Basic Environmental Engineering and Pollution Abatement
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Lecture 32
Secondary treatment equipment 2

Hello everyone, now we will discuss on the topic secondary treatment equipment part 2. And in this class we will be focusing on the trickling filter, anaerobic sludge blanket reactor and lagoon.

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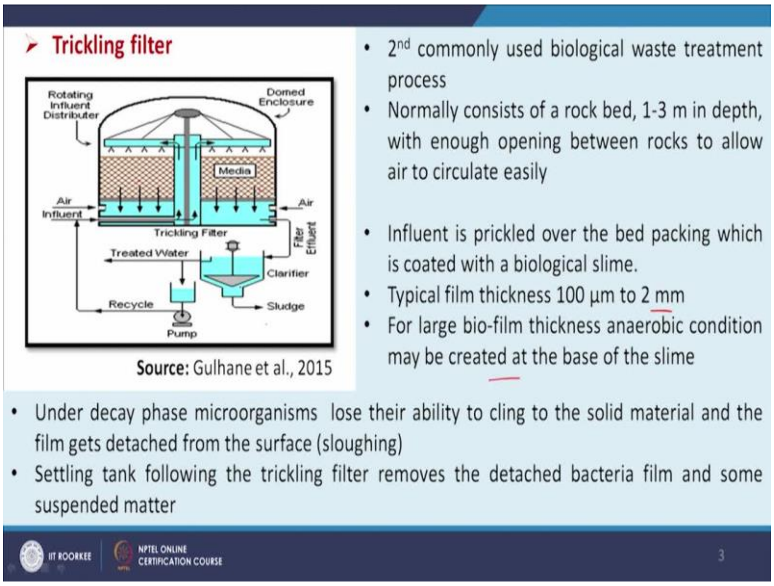

So, trickling filter as you know in this filter microbial layer is formed on some solid support and then water is passed through it and then microbes work on the organic compounds present in it and degrade it and the water is purified. So, here in this slide if we see that this is our influent here it is sprayed and this is domed enclosure and we have some media here and air influent passed here so aerobic condition is provided otherwise it will be anaerobic condition.

So, aerobic condition is provided, water spray from the top and there is a microbial layer which is developed on the material used in this media. Then after degradation of the organic compounds the water is collected here and then it is going for clarifier and then sludge and water that is going for further tertiary treatment. So this is the working of the tickling filter. And this is second commonly used biological waste treatment process and normally consists of a rock bed 1 - 3 m in depth with enough opening between rocks to allow air to circulate easily.

Influent is pickled over the bed packing which is coated with a biological slime and typical film thickness is 100 µm to 2 mm. And for large biofilm thickness anaerobic conditions may be created at the base of the slime. So, if it is a large then at the base part maybe anaerobic condition. And under decay phase microorganisms lost their ability to cling to the solid material and the film gets detached from the surface after certain time when microbes are dead. So that can be detached from the surface and we will be going out with the water. And settling tank following the tickling filter removes the detached bacteria film and some suspended matter. So, that is the need for the seperation of the sludge.

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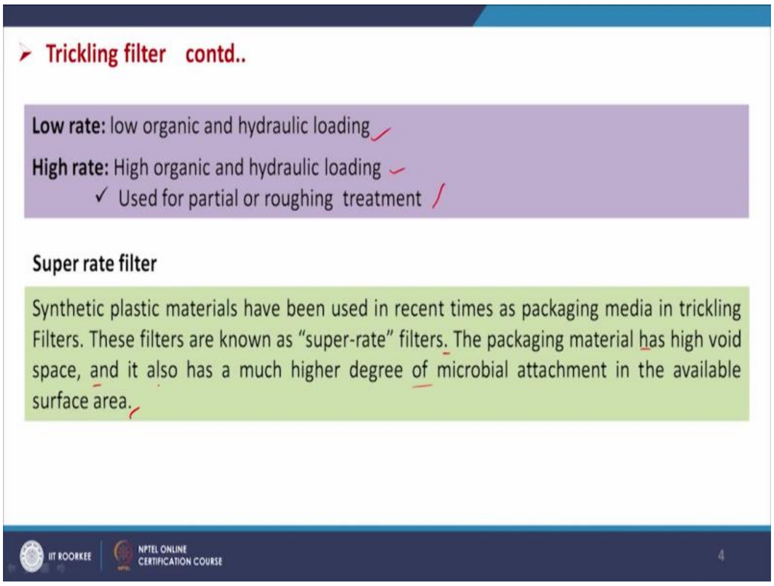

Now, here also in case of tickling filter, it may be low rate or high rate and another is super rate. So lower it means low organic and hydraulic loading and higher it means high organic and hydraulic loading and this is basically used for partial or roughing treatment suddenly and we are giving more organic load. So it may not be completely treated. So that is for rough treatment or partial treatment this is used then high-rate we can get and throughput is less in that case. And super rate filter is also there.

In this case synthetic plastic materials have been used in recent times as packing material in tickling filter and these filters are known as Super rate filters, the packing material has high void space and it also has a much higher degree of microbial attachment in the available surface area. So, these microbial layer development will be influenced by many factors. One is the heterogeneity of the surface and the affinity between the compatibility of the microorganisms with the surface of the medium. So, plastics materials has shown very good performance in their respect and they are able to give super trickling filter.

