Technical presentation

JAN 2017

Ref: The SansOx OxTube, EU Innovation Award Winner in 2014

EFFICIENT DISSOLVING OF GASES IN LIQUIDS

INTRODUCTION

OxTube Modules:	*Vortex ccw, Ejector, Vortex cw, Impulse and Micro Bubbling Module, GasRemover and Undissolved Gas Recycling*
Process:	*Reduction of dissolving resistance factor K*
Ref.:	*Two film theory, study on the main present processes, idea creation, experimental studies and test runs*

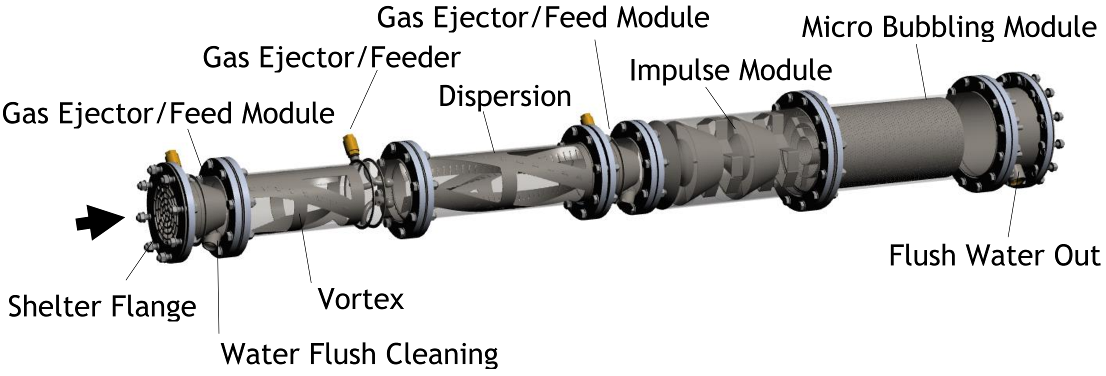

Fig. 1: The OxTube

OxTube dissolving process principles and basics on its performance are presented here. Applications are not discussed here.

The present dissolving and liquid treatment processes were investigated by the means of their long lasting and un-efficient process. The theoretical condition as well as dissolving speed for air gas and oxygen were defined at the beginning of the OxTube development.

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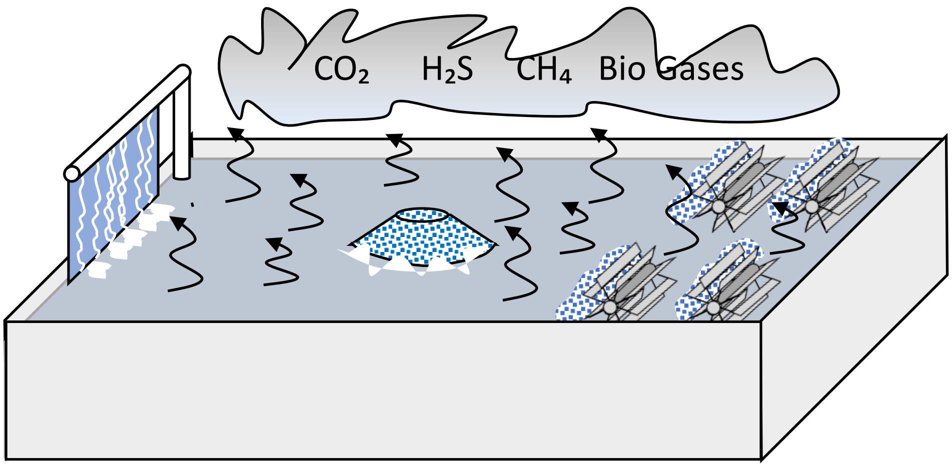


Fig. 2: The present surface and bottom aeration systems are inefficient and energy intensive mainly due to their still water mixing or no mixing and low oxygen concentration of atmosphere above the still water pool. In practice, reaction gases are transferred back in the water.

