

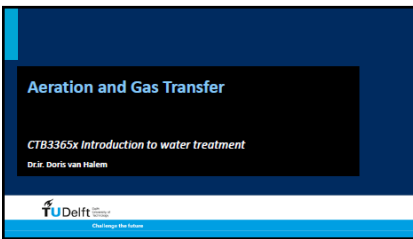
## D4b – Aeration



Doris van Halem

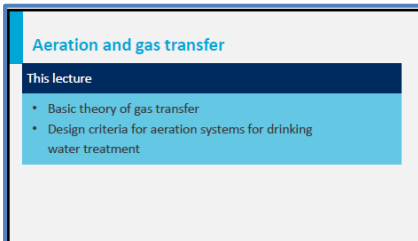


Did you know that there are not just gasses in your glass of sparkling coke, but also in the tap water you drink?

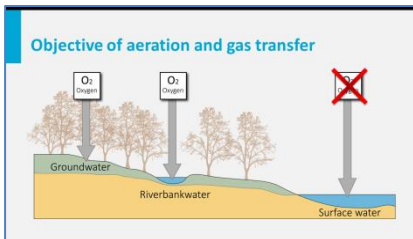


Welcome to the water treatment lecture about Aeration and Gas Transfer.

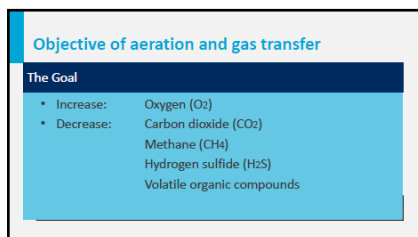
My name is Doris van Halem and I am an Assistant Professor in Drinking Water.



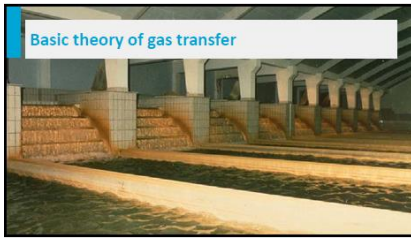
After this lecture you should be able to explain the basic mechanisms of gas transfer and the key design criteria for different aeration systems applied for drinking water treatment.



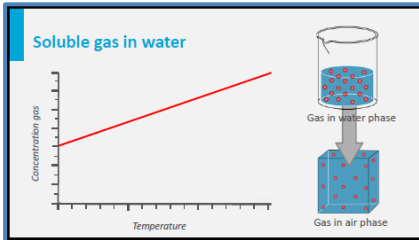
Aeration is the treatment process in which water is brought in close contact with air to change the content of the dissolved gases in water.



For the treatment of groundwater, the aims are to increase the oxygen content and decrease the content of carbon dioxide, methane, hydrogen sulfide and volatile organic compounds.



However, before I will introduce you to technologies that are used for aeration, I will first tell you about the basic theory of gas transfer.



Gases are, to some extent, soluble in water. The concentration of a gas in the water phase is in equilibrium linear to the concentration of the gas in the air phase, this equilibrium is conform Henry's Law.

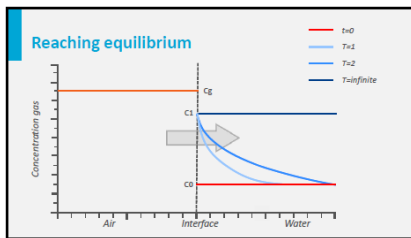
**Henry's law**

$C_w = k_D \cdot C_a$

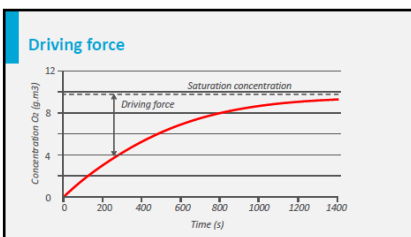
$C_w$  = saturation concentration of the gas in water [g/m<sup>3</sup>]  
 $C_a$  = concentration of gas in air [g/m<sup>3</sup>]  
 $k_D$  = distribution coefficient [-]

