** After completion of the course, the student can able to | | | | | | |
| **CO-1:**Understand about quality of water and purification process | | | | | | |
| **CO-2:**Select appropriate technique for treatment of waste water. | | | | | | |
| **CO-3:**Assess the impact of air pollution | | | | | | |
| **CO-4:**Understand consequences of solid waste and its management | | | | | | |
| **CO-5:**Design domestic plumbing systems. | | | | | | |
| **Unit – I** | **Water quality and treatment** | | | | | |
| Basic concept of EIA : Initial environmental Examination, Elements of EIA, - factors affecting E-I-A Impact evaluation and analysis, preparation of Environmental Base map, Classification of environmental parameters | | | | | | |
| **Unit – II** | **Sewage and Treatment** | | | | | |
| E I A Methodologies: introduction, Criteria for the selection of EIA Methodology, E I A methods, Ad-hoc methods, matrix methods, Network method Environmental Media Quality Index method, overlay methods and cost/benefit Analysis | | | | | | |
| **Unit – III** | **Air Pollution** | | | | | |
| Introduction and Methodology for the assessment of soil and ground water, Delineation of study area, Identification of actives. Procurement of relevant soil quality, Impact prediction, Assessment of Impact significance, Identification and Incorporation of mitigation measures. E I A in surface water, Air and Biological environment: Methodology for the assessment of Impacts on surface water environment, Air pollution sources, Generalized approach for assessment of Air pollution Impact | | | | | | |
| **Unit – IV** | **Solid Waste Management** | | | | | |
| Introduction - Assessment of Impact of development Activities on Vegetation and wildlife, environmental Impact of Deforestation – Causes and effects of deforestation.  **ENVIRONEMNTAL AUDIT :**  Introduction - Environmental Audit & Environmental legislation objectives of Environmental Audit, Types of environmental Audit, Audit protocel, stages of Environmental Audit, onsite activities, evaluation of Audit data and preparation of Audit report. | | | | | | |
| **Unit – V** | **Domestic Plumbing** | | | | | |
| Post Audit activities, The Environmental protection Act, The water preventation Act, The Air (Prevention & Control of pollution Act.), Wild life Act.Case studies and preparation of Environmental Impact assessment statement for various Industries. | | | | | | |
| **Textbooks:** | | | | | | |
| 1.A.V. Oppenheim, A.S. Willsky and S.H. Nawab, “Signals and Systems”, 2nd Edition, PHI, 2009.  2. Simon Haykin and Van Veen, “Signals & Systems”, 2nd Edition, Wiley, 2005. | | | | | | |
| **Reference Books:** | | | | | | |
| 1. BP Lathi, “Principles of Linear Systems and Signals”, 2nd Edition, Oxford University Press, 015.  2. Matthew Sadiku and Warsame H. Ali, “Signals and Systems A primer with MATLAB”, CRC Press, 2016.  3. Hwei Hsu, “Schaum's Outline of Signals and Systems”, 4thEdition, TMH, 2019 | | | | | | |

**UNIT-I**

**WATER QUALITY AND TREATMENT**

### RawWaterSource

Thevarious sourcesofwater canbeclassifiedinto two categories:

1. Surfacesources,suchas
2. Ponds and lakes;
3. Streamsandrivers;
4. Storagereservoirs;and
5. Oceans, generallynotusedforwater supplies,atpresent.
6. Sub-surfacesourcesorundergroundsources,suchas
   1. Springs;
   2. Infiltrationwells;and
   3. WellsandTube-wells.

### WaterQuantityEstimation

Thequantityofwaterrequiredformunicipaluses forwhichthewatersupply schemehas tobedesigned requiresfollowingdata:

1. Waterconsumptionrate***(PerCapitaDemandinlitersperdayperhead)***
2. Populationto beserved.

Quantity=PercapitademandxPopulation

**WaterConsumptionRate**

It is very difficult to precisely assess the quantity of water demanded by the public, since thereare many variable factors affecting water consumption. The various types of water demands,whichacitymayhave,may bebrokenintofollowingclasses:

**WaterConsumption forVariousPurposes:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.No** | **Types ofConsumption** | **Normal**  **Range(lit/capita/day)** | **Average** | **%** |
| 1 | DomesticConsumption | 65-300 | 160 | 35 |
| 2 | Industrial and CommercialDemand | 45-450 | 135 | 30 |
| 3 | PublicUses including FireDemand | 20-90 | 45 | 10 |
| 4 | LossesandWaste | 45-150 | 62 | 25 |

### FireFightingDemand:

The per capita fire demand is very less on an average basis but the rate at which the water isrequired is very large. The rate of fire demand is sometimes traeted as a function of populationandisworked out fromfollowingempirical formulae:

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Authority** | **Formulae(Pin thousand)** | **Q for 1**  **lakhPopulation)** |
| 1 | American  InsuranceAssociation | Q(L/min)=4637√P(1-0.01√P) | 41760 |
| 2 | Kuchling'sFormula | Q(L/min)=3182 √P | 31800 |

|  |  |  |  |
| --- | --- | --- | --- |
| 3 | Freeman's Formula | Q(L/min)= 1136.5(P/5+10) | 35050 |
| 4 | Ministryof  Urban  Development  ManualFormula | Q(kilo liters/d)=100√PforP>50000 | 31623 |

### Factorsaffectingpercapitademand:

* + Sizeofthecity:Per capitademandforbigcitiesisgenerally large as compared to thatfor smallertownsasbigcitieshavesewered houses.
  + Presence ofindustries.
  + Climaticconditions.
  + Habitsofpeopleandtheireconomicstatus.
  + Quality of water: If water is aesthetically & medically safe, the consumption will increaseaspeoplewillnotresorttoprivatewells,etc.
  + Pressurein thedistribution system.
  + Efficiency of water works administration: Leaks in water mains and services; andunauthoriseduseofwatercan be keptto aminimum bysurveys.
  + Costofwater.
  + Policy of metering and charging method: Water tax is charged in two different ways: onthebasis ofmeter readingandon the basisofcertainfixedmonthlyrate.

### FluctuationsinRate ofDemand

AverageDailyPerCapita Demand

= Quantity Requiredin 12 Months/(365xPopulation)

Ifthisaveragedemandissuppliedatallthetimes,itwillnotbesufficienttomeetthefluctuations.

* ***Seasonal variation***: The demand peaks during summer. Firebreak outs are generallymore insummer,increasingdemand.So,thereisseasonalvariation.
* ***Daily variation*** depends on the activity. People draw out more water on Sundays andFestivaldays,thusincreasingdemand on thesedays.
* ***Hourlyvariations***areveryimportantastheyhaveawiderange.Duringactivehousehold working hours i.e. from six to ten in the morning and four to eight in theevening, the bulk of the daily requirement is taken. During other hours the requirement isnegligible. Moreover, if a fire breaks out, a huge quantity of water is required to besupplied during short duration, necessitating the need for a maximum rate of hourlysupply.

So, an adequate quantity of water must be available to meet the peak demand. To meet all thefluctuations,thesupplypipes,servicereservoirsanddistributionpipesmustbeproperlyproportioned. The water is supplied by pumping directly and the pumps and distribution systemmust be designed to meet the peak demand. The effect of monthly variation influences thedesign of storage reservoirs and the hourly variations influencesthe design of pumps andservicereservoirs.As thepopulationdecreases,the fluctuationrateincreases.

***Maximumdailydemand*** =1.8 x average daily demand

#### Maximumhourly demandofmaximum dayi.e.Peak demand

=1.5 xaveragehourlydemand

=1.5 xMaximumdailydemand/24

=1.5x(1.8 xaveragedailydemand)/24

=2.7xaveragedailydemand/24

=2.7 xannual averagehourlydemand

### DesignPeriods&PopulationForecast

This quantity should be worked out with due provision for the estimated requirements of thefuture . The future period for which a provision is made in the water supply scheme is known asthe**design period**.

Designperiod is estimatedbased onthefollowing:

* Usefullifeof the component,consideringobsolescence,wear,tear,etc.
* Expandabilityaspect.
* Anticipated rate of growth of population, including industrial, commercial developments &migration-immigration.
* Availableresources.
* Performanceofthesystemduring initial period.

### PopulationForecastingMethods

The various methods adopted for estimating future populations are given below. The particularmethod to be adopted for a particular case or for a particular city depends largely on the factorsdiscussed in the methods, and the selection is left to the discrection and intelligence of thedesigner.

1. ArithmeticIncreaseMethod
2. GeometricIncreaseMethod
3. *IncrementalIncreaseMethod*
4. Decreasing RateofGrowthMethod
5. *SimpleGraphicalMethod*
6. *ComparativeGraphicalMethod*
7. RatioMethod
8. *LogisticCurveMethod*

### PopulationForecast byDifferentMethods

**Problem:**Predict the population for the years 1981, 1991, 1994, and 2001 from the followingcensus figuresofatownbydifferent methods.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | 1901 | 1911 | 1921 | 1931 | 1941 | 1951 | 1961 | 1971 |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Population:(thousands) | 60 | 65 | 63 | 72 | 79 | 89 | 97 | 120 |

### Solution:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Year | Population:(thousands) | Increment  perDecade | IncrementalIncrease | Percentage Increment perDecade |
| 1901 | 60 | - | - | - |
| 1911 | 65 | +5 | - | (5+60) x100=+8.33 |
| 1921 | 63 | -2 | -3 | (2+65)x100=-3.07 |
| 1931 | 72 | +9 | +7 | (9+63) x100=+14.28 |
| 1941 | 79 | +7 | -2 | (7+72) x100=+9.72 |
| 1951 | 89 | +10 | +3 | (10+79)x100=+12.66 |
| 1961 | 97 | +8 | -2 | (8+89)x100=8.98 |
| 1971 | 120 | +23 | +15 | (23+97)x100=+23.71 |
| Netvalues | 1 | +60 | +18 | +74.61 |
| Averages | - | 8.57 | 3.0 | 10.66 |

+=increase;-=decrease

#### ArithmeticalProgressionMethod:

Pn=P +ni

Averageincreasesperdecade=i=8.57Population forthe years,

1981=population 1971+ni,heren=1decade

=120+8.57=128.57

1991=population 1971+ni,heren=2decade

=120 +2x8.57=137.14

2001=population 1971+ni,heren=3decade

=120 +3x8.57=145.71

1994=population 1991 +(population2001 -1991)x 3/10

=137.14 +(8.57)x3/10=139.71

#### IncrementalIncreaseMethod:

Population forthe years,

1981=population 1971+averageincreaseperdecade+average incrementalincrease

=120 +8.57 +3.0=131.57

1991=population 1981 +11.57

=131.57+11.57=143.14

2001=population 1991 +11.57

=143.14+11.57=154.71

1994=population1991 +11.57 x3/10

=143.14+3.47=146.61

#### GeometricProgressionMethod:

Averagepercentage increaseperdecade =10.66Pn=P (1+i/100)n

Population for 1981 =Population1971x (1+i/100)n

=120 x(1+10.66/100),*i=10.66,n=1*

=120 x110.66/100*=* 132.8

Population for 1991 =Population1971x (1+i/100)n

=120 x (1+10.66/100)2,*i =10.66,n= 2*

=120 x1.2245*=*146.95

Population for 2001 =Population1971x (1+i/100)n

=120 x (1+10.66/100)3,*i =10.66,n= 3*

=120 x1.355*=*162.60

Populationfor1994 =146.95+(15.84 x3/10)=151.70

### IntakeStructure

The basic function of the intake structure is to help in safely withdrawing water from the sourceover predetermined pool levels and then to discharge this water into the withdrawal conduit(normally calledintake conduit),throughwhichitflowsuptowatertreatmentplant.

### FactorsGoverning LocationofIntake

1. As faraspossible, the siteshouldbenear thetreatmentplant sothatthe cost ofconveyingwatertothecityisless.
2. The intake must be located in the purer zone of the source to draw best quality waterfromthesource,therebyreducingloadon the treatmentplant.
3. The intake must never be located at the downstream or in the vicinity of the point ofdisposalofwastewater.
4. The site should be such as to permit greater withdrawal of water, if required at a futuredate.
5. The intake mustbe located ataplace fromwhereitcan draw watereven duringthedriestperiodoftheyear.
6. Theintakesiteshouldremaineasilyaccessibleduringfloodsandshouldnoygetflooded. Moreover, the flood waters should not be concentrated in the vicinity of theintake.

### DesignConsiderations

1. sufficientfactor ofsafetyagainstexternalforcessuchasheavy currents, floatingmaterials,submergedbodies,icepressure,etc.
2. shouldhave sufficient selfweightsothat itdoesnotfloatbyupthrustof water.

### TypesofIntake

Dependingonthesource ofwater,theintakeworksare classifiedasfollows:

### Pumping

A pump is a device, which converts mechanical energy into hydraulic energy. It lifts water from alower to a higher level and delivers it at high pressure. Pumps are employed in water supplyprojects atvariousstagesforfollowingpurposes:

1. Tolift rawwater fromwells.
2. Todelivertreatedwaterto theconsumer at desiredpressure.
3. To supplypressuredwaterforfirehydrants.
4. Toboostuppressurein watermains.
5. Tofill elevatedoverhead watertanks.
6. Tobackwashfilters.
7. Topumpchemicalsolutions,neededforwatertreatment.

### ClassificationofPumps

Basedon principleofoperation,pumpsmaybe classified asfollows:

1. Displacementpumps(reciprocating,rotary)
2. Velocitypumps(centrifugal,turbine andjet pumps)
3. Buoyancypumps(airliftpumps)
4. Impulsepumps(hydraulicrams)

### CapacityofPumps

Work doneby thepump,

H.P.=wQH/75

where,w=specificweightofwater kg/m3, Q=dischargeofpump,m3/s; and H=totalheadgainstwhichpumphastowork.

H=Hs+ Hd+ Hf+(lossesdue to exit,entrance,bends,valves,and so on)where,Hs=suctionhead,Hd=delivery head,and Hf=frictionloss.

Efficiency of pump (E) = wQH/Brake H.P.Total brakehorse powerrequired=wQH/E

Provideevennumberofmotorssay2,4,with theirtotalcapacity beingequalto thetotalBHP andprovidehalfofthe motorsrequired asstand-by.

### Conveyance

There are two stagesinthetransportationofwater:

1. Conveyanceofwater fromthesourcetothetreatmentplant.
2. Conveyanceof treatedwaterfromtreatmentplant tothedistributionsystem.

Inthefirststagewateristransportedbygravityorbypumpingorbythecombinedactionofboth,dependingupontherelativeelevationsofthetreatmentplantandthesourceofsupply.In the second stage water transmission may be either by pumping into an overhead tank andthensupplyingbygravityor bypumpingdirectly into thewater-mainfordistribution.

### FreeFlowSystem

Inthissystem,thesurfaceofwaterintheconveyingsectionflowsfreelyduetogravity.Insucha conduit the hydraulic gradient line coincide with the water surface and is parallel to the bed ofthe conduit. It is often necessary to construct very long conveying sections, to suit the slope ofthe existing ground. The sections used for free-flow are: Canals, flumes, grade aqueducts andgradetunnels.

### PressureSystem

In pressure conduits, which are closed conduits, the water flows under pressure above theatmospheric pressure. The bed or invert of the conduit in pressure flows is thus independant ofthe grade of the hydraulic gradient line and can, therefore, follow the natural available groundsurface thus requiring lesser length of conduit. The pressure aqueducts may be in the form ofclosed pipes or closed aqueducts and tunnels called *pressure aqueducts or pressure tunnels*designed for the pressure likely to come on them. Due to their circular shapes, every pressureconduit is generally termed as a *pressure pipe*. When a pressure pipe drops beneath a valley,stream,orsomeotherdepression,itiscalledadepressedpipeoran*invertedsiphon*.Depending upon the construction material, the pressure pipes are of following types: Cast iron,steel, R.C.C, hume steel, vitrified clay, asbestos cement, wrought iron, copper, brass and lead,plastic,andglassreinforcedplasticpipes.

### HydraulicDesign

The design of water supply conduits depends on the resistance to flow, available pressure orhead, and allowable velocities of flow. Generally, Hazen-William's formula for pressure conduitsandManning'sformulaforfreeflow conduitsareused.

Hazen-William'sformula

U=0.85CrH0.63S0.54

Manning'sformula

U=1/nrH2/3S1/2

where, U=velocity,m/s;rH= hydraulic radius,m;S=slope,C=Hazen-William'scoefficient, andn

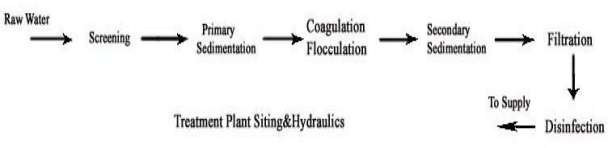
= Manning'scoefficient.

Darcy-Weisbachformula

hL=(fLU2)/(2gd)

The available raw waters must be treated and purified before they can be supplied to the publicfor their domestic, industrial or any other uses. The extent of treatment required to be given tothe particularwaterdepends upon the characteristics and quality ofthe availablewater,andalsouponthequalityrequirementsfor the intendeduse..

Thelayoutofconventionalwatertreatment plantis asfollows:



Depending upon the magnitude of treatment required, proper unit operations are selected andarranged in the proper sequential order for the purpose of modifying the quality of raw water tomeet thedesiredstandards.IndianStandardsfor drinkingwateraregivenin thetablebelow.

### WaterDistributionSystems

The purpose of distribution system is to deliver water to consumer with appropriate quality,quantity and pressure. Distribution system is used to describe collectively the facilities used tosupplywaterfromitssource tothepointofusage.

### RequirementsofGoodDistributionSystem

1. Waterqualityshouldnotgetdeteriorated inthedistributionpipes.
2. Itshould becapable ofsupplyingwateratallthe intended placeswith sufficientpressurehead.
3. Itshouldbecapable ofsupplying therequisiteamountofwater during firefighting.
4. Thelayoutshouldbesuch thatnoconsumer would bewithoutwater supply,duringtherepairofanysectionofthesystem.
5. All the distribution pipes should be preferably laid one metre away or above the sewerlines.
6. Itshouldbe fairlywater-tightas tokeep lossesdueto leakagetotheminimum.

### LayoutsofDistributionNetwork

The distribution pipes are generally laid below the road pavements, and as such their layoutsgenerally follow the layouts of roads. There are, in general, four different types of pipe networks;anyoneofwhicheithersinglyorincombinations, canbeusedfor aparticularplace.They are:

*Dead End SystemGrid Iron SystemRing SystemRadialSystem*

### DistributionReservoirs

Distribution reservoirs, also called service reservoirs, are the storage reservoirs, which store thetreated water for supplying water during emergencies (such as during fires, repairs, etc.) andalsotohelp inabsorbing thehourlyfluctuations in thenormalwaterdemand.

### FunctionsofDistributionReservoirs:

* toabsorbthehourlyvariationsindemand.
* tomaintainconstantpressureinthedistributionmains.
* waterstored canbesupplied during emergencies.

### LocationandHeightofDistributionReservoirs:

* should belocatedascloseas possibletothecenter ofdemand.
* waterlevelinthereservoirmustbeatasufficientelevationtopermitgravityflowatanadequatepressure.

### TypesofReservoirs

1. Undergroundreservoirs.
2. Smallgroundlevelreservoirs.
3. Largegroundlevelreservoirs.
4. Overheadtanks.

### StorageCapacityof DistributionReservoirs

Thetotal storagecapacityofadistributionreservoiristhesummationof:

1. *BalancingStorage:*The quantity ofwater required to be stored in the reservoir forequalising or balancing fluctuating demand against constant supply is known as thebalancing storage (or equalising or operating storage). The balance storage can beworkedoutby ***masscurvemethod***.
2. *Breakdown Storage:* The breakdown storage or often called emergency storage is thestorage preserved in order to tide over the emergencies posed by the failure of pumps,electricity, or any othe mechanism driving the pumps. A value of about 25% of the totalstorage capacity of reservoirs, or 1.5 to 2 times of the average hourly supply, may beconsideredas enoughprovisionforaccountingthisstorage.
3. ***Fire Storage:*** The third component of the total reservoir storage is the fire storage. Thisprovision takes care of the requirements of water for extinguishing fires. A provision of 1to4perpersonperdayissufficientto meettherequirement.

Thetotalreservoirstoragecanfinally beworkedoutbyaddingallthethreestorages.

### PipeNetworkAnalysis

Analysis of water distribution system includes determining quantities of flow and head losses inthe various pipe lines, and resulting residual pressures. In any pipe network, the following twoconditionsmustbesatisfied:

1. Thealgebraicsumofpressuredrops arounda closedloop mustbezero,i.e.therecanbenodiscontinuityinpressure.
2. The flow entering a junction must be equal to the flow leaving that junction; i.e. the law ofcontinuity mustbe satisfied.

Based on these two basic principles, the pipe networks are generally solved by the methods ofsuccessive approximation. The widely used method of pipe network analysis is the Hardy-Crossmethod.

### Hardy-CrossMethod

This method consists of assuming a distribution of flow in the network in such a way that theprinciple of continuity is satisfied at each junction. A correction to these assumed flows is thencomputed successively for each pipe loop in the network, until the correction is reduced to anacceptable magnitude.

IfQais the assumedflowandQis the actualflowinthepipe,then thecorrectiondisgivenbyd=Q-Qa;orQ=Qa+d

Now,expressingthehead loss (HL)asHL=K.Qx

we have,theheadlossinapipe

=K.(Qa+d)x

=K.[Q x+x.Qx-1d +negligibleterms]

=K.[Q x+x.Qx-1d]

Now,aroundaclosedloop,thesummation ofheadlosses mustbezero.

SK.[Q x +x.Qx-1d]=0

orSK.Qx=-SKx Qx-1d

Since,disthesame forallthepipesoftheconsideredloop,itcanbetakenoutofthesummation.

SK.Qx=-d.SKxQx-1

ord=-SK.Qx/Sx.KQx-1

Sinced is giventhesamesign(direction) in allpipesoftheloop, thedenominatoroftheaboveequationis takenastheabsolutesumoftheindividual itemsinthesummation.Hence,

ord=-SK.Qax/S l x.KQax-1 l

ord=-SHL/x.SlHL/Qal

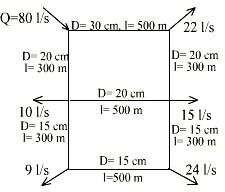
whereHListheheadlossforassumedflowQa.

The numerator in the above equation is the algebraic sum ofthe head losses in the variouspipes of the closed loop computed with assumed flow. Since the direction and magnitude of flowinthesepipesisalreadyassumed,theirrespectiveheadlosseswithdueregardtosigncanbeisthencalculated.Finallythevalueofdisfoundoutforeachloop,andtheassumedflowsarecorrected.Repeated adjustments aremadeuntil thedesired accuracyisobtained.

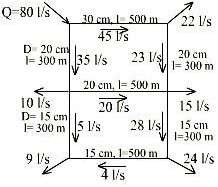
ThevalueofxinHardy-Crossmethodisassumedtobeconstant(i.e.1.85forHazen-William'sformula,and 2forDarcy-Weisbachformula)

#### FlowinPipesofaDistribution NetworkbyHardy CrossMethod

**Problem:**Calculatetheheadlossesandthecorrectedflowsinthevariouspipesofadistribution network as shown in figure. The diameters and the lengths of the pipes used aregivenagainsteach pipe.Compute correctedflowsafteronecorrections.



**Solution:**First of all, the magnitudes as well as the directions of the possible flows in each pipeare assumed keeping in consideration the law of continuity at each junction. The two closedloops,ABCDandCDEFarethenanalyzedbyHardyCrossmethodaspertables1&2respectively,andthe correctedflowsarecomputed.



=4.86l/s=5l/s(say)Hence,correctedflows afterfirst correctionare:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Pipe | AB | BC | CD | DA |
| Corrected flows afterfirstcorrectioninl/s | +48 | +28 | -15 | -30 |

### Table2

**Considerloop DCFE**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Pipe** | **Assumedflow** | | **Diaofpipe** | | **Lengthof pipe(m)** | **K= L**  **470d4.87** | **Q1.85**  **a** | **HL=**  **K.Q 1.85a** | **lHL/Qal** |
|  | inl/sec | incumecs | d inm | d4.87 |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| DC | (+)20 | +0.020 | 0.20 | 3.95  X10-4 | 500 | 2690 | 7.2X10-  4 | +1.94 | 97 |
| CF | (+)28 | +0.028 | 0.15 | 9.7X10- | 300 | 6580 | 1.34 | +8.80 | 314 |
| FE | (-)8 | -0.008 | 0.15 | 5 | 500 | 10940 | X10-3 | -1.47 | 184 |
| ED | (-)5 | -0.005 | 0.15 | 9.7X10-  5 | 300 | 6580 | 1.34  X10-4 | -0.37 | 74 |
|  |  |  |  | 9.7X10- |  |  | 5.6X10- |  |  |
|  |  |  |  | 5 |  |  | 5 |  |  |
| S |  |  |  |  |  |  |  | +8.9 | 669 |

Forloop ABCD, wehaved=-SHL/x.SlHL/Qal

=(-)+8.9/(1.85 X669) cumecs

=(-) (+8.9 X1000)/(1.85X669)) l/s

=-7.2l/s

Hence,correctedflowsafterfirstcorrectionare:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Pipe | | | DC | CF | FE | ED |
| Corrected | flows | after | + | + | - | - |

### WaterQuality

The raw or treated water is analysed by testing their physical, chemical and bacteriologicalcharacteristics:

#### PhysicalCharacteristics:

TurbidityColour

Taste and OdourTemperature

#### ChemicalCharacteristics:

pHAcidityAlkalinityHardnessChloridesSulphatesIronSolidsNitrates

#### BacteriologicalCharacteristics:

Bacterial examination of water is very important, since it indicates the degree of pollution. Waterpolluted by sewage contain one or more species of disease producing pathogenic bacteria.Pathogenic organisms cause water borne diseases, and many non pathogenic bacteria such as***E.Coli***, a member of coliform group, also live in the intestinal tract of human beings. ***Coliform***itselfis not a harmful group but it has more resistance to adverse condition than any othergroup. So, if it is ensured to minimize the number of coliforms, the harmful species will be veryless.So,coliformgroupservesasindicatorofcontaminationofwaterwithsewageandpresenceofpathogens.

Themethodstoestimatethebacterialqualityofwaterare:

StandardPlateCountTestMostProbableNumberMembraneFilterTechnique

**IndianStandardsfordrinkingwater**

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Desirable-Tolerable** | ***If no alternative sourceavailable, limit extendedupto*** |

|  |  |  |
| --- | --- | --- |
| **Physical** | | |
| Turbidity(NTUunit) | <10 | 25 |
| Colour(Hazenscale) | <10 | 50 |
| TasteandOdour | Un-objectionable | Un-objectionable |
| **Chemical** | | |
| pH | 7.0-8.5 | 6.5-9.2 |
| TotalDissolved Solidsmg/l | 500-1500 | 3000 |
| TotalHardnessmg/l (as CaCO3) | 200-300 | 600 |
| Chlorides mg/l(asCl) | 200-250 | 1000 |
| Sulphatesmg/l (asSO4) | 150-200 | 400 |
| Fluoridesmg/l(asF) | 0.6-1.2 | 1.5 |
| Nitratesmg/l (asNO3) | 45 | 45 |
| Calciummg/l (asCa) | 75 | 200 |
| Ironmg/l(asFe ) | 0.1-0.3 | 1.0 |

**ModuleII**

The typical functions of each unit operations are given in the following table:FunctionsofWaterTreatmentUnits

|  |  |
| --- | --- |
| **Unittreatment** | **Function(removal)** |
| Aeration,  chemicalsuse | Colour, Odour,Taste |
| Screening | Floatingmatter |
| Chemicalmethods | Iron,Manganese,etc. |
| Softening | Hardness |
| Sedimentation | Suspended matter |
| Coagulation | Suspendedmatter, a partofcolloidal matterandbacteria |
| Filtration | Remainingcolloidaldissolvedmatter,bacteria |
| Disinfection | Pathogenic bacteria, Organic matterandReducingsubstances |

Thetypesof treatmentrequiredfordifferent sourcesaregivenin thefollowingtable:

|  |  |
| --- | --- |
| **Source** | **Treatmentrequired** |
| 1.Groundwaterandspringwaterfairlyfreefromcontamination | Notreatment orChlorination |
| 2. Ground water with chemicals, minerals andgases | Aeration, coagulation (ifnecessary), filtration and  disinfection |
| 3.Lakes,surfacewaterreservoirs with lessamount ofpollution | Disinfection |
| 4. Other surface waters such as rivers, canalsandimpoundedreservoirswithaconsiderableamount ofpollution | Completetreatment |

### Aeration

* Aerationremovesodour andtastesduetovolatile gaseslikehydrogensulphideandduetoalgaeand relatedorganisms.
* Aeration also oxidise iron and manganese, increases dissolved oxygen content in water,removesCO2andreducescorrosionandremovesmethaneandotherflammablegases.
* Principle of treatment underlines on the fact that volatile gases in water escape intoatmosphere from the air-water interface and atmospheric oxygen takes their place inwater, provided the water body can expose itself over a vast surface to the atmosphere.This process continues until an equilibrium is reached depending on the partial pressureofeach specificgasin the atmosphere.