DISSOLVING PROCESS

The most present dissolving processes try to copy the processes in the nature like mixing, flowing, dropping, paddling, dripping, raining, trickling, water falling, bubble generation by compressed air and diffusor, plasma by electrical arc etc. Regarding the present systems there are the following main drawbacks identified:

- Dissolving resistance K factor is not reduced nor even considered. In some cases, K factor is even increased according to research.
- Energy consumption is high in general due to fact that dissolving process is separated from liquid flow, i.e. kinematic energy of the flow is not used.
- Aeration is done for a minor part of the liquid to be treated while the major part remains passive, i.e. on the surface or bottom of huge volume vessels.
- The huge vessel with passive liquid in it is a breeding ground for various bacteria, plans and algae.
- Oxygen concentration of the air above aeration vessels is low due to strong fermentation and bio gasification. Smell can be identified on the vessels, so with a surface aeration the bio gases dissolve in the water due to fact that dissolving resistance of oxygen is greater than these gases. Surface aeration is useless when strong smell can be identified above the surface.
- Water falls can separate dissolved oxygen from water. Oxygen content in the air above water falls is higher than in surroundings due to this fact. Direct hit energy is used for oxygen concentration reduction in process waters.

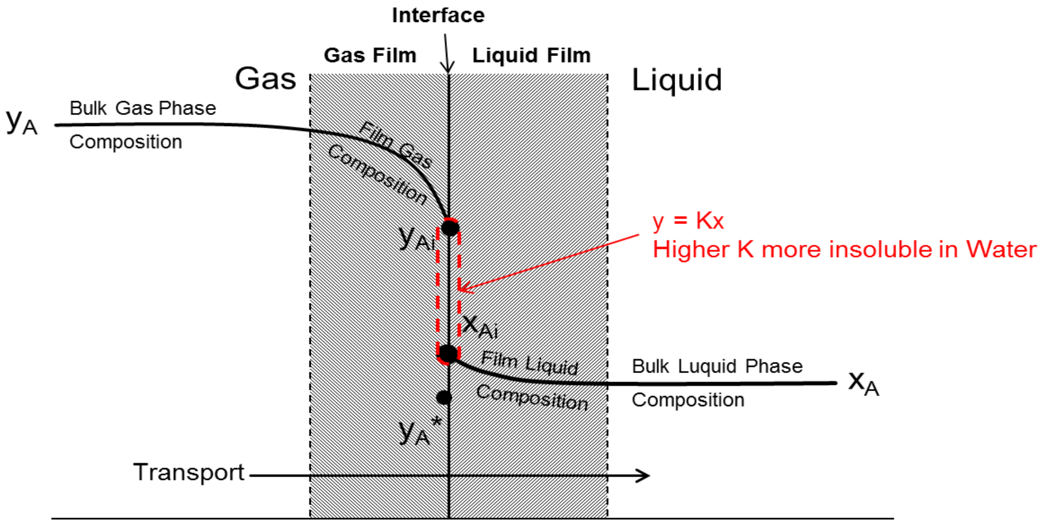
- The vessels are impossible to keep clean and so, the treatment efficiency is reduced by this nasties all around.
- Dissolving resistance is high in general when the liquid is kept long time still in a vessel, i.e. the liquid gets saturated very complex way, and is lacking free places.
- The surface of still water in a vessel gets stiffer and tighter and surface tension gets stronger, which increases dissolving resistance.

