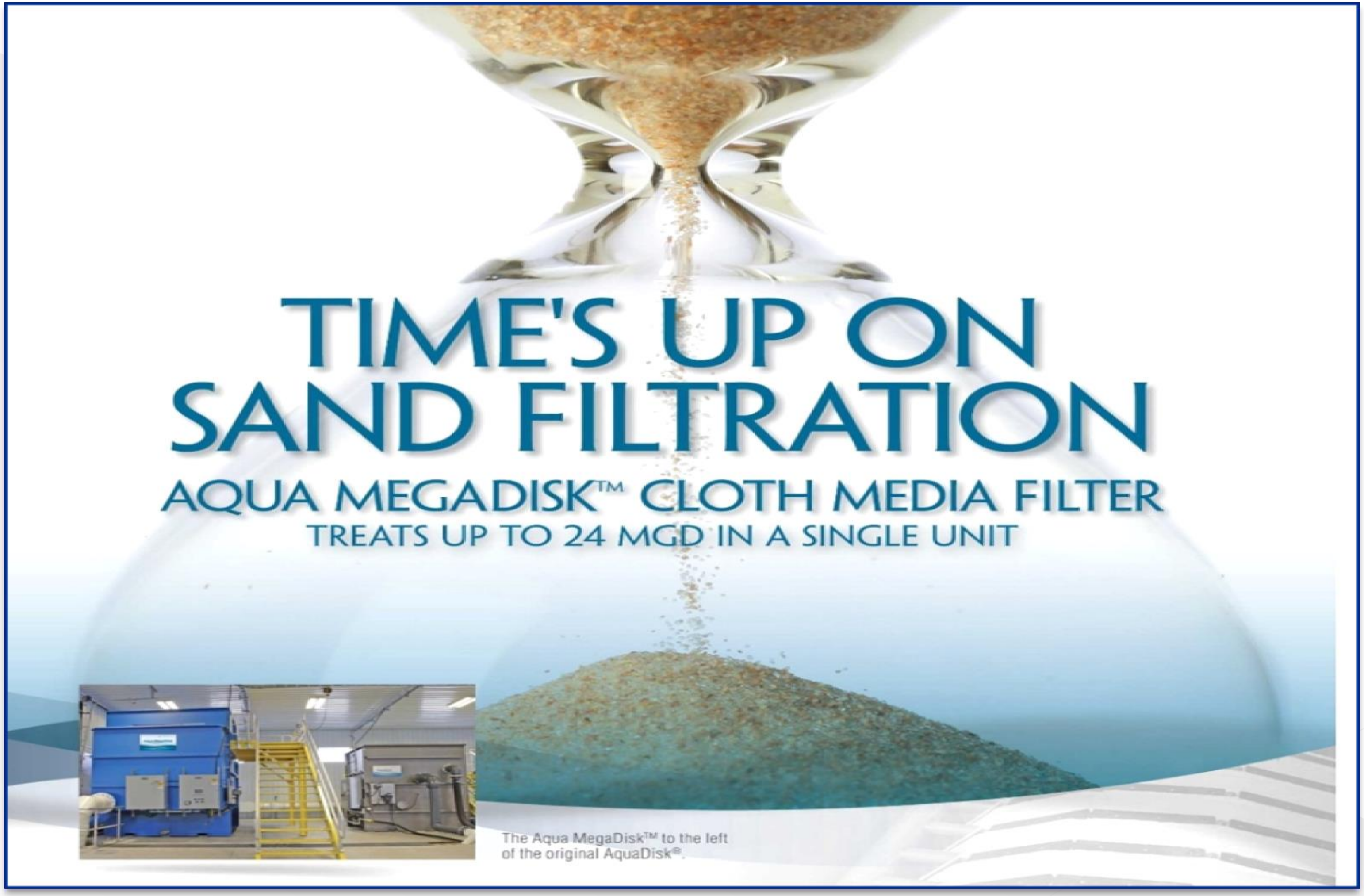
# Filtration



# TIME'S UP ON SAND FILTRATION

## AQUA MEGADISK™ CLOTH MEDIA FILTER

TREATS UP TO 24 MGD IN A SINGLE UNIT

The Aqua MegaDisk™ to the left of the original AquaDisk®.