	$k_D$	MW	0°C	15°C	20°C
nitrogen (N <sub>2</sub> )	20		0.013	0.019	0.018
oxygen (O <sub>2</sub> )	32		0.040	0.029	0.023
methane (CH <sub>4</sub> )	16		0.005	0.043	0.034
carbon dioxide (CO <sub>2</sub> )	44	1.710	1.330	0.842	
hydrogen sulfide (H <sub>2</sub> S)	34	4.690	3.850	2.870	
ammonia (NH <sub>3</sub> )	17	-	3.20	1.31	
tri (C <sub>2</sub> H <sub>5</sub> )	133.5	-	3.90	1.43	
chloroform (CHCl <sub>3</sub> )	119.5	-	9.0	7.87	
ammonia	17	-	0.94	0.76	

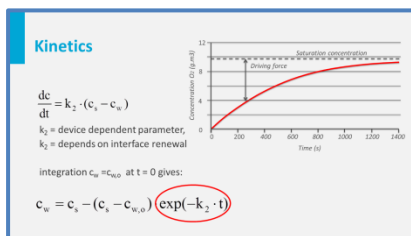
The equilibrium concentration is also called the "saturation concentration". For oxygen in water in equilibrium with the atmosphere, the saturation concentration is approximately 12 mg/L at 10 degrees Celsius.



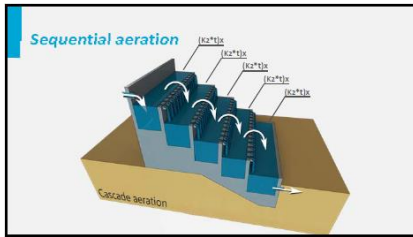
Equilibrium is not achieved at once during intensive contact between water and air. Rather, the gas exchange takes place at a rate that is linear to the driving force. This driving force is the difference between the actual concentration and the equilibrium concentration.



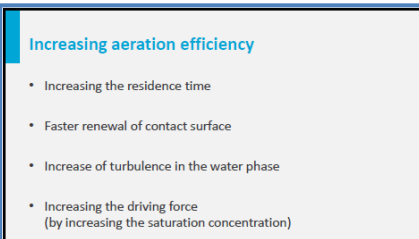
The gas transfer coefficient depends on the magnitude of the contact surface area between water and air, and on the rate at which this surface is replaced. The figure shows the profile for the oxygen concentration in an aeration device. Initially, the concentration increases rapidly, but this increase is slowed down due to the reduced driving force.



For a certain aeration system, the gas transfer coefficient can be assumed to be constant. It should be noted though that an aeration device has different  $k_2t$ -values for different gases. The efficiency of aeration can be defined as the achieved decrease in the driving force, divided by the possible decrease in the driving force.

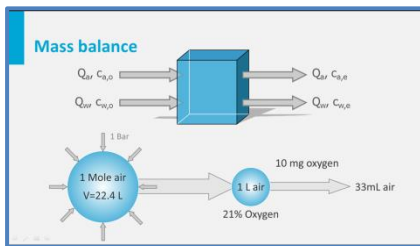


When aerating sequentially the efficiency will be equal per step, because the  $k_2t$ -value of the same device is equal. This occurs, for example, in aeration with cascades, where the water makes the same falling motion at each step. Now, when designing a gas transfer installation it is good to know how you can increase the efficiency.

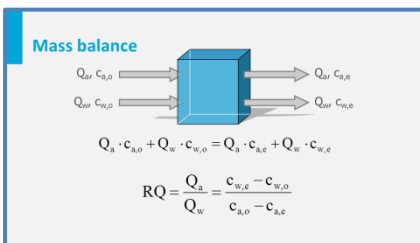


The efficiency of aeration can be increased by increasing the  $k_2t$ -value of the device, for example, by increasing the residence time, by faster renewal of contact surface, or by increase of turbulence in the water phase.