### TypesofAerators

1. Gravityaerators
2. Fountain aerators
3. Diffusedaerators
4. Mechanicalaerators.

**Gravity Aerators (Cascades):** In gravity aerators, water is allowed to fall by gravity such that alargeareaofwateris exposedto atmosphere,sometimesaidedbyturbulence.

**Fountain Aerators:** These are also known as spray aerators with special nozzles to produce afine spray. Each nozzle is 2.5 to 4 cm diameter discharging about 18 to 36 l/h. Nozzle spacingshouldbesuchthateach m3ofwaterhas aeratorareaof0.03 to0.09m2foronehour.

**Injection or Diffused Aerators:** It consists of a tank with perforated pipes, tubes or diffuserplates, fixed at the bottom to release fine air bubbles from compressor unit. The tank depth iskept as 3 to 4 m and tank width is within 1.5 times its depth. If depth is more, the diffusers mustbe placed at 3 to 4 m depth below water surface. Time of aeration is 10 to 30 min and 0.2 to 0.4litresofairisrequired for 1litre ofwater.

**MechanicalAerators:** Mixingpaddlesasinflocculationareused.Paddlesmay beeithersubmerged oratthesurface.

### Settling

Solidliquidseparationprocessinwhichasuspensionisseparatedintotwophases–

* Clarifiedsupernatantleavingthetopof thesedimentationtank(overflow).
* Concentratedsludgeleavingthe bottomofthesedimentationtank(underflow).

#### PurposeofSettling

* Toremovecoarsedispersedphase.
* Toremovecoagulatedandflocculatedimpurities.
* Toremoveprecipitatedimpuritiesafterchemicaltreatment.
* Tosettlethesludge(biomass)afteractivated sludgeprocess/trickingfilters.

#### PrincipleofSettling

* Suspendedsolids presentin waterhavingspecificgravitygreater thanthatofwater tendtosettle downbygravity assoonastheturbulenceisretardedbyofferingstorage.
* Basin inwhich theflowisretardediscalled***settlingtank***.
* Theoreticalaveragetimeforwhichthewaterisdetainedinthesettlingtankiscalledthe

***detentionperiod***.

#### Types ofSettling

Type I: ***Discrete particle settling*** - Particles settle individually without interaction withneighboringparticles.

TypeII:***FlocculentParticles***–Flocculationcausestheparticlestoincreaseinmassandsettleat afasterrate.

Type III: ***Hindered or Zone settling*** –The mass of particles tends to settle as a unit withindividual particles remaining in fixed positions with respect to each other.TypeIV:***Compression***–Theconcentrationofparticlesissohighthatsedimentationcanonlyoccurthroughcompactionofthestructure.

#### TypeISettling

* Size,shapeand specificgravityoftheparticles donot change withtime.
* Settling velocityremainsconstant.

Ifaparticle issuspendedin water,itinitiallyhastwoforces actinguponit:

***forceofgravity***: Fg=ρpgVp

***Buoyantforce***quantified by Archimedesas: Fb=ρgVp

Ifthedensityoftheparticle differsfrom thatof the water,anet forceisexertedand theparticleisaccelaratd inthedirectionoftheforce:Fnet=(ρp-ρ)gVp

Thisnet forcebecomesthedrivingforce.

Once the motion has been initiated, a third force is created due to viscous friction. This force,calledthe***dragforce***,isquantifiedby:Fd=CDApρv2/2

CD= dragcoefficient.

Ap =projectedareaof theparticle.

Because the drag force acts in the opposite direction to the driving force and increases as thesquare of the velocity, accelaration occurs at a decreasing rate until a steady velocity is reachedata pointwherethedrag forceequalsthe driving

force:

(ρp-ρ)gVp=CDApρv2/2Forspherical particles,Vp=∏d3/6and Ap=∏d2/4

Thus,v2=4g(ρp-ρ)d

3CDρ

Expressions for CD change with characteristics of different flow regimes. For laminar, transition,andturbulentflow,thevaluesofCDare:

CD = 24 (laminar)Re

CD=0.4(turbulent)

where ReistheReynoldsnumber:

Re=ρvd

μ

Reynolds number less than 1.0 indicate laminar flow, while values greater than 10 indicateturbulentflow.Intermediatevaluesindicatetransitionalflow.

#### StokesFlow

For laminarflow,terminalsettlingvelocityequation becomes:

v=(ρp-ρ

)gd218μ

whichis knownasthe ***stokesequation***.

#### TransitionFlow

Needtosolve non-linearequations:

v2=4g(ρp-ρ)d

Re=ρvd

μ

* Calculatevelocityusing Stokeslaworturbulentexpression.
* CalculateandcheckReynoldsnumber.
* Calculate CD.
* Use generalformula.
* Repeat fromstep2untilconvergence.

#### TypesofSettlingTanks

* Sedimentation tanks may function either intermittently or continuously. The intermittenttanks also called quiescent type tanks are those which store water for a certain periodand keep it in complete rest. In a continuous flow type tank, the flow velocity is onlyreducedandthewaterisnotbroughttocompleterestasis donein anintermittenttype.
* Settlingbasinsmaybeeitherlongrectangularorcircularinplan.Longnarrowrectangular tanks with horizontal flow are generally preferred to the circular tanks withradialorspiralflow.

#### LongRectangularSettlingBasin

* Long rectangular basins are hydraulically more stable, and flow control for large volumesiseasierwiththisconfiguration.
* A typicallongrectangular tankhavelengthranging from 2to4 timestheirwidth.Thebottomisslightlyslopedtofacilitatesludgescraping.Aslowmovingmechanicalsludge

scraper continuously pulls the settled material into a sludge hopper from where it ispumpedoutperiodically.

**Drag ofsedimentationtank**

Alongrectangular settlingtankcanbedividedintofourdifferentfunctional zones:

***Inlet zone:*** Region in which the flow is uniformly distributed over the cross section such that theflowthroughsettlingzone followshorizontalpath.

***Settlingzone:***Settlingoccursunderquiescent conditions.

***Outletzone:***Clarified effluentis collectedanddischargethroughoutletweir.

***Sludgezone:***Forcollection ofsludgebelowsettlingzone.

#### InletandOutletArrangement

***Inletdevices:***Inletsshallbedesignedtodistributethewaterequallyandatuniformvelocities.A baffle should be constructed across the basin close to the inlet and should project several feetbelowthewatersurfacetodissipateinletvelocitiesandprovideuniformflow;

***Outlet Devices:*** Outlet weirs or submerged orifices shall be designed to maintain velocitiessuitableforsettlinginthebasinandtominimizeshort-circuiting.Weirsshallbeadjustable,andat least equivalent in length to the perimeter of the tank. However, peripheral weirs are notacceptableastheytendtocauseexcessiveshort-circuiting.

#### WeirOverflowRates

Large weir overflow rates result in excessive velocities at the outlet. These velocities extendbackward into the settling zone, causing particles and flocs to be drawn into the outlet. Weirloadings are generally used upto 300 m3/d/m. It may be necessary to provide special inboardweirdesigns as showntolowertheweiroverflow rates.

#### InboardWeir Arrangement toIncreaseWeirLength



***CircularBasins***

* Circularsettlingbasinshavethesamefunctionalzonesasthelongrectangularbasin,but the flow regime is different. When the flow enters at the center and is baffled to flowradiallytowardstheperimeter,thehorizontalvelocityofthewateriscontinuously

decreasingasthedistancefromthecenterincreases.Thus,theparticlepathinacircular basin is a parabola as opposed to the straight line path in the long rectangulartank.

* Sludgeremovalmechanismsincirculartanksaresimplerand require lessmaintenance.

#### SettlingOperations

* Particlesfalling throughthesettling basinhavetwocomponentsofvelocity:
  1. Verticalcomponent:vt=(ρp-ρ)gd2

18μ

* 1. Horizontalcomponent:vh=Q/A

The path of the particle is given by the vector sum of horizontal velocity vh and verticalsettlingvelocityvt.

* Assume that a settling column is suspended in the flow of the settling zone and that thecolumn travels with the flow across the settling zone. Consider the particle in the batchanalysis for type-1 settlingwhich was initially atthe surface and settled through thedepth of the column Z0, in the time t0. If t0 also corresponds to the time required for thecolumntobecarriedhorizontallyacrossthesettlingzone,thentheparticlewillfallintothe sludge zone and be removed from the suspension at the point at which the columnreaches theendofthesettlingzone.
* All particles with vt>v0 will be removed from suspension at some point along the settlingzone.
* Now consider the particle with settling velocity < v0. If the initial depth of this particle wassuchthatZp/vt=t0,thisparticlewillalsoberemoved.Therefore,theremovalofsuspended particles passing through the settling zone will be in proportion to the ratio oftheindividualsettlingvelocitiestothe settlingvelocityv0.
* Thetimet0correspondsto theretentiontimein thesettlingzone.
* t= V=LZ0W
* Q

Q

Therefore, Z0 = LZ0Wand v0=Q

v0 Q LW

orv0=Q

AS

Thus, the depth of the basin is not a factor in determining the size particle that can be removedcompletelyinthesettlingzone.ThedeterminingfactoristhequantityQ/As,whichhastheunitsof velocity and is referred to as the overflow rate q0. This overflow rate is the design factor forsettling basins and corresponds to the terminal setting velocity of the particle that is 100%removed.

#### DesignDetails

1. Detention period: for plain sedimentation: 3 to 4 h, and for coagulated sedimentation: 2to2.5h.
2. Velocityof flow:Notgreaterthan30cm/min(horizontalflow).
3. Tankdimensions:L:B=3to5:1.Generally L=30 m(common)maximum100m.Breadth=6mto 10 m.Circular:Diameternotgreaterthan 60 m. generally20to 40m.

4.Depth 2.5 to5.0m(3m).

1. SurfaceOverflowRate:Forplainsedimentation12000to18000L/d/m2tankarea;forthoroughlyflocculatedwater24000to30000 L/d/m2tankarea.
2. Slopes:Rectangular1%towardsinletandcircular8%.

## SedimentationTank Design

## Problem: Design a rectangular sedimentation tank to treat 2.4 million litres of raw water perday.The detentionperiodmay beassumedtobe3hours.

## Solution: Rawwaterflowperdayis2.4x 106l.Detentionperiodis3h.Volumeoftank=FlowxDetentionperiod=2.4 x103x 3/24=300 m3Assumedepthoftank=3.0m.

## Surfacearea =300/3 = 100m2L/B=3(assumed).L=3B.

## 3B2=100m2i.e.B=5.8mL=3B=5.8X3 =17.4m

## Hence surfaceloading(Overflowrate) =2.4x 106=24,000l/d/m2<40,000 l/d/m2(OK)

## 100

#### General PropertiesofColloids

1. Colloidalparticlesaresosmallthattheir***surfacearea***inrelationtomass isverylarge.
2. ***Electricalproperties***:Allcolloidalparticles areelectricallycharged.Ifelectrodesfroma

D.C. source are placed in a colloidal dispersion, the particles migrate towards the pole ofoppositecharge.

1. Colloidal particles are in constant motion because of bombardment by molecules ofdispersion medium. This motion is called ***Brownian motion*** (named after Robert Brownwhofirstnoticedit).
2. ***Tyndall effect:*** Colloidal particles have dimensioThese are reversible upon heating. e.g.organicsinwater.
3. ***Adsorption:*** Colloids have high surface area and hence have a lot of active surface foradsorption to occur. The stability of colloids is mainly due to preferential adsorption ofions.There aretwotypesofcolloids:
   1. Lyophobiccolloids:thataresolventhating.Theseareirreversibleuponheating.

e.g.inorganiccolloids,metalhalides.

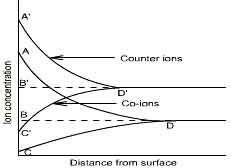
* 1. Lyophilic colloids:that are solvent loving. These are reversible upon heating. e.g.organicsinwater.

#### CoagulationandFlocculation

* Colloidal particles are difficult to separate from water because they do not settle bygravity andareso smallthattheypass throughtheporesoffiltrationmedia.
* Toberemoved,theindividualcolloids must aggregateandgrowinsize.
* The aggregation of colloidal particles can be considered as involving two separate anddistinctsteps:
  + 1. Particletransporttoeffectinterparticlecollision.
    2. Particledestabilizationtopermit attachment whencontactoccurs.

Transport step is known as ***flocculation*** whereas ***coagulation*** is the overall processinvolvingdestabilizationandtransport.

#### ElectricalDoubleLayer



Although individual hydrophobic colloids have an electrical charge, a colloidal dispersion doesnot have a net electrical charge. The diffuse layer in a colloidal dispersion contains a quantity ofcounter ions sufficient to balance the electrical charge on the particle. The charge distribution inthe diffuse layer of a negatively charged colloid can be represented by the curve ABCD in thefigure. The ions involved inthis electroneutrality are arranged in such a way as to constitutewhatiscalled***electricaldoublelayer***.

Net repulsion force, which may be considered as energy barrier must be overcome beforeaggregation occurs.Themagnitudeofenergy barrierdepends on(1) chargeontheparticle,and

1. ioniccomposition ofwater.



#### DestabilizationofColloidalDispersion

Particledestabilization can beachieved byfourmechanisms:

* + Changecharacteristicsofmedium-*Compressionofdoublelayer****.***
  + Changecharacteristics of colloidparticles-*Adsorptionandchargeneutralization*.
  + Providebridges-

1. *Enmeshmentinaprecipitate****.***
2. *Adsorptionandinterparticlebridging****.***

#### Flocculation

Flocculation is stimulation by mechanical means to agglomerate destabilised particles intocompact,fastsettleableparticles(orflocs).Flocculationorgentleagitationresultsfrom velocity

differences or gradients in the coagulated water, which causes the fine moving, destabilizedparticles to come into contact and become large, readily settleableflocs. It is a common practiceto provide an initial rapid (or) flash mix for the dispersal of the coagulant or other chemicals intothewater.Slowmixingisthendone,duringwhichthegrowthofthe floc takesplace.

***Rapid or Flash mixing*** is the process by which a coagulant is rapidly and uniformly dispersedthrough the mass of water. This process usually occurs in a small basin immediately precedingor at the head of the coagulation basin. Generally, the detention period is 30 to 60 seconds andthe head loss is20 to 60 cmsofwater.Here colloids aredestabilised and the nucleus for theflocisformed.

***Slow mixing*** brings the contacts between the finely divided destabilisedmatter formed duringrapidmixing.

#### PerikineticandOrthokineticFlocculation

Theflocculationprocesscan be broadlyclassifiedintotwotypes,perikinetic andorthokinetic.

Perikinetic flocculation refers to flocculation (contact or collisions of colloidal particles) due toBrownian motion of colloidal particles. The random motion of colloidal particles results from theirrapidandrandombombardmentby themoleculesofthefluid.

Orthokinetic flocculation refers to contacts or collisions of colloidal particles resulting from bulkfluid motion, such as stirring. In systems of stirring, the velocity of the fluid varies both spatially(from point to point) and temporally (from time to time). The spatial changes in velocity areidentified by a velocity gradient, G. G is estimated as G=(P/μV)1/2, where P=Power, V=channelvolume,andμ=Absolute viscosity.

#### MechanismofFlocculation

*Gravitational flocculation:* Baffle type mixing basins are examples of gravitational flocculation.Water flows by gravity and baffles are provided in the basins which induce the required velocitygradients forachievingflocformation.

*Mechanical flocculation:* Mechanical flocculator consists of revolving paddles with horizontal orvertical shaftsorpaddlessuspendedfromhorizontal oscillating beams,movingupanddown.

**CoagulationinWaterTreatment**

* + SaltsofAl(III)andFe(III) are commonlyused ascoagulantsinwater and wastewatertreatment.
  +  When a salt of Al(III) and Fe(III) is added to water, it dissociates to yield trivalent ions,which hydrate to form aquometal complexes Al(H2O) 3+ and Fe(H O) 3+.ThesecomplexesthenpassthroughaseriesofhydrolyticreactionsinwhichH2OmoleculesinthehydrationshellarereplacedbyOH-ionstoformavarietyofsolublespeciessuchasAl(OH)2+andAl(OH)2+.Theseproductsarequiteeffectiveascoagulantsastheyadsorbvery stronglyontothesurface ofmostnegativecolloids.

### DestabilizationusingAl(III)andFe(III)Salts

* + Al(III)andFe(III) accomplishdestabilizationbytwomechanisms:

(1)Adsorptionand chargeneutralization.(2)Enmeshmentin asweep floc.

* + InterrelationsbetweenpH,coagulantdosage,andcolloidconcentrationdeterminemechanismresponsibleforcoagulation.
  + Charge on hydrolysis products and precipitation of metal hydroxides are both controlledby pH.The hydrolysisproducts possess a positive charge atpH valuesbelow iso-electric point of the metal hydroxide. Negatively charged species which predominateaboveiso-electricpoint,areineffectiveforthedestabilizationofnegativelychargedcolloids.
  + Precipitationofamorphousmetal hydroxideis necessaryforsweep-floccoagulation.
  + ThesolubilityofAl(OH)3(s)andFe(OH)3(s)isminimalataparticularpHandincreasesas the pH increases or decreases from that value. Thus, pH must be controlled toestablishoptimumconditionsforcoagulation.

Alum and Ferric Chloride reacts with natural alkalinity inwateras follows:Al2(SO4)3.14H2O+6HCO3-2Al(OH)3(s)+6CO2 +14H2O+3 SO2-

* + FeCl3+3HCO3-Fe(OH)3(S)+3CO2+3Cl-

### JarTest

Thejartestisacommonlaboratoryprocedureusedtodeterminetheoptimumoperatingconditions for water or wastewater treatment. This method allows adjustments in pH, variationsin coagulant or polymer dose, alternating mixing speeds, or testing of different coagulant orpolymer types, on a small scale in order to predict the functioning of a large scale treatmentoperation.

### JarTestingApparatus

The jar testing apparatus consists of six paddles which stir the contents of six 1 liter containers.Onecontaineractsasacontrolwhiletheoperatingconditionscanbevariedamongtheremaining five containers. A rpm gage at the top-center of the device allows for the uniformcontrolofthe mixingspeedinallofthe containers.

### Jar Test Procedure

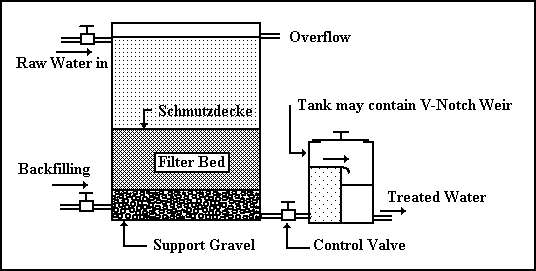
* + Thejar test proceduresinvolves the followingsteps:
  + Fill the jar testing apparatus containers with sample water. One container will be used asa control while the other 5 containers can be adjusted depending on what conditions arebeing tested. For example, the pH of the jars can be adjusted or variations of coagulantdosagescan beadded todetermineoptimumoperatingconditions.
  + Add the coagulant to each container and stir at approximately 100 rpm for 1 minute. Therapidmix stage helps todisperse thecoagulantthroughouteachcontainer.
  + Turnoffthemixersandallowthecontainerstosettlefor30to45minutes.Thenmeasure thefinal turbidityineachcontainer.
  + Reduce the stirring speed to 25 to 35 rpm and continue mixing for 15 to 20 minutes. Thisslower mixing speed helps promote floc formation by enhancing particle collisions whichleadtolarger flocs.
  + Residualturbidityvs.coagulantdoseisthenplottedandoptimalconditionsaredetermined. The values that are obtained through the experiment are correlated andadjusted inordertoaccountfor the actual treatmentsystem.

### Filtration

* + The resultant water after sedimentation will not be pure, and may contain some very finesuspended particles and bacteria in it. To remove or to reduce the remaining impuritiesstill further, the water is filtered through the beds of fine granular material, such as sand,etc. The process of passing the water through the beds of such granular materials isknownasFiltration.

### HowFiltersWork:FiltrationMechanisms

* + Therearefourbasic filtrationmechanisms:
  + ***SEDIMENTATION*** : The mechanism of sedimentation is due to force of gravity and theassociate settling velocity of the particle, which causes it to cross the streamlines andreach thecollector.
  + ***INTERCEPTION*** :Interceptionofparticlesiscommon forlargeparticles.Ifalargeenough particle follows the streamline, that lies very close to the media surface it will hitthemediagrain andbecaptured.
  + ***BROWNIANDIFFUSION***:Diffusiontowardsmediagranulesoccursforverysmallparticles, such as viruses. Particles move randomly about within the fluid, due to thermalgradients. This mechanism is only important for particles with diameters < 1 micron.***INERTIA*** :Attachment by inertiaoccurswhenlargerparticlesmove fastenough totravelofftheirstreamlinesandbumpinto mediagrains.



### FilterMaterials

***Sand:*** Sand, either fine or coarse, is generally used as filter media. The size of the sand ismeasured and expressed by the term called effective size. *The effective size*, i.e. D10 may bedefined as the size of the sieve in mm through which ten percent of the sample ofsand byweight will pass. The uniformity in size or degree of variations in sizes of particles is measuredandexpressed bythetermcalled*uniformitycoefficient*. Theuniformitycoefficient,i.e.(D60/D10)

may be defined as the ratio of the sieve size in mm through which 60 percent of the sample ofsandwillpass,tothe effectivesizeofthesand.

***Gravel:*** The layersofsand may be supported on gravel,which permitsthe filtered watertomovefreelytotheunder drains,and allowsthewashwatertomoveuniformlyupwards.

***Othermaterials:***Insteadofusingsand,sometimes,anthrafiltisusedasfiltermedia.Anthrafiltis made from anthracite, which is a type of coal-stone that burns without smoke or flames. It ischeaperand hasbeenabletogiveahigh rateoffiltration.

### TypesofFilter

***Slowsandfilter:***Theyconsistoffinesand,supportedbygravel.Theycaptureparticlesnearthe surface of the bed and are usually cleaned by scraping away the top layer of sand thatcontains the particles.

***Rapid-sand filter:*** They consist of larger sand grains supported by gravel and capture particlesthroughout the bed. They are cleaned by backwashing water through the bed to 'lift out' theparticles.

***Multimedia filters:*** They consist of two or more layers of different granular materials, withdifferent densities. Usually, anthracite coal, sand, and gravel are used. The different layerscombinedmayprovidemoreversatilecollectionthanasinglesandlayer.Becauseofthedifferencesindensities,thelayersstayneatly separated,evenafter backwashing.

### PrinciplesofSlowSandFiltration

* + In a slow sand filter impurities in the water are removed by a combination of processes:sedimentation,straining,adsorption,andchemicalandbacteriologicalaction.
  + During the first few days, water is purified mainly by mechanical and physical-chemicalprocesses. The resulting accumulation of sediment and organic matter forms a thin layeron the sand surface, which remains permeable and retains particles even smaller thanthespacesbetweenthe sandgrains.
  + As this layer (referred to as “Schmutzdecke”) develops, it becomes living quarters of vastnumbers of micro-organisms which break down organic material retained from the water,convertingitinto water,carbondioxideandother oxides.
  + Most impurities, including bacteria and viruses, are removed from the raw water as itpasses through the filter skin and the layer of filter bed sand just below. The purificationmechanismsextendfromthefilterskintoapprox.0.3-0.4mbelowthesurfaceofthefilter bed, gradually decreasing in activity at lower levels as the water becomes purifiedandcontains lessorganicmaterial.
  + When the micro-organisms become well established, the filter will work efficiently andproduce high quality effluent which is virtually free of disease carrying organisms andbiodegradableorganic matter.
  + They are suitable for treating waters with low colors, low turbidities and low bacterialcontents.

### SandFiltersvs. RapidSand Filters

* + ***Basematerial:***InSSFitvariesfrom3to65mminsizeand30to75cmindepthwhilein RSF it varies from 3 to 40 mm in size and its depth is slightly more, i.e. about 60 to 90cm.
  + ***Filter sand:*** In SSF the effective size ranges between 0.2 to 0.4 mm and uniformitycoefficientbetween1.8to2.5or3.0.InRSFtheeffectivesizerangesbetween0.35to

0.55anduniformitycoefficientbetween 1.2to1.8.

* + ***Rate of filtration:*** In SSF it is small, such as 100 to 200 L/h/sq.m. of filter area while inRSFitislarge,suchas3000to 6000L/h/sq.m.offilterarea.
  + ***Flexibility:*** SSF are not flexible for meeting variation in demand whereas RSF are quiteflexible formeetingreasonablevariationsindemand.
  + ***Post treatment required:*** Almost pure water is obtained from SSF. However, water maybedisinfected slightly tomakeitcompletely safe.DisinfectionisamustafterRSF.
  + ***Methodofcleaning:***Scrappingandremovingofthetop1.5to3cmthicklayerisdonetocleanSSF.TocleanRSF,sandisagitatedandbackwashedwithorwithoutcompressedair.
  + ***Loss of head:*** In case ofSSF approx. 10 cm is the initial loss, and 0.8 to 1.2m is thefinal limit when cleaning is required. For RSF 0.3m is the initial loss, and 2.5 to 3.5m isthefinallimitwhencleaningisrequired.

### CleanWaterHeadloss

Several equations have beendevelopedtodescribetheflowofcleanwater throughaporousmedium.Carman-Kozenyequationused tocalculatehead lossis as follows:

h=f (1-n)Lvs2

Φn3dg

f =150(1-n)+1.75

Ng

where, h=headloss, mf = friction factorn =porosity

Φ = particle shape factor (1.0 for spheres, 0.82 for rounded sand, 0.75 for average sand,0.73forcrushedcoaland angular sand)

L=depthoffilterbedorlayer,md=grainsizediameter,m

vs=superficial(approach)filtrationvelocity,m/sg=accelarationduetogravity,9.81m/s2

p=fractionofparticles(basedonmass)withinadjacentsievesizesdg=geometricmeandiameterbetweensievesizesd1andd2

Ng=Reynoldsnumber

μ=viscosity,N-s/m2

### BackwashingofRapidSand Filter

* + For a filter to operate efficiently, it must be cleaned before the next filter run. If the waterapplied to a filter is of very good quality, the filter runs can be very long. Some filters canoperate longer than one week before needing to be backwashed. However, this is notrecommended as long filter runs can cause the filter media to pack down so that it isdifficulttoexpand thebedduringthe backwash.
  + Treatedwaterfromstorageisusedforthebackwashcycle.Thistreatedwaterisgenerallytakenfromelevatedstoragetanksorpumpedinfromthe clearwell.
  + The filter backwash rate has to be great enough to expand and agitate the filter mediaand suspend the floc in the water for removal. However, if the filter backwash rate is toohigh,mediawillbewashed fromthefilterintothetroughs andoutofthefilter.

### Whenis BackwashingNeeded

Thefiltershouldbebackwashedwhen thefollowingconditionshavebeenmet:

* + The head loss is so high that the filter no longer produces water at the desired rate;and/orFlocstartstobreakthroughthefilterandtheturbidityinthefiltereffluentincreases; and/orAfilterrun reachesagivenhourofoperation.

### Operational TroublesinRapidGravityFilters

#### AirBinding:

* + When the filter is newly commissioned, the loss of head of water percolating through thefilter is generally very small. However, the loss of head goes on increasing as more andmore impuritiesgettrappedintoit.
  + Astageisfinallyreachedwhenthefrictionalresistanceofferedbythefiltermediaexceeds the static head of water above the and bed. Most of this resistance is offered bythetop10to15cmsandlayer.Thebottomsandactslikeavacuum,andwaterissuckedthrough thefiltermediaratherthangetting filteredthroughit.
  + The negative pressure so developed, tends to release the dissolved air and other gasespresent in water. The formation of bubbles takes place which stick to the sand grains.ThisphenomenonisknownasAirBindingastheairbindsthefilterandstopsitsfunctioning.
  + To avoid such troubles, the filters are cleaned as soon as the head loss exceeds theoptimum allowablevalue.

#### FormationofMudBalls:

* + The mud from the atmosphere usually accumulates on the sand surface to form a densemat. During inadequate washing this mud may sink down into the sand bed and stick tothesandgrainsandotherarrestedimpurities,therebyformingmudballs.

#### CrackingofFilters:

* + Thefinesandcontainedinthetoplayersofthefilterbedshrinksandcausesthedevelopment of shrinkage cracks in the sand bed. With the use of filter, the loss of headand, therefore, pressure on thesand bed goes on increasing, which further goes onwideningthesecracks.

### RemedialMeasurestoPrevent Crackingof FiltersandFormationofMudBalls

* + Breakingthetopfinemud layerwith rakes andwashingoff theparticles.
  + Washing thefilterwithasolution ofcaustic soda.
  + Removing, cleaningandreplacingthedamagedfiltersand.

**Standard design practice of Rapid Sand filter:** Maximum length of lateral = not less than 60times its diameter. Spacing of holes = 6 mm holes at 7.5 cm c/c or 13 at 15 c/c. C.S area oflateral = not less than 2 times area of perforations. C.S area of manifold = 2 times total area oflaterals. Maximum loss of head = 2 to 5 m. Spacing of laterals = 15 to 30 cm c/c. Pressure ofwash water at perforations = not greater than 1.05 kg/cm2. Velocity of flow in lateral = 2 m/s.Velocityofflowinmanifold=2.25m/s.Velocityofflowinmanifoldforwashwater=1.8to2.5m/s. Velocity of rising washwater= 0.5 to 1.0 m/min. Amount of washwater = 0.2 to 0.4% of totalfiltered water. Time of backwashing = 10 to 15 min. Head of water over the filter = 1.5 to 2.5 m.Freeboard=60 cm.Bottomslope =1to60towardsmanifold.