**Filtration :**

The coagulation, flocculation, and sedimentation processes remove much of the colloidal material that
cause turbidity.
The common process used for further removal of colloidal matter is filtration.
Filtration is one of the oldest forms of water treatment. In fact,
filtration is one of the oldest forms of water treatment.
In tact, filtration is nature's own water treatment mechanism.
Water flowing slowly through porous sand and rock formations within the earth is cleaned and purified.
The filtration process used in water treatment involves flow through a bed of granular media,
such as sand,
anthracite, garnet or activated carbon. As the water passes through the media,
the suspended particles are entrapped in the pore spaces of the media and thus removed from the water stream.

# Theory of Filtration:-

The mechanisms by which granular filtration media remove soils from water are complex and are fully understood.

Common theories are (1) straining, (2) sedimentation, (3) impaction, and (4) interception.

A brief discussion of each mechanism follows :-

Some colloidal particles are too large to pass through pore spaces in the filter media bed.

These particles become trapped and are removed. The removed mechanism, is called straining.

This mechanism plays an important role in the direct filtration process, where flocculated water is ted directly into the filters.

Water flowing through the filter bed is usually laminar with the velocity and direction constantly

changing because of the obstruction by the media grains. In low – velocity Zones,

some particles are removed by sedimentation.

other particles have too large a mass to follow sharp turns in the flow streamlines

The inertia of these particles carries them out of the flow stream

These particles strike the medium and are held there because inertia is greater than the hydrodynamic
force.
Thus, the removed of particles is by interception.
In some cases, the flow streamlines pass very close to a media grain. At times,
a particle following these stream lines will touch a media grain and become logded .
these particles are removed by interception.

**Type of Filters:-**

Filter types commonly utilized in water treatment are classified on the basis of
(1) filtration rate,
(2) driving force,
and (3) direction of flow.
Filters classified by filtration rate.
Filters can be classified as slow sand filters, rapid sand.
Filters, and (high rate filters or pressure filters).

| **Parameter** | **Slow sand filter** | **Rapid sand filter** | **Pressure filter<br>(highrate filter)** |
|---|---|---|---|
| Head of the water above the bed of sand (m) | (0.9 – 1.16)<br>Or ingeaeral(2–3) m | (0.9 – 1.6)<br>Or ingeaeral (2– 3) m | > 3m |
| Velocity of water (m / hr) [ rate of filtration, or hydraulic application rate] | (0.1 – 0.4) m/ hr<br>Or<br>(2.4 – 9.60)<br>$m^2$ / $m^2$ .day<br>or less than<br>/ $m^2$ .day | (4-6) m/ hr<br>$m^3$<br>$m^2$ .day<br>Or (96 – 144)<br>Or<br>Approximately<br>/ $m^2$ .day | (6-12) m/hr<br>Or<br>(144-288)<br>$m^3$ / $m^2$.dy<br>or<br>greater then / $m^2$ .day |
| (D10)<br>Effective size of sand particles (mm)<br>(sieve size that permits 10% of sand by weight to pass). | 0.25 – 0.35 | 0.45 0.55 | 0.45-0.55 |
| D 60<br>D 10<br>Uniformity coefficient (ratio between the sieve size that will pass 60% and the effective size, = U.C | 2-3 | ≤ 1.5 | 1.25 – 1.35 |
| Thickness of sand bed | (1 – 1.5) m |  | (60 75) cm |
| Thickness of gravel bed | (0.3 – 0.5) m | (38 – 60) cm | (0.45 – 0.60)m |

**Filters classified by Driving Force:-**

Filters utilized in water treatment are also classified as gravity or pressure filters.

The major major differences between gravity and pressure filters are the head required to force the water through the media bed and the type of uessel used to contain the filter unit .

**Filters classified by direction of flow**

Filters systems are classified as downflow or upflow. Downflow filters are the type most commonly used in water treatment in water treatment.

In this type of system, the flow through the media bed is downward as is illustrated in Figure ().

In upflow filtration, the water flows upward through the media bed, as is illustrated in figure ( ).