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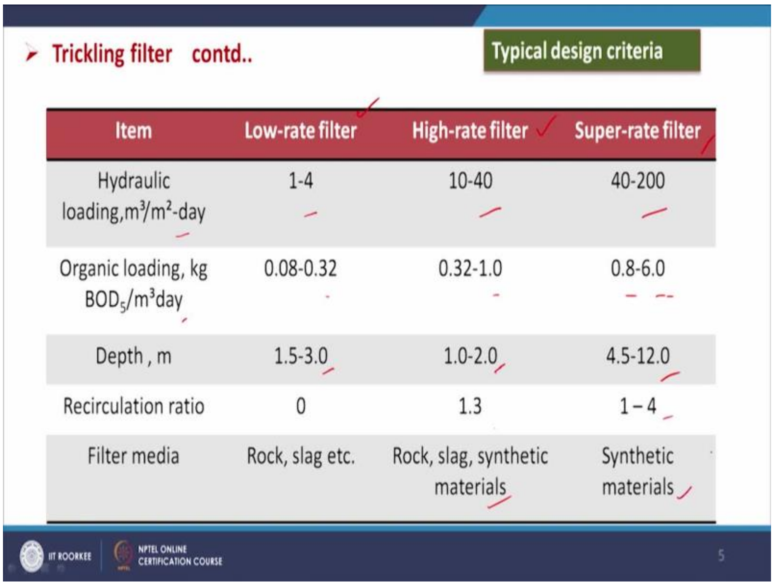

Item	Low-rate filter	High-rate filter	Super-rate filter
Hydraulic loading, m^3/m^2-day	1-4	10-40	40-200
Organic loading, kg BOD_5/m^3day	0.08-0.32	0.32-1.0	0.8-6.0
Depth , m	1.5-3.0	1.0-2.0	4.5-12.0
Recirculation ratio	0	1.3	1 – 4
Filter media	Rock, slag etc.	Rock, slag, synthetic materials	Synthetic materials

Now, some typical design criteria for low rate, high rate and super rate filters are provided in this slide. Here we see the hydraulic loading that is m^3/m^2-day that is equal to 1 to 4 for low-rate filter, but here is 10 to 40 high-rate filter and 40 to 200 super rate filter. So, very high you see up to 200. And then organic loading kg BOD_5/m^3day. Here we see 0.08 to 0.32 and 0.32 to 1.0 and 0.8 to 6, so organic loading rate is very high.

So we can use more organic containing material or the wastewater, and depth we see 1.5 to 3 and 1 to 2 and 4.5 to 12 again the super rate depth is more and recirculation ratio, so recirculation ratio is more in Super rate filter, but, this is lower in case of high-rate filter and negligible in case of low-rate filter. And filter media rock slag in case of low-rate filter in case of high-rate filter rock slag synthetic materials and Super rate only synthetic materials.

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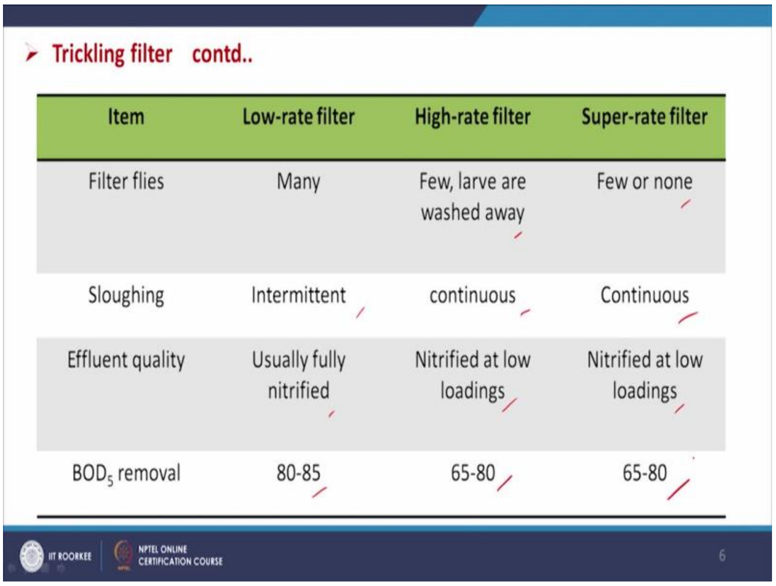
➢ Trickling filter contd..

Item	Low-rate filter	High-rate filter	Super-rate filter
Filter flies	Many	Few, larve are washed away	Few or none
Sloughing	Intermittent	continuous	Continuous
Effluent quality	Usually fully nitrified	Nitrified at low loadings	Nitrified at low loadings
BOD_5 removal	80-85	65-80	65-80

And filter flies, if we see the low rate many flies out there, but a high rate filter few larvae are washed away and since the flow rate is very high loading rate is very high. So, few or none so, flies are not able to grow there and then sloughing intermittent in case of low rare filter and it is continuous in high rate filter and super rate filter it is also continuous and effluent quality, usually fully nitrified in case of low rate filter and nitrified at low loadings and nitrified at low loadings.

So, this is super rate filter and BOD_5 removal 80 to 85 % in this case, high rate 65 to 80 % and this case also super rate also 65 to 80 %. So, we do see, if we go for a higher rate, certainly the removal will be lower. So, this is also evident from this table. Now, we will see the modeling aspect of the trickling filter. So, although it is an established process, but the microbial layer which is developed on the material or in the media, that is not very stable.

So, because of the uncertainty of this and the flow uncertainty maybe clogged or something else, the uniform flow we may not get so, because of this complexity in the systems, although, many people attempted to develop some past principle with models, but still no effective models are developed.

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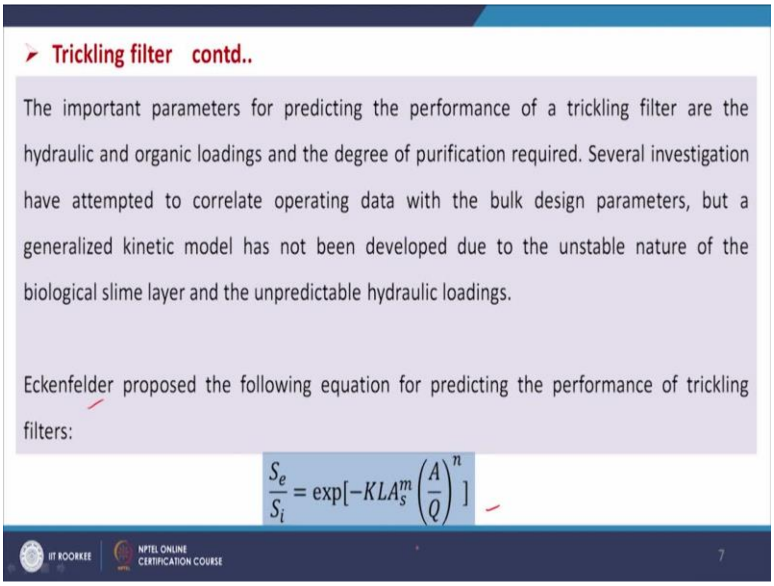

