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Modelling a Water Treatment Plant

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Water Parameters

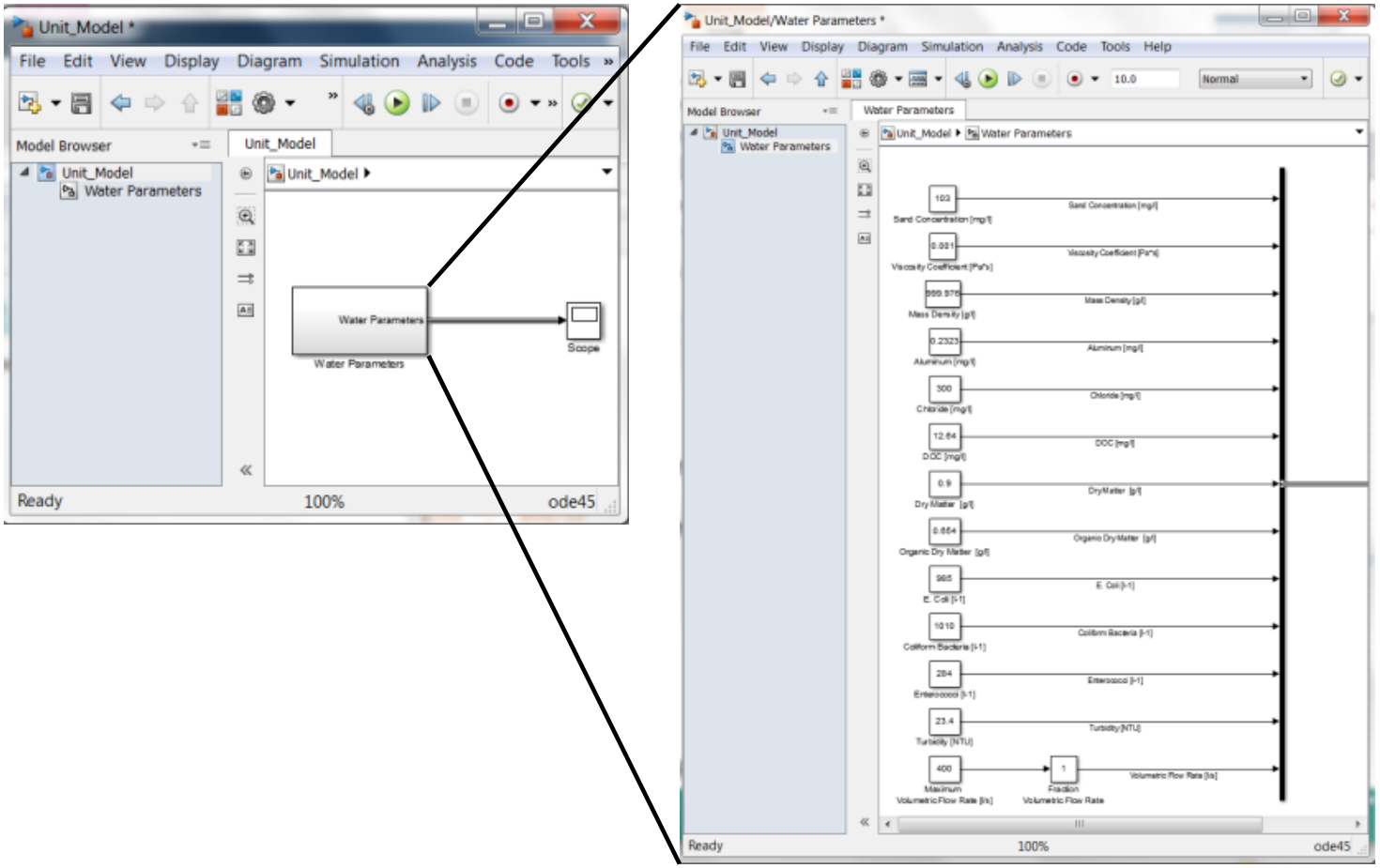
- Water parameters used in this model (in reality there are many more)
  - Sand Concentration and Grain Size
  - Mass Density
  - Concentration of the following materials
    - Aluminum
    - Dissolved Organic Carbon
    - Chloride
    - Dry Matter
    - Organic Dry Matter
    - E. Coli
    - Coliform Bacteria
    - Enterococci
  - Turbidity
  - Volumetric Flow Rate