This type of system is rarely used in granular filters, but it is sometimes used in granular activated carbon beds.

|  | **Slow sand filter** | **Rapid sand filter** |
|---|---|---|
| Filteration rate (m / hr) | (0.4 – 1.5) m/ hr |  |
| Length of run | = (9.6 – 36) m/hr | M d<br>M<br>d |
| Effective size of sand | (40 – 60) day |  |
| Vniformity coefficient | (0.1 – 0.3) mm | (5-10) (120 – 240) (m\hr) ( ) (24- 48) hrs |
| Area (size unit) | (2-3) | (0.45 – 0.55) mm |
| Depth of layer sand | (2000 – 6000) m$^2$ | (1.25 – 1.35) |
| Depth of Gravel layer | (1-1.4) m | (4 × 5 to 8 × 10) m$^2$ |
| Effective size of G – L (gravel – layer) | (0.25 – 0.3m) | (0.6 – 0.75)m |
| Under drained system | تصل ٠,٥ | (0.45 – 0.6m) |
| Depth of water above sand | (5 – 50 )mm | Manifolded lateral or |
| Time of cleaning | Top bottom | Wheeler bottom or |
| Length of run | Open jointed pipe | Diffuser plate or |
| Method of cleaning | Covered with blocks | (5 – 10) m |
| Cost of Construction | (0.9 – 1.6) , when (0.9 – 1.6) m | ( 5- 10)m |
| Cost of operation | Depth is between | Back washing |
| Water required for cleaning | (1.25 -2) filter may be | Low high |
| Pr parathion treatment | Cleaned | 2% of water |
| Or head loss | One day | Filtered. |
|  | Scraping of washing | Flocculation and |
|  | Of the top layer of sand of the thickness | Sedimentation |

## Rapid sand filter : المرشح الرملي السريع

يستعمل المرشح الرملي السريع للمياه المعاملة مسبقاً ويستعمل حتى في المياه الصناعية

Rate ( 5-10 m/ hr) (120 – 240) m/ day or more

The bed by reverse flow of filtered water.

Time of cleaning = ( 5 -10) min.

## pressure filter:

هو نوع من المرشح الرملي السريع ولكن يكون مغلق ويتم الترشيح بواسطة الضغط وهو أما عمودي أو أفقي .

Sand bed (60 – 75 ) cm

$D_{10}$ (0.45 – 0.55)

$\frac{D_{60}}{D_{10}}$ ( 1.25 – 1.35)

As Rapid sand filter

Gravel bed (0.45 – 0.6) m

Rate of filtration ≤ 15 m/ hr <u>or</u> ≤ 360 m / day

Pressure is up to 10 atmospher.

The pressure filter is a type of rapid sand filter which is in a closed container and through which the water passes under pressure. (normally 10 atmosphere pressure)

## Filter Media

Filters are classified as (single or mono) medium, dual media, or mixed (or multi) media.

Single – medium– filters : utilize a single material, most commonly well – graded sand. Typical effective size, uniformity coefficients, and bed depths for single – medium filters are listed in Table ( ).

In a single – medium filter, after backwashing, larger grains settle faster than smaller grains, in a phenomenon called (stratification or reverse) gradation.

This phenomena is illustrated in figure ( ) . Reverse gradation is the major disadvantage of the single – medium filter. This problem can be minimized by specifying a layer – diameter medium with a uniformity coefficient close to unity (less than 1.40) and by using a deep medium.

# Table ( ): Typical  Media Design Values for Various Filters

| parameter | Single – medium filters | Dual – media filters | Mixed – Media filters |
|---|---|---|---|
| Anthracite layer | 0.50 – 1.50 | 0.70 – 2.0 | 1.0 – 2.0 |
| Effective size, mm | 1.2 – 1.7 | 1.3 – 1.8 | 1.40 – 1.8 |
| Litormily coefficient | 50 – 150 | 30 – 60 | 50 – 130 |
| Depth, cm | 0.45 – 1.0 | 0.45 – 0.60 | 0.40 – 0.80 |
| Sand layer | 1.2 – 1.7 | 1.2 – 1.7 | 1.2 – 1.7 |
| Effective size, mm | 50 – 150 | 20 – 40 | 20 – 40 |
| Uniformity coefficient | Sand only | Sand + Anthracite coal | 0.20 – 0.80 |
| Depth, cm | | | 1.5 – 1.8 |
| Garnet layer | | | 5 – 15 |
| Effective size, mm | | | Sand + Anthracite coal + garnet |
| Uniformity coefficient | | | |
| Depth , cm | | | |

## Dual – Media Filters

Another solution to the problem of reverse gradation is the dual – media filter. Typical dual media filters utilize anthracite coal and qaartz sand as filter media

The anthracite with a specific gravity of 1.55 is lighter than the sand which has a specific gravity of 2.65. therefore, a large anthracite grain has the same settling velocity as a much smaller sand grain

This characteristic allows coal grains to be placed on top of smaller sand grains to create a gradation as shown in figure. ( ).