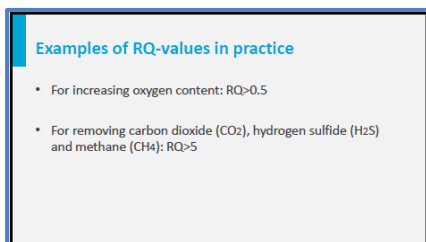
The driving force can also be increased. This can be done by increasing the saturation concentration. For aeration of drinking water this can be achieved by applying a higher operating pressure, for example with deep well aeration, or by applying pure oxygen instead of air. Another alternative is vacuum gas transfer.



When considering the mass balance, the amount of air needed for the addition of oxygen can be easily calculated. The volume of 1 mole air is 22.4 liters at 1 bar, so 1 liter air with 21% oxygen is 0.3 grams of oxygen. To get 10 mg oxygen in 1 liter of water, theoretically, only 33 milliliter of air is needed.




According to the mass balance, the gas mass that is removed from the water is equal to the gas mass that is transported in the air. Therefore, the volumetric air-water ratio per time unit is of importance; this air-water ratio is called RQ. RQ is calculated by dividing the air (or gas) flow by the water flow.



In practice, an RQ of 0.5 is required for an increase in the oxygen content, which is 15 times more than the 33mL that is theoretically needed. To prevent a limitation in the removal of carbon dioxide, hydrogen sulfide or methane a minimum RQ of 5 is needed. When a high level of removal is desired, a higher RQ-value is obviously required. This is, for example, the case when removing toxic, volatile compounds, like chloroform and trihalomethanes, which can be present in groundwater because of pollution.

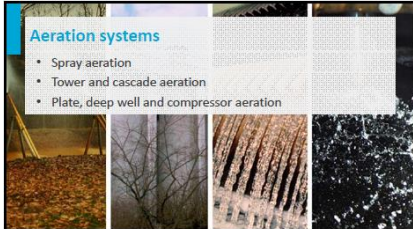
**Examples of RQ-values**

- RQ values for bubble aeration are typically <1
- For tower and plate aerators RQ reach >10



**Aeration systems**

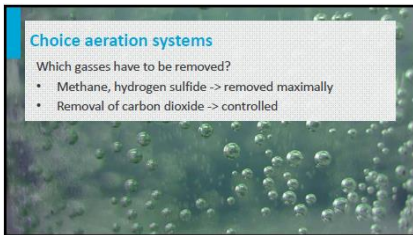
- Spray aeration
- Tower and cascade aeration
- Plate, deep well and compressor aeration



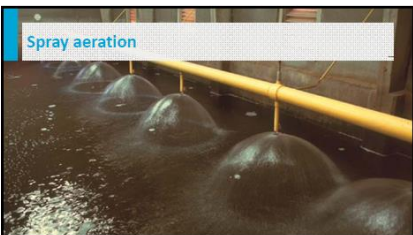
**Choice aeration systems**

Which gasses have to be removed?

- Methane, hydrogen sulfide -> removed maximally
- Removal of carbon dioxide -> controlled



**Spray aeration**



**Spray aeration**

Design choices:

- Upwards or downwards
- Separate room or above the sand filter
- Single or double spraying



In the case of bubble aeration the RQ-value is typically smaller than 1.

In the case of tower aerators and plate aerators RQ-values of 10 and higher are applied.

The differences in RQ-values cause, to a great extent, the differences in efficiency of these systems for specific gasses.

Now you know the theory of gas transfer that is needed to design basic aeration systems for drinking water treatment.

I have already briefly mentioned different technologies, such as cascades, tower and bubble aeration; however, in the upcoming sheets I will introduce you to the key design criteria for different aeration systems.

Gas transfer can be achieved during drinking water treatment with various aeration systems:

Spray aeration, which consists of dropping the water through the air in fine droplets;

Tower and cascade aeration, in which water is divided into thin layers;

Plate, deep well and compressor aerators, in which small bubbles of air are blown through the water.

Technically, these systems can be realized in a great number of ways and the choice for a certain system is, to a great extent, determined by the gasses that have to be removed.