EFFICIENT DISSOLVING PROCESS

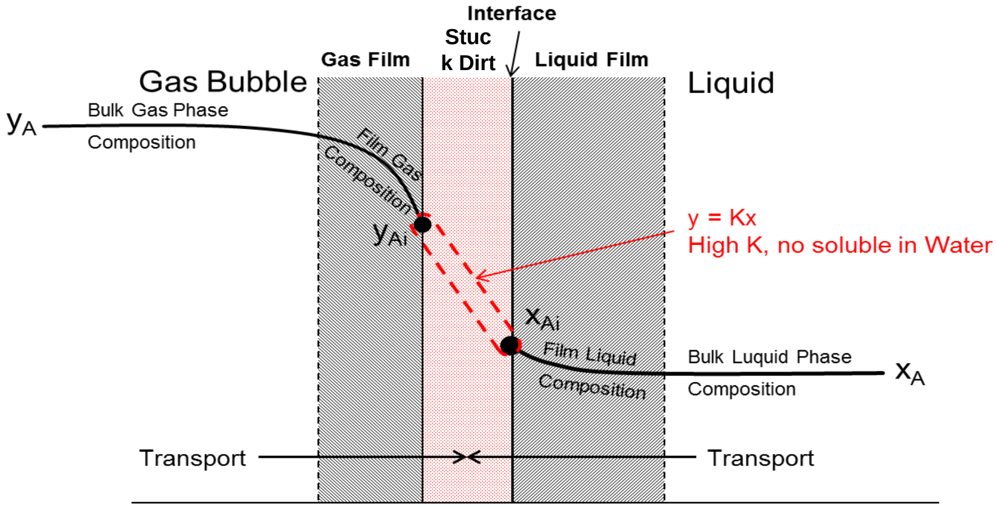
The most common theory of gas dissolving by diffusion is presented as Two Film Theory. Its key issues are illustrated in Fig. 3. According to the theory, the material phases have surrounding this films that causes the dissolving resistance in principle. In standard cases, the transportation is from gas to liquid. However, in practice there are unfavorable reactions and composites between the layers that could cause even both direction transportation. When considering oxygenation or aeration this is presented as COD and BOD.

Theoretically, gases are transported by dissolving in waters immediately, when

- The molecules are arranged close together
  - The dissolving resistance is reduced to minimum.
  - In aeration case it is essential that fresh air is sucked or led into dissolving process directly, i.e. dissolving competition with other gases and impurities should be avoided.
  - Gases to be dissolved are led directly in the liquid to be treated.
  - The liquid to be treated has places for gas molecules or these places should be arranged. Passive still water kept long time in a vessel has very limited amount of places for air gases or pure oxygen.
  - The liquid is kept merely in moving proper way than still in order to minimize unfavorable breeding, reactions and uncertainties.
  - The dissolving area is kept clean and steady.
  - Dissolving concentrate rate can be increased by gas overdosing when probability to fill all gas diffusion places is enhanced. Gas overdosing increases gas consumption.
  - Dissolving efficiency and high concentrate can be achieved by undissolved gas recycling.



A) Standard condition



B) Condition in practice with dirt

Fig. 3: Illustration of two film theory in standard condition A) and in practice B). In the OxTube process surrounding films of the phases are broken, stuck dirt split and the molecules to be dissolved are pressed against each other. Kinematic energy is used all the way in the integrated process.
Source: Common illustration on Two Film Theory in several research publications, and conclusions collected from practical research reports

OXTUBE PROCESS IN BRIEF

The main issues in development of the OxTube, were those which increase the dissolving resistance K factor. The present dissolving and liquid treatment processes were investigated by means of their long lasting and un-efficient process. The theoretical condition as well as dissolving speed for air gas and oxygen were defined.

The OxTube dissolving process is based on the following features:

- OxTube is a continuous process that ensures that the liquid is treated all around.
- OxTube is designed by such a principle which ensures it to keep clean without undesirable phenomena. The cartridges are easy to exchange and washable in a washing machine.
- The treatment time could be less than a second in one factor dissolving and few seconds in more complex condition
- The liquid to be treated is formed in vortex flow in order to lengthen molecular phases, to thin the surrounding layers and to take the liquid in proper control in the flow.
- The gas to be dissolved is fed or sucked in the vortex flow. The gas feed can be downstream or counter current to the vortex flow.
- The gas and liquid are mixed efficiently to homogenous mix, and all the layers over the phases and between them are tensioned and split at the same time.
- The treated phases and composites are hit on conical or inclined surfaces in order to create theoretically optimal condition and energy for dissolving.
- The fifth step could be direct micro bubbling if the proper dissolving needs more time.

Dissolving efficiency of OxTube is presented in Fig. 4. These results are based on the first step in the development. Later in practice the DO (dissolved oxygen) level of 55 mgO_2/l was achieved in three seconds process time with pure oxygen feed. This can be guaranteed in natural waters in normal health condition.