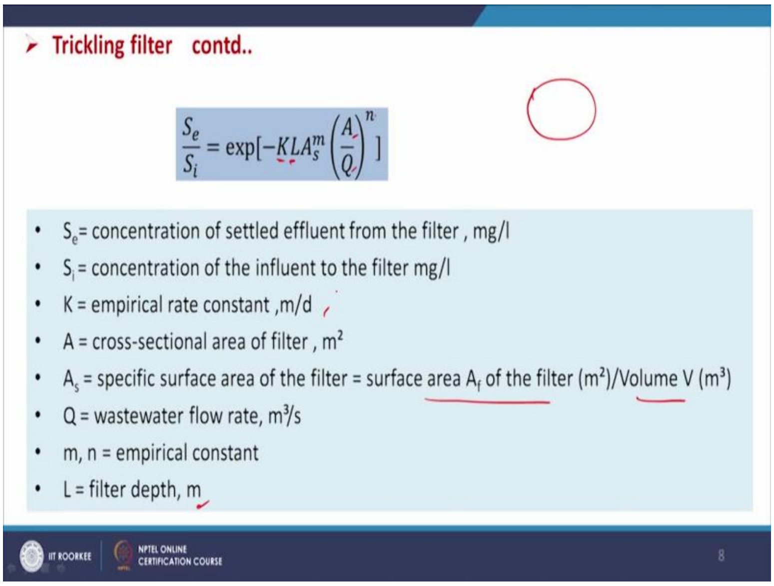

And you see here in this case, the important parameters for predicting the performance of a tinkling filter or the hydraulic and organic loadings and the degree of purification required. Several investigations have attempted to correlate operating data with the bulk design parameters, but a generalized kinetic model has not been developed due to unstable nature of the biological slime layer and unpredictable hydraulic loadings.

Now, here we will see one empirical relationship this has been proposed by Eckenfelder, so, Eckenfelder proposed this equation the following equation for predicting the performance of tickling filter. So, here we are getting

$$\frac{S_e}{S_i} = \exp\left[-KLA_s^m \left(\frac{A}{Q}\right)^n\right]$$

Where S_e is the concentration of settled effluent from the filter that means, in the settled effluent, what is the concentration of the organic compounds, so, that is we are getting S_e and S_i concentration of the influent to the filter.

So, the water which is getting entry into the filter, what is the concentration of the organic compound there S_i and K is the empirical rate constant m/d and these values will be constant for a particular system and A is the cross sectional area of the filter. So, which filter we are using. So, that is the cross sectional area of the filter. And A_s is the specific surface area of the filter. So, packing material is there,then what is the specific surface area, the surface area of the filter divided by volume. And Q is the flow rate of wastewater m^3/s and m and n these are 2 constant empirical constant and, L is the filter depth. So, this is the expression which it used to design the tickling filter to find out the length of the tingling filter, if we know the diameter of it or the vice versa.

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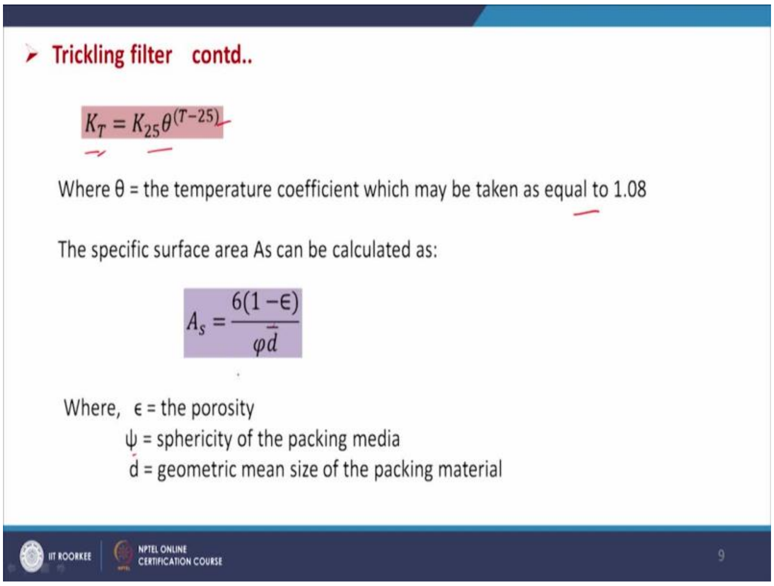

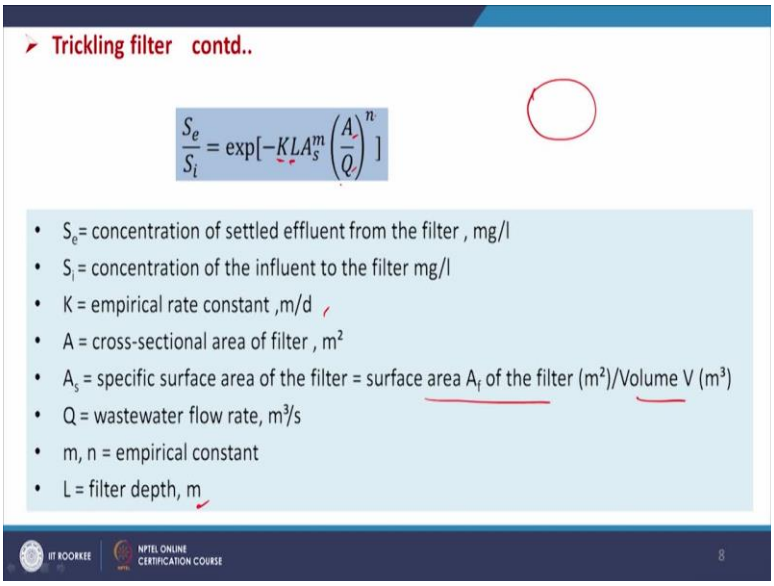

Now this case the empirical rate constant and this empirical rate constant that can be dependent on temperature and at any temperature K_T

$$K_T = K_{25}\theta^{(T-25)}$$

Where θ is the temperature coefficient, which may be taken as equal to 1.08, and by using this formula, we can get the value of K_T at any temperature. And now, we have to calculate A_s, Q, L etc. So, we will be seeing here A_s specific surface area. So, a specific surface area that means surface area by volume. So, this can be written as

$$A_s = \frac{6(1-\epsilon)}{\varphi \bar{d}}$$

Where d is equal to geometric mean size of the packing material. So, $\bar{d}$ or d whatever you can mention, either d or $\bar{d}$.