## Mixed – Media Filters

Mixed media filters are similar to dual – media filters, except that several materials are used. Typically three materials are used: anthracite with specific gravity of 1.55, sand with a specific gravity of 2.65, and garnet with a specific gravity of 4.05. mixed – media filters are basically improved dual – media filters, with increased filters is much higher than that of dual – media filters, because garnet is quite expensive

## Hydralics of filters

The earlest formula due to Darcy is :-

(1) (Darcy's Low):-

$$\frac{h}{\ell} = \frac{V}{k} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

h: hoss of head in bed of depth $\ell$

$\ell$ : filter depth

V : velocity, k: coefficient of permeability.

(2) rose (1945):-

$$\frac{h}{\ell} = 1.067\, C_D \frac{V^2}{g.d.¥} * \frac{l}{f\hat{}4} \quad \ldots\ldots(2) \text{ for uniform bed}$$

f: bed porosity = $\frac{\text{Vol. of voids}}{\text{Total volume}}$

ψ: partical shape factor $\longrightarrow$ $\Psi = \frac{\overset{f^3}{A_0}}{A}$ $\quad \frac{\text{Surface area of sp here}}{\text{Actual surface area of partical}}$

d: characteristrc diameter of bed particals

$C_D$ : Newton's drag coefficient $= \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34$

Carman – Kozeny eq.(1937)

$$V_{sp.} = \frac{٤}{٣} \pi R^3$$

U= velocity of filtration

$$\frac{h}{\ell} = E \frac{1-f}{f^3} \frac{V^2}{g.d.\psi} \quad ..............(3)$$

$$E = 150 \left[ \frac{1-f}{Re} \right] + 1.75$$

$d = \frac{6\,V}{A}$ for spherical partical.

$\psi = \perp$

volume

For other shape $d = \frac{6\,V}{\psi A}$

Then, from eq. (2) + eq.(3), the result is :-

$\frac{h}{\ell} = 0.178.\ CD \ \frac{V^2}{g.f^4} \qquad \frac{A}{V}$ (from substitution d=6V\ψA in Eq.(2))

$\frac{h}{\ell} = E \ \frac{1-f}{f^3} \ \frac{V^2}{g} \qquad \frac{A}{V6}$ (from substitution d=6V\ψA in Eq.(3))

## Typical values of ψ ( partical shape factor):-

| Material | | ψ |
|---|---|---|
| Mice flakes | مشتريات | 0.28 |
| Crushed glass | زجاج كسر | 0.65 |
| Angular sand | رمل مدور | 0.73 |
| Worn sand | شبه كروي | 0.89 |
| Spherical | كروي | 1 |

*Filter are normally used with graded sand of (0.5 – 100) mm so that,
we can obtained the following formula:-

$$\frac{A}{V} = \frac{6}{\Psi} \sum \frac{p}{d} \quad \text{[ non uniformly bed]}$$

p: portion (weight) of particles of size d (from sive analysis)

$$\frac{h}{\ell} = 1.067 \cdot \frac{V^2}{g.\ \psi.f^4} \sum C_D \cdot \frac{p}{d}$$

m

day

**Ex :**

A filter bed is made of 0.4 mm size angular sand has on overall depth of 750 mm and porosity of 42 percent, use the Rose formula to estimate the head loss of the clcan bed at a filteratio rate of 120 m \ day (Kinematic viscosity (U)) of water = 1.01 * $10^{-10\ m2}$ / s).

**Sol.:-**

Filteration rate = 120 $\frac{m}{day}$ = 120 / (24* 60*60) = 1.39 * $10^{-3}$ m/ sec.

$$Re = \frac{v.d}{\upsilon} = \frac{1.39 * 10^{-3} * 4 * 10^{-4}}{1.01 * 10^{-6}} = 0.55 \text{ ( Laminar ar flow).}$$

$$CD = \left( \frac{24}{0.55} + \frac{3}{\sqrt{0.55}} + 0.34 \right) = 48.01$$

$$\frac{h}{\ell} = 1.067\ CD\ \frac{V^2}{g.d.\ \psi}\ \frac{1}{f^4}$$ [ Rose formula for uniform bed]

$$\frac{h}{\ell} = 1.067\ (48.01) = \frac{(1.39 * 10^{-3})^2}{9.81\ (4 * 10^{-4})\ (0.73)\ (0.42)^4} = 1.11$$