Q=(1.71xbxh3/2)

whereQisinm3/s,bisinm,hisin m.L:B=1.25 to1.33:1.

#### RapidSandFilterDesign

**Problem:**Designarapidsandfiltertotreat10millionlitresofrawwaterperdayallowing0.5%of filtered water for backwashing. Half hour per day is used for bakwashing. Assume necessarydata.

**Solution:**Totalfilteredwater=10.05x24x106=0.42766Ml/h

24x23.5

Letthe rate offiltrationbe5000l /h / m2ofbed.Areaoffilter=10.05x106x1=85.5m2

23.5 5000

Providetwounits.Eachbedarea85.5/2=42.77.L/B =1.3;1.3B2=42.77B=5.75 m;L=5.75x1.3=7.5m

Assumedepthofsand=50to75cm.Underdrainagesystem:

Totalarea ofholes =0.2 to0.5%ofbedarea.Assume0.2%ofbed area=0.2x42.77 =0.086m2

100

Area oflateral = 2(Areaofholes oflateral)Areaofmanifold=2(Areaoflaterals)

So,areaofmanifold=4xareaofholes=4 x0.086=0.344 =0.35m2.Diameter ofmanifold=(4x0.35/П)1/2=66 cm

Assumec/c oflateral =30cm.Total numbers =7.5/0.3 =25oneitherside.Lengthoflateral =5.75/2-0.66/2=2.545m.

C.S.areaoflateral=2x areaofperforationsperlateral.Takediaofholes =13mm

Numberofholes:nП(1.3)2=0.086x 104=860cm2

4

n=4x860=648,say 650

Spacingofholes=2.545/13=19.5cm.

C.S.areaoflateral=2 x areaofperforationsperlateral=2 x 17.24 =34.5cm2.Diameter oflateral =(4x34.5/П)1/2=6.63cm

Check:Lengthoflateral<60d=60x 6.63 =3.98 m.l=2.545m(Henceacceptable).Risingwashwatervelocityinbed=50cm/min.

Washwaterdischargeperbed =(0.5/60)x5.75 x7.5=0.36 m3/s.Velocity offlowthroughlateral= 0.36 =0.36x104 =2.08 m/s(ok)

Totallateral area 50x34.5Manifoldvelocity=0.36=1.04m/s<2.25 m/s(ok)

0.345

Washwatergutter

Dischargeofwashwaterperbed=0.36m3/s.Sizeofbed =7.5x5.75m.Assume3 troughsrunninglengthwiseat5.75/3=1.9 mc/c.

Dischargeofeachtrough=Q/3=0.36/3 =0.12 m3/s.

Q =1.71 x b x h3/2Assumeb =0.3m

h3/2=0.12=0.234

1.71x0.3

h=0.378m=37.8 cm=40cm

=40 +(free board)5 cm =45 cm;slope1in 40Clearwaterreservoirforbackwashing

For4hfiltercapacity,Capacity oftank=4x5000x 7.5x 5.75x 2=1725 m3

1000

Assumedepthd=5 m.Surfacearea=1725/5= 345m2L/B=2;2B2=345;B =13m&L =26 m.

Dia ofinletpipecomingfrom twofilter = 50cm.

Velocity<0.6m/s.Diameter ofwashwaterpipetooverhead tank= 67.5cm.Aircompressorunit=1000lofair/ min/m2bed area.

For5 min,airrequired =1000x5x7.5x5.77x2 =4.32m3ofair.

### Disinfection

The filtered water may normally contain some harmful disease producing bacteria in it. Thesebacteria must be killed in order to make the water safe for drinking. The process of killing thesebacteriaisknownasDisinfectionorSterilization.

### DisinfectionKinetics

When a single unit of microorganisms is exposed to a single unit of disinfectant, the reduction inmicroorganismsfollowsafirst-orderreaction.

dN/dt=-kN N=N0e-kt

ThisequationisknownasChick‟sLaw:-

N = number of microorganism (N0 is initial number)k=disinfection constant

t=contacttime

### MethodsofDisinfection

1. ***Boiling:*** The bacteria present in water can be destroyed by boiling it for a long time.However it is not practically possible to boil huge amounts of water. Moreover it cannottakecareoffuturepossible contaminations.
2. ***Treatment with Excess Lime:*** Lime is used in water treatment plant for softening. But ifexcess lime is added to the water, it can in addition, kill the bacteria also. Lime whenadded raises the pH value o water making it extremely alkaline. This extreme alkalinityhas been found detrimental to the survival of bacteria. This method needs the removal ofexcess lime from the water before it can be supplied to the general public. Treatment likerecarbonationforlime removalshouldbeused after disinfection.
3. ***Treament with Ozone:*** Ozone readily breaks down into normal oxygen, and releasesnascent oxygen. The nascent oxygen is a powerful oxidising agent and removes theorganicmatteraswellasthe bacteriafromthewater.
4. ***Chlorination:*** The germicidal action of chlorine is explained by the recent theory of*Enzymatic hypothesis*, according to which the chlorine enters the cell walls of bacteriaandkilltheenzymeswhichareessential forthemetabolicprocesses oflivingorganisms.

### ChlorineChemistry

Chlorine is added to the water supply in two ways. It is most often added as a gas, Cl2(g).However, it also can be added as a salt, such as sodium hypochlorite (NaOCl) or bleach.Chlorinegas dissolvesinwaterfollowingHenry'sLaw.

Cl2(g)Cl2(aq)KH=6.2x10-2

Oncedissolved,thefollowingreactionoccursforminghypochlorousacid(HOCl):Cl2(aq)+H2OHOCl+H++Cl-

Hypochlorousacid isaweakacid that dissociates toformhypochloriteion(OCl-).

HOCl OCl-+H+Ka=3.2 x10-8

Allformsofchlorinearemeasuredasmg/LofCl2(MW=2x35.45=70.9g/mol)Hypochlorous acid andhypochlorite ioncompose whatiscalled thefree chlorine residual.These free chlorine compounds can react with many organic and inorganic compounds to formchlorinated compounds. If the products of these reactions posses oxidizing potential, they areconsidered the combined chlorine residual. A common compound in drinking water systems thatreacts with chlorine to form combined residual is ammonia. Reactions between ammonia andchlorineformchloramines,whichismainlymonochloramine(NH2Cl),althoughsomedichloramine (NHCl2) and trichloramine (NCl3) also can form. Many drinking water utilities usemonochloramine as a disinfectant. If excess free chlorine exits once all ammonia nitrogen hasbeenconvertedtomonochloramine,chloraminespeciesareoxidizedthroughwhatistermedthe breakpoint reactions. The overall reactions of free chlorine and nitrogen can be representedbytwosimplifiedreactionsasfollows:

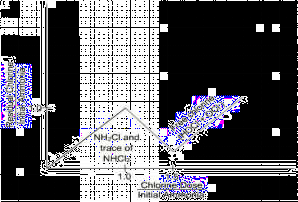
Monochloramine Formation Reaction. This reaction occurs rapidly when ammonia nitrogen iscombinedwithfreechlorineup toa molarratioof1:1.

HOCl+NH3 NH2Cl+HOCl

**Breakpoint Reaction**: When excess free chlorine is added beyond the 1:1 initial molar ratio,monochloramineisremovedasfollows:

2NH2Cl+HOClN2(g)+3H++3Cl-+H2O

The formation of chloramines and the breakpoint reaction create a unique relationship betweenchlorinedoseandthe amountand formofchlorineasillustratedbelow.



### FreeChlorine, Chloramine,and AmmoniaNitrogenReactions

**ChlorineDemand**

Freechlorineandchloraminesreadilyreactwithavarietycompounds,includingorganicsubstances, and inorganic substances like iron and manganese. The stoichiometry of chlorinereactions withorganicscanbe representedasshownbelow:

### HOCl:



**OCl-:**



1/10C5H7O2N +HOCl 4/10CO2+1/10HCO3-+1/10NH4++H++ Cl-+1/10H2O

1/10C5H7O2N + OCl- 4/10CO2+1/10HCO3-+1/10NH4++Cl-+1/10H2O

### NH2Cl:



1/10C5H7O2N +NH2Cl+ 9/10H2O4/10CO2+1/10HCO3-+11/10NH4++Cl-

Chlorine demand can be increased by oxidation reactions with inorganics, such as reduced ironat corrosion sites at the pipe wall. Possible reactions with all forms of chlorine and iron are asfollows:

### TreatmentPlantLayoutandSiting

***Plant layout*** is the arrangement of designed treatment units on the selected site. ***Siting*** is theselection of site for treatment plant based on features as character, topography, and shoreline.Site development should take the advantage of the existing site topography. The followingprinciplesareimportanttoconsider:

1. A site on a side-hill can facilitate gravity flow that will reduce pumping requirements andlocatenormalsequence ofunitswithoutexcessiveexcavationorfill.
2. When landscaping is utilized it should reflect the character of the surrounding area. Sitedevelopment should alter existing naturally stabilized site contours and drainage as littleaspossible.
3. Thedevelopedsiteshouldbecompatiblewiththeexistinglandusesandthecomprehensivedevelopmentplan.

### TreatmentPlantHydraulics

***Hydraulicprofile***isthegraphicalrepresentationofthehydraulicgradelinethroughthetreatment plant. The head loss computations are started in the direction of flow using watersurface in the influent of first treatment unit as the reference level. The ***total available head*** atthe treatment plant is the difference in water surface elevations in the influent of first treatmentunit and that in the effluent of last treatment unit. If the total available head is less than the headloss through the plant, flow by gravity cannot be achieved. In such cases pumping is needed toraisethe headsothat flow by gravitycanoccur.

There are many basic principles that must be considered when preparing the hydraulic profilethroughthe plant.Somearelisted below:

1. Thehydraulicprofilesare preparedatpeakandaverage designflowsandat minimuminitialflow.
2. Thehydraulicprofileisgenerally preparedforallmain pathsof flowthroughtheplant.
3. Theheadlossthroughthetreatment plantisthesumofheadlosses inthetreatmentunitsandthe connecting pipingand appurtenances.
4. Theheadlossesthroughthe treatmentunitincludethefollowing:
   1. Headlossesatthe influentstructure.
   2. Headlossesattheeffluentstructure.
   3. Headlossesthroughtheunit.
   4. Miscellaneous andfreefall surfaceallowance.
5. Thetotal loss throughtheconnecting pipings,channelsandappurtenances is thesumoffollowing:
   1. Head lossdue toentrance.
   2. Head lossdue toexit.
   3. Head lossduetocontractionandenlargement.
   4. Head lossduetofriction.
   5. Head lossduetobends,fittings, gates,valves,andmeters.
   6. Headrequiredoverweirandotherhydraulic controls.
   7. Free-fallsurfaceallowance.

### WastewaterQuantityEstimation

Theflowofsanitarysewagealoneintheabsenceofstormsindryseasonisknownasdryweatherflow (DWF).

### Quantity=Per capitasewagecontributedper dayxPopulation

Sanitary sewage is mostly the spent water of the community draining into the sewer system. Ithas been observed that a small portion of spent water is lost in evaporation, seepage in ground,leakage,etc.Usually 80%ofthewatersupply may beexpectedto reachthesewers.

### FluctuationsinDryWeather Flow

Since dry weather flow depends on the quantity of water used, and as there are fluctuations inrate of water consumption, there will be fluctuations indry weather flow also. In general, it canbe assumed that (i) Maximum daily flow = 2x average daily flow and (ii) Minimum daily flow =2/3x(averagedailyflow).

### PopulationEquivalent

Population equivalent is a parameter used in the conversion of contribution of wastes fromindustrial establishments for accepting into sanitary sewer systems. The strength of industrialsewageis,thus,writtenas

Std.BOD5= (Std. BOD5ofdomesticsewage per personperday)x(population equivalent)

### DesignPeriods&PopulationForecast

This quantity should be worked out with due provision for the estimated requirements of thefuture. The future period for which a provision is made in the water supply scheme is known asthe **design period**. It is suggested that the construction of sewage treatment plant may becarried out in phases with an initial design period ranging from 5 to 10 years excluding theconstructionperiod.

Designperiod is estimatedbased onthefollowing:

* Usefullifeofthe component,consideringobsolescence,wear,tears,etc.
* Expandabilityaspect.
* Anticipated rate of growth of population, including industrial, commercial developments &migration-immigration.
* Availableresources.
* Performanceofthesystemduring initial period.

### Populationforecastingmethods:

The various methods adopted for estimating future populations are given below. The particularmethod to be adopted for a particular case or for a particular city depends largely on the factorsdiscussed in the methods, and the selection is left to the discretion and intelligence of thedesigner.

1. *ArithmeticIncreaseMethod*
2. *GeometricIncreaseMethod*
3. *IncrementalIncreaseMethod*
4. *DecreasingRateofGrowthMethod*
5. *SimpleGraphicalMethod*
6. *ComparativeGraphicalMethod*
7. *Ratio Method*
8. *Logistic CurveMethod*

### WastewaterCharacterization

To design a treatment process properly, characterization of wastewater is perhaps the mostcritical step. Wastewater characteristics of importance in the design of the activated sludgeprocess canbegroupedintothefollowingcategories:

TemperaturepH

ColourandOdourCarbonaceous substratesNitrogen

PhosphorousChlorides

Total and volatile suspended solids (TSS and VSS)Toxicmetalsand compounds

### DesignofSewers

Thehydraulicdesignofsewersanddrains,whichmeans findingouttheirsectionsandgradients,isgenerallycarried outonthesame linesasthatofthewater supplypipes.However,

there are two major differences between characteristics of flows in sewers and water supplypipes.Theyare:

* The sewage contain particles in suspension, the heavier of which may settle down at thebottom of the sewers, as and when the flow velocity reduces, resulting in the clogging ofsewers. To avoid silting of sewers, it is necessary that the sewer pipes be laid at such agradient, as togenerate selfcleansingvelocitiesatdifferentpossibledischarges.
* The sewer pipes carry sewage as gravity conduits, and are therefore laid at a continuousgradient in the downward direction upto the outfall point, from where it will be lifted up,treatedand disposedof.

Hazen-William'sformula;U=0.85Cr0.63S0.54

H

Manning'sformula: U=1/nrH2/3S1/2

where, U=velocity,m/s;rH= hydraulic radius,m;S=slope,C=Hazen-William'scoefficient, andn

=Manning'scoefficient.

Darcy-Weisbachformula: hL= (fLU2)/(2gd)

### MinimumVelocity

The flow velocity in the sewers should be such that the suspended materials in sewage do notget silted up; i.e. the velocity should be such as to cause automatic self-cleansing effect. Thegeneration ofsuch a minimum*self cleansing velocity* in the sewer,atleastonce a day, isimportant, because if certain deposition takes place and is not removed, it will obstruct free flow,causingfurtherdepositionand finally leadingto thecompleteblockingofthesewer.

### MaximumVelocity

The smooth interior surface of a sewer pipe gets scoured due to continuous abrasion caused bythesuspendedsolidspresentinsewage.Itis,therefore,necessarytolimitthemaximumvelocity in the sewer pipe. This limiting or non-scouring velocity will mainly depend upon thematerialofthesewer.

### EffectsofFlowVariationonVelocityinaSewer

Due to variation in discharge, the depth of flow varies, and hence the hydraulic mean depth (r)varies. Due to the change in the hydraulic mean depth, the flow velocity (which depends directlyon r2/3) gets affected from time to time. It is necessary to check the sewer for maintaining aminimum velocity of about 0.45 m/s at the time of minimum flow (assumed to be 1/3rd of averageflow). The designer should also ensure that a velocity of 0.9 m/s is developed atleast at the timeof maximum flow and preferably during the average flow periods also. Moreover, care should betaken to see that at the time of maximum flow, the velocity generated does not exceed thescouringvalue.

### SewerAppurtenances

Sewer appurtenances are the various accessories on the sewerage system and are necessaryfor the efficient operation of the system. They include man holes, lamp holes, street inlets, catchbasins,inverted siphons,andsoon.

**Man-holes:**Manholesaretheopeningsofeithercircularorrectangularinshapeconstructedon the alignment of a sewer line to enable a person to enter the sewer for inspection, cleaningand flushing. They serve as ventilators for sewers, by the provisions of perforated man-holecovers.Also theyfacilitatethelayingofsewerlinesinconvenientlength.

Man-holes are provided at all junctions of two or more sewers, whenever diameter of sewerchanges, whenever direction of sewer line changes and when sewers of different elevations jointogether.

### SpecialMan-holes:

Junction chambers: Man-holeconstructed at the intersectionoftwo largesewers.

Dropman-hole:Whenthedifferenceinelevationoftheinvertlevelsoftheincomingandoutgoing sewers of the man-hole is more than 60 cm, the interception is made by dropping theincomingsewerverticallyoutsideandthenitisjointed totheman-holechamber.

Flushing man-holes: They are located at the head of a sewer to flush out the deposits in thesewerwithwater.

**Lamp-holes:** Lamp holes are the openings constructed on the straight sewer lines between twoman-holes which are far apart and permit the insertion of a lamp into the sewer to find outobstructionsifanyinsidethe sewersfromthenextman-hole.

**Streetinlets:**Streetinletsaretheopeningsthroughwhichstormwaterisadmittedandconveyedtothestormsewerorcombinedsewer.Theinletsarelocatedbythesidesofpavementwithmaximumspacingof30 m.

**Catch Basins:** Catch basins are small settling chambers of diameter 60 - 90 cm and 60 - 75 cmdeep, which are constructed below the street inlets. They interrupt the velocity of storm waterentering through the inlets and allow grit, sand, debris and so on to settle in the basin, instead ofallowingthem toenterintothe sewers.

**Inverted siphons:** Thesearedepressed portionsofsewers,whichflow fullunderpressuremore than the atmospheric pressure due to flow line being below the hydraulic grade line. Theyare constructed when a sewer crosses a stream or deep cut or road or railway line. To clean thesiphon pipe sluice valve is opened, thus increasing the head causing flow. Due to increasedvelocitydepositsofsiphonpipeare washedinto thesump,fromwherethey areremoved.

### Pumpingof Sewage

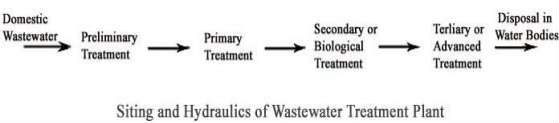
Pumpingofsewageisrequiredwhenitisnotpossibletohaveagravitationalflowfortheentiresewerageproject.

Sufficientpumpingcapacityhastobeprovided tomeet thepeakflow,atleast50%asstand by.

### Typesofpumps:

1. Centrifugalpumpseitheraxial,mixedandradialflow.
2. Pneumaticejector pumps.

The raw sewage must be treated before it is discharged into the river stream. The extent oftreatment required to be given depends not only upon the characteristics and quality of thesewage but also upon the source of disposal, its quality and capacity to tolerate the impuritiespresentinthesewageeffluentswithoutitselfgettingpotentiallypolluted.Thelayoutofconventionalwastewatertreatmentplantisasfollows:



Indian Standardsfordischarge ofsewagein surface watersaregiven in the table below.

### IndianStandardsforDischargeofSewageinSurfaceWaters

|  |  |
| --- | --- |
| **CharacteristicoftheEffluent** | **Tolerance *limit for Discharge of Sewage in SufaceWaterSources*** |
| BOD5 | 20mg/L |
| TSS | 30mg/L |

The unit operations and processes commonly employed in domestic wastewater treatment, theirfunctions andunitsusedtoachievethesefunctionsaregiveninthefollowingtable:

### UnitOperations/Processes,TheirFunctionsandUnitsUsedforDomesticWastewaterTreatment

|  |  |  |
| --- | --- | --- |
| **UnitOperations/Processes** | **Functions** | **TreatmentDevices** |
| Screening | Removal of largefloating,suspendedand  settleablesolids | Bar racks and screens of variousdescription |
| GritRemoval | Removal of inorganic suspendedsolids | Grit chamber |
| PrimarySedimentation | Removal oforganic/inorganic  settleablesolids | Primarysedimentationtank |
| Aerobic BiologicalSuspended  GrowthProcess | Conversion ofcolloidal, dissolvedandresidualsuspendedorganicmatterintosettleablebioflocandstableinorganics | Activatedsludgeprocessunitsandits modifications, Waste stabilisationponds,Aeratedlagoons |
| AerobicBiologicalAttachedGrowthProcess | sameasabove | Tricklingfilter,Rotatingbiologicalcontactor |
| Anaerobicbiologicalgrowthprocesses | Conversion of organic matter intoCH4&CO2andrelativelystableorganicresidue | Anaerobicfilter,Fluidbedsubmerged media anaerobic reactor,Upflowanaerobicsludgeblanketreactor, Anaerobic rotating biologicalcontactor |
| AnaerobicStabilizationofOrganic Sludges | sameasabove | Anaerobicdigestor |

**Screening**

A screen is a device with openings for removing bigger suspended or floating matter in sewagewhich would otherwise damage equipment or interfere with satisfactory operation of treatmentunits.

### TypesofScreens

**Coarse Screens:** Coarse screens also called racks, are usually bar screens, composed ofvertical or inclined bars spaced at equal intervals across a channel through which sewage flows.Bar screens with relatively large openings of 75 to 150 mm are provided ahead of pumps, whilethoseahead ofsedimentationtankshavesmalleropeningsof50 mm.

Bar screens are usually hand cleaned and sometimes provided with mechanical devices. Thesecleaning devices are rakes which periodically sweep the entire screen removing the solids forfurther processing or disposal.

Hand cleaned racks are set usually at an angle of 45° to thehorizontal to increase the effective cleaning surface and also facilitate the raking operations.Mechanicalcleanedracksaregenerallyerectedalmostvertically.Suchbarscreenshaveopenings25%inexcessofthecross sectionofthesewagechannel.

**Medium Screens:** Medium screens have clear openings of 20 to 50 mm.Bar are usually 10 mmthick on the upstream side and taper slightly to the downstream side. The bars used for screensare rectangular in cross section usually about 10 x 50 mm, placed with larger dimension paralleltotheflow.

**Fine Screens:** Fine screens are mechanically cleaned devices using perforated plates, wovenwire cloth or very closely spaced bars with clear openings of less than 20 mm. Fine screens arenotnormally suitableforsewagebecauseofcloggingpossibilities.

Themostcommonly usedbartypescreenisshown infigure:

### Velocity

The velocity of flow ahead of and through the screen varies and affects its operation. The lowerthe velocity through the screen, the greater is the amount of screenings that would be removedfromsewage. However,thelowerthevelocity,the greaterwouldbetheamountofsolidsdeposited in the channel. Hence, the design velocity should be such as to permit 100% removalof material of certain size without undue depositions. Velocities of ***0.6 to 1.2 mps through theopen area for the peak flows*** have been used satisfactorily. Further, the velocity at low flows intheapproach channelshould***not belessthan0.3mps***toavoiddepositionofsolids.

### Head loss

Head loss varies with the quantity and nature of screenings allowed to accumulate betweencleanings. The head loss created by a clean screen may be calculated by considering the flowand the effective areas of screen openings, the latter being the sum of the vertical projections ofthe openings. The head loss through clean flat bar screens is calculated from the followingformula:

K=barshapefactor(2.42forsharpedgerectangularbar,1.83forrectangularbarwithsemicircle upstream, 1.79 for circular bar and 1.67 for rectangular bar with both u/s and d/s faceassemicircular).

W=maximumwidthofbaru/sofflow,m

b= minimumclearspacingbetween bars, m

hv=velocityheadofflowapproachingrack, m=v2/2gθ = angle ofinclinationofrackwith horizontal

Theheadlossthrough finescreenis givenbyh=(1/2g)(Q/CA)

where, h = head loss, mQ=discharge,m3/s

C = coefficient of discharge (typical value 0.6)A=effectivesubmerged openarea,m2

Thequantityofscreenings depends onthenatureofthewastewaterand thescreenopenings.

### EqualizationTanks

Theequalizationtanksareprovided(i)tobalancefluctuatingflowsorconcentrations,(ii)toassist self neutralization, or (iii) to even out the effect of a periodic "slug" discharge from a batchprocess.

### TypesofEqualizationTanks

Equalizationtanksaregenerallyofthreetypes:

1. Flowthroughtype
2. Intermittentflowtype
3. Variableinflow/constantdischargetype

Thesimple***flowthroughtype***equalizationtankismainlyusefulinassistingselfneutralizationor evening out of fluctuating concentrations, not for balancing of flows since a flow through typetankoncefilled, givesoutputequalto input.

Flow balancing and self-neutralization are both achieved by using two tanks, intermittently oneafter another. One tank is allowed to fill up after which it is checked for pH (or any otherparameter) and then allowed to empty out. The second tank goes through a similar routine.***Intermittentflowtype***tanksare economicfor small flows fromindustries.

When flows are large an equalization tank of such a size may have to be provided that ***inflowcan be variable while outflow is at a constant rate***,generallybyapump.Thecapacityrequiredisdeterminedfromaplotofthecumulativeinflowandaplotoftheconstantrateoutflow and measuring the gaps between the two plots. A factor of safety may be applied ifdesired.

Generally, ***detention time*** vary from 2 to 8 hours but may be even 12 hours or more in somecases. When larger detention times are required, the equalization unit is sometimes provided intheformoffacultativeaeratedlagoon.

### GritChambers

Grit chambers are basin to remove the inorganic particles to prevent damage to the pumps, andtopreventtheiraccumulationinsludgedigestors.

### Typesof GritChambers

Grit chambers are of two types: mechanically cleaned and manually cleaned. In ***mechanicallycleaned*** grit chamber, scraper blades collect the grit settled on the floor of the grit chamber. Thegritsocollectediselevatedtothegroundlevelbyseveralmechanismssuchasbucketelevators,jetpumpandairlift.Thegritwashingmechanismsarealsoofseveraldesignsmostof which are agitation devices using either water or air to produce washing action. ***Manuallycleaned*** grit chambers should be cleaned atleast once a week. The simplest method of cleaningisby meansof shovel.

### AeratedGritChamber

An aerated gritchamberconsistsofa standard spiral flow aeration tankprovided with airdiffusiontubesplacedononesideofthetank.Thegritparticlestendtosettledowntothebottom of the tank at rates dependant upon the particle size and the bottom velocity of roll of thespiral flow, which in turn depends on the rate of air diffusion through diffuser tubes and shape ofaeration tank. The heavier particles settle down whereas the lighter organic particles are carriedwithrollofthe spiralmotion.

### PrincipleofWorkingofGrit Chamber

Grit chambers are nothing but like sedimentation tanks, designed to separate theintendedheavier inorganic materials (specific gravity about 2.65) and to pass forward the lighter organicmaterials. Hence, the flow velocity should neither be too low as to cause the settling of lighterorganicmatter,norshould itbe too high asnotto cause the settlementofthe siltand gritpresent in the sewage. This velocity is called "differential sedimentation and differential scouringvelocity". The scouring velocity determines the optimum ***flow through velocity***. This may beexplained by the fact that the critical velocity of flow 'vc' beyond which particles of a certain sizeand density once settled, may be again introduced into the stream of flow. It should always beless than the scouring velocity of grit particles. The critical velocity of scour is given by Schield'sformula:

V=3to4.5 (g(Ss-1)d)1/2

A horizontal velocity of flow of 15 to 30 cm/sec is used at peak flows. This same velocity is to bemaintained at all fluctuation of flow to ensure that only organic solids and not the grit is scouredfromthebottom.

### Typesof VelocityControl Devices

1. Asutro weirin achannel ofrectangular crosssection,withfreefall downstream ofthechannel.
2. Aparabolic shapedchannelwith arectangularweir.
3. Arectangularshapedchannel with aparshallflume attheendwhich would also helpeasy flowmeasurement.

### DesignofGrit Chambers

**SettlingVelocity**

The settling velocity of discrete particles can be determined using appropriate equationdependingupon Reynoldsnumber.

* Stoke'slaw:v=g(Ss-1)d2
* 18μ

Stoke's lawholdsgoodforReynoldsnumber,Rebelow1.

Re=ρvd

μ

For grit particles of specific gravity 2.65 and liquid temperature at 10°C, μ =1.01 x 10-6m2/s. Thiscorresponds toparticlesofsizeless than0.1mm.

* Transition law: The design of grit chamber is based on removal of grit particles withminimum size of 0.15 mm and therefore Stoke's law is not applicable to determine thesettlingvelocityofgritparticles fordesignpurposes.

v2=4g(ρp-ρ)d3CDρ

where, CD= drag coefficient Transition flow conditions hold good for Reynolds number,Rebetween1and1000.In thisrangeCDcanbeapproximatedby

CD=18.5=18.5

R0.6(ρvd/μ )0.6

### PrimarySedimentation

Primarysedimentationinamunicipalwastewatertreatmentplantisgenerallyplainsedimentation withoutthe use ofchemicals.In treatingcertain industrialwastes chemicallyaided sedimentation may be involved. In either case, it constitutes ***flocculent settling***, and theparticles do not remain discrete as in the case of grit, but tend to agglomerate or coagulateduringsettling.Thus,theirdiameterkeepsincreasingandsettlementproceedsatanoverincreasingvelocity.Consequently,theytracea curvedprofile.