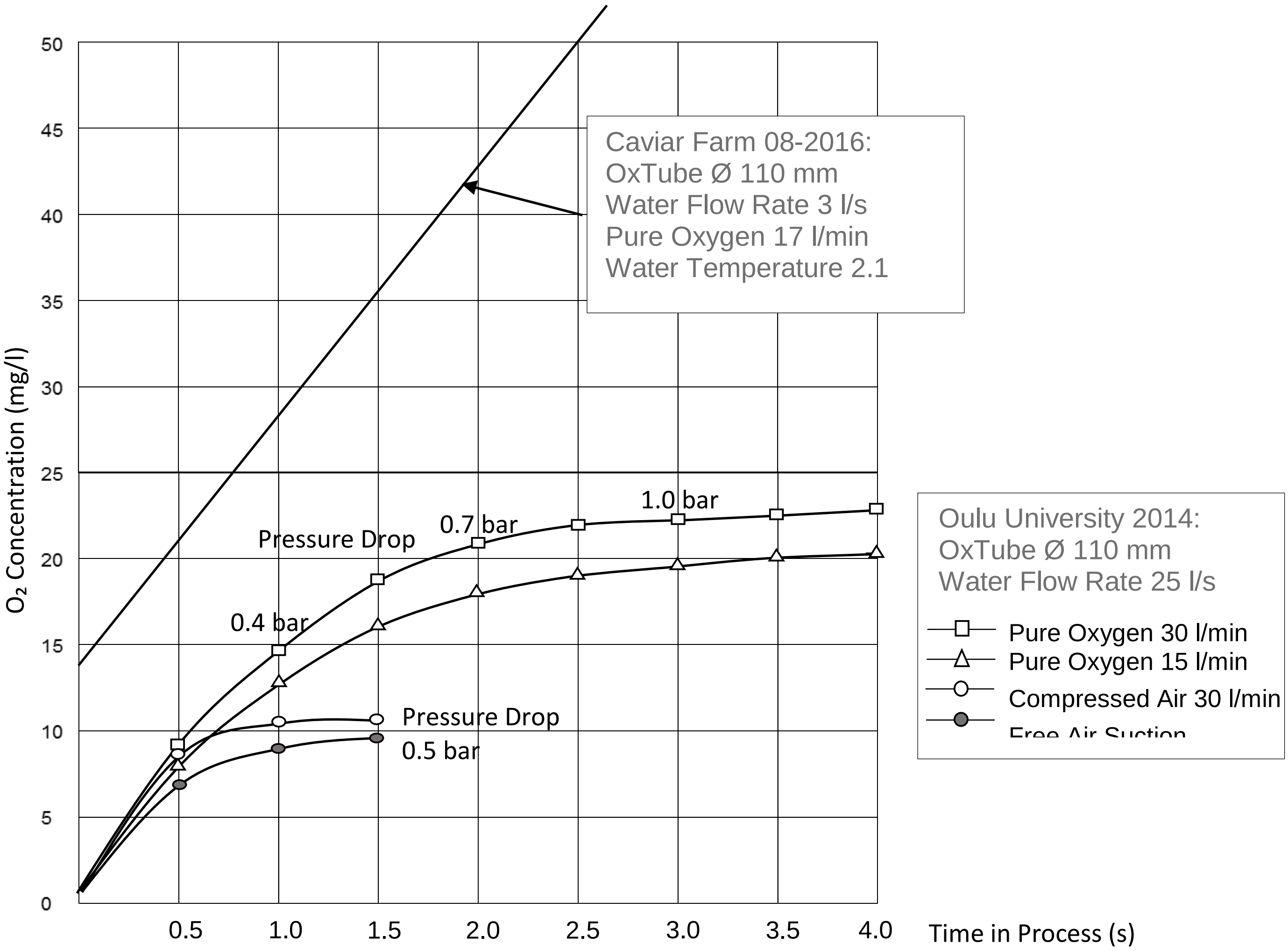
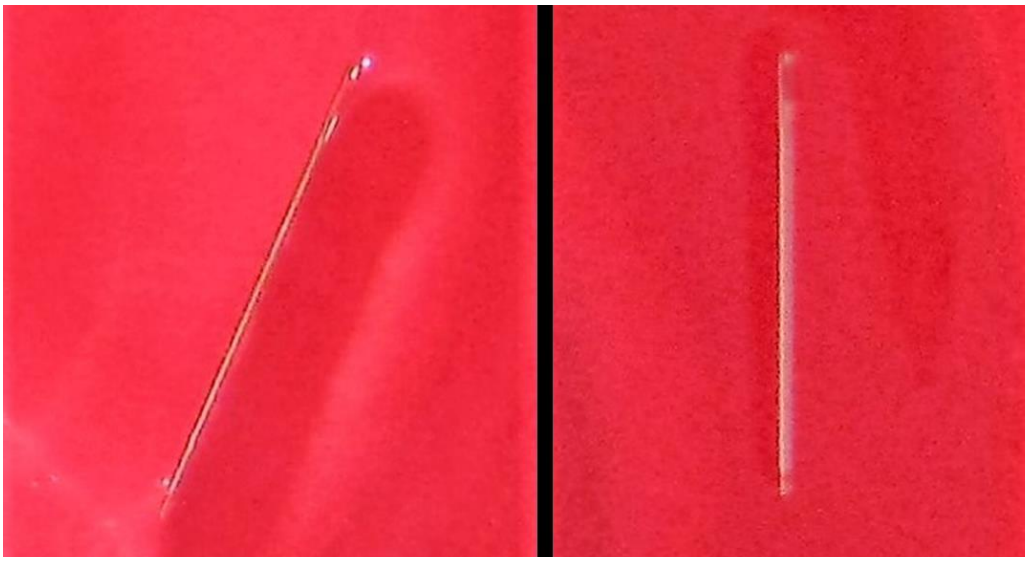