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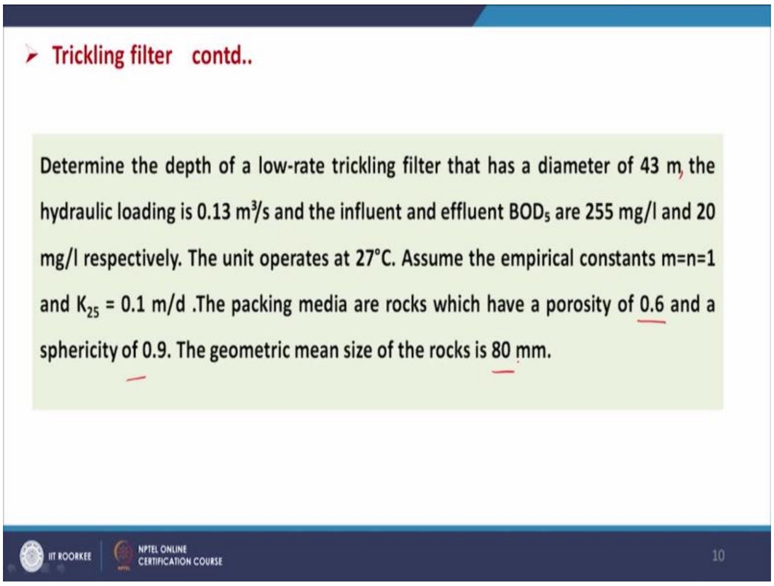

Now, we will be solving one numerical problem, the statement is determined up depth of a low rate trickling filter that has a diameter of 43 m, the hydraulic loading is 0.13 m^3/s and the influent and effluent BOD_5 are 255 mg/L and 20 mg/L respectively, the unit operates at 27 ^oC. Assume the empirical constants m equal to n equal to 1 and K_{25} is equal to 0.1 m/d. The packing media are rocks which have a porosity of 0.6 and a sphericity of 0.9. The geometric mean size of the rocks each 80 mm. So, these are the given data on the basis of which we have to determine the depth of the low rate tickling filter.

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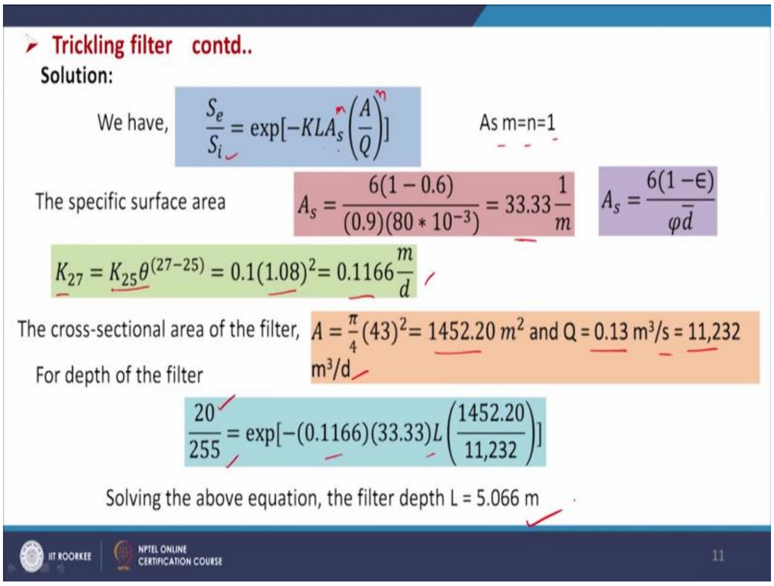

So, here we have

$$\frac{S_e}{S_i} = \exp\left[-KLA_s^m\left(\frac{A}{Q}\right)^n\right], \quad m=n=1$$

Now, the specific surface area A_s

$$A_s = \frac{6(1-\epsilon)}{\varphi \bar{d}} \quad , \quad A_s = \frac{6(1-0.6)}{(0.9)(80*10^{-3})} = 33.33\,\frac{1}{m}$$

$$K_{27} = K_{25}\theta^{(27-25)} = 0.1(1.08)^2 = 0.1166\,\frac{m}{d}$$

Now we have to calculate the cross-sectional area that is A

$A = \frac{\pi}{4}(43)^2 = 1452.20\ m^2$ and Q = 0.13 m^3/s = 11,232 m^3/d

Then what will be the depth of the filter,

$$\frac{20}{255} = \exp\left[-(0.1166)(33.33)L\left(\frac{1452.20}{11{,}232}\right)\right]$$