Thesettlingtankdesigninsuch casesdependsonboth***surfaceloading***and***detentiontime***.

Long tube settling tests can be performed in order to estimate specific value of surface loadingand detention time for desired efficiency of clarification for a given industrial wastewater usingrecommended methods of testing. Scale-up factors used in this case range from 1.25 to 1.75 fortheoverflowrate,andfrom1.5to2.0fordetentiontimewhenconvertinglaboratoryresultstotheprototypedesign.

For primary settling tanks treating municipal or domestic sewage, laboratory tests are generallynotnecessary,andrecommendeddesignvaluesgivenintablemaybeused.Usinganappropriate value ofsurface loadingfromtable,the required tankarea is computed.Knowingthe average depth, the detention time is then computed. Excessively high detention time (longerthan 2.5 h) must be avoided especially in warm climates where anaerobicity can be quicklyinduced.

**Designparametersforsettlingtank**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Typesofsettling | Overflowm3m2/day | rate | Solidsloadingkg/m2/day | | Depth | Detentiontime |
|  | Average | Peak | Average | Peak |  |  |
| Primarysettling only | 25-30 | 50-60 | - | - | 2.5-  3.5 | 2.0-2.5 |
| Primary settlingfollowed | 35-50 | 60- | - | - | 2.5- |  |
| bysecondarytreatment | 120 | 3.5 |
| Primary settlingwithactivated | 25-35 | 50-60 | - | - | 3.5-  4.5 | - |
| sludge return |  |  |  |  |  |  |
| Secondarysettlingfortricklingfilters | 15-25 | 40-50 | 70-120 | 190 | 2.5-  3.5 | 1.5-2.0 |
| Secondarysettlingforactivatedsludge(excludingextendedaeration) | 15-35 | 40-50 | 70-140 | 210 | 3.5-  4.5 | - |
| Secondary settling for extendedaeration | 8-15 | 25-35 | 25-120 | 170 | 3.5-  4.5 | - |

### ClassificationofMicroorganisms

1. ***NutritionalRequirements***:Onthebasisofchemicalformofcarbonrequired,microorganisms areclassifiedas
   1. Autotrophic:organismsthatuseCO2orHCO-astheirsolesourceofcarbon.
   2. Heterotrophic:organisms thatusecarbonfromorganiccompounds.

***Energy Requirements***: On the basis of energy source required, microorganisms areclassifiedas

.Phototrophs: organismsthatuselightastheirenergysource.

1. Chemotrophs: organisms that employ oxidation-reduction reactions to provideenergy. They are further classified on the basis of chemical compounds oxidized(i.e.,electrondonor)
   1. Chemoorganotrophs: Organisms that use complex organic molecules astheirelectrondonor.
   2. Chemoautotrophs: Organisms that use simple inorganic molecules suchashydrogen sulfideorammoniaastheirelectrondonor.

***TemperatureRange***:Onthebasisoftemperaturerangewithinwhichtheycanproliferate,microorganismsareclassifiedas

. Psychrophilic:organisms whosegrowthisoptimumwithin15 to30°C.

1. Mesophilic:organismswhosegrowthisoptimum within30 to45°C.
2. Thermophilic: organismswhosegrowthisoptimumwithin45 to70°C.

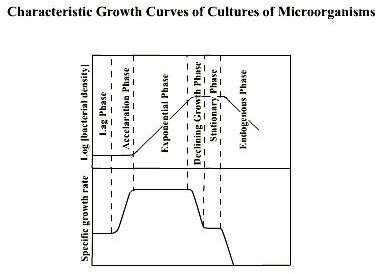
***OxygenRequirements***:Onthebasisofoxygenrequirementmicroorganismsareclassifiedas

.Aerobes: organismsthatusemolecularoxygenaselectronacceptor.

1. Anaerobes: organisms that use some molecule other than molecular oxygen aselectron acceptor.
2. Facultative organisms : organisms that can use either molecular oxygen or someotherchemical compoundaselectronacceptor.

### GrowthPatternofMicroorganisms

When a small number of viable bacterial cells are placed in a close vessel containing excessivefood supply in a suitable environment, conditions are established in which unrestricted growthtakes place. However, growth of an organism do not go on indefinitely, and after a characteristicsize is reached, the cell divides due to hereditary and internal limitations. The growth rate mayfollowapatternsimilarto asshowninfigure



Thecurveshown maybedivided intosixwell definedphases:

1. *LagPhase*:adaptation tonew environment,longgenerationtime andnull growthrate.
2. *Accelarationphase*:decreasinggenerationtimeandincreasing growthrate.
3. *Exponentialphase*:minimalandconstantgenerationtime,maximalandconstantspecific growthrateand maximumrateofsubstrateconversion.
4. *Declining growth phase*: increasing generation time and decreasing specific growth ratedue to gradual decrease in substrate concentration and increased accumulation of toxicmetabolites.
5. *Stationary phase*: exaustion of nutrients, high concentration of toxic metabolites, andcellsinastateofsuspendedanimation.
6. *Endogenousphase*: endogenousmetabolism,highdeathrate andcelllysis.

### BiomassGrowth Rate

Themostwidely used expressionforthegrowthrateof microorganismsisgivenbyMonod:

Totalrateofmicrobial growth,dx=μmXS

dt Ks+S

where,

μm=maximum specificgrowthrateX=microorganismconcentrationS=substrateconcentration

Ks=substrate concentrationat one halfthemaximum growthrateSimilarly,rateofsubstrateutilization,

dS= k X SdtKs+S

where,

k =maximumspecificsubstrateutilizationrate

### MaintenanceasEndogenousRespiration

Net growth rate of micro organisms is computed by subtracting from the total growth rate, therate of micro organisms endogenously decayed to satisfy maintenance energy requirement.Therefore,

Netrateofmicrobialgrowth=μmX S-kdX

Ks+S

where,kd=endogenousdecaycoefficient

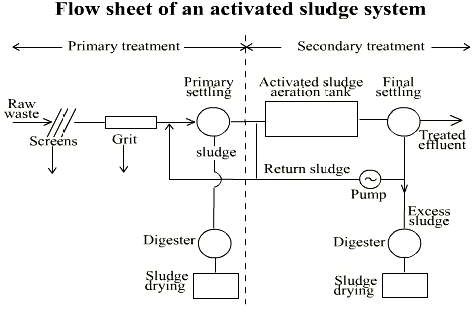
### GrowthYield

Growth yield is defined as the incremental increase in biomass which results from the utilizationoftheincremental amountofsubstrate.Themaximum specificgrowthrateisgivenby:m=Y.k

where, Y is the maximum yield coefficient and is defined as the ratio of maximum mass of cellsformed to the massofsubstrate utilized.The coefficientsY, kd, kand Ksaredesignated askinetic coefficients. The values of kinetic coefficients depend upon the nature of wastewater andoperational and environmental conditions in biological reactor. The biological reactors can becompletely mixed flow orplug flow reactorwithor withoutrecycle.

### ActivatedSludgeProcess

The most common suspended growth process used for municipal wastewater treatment is theactivatedsludge processasshownin figure:



Activatedsludgeplantinvolves:

1. wastewateraerationinthepresenceofamicrobialsuspension,
2. solid-liquidseparationfollowingaeration,
3. dischargeof clarifiedeffluent,
4. wastingofexcess biomass,and
5. return of remainingbiomass tothe aerationtank.

Inactivatedsludgeprocesswastewatercontainingorganicmatterisaeratedinanaerationbasin in which micro-organisms metabolize the suspended and soluble organic matter. Part oforganic matter is synthesized into new cells and part is oxidized to CO2 and water to deriveenergy. In activated sludge systems the new cells formed in the reaction are removed from theliquid stream in the form of a flocculent sludge in settling tanks. A part of this settled biomass,described as activated sludge is returned to the aeration tank and the remaining forms waste orexcesssludge.

### ActivatedSludgeProcessVariables

The main variables of activated sludge process are the mixing regime, loading rate, and the flowscheme.

### MixingRegime

Generally two types of mixing regimes are of major interest in activated sludge process: ***plugflow*** and ***complete mixing***. In the first one, the regime is characterized by orderly flow of mixedliquor through the aeration tank with no element of mixed liquor overtaking or mixing with anyotherelement.Theremaybelateralmixingofmixedliquorbuttheremustbenomixingalongthepathof flow.

In complete mixing, the contents of aeration tank are well stirred and uniform throughout. Thus,atsteadystate,theeffluentfromtheaerationtankhasthesamecompositionastheaerationtankcontents.

The type of mixing regime is very important as it affects (1) oxygen transfer requirements in theaeration tank, (2) susceptibility of biomass to shock loads, (3) local environmental conditions intheaerationtank,and(4)the kineticsgoverningthetreatmentprocess.

### LoadingRate

A loadingparameterthathasbeendevelopedovertheyearsis the***hydraulicretentiontime***

(HRT),θ,d

θ=V

Q

V=volumeofaerationtank, m3,and Q= sewageinflow,m3/d

Another empirical loading parameter is ***volumetric organic loading*** which is defined as theBODappliedperunitvolumeofaerationtank,perday.

Arational loadingparameter which hasfoundwideracceptanceand ispreferredis***specificsubstrateutilizationrate***,q,perday.

q=Q(SO-Se)VX

A similar loading parameter is ***mean cell residence time*** or ***sludge retention time*** (SRT), θc, dθc=V X

QwXr +(Q-QwXe)

where SO and Se are influent and effluent organic matter concentration respectively, measuredas BOD5 (g/m3), X,Xe and Xr are MLSS concentration in aeration tank,effluentand returnsludge respectively,andQw=wasteactivatedsludgerate.

Understeadystate operationthemassofwaste activatedsludgeis givenby

QwXr=YQ(SO-Se)-kdXV

whereY=maximumyieldcoefficient(microbialmasssynthesized/massofsubstrateutilized)and kd=endogenousdecay rate(d-1).

Fromtheaboveequationitis seen that1/θc =Yq-kd

IfthevalueofSeis smallascomparedSO,qmayalsobeexpressedas***FoodtoMicroorganismratio***, F/M

F/M =Q(SO-Se)/ XV =QSO/ XV

The θc value adopted for design controls the effluent quality, and settleability and drainability ofbiomass,oxygenrequirementand quantityofwasteactivatedsludge.

### FlowScheme

Theflow schemeinvolves:

* the patternofsewageaddition
* the pattern ofsludgereturntotheaerationtankand
* the patternofaeration.

Sewage addition may be at a single point at the inlet end or it may be at several points along theaeration tank. The sludge return may be directly from the settling tank to the aeration tank orthrough a sludge reaeration tank. Aeration may be at a uniform rate or it may be varied from theheadofthe aeration tankto itsend.

### ConventionalSystemanditsModifications

Theconventionalsystemmaintainsaplugflowhydraulicregime.Overtheyears,severalmodificationstotheconventionalsystemhavebeendevelopedtomeetspecifictreatmentobjectives. In ***step aeration*** settled sewage is introduced at several points along the tank lengthwhichproducesmoreuniformoxygendemandthroughout.***Taperedaeration***attemptstosupply air to match oxygen demand along the length of the tank. ***Contact stabilization*** providesfor reaeration of return activated sludge from from the final clarifier, which allows a smalleraerationorcontacttank.***Completely mixed*** processaimsatinstantaneousmixingoftheinfluent waste and return sludge with the entire contents of the aeration tank. Extended aerationprocessoperatesataloworganicload producinglesserquantity ofwellstabilizedsludge.

### DesignConsideration

Theitemsforconsiderationinthedesignofactivatedsludgeplantareaerationtankcapacityand dimensions, aeration facilities, secondary sludge settling and recycle and excess sludgewasting.

### AerationTank

The**volume ofaerationtank**iscalculatedfor theselected valueofcbyassumingasuitablevalueofMLSSconcentration,X.

VX =YQθc(SO -S)

1+kdθc

Alternately, the tank capacity may be designed fromF/M =QSO/XV

Hence, the **first step** in designing is to choose a suitable value of θ***c (or F/M***) which depends ontheexpectedwintertemperatureofmixedliquor,thetypeofreactor,expectedsettlingcharacteristics of the sludge and the nitrification required. The choice generally lies between 5days in warmer climates to 10 days in temperate ones where nitrification is desired alongwithgoodBOD removal,and completemixingsystemsare employed.

The**secondstep**istoselecttwointerrelatedparameters***HRT,tandMLSSconcentration***.Itis seen that economy in reactor volume can be achieved by assuming a large value of X.However, it is seldom taken to be more than 5000 g/m3. For typical domestic sewage, the MLSSvalue of 2000-3000 mg/l if conventional plug flow type aeration system is provided, or 3000-5000 mg/l for completely mixed types. Considerations which govern the upper limit are: initialand running cost of sludge recirculation system to maintain a high value of MLSS, limitations ofoxygen transfer equipment to supply oxygen at required rate in small reactor volume, increasedsolids loading on secondary clarifier which may necessitate a larger surface area, design criteriafor the tankandminimumHRTfortheaerationtank.

The **length** of the tank depends upon the type of activated sludge plant. Except in the case ofextended aeration plants and completely mixed plants, the aeration tanks are designed as longnarrow channels. The **width** and **depth** of the aeration tank depends on the type of aerationequipmentemployed.The depth controltheaerationefficiency andusuallyrangesfrom3 to4.5

m. The width controls the mixing and is usually kept between 5 to 10 m. **Width-depth ratio**should be adjusted to be between 1.2 to 2.2. The length should not be less than 30 or notordinarily longerthan100m.

### OxygenRequirements

Oxygen is reqiured in the activated sludge process for the oxidation of a part of the influentorganic matter and also for the endogenous respiration of the micro-organisms in the system.Thetotaloxygenrequirementofthe process may be formulated asfollows:

O2required (g/d)= Q(SO -S)-1.42QwXr

*f*

where,f=ratioofBOD5toultimateBODand1.42=oxygendemandofbiomass (g/g)

Theformula doesnotallowfornitrification butallowsonlyfor carbonaceous BODremoval.

### AerationFacilities

The aeration facilities ofthe activated sludge plantaredesigned to provide the calculatedoxygendemandofthewastewateragainstaspecificlevelofdissolvedoxygeninthewastewater.

### SecondarySettling

Secondarysettlingtanks,whichreceivethebiologicallytreatedflowundergozoneorcompression settling. ***Zone settling*** occurs beyond a certain concentration when the particlesare close enough together that interparticulate forces may hold the particles fixed relative to oneanothersothatthewholemasstendstosettleasasinglelayeror"blanket"ofsludge.Therateat which a sludge blanket settles can be determined by timingits position in a settlingcolumntestwhoseresultscan beplotted as shownin figure.

***Compression settling*** may occur at the bottom of a tank if particles are in such a concentrationas to be in physical contact with one another. The weight of particles is partly supported by thelower layers of particles, leading to progressively greater compression with depth and thickeningof sludge. From the settling column test, the limiting solids flux required to reach any desiredunderflowconcentrationcanbeestimated,from whichtherquiredtankareacanbecomputed.

Thesolidsloadonthe clarifierisestimated in termsof(Q+R)X, whiletheoverflow rateorsurface loading is estimated in terms of flow Q only (not Q+R) since the quantity R is withdrawnfrom the bottom and does not contribute to the overflow from the tank. The secondary settlingtank is particularly sensitive to fluctuations in flow rate and on this account it is recommendedthat the units be designed not only for average overflow rate but also for peak overflow rates.Beyond an MLSS concentration of 2000 mg/l the clarifier design is often controlled by the solidsloading rate rather than the overflow rate. Recommended design values for treating domesticsewageinfinalclarifiersandmechanicalthickeners(whichalsofallinthiscategoryofcompressionsettling)aregiveninlecture22.

### SludgeRecycle

The MLSS concentration in the aeration tank is controlled by the sludge recirculation rate andthesludge settleability andthickeningin the secondary sedimentationtank.

Qr = XQ Xr

whereQr= Sludgerecirculationrate, m3/d

The sludge settleability is determined by sludge volume index (SVI) defined as volume occupiedin mL by one gram of solids in the mixed liquor after settling for 30 min. If it is assumed thatsedimentation of suspended solids in the laboratory is similar to that in sedimentation tank, thenXr = 106/SVI. Values of SVI between 100 and 150 ml/g indicate good settling of suspendedsolids. The Xr value may not be taken more than 10,000 g/m3 unless separate thickeners areprovided to concentrate the settled solids or secondary sedimentation tank is designed to yield ahighervalue.

### ExcessSludgeWasting

The sludge in the aeration tank has to be wasted to maintain a steady level of MLSS in thesystem.TheexcesssludgequantitywillincreasewithincreasingF/Manddecreasewithincreasing temperature. Excess sludge may be wasted either from the sludge return line ordirectlyfromtheaerationtankasmixedliquor.Thelatterispreferredasthesludgeconcentration is fairly steady in that case. The excess sludge generated under steady stateoperationmay beestimated by

θc = VXQwXr

orQwXr=YQ(SO-S)-kdXV

### DesignofCompletelyMixedActivatedSludgeSystem

Design a completely mixed activated sludge system to serve 60000 people that will give a finaleffluent that is nitrified and has 5-day BOD not exceeding 25 mg/l. The following design data isavailable.

Sewage flow =150l/person-day=9000m3/dayBOD5=54g/person-day=360mg/l ;BODu=

1.47 BOD5Total kjeldahlnitrogen (TKN) = 8 g/person-day = 53 mg/lPhosphorus = 2 g/person-day = 13.3 mg/l Winter temperature in aeration tank = 18°C Yieldcoefficient Y = 0.6 ; Decay constant Kd = 0.07 per day ; Specific substrate utilization rate = 0.038mg/l)-1 (h)-1 at 18°C Assume 30% raw BOD5 is removed in primary sedimentation, and BOD5goingtoaeration is,therefore,252 mg/l(0.7x360mg/l).

Design:

1. ***Selectionof***θ***c,tandMLSSconcentration*:**

Considering the operating temperature and the desire to have nitrification and good sludgesettling characteristics, adopt θc = 5d. As there is no special fear of toxic inflows, the HRT, t maybekeptbetween3-4 h,andMLSS=4000 mg/l.

#### EffluentBOD5:

Substrateconcentration,S=1 (1/θc+kd)= 1(1/5+0.07)

(0.038)(0.6)

S=12mg/l.

Assume suspended solids(SS)ineffluent=20mg/landVSS/SS=0.8.

If degradable fraction of volatile suspended solids (VSS) =0.7 (check later), BOD5 of VSS ineffluent=0.7(0.8x20)=11mg/l.

Thus,totaleffluentBOD5=12+11=23 mg/l(acceptable).

#### AerationTank:

VX=YQθc(SO -S)whereX=0.8(4000)=3200mg/l1+kdθc

or3200V=(0.6)(5)(9000)(252-12)

[1 +(0.07)(5)]

V=1500m3

Detentiontime,t=1500x24=4h

9000

F/M=(252-12)(9000)=0.45 kgBOD5perkgMLSSperday(3200)(1500)

Let theaeration tankbeintheformoffoursquareshaped compartmentsoperated intwoparallelrows,eachwithtwocellsmeasuring11mx11mx3.1m

#### ReturnSludgePumping:

Ifsuspendedsolids concentrationofreturnflowis1% = 10,000mg/lR= MLSS=0.67

(10000)-MLSS

Qr=0.67x9000=6000m3/d

#### SurplusSludgeProduction:

Net VSS produced QwXr = VX = (3200)(1500)(103/106) = 960 kg/dθc (5)

orSSproduced =960/0.8=1200 kg/d

If SS are removed as underflow with solids concentration 1% and assuming specific gravity ofsludgeas1.0,

Liquidsludgetoberemoved=1200x100/1 =120,000kg/d=120m3/d

#### OxygenRequirement:

Forcarbonaceousdemand,

oxygenrequired= (BODuremoved) - (BODuof solids leaving)

=1.47 (2160kg/d)-1.42(960kg/d)

=72.5kg/h

Fornitrification, oxygenrequired= 4.33(TKN oxidized,kg/d)

Incoming TKNat8.0g/person-day =480kg/day.Assume30%is removedinprimarysedimentation andthe balance 336kg/dayis oxidizedtonitrates.Thus,oxygen required

=4.33x336=1455kg/day =60.6kg/h

Totaloxygenrequired =72.5+60.6=133kg/h= 1.0 kg/kgofBODuremoved.Oxygenuptakerate per unittankvolume=133/1500 = 90.6mg/h/ltankvolume

#### PowerRequirement:

Assume oxygenation capacity of aerators at field conditions is only 70% of the capacity atstandard conditions and mechanical aerators are capable of giving 2 kg oxygen per kWh atstandardconditions.

Powerrequired =136 =97kW(130hp)

0.7x2

=(97x24x 365)/60,000=14.2kWh/year/person

### TheoryofAeration

Aeration is a gas-liquid mass transfer process in which the driving force in the liquid phase is theconcentrationgradient(Cs-C)forslightly solublegases.

Mass transferperunittime =KL.a (Cs-C)where,KL=Liquid filmcoefficient

=Diffusion coefficient of liquid (D)Thickness offilm(Y)

a=Interficialarea perunitvolume

Cs=saturationconcentrationatthegas-liquidinterfaceandC= somelowervalueinthebody oftheliquid.

The value of a increases as finer and finer droplets are formed, thus increasing the gas transfer.However, in practice, it is not possible to measure this area and hence the overall coefficient(KL.a)perunittime,isdeterminedby experimentation.

### AdjustmentforFieldConditions

Theoxygentransfercapacityunder field conditionscanbecalculatedfrom thestandardoxygentransfercapacityby theformula:

N =[Ns(Cs- CL)x 1.024T-20α]/9.2

where,

N =oxygentransferredunderfield conditions,kgO2/h.

Ns=oxygentransfercapacityunderstandardconditions, kg O2/h.Cs=DO saturationvaluefor sewage atoperatingtemperature.

CL=operating DO level in aerationtankusually1to2mg/L.T= Temperature,degree C.

α=Correctionfactor foroxygen transferforsewage,usually0.8to0.85.

### AerationFacilities

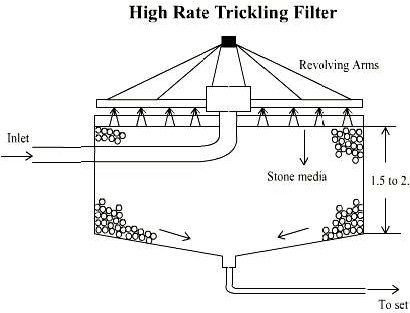
* Oxygenmaybesuppliedeitherbysurfaceaeratorsordiffusedaeratorsemployingfineorcoarsediffusers.
* Theaerationdevicesapartfromsupplyingtherequiredoxygenshallalsoprovideadequate mixingin order thatthe entire MLSS present in the aeration tankwill beavailableforbiologicalactivity.
* Aerators are rated based on the amount of oxygen they can transfer to tap water understandardconditions of20°C,760mmHgbarometricpressureandzeroDO.

### TricklingFilters

* Trickling filter is an ***attached growth process*** i.e. process in which microorganismsresponsible for treatmentareattached to aninertpackingmaterial.Packingmaterialused in attached growth processes include rock, gravel, slag, sand, redwood, and a widerangeofplastic andothersyntheticmaterials.

### ProcessDescription

* The wastewater in trickling filter is distributed over the top area of a vessel containingnon-submergedpackingmaterial.
* Air circulation in the void space, by either natural draft or blowers,provides oxygen forthemicroorganismsgrowingasanattachedbiofilm.
* During operation, the organic material present in the wastewater is metabolised by thebiomass attached to the medium. The biological slime grows in thickness as the organicmatter abstracted from theflowingwastewateris synthesizedintonewcellularmaterial.
* The thickness of the aerobic layer is limited by the depth of penetration ofoxygen intothemicrobiallayer.
* Themicro-organismsnearthemediumfaceentertheendogenousphaseasthesubstrate is metabolised before it can reach the micro-organisms near the medium faceas a result of increased thickness of the slime layer and loose their ability to cling to themedia surface. The liquid then washes the slime off the medium and a new slime layerstartsto grow.Thisphenomenonoflosingtheslimelayeriscalled***sloughing***.
* The sloughed off film and treated wastewater are collected by an underdrainage whichalso allows circulation of air through filter. The collected liquid is passed to a settling tankused forsolid-liquidseparation.



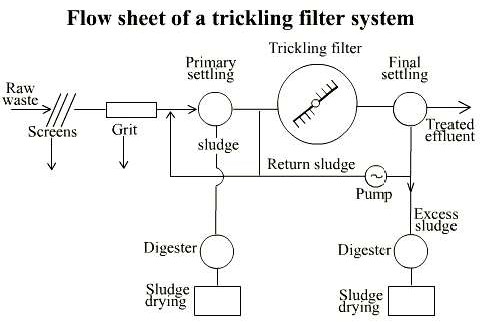
### TypesofFilters

Trickling filters are classified as high rate or low rate, based on the organic and hydraulicloadingappliedto theunit.

|  |  |  |  |
| --- | --- | --- | --- |
| S.No. | Design Feature | Low RateFilter | HighRateFilter |
| 1. | Hydraulic  loading,m3/m2.d | 1-4 | 10-40 |
| 2. | Organic  loading,kgBOD/m3.d | 0.08-0.32 | 0.32 -1.0 |
| 3. | Depth,m. | 1.8 -3.0 | 0.9-2.5 |
| 4. | Recirculationratio | 0 | 0.5 -3.0 (domesticwastewater)upto8forstrongindustrialwastewater. |

* The hydraulic loading rate is the total flow including recirculation appied on unit area ofthe filter in a day, while the organic loading rate is the 5 day 20°C BOD, excluding theBODofthe recirculant,appliedperunitvolumein aday.
* Recirculationisgenerallynotadoptedinlow ratefilters.
* A well operated low rate trickling filter in combination with secondary settling tank mayremove 75 to 90% BOD and produce highly nitrified effluent. It is suitable for treatment oflowtomediumstrengthdomesticwastewaters.
* The high rate trickling filter, single stage or two stage are recommended for medium torelatively high strength domestic and industrial wastewater. The BOD removal efficiencyisaround75 to90%buttheeffluentisonly partiallynitrified.
* Single stage unit consists of a primary settling tank, filter, secondary settling tank andfacilities for recirculation of the effluent. Two stage filters consist of two filters in serieswith a primary settling tank, an intermediate settling tank which may be omitted in certaincasesand afinal settlingtank.

### Process Design



Generally trickling filter design is based on empirical relationships to find the required filtervolume for adesigned degreeofwastewatertreatment. Typesofequations:

* 1. NRCequations(NationalResearchCouncilofUSA)
  2. Rankinsequation
  3. Eckenfilderequation
  4. Galler andGotaasequation

NRC and Rankin's equations are commonly used. NRC equations give satisfactory values whenthere is no re-circulation, the seasonal variations in temperature are not large and fluctuationswithhighorganicloading.Rankin'sequationisusedforhigh ratefilters.

***NRC equations*:** These equations are applicable to both low rate and high rate filters. Theefficiencyofsinglestageor firststage oftwostage filters,E2isgivenby

E2=100

1+0.44(*F1.BOD*/V1.Rf1)1/2

For thesecondstage filter, theefficiencyE3isgivenby

E3= 100 [(1+0.44)/(1-

E2)](*F2.BOD*/V2.Rf2)1/2

where E2= % efficiency in BOD removal of single stage or first stage of two-stage filter, E3=%efficiency of second stage filter, *F1.BOD*= BOD loading of settled raw sewage in single stage of thetwo-stage filter in kg/d, *F2.BOD*= *F1.BOD*(1- E2)= BOD loading on second-stage filter in kg/d, V1=volume of first stage filter, m3; V2= volume of second stage filter, m3; Rf1= Recirculation factor forfirst stage, R1= Recirculation ratio for first stage filter, Rf2= Recirculation factor for second stage,R2=Recirculationratioforsecond stagefilter.

**Rankins equation:** This equation also known as Tentative Method of Ten States USA has beensuccessfullyusedoverwiderangeoftemperature.Itrequiresfollowingconditionstobeobservedforsinglestage filters:

1. Rawsettleddomesticsewage BOD appliedtofiltersshouldnot exceed1.2kgBOD*5*/day/m3filtervolume.
2. Hydraulicload(includingrecirculation) shouldnotexceed30m3/m2filtersurface-day.

Recirculation ratio (R/Q) should be such that BOD entering filter (including recirculation) is notmore than three times the BOD expected in effluent. This implies that as long as the aboveconditionsare satisfiedefficiency isonly a functionofrecirculation andis givenby:

E=(R/Q)+1(R/Q)+1.5

### Other AerobicTreatmentUnits

1. ***Stabilization ponds***: The stabilization ponds are open flow through basins specificallydesigned and constructed to treat sewage and biodegradable industrial wastes. Theyprovidelongdetentionperiodsextendingfromafewtoseveraldays.
2. ***Aeratedlagoons***:Pondsystems,inwhichoxygenisprovidedthroughmechanicalaeration ratherthanalgal photosynthesis arecalledaeratedlagoons.
3. ***Oxidationditch***:Theoxidationditchisamodifiedformof"extendedaeration"ofactivated sludge process. The ditch consists of a long continuous channel oval in shapewithtwosurface rotorsplacedacross thechannel.