CHLORIDE

Values of Water Parameters

- For our model we suggest the following initial values for these parameters
  - Sand Concentration and Grain Size — 750 mg/l and 0.0002 m
  - Mass Density — 999.976 g/l
  - Concentration of the following materials
    - Aluminum — 0.2323 mg/l
    - Dissolved Organic Carbon — 12.64 mg/l
    - Chloride — 300 mg/l
    - Dry Matter — 1.8 g/l
    - Organic Dry Matter — 0.6 g/l (i.e. 1/3 of the Dry Matter)
    - E. Coli — 985 l^{-1}
    - Coliform Bacteria — 1010 l^{-1}
    - Enterococci — 284 l^{-1}
  - Turbidity — 23.4 NTU (Nephelometric Turbidity Unit)
  - Maximum Volumetric Flow Rate — 400 l/s

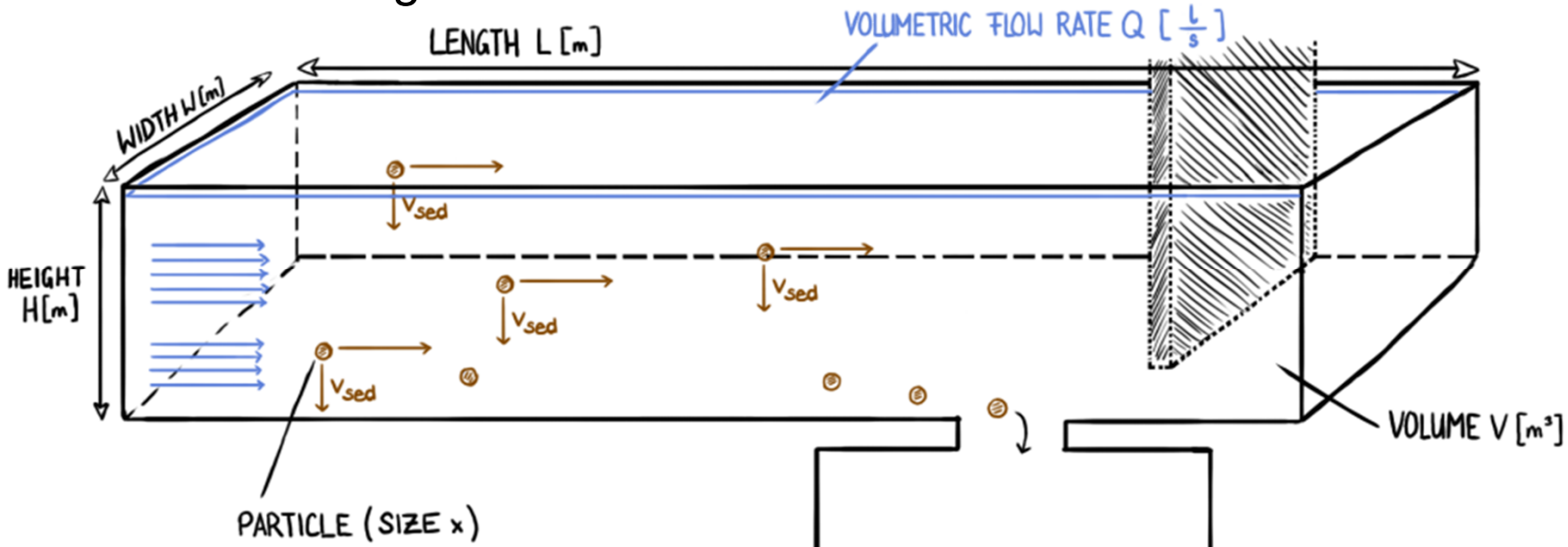
Modelling Water Parameters



Modelling Water Parameters: Exercise

- Build a Simulink® model that represents the water parameters described in this unit in a bus.
- Group your function blocks in a subsystem.
- Observe some of the paramerers in displays or socpes.

Equations for Modelling a Grit Chamber



SEDIMENTATION VELOCITY:

$$v_{sed} = \sqrt{\frac{4}{3} \cdot \frac{x \cdot \Delta\rho \cdot g}{\zeta \cdot \rho}}$$

SEDIMENTATION TIME:

$$t_{sed} = \frac{H}{v_{sed}} \quad [s]$$

FLOW TIME:

$$t_a = \frac{V}{Q} \quad [s]$$

$$\frac{dc(t)}{dt} = \frac{-v_{sed} \cdot c(t)}{H}$$

$$\rightarrow \quad c(t_a) = \left(e^{-\frac{v_{sed}}{H} \cdot \frac{V}{Q}}\right) \cdot c_0$$

$$= \left(e^{-\frac{v_{sed}}{H} \cdot t_a}\right) \cdot c_0$$

ρ : WATER DENSITY

$\Delta\rho$: DENSITY DIFFERENCE BETWEEN SAND & WATER (SAND DENSITY: 1500 $\frac{g}{l}$)