For example, methane and hydrogen sulfide have to be removed maximally, because any remaining content will affect the post filters.

The removal of carbon dioxide, on the other hand, has to be controlled, because its level influences the pH and with that the saturation index (or SI).

Let's start with spray aeration.

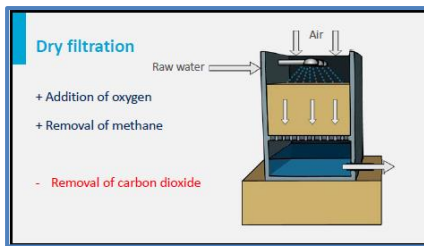
As the name suggests, the water is sprayed through the air onto the water surface, a solid body or against another spray of water.

In all cases the water is distributed over a large area, in order to increase its contact surface with the air.

Over the course of time, a great number of sprayers and spray methods have been developed.

For the treatment of groundwater, spraying can be applied either upwards or downwards.

Also, the spraying can be done in a separate room or directly above the sand filter.



When intensive gas transfer is needed, double spraying is employed, for example with a spraying room above a sand filter.

In the case of dry filtration, spraying is always used to distribute the water evenly of the filter bed.

The spraying room has to be ventilated with a flow that results in the desired RQ-value for the aeration transfer.

This air is filtered in advance to avoid contamination of the microbiologically reliable groundwater by contaminants in the atmosphere.

Spraying is efficient for the addition of oxygen and the removal of methane, but less efficient for the removal of carbon dioxide.

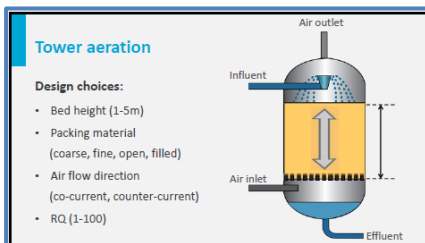
If iron is present in the groundwater, the addition of oxygen to the water results,

almost directly in the oxidation of the dissolved  $Fe^{2+}$  to  $Fe^{3+}$ .

Therefore, on the walls and pipes of the spraying systems, iron deposits are often found.

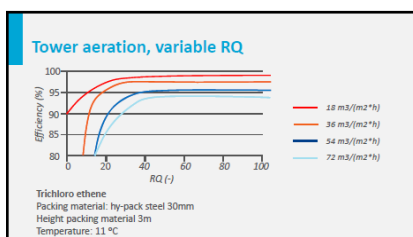


Tower aeration is a system where water is distributed over a column with packing material, through which air is blown.



With tower aeration very good removal of gasses is possible, and the tower can be configured by a few clear design choices, namely :

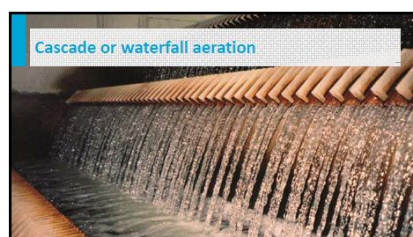
bed height,  
type of packing material,  
air flow direction  
and choice of RQ.



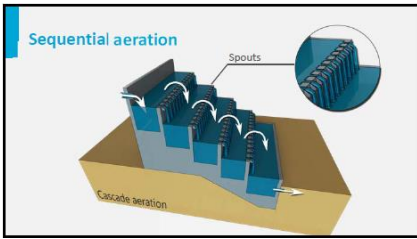
Tower aeration is not very sensitive to variations in hydraulic load.

It is, however, sensitive to fouling, which makes regular replacement or cleaning of the packing material necessary if the water contains iron.

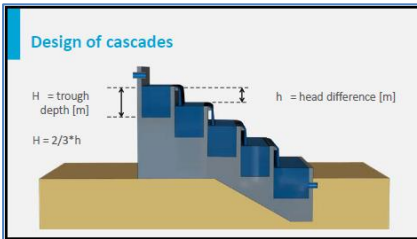
Tower aeration can also be applied in a pressure vessel, with a vacuum the gasses can be removed from the water.