h= 1.11 * 0.75 = 0.833 m

## Setting velocity of filter media

The setting velocity of the filter media can be calculated from Newton's or stoke's law.
In order for the backwash system to operate without washing out of the filter media,
it is important particularly for dual and mixed – media filters that the system
be designed so that the entire filter bed has approximately the same settling velocity.
The following equation can be used to calculate the size of the media grains with difference specific gravities and equal settling velocities:-

$$d2 = d1 \left( \frac{S_{g1} - 1}{S_{g2} - 1} \right)$$

or , in another form

$$\frac{d1}{d2} = \frac{P_2 - P_w}{P_1 - P_w}$$

**Where**

d2 = effective size of the media with a specific gravity of $Sg_2$ or $P_{2,}$ (mm).
d1= effective size of the media with a specific gravity of $Sg_1$ or $P_{1,}$ (mm).

**Ex:-**

Determine the particle sizes of anthracite and ilmenite which have settling velocities equal to that of sand of 0.50 mm in diameter.

**Solution:- for the anthracite**

$$dl = 0.5\left[\frac{2.6 - 1}{1.5 - 1}\right]^{2/3} = 1.1\ \text{mm} > 0.50\ \text{mm}$$

**For ilmenite**

$$dl = 0.5\left[\frac{2.6 - 1}{4.2 - 1}\right]^{2/3} = 0.3\ \text{mm} < 0.5\ \text{mm}$$

thus anthracite smaller than 1.1 mm would remain above 0.5 mm sand, and grain of ilmenite Larger than 0.30 mm would remain below it.

d=1.10 mm (anthracite coal)
d= 0.50 mm (sand)
d= 0.3 mm (ilmenite coal)

**Filter cleaning or Backwashing or ( the filter unit and Wash water troughs):-**

A filter cell must be cleaned when either (1) the head less through the filter exceeds the design value (2) turbidity break through causes the effluent quality to be less than a minimum acceptable level, or (3) a pre –

selected maximum filter run time has passed since it was last cleaned.

Filter units are cleaned by backwashing.

This involves passing water upward through the filter media at a velocity sufficient to expand the bed and wash out the accumulated solids. During backwash, the filter media is expande or fluidized.

The particles become separated and the space between them become greater, increasing the porosity

The rising washwater, after passing through the media, flows into washwater troughs.

The lips of the troughs are horizontal and are all placed at the same height, usually at a distance equal to the rate of washwater rise per minute, (600 to 900 mm), above the sand level.

In small units the troughs discharge to a gullet on one side, while in large units they discharge into a central gullet which divided the unit into two section ( see figure( )).

The troughs must be made of such capacity that the sides will act as free – falling weirs for the washwater. A freeboard of ( 50 to 100) mm is provided at the upper end.

Trough 100 toms may slope toward the outlets but usually are horizontal.

The dimensions of washwater troughs can be obtained from the following formula.

$$Y = 1.73 \sqrt[3]{\frac{Q2}{g.b2}}$$

**In which:-**

Q = the total amount of water received by the trough,
b= width of the trough
y = depth of the water at the upper end of the trough
g = acceleration of gravity.

**Ex:-**

A V – bottom trough with a horizontal bottom is to receive washwater from a section of filter bed 2m wide and 3m long. The washwater rate is 0.60 m/ min. the trough width is approximately equal to its depth.

**Solution:-**

The maximum flow in the trough $= V_b * \text{filter area}$

$= 0.60 * 3 * 2 = 3.60\ m^3\ / \min$

$= 0.60\ m^3\ / \sec$

If b = y, then:-

$$y^5 = (1.73)^3 * \frac{(0.06)^2}{9.80} \Rightarrow y = 0.29m$$

The actual channel dimensions might be as shown in figure ( ). This provides equivalent area of flow (0.084 $m^2$) and a freeboard of 50 mm at the upper end.

**the washing process :-**

The washing consists of passing filtered water upward through the bed at such a velocity that it causes the sand bed to expand until its thickness is (25 to 40) percent greater than during filtering. The grains move through the rising water, rub against each other, and are cleaned of deposits. A bed is usually washed when the gaage provided for the purpose shows that the fircition head through the bed has reached ( 2 to 3) m or whatever amount the operator deems the advisable limit.

Necessity for washing, however, is indicated not only by loss of head but by the presence of floc in the effluent.

The expansion of granular bed during backwash can be calculater as follow.