ζ : DRAG COEFFICIENT (ASSUMED 1.2)

Equations for Modelling a Grit Chamber

Sedimentation Speed:

$$v_{sed} = \sqrt{\frac{4}{3} * \frac{x * \Delta\rho * g}{\zeta * \rho}}$$

Whereas:

x is the size of the sand grains (see water parameters)

g is the gravity constant (9.81 m/s²)

ρ is the water's density (see water parameters)

$\Delta\rho$ is the density difference between sand and water (we assume a density of the sand of 1500 g/l)

ζ is the drag coefficient (assumed 1.2)

Equations for Modelling a Grit Chamber

Time needed for the water to pass the chamber horizontally :

$$t_a = \frac{V}{Q}$$

Whereas:

V is the volume of the chamber (Length: 12m, Width: 3m, Height: 1m)

Q is the Volumetric Flow Rate (see water parameters)

Equations for Modelling a Grit Chamber

Differential equation describing the concentration of grit in the water:
(source: Burkhart, M. (2002). Diploma Thesis: „Erprobung und Optimierung von Vorklärbeckenmodellen“ University of Kaiserslautern)

$$\frac{dc(t)}{dt} = \frac{-v_{sed} * c(t)}{H}$$

Solution of the differential equation:

$$c(t) = c_0 * e^{-\frac{v_{sed}}{H} * t}$$

Grit concentration when the water leaves the chamber (for $t = t_a$):

$$c(t_a) = c_0 * e^{-\frac{v_{sed}}{H} * \frac{V}{Q}}$$

Whereas:

$Vsed$ is the sedimentation speed (see previous slides)

H is the height of the chamber (1m)

$c(t)$ is the concentration of grit in the water depending on the time the water remains in the chamber

c_0 is the concentration of grit in the water when the water enters the chamber

Modelling a Grit Chamber: Exercise

- Expand your Simulink® model from the previous unit in the following way:
  - Build a subsystem that represents the Grit Chamber.
    - The subsystem must have one input port where the bus that combines the signal lines describing the single water parameters enters the subsystem.
    - Select necessary parameters from the bus using a bus selector function block
    - In an output port, the bus including the updated value of the sand concentration must leave the subsystem again.
  - Implement the equation that describes the grit concentration when the water leaves the grit chamber.
  - Update the value for the grit concentration in the bus using a Bus Assignment function block.
  - Make sure that all units are consistent in your formulas (i.e. not mixing e.g. mm and m or g and kg).

Equations for Modelling a Coagulation Basin

Determining the amount of flocking agent:

(source of the data that were used to determine the approximating equation:
Fiebiger, C. (2006). „Untersuchungen zu Eintrag, Verteilung und Verbleib natürlicher organischer Wasserinhaltstoffe aus moorgeprägten Einzugsgebieten von Trinkwasserspeichern.“
Dresden: Technical University of Dresden)

$$c_{fa} = \frac{c_{DOC} - 0{,}6286}{1{,}7143}$$

Whereas:

c_{fa} is the concentration of the flocking agent to be added

c_{DOC} is the concentration of the Dissolved Organic Carbon in the water (see water parameters)

Equations for Modelling a Coagulation Basin

Determining the concentrations of aluminum and chloride:

$$c_{Al,new} = c_{Al,old} + c_{fa} * 0{,}28$$

$$c_{Cl,new} = c_{Cl,old} + c_{fa} * 0{,}368$$

Whereas:

c_{fa} is the concentration of the flocking agent to be added (see previous slide)

$c_{Al,\ old}$ is the concentration of aluminum in the raw water (see water parameters)

$c_{Al,\ new}$ is the concentration of aluminum after adding the flocking agent

$c_{Cl,\ old}$ is the concentration of chloride in the raw water (see water parameters)

$c_{Cl,\ new}$ is the concentration of chloride after adding the flocking agent

Equations for Modelling a Coagulation Basin

Modelling the Elimination of DOC in the Water:

(source of the data that were used to determine the approximating equation:
Yang, Z., Gao, B., & Yue, Q. (2010). Coagulation performance and residual aluminum speciation of Al2(SO4)3 and polyaluminium chloride (PAC) in Yellow River water treatment. Chemical Engineering Journal (165), S. 122-132)

$$c_{DOC,new} = c_{DOC,old} - \frac{c_{DOC,old} * (14{,}314 * \ln(c_{fa}) - 6{,}1091)}{100}$$