L= 5.066 m

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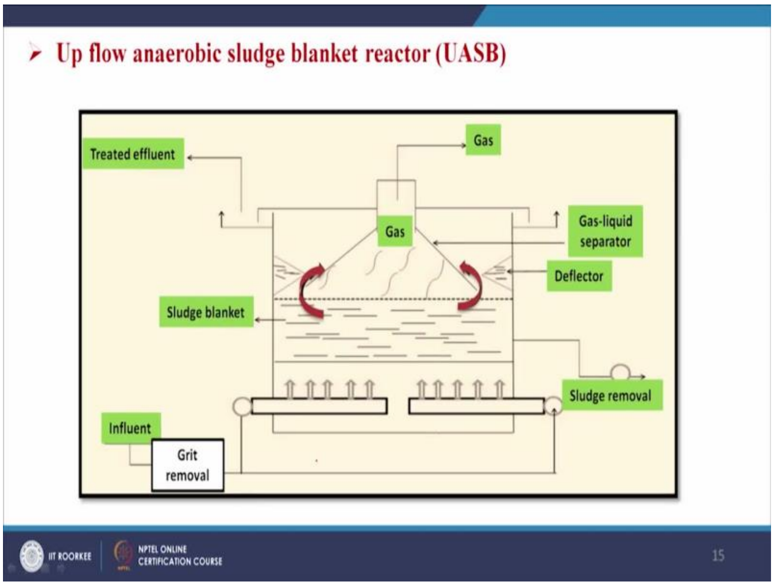

Now we will discuss on UASB that is up flow anaerobic sludge blanket reactor. So, in this case like this, so we have influent to be there and then treated effluent we will go through this and there will be some anaerobic zone and sludge blanket you will get and sludge will be collected from this and from the top gas will be collected. So this is the anaerobic sludge blanket reactor.

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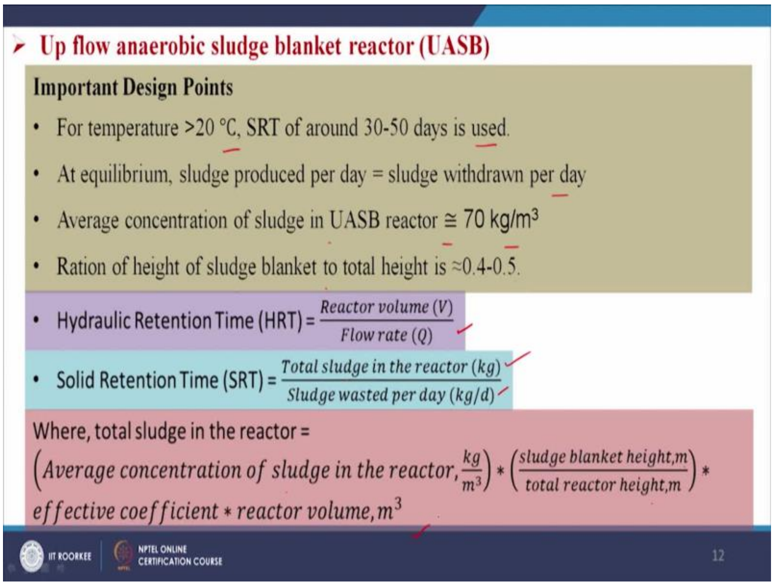

So for this UASB important design points are, temperature greater than 20 ^{o}C, SRT solid retention time 30 to 50 days is used and at equilibrium sludge produced per day is equal to sludge withdrawn per day, an average concentration of sludge in UASB reactors is 70 kg/m^3 and ratio of height of sludge blanket to total height is 0.4 to 0.5. So, what is the height of the sludge blanket and total height that ratio if we see that 0.4 to 0.5, So this is a typical design parameter we can use this for design purpose also.

$$\text{Hydraulic Retention Time (HRT)} = \frac{\text{Reactor volume (V)}}{\text{flow rate (Q)}}$$

$$\text{Solid Retention Time (SRT)} = \frac{\text{Total sludge in the reactor (kg)}}{\text{Sludge wasted per day (kg/d)}}$$

Where total sludge in the reactor

$$= \left(\text{Average concentration of sludge in the reactor,} \frac{\text{kg}}{\text{m}^3}\right) * \left(\frac{\text{sludge blanket height, m}}{\text{total reactor height, m}}\right) * \text{effective coefficient} * \text{reactor volume, m}^3$$

This is the expression which is used to calculate the total sludge in the reactor.

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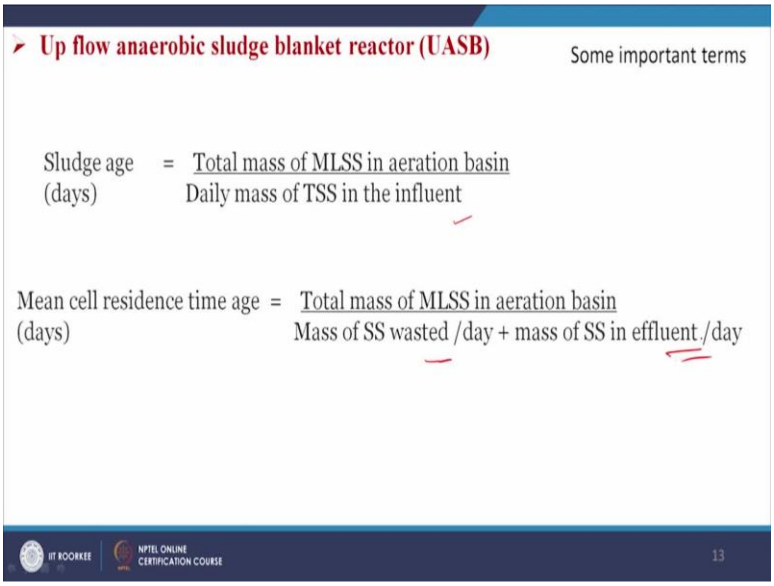

And SRT solid retention time which you have defined here similar term are used in other applications also like sludge age,

$$\text{Sludge age (days)} = \frac{\text{Total mass of MLSS in aeration basin}}{\text{Daily mass of TSS in the influent}}$$

$$\text{Mean cell residence time age (days)} = \frac{\text{Total mass of MLSS in aeration basin}}{\text{Mass of SS wasted /day} + \text{mass of SS in effluent /day}}$$

So, which is going to this sludge and this is going to the water so, these we have discussed in the previous class and here sometimes SRT and sludge age and these mean cell residence times are important and these 3 have different meaning and applications so it is again discussed here.