Cascade or waterfall aeration divides the water in a thin layer by letting it fall over a sharp edge.



There are many different designs around, but the most efficient types use spouts where the water falls through. This cascading forces air bubbles into the water and, because of the turbulence, these are separated into many small bubbles.



As a rule of thumb, the trough has a minimum depth of 66% of the fall height in order to obtain sufficient contact time. The water flow rate, and directly linked its contact with the air, depends on the fall height.

**Cascade efficiency**

Efficiency per step  

$$K = \frac{c_e - c_o}{c_s - c_o} = 1 - (1 - k)^n$$

K = total efficiency  
 k = efficiency per step,  
 k = f (h, type of gas)  
 n = number of steps

h (m)	0.2	0.4	0.6	0.8	1.0	1.2
k	14	25	38	48	51	55
k <sub>CO<sub>2</sub></sub> (%)	14	14	15	15	15	15
k <sub>O<sub>2</sub></sub> (%)	27	39	48	56	56	62

In practice, a maximum fall height of 1 meter per step is chosen, because the efficiency barely increases above this height.

A higher efficiency can be obtained by increasing the number of steps, either side-by-side or on top of each other. The efficiency of a cascade depends little on the hydraulic load, and is therefore a very robust way of aerating, independent of fluctuating production capacity or iron deposits.



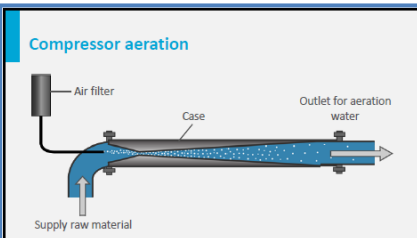
The last group of aeration systems in this lecture are the bubble aerators, consisting of plate, deep well and compressor aerators.

Bubble aerators have the advantage that they can be easily incorporated in the treatment scheme.

Namely, the required energy is not extracted from the water phase, but given to the air phase.

This makes the gas transfer much more flexible than in other aeration systems.

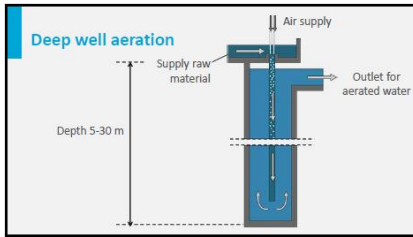
Additionally, compressor or deep well aerators are used when the removal of carbon dioxide is undesirable.



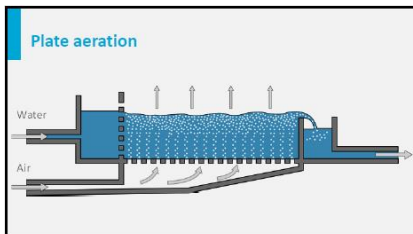
In a compressor aerator, air is directly injected into a water pipe through a compressor, just before a narrowing in the pipe.

This causes a higher turbulence leading to small air bubbles and good mixing.

In the figure, Venturi aeration is depicted, which is a variant of compressor aeration and was often applied in the past.



For deep well aeration, air is brought into a vertical tube, where the mixture flows down to a depth of 5 to 30 meters. Here, the water flows out of the tube into a larger shaft. Because of the high hydrostatic pressure, a very high transfer of oxygen is achieved, within an exceptional small space. Oxygen can be added to the water, but gas removal rarely occurs.



With plate aeration, a large amount of air is blown through a thin layer of water. The air is injected through many small holes in the bottom. The large amount of air causes strong turbulence and a good gas transfer, despite the short residence time. With this system a very good methane removal can be achieved, and also considerable carbon dioxide removal. The system is very sensitive to fouling; the small holes can clog due to iron and calcium deposits.



Well, we have come to the end of this video lecture where I introduced you to the basic mechanisms of gas transfer and the key design criteria for different aeration systems applied for drinking water treatment. I thank you for watching and invite you to post your questions on the discussion board.