Whereas:

c_{fa} is the concentration of the flocking agent to be added (see previous slide)

$c_{DOC,\ old}$ is the concentration of DOC in the raw water (see water parameters)

$c_{DOC,\ new}$ is the concentration of DOC after adding the flocking agent

Equations for Modelling a Coagulation Basin

Modelling the Turbidity:

(source of the data that were used to determine the approximating equation:
Gao, B.-Y., Chu, Y.-B., Yue, Q.-Y., Wang, B.-J., & Wang, S.-G. (2005). Characterization and coagulation of a polyaluminum chloride (PAC) coagulant with high Al13 content.
Journal of Environmental Management (76), S. 143-147)

$$Turbidity = 65{,}795 * e^{-0{,}806 * c_{fa}}$$

Whereas:

c_{fa} is the concentration of the flocking agent to be added (see previous slide)

Equations for Modelling a Coagulation Basin

Modelling the Size of the Generated Flakes:

(source of the data that were used to determine the approximating equation:
Zhang, P., Wu, Z., Zhang, G., Zeng, G., Zhang, H., Li, J., et al. (2008). Coagulation characteristics of polyaluminum chlorides PAC-Al30 on humic acid removal from water.
Separation and Purification Technology (63))

Detention Period of the Water in the Coagulation Basin:

$$t_d = \frac{V}{Q}$$

$$d_{Flake} = -0{,}1327 * \left(\frac{t_d}{60}\right)^2 + 12{,}667 * \frac{t_d}{60} - 32{,}917$$

Whereas:

V is the volume of the Coagulation Basin (450 m³)

Q is Volumetric Flow Rate (see water parameters)

t_d is the detention period [s]

d_{Flake} is the diameter of the emerging flakes [micro meters]

Modelling a Coagulation Basin: Exercise

- Expand your Simulink® model from the previous unit in the following way:
  - Using Simulink® , build a subsystem that represents the Coagulation basin. This basin consists of several other subsystems:
    - Computing the amount of added flocking agent (mandatory)
    - Computing the amount of dry matter added to the water (mandatory)
    - Computing the turbidity of the water when it leaves the basin (optional)
    - Computing the reduction in DOC (mandatory)
    - Computing the flake size (mandatory)
    - Computing the concentration of aluminum as well as chloride in the water (optional)
  - Update the corresponding water parameters in the bus
  - Integrate your subsystem into your complete system of the plant which has already been implemented and instrument the simulation model at will.
  - Make sure that all units are consistent in your formulas (i.e. not mixing e.g. mm and m or g and kg).

Equations for Modelling a Sedimentation Basin

Differences in computing the sedimentation speed with respect to the Grit Chamber:

- The flake size will be used instead of the size of the grit
- The flake density will be used (we assume a density of 1050 g/l)
- The drag coefficient of the flakes is assumed as being 1.8

Differences in computing the volume of the Sedimentation Basin (for determining the sludge concentration at the outflow):

- The basin is assumed as being cylindrical with a
  - Radius of 7,5 meters and a
  - Height of 2,5 meters, yielding a volume of approx. 442 m^3

Equations for Modelling a Sedimentation Basin

Differences in computing the sludge concentration at the outflow:

- Instead of sand, dry matter is settling in that process
- In addition to computing the new concentration of dry matter, the amount of sludge produced has to be computed:

$$amount_{Sludge} = Q * (c_{dm,old} - c_{dm,new}) * 3{,}6$$

Whereas:

$amount_{Sludge}$ is the amount of produced Sludge [kg/h]

Q is Volumetric Flow Rate [l/s] (see water parameters)

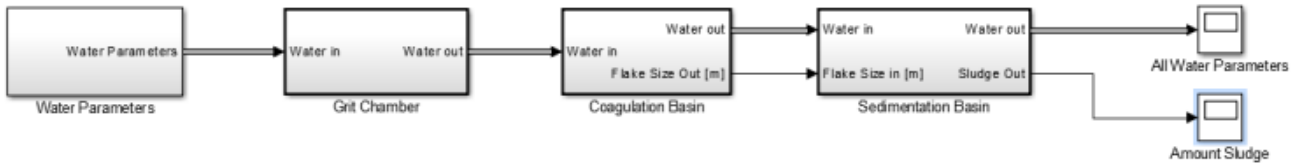
$c_{dm,old}$ is the concentration of dry matter at the inflow of the sedimentaion basin [g/l]