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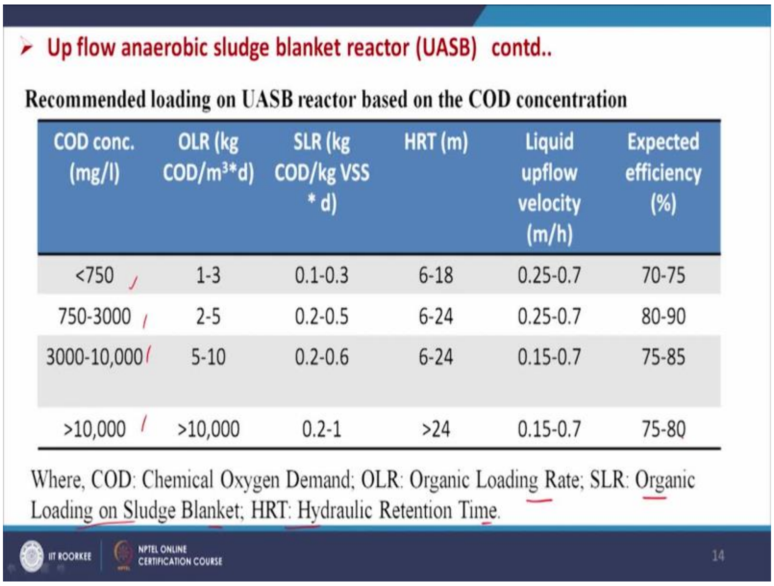

Up flow anaerobic sludge blanket reactor (UASB) contd..

Recommended loading on UASB reactor based on the COD concentration

COD conc. (mg/l)	OLR (kg COD/m³*d)	SLR (kg COD/kg VSS * d)	HRT (m)	Liquid upflow velocity (m/h)	Expected efficiency (%)
<750	1-3	0.1-0.3	6-18	0.25-0.7	70-75
750-3000	2-5	0.2-0.5	6-24	0.25-0.7	80-90
3000-10,000	5-10	0.2-0.6	6-24	0.15-0.7	75-85
>10,000	>10,000	0.2-1	>24	0.15-0.7	75-80

Where, COD: Chemical Oxygen Demand; OLR: Organic Loading Rate; SLR: Organic Loading on Sludge Blanket; HRT: Hydraulic Retention Time.

Now, if we see apart from these some other parameters are also very important that is OLR that is organic loading rate, SLR organic loading on sludge blanket and HRT hydraulic retention time. So, these are also very important parameters which need to be considered for UASB study or design aspect and here its performance depends on the organic concentration in the influent water. So, COD concentration if we increase gradually we will see these values are changing all OLR, SLR, HRT and liquid up flow velocity these are also changing to some extent and then expected efficiency is also varying. So, these are some parameters which need to be maintained to maintain the performance of the UASB reactor.

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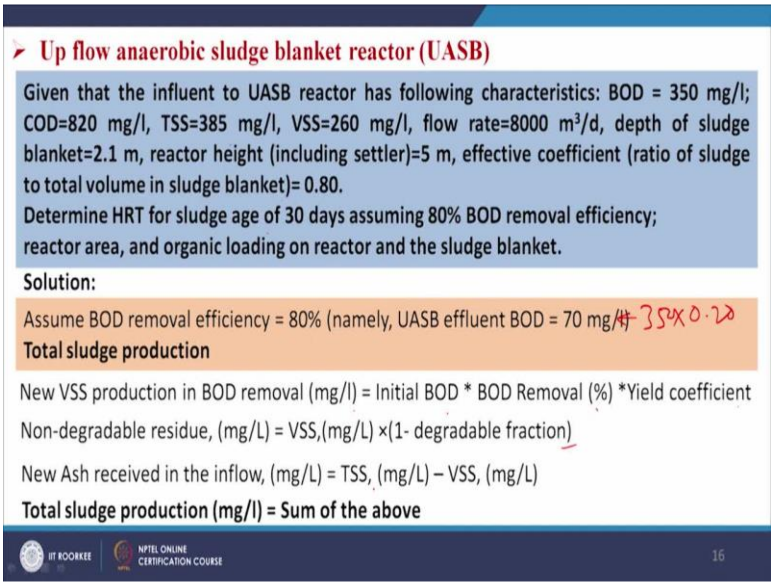

Now we will see one numerical column given that the influent to UASB reactor has following characteristics BOD equal to 350 mg/L COD equal to 820 mg/L, TSS equal to 385 mg/L, VSS is equal to 260 mg/L, flow rate 8000 m^3/d, depth of sludge blanket is 2.1 m, reactor height including settler is 5 m, effective coefficient ratio of sludge to total volume in sludge blanket. So that is equal to 0.80 and then determine HRT for sludge age of 30 days assuming 80 % BOD removal efficiency, reactor area and organic loading on reactor and the sludge blanket, so these we have to calculate and these are the given data.

So what we will do, we will be using different expressions we have already discussed and, in this case, say 80 % BOD removal. And initial BOD is 350 mg/L.

So, the BOD removal efficiency = 80%

So, UASB effluent BOD = 350*0.20 =70 mg/L.

Then total sludge production,

New VSS production in BOD removal (mg/l) = Initial BOD * BOD Removal (%) *Yield coefficient

Non-degradable residue, (mg/L) = VSS, (mg/L) × (1- degradable fraction)

New Ash received in the inflow, (mg/L) = TSS, (mg/L) – VSS, (mg/L)