### AnaerobicTreatment

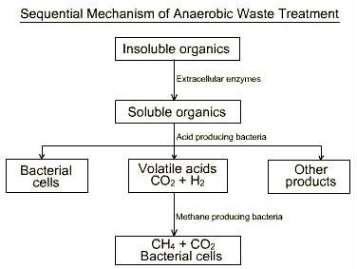
Theanaerobicwastetreatmentprocessisaneffectivemethodforthetreatmentofmanyorganic wastes. The treatment has a number of advantages over aerobic treatment process,namely,

* theenergy inputofthesystemislowasnoenergyisrequredforoxygenation,
* lower production ofexcesssludge(biologicalsynthesis) perunitmassofsubstrateutilized,
* lower nutrientrequirementduetolower biologicalsynthesis, and
* degradationleadstoproductionofbiogas which is avaluable sourceofenergy.

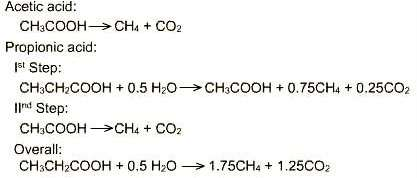
### FundamentalMicrobiology

The anaerobic treatment of organic wastes resulting in the production of carbon dioxide andmethane, involves two distinct stages. In the first stage, complex waste components, includingfats, proteins, and polysaccharides are first hydrolyzed by a heterogeneous group of facultativeandanaerobicbacteria.These bacteriathensubject the productsofhydrolysistofermentations,

-oxidations,andothermetabolicprocessesleadingtotheformationofsimpleorganiccompounds,mainlyshort-chain(volatile)acidsandalcohols.Thefirststageiscommonlyreferred to as "***acid fermentation***". However in the second stage the end products of the firststage are converted to gases (mainly methane and carbon dioxide) by several different speciesofstrictlyanaerobicbacteria. This stageisgenerally referredtoas"***methanefermentation***".



The primary acids produced during acid fermentation are propionic and acetic acid. It is reportedthat only one group of methane bacteria is necessary for methane fermentation of acetic acid,whereas propionic acid, which is fermented through acetic acid requires two different groups ofmethanebacteria. The methane fermentation reactionsforthese twoacidsare:



The bacteria responsible for acid fermentation are relatively tolerant to changes in pH andtemperature and have a much higher rate of growth than the bacteria responsible for methanefermentation. As a result, methane fermentation is generally assumed to be the rate limiting stepinanaerobicwastewatertreatment.

### AnaerobicReactor

Varioustypesofanaerobicunitsthat have beendevelopedareasfollows:

* **Upflowanaerobic filters**packedwitheitherpebbles,stones,PVCsheets,etc.asmedia to support submerged biological growths (fixed film). The units are reported toworkwellbutalikely problemisaccumulationofsolidsintheinterstices.
* **Downflow anaerobic filters** packed with similar media as above but not to be confusedwithusualtricklingfilterswhichareaerobic.Intheanaerobicunits,theinletandoutletareso placedthatthe mediaandfixed filmstaysubmerged.
* **UASB type units** in which no special media have to be used since the sludge granulesthemselvesactas the'media'andstay insuspension.Thesearecommonlypreffered.
* **Fluidized bed units** filled with sand or plastic granules are used with recirculation underrequired pressure to keep the entire mass fluidized and the sludge distributed over theentire reactorvolume.Theirpowerconsumptionishigher.

### UASBUnits

**UASB type units** are one in which no special media have to be used since the sludge granulesthemselves act as the 'media' and stay in suspension. UASB system is not patented. A typicalarrangement ofaUASBtypetreatmentplantformunicipal sewagewouldbeas follows:

1. Initialpumping
2. Screeninganddegritting
3. MainUASBreactor
4. Gascollection and conversion orconveyance
5. Sludgedryingbed
6. Posttreatmentfacility

In the UASB process, the whole waste is passed through the anaerobic reactor in an upflowmode, with a hydraulic retention time (HRT) of only about 8-10 hours at average flow. No priorsedimentation is required. The anaerobic unit does not need to be filled with stones or any othermedia; the upflowing sewage itself forms millions of small "granules" or particles of sludge whichare held in suspension and provide a large surface area on which organic matter can attach andundergo biodegradation. A high solid retention time (SRT) of 30-50 or more days occurs withinthe unit. No mixers or aerators are required. The gas produced can be collected and used ifdesired. Anaerobic systems function satisfactorily when temperatures inside the reactor areabove18-20°C.Excesssludgeisremovedfromtimetotimethroughaseparatepipeandsenttoasimplesand bedfordrying.

### DesignApproach

**Size of Reactor**: Generally, UASBs are considered where temperature in the reactors will beabove 20°C.Atequilibriumcondition,sludge withdrawn hasto be equal to sludge produceddaily.Thesludgeproduceddailydependsonthecharacteristicsoftherawwastewatersinceitis the sum total of (i) the new VSS produced as a result of BOD removal, the yield coefficientbeing assumed as 0.1 g VSS/ g BOD removed, (ii) the non-degradable residue of the VSScoming in the inflow assuming 40% of the VSS are degraded and residue is 60%, and (iii) Ashreceivedintheinflow,namely TSS-VSSmg/l.Thus,atsteadystateconditions,

SRT= Total sludge present in reactor, kgSludge withdrawn perday,kg/d

=30 to 50days.

Anotherparameteris HRTwhichisgiven by:

HRT= Reactorvolume,m3

Flow rate,m3/h

=8to10hor moreataverageflow.

The reactor volume has to be so chosen that the desired SRT value is achieved. This is done bysolving for HRT from SRT equation assuming (i) depth of reactor (ii) the effective depth of thesludge blanket, and (iii) the average concentration of sludge in the blanket (70 kg/m3). The fulldepth of the reactor for treating low BOD municipal sewage is often 4.5 to 5.0 m of which thesludge blanket itself may be 2.0 to 2.5 m depth. For high BOD wastes, the depth of both thesludge blanket and the reactor may have to be increased so that the organic loading on solidsmaybe keptwithintheprescribed range.

Once the size of the reactor is fixed, the upflow velocity can be determined fromUpflowvelocitym/h=Reactorheight

HRT,h

Using average flow rate one gets the average HRT while the peak flow rate gives the minimumHRT at which minimum exposure to treatment occurs. In order to retain any flocculent sludge inreactor at all times, experience has shown that the upflow velocity should not be more than 0.5m/h at average flow and not more than 1.2 m/h at peak flow. At higher velocities, carry over ofsolids mightoccurand effluent quality may be deteriorated. The feed inletsystemisnextdesigned so thattherequiredlengthandwidthofthe UASBreactor aredetermined.

The settling compartment is formed by the sloping hoods for gas collection. The depth of thecompartment is 2.0 to 2.5 m and the surface overflow rate kept at 20 to 28 m3/m2-day (1 to 1.2m/h) at peak flow. The flow velocity through the aperture connecting the reaction zone with thesettling compartment is limited to not more than 5 m/h at peak flow. Due attention has to be paidto the geometry of the unit and to its hydraulics to ensure proper working of the "Gas-Liquid-Solid-Separator (GLSS)" the gas collection hood, the incoming flow distribution to get spatialuniformity and the outflowingeffluent.

### PhysicalParameters

A single modulecan handle10to15MLDofsewage.Forlargeflowsanumberofmodulescouldbe provided.Somephysicaldetails ofatypicalUASBreactor modulearegiven below:

|  |  |
| --- | --- |
| Reactorconfiguration | Rectangular orcircular.Rectangularshapeis preferred |
| Depth | 4.5 to5.0mforsewage. |
| Widthordiameter | To limit lengths of inlet laterals to around 10-12 m for facilitating uniformflowdistributionandsludge withdrawal. |
| Length | Asnecessary. |
| Inletfeed | gravity feed from top (preferred for municipal sewage) or pumped feedfrom bottom through manifold and laterals (preferred in case of solubleindustrialwastewaters). |
| Sludgeblanketdepth | 2to2.5mforsewage.Moredepthisneededfor strongerwastes. |
| Deflector/GLSS | Thisisadeflectorbeamwhichtogetherwiththegashood(slope60)forms a "gas-liquid-solid-separator" (GLSS) letting the gas go to the gascollectionchannelattop,whiletheliquidrisesintothesettlercompartmentandthesludgesolidsfallbackintothesludgecompartment.Theflowvelocitythroughtheapertureconnectingthereaction zone with the settling compartmentt is generally limited to about5m/hatpeakflow. |
| Settlercompartment | 2.0-2.5min depth.Surface overflowrateequals20-28m3/m2/d atpeakflow. |

### Process DesignParameters

Afewprocess designparametersforUASBsare listedbelowformunicipalsewageswithBODabout200-300mg/l andtemperaturesabove20°C.

|  |  |
| --- | --- |
| HRT | 8-10hoursataverageflow(minimum4 hoursatpeakflow) |
| SRT | 30-50daysormore |
| Sludgeblanket concentration (average) | 15-30 kgVSSper m3.About70kgTSS perm3. |
| Organicloadingonsludge blanket | 0.3-1.0 kgCOD/kgVSSday(evenupto10kgCOD/kgVSSdayforagro-industrialwastes). |
| Volumetricorganicloading | 1-3kgCOD/m3day fordomesticsewage(10-15kgCOD/m3dayforagro-industrialwastes) |
| BOD/CODremovalefficiency | Sewage 75-85%forBOD.74-78%for COD. |
| Inletpoints | Minimum1point per3.7-4.0m2floorarea. |
| Flowregime | Eitherconstant rateforpumped inflowsortypically |

|  |  |
| --- | --- |
|  | fluctuatingflowsforgravitysystems. |
| Upflowvelocity | About0.5 m/hataverageflow,or 1.2 m/hatpeakflow,whicheverislow. |
| Sludgeproduction | 0.15-0.25kg TSperm3sewagetreated. |
| Sludgedrying time | Sevendays(in India) |
| Gasproduction | Theoretical 0.38m3/kg COD removed.Actual 0.1-0.3m3per kgCOD removed. |
| Gasutilization | Methodofuseisoptional.1m3biogaswith75%methanecontent isequivalentto1.4kWhelectricity. |
| Nutrients nitrogen andphosphorusremoval | 5to10% only. |

### Nitrification-DenitrificationSystems

Acertainamountofnitrogenremoval(20-30%)occursinconventionalactivatedsludgesystems. Nitrogen removal ranging from 70 to 90 % can be obtained by use of nitrification-denitrificationmethodinplantsbasedonactivatedsludgeandothersuspendedgrowthsystems. Biological denitrification requires prior nitrification of all ammonia and organic nitrogenintheincomingwaste.

### Nitrification

There are two groups of chemoautotrophic bacteria that can be associated with the process ofnitrification. One group (*Nitrosomonas*) derives its energy through the oxidation of ammonium tonitrite, whereas the other group (*Nitrobacter*) obtains energy through the oxidation of nitrite tonitrate. Both the groups, collectively called *Nitrifiers*, obtain carbon required, from inorganiccarbonforms.Nitrificationofammoniatonitrateisa twostepprocess:

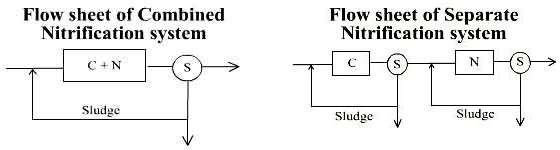
NitrosomonasNitrobacter

NH3 NH4 NO2 NO3

Stoichiometrically, 4.6 kg of oxygen is required for nitrifying 1 kg of nitrogen. Under steady stateconditions,experimentalevidencehasshownnitriteaccumulationtobeinsignificant.Thissuggests that the rate-limiting step for the conversion of ammonium to nitrate is the oxidation ofammoniumtonitrite by the genusNitrosomonas.

### CombinedandSeparateSystemsofBiologicalOxidation&Nitrification

Following figure shows flow sheets for combined and separate systems for biological oxidationandnitrification.



***Combined system*** is favoured method of operation as it is less sensitive to load variations -owing to larger sized aeration tank - generally produces a smaller volume of surplus sludgeowingtohighervaluesofcadopted,and better sludge settleability.

Care should be taken to ensure that the oxygenation capacity of aeration tank is sufficient tomeetoxygenuptakeduetocarbonaceousdemandandnitrification.Recyclingofsludgemustbe rapid enough to prevent denitrification (and rising sludge) owing to anoxic conditions in thesettlingtank.

In ***separate system***, the first tank can be smaller in size since a higher F/M ratio can be used,butthismakesthesystemsomewhatmoresensitivetoloadvariationsandalsotendstoproduce more sludge for disposal. An additional settling tank is also necessary between the twoaeration tanks to keep the two sludges separate. A principal advantage of this system is itshigher efficiency of nitrification and its better performance when toxic substances are feared tobeintheinflow.

### .BiologicalDenitrification

Whenatreatmentplantdischargesintoreceivingstreamwithlowavailablenitrogenconcentration and with a flow much larger than the effluent, the presenceofnitrate in theeffluentgenerallydoesnotadverselyaffectstreamquality.However,ifthenitrateconcentrationin the stream is significant, it may be desirable to control the nitrogen contentof the effluent, ashighly nitrified effluents can stillaccelarate algal blooms. Even more critical is the case wheretreatment plant effluent is dischargeddirectly into relatively still bodies of water such as lakes orreservoirs.Anotherargumentforthecontrolofnitrogenintheaquaticenvironmentistheoccurence of infantile methemoglobinemia,which results from high concentration of nitratesindrinkingwater.

Thefourbasicprocessesthatareusedare: (1)ammoniastripping,(2)selective ionexchange,

1. breakpointchlorination,and(4)biologicalnitrification/denitrification.

***Biological nitrification/denitrification***is a two step process. The first step is nitrification, whichisconversion ofammonia tonitratethroughtheactionofnitrifyingbacteria. Thesecondstepis

nitrate conversion (denitrification), which is carried out by facultative heterotrophic bacteriaunderanoxicconditions.

### MicrobiologicalAspectsofDenitrification

* + Nitrateconversiontakesplacethroughbothassimilatoryanddissimilatorycellularfunctions. In ***assimilatory denitrification***, nitrate is reduced to ammonia, which thenserves as a nitrogen source for cell synthesis. Thus, nitrogen is removed from the liquidstreamby incorporatingitintocytoplasmicmaterial.
  + In***dissimilatorydenitrification***,nitrateservesastheelectronacceptorinenergymetabolism and is converted to various gaseous end products but principally molecularnitrogen,N2,whichisthenstripped fromtheliquidstream.
  + Because the microbial yield under anoxic conditions is considerably lower than underaerobicconditions,arelativelysmallfractionofthenitrogenisremovedthroughassimilation.Dissimilatorydenitrificationis,therfore,theprimarymeansbywhichnitrogenremovalisachieved.
  + A carbon source is also essential as electron donor for denitrification to take place. Thissource may be in the form of carbon internally available in sewage or artificially added(eg.asmethanol).SincemostcommunitywastewatershaveahigherratioofBOD:N,the internallyavailable carbon becomesattractiveand economicalfordenitrification.

Denitrification releases nitrogen which escapes as an inert gas to the atmosphere whileoxygen released stays dissolved in the liquid and thus reduces the oxygen input neededintothesystem.Eachmoleculeofnitrogenneeds4moleculesofoxygenduringnitrification but releases back 2.5 molecules in denitrification. Thus, theoretically, 62.5%oftheoxygenused isreleasedbackindenitrification.

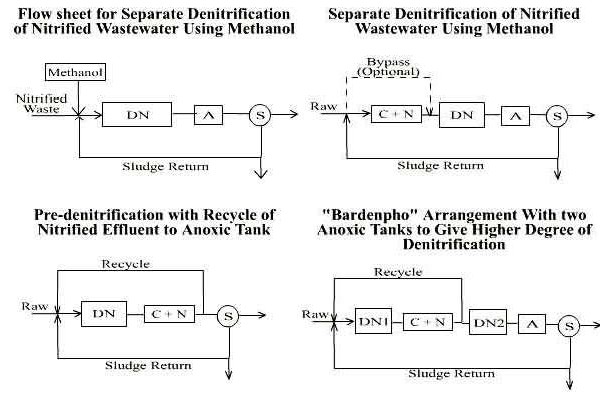
### TypicalFlowsheetsforDenitrification

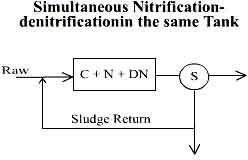
Denitrification in suspended growth systems can be achieved using anyone of the typicalflowsheetsshowninthe figure.

* + The use of methanol or any other artificial carbon source should be avoided as far aspossible since it adds to the cost of treatment and also some operating difficulties mayarisefro dosing rate of methanol. Too much would introduce an unnecessary BOD in theeffluentwhiletoolittlewouldleavesomenitratesundernitrified.
  + A moresatisfactory arrangementwould be to use the carbon contained in thewasteitself. However, the anoxic tank has to be of sufficient detention time for denitrification tooccur which, has a slower rate; since the corresponding oxygen uptake rate of the mixedliquor is mainly due to endogenous respiration and is thus low. The denitrification rate,therefore,ina way alsodependsontheF/Mratio inthe prioraerationtank.
  + Consequently, if desired, a portion of the raw waste may be bypassed to enter directlyintotheanoxictankandthuscontributetoanincreasedrespirationrate.Thisreduces

thesizesofboththeanoxicandaerationtanks,butthedenitrificationefficiencyisreducedasthebypassedunnitrifiedammoniacannotbedenitrified.

* + Byreversingtherelativepositionsofanoxicandaerobictanks,theoxygenrequirementof the waste in its anoxic state is met by the release of oxygen from nitrates in therecycled flow taken from the end of nitrification tank. Primary settling of the raw wastemaybeomitted so astobringmorecarbon intotheanoxictank.
  + More complete nitrification-denitrification can be achieved by Bardenpho arrangement.The first anoxic tank has the advantage of higher denitrification rate while the nitratesremaining in the liquor passing out of the tank can be denitrified further in a secondanoxictankthroughendogenous respiration.
  + The flow from anoxic tank is desirable to reaerate for 10-15 minutes to drive off nitrogengasbubblesand addoxygen priortosedimentation.





#### Removal

Phosphorus precipitation is ususally achieved by addition of chemicals like calcium hydroxide,ferrousorferricchloride,oralum,eitherintheprimary orthefinalsettlingtank.

Alum is more expensive and generates more hydroxide, which creates extra sludge, that isdifficulttodewater.Useoflimeresultsinanincreaseofapproximately50%insurplussludge,but the sludge is reported to have good dewatering properties. When using iron salts, a molarratio of 1.0:1.4 of iron to phosphorus is reported to give 91-96% removal of total phosphorususingferrouschloridedoseddirectlybeneath the aerator.

Chemicaladditionpriortobiologicaltreatmentisfeasibleifaprimarysettlingtankexistsasinthecaseoftheconventionalactivatedsludgeprocess.Thedoserequirementthenincreases,butchemicalprecipitationalsoimprovesorganicremoval,thusreducingBODloadonthebiological treatment. For extended aeration plants there is no primary settling; chemical additionhasto bedone inthe finalsettlingtank.

### ResidualManagement

In all biological waste treatment processes some surplus sludge is produced. The ***objective ofresidualmanagement*** is:

* + Reductionofwatercontent.
  + Stabilizationof sludgesolids.
  + Reductionin sludgesolidsvolume.

In facultative type ***aerated lagoons*** and algal ***waste stabilization ponds***, the surplus sludgesettles out in the unit itself and is removed only once in a few years after emptying the unit,exposing the wet sludge to natural drying, and carting away the dried sludge for agricultural useorlandfilling.

In ***extended aeration process*** where aerobic digestion of surplus sludge is done, the sludgecanbe taken directlyfordewateringand disposal.

In case of ***activated sludge*** and ***trickling filter*** plants, the sludge is taken (along with theprimarysludge)toasludgedigesterforfurtherdemineralizationandthereafteritis dewatered.

### SludgeDewateringMethods

* + Natural:sludgedryingbeds,sludgelagoons
  + Mechanical:sludgethickeners,centrifuges, vacuumfilters,filter press
  + Physical:heat drying,incineration

### DisposalofSludge

Finaldisposal ofsludgeistoland andsometimestothesea,inone of thefollowingways:

* + Agricultural useofdriedorwetsludge.
  + Useofdriedsludgeas landfillinabsenceofagriculturaldemand.
  + Spreadingwetsludgeonerodedorwasteland,contouringthefield,soastograduallybuildupatopsoilofagriculturalvalue.
  + Disposing off wet sludge along with solid wastes for (i) composting, or (ii) sanitarylandfill.
  + Transportinganddumping into thesea.

#### SludgeCharacteristics

For the rational design of sludge drying systems, it is esstential to know a few characteristics ofsludges, such as moisture content as affected by the nature and extent of organic and othermattercontainedinthem,theirspecificgravity,weightandvolumerelationships,theirdewateringcharacteristics,etc.Thespecificgravityofsludgeis veryclosetothat ofwateritself,

* 1. forbiological sludge and1.02fromalumsludge.

#### Stepwisereductioninmoisturecontentindewateringextendedaerationsludge

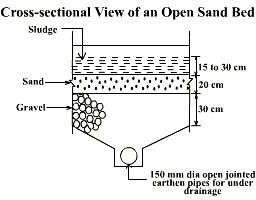
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sludge source | Moisture content | Weight,g/person-day | | |
|  | %byweight | Solids | Water | Total |
| Initialmoisturecontent | 99 | 30 | 2970 | 3000 |
| Afterthickening | 96 | 30 | 720 | 750 |
| Afterother mechanicalprocess | 90 | 30 | 270 | 300 |
| Afternatural orphysicaldrying | 60 | 30 | 45 | 75 |

It is evident that the bulk of the water is removed in the thickener. Thereafter, the bulk of theremainingmoisture is removedin freedrainage. Evaporationremoves theleastbut,infact,

takes the longest time. The final "dried" sludge still has considerable moisture in it, but thesludgeis now "handleable".

### SandBedsforSludgeDrying

Sandbeds aregenerallyconstructedasshown in thetypical cross-sectionalview.



Sludge is generally spread over the sand which is supported on a gravel bed, through which islaid an open-joint earthen pipe 15 cm in diameter spaced about 3 m apart and sloping at agradient of 1 in 150 towards the filtrate sump. The drying beds are often subdivided into smallerunits, each bed 5-8 m wide and 15-50 m long. The drying time averages about 1-2 weeks inwarmerclimates,and3-6orevenmoreinunfavourableones.

### SludgeDigestion

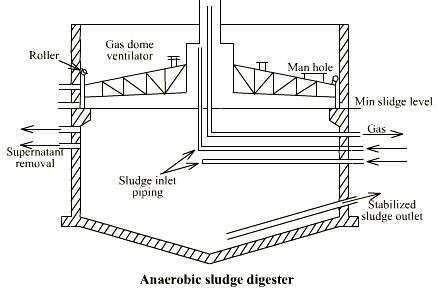
Sludge digestion involves the treatment of highly concentrated organic wastes in the absence ofoxygenbyanaerobicbacteria.Theanaerobictreatmentoforganicwastesresultingintheproductionofcarbondioxideandmethane,involvestwodistinctstages.In the firststage,referred to as "***acid fermentation***", complex waste components, including fats, proteins, andpolysaccharides are first hydrolyzed by a heterogeneous group of facultative and anaerobicbacteria. These bacteria then subject the products of hydrolysis to fermentations, b-oxidations,and other metabolic processes leading to the formation of simple organic compounds, mainlyshort-chain (volatile) acids and alcohols. However in the second stage, referred to as "***methanefermentation***", the end products of the first stage are converted to gases (mainly methane andcarbondioxide)by severaldifferentspeciesofstrictlyanaerobicbacteria.

The bacteria responsible for acid fermentation are relatively tolerant to changes in pHandtemperature and have a much higher rate of growth than the bacteria responsible for methanefermentation. If the pH drops below 6.0, methane formation essentially ceases, and more acidaccumulates,thusbringingthedigestionprocesstoastandstill.Asaresult,methanefermentationis generallyassumedtobetheratelimitingstepinanaerobicwastewater

treatment. The methane bacteria are highly active in mesophilic (27-43°C) with digestion periodoffourweeksandthermophilicrange(35-40°C)withdigestionperiodof15-18days.Butthermophilicrangeisnotpractisedbecauseofodourandoperationaldifficulties.

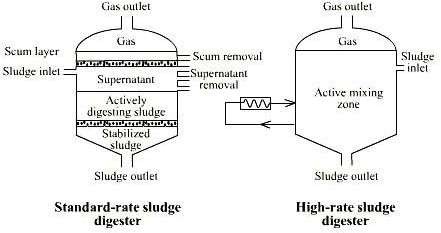
### DigestionTanksor Digesters

A sludge digestion tank is a RCC or steel tank of cylindrical shape with hopper bottom and iscoveredwithfixedorfloatingtypeofroofs.

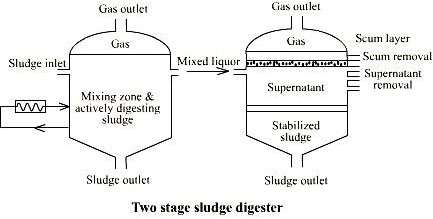


### TypesofAnaerobicDigesters

The anaerobic digesters are of two types: standard rate and high rate. In the standard ratedigestionprocess,the digestercontentsareusuallyunheatedandunmixed.Thedigestionperiod may vary from 30 to 60 d. In a high rate digestion process, the digester contents areheatedand completely mixed.The requireddetentionperiodis 10 to20d.



Often a combination of standard and high rate digestion is achieved in two-stage digestion. Thesecondstagedigestermainlyseparatesthedigestedsolidsfromthesupernatantliquor:althoughadditionaldigestionandgasrecoverymay alsobeachieved.



### DesignDetails

Generally digesters aredesigned to treatforacapacityupto4 MLD.

* + 1. Tanksizesarenotlessthan6 mdiameterandnotmore than55mdiameter.
    2. Liquiddepthmay be4.5to6mandnotgreaterthan9m.
    3. Thedigestercapacitymaybedeterminedfromtherelationship

V =[Vf-2/3 (Vf-Vd)]t1+Vdt2

where V = capacity of digester in m3, Vf = volume of fresh sludge m3/d, Vd = volume ofdaily digested sludge accumulation in tank m3/d, t1= digestion time in days required fordigestion,d,and t2=periodofdigested sludge storage.

### GasCollection

The amount of sludge gas produced varies from 0.014 to 0.028 m3 per capita. The sludge gas isnormally composed of 65% methane and 30% carbondioxide and remaining 5% of nitrogen andotherinert gases,withacalorificvalueof5400 to5850 kcal/m3.

### TreatmentPlantLayoutandSiting

***Plantlayout***isthearrangementofdesignedtreatmentunitsontheselectedsite.Thecomponents that need to be included in a treatment plant, should be so laid out as to optimizeland requirement, minimize lengths of interconnecting pipes and pumping heads. Access forsludge andchemicalstransporting, andforpossible repairs, should be provided inthelayout.

***Siting***istheselectionofsitefortreatmentplantbasedonfeaturesascharacter,topography,and shoreline. Site development should take the advantage of the existing site topography. Thefollowingprinciplesareimportantto consider:

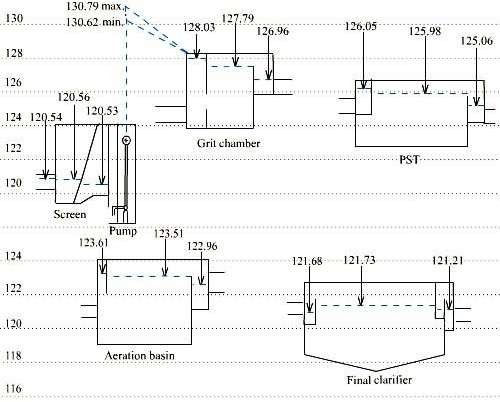
1. A site on a side-hill can facilitate gravity flow that will reduce pumping requirements andlocatenormalsequence ofunitswithoutexcessiveexcavationorfill.
2. When landscaping is utilized it should reflect the character of the surrounding area. Sitedevelopment should alter existing naturally stabilized site contours and drainage as littleaspossible.
3. Thedevelopedsiteshouldbecompatiblewiththeexistinglandusesandthecomprehensivedevelopmentplan.

### TreatmentPlantHydraulics

***Hydraulicprofile***isthegraphicalrepresentationofthehydraulicgradelinethroughthetreatment plant. If the high water level in the receiving water is known, this level is used as acontrol point, and the head loss computations are started backward through the plant. The ***totalavailablehead*** atthetreatmentplantisthedifferenceinwatersurfaceelevationsintheinterceptor and the water surface elevation in the receiving water at high flood level. If the totalavailableheadislessthantheheadlossthroughtheplant,flowbygravitycannotbeachieved.Insuchcasespumpingisneeded to raisetheheadso that flow bygravitycanoccur.