$c_{dm,new}$ is the concentration of dry matter at the outflow of the sedimentaion basin [g/l]

3,6 is the factor to convert g/s to kg/h

Modelling a Sedimentation Basin: Exercise

- Expand your Simulink® model from the previous unit in the following way:
  - Implement a sedimentation basin using the modified formulas as shown in this unit as well as the modified parameters.
  - Your implementation can use the implementation of the Grit Chamber as a basis.
  - Implement the sedimentation basin as a subsystem in your Simulink® model, too. The model then could probably look similar to the one below
  - Update the corresponding water parameters in the bus
  - Instrument your model at will.
  - Make sure that all units are consistent in your formulas (i.e. not mixing e.g. mm and m or g and kg).



Equations for Modelling a (Grit or Activated Carbon) Filter

Modelling the concentration of (organic) dry matter after filtering:

$$c_{out} = c_{in} * e^{-\lambda * z}$$

Whereas:

c_{out} is the concentration of the (organic) dry matter at the outflow of the filter

c_{in} is the concentration of the (organic) dry matter at the inflow of the filter (see water parameters)

z is the thickness of the layer of filtering material (2m)

λ is an efficiency parameter of the filter

Equations for Modelling a (Grit or Activated Carbon) Filter

Modelling the parameter λ:

$$\lambda = (1 - \frac{\sigma}{\sigma_s}) * \lambda_0$$

Whereas:

σ is the current load of the filter

σ_s is the saturation load of the filter (20 kg/m³)

λ_0 is the initial efficiency parameter of the filter

Equations for Modelling a (Grit or Activated Carbon) Filter

Modelling the initial effectiveness parameter λ_0:

$$\lambda_0 = -\frac{\ln \frac{c_{des}}{c_{in}}}{z}$$

Whereas:

c_{des} is the desired concentration of the (organic) dry matter at the outflow of the filter

c_{in} is the concentration of the (organic) dry matter at the inflow of the filter

z is the thickness of the layer of filtering material

c_{des} / c_{in} is assumed to be 0.1

Equations for Modelling a (Grit or Activated Carbon) Filter

Modelling the current load of the filter:

$$\sigma(0) = 0$$

$$\sigma(t+\Delta t) = \sigma(t) + \int_{t}^{t+\Delta t} \frac{c_{in} - c_{out}(u)}{z} * v_f du$$

Whereas:

σ is the current load of the filter

c_{out} is the concentration of the (organic) dry matter at the outflow of the filter

c_{in} is the concentration of the (organic) dry matter at the inflow of the filter (see water parameters)

z is the thickness of the layer of filtering material (2m)

v_f is the velocity at which the water flows through the filter

Equations for Modelling a (Grit or Activated Carbon) Filter

Modelling the velocity at which the water passes through the filter:

$$v_f = \frac{Q}{L * W}$$

Whereas:

Q is the volumetric flow rate (see water parameters); here its unit is m³/s

L is the length of the filter basin (10 m)

W is the width of the filter basin (5 m)

v_f is the velocity at which the water flows through the filter

Modelling a (Grit or Activated Carbon) Filter: Exercise

- Expand your Simulink® model of the previous unit in the following way:
  - Implement a subsystem in your model representing a Grit Filter, using the formulas presented in this unit.
    - The Grit Filter filters out dry matter. Update the concentration of dry matter in the bus using its newly computed concentration.
    - Additionally update the organic dry matter in the bus. Up to now, organic dry matter has not been treated separately. This will be the case in the Activated Carbon Filter. For that reason we have to use a correct value of organic dry matter.
    - Therefore, set the value of organic dry matter at a third of the value of dry matter.

Modelling a (Grit or Activated Carbon) Filter: Exercise

- Expand your Simulink® model from the previous unit in the following way:
  - Additionally implement a subsystem that represents an Activated Carbon Filter.
    - It will be an exact copy of the Grit Filter with the following exceptions:
      - It computes a new value for organic dry matter
      - Therefore, the computation of the organic dry matter as done in the Grit Filter is obsolete.
      - The filter parameters are:
        - Length: 5m, Width: 4m, Height: 2m
        - Saturation load: 100 kg/m³
  - Instrument your model at will.
  - Make sure that all units are consistent in your formulas (i.e. not mixing e.g. mm and m or g and kg).