The velocity which just begins to expand the bed is:-

$$V_b = \frac{0.3682\,(D_{60})^{1.82}\,[p\,(p_s - P)]^{0.98}}{M\ 0.88}$$

(Backwash velocity the velocity which that the medium begins to expanded)

**In which:-**

Vb = backwash velocity in (m / min)

D60= $D_{10}$ * U . C

$P_s$ = density of the medium

P = density of the water

M= viscosity of water in (CP)

Since P and M are temperature dependent it is obvious that $V_b$ will vary with temperature and provision should be made for varjing backwash velocity with season.

The backwash velocity must be sufficiently great to carry off the suspended malter removed by the filter, yet not so great as to wash out the filter medium. As practical matter this means, for most suspensions, that the backwash rate must exceed (0.3 m/ min), but be less than ( 10 $D_{60}$ m/ min) for sand.

and less than (4.7 $D_{60}$ m / min) for anthracite . or in onther words

$0.3$ m/ min $\leq U_b \leq 10 D_{60}$ (m/ min) for sand, D (in mm).

And

$0.3$ m/ min $\leq U_b \leq 4.7 D_{60}$ (m/ min) for sand, D (in mm).

The bed is completely fluidized when the frictional force exerted by the washwater equals the particle weight and when the superficial approach velocity of the backwash exceeds.

$V_b = V_t * f^{4.5}$ = Fluidization velocity (velocity just before expansion)

Where f is the porosity of the medium.

**The expansion equation of medium is :-**

$$\frac{Le}{L} = \frac{1-f}{1-f_e^{\,0.22}} = \frac{1-f}{1-\left(\frac{Vb}{Vs}\right)^{0.22}}$$

**Where:-**

Le = height of sand layer during backwash process.
L= original height of sand layer.
f= porosity of original sand layer.
fe = porosity of expanded sand layer.
$V_b$ = backwash velocity.
$V_s$ = settling velocity of sand particles.

**Note:-**

Le = (1.25 – 1.4) L
Or
e= (25 – 40)%
greater than L

**Ex:-**

Calculate the terminal velocity and fluidization velocity of filter sand with an effective size of 0.55 mm, a unitormity coefficient of 1.5 and a specific gravity of 2.65. the porosity of sand is 0.45.

**Note :-** M= 1.004 CP.

**SOLUTION:-**

$U_t$ = 10 * (1.50 * 0.55) = 8.25 m / min

= terminal velocity of sand particles.

$U_b$ = 8.25 * $(0.45)^{4.5}$

= 0.23 m / min = fluidization velocity of sand (velocity not expand the sand)

$$U_{b\,=}\ \frac{0.3682\,(1.50 * 0.55)^{1.82}\,[\,1\,(2.65 - 1\,)]^{0.94}}{(1.004)^{0.88}} = 0.39 \text{ m / min}$$

= 0.39 m / min (velocity just begins to expand the bed).

When the bed is 10 percent expanded or,

$V_b = 0.1\ V_t$

Thus for sand beds

$V_{b\,=\,D}60$

And for anthracite

$V_b = 0.47\ D_{60}$

In which $V_b$ is in (m / min), and $D_{60}$ is in (mm).

The rates above are for a temperature of 20 C◦ but can be corrected for other a temperatures by

$V_b(T) = V_b\ (20) * M_T^{-1/3}$

In which $M_T$ is the viscosity in (C .P) at the temperature in question.

**Ex:-**

determine the appropriate backwash rate for a sand medium with an effective size of 0.5 mm and a unitormity coefficient of 1.5 at 5 and 35C◦

**Solution :-**

$D_{60} = 0.5 * 1.5 = 0.75$ mm

$V_b\ (20) = D_{60} = 0.75$mm

$V_b\ (5) = 0.75\ (1.52)^{-1/3} = 0.65$ m/ min

$V_b\ (35) = 0.75\ (o.71)^{-1/3} = 0.84$ m/ min

**The head lost on backwash may be written as:-**

$H = hf + hg + hu + hp$

$hf = L\,(1-f)\,(P_s - P)$

**in which :-**

hf = head loss in the expanded bed

L= depth of unexpanded bed

f= porosity of the medium

$P_s$ = density of the medium

P= density of the water

$$hg = 200L_g \frac{V_b\,M}{Pg\,Ø^2 D_{60}^2} \frac{(1-f)^2}{f^3}$$

**In which:-**

hg = head lost in gravel layer.

Lg = depth of the gravel

Ø = shape factor