There are many basic principles that must be considered when preparing the hydraulic profilethroughthe plant.Somearelisted below:

1. The hydraulic profiles are prepared at peak and average design flows and at minimuminitialflow.
2. Thehydraulicprofileisgenerally preparedforallmain pathsof flowthroughtheplant.
3. Theheadlossthroughthetreatment plantisthesumofheadlosses inthetreatmentunitsandthe connecting pipingand appurtenances.
4. Theheadlossesthrough thetreatmentunitincludethefollowing:
   1. Headlossesat the influentstructure.
   2. Headlossesattheeffluentstructure.
   3. Headlossesthroughtheunit.
   4. Miscellaneous andfreefall surfaceallowance.
5. Thetotallossthroughthe connectingpipings,channelsand appurtenancesisthesumoffollowing:
   1. Head lossdue toentrance.
   2. Head lossdue toexit.
   3. Head lossduetocontractionandenlargement.
   4. Head lossduetofriction.
   5. Head lossdue tobends,fittings, gates,valves,andmeters.
   6. Headrequiredoverweirandotherhydrauliccontrols.
   7. Free-fallsurfaceallowance.



### TreatedEffluentDisposal

The proper disposal of treatment plant effluent or reuse requirements is an essential part ofplanning and designing wastewater treatment facilities. Different methods of ultimate disposal ofsecondary effluentsarediscussedasfollows.

### NaturalEvaporation

Theprocessinvolveslargeimpoundmentswithnodischarge.Dependingontheclimaticconditionslargeimpoundmentsmaybenecessaryifprecipitationexceedsevaporation.Therefore, considerations must be given to net evaporation, storage requirements, and possiblepercolation and groundwater pollution. This method is particularly beneficial where recovery ofresiduesisdesirablesuchas fordisposalofbrines.

### GroundwaterRecharge

Methods forgroundwaterrecharge include rapidinfiltrationbyeffluentapplicationorimpoundment,intermittentpercolation,anddirectinjection.Inallcasesrisksforgroundwater

pollution exists. Furthermore, direct injection implies high costs of treating effluent and injectionfacilities.

### Irrigation

Irrigation has been practiced primarily as a substitute for scarce natural waters or sparse rainfallin arid areas.In most cases food chain crops (i.e. cropsconsumedby humansand thoseanimals whose products are consumed by humans) may not be irrigated by effluent. However,fieldcropssuchascotton,sugarbeets,andcropsforseedproductionaregrownwithwastewatereffluent.

Wastewater effluenthas beenusedforwateringparks,golfcoursesandhighwaymedians.

### Recreational Lakes

The effluent fromthe secondary treatment facility is stored in a lagoon for approximately 30days. The effluent from the lagoon is chlorinated and then percolated through an area of sandand gravel, through which it travels for approximately 0.5 km and is collected in an interceptortrench. Itisdischargedintoa series oflakesusedfor swimming,boatingand fishing.

### Aquaculture

Aquaculture, or the production of aquatic organisms (both flora and fauna), has been practicedforcenturiesprimarilyforproductionoffood,fiberandfertilizer.Lagoonsareusedforaquaculture, although artificial and natural wetlands are also being considered. However, theuncontrolled spread of water hyacinths is itself a great concern because the flora can clogwaterwaysandruinwaterbodies.

### MunicipalUses

Technology is now available to treat wastewater to the extent that it will meet drinking waterqualitystandards.However,directreuseoftreatedwastewaterispracticableonlyonanemergencybasis.Manynaturalbodiesofwaterthatareusedformunicipalwatersupplyarealso used for effluent disposal which is done to supplement the natural water resources byreusingthe effluentmanytimesbefore itfinallyflowstothesea.

### IndustrialUses

Effluent has been successfully used as a cooling water or boiler feed water. Deciding factors foreffluent reuse by the industry include (1) availability of natural water, (2) quality and quantity ofeffluent, and cost of processing, (3) pumping and transport cost of effluent, and (4) industrialprocess waterthatdoesnotinvolvepublichealthconsiderations.

### DischargeintoNaturalWaters

Discharge into natural waters is the most common disposal practice. The self-purification orassimilativecapacityofnaturalwatersisthus utilized to provide theremaining treatment.

### StabilizationPonds

* The***stabilizationponds***areopenflowthroughbasinsspecificallydesignedandconstructed to treat sewage and biodegradable industrial wastes. They provide longdetentionperiodsextendingfromafew to severaldays.
* Pondsystems,inwhichoxygenisprovidedthroughmechanicalaerationratherthanalgalphotosynthesisarecalled*aeratedlagoons*.
* Lightly loaded ponds used as tertiary step in waste treatment for polishing of secondaryeffluentsand removalofbacteriaare called***maturationponds***.

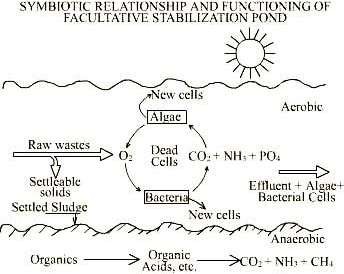
### ClassificationofStabilizationPonds

Stabilizationpondsmaybeaerobic,anaerobicorfacultative.

* ***Aerobic ponds*** are shallow ponds with depth less than 0.5 m and BOD loading of 40-120 kg/ha.d so as to maximize penetration of light throughout the liquid depth. Suchpondsdevelopintensealgalgrowth.
* ***Anaerobic ponds*** are used as pretreatment of high strength wastes with BOD load of400-3000kg/ha.dSuchpondsareconstructedwithadepthof2.5-5maslightpenetrationisunimportant.
* ***Facultative pond*** functions aerobically at the surface while anaerobic conditions prevailat the bottom.They are often about 1 to 2 m in depth. The aerobic layer acts as a goodcheckagainstodourevolutionfromthe pond.

### MechanismofPurification

The functioning of a facultative stabilization pond and symbiotic relationship in the pond areshownbelow.Sewageorganicsarestabilizedbybothaerobicandanaerobicreactions.Inthetop aerobic layer,where oxygen is supplied through algal photosynthesis,the non-settleableanddissolvedorganicmatterisoxidizedtoCO2andwater.Inaddition,someoftheendproducts of partial anaerobic decomposition such as volatile acids and alcohols, which maypermeate toupperlayersare alsooxidizedperiodically.The settledsludge mass originatingfrom raw waste and microbial synthesis in the aerobic layer and dissolved and suspendedorganics in the lower layers undergo stabilization through conversion to methane which escapesthepond informofbubbles.



### FactorsAffectingPondReactions

Variousfactorsaffectponddesign:

* wastewater characteristicsandfluctuations.
* environmentalfactors(solarradiation, light,temperature)
* algalgrowth patternsand theirdiurnal andseasonalvariation)
* bacterialgrowthpatternsanddecayrates.
* solidssettlement,gasification,upwarddiffusion,sludgeaccumulation.

Thedepthofaerobiclayerinafacultativepondisafunctionofsolarradiation,wastecharacteristics,loadingandtemperature.Astheorganicloadingisincreased,oxygenproductionbyalgaefallsshortoftheoxygenrequirementandthedepthofaerobiclayerdecreases.Further,thereisadecreasein the photosyntheticactivity ofalgaebecause ofgreaterturbidity andinhibitory effectofhigherconcentrationoforganicmatter.

Gasification of organic matter to methane is carried out in distinct steps of acid production byacid forming bacteria and acid utilization by methane bacteria. If the second step does notproceed satisfactorily, there is an accumulation of organic acids resulting in decrease of pHwhichwouldresultincompleteinhibitionofmethanebacteria.Twopossiblereasonsforimbalance between activities of methane bacteria are: (1) the waste may contain inhibitorysubstances which would retard the activity of methane bacteria and not affect the activity of acidproducers tothesame extent.(2)Theactivityofmethanebacteriadecreasesmuchmorerapidlywithfallintemperature ascompared totheacidformers.

Thus,yearroundwarmtemperatureand sunshineprovideanideal environmentforoperationoffacultativeponds.

### AlgalGrowth andOxygen Production

Algal growth converts solar energy to chemical energy in the organic form. Empirical studieshave shown that generallyabout6%ofvisible lightenergycanbeconverted toalgal energy.

Thechemicalenergy containedinanalgalcellaverages6000calories pergramofalgae.

Dependingonthesky clearancefactor foranarea, theaverage visible radiationreceivedcanbeestimatedasfollows:

Avg.radiation=Min.radiation+[(Max.radiation-Min.radiation)x skyclearancefactor]

Oxygen production occurs concurrently with algal production in accordance with followingequation:

106C02+16NO3+HPO4+122H2O+18H+ C106H263O110N16P1+138O2

On weight basis,theoxygenproductionis1.3times thealgalproduction.

### Areal OrganicLoading

ThepermissiblearealorganicloadingforthepondexpressedaskgBOD/ha.dwilldependontheminimumincidenceofsunlightthatcanbeexpectedatalocationandalsoonthepercentage of influent BOD that would have to be satisfied aerobically. The Bureau of IndianStandards has related the permissible loading to the latitude of the pond location to aerobicallystabilize the organic matter and keep the pond odour free. The values are applicable to towns atsea levels and where sky is clear for nearly 75% of the days in a year. The values may bemodified for elevations above sea level by dividing by a factor (1 + 0.003 EL) where EL is theelevationofthe pondsite aboveMSLinhundred meters.

### DetentionTime

Theflowofsewagecanapproximateeitherplugfloworcompletemixingordispersedflow. IfBOD exertionis describedbyfirstorderreaction,thepondefficiency is givenby:

forplugflow:Le/Li =e-k1t

forcomplete mixing:Le/Li=1

1+k1t

For dispersed flow the efficiency of treatment for different dgrees of intermixing is characterizedbydispersionnumbers.Choiceofalargervaluefordispersionnumberorassumptionofcomplete mixingwouldgiveaconservativedesignandisrecommended.

### Depth

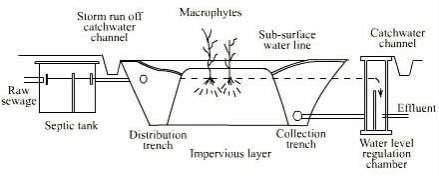
Having determined the surface area and detention capacity, it becomes necessary to considerthe depth of the pond only in regard to its limiting value. The optimum range of depth forfacultativepondsis1.0- 1.5m.

### AquaticPlantSystems

Aquatic systems in waste treatment are either free floating growths harnessed in the form ofbuilt-uppondsforwastetreatmentsuchas***duckweedandhyacinthponds***orrootedvegetations(reeds)whichemerge outof shallow waterscultivatedin***constructedwetlands***.

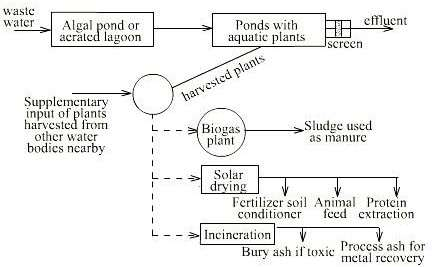
* ***Natural wetlands*** exists all over the world. They generally have saturated soil conditionsand abound in rooted vegetation which emerges out of shallow waters in the euphoticzone.Theymayalsohavephytoplankton.Naturalwetlandscanbeintegratedwithwastewatertreatmentsystems.
* ***Constructedwetlands*** areman-madefortreatmentofwastewater,minedrainage,stormdrainage,etc.Theyhaverootedvegetation.

### LongitudinalSection Through a TypicalReed Bed With Gravel,Sand or Selected SoilWithHorizontalFlow ofWastewater



* ***Aquatic plant ponds*** consisting of free floating macrophytes, such as water hyacinths,duckweeds, etc. have been cultured in ponds either for their ability to remove heavymetals,phenols,nutrients,etc.fromwastewatersortoassistingivingfurthertreatmentto pretreated wastewaters to meet stringent discharge standards while at the same timeproducingnew plantgrowthsfortheir gasproductionorfoodvalue.

**Conceptualflowsheetshowingwastetreatment usinganaquaticplant pond**



### SepticTank

Septic tanks are horizontal continuous flow, small sedimentation tanks through which sewage isallowed to flow slowly to enable the sewage solids to settle to the bottom of the tank, where theyare digested anaerobically. The tank is de-sludged at regular intervals usually once every 1-5years.

### Cesspool

It is a pit excavated in soil with water tight lining and loose lining by stone or brick to provide forleaching of wastewater by sides and the pit is covered. The leaching type is suitable for poroussoils. The capacity should not be less than one day's flow into the pit. If all the water in a test pitof one meter diameter and 2 m deep, disappears in 24 hours, such soil is best suitable forcesspools.Thebottomofthecesspoolmustbewellabovethegroundwaterlevel.Aftersometime the sides of pit get clogged by the sewage solids, reducing the leaching capacity. Atoverflow level, an outlet is provided to take-off unleached liquid into a seepage pit. The settledmatter is removed at intervals. Water tight cesspools are cleaned every 6 months and theircapacity mustnotbe lessthan 70l/person/month.

### Seepage Pit

The seepage pit is needed to discharge the effluent of cesspool, aquaprivy, septic tankorsullage from bathrooms and kitchens. The difference between seepage pit and cesspool is thattheseepagepitiscompletely filledupwithstones.Thefinesuspendedsolidsadheretothe

surfaceofstonesandgetdecomposed bythezooglealfilm,whichare onthestonesand theeffluentisleached intothesidewalls.

**Unit V Airpollution**

Concentrationsofairpollutantsarecommonly expressed asthe mass ofpollutantperUnitvolumeofairmixture,as mg/m3,μg/m3,ng/m3

Concentration of gaseous pollutants may also be expressed as volume of pollutant per millionvolumesoftheairpluspollutantmixture(ppm)where1ppm=0.0001%byvolume.Itissometimes necessarytoconvertfromvolumetricunitstomassperunitvolumeandvice versa.

The relation ship between ppm and mg/m3 depends on the gas density, which in turn dependson:™Temperature,Pressure,Molecularweightofthe pollutant

The following expression can be uses to convert of between ppm and mg/m3 at any temperatureorpressure.



Simply multiply the calculated value of mg/m3 by 1000 to obtain μg/m3. The constant 22.4 is thevolume in liter occupied by 1 mole of an ideal gas at standard concentration (0c and 1 atm.).One 14 mole of any substance is a quantity of that substance whose mass in grams numericallyequalsitsmolecularweight

SourcesandClassification ofpollutants

Air pollution may be defined as any atmospheric condition in which certain substances arepresentinsuchconcentrationsthattheycanproduceundesirableeffectson manandhisenvironment. These substances include gases (SOx, NOx, CO, HCs, etc) particulate matter(smoke,dust,fumes,aerosols)radioactivematerialsandmanyothers.Mostofthesesubstances are naturally present in the atmosphere in low (background) concentrations and areusually considered to be harmless. A particular substance can be considered as an air pollutantonly when its concentration is relatively high compared with the back ground value and causesadverseeffects.

Air pollution is a problem of obvious importance in most of the world that affects human, plantand animal health. For example, there is good evidence that the health of 900 million urbanpeople suffers daily because of high levels of ambient air sulfur dioxide concentrations. Airpollution isoneofthe6mostseriousenvironmentalproblemsin societiesatalllevel of

economic development. Air pollution can also affect the properties of materials (such as rubber),visibility, and the quality of life in general. Industrial development has been associated withemission to air of large quantities of gaseous and particulate emissions from both industrialproductionandfromburningfossil fuelsforenergyandtransportation.

When technology was introduced to control air pollution by reducing emissions of particles,itwas found that the gaseous emissions continued and caused problems of their own. Currentlyefforts to control both particulate and gaseous emissions have been partially successful in muchof the developed world, but there is recent evidence that air pollution is a health risk even underthese relativelyfavorableconditions.

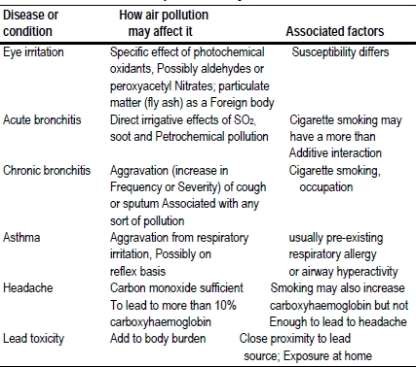
In societies that are rapidly developing sufficient resources may not be invested in air pollutioncontrol because of other economic and social priorities. The rapid expansion of the industry inthese countries has occurred at the same time as increasing traffic from automobiles and trucks,increasing demands for power for the home, and concentration of the population in large urbanareas called mega cities. The result has been some of the worst air pollution problem in theworld.

In many traditional societies, and societies where crude household energy sources are widelyavailable, air pollution is a serious problem because of inefficient and smoky fuels used to heatbuildings and cook. This causes air pollution both out door and indoors. The result can be lungdisease,eyeproblems,andincreasedriskofcancer.

The quality of air indoors is a problem also in many developed countries because buildings werebuilt to be airtight and energy efficient. Chemicals produced by heating and cooling systems,smoking and evaporation from buildings materials accumulate indoors and create a pollutionproblem.

The health effects of ambient air pollution have been difficult to document with certainty untilrecent years. This is because of methodological problems in assessing exposure, other factorsthatcause respiratorydisease(suchascigarettesmoking,respiratorytractinfections,andallergies),andthe difficulty ofstudyingsucheffectsinlargepopulations.

Recently, however, a series of highly sophisticated and convincing studies from virtually everycontinent have demonstrated that air pollution has a major effect on human health. Respiratorysymptoms are the most common adverse health effects from air pollution of all types. FollowingTable presents a summary of major health effects thought to be caused by community airpollution. Respiratory effects of air pollution, particularly complicating chronic bronchitis, mayplaceanadditionalstrain ontheheartaswell.



Airpollution is associated with increased riskofdeath fromheartdisease and lungdisease,evenatlevelsbelowthoseknowntobeacutelytoxictotheheart.Mucosalirritationintheformof acute or chronic bronchitis, nasal tickle, or conjunctivitis is characteristic of high levels of airpollution,although individualsvaryconsiderablyintheir susceptibility to sucheffects.

The eye irritation is particularly severe, in the setting of high levels of particulates (which need tobeintherespirablerangedescribedandmaybequitelargesootparticles)orofhighconcentrationsofphotochemicaloxidantsandespeciallyaldehydes.

There is little evidence to suggest that community air pollution is a significant cause of cancerexcept in unusual and extreme cases. However, emissions from particular sources may becancer-causing. Examples of cancer associated with community air pollution may include point-source emissions from some smelters with poor controls that release arsenic, which can causelung cancer. Central nervous system effects, and possibly learning disabilities in children, mayresult from accumulated body burdens of lead, where air pollution contributes a large fraction ofexposurebecauseofleadadditivesingasoline.

Thesehealtheffectsarebettercharacterizedforpopulationsthanforindividualpatients.Establishing a relationship between the symptoms of a particular patient and exposure to airpollution is more difficult than interpreting the likely health effects on an entire community. It isimportant to understand that these pollutants are seasonal in their pattern. Both ozone andsulfates,togetherwithultrafineparticulates,tendtooccurtogetherduringthesummermonthsinmostdevelopedareas.Ozone,oxidesofnitrogen,aldehydes,andcarbonmonoxidetendto

occur together in association with traffic, especially in sunny regions. Some pollutants, such asradon, are only hazards indoors or in a confined area. Others are present both indoors andoutdoors,withvaryingrelativeconcentrations.

**Classifications of Air Pollutants**Air pollutants can be classified asa.CriteriaPollutants

There are 6 principal, or “criteria” pollutants regulated by the US-EPA and most countries in theworld:

* Totalsuspendedparticulatematter(TSP),withadditionalsubcategoriesofparticlessmaller then 10 µm in diameter (PM10), and particles smaller than 2.5 µm in diameter (PM2.5).PM can exist in solid or liquid form, and includes smoke, dust, aerosols, metallic oxides, andpollen.SourcesofPMincludecombustion,factories,construction,demolition,agriculturalactivities, motor vehicles, and wood burning. Inhalation of enough PM over time increases theriskofchronicrespiratorydisease.
* Sulfur dioxide (SO2). This compound is colorless, but has a suffocating, pungent odor.The primary source of SO2 is the combustion of sulfur-containing fuels (e.g., oil and coal).ExposuretoSO2cancausetheirritationoflungtissuesandcandamagehealthandmaterials.
* Nitrogen oxides (NO and NO2). NO2 is a reddish-brown gas with a sharp odor. Theprimary source of this gas is vehicle traffic, and it plays a role in the formation of troposphericozone. Large concentrations can reduce visibility and increase the risk of acute and chronicrespiratory disease.
* Carbonmonoxide(CO).Thisodorless,colorlessgasisformedfromtheincompletecombustion of fuels. Thus, the largest source of CO today is motor vehicles. Inhalation of COreducestheamountofoxygeninthebloodstream,andhighconcentrationscanleadtoheadaches,dizziness,unconsciousness,anddeath.
* Ozone(O3).Tropospheric(“low-level”)ozoneisasecondarypollutantformedwhensunlight causes photochemical reactions involving NOX and VOCs. Automobiles are the largestsourceofVOCsnecessaryforthese reactions.Ozoneconcentrationstendtopeakintheafternoon, and can cause eye irritation, aggravation of respiratory diseases, and damage toplantsandanimals.
* Lead (Pb). The largest source of Pb in the atmosphere has been from leaded gasolinecombustion, but with the gradual elimination worldwide of lead in gasoline, air Pb levels havedecreased considerably. Other airborne sources include combustion of solid waste, coal, andoils, emissions from iron and steel production and lead smelters, and tobacco smoke. Exposureto Pb can affect the blood, kidneys, and nervous, immune, cardiovascular, and reproductivesystems.

1. ToxicPollutants

Hazardousairpollutants(HAPS),alsocalledtoxicairpollutantsorairtoxics,arethosepollutants that cause or may cause cancer or other serious health effects, such as reproductiveeffectsorbirthdefects.TheUS-EPAis required tocontrol188 hazardous airpollutants

Examples of toxic air pollutants include benzene, which is found in gasoline; perchlorethlyene,which is emitted from some dry cleaning facilities; and methylene chloride, which is used as asolventandpaintstripperby anumberofindustries.

1. RadioactivePollutants

Radioactivity is an air pollutant that is both geogenic and anthropogenic. Geogenic radioactivityresults from the presence ofradionuclides,which originate either fromradioactive minerals intheearth‟scrustorfromtheinteractionofcosmicradiationwithatmosphericgases.Anthropogenic radioactive emissions originate from nuclear reactors, the atomic energy industry(mining and processing of reactor fuel), nuclear weapon explosions, and plants that reprocessspentreactorfuel.Sincecoalcontainssmallquantitiesofuraniumandthorium,theseradioactive elements can be emitted into the atmosphere from coal-fired power plants and othersources.

1. IndoorPollutants

When a building is not properly ventilated, pollutants can accumulate and reach concentrationsgreater than those typically found outside. This problem has received media attention as “SickBuilding Syndrome”. Environmental tobacco smoke (ETS) is one of the main contributors toindoor pollution, as are CO, NO, and SO2, which can be emitted from furnaces and stoves.Cleaning or remodeling a house is an activity that can contribute to elevated concentrations ofharmful chemicals such as VOCs emitted from household cleaners, paint, and varnishes. Also,whenbacteriadie,theyreleaseendotoxinsintotheair,whichcancauseadversehealtheffects31. So ventilation is important when cooking, cleaning, and disinfecting in a building. Ageogenic source ofindoorairpollutionisradon32.

Otherclassifications

Airpollutantscomeintheformof***gases***andfinelydivided***solid***and***liquid***aerosols.

*Aerosols*arelooselydefinedas“anysolidor liquidparticlessuspendedintheair”(1).

Air pollutants can also be of*primary* or *secondary* nature. *Primary air pollutants* are the onesthatareemitteddirectly intotheatmosphereby thesources(suchaspower-generatingplants).

*Secondary air pollutants* are the ones that are formed as a result of reactions between primarypollutantsand otherelements intheatmosphere,suchas ozone.

### Typesof pollutants

SulfurDioxide

Sulfur dioxidewas a serious problem in air pollution in the earliest daysofindustrialization. Ithas been the major problem in reducing or acidifying air pollution during the period of rapideconomicgrowthinmanycountries.In1953,Amduretal.studiedtheeffectsofsulfurdioxideon humans and found that, at least in acute exposures, concentrations of up to 8 ppm causedrespiratorychangesthatweredosedependent.(Thisisoneofthefirststudiestousephysiologicalmeasurementsasanindicationoftheeffectsofairpollution.)Laterstudiesrevealed that the main effect of sulfur dioxide is broncho constriction (closing of the airwayscausing increased resistance to breathing) which is dose dependent, rapid, and tended to peakat 10 minutes (Folinsbee, 1992). Persons with asthma are particularly susceptible and in factasthmatics suffer more from the effects of sulfur dioxide than does the general public. Personswith asthma who exercise will typically experience symptoms at 0.5 ppm, depending on theindividual.

Sulfate, the sulfur-containing ion present in water, remains a major constituent of air pollutioncapable of forming acid. Sulfate itself appears to be capable of triggering broncho constriction inpersons with airways reactivity and it is a major constituent of ultrafine particulates. There areother acid ingredients in air pollution, such as nitric acid, but less is know about them. Theseacids, though, cause a phenomenon known as acid rain, with their emission into the air byindustry andmotorvehicles.

Because of their small size and tendency to ride along on particulates, acid aerosols such assulfurdioxide,sulfatesandnitrogendioxidetendtodepositdeeplyinthedistallungandairspace. They appear to provoke airways responses in an additive or synergistic manner withozone.Theyhavealsobeenimplicatedincausingmortalityinassociationwithultrafineparticulates.

SO2 and sulfates are the principal chemical species that cause acid precipitation. They may betransportedlongdistancesintheatmosphereawayfromtheirsourceandresultinacidificationofwaterandsoils.

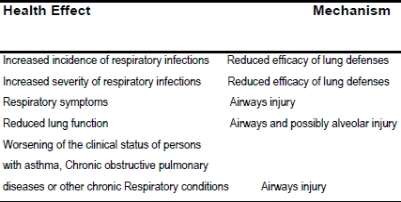
NitrogenDioxide

Nitric oxide (NO) is produced by combustion. Nitrogen dioxide (NO2), which has greater healtheffects, is a secondary pollutant created by the oxidation of NO under conditions of sunlight, ormay be formed directly by higher temperature combustion in power plants or indoors from gasstoves. Levels of exposure to nitrogen dioxide that should not be exceeded (WHO guidelinelevels)arerespectively400μg/m3(0.21partspermillion(ppm)foronehourand150μg/m3(0.08 ppm)for24hours.

The direct effects of nitrogen oxide include increased infectious lower respiratory disease inchildren (including longterm exposure as in houses with gas stoves) and increased asthmaticproblems.Extensivestudiesoftheoxidesofnitrogenhaveshownthattheyimpairhostdefensesintherespiratorytract,increasingtheincidenceandseverityofbacterialinfections

after exposure. They have a marked effect in reducing the capacity of the lung to clear particlesandbacteria.

NO2 also provokes broncho-constriction and asthma in much the same way as ozone but it isless potent than ozone in causing asthmatic effects. Despite decades of research, however, thefulleffects ofNO2are notknown.Knownhumanhealtheffectsaresummarizedbelow:



Particulatesmatter

Particle matter in the air (aerosols) is associated with an elevated risk of mortality and morbidity(including cough and bronchitis), especially among populations such as asthmatics and theelderly. As indicated, they are released from fireplaces, wood and coal stoves, tobacco smoke,dieselandautomotiveexhaust,andothersourcesofcombustion.TheUSEnvironmentalprotection Agency (EPA) sets a standard of 265 μg/m3 in ambient air, but does not have astandard for indoor air levels. Usual concentrations range from 500 μg/m3 in bars and waitingrooms to about 50 μg/m3 in homes. In developed countries, tobacco smoke is the primarycontributortorespirableparticlesindoors.

#### Particulatematter(PM10)

Larger particulates, which are included in PM10 (particulates 10 μm and smaller) consist mostlyof carbon-containing material and are produced from combustion; some fraction of these areproduced by wind blowing soil into the air. These larger particulates do not seem to have asmucheffectonhumanhealthasthe smallerparticulates.

#### Particulatematter(PM2.5)

In recent years we have learned a great deal about the health effects of particles. As notedabove, particulates in urban air pollution that are extremely small, below 2.5 μm in diameter, aredifferentintheir chemicalcompositionthanlarger particles. ParticulatesinthefractionPM2.5

(2.5 μm and below) contain a proportionately larger amount of water and acid forming chemicalssuch as sulfate and nitrate, as well as trace metals. These smaller particulates penetrate easilyand completely into buildings and are relatively evenly dispersed throughout urban regionswhere they are produced. Unlike other air contaminants that vary in concentration from place toplacewithinanarea,PM2.5 tendstoberatheruniformlydistributed.