Equations for Modelling an Ultraviolet Disinfection System

Technical Data used in our model:

Volume of the whole system:
1000 l

Surface area of the lamps:
100 m²

Irradiation dose:
400 J/m²
(equivalent to 40 mJ/mc²)

Equations for Modelling an Ultraviolet Disinfection System

Modelling the irradiance:

$$E = \frac{P}{A}$$

Modelling the detention period

$$t = \frac{V}{Q}$$

Modelling the irradiation dose (energy dose)

$$D = E * t$$

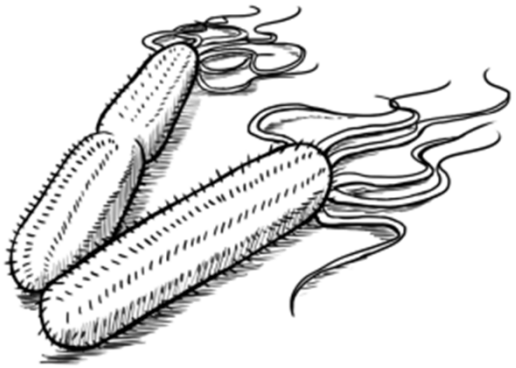
Whereas:

- E is the irradiation (energy per area)
- P is the power of the lamps (16 kW)
- A is the total surface area of the lamps (100 m²)
- t is the detention period [s]
- V is the total volume of the disinfection system (1000 l)
- Q is the volumetric flow rate through the plant [l/s] (see water parameters)
- D is the irradiation dose (energy dose). It has to be computed in [mJ/cm²]

Equations for Modelling an Ultraviolet Disinfection System

Modelling the decrease in microorganisms:

$$N = N_0 * e^{-KD}$$



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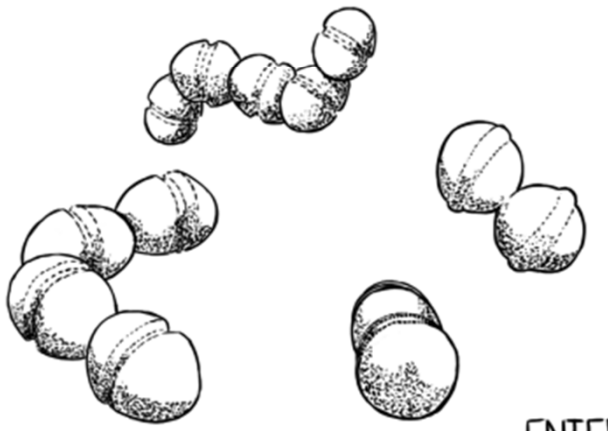


ENTEROCOCCI

Whereas:

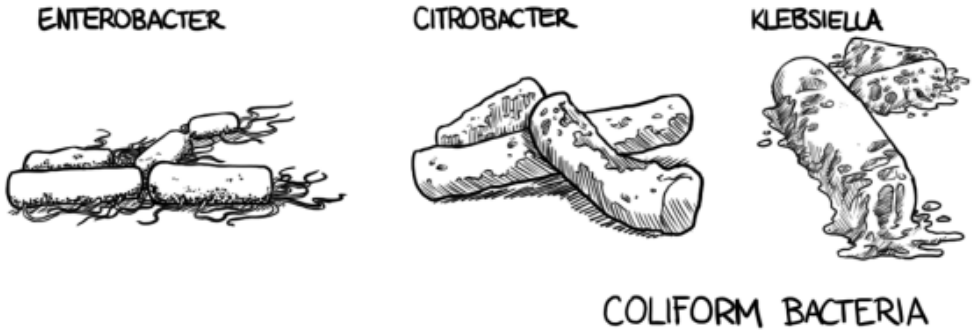
D is the irradiation dose

N_0 is the number of microorganisms at the inflow

N is the number of microorganisms at the outflow

K is some empirically determined value that describes the sensitivity of the specific bacteria to UV-light.

We specify K as:
0,14 for E. Coli
0,2 for Coliform Bacteria
0,16 for Enterococci

Modelling an Ultraviolet Disinfection System: Exercise

- Expand your Simulink® model from the previous unit in the following way:
  - Implement a subsystem in your model representing an Ultraviolet Disinfection System, using the formulas presented in this unit.
    - Model the effect of the disinfection of the three kinds of bacteria mentioned in the text.
    - Update the concentration of these bacteria in the bus using their newly computed concentration.
  - Make sure that all units are consistent in your formulas (i.e. not mixing e.g. mm and m or g and kg).
  - Instrument your model at will.