Total sludge production (mg/l) = Sum of the above

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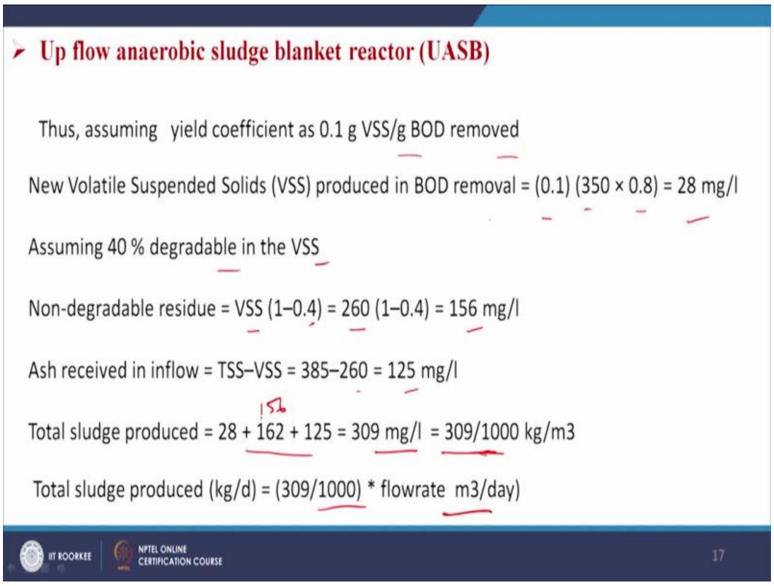

Thus, assuming yield coefficient as 0.1 g VSS/g BOD removed

New Volatile Suspended Solids (VSS) produced in BOD removal = (0.1) (350 × 0.8) = 28 mg/l

Assuming 40 % degradable in the VSS

Non-degradable residue = VSS (1–0.4) = 260 (1–0.4) = 156 mg/l

Ash received in inflow = TSS–VSS = 385–260 = 125 mg/l

Total sludge produced = 28 + 156 + 125 = 309 mg/l = 309/1000 kg/m^3

Total sludge produced (kg/d) = (309/1000) * flowrate m^3/day)

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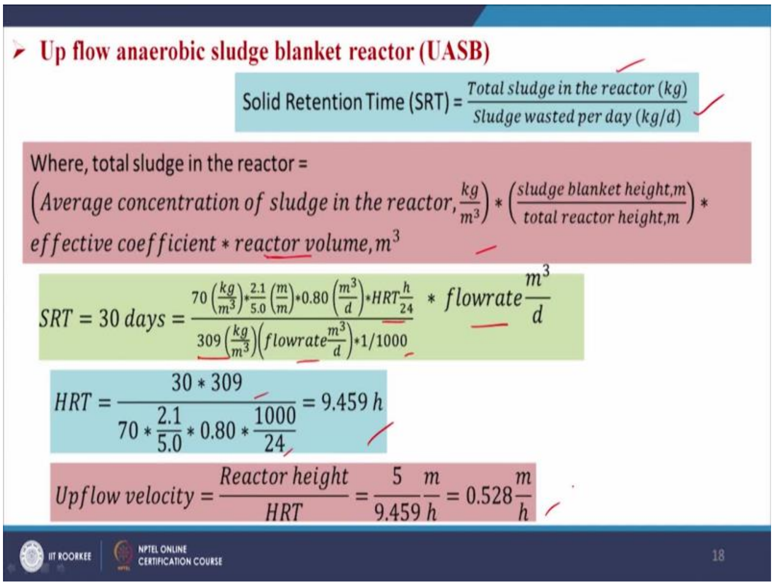

Now, solid retention time SRT

$$\text{Solid Retention Time (SRT)} = \frac{\text{Total sludge in the reactor (kg)}}{\text{Sludge wasted per day (kg/d)}}$$

Where, total sludge in the reactor

$$= \left(\text{Average concentration of sludge in the reactor,} \frac{\text{kg}}{\text{m}^3}\right) * \left(\frac{\text{sludge blanket height, m}}{\text{total reactor height, m}}\right) * \text{effective coefficient} * \text{reactor volume, m}^3$$

$$\text{SRT} = 30 \text{ days} = \frac{70\left(\frac{\text{kg}}{\text{m}^3}\right) * \frac{2.1}{5.0}\left(\frac{\text{m}}{\text{m}}\right) * 0.80\left(\frac{\text{m}^3}{\text{d}}\right) * \text{HRT}\frac{\text{h}}{24}}{309\left(\frac{\text{kg}}{\text{m}^3}\right)\left(\text{flowrate}\frac{\text{m}^3}{\text{d}}\right) * 1/1000} * \text{flowrate}\frac{\text{m}^3}{\text{d}}$$

$$\text{HRT} = \frac{30 * 309}{70 * \frac{2.1}{5.0} * 0.80 * \frac{1000}{24}} = 9.459 \text{ h}$$

$$\text{Upflow velocity} = \frac{\text{Reactor height}}{\text{HRT}} = \frac{5}{9.459\text{ h}}\frac{\text{m}}{} = 0.528\frac{\text{m}}{\text{h}}$$

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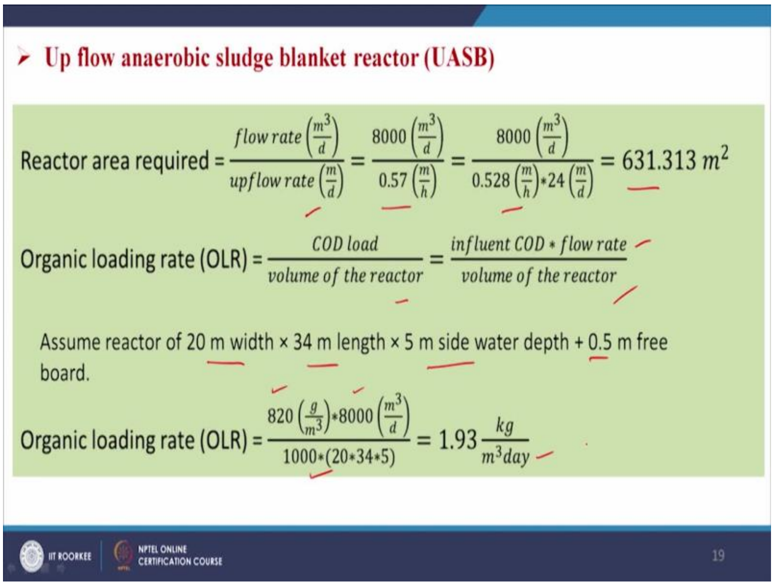