PM2.5 sulfate and ozone cannot be easily separated because they tend to occur together inurban air pollution. Recent research strongly suggests that at least PM2.5 and sulfate, andprobably ozone as well, cause an increase in deaths in affected cities. The higher the airpollution levels for these specific contaminants, the more excess deaths seem to occur on anygiven day, above the levels that would be expected for the weather and the time of year.Likewise,accountingforthetimeoftheyearandtheweather,therearemorehospitaladmissions for various conditions when these contaminants are high. Ozone, particularly, islinked with episodes of asthma, but all three seem to be associated with higher rates of deathsfrom and complaints about lung disease and heart disease. It is not yet known which is thepredominant factor in the cause of these health effects, and some combination of each may beresponsibleforsomeeffects.Althoughtheeffectofairpollutionisclearlypresentinthestatistics, air pollution at levels common in developed countries is probably much less of a factorin deaths and hospital admissions than the weather, cigarette smoking, allergies, and viralinfections. However, the populations exposed to air pollution are very large, and even if only 5%of all excess deaths during a one-week period are related to air pollution in a major city, areasonable estimate, this means that thousands of deaths could be prevented. One unexpectedfinding of this research is that the effect of particulate air pollution on deaths and hospitaladmissions is continuous from high levels to low levels of exposure. In other words, there is noobvious level below which the public is clearly protected, and even at low levels of air pollution,some excess deaths still seem to occur. At first, it was thought that these deaths representedsick people who would soon die anyway. If this were true, one would expect there to be fewerdeaths than expected when air pollution levels returned to normal or below normal, but a carefulstudy of the death rate during and just after periods of high air pollution levels does not seem toshow this. At the much greater levels encountered in many developing countries, the effect islikely to be proportionately greater. There are many factors at work that complicate such studiesindevelopingcountries.Theveryhighratesofrespiratorydiseaseduringthewinteramongeven non smokers in some northern Chinese cities, for example, has been attributed to airpollution and this is likely to be true, however, cigarette smoking, indoor air pollution from coal-firedstoves,crowdedconditionsandtheriskofviralinfectionsmay alsobeimportantfactors.

There remains much more work to do to understand this problem, but the essential messageseemsclear:atany level,particulateairpollutionandpossibly ozoneareassociatedwithdeaths,andboth are clearlyassociatedwithhospitaladmissionsand healthrisks.

Hydrocarbons

Most hydrocarbons such as aliphatic and salicylic hydrocarbons are generally biochemical inertatambientlevelsandthuspresentlittle hazards. Aromatichydrocarbonsuch,ontheotherhand

arebiochemical and biologically active aremoreirritatingto mucousmembranes compoundslike benzo(a) Pyrene are known to be potent carcinogens. HCs are included among the criteriaairpollutants,chieflybecauseoftheirroleascatalystsinthe formationofphotochemicalsmog.

Lead

Lead is the best studied of these trace metals. It is known to be a highly toxic substance thatparticularlycausesnervedamage.Inchildren,thiscanresultinlearningdisabilitiesandneurobehavioral problems. An estimated 80 – 90% oflead in ambient air is thought to bederived from the combustion of leaded petrol. Due to its effects on the behavior and learningabilities of children even at low levels of exposure, efforts throughout the world are directed atremovingleadfromgasoline.TheWHOguidelinesvalueforlong-termexposuretoleadintheairis0.5–1.0μg/m3/year).

**Influenceofmeteorologicalphenomenaonairquality**

Meteorologyspecifieswhathappentopufforplumeofpollutantsfromthetimeitisemittedtothe time it is detected at some other location. The motion of the air causes a dilution of airpollutant concentration and we would like to calculate how much dilution occurs as a function ofthemeteorologyoratmospheric condition.

Air pollutants emitted from anthropogenic sources must first be transported and diluted in theatmospherebeforetheseundergovariousphysicalandphotochemicaltransformationandultimately reach their receptors. Otherwise, the pollutant concentrations reach dangerous levelnear the source ofemission. Hence, it is important that we understand the natural processesthatareresponsible for theirdispersion.The degree ofstability ofthe atmosphere in turndependson the rate ofchange ofambienttemperature withaltitude.

VERTICALDISPERSIONOFPOLLUTANTS

Asaparcelofairintheatmosphererises,itexperiencesdecreasingpressureandthusexpands. This expansion lowers the temperature of the air parcel, and therefore the air cools asit rises. The rate at which dry air cools as it rises is called the dry adiabatic lapse rate and isindependent of the ambient air temperature. The term adiabatic means that there is no heatexchange between the rising parcel of air under consideration and the surrounding air. The dryadiabatic lapse rate can be calculated from the first law of thermodynamics (1°C per 100m). Asthe air parcel expands, it does work on the surroundings. Since the process is usually rapid,thereisnoheattransferbetweentheairparcelandthe surroundingair.

*Saturatedadiabaticlapserate,(Γs)*

Unlike the dry adiabatic lapse rate, saturated adiabatic lapse rate is not a constant, since theamountofmoisturethattheaircanholdbeforecondensationbeginsisafunctionoftemperature. A reasonable average value of the moist adiabatic lapse rate in the troposphere isabout6°C/Km.

### Example

An air craft flying at an altitude of 9 km draws in fresh air at - 40°C for cabin ventilation. If thatfresh air is compressed to the pressure at sea level, would the air need to be heated or cooled ifitistobedeliveredtothe cabinat20°C.

### Solution

Asthe air iscompressed,itwarms up it iseven easier for the air to hold whatevermoisture itmay have, had .so there is no condensation to worry about and the dry adiabatic lapse rate canbeused,At10°Cperkm,compressionwillraisetheairtemperatureby

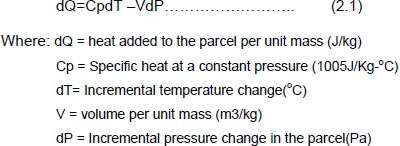
10x9=90°Cmakingit -40+90°c=50°C

It needs to betheair conditionedTheairinmotion iscalledwind**,**airwhichisrushingfrom anareaofhighpressure towardsanareaoflow pressure.Whenthe weather-manreportsthewindtous heusesa measuringsystemworkedoutin 1805byAdoniralBeaufort.Forexample,a“moderatebreeze”isawindof13to18milesanhour.Obviouslyairqualityatagivensitevaries tremendously from day to day, even though the emissions remain relatively constant. Thedeterminingfactors haveto dotheweather:howstrongthe windsare,whatdirection they areblowing,thetemperature profile ,howmuchsunlightavailabletopowerphotochemicalreactions,and how longithasbeensincethe laststrongwindsorprecipitationwereabletocleartheair.Airquality isdependentonthedynamicsoftheatmosphere,thestudy ofwhichiscalled*meteorology*

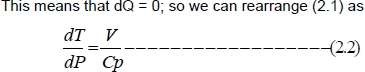
Temperaturelapserateand stability

The ease with which pollutants can disperse vertically into the atmosphere is largely determinedby the rate of change of air temperature with altitude. For some temperature profiles the air isstable,thatis,airatagivenaltitudehasphysicalforcesactingonitthatmakeitwanttoremainat that elevation. Stable air discourages the dispersion and dilution of pollutants. For othertemperature profiles, the air is unstable. In this case rapid vertical mixing takes place thatencouragespollutantdispersalandincreaseairquality.Obviously,verticalstabilityoftheatmosphere is an important factor that helps determine the ability of the atmosphere to diluteemissions;hence,itiscrucialtoairquality.Letusinvestigatetherelationshipbetweenatmospheric stability and temperature. It is useful to imagine a “parcel” of air being made up of anumber of air molecules with an imaginary boundary around them. If this parcel of air movesupwardintheatmosphere,itwillexperiencelesspressure,causingittoexpandandcool.Onthe other hand, if it moves dawn ward, more pressure will compress the air and its temperaturewill increase. As a starting point, we need a relationship that expires an air parcel‟s change oftemperatureasitmovesupordownintheatmosphere.Asitmoves,wecanimagineits

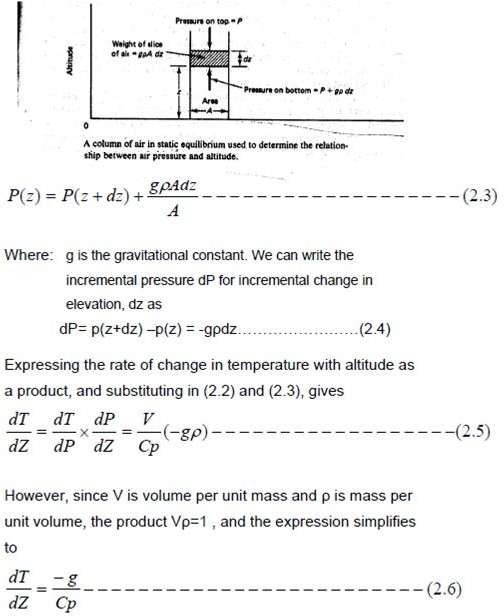
temperature, pressure and volume changing, and we might imagine its surrounding adding orsubtractingenergy from the parcel. Ifwe make small changes in these quantities,and applyboth the ideal gas law and the first law of thermodynamics, it is relatively straightforward to drivethefollowingexpression.



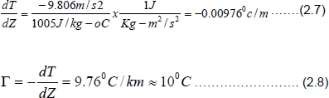
Letusmakethequiteaccurateassumptionthatastheparcelmoves,thereisnoheattransferredacross its boundary,thatis,thatthisprocessis *adiabatic*



Theaboveequationgivesusanindicationofhowatmosperictemperaturewouldchangewithair pressure, but what are really interested in is how it changes with altitude .To do that we needto know how pressure and altitude are related. Consider a static column of air with a crosssectionA,asshowninfigure.AhorizontalsliceofairinthatcolumnofthicknessdZanddensityρ will have mass ρAdZ. If the pressure at the top of the slice due to the weight of air above it isP(Z+dZ), then the pressure at the bottom of the slice ,P(Z) will be P(z+dz)plus the added weightperunitareaofthe sliceitself:



The negative sign indicates that temperature decreases with increasing altitude. Substituting theconstant g =9.806m/s2, and the constant –volume specific heat of dry air at room temperature,Cp1005J/kg.0C in(2

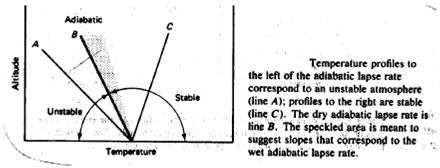


.6)yields

ATMOSPHERICSTABILITY

The ability of the atmosphere to disperse the pollutants emitted in to it depends to a large extenton the degree of stability. A comparison of the adiabatic lapse rate with the environmental lapserate gives an idea of stability of the atmosphere. When the environmental lapse rate and the dryadiabaticlapserateareexactlythesame,araisingparcelofairwillhavethesamepressureand temperature and the density of the surroundings and would experience no buoyant force.Such atmosphere is said to be neutrally stable where a displaced mass of air neither tends toreturn toitsoriginalpositionnortendsto continue itsdisplacement

Whentheenvironmentallapserate(-dT/dz.)Envisgreaterthanthedryadiabaticlapserate,Γthe atmosphere is said to be super adiabatic. Hence a raising parcel of air, cooling at theadiabatic rate, will be warmer and less dense than the surrounding environment. As a result, itbecomes more buoyant and tends to continue it‟s up ward motion. Since vertical motion isenhanced by buoyancy, such an atmosphere is called unstable. In the unstable atmosphere theair from different altitudes mixes thoroughly. This is very desirable from the point of view ofpreventingpollution,sincetheeffluentswillberapidlydispersedthroughoutatmosphere.Onthe other hand, when the environmental lapse rate is less than the dry adiabatic lapse rate, arising air parcel becomes cooler and denser than its surroundings and tends to fall back to itsoriginal position. Such an atmospheric condition is called stable and the lapse rate is said to besub adiabatic. Under stable condition their is very little vertical mixing and pollutants can onlydisperse very slowly. As result, their levels can build up very rapidly in the environment. Whentheambientlapserateandthedryadiabaticlapserateareexactlythesame,theatmospherehas neutral stability. Super adiabatic condition prevails when the air temperature drops morethan 1°C /100m; sub adiabatic condition prevail when the air temperature drops at the rate lessthan1°c/100m

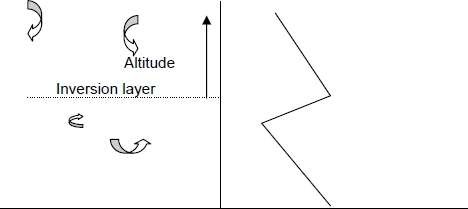


Inversion

Atmospheric inversion influences the dispersion of pollutantsby restricting vertical mixing. Thereareseveralwaysbywhichinversionlayerscanbeformed .Oneofthemostcommontypesis

the elevated **subsidence inversion**, This is usually associated with the sub tropical anti cyclonewhere the air is warmed by compression as it descends in a high pressure system and achievestemperature higher than that of the air under neath. If the temperature increase is sufficient, aninversionwillresult

* Itlastsformonthsonend
* Occurat higherelevation
* Morecommoninsummer thanwinter



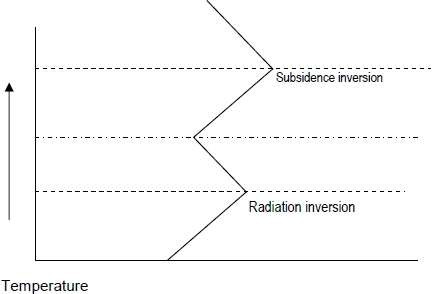
Thesubsidenceis caused by air flowingdown toreplaceair,which hasflowedoutofthehigh-pressureregion

RadiationInversion

The surface of the earth cools down at night by radiating energy toward space. On cloudy night,the earth‟s radiation tends to be absorbed by water vapor, which in turn reradiates some of thatenergy back to the ground. On the clear night, however, the surface more readily radiate energytospace,andthusgroundcoolingoccursmuchmorerapidly.Asthegroundcools,thetemperature of the air in contact with the ground also drops. As is often the case on clear winternights, the temperature of this air just above the ground becomes colder than the air above it,creating an inversion. Radiation inversions begins to form at dusk .As the evening progresses,the inversion extends to a higher and higher elevation, reaching perhaps a few hundred metersbefore the morningsunwarmstheground again,breakingup theinversion.

Radiation inversion occurs close to the ground, mostly during the winter, and last for only amatter of hours. They often begin at about the time traffic builds up in the early evening, whichtrapsautoexhaustatgroundlevelandcauseselevatedconcentrationofpollutionforcommuters. With out sunlight, photochemical reactions can not takes place, so the biggestproblemis usually accumulation ofcarbon monoxide (CO). In the morning,as the sun warmsthe ground and the inversion begins to the break up, pollutants that have been trapped in thestableairmassaresuddenlybroughtbacktoearthinaprocessknownasfumigation.Fumigationcancauseshortlivedhighconcentrationsofpollutionatgroundlevel.

Radiation inversions are important in another context besides air pollution. Fruit growers inplaces like California have long known that their crops are in greatest danger of frost damage onwinter nights when the skies are clear and a radiation inversion sets in. Since the air even a fewmeters up is warmer than the air at crop level, one way to help protect sensitive crops on suchnightsissimply tomixtheairwithlarge motordrivenfans.



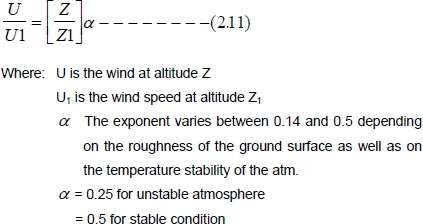
The third type of inversion, know as advective inversion is formed when warm air moves over acold surface or cold air. The inversion can be a ground based in the former case, or elevated inthe latter case. An example of an elevated advective inversion occurs when a hill range forces awarmlandbreezeto follow athigh levelsandcoolseabreathes flowsat low levelintheoppositedirection.

TOPOGRAPHICALEFFECTS

In large bodies of water the thermal inertia of the water causes a slower temperature changethan the near by land. For example, along an ocean coastline and during periods of high solarinput, the daytime air temperature over the ocean is lower than over the land. The relative warmairoverthelandrisesandreplacedbycooleroceanair.Thesystem isusuallylimitedtoaltitudes of several hundred meters,which of course, is where pollutants are emitted. Thebreezedevelopsduringthedayandstrongestinmidafternoon.Atnighttheoppositemayoccur, although, usually not with such large velocities. At night the ocean is relatively warm andthe breeze is from the cooler land the warmer ocean. The on shore breeze is most likely in thesummer months, while the off-shore land breeze more likely occur in winter months. A secondcommon wind system caused by topographical effect is the mountain - valley wind. In this casethe airtends to flow down thevalley atnightValleysarecoolerathigherelevation and thedriving force for the airflow result from the differential cooling. Similarly, cool air drains off themountainatnightandflowsintothevalley.Duringthe day lighthours an opposite flowmay

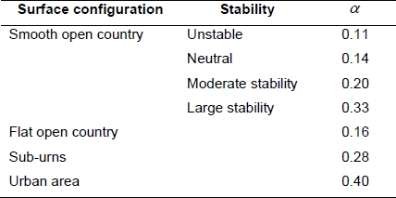
occur as the heated air adjacent to the sun warmed ground begins to rise and flow both up thevalley and up the mountain slopes. However, thermal turbulence may mask the daytime up-slope flow so that it is not as strong as the nighttime down - slope flow. Both the sea breeze andthe mountain valley wind are important in meteorology of air pollution. Large power stations areoftenlocatedonoceancostsoradjacenttolargelakes.Inthiscasethestackeffluentwilltendtodriftoverthelandduringthe dayandmay besubjectedtofumigation.

Windvelocityand turbulence



The wind velocity profile is influenced by the surface roughness and time of the day. During theday, solar heatingcauses thermal turbulence or eddies set up convective currents so thatturbulent mixing is increased. This results in a more flat velocity profile in the day than that atnight.Thesecondtypeofturbulenceisthemechanicalturbulence,whichisproducedbyshearing stress generated by air movement over the earth‟s surface. The greater the surfaceroughness, the greater the turbulence. The mean wind speed variation with altitude istheplanetary boundarylayercanberepresentedbya simpleempiricalpower.

In practice, because of the appreciable change in wind speed with altitude, a wind speed valuemust be quoted with respect to the elevation at which it is measured. This reference height forsurfacewindmeasurementisusually10meters



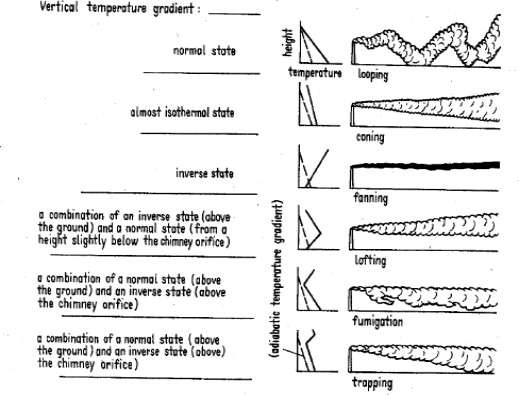
Atmospheric turbulence is characterized by different sizes of eddies. These eddies are primarilyresponsiblefordilutingandtransportingthepollutantsinjectedintotheatmosphere.Ifthesizeof the eddies is larger then the size of the plume or a puff then the plume or the puff will betransported down wind by the eddy with little dilution. Molecular diffusion will ultimately dissipatethe plume or the puff. If the eddy is smaller than the plume or the puff, the plume or the puff willbedisperse uniformlyas theeddy entrainsfreshairatitsboundary.

### Plumebehavior

Thebehaviorofaplumeemittedfroman elevatedsource such as atallstackdependson thedegreeofinstability oftheatmosphereandthe prevailingwindturbulence.

Classificationofplumebehavior

1. **Looping:** it occurs under super adiabatic conditions with light to moderate windspeedson a hot summer after noon when large scale thermal eddies are present. The eddies carryportion of a plume to the ground level for short time periods, causing momentary high surfaceconcentration of pollutants near the stack. Thus the plume moves about vertically in a spasticfashionandthe exhaustgasesdisperserapidly
2. **Conning:** It occurs under cloudy skies both during day and night, when the lapse rate isessentiallyneutral.Theplumeshapeisverticallysymmetricalabouttheplumelineandthemajor part of the pollutant concentration is carried down -wind fairly far before reaching thegroundlevel.
3. **Fanning:** occurs when the plume is dispersed in the presence of very light winds as aresultofstrongatmosphericinversions.Thestablelapseratesuppressestheverticalmixing,butnotthehorizontalmixingentirely.Forhighstacks, fanningisconsideredafavourablemeteorologicalcondition becausethe plumedoesnotcontribute togroundpollution.
4. **Fumigation:** here a stable layer of air lies a short distance above the release point of theplume and the unstable air layer lies below the plume .This unstable layer of air causes thepollutant to mix down -wind toward the ground in large lumps, but fortunately this condition isusually of short duration lasting for about 30 minutes Fumigation is favored by clear skies andlightwinds,anditismorecommon inthesummerseasons.
5. **Lofting :** The condition for lofting plume are the inverse of those for fumigation , when thepollutants are emitted above the inverse layer , they are dispersed vigorously on the up warddirection since the top of the inversion layer acts as a barrier to the movement of the pollutantstowardstheground.
6. **Trapping:** occurs when the plume effluent is caught between two inversion layers. Thediffusion of the effluent is severely restricted to the unstable layer between the two unstablelayers.

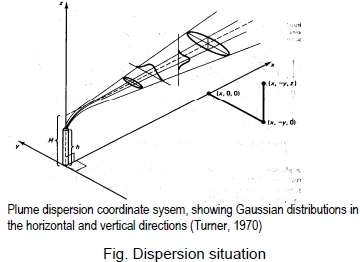


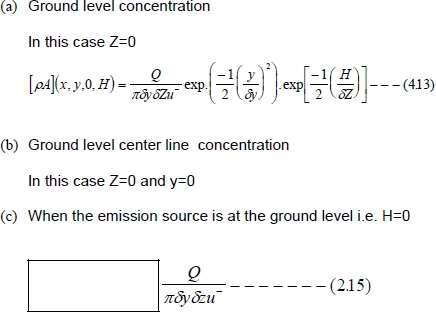
PLUMEDISPERSION

Dispersionistheprocessbywhichcontaminantsmovethroughtheairandaplumespreadsover a large area, thus reducing the concentration of pollutants it contains. The plume spreadsboth horizontally and vertically. If it is gaseous, the motion of the molecules follows the low ofgaseousdiffusionThemostcommonlyusedmodelforthedispersionofgaseousairpollutantsistheGaussian,developedbyPasquill,inwhichgasesdispersedintheatmosphereareassumedto exhibitideagasbehavior

TheGaussianplume model

Thepresenttendencyis to interpretdispersiondataintermsoftheGaussianmodel.Thestandarddeviationsare relatedto the eddydiffusivities

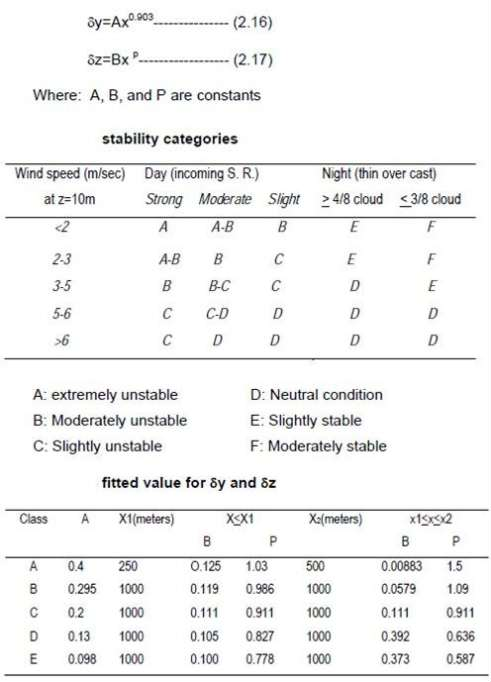


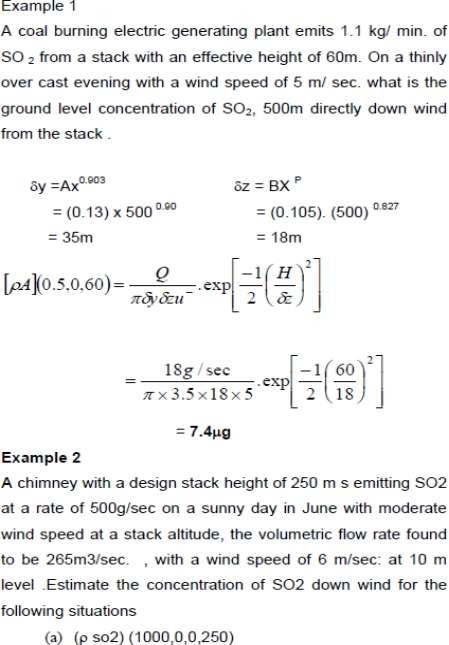


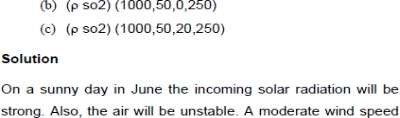
⎦⎥

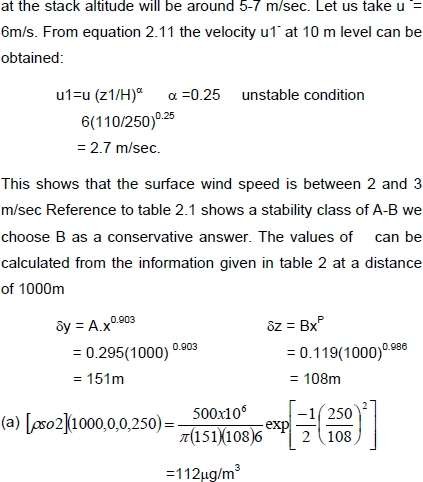
**Estimationof** δ*yand*δ*z*

The values of δ*yand*δ*z*have been shown to be related to the diffusion coefficient in the y and zdirections .As might be expected, δy and δz are functions of down wind distance x from thesource as well as the atmospheric stability conditions. Based on the experimental observation ofthe dispersion of plumes, pasquill and Gifford have devised a method for calculating, δy and δzofthe spreadingplume fromknowledgeofthe atmosphericstability.Sixcategoriesoftheatmospheric stability; A through F, were suggested and these are shown in the table 2.1 as afunctionofwindandsolarradiation











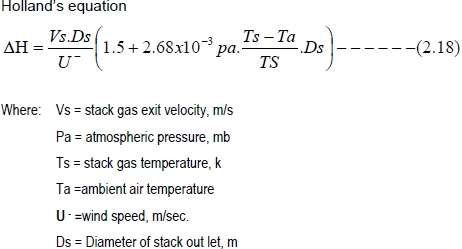
Plumerise

Generally,effluentplumesfromthechimneystacksarereleasedintotheatmosphereatelevated temperatures. The rise of the plume after release to the atmosphere is caused bybuoyancy and the vertical momentum of the effluent. Under windless conditions, the plume risesvertically but more often it is bent as a result of the wind that is usually present. This rises of theplume adds to the stack an additional height ΔH, such that the height H of the virtual origin isobtained by adding the term ΔH, the plume rise, the actual height of the stack, Hs. The plumecenter line height H = Hs +ΔH is known as the effective stack height and it is this height that isusedintheGaussianplumecalculations.

### Plumerise

Estimationofplumerise

### Buoyantplumes



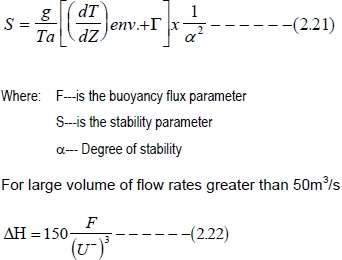
In the case of buoyant plumes, the influence of buoyancy is much greater than the influence ofvertical momentum. Such plumes are usually obtained when the release temperatures are morethan50cgreaterthan ambientatmospherictemperatures.

### Plumeriseunderstableandcalmconditions

When there is little or no wind, the bending of the plume is negligible small and it rises to someheight where the buoyancy force is completely dissipated. The recommended equation for suchasituation is





.

### Non- buoyantplumes

Forsourcesattemperatureclosetotheambientorlessthan50°Caboveambientandhavingexitspeedofatleast10m/sec,thefollowingequationcanbe used



**AIRPOLLUTIONCONTROL**

Pollutioncontrolequipmentcanreduceemissionsbycleaningexhaustanddirtyairbeforeit

leaves the business. A wide variety of equipment can be used to clean dirty air. DNR engineerscarefully study and review how these controls may work and the methods and requirements areputintoapermit-a majordutyperformed by theDNR.

### ProcessControls

There are other ways to reduce emissions besides using pollution control equipment--preventemissions to begin with. Air quality permits help minimize, reduce or prevent emissions as muchaspossiblebyplacingrequirementson how thingsaredone.

Permitscanspecifythequantity,type,orqualityoffuelorothersubstanceusedinaprocess.Forexample,apermitmightspecifythemaximum percentof sulfur thatcanexistinthecoalto

reduce sulfur dioxide emissions. A permit may specify the quantity of volatile chemicals in paint,solvent, adhesive or other product used in large quantity during manufacturing. Permits can alsohelp reduce the impact of emitted pollutants on local air by specifying smokestack height andother factors.

Engineers can also set combustion specifications to minimize emissions. For example, to helpreduce nitrogen oxide formation, the combustion conditions in the furnace can be altered. Theflame temperature can be lowered or raised, the amount of time air remains in the combustionchamber can be altered, or the mixing rate of fuel and air can be changed. These options areoften reviewed, studied and best choices made depending upon cost, plant design and manyothervariables.

*GRAVITYSETTLINGCHAMBERS*

Thisisasimpleparticulatecollectiondeviceusingtheprincipleofgravitytosettletheparticulate matter in a gas stream passing through its long chamber. The primary requirement ofsuch a device would be a chamber in which the carrier gas velocity is reduced so as to allow theparticulate matter to settle outofthe moving gas streamunderthe action ofgravity.Thisparticulate matter is then collected at the bottom of the chamber. The chamber is cleanedmanually todisposethewaste.

Thegasvelocitiesinthesettlingchambermustbesufficientlylowfortheparticlestosettleduetogravitationalforce.Literatureindicatesthatgasvelocitylessthanabout3m/sisneededto prevent re-entrainment of the settled particles. The gas velocity of less than 0.5 m/s willproduce good results.

Curtains, rods, baffles and wire mesh screens may be suspended in the chamber to minimizeturbulence and to ensure uniform flow. The pressure drop through the chamber is usually lowandisdueto the entranceandexitlosses.

The velocity of the particles in the settlingchamber can be obtained by Stokes‟ law asfollows:

**Vs= (g(rp –r) D2 )/18 µ**

Where,

D=Diameterof the particle.

g = accelerationdue togravityrp=density oftheparticle

r=densityofthe gas

µ=viscosityofthegas

Theadvantagesofsettling chambersare:

1. lowinitialcost,
2. simpleconstruction,
3. lowmaintenancecost,
4. low pressuredrop,
5. dryandcontinuousdisposalofsolidparticles,
6. useofanymaterialforconstruction, and
7. temperature and pressure limitations will only depend on the nature of theconstructionmaterial.

Thedisadvantagesofthisdevice are

1. largespacerequirementsand
2. onlycomparativelylargeparticles(greaterthan10micron) canbecollected.

Because of the above advantages and disadvantages, settling chambers are mostly used aspre-cleaners. They are sometimes used in the process industries, particularly in the food andmetallurgical industries as the first step in dust control. Use of settling chambers as pre-cleanerscan also reduce the maintenance cost ofhigh efficiency control equipment,whichis moresubjecttoabrasivedeterioration.

*CYCLONES:*

Settlingchambersdiscussedabovearenoteffectiveinremovingsmallparticles.Therefore,one needs a device that can exert more force than gravity force on the particles so that they canberemovedfromthegasstream.Cyclonesusecentrifugalforcesforremovingthefineparticles.Theyarealsoknownascentrifugalorinertialseparators.

The cyclone consists of a vertically placed cylinder which has an inverted cone attached to itsbase. The particulate laden gas stream enters tangentially at the inlet point to the cylinder. Thevelocity of this inlet gas stream is then transformed into a confined vortex, from which centrifugalforces tend to drive the suspended particles to the walls of the cyclone. The vortex turns upwardafter reaching at the bottom of the cylinder in a narrower inner spiral. The clean gas is removedfromacentralcylindricalopeningatthetop,whilethedustparticlesarecollectedatthebottominastoragehopperbygravity.

The efficiency of a cyclone chiefly depends upon the cyclone diameter. For a given pressuredrop, smaller the diameter, greater is the efficiency, because centrifugal action increases withdecreasing radius ofrotation. Centrifugal forces employed in modern designs vary from 5 to2500 times gravity depending on the diameter of the cyclone. Cyclone efficiencies are greaterthan 90% for the particles with the diameter of the order of 10 µ. For particles with diameterhigherthan 20 µ,efficiencyisabout95%.

Theefficiency ofacyclonecanbeincreasedbytheuseof cycloneseither inparallelorinseries.Abriefexplanationofbotharrangementsis givenbelow:

MultipleCyclones:

Abatteryofsmallercyclones,operatinginparallel,designedforaconstantpressuredropineachchamber.The arrangementis compact,withconvenientinletand outletarrangements.They cantreatalarge gasflow,capturingsmallerparticles.

Cyclonesinseries:

Two cyclones are usedin series.Thesecondcycloneremovestheparticles thatwerenotcollected inthefirst cyclone,because of thestatistical distributionacrosstheinlet,oraccidentalre-entrainmentduetoeddycurrents andre-entrainmentin thevortexcore,thusincreasingthe efficiency.

Theadvantagesofcyclonesare:

1. lowinitialcost,
2. simpleinconstruction andoperation,
3. low pressuredrop,
4. lowmaintenancerequirements,
5. continuousdisposalofsolidparticulatematter,and
6. useofany material in theirconstructionthat canwithstand thetemperatureandpressure requirements.

Thedisadvantagesofcyclones include:

1. lowcollectionefficiencyforparticlesbelow5–10µindiameter,
2. severe abrasion problems can occur during the striking of particles on the wallsofthecyclone,and
3. adecreasein efficiencyatlowparticulateconcentration.

Typicalapplicationsof cyclonesare:

1. For the control of gas borne particulate matter in industrial operations such ascementmanufacture, food and beverage,mineralprocessingandtextileindustries.
2. To separate dust in the disintegration operations, such as rock crushing, ore handlingandsandconditioninginindustries.
3. Torecover catalystdusts in thepetroleumindustry.
4. Toreduce theflyashemissions.

Theoperatingproblems are:

1. Erosion: Heavy, hard, sharp edged particles, in a high concentration, moving at a highvelocityinthecyclone,continuouslyscrapeagainstthewallandcanerodethemetallicsurface.
2. Corrosion: If the cyclone is operating below the condensation point, and if reactive gasesare present in the gas stream, then corrosion problems can occur. Thus the product should be

above thedewpointor astainless steelalloyshouldbeused.

1. Build – up:A dustcake builds up on the cyclone walls,especially around the vortexfinder, at the ends of any internal vanes, and especially if the dust is hygroscopic. It can be asevereproblem.

*ELECTROSTATICPRECIPITATORS:*

Electrostatic precipitators (ESP) are particulate collection devices that use electrostatic force toremove the particles less than 5 micron in diameter. It is difficult to use gravity settlers andcycloneseffectivelyforthesaidrangeofparticles.Particlesassmallasone-tenthofamicrometercanberemovedwith almost100% efficiencyusingelectrostaticprecipitators.

The principle behind all electrostatic precipitators is to give electrostatic charge to particles in agiven gas stream and then pass the particles through an electrostatic field that drives them to acollectingelectrode.

The electrostaticprecipitatorsrequire maintenance ofa high potential difference between thetwoelectrodes,oneisadischargingelectrodeandtheotherisacollectingelectrode.Becauseof the high potential difference between the two electrodes, a powerful ionizing field is formed.Veryhighpotentials– ashighas100kVareused.Theusualrangeis40-60kV.Theionization creates an active glow zone (blue electric discharge) called the „corona‟ or „coronaglow‟.Gasionizationisthedissociationof gasmoleculesintofreeions.

Astheparticulatein thegaspassthrough the field,theygetchargedand migrate to theoppositely charged collecting electrode, lose their charge and are removed mechanically byrapping,vibration,orwashingtoahopperbelow.

Insummary, thestepbystepprocessofremovingparticles usingESPs is:

1. Ionizingthegas.
2. Charging thegasparticles.
3. Transporting theparticlestothecollectingsurface.
4. Neutralizing,orremoving thechargefromthe dustparticles.
5. Removingthedustfrom the collecting surface.

Themajorcomponents ofelectrostatic precipitators are:

1. Asourceofhighvoltage
2. Dischargeandcollectingelectrodes.
3. Inletandoutletfor thegas.
4. A hopperforthedisposalofthecollectedmaterial.
5. Anoutercasingtoform anenclosurearound theelectrodes.

The ESP is made of a rectangular or cylindrical casing. All casings provide an inlet and outletconnection for the gases, hoppers to collect the precipitated particulate and the necessarydischarge electrodes and collecting surfaces. There is a weatherproof, gas tight enclosure overtheprecipitatorthathousesthehigh voltage insulators.

Electrostatic precipitators also usually have a number of auxiliary components, which includeaccess doors, dampers, safety devices and gas distribution systems. The doors can be closedand bolted under normal conditions and can be opened when necessary for inspection andmaintenance.Dampersareprovidedtocontrolthequantityofgas.Itmayeitherbeaguillotine,alouverorsomesuch otherdevicethatopensandcloses toadjustgasflow.

Thesafetygroundingsystemisextremelyimportantandmustalwaysbeinplaceduringoperation and especially during inspection. This commonly consists of a conductor, one end ofwhich is grounded to the casing, and the other end is attached to the high voltage system by aninsulatedoperatinglever.

The precipitator hopper is an integral part of the precipitator shell and is made of the samematerial as the shell. Since ESPs require a very high voltage direct current source of energy foroperation,transformersarerequiredtostepupnormalservicevoltagestohighvoltages.Rectifiersconvertthealternatingcurrentto unidirectionalcurrent.

Typesof electrostaticprecipitators:

There are many types of ESPs in use throughout the world. A brief description of three differenttypesisgivenbelow:

### Singlestageortwostage:

InasinglestageESP,gasionizationandparticulatecollectionarecombinedinasinglestep.An example is the “Cottrell” single-stage precipitator. Because it operates at ionizing voltagesfrom 40,000 to 70,000 volts, DC, it may also be called a high voltage precipitator. It is usedextensively for heavy duty applications such as utility boilers, large industrial boilers and cementkilns.

Inthetwo-stageprecipitatorparticlesareionizedinthefirstchamberandcollectedinthesecond chamber.For example, “Penny”– the two stage precipitator uses DC voltages from11,000 to 14,000 volts for ionization and is referred to as a low voltage precipitator. Its use islimited to low inlet concentration, normally not exceeding 0.025 grains per cubic feet. It is themost practical collection technique for many hydrocarbon applications, where the initial clearexhauststackturnsinto avisibleemissionasvaporcondenses.

### PipetypeorPlatetype:

In the pipe type electrostatic precipitators, a nest of parallel pipes form the collecting electrodes,which may be round, or square. Generally the pipe is about 30 cm in diameter or less. Mostcommonlyawire withasmallradius ofcurvature,suspendedalongtheaxisofeach pipe,is

used. The wires must be weighted or supported to retain proper physical tension and location,electrically insulated from the support grid and strong enough to withstand rapping or vibrationfor cleaningpurpose.Thegasflowisaxial frombottomtotop.

Thepipeelectrodes,maybe2-5mhigh.Spacingbetweenthedischargeelectrodeandcollecting electrode ranges from 8-20 cm. Precipitation of the aerosol particles occurs on theinner pipe walls, from which the material can be periodically removed by rapping of pipes or byflushing water. Thepipetypeprecipitatorisgenerallyused for theremovalofliquid particles.

In the plate type precipitators the collection electrodes consist of parallel plates. The dischargeelectrodes are again wires with a small curvature. Sometimes square or twisted rods can beused. The wires are suspended midway between the parallel plates and usually hang free with aweight suspended at the bottom to keep them straight. Discharge electrodes are made fromnon-corrosive materials like tungsten, and alloys of steel and copper. The gas flow is parallel totheplates.

The plates may be 1-2 m wide and 3-6 m high. The parallel plates should be at equally spacedintervals (between 15and 35 cm).The collection ofthe aerosols takes place on the inner sideof the parallel plates. The dust material can be removed by rappingeither continuously orperiodically.Thedustparticlesremovedfallinto thehopper atthebase oftheprecipitator.

Collection electrodes should have a minimum amount of collection surface, bulking resistance,resistanceto corrosionandaconsistenteconomicdesign.

Plate type precipitators are horizontal or vertical, dependingon the direction ofthe gas flow.Gas velocities are maintained at 0.5-0.6 m/s in these precipitators. They‟re used for collection ofsolidparticulate.

### Dryand WetPrecipitators:

If particulate matter is removed from the collecting electrodes, by rapping only, it is known as adry precipitator. If, on the other hand, water or any other fluid is used for removal of the solidparticulate matter, then it is known as a wet precipitator. In general, wet precipitators are moreefficient.However,itis thedry typeplate precipitatorsthatarepredominantlyused.

Efficiency:

Generally, the collection efficiency of the electrostatic precipitator is very high, approaching100%. Many installations operate at 98 and 99% efficiency. Some materials ionize more readilythanothersandarethusmore adapted to removalby electrostatic precipitation.

Acidmistsandcatalystrecoveryunitshaveefficienciesinexcessof99%.However,formaterials like carbon black, which have very low efficiencies due to very low collection capacity,by proper combination of an ESP with a cyclone, very high efficiencies can be achieved.ThegasenteringtheESPmaybepre-treated(i.e.,removingaportionofparticulate)byusing

certain mechanical collectors or by adding certain chemicals to the gas to change the chemicalproperties of the gas to increase their capacity to collect on the discharge electrode and thusincreasetheefficiency.

Thefactorsaffectingtheefficiencyofelectrostaticprecipitatorsareparticleresistivityandparticlere-entrainment. Bothare explainedbelow:

### ParticleResistivity:

Dust resistivity is a measure of the resistance of the dust layer to the passage of a current. Forpracticaloperation,theresistivityshouldbe107and1011ohm-cm.Athigherresistivities,particlesaretoodifficulttocharge.Higherresistivityleadstoadecreaseinremovalefficiency.At times, particles of high resistivity may be conditioned with moisture to bring them into anacceptable range.

Iftheresistivityoftheparticlesistoolow,(<10ohm–cm),littlecanbedonetoimproveefficiency.Thisisduetothefactthattheparticlesacceptachargeeasily,buttheydissipateitso quickly at the collector electrode, that the particles are re- entrained in the gas stream. Thisresults inlowefficiency.

Particle resistivity depends upon the composition of the dust and the continuity of the dust layer.Resistivity is also affected by the ESP operating temperature and by the voltage gradient thatexistsacrossthe dustlayer.

### Particlere-entrainment:

This is a problem associated with particle charging. It occurs primarily in two situations – due toeitherinadequateprecipitatorarea,orinadequatedustremovalfromthehopper.Re-entrainment reduces the precipitator performance, because of the necessity of recollecting thedust that had been previously removed from the carrier gas. The problem can be overcome by aproper design oftheESPandnecessarymaintenance.

Theadvantagesofusing theESPare:

1. Highcollectionefficiency.
2. Particles as small as0.1 microncanberemoved.
3. Lowmaintenanceandoperatingcost.
4. Lowpressuredrop (0.25-1.25cmof water).
5. Satisfactoryhandlingof a large volume ofhightemperaturegas.
6. Treatmenttimeisnegligible(0.1-10s).
7. Cleaningis easybyremovingtheunits ofprecipitatorfromoperation.
8. Thereis nolimit tosolid, liquidor corrosivechemicalusage.

ThedisadvantagesofusingtheESPare:

1. Highinitialcost.
2. Space requirement ismorebecauseof thelargesize oftheequipment.
3. Possibleexplosionhazardsduringcollectionof combustiblegasesorparticulate.
4. Precautionsarenecessary to maintainsafetyduringoperation.Propergasflowdistribution,particulateconductivityandcoronasparkoverratemustbecarefullymaintained.
5. Thenegativelychargedelectrodesduringgasionizationproducetheozone.

The important applications of ESPs in different industries throughout the world are given asbelow:

1. Cementfactories:
2. Cleaningtheflue gasfromthecementkiln.
3. Recovery ofcementdustfromkilns.
4. Pulpand papermills:

a)Soda-fumerecoveryin theKraft pulp mills.

1. SteelPlants:
2. Cleaningblastfurnacegastouse itas afuel.
3. Removingtarsfrom cokeovengases.
4. Cleaningopenhearthandelectricfurnacegases.
5. Non-ferrousmetalsindustry:
6. Recoveringvaluable materialfromthefluegases.
7. Collecting acidmist.
8. ChemicalIndustry:
9. Collectionofsulfuric andphosphoricacid mist.
10. Cleaningvarious typesof gas,such as hydrogen, CO2, andSO2.
11. Removingthedust fromelemental phosphorousin thevaporstate.
12. PetroleumIndustry:

a)Recoveryofcatalyticdust.

1. CarbonBlackindustry:

a)Agglomeration andcollection ofcarbonblack.

1. ElectricPowerIndustry:

a)Collectingflyashform coal-firedboilers.

*SCRUBBERS:*

Scrubbers are devices that remove particulate matter by contacting the dirty gas stream withliquid drops. Generally water is used as the scrubbing fluid. In a wet collector, the dust isagglomerated withwaterandthenseparatedfromthe gastogetherwiththewater.

The mechanism of particulate collection and removal by a scrubber can be described as a four-stepprocess.

1. Transport: Theparticlemustbetransported tothe vicinity of the water droplets which are usually 10 to1000timeslarger.
2. Collision:Theparticlemustcollidewiththedroplet.
3. Adhesion: Thisis promoted by thesurfacetensionproperty.
4. Precipitation:Thisinvolvestheremovalofthedroplets, containing the dust particles from the gasphase.

Thephysicalprinciplesinvolvedintheoperationofthescrubbersare:i)impingement,ii)interception,iii)diffusionand iv)condensation.Abriefdescriptionisgivenbelow:

### Impingement:

Whengascontainingdustis sweptthrough an areacontainingliquiddroplets,dustparticles will impinge upon the droplets and if they adhere, they will be collected by them. If theliquid droplet isapproximately100 to300timesbigger than thedust particle,thecollectionefficiencyoftheparticlesismore,becausethenumbers ofelasticcollisionsincrease.

### Interception:

Particles thatmovewiththegasstreammaynotimpingeonthedroplets,butcanbecaptured becausetheybrushagainstthedropletandadhere there.Thisisknownasinterception.

### Diffusion:

Diffusion of the particulate matter on the liquid medium helps in the removal of theparticulate matter.

### Condensation:

Condensation of the liquid medium on the particulate matter increases the size and weightoftheparticles.Thishelpsineasyremovalofthe particles.

Thevarioustypesofscrubbersare:

1. Spraytowers.
2. Venturiscrubbers.
3. Cyclonescrubbers.
4. Packedscrubbers.
5. Mechanicalscrubbers.

Thesimplertypesofscrubberswithlowenergyinputsareeffectiveincollectingparticlesabove5 – 10 µ in diameter, while the more efficient, high energy input scrubbers will perform efficientlyforcollectionofparticlesassmallas1–2µindiameter.

Theadvantagesofscrubbersare:

1. Lowinitialcost.
2. Moderatelyhighcollectionefficiencyforsmallparticles.
3. Applicablefor hightemperatureinstallations.
4. Theycansimultaneouslyremoveparticlesandgases.
5. There is noparticle re-entrainment.

Thedisadvantagesofscrubbers are:

1. Highpowerconsumptionforhigherefficiency.
2. Moderate to highmaintenancecostsowingtocorrosionandabrasion.
3. Wetdisposal ofthecollectedmaterial.

Thescrubbers areusedin avarietyofapplications.Someof thesituationsare:

1. They‟reparticularlyusefulinthecaseofahotgasthatmust becooledforsomereason.
2. If the particulate matter is combustible or if any flammable gas is present, even intraceamounts,in thebulk gasphase,ascrubberispreferredto anelectrostaticprecipitator.
3. Scrubberscanbeusedwhenthere arewastewatertreatmentsystemsavailableonthesite,withadequatereservecapacitytohandlethe liquideffluent.
4. Scrubbers are also used when gas reaction and absorption are required simultaneouslywithparticulatecontrol.

*FABRICFILTERS:*

Fabricfiltrationisoneofthemostcommontechniquestocollectparticulatematterfromindustrial waste gases. The use of fabric filters is based on the principle of filtration, which is areliable, efficient and economic methods to remove particulate matter from the gases. The airpollutioncontrolequipmentusingfabricfiltersare knownasbaghouses.

### BagHouses

Abaghouseorabagfilterconsistsofnumerousverticallyhanging,tubularbags,4to18inchesindiameterand10to40feetlong.Theyaresuspendedwiththeiropenendsattachedtoamanifold.Thenumberofbagscanvaryfromafewhundredstoathousandormoredependinguponthesizeofthebaghouse.Baghousesareconstructedassingleorcompartmental units. In both cases, the bags are housed in a shell made of rigid metal material.Occasionally, it is necessary to include insulation with the shell when treating high temperatureflue gas. This is done to prevent moisture or acid mist from condensing in the unit, causingcorrosionandrapiddeteriorationofthebaghouse.

Hoppers are used to store the collected dust temporarily before it is disposed in a landfill orreused in the process. Dust should be removed as soon as possible to avoid packing whichwould make removal very difficult. They are usually designed with a 60 degrees slope to allowdustto flow freelyfromthetop ofthe hopper tothebottomdischargeopening. Sometimes

devices such as strike plates, poke holes, vibrators and rappers are added to promote easy andquickdischarge. Access doors or ports are also provided. Access ports provide for easiercleaning,inspectionandmaintenanceofthehopper.Adischargedeviceisnecessaryforemptying the hopper. Discharge devices can be manual (slide gates, hinged doors and drawers)orautomatictrickle valves, rotaryairlockvalves,screwconveyorsorpneumaticconveyors).

### FilterMedia

Woven and felted materials are used to make bag filters. Woven filters are used with low energycleaning methods such as shaking and reverse air. Felted fabrics are usually used with lowenergy cleaning systems such as pulse jet cleaning. While selecting the filter medium for baghouses,thecharacteristicsandpropertiesofthecarriergasanddustparticlesshouldbeconsidered.Thepropertiesto benotedinclude:

1. Carriergastemperature
2. Carriergascomposition
3. Gasflowrate
4. Size and shape ofdust particles anditsconcentration

The abrasion resistance, chemical resistance, tensile strength and permeability and the cost ofthefabric shouldbe considered.Thefibersusedforfabricfilters canvarydependingon theindustrial application.Some filtersare madefromnaturalfibers suchascottonorwool.Thesefibers are relatively inexpensive, but have temperature limitations (< 212 F) and only averageabrasionresistance.Cottonisreadilyavailable makingitverypopular forlowtemperaturesimple applications. Wool withstands moisture very well and can be made into thick felts easily.Synthetic fibers such as nylon, orlon and polyester have slightly highertemperature limitationsand chemical resistance. Synthetic fibers are more expensive than natural fibers. Polypropyleneis the most inexpensive synthetic fiber and is used in industrial applications such as foundries,coal crushers and food industries. Nylon is the most abrasive resistant synthetic fiber making itusefulforapplicationsfilteringabrasivedusts.Differenttypesoffiberswith

varyingcharacteristicsareavailablein themarket.

### Fabric Treatment

Fabrics are usually pre-treated, to improve their mechanical and dimensional stability. They canbetreatedwithsilicone to givethembettercakereleaseproperties.Naturalfibers (woolandcotton)are usuallypreshrunkto eliminatebag shrinkage duringoperation.Bothsyntheticandnatural fabrics usually undergo processes such as calendering, napping, singeing, glazing orcoating. These processes increase the fabric life and improve dimensional stability and ease ofbagcleaning.

1. Calendering:

Thisis thehighpressure pressingofthefabricbyrollerstoflatten,smooth,ordecoratethematerial.Calenderingpushes thesurfacefibersdownonto thebodyofthefiltermedium.Thisisdoneto increasesurfacelife,dimensional stabilityand togive amoreuniform

surfaceto bagfabric.

1. Napping:

Thisisthescrapingofthefilter surfaceacross metalpointsorburrsona revolvingcylinder. Napping raises the surface fibers, that provides a number of sites for particle collectionbyinterceptionordiffusion.Fabricsusedforcollecting stickyoroilydustsare occasionallynappedto provide goodcollectionandbagcleaningease.

1. Singeing:

Thisisdonebypassingthefiltermaterialoveranopenflame, removinganystraggly surface fibers.Thisprovidesa moreuniformsurface.

1. Glazing:

This is the high pressure pressing of the fiber at elevated temperatures. The fibersare fused to the body of the filter medium. Glazing improves the mechanical stability of the filterandhelpsreducebagshrinkage thatoccursfromprolonged use.

1. Coating:

Coatingorresintreatinginvolves immersingthefiltermaterial in natural orsynthetic resinsuchas polyvinyl chloride,cellulose acetate orurea-phenol. This isdonetolubricate the woven fibers or to provide high temperature durability or chemical resistance forvarious fabricmaterial.

### Operationofa baghouse:

The gas entering the inlet pipe strikes a baffle plate, which causes larger particles to fall into ahopperduetogravity.Thecarriergasthenflowsupwardintothetubesandoutwardthroughthe fabric leaving the particulate matter as a "cake" on the insides of the bags. Efficiency duringthepre-coatformationislow,butincreasesas thepre-coat(cake)is formed,untila finalefficiency of over 99% is obtained. Once formed, the pre-coat forms part of the filtering medium,which helps in further removal of the particulate. Thus the dust becomes the actual filteringmedium. The bags in effect act primarily as amatrix to support the dust cake. The cake isusually formed within minutes or even seconds. The accumulation of dust increases the airresistance of the filter and therefore filter bags have to be periodically cleaned. They can becleaned by rapping, shaking or vibration, or by reverse air flow, causing the filter cake to beloosened and to fall into the hopper below. The normal velocities at which the gas is passedthrough the bags at 0.4-1m/min. There are many types of "filter bags" depending on the bagshape,typeofhousingandmethodofcleaningthefabric.

### Efficiency:

Theefficiencyofbagfiltersmaydecreaseonaccountof thefollowingfactors:

1. **Excessive filter ratios** - 'Filter ratio' is defined as the ratio of the carrier gas volume togross filter area, per minute flow of the gas. Excessive filter ratios lower particulate removalefficiencyandresultinincreasedbagwear.Therefore,lowfilterratiosarerecommended.Therefore,lowfilter ratiosare recommended forhighconcentrationofparticulate.
2. **Improper selection of filter media** - While selecting filter media, properties such astemperature resistance, resistance to chemical attack and abrasion resistance should be takenintoconsideration.

OperatingProblems:

Various problemsduringtheoperation ofabag houseare:

1. Cleaning -

Atintervalsthebagsgetcloggedupwithacoveringofdustparticlesthatthegascannolongerpass throughthem.Atthatpoint,thebagshave tobe cleanedbyrapping,shakingorby reverseair flow by apulsejet.

1. Ruptureofthe cloth-

The greatest problem inherent in cloth filters is the rupture of cloth, which resultsfrom shaking. It is often difficult to locate ruptures and when they‟re found the replacement timeisoften considerable.

1. Temperature-

Fabric filters will not perform properly if a gross temperature overload occurs. If thegas temperature is expected to fluctuate, a fiber material that will sustain the upper temperaturefluctuationmustbeselected.

Also,whenevertheeffluentcontains areactive gaslikeSO2which canformanacid wheneverthe temperature in the bag house falls below the dew point it can create problems. Sometimes itmayevenbenecessary toprovideanauxiliary heatertomakesure thatthetemperature in thebaghousedoesnotfall below acidgasdew point.

1. Bleeding -

This is the penetration of the fabric by fine particles, which is common in fabricfiltration. It canoccurifthe weave is tooopenor thefilterratio isveryhigh.Thesolutionistouseadouble layermaterialora thickwovenfabric.

1. Humidity-

This is a common and important problem, especially if the dust is hygroscopic. Itwould therefore be advisable to maintain moisture free conditions within the bag house, as aprecautionarymeasure.

1. Chemicalattack-

This is another problem associated with fabric filters. The possibility of chemicalattack due to corrosive chemicals present in the effluent. A proper choice of fabric filter willavoidthisproblem.

Filtercleaningmechanisms:

Thefollowingmechanismsare usedforcleaningthefiltersinabaghouse:

1. Rapping
2. Shaking
3. Reverseair flow(backwash)
4. Pulse jet

### Multi-CompartmentTypeBagHouse:

Iftherequirementsoftheprocessbeingcontrolledaresuchthatcontinuousoperationisnecessary, the bag filter must be of a multi-compartment type to allow individual units of the bagfilter to be successively off-stream duringshaking. This is achieved either manually insmallunits or by programming control in large, fully automatic units. In this case, sufficient cloth areamust be provided to ensure that the filtering efficiency will not be reduced during shaking offperiods,whenanyoneoftheunitsisoff-stream.

Theadvantagesofafabricfilter are:

1. High collection efficiencies for all particle sizes, especially for particles smaller than 10micronindiameter.
2. Simple constructionandoperation.
3. Nominalpower consumption.
4. Drydisposalofcollectedmaterial.

Thedisadvantagesofafabricfilterare:

1. Operating limits are imposed by high carrier gas temperatures, high humidity andotherparameters.
2. Highmaintenanceand fabric replacementcosts.Baghousesaredifficult tomaintainbecause of the difficulty in finding and replacing even a single leaking bag. Also as general rule,about1/4thofthe bagswillneedreplacementeveryyear.
3. Largesize ofequipment.
4. Problemsinhandlingdustswhich mayabrade, corrode,orblindthecloth.

Theapplicationsofafabricfilterare:

Fabricfiltersfind extensiveapplicationin thefollowingindustriesandoperations:

1. Metallurgicalindustry
2. Foundries
3. Cementindustry
4. Chalkandlimeplants
5. Brickworks
6. Ceramicindustry
7. Flourmills

Cost:

A bag filter is comparatively expensive to install. Its power consumption is moderate. In mostcases,themaintenancecostishighbecausethebagshavetoberepairedorreplacedregularly.Thenature ofthegasand thedustdecidethefrequencyofsuchmaintenancework.