So, then reactor area,

$$\text{Reactor area required} = \frac{\text{flow rate}\ \left(\frac{m^3}{d}\right)}{\text{upflow rate}\ \left(\frac{m}{d}\right)} = \frac{8000\ \left(\frac{m^3}{d}\right)}{0.57\ \left(\frac{m}{h}\right)} = \frac{8000\ \left(\frac{m^3}{d}\right)}{0.528\ \left(\frac{m}{h}\right) * 24\ \left(\frac{m}{d}\right)}$$

Reactor area required = 631.313 m^2

$$\text{Organic loading rate (OLR)} = \frac{\text{COD load}}{\text{volume of the reactor}} = \frac{\text{influent COD} * \text{flow rate}}{\text{volume of the reactor}}$$

Assume reactor of 20 m width × 34 m length × 5 m side water depth + 0.5 m free board.

$$\text{Organic loading rate (OLR)} = \frac{820\ \left(\frac{g}{m^3}\right) * 8000\ \left(\frac{m^3}{d}\right)}{1000 * (20 * 34 * 5)} = 1.93\ \frac{kg}{m^3 day}$$

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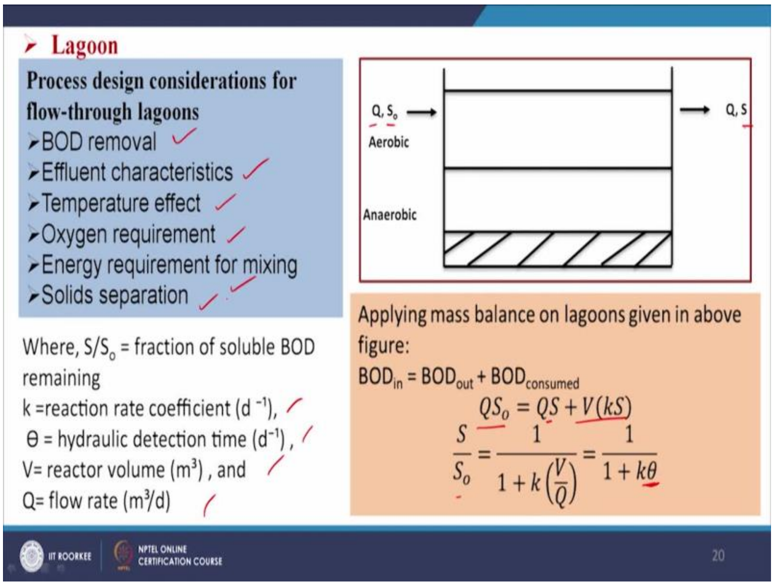

Now, we will discuss on the lagoon. So, lagoon we see that this very cheaper method for biological treatment of wastewater and here if it is a lagoon. So, Q flow rate and S_o inlet organic concentration, then S is the organic concentration in the outlet. So, in this case, if we apply the mass balance, then we will get

$$BOD_{in} = BOD_{out} + BOD_{consumed}$$

$$QS_o = QS + V(kS)$$

$$\frac{S}{S_o} = \frac{1}{1 + k\left(\frac{V}{Q}\right)} = \frac{1}{1 + k\theta}$$

when S/S_o is the fraction of the soluble BOD remaining. So, this is S and this is S_o, what is the fraction remaining in it and K reaction rate coefficient and theta hydraulic retention time be reactor volume and Q flow rate. So, this is a expression which relates S and S_o in a lagoon. And the lagoon performance depends on different factors like say BOD removal, effluent characteristics, temperature effect, and oxygen requirement, energy requirement for mixing, solid separation needed. So, all those things will be considered for the design of the lagoon.

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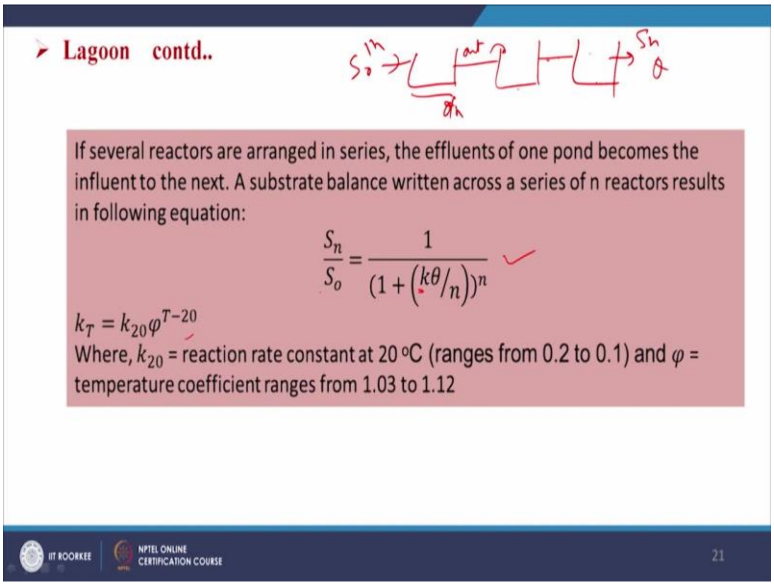

So, this is for one lagoon we are discussing, but it may happen that number of lagoons are in series, in that case, we can correlate the output and input, the outlet and inlet concentration. So, if number of lagoons in the series so, this is our inlet. So, this is our outlet, so, this outlet will be the inlet for this one. So, again this is outlet, this outlet is the inlet for this one. So, that way it will begin.

So, for this particular tank save the volume that is for this particular lagoon

$$\frac{S_n}{S_o} = \frac{1}{(1 + (k\theta/n))^n}$$

Where n will be number of tanks we are using number of lagoons we are using, so, that will be divided by Θ/n. So, this is the residence time here total residence time theta, so that will be Θ/n in each, we are equal volume.

So, this will be the expression which can be used for the finding out the relationship between the final concentration here that is S_n and this is your S_o, And again we can use the k_T

$$K_T = K_{20}\theta^{(T-20)}$$

This k_T will be used here we will be knowing the value of Θ and we will be knowing the number and we can calculate the A_C or S_n and find out the relationship between S_n and S_o ratio. So, up to this in this class, thank you very much for your presence.