Fig. 4: Dissolving performance of OxTube in aeration and oxygenation measured as oxygen concentrate achieved and as related process time. After the development DO level of 55 mgO_2/l has been achieved within 3 second process time by pure Oxygen feed.

Surface tension is reduced significantly by the OxTube aeration process which is one significant factor to reduce the dissolving resistance factor K. This is illustrated in a simple test with high purity Swiss tap water in Fig. 5.



A) Untreated Swiss tapwater

B) After OxTube aeration, process time 0,2 s

Fig. 5: OxTube aeration reduces surface tension of water. The nail floats on untreated Swiss tap water but it sinks in OxTube aerated water.

Viscosity of the water is reduced by the OxTube aeration as presented in Table 1. This is a significant evidence of dissolving resistance reduction and quick dissolving. The mass flow of the water was increased by the same rate. This reduces energy consumption.

OxTube Aeration	Comparison of Without and With Air Ejection		
OxTube D20	Swiss Tap Water	J. Pylkkanen	15.4.2016
Test No	Without Air Ejection	With Air Ejection	Change %
Test 1			
Q (l/s)	0.182	0.190	4,4
v in (m/s)	0.905	0.945	
Viscosity (Pas = Ns/m²)	$1{,}002 \times 10^{-3}$	$0{,}958 \times 10^{-3}$	-4,4
Test 2			
Q (l/s)	0,203	0,222	9,4
v in (m/s)	1,01	1,104	
Viscosity (Pas = Ns/m²)	$1{,}002 \times 10^{-3}$	$0{,}908 \times 10^{-3}$	-9,4
Test 3			
Q (l/s)	0,235	0,267	13,6
v in (m/s)	1,17	1,33	
Viscosity (Pas = Ns/m²)	$1{,}002 \times 10^{-3}$	$0{,}867 \times 10^{-3}$	-13,6
Test 4			
Q (l/s)	0,286	0,316	10,7
v in (m/s)	1,42	1,57	
Viscosity (Pas = Ns/m²)	$1{,}002 \times 10^{-3}$	$0{,}895 \times 10^{-3}$	-10,7
Test 5			
Q (l/s)	0,571	0,632	10,5
v in (m/s)	2,84	3,14	
Viscosity (Pas = Ns/m²)	$1{,}002 \times 10^{-3}$	$0{,}897 \times 10^{-3}$	-10,5

Table 1: Impact on viscosity of OxTube aeration

DO transfer efficiency according to the first tests in term of kgO_2/kW is presented in Table 2. This has been improved a lot after development. Further, OxTube dissolving energy used is kinetic energy of the flow that can be already available in many places of liquid transportation by pumping.

Design parameters:

- Air feed by ejection 2.5 kgO_2/kWh
- Air feed by compressor 4.5 kgO_2/kWh
- O_2 feed 4.5 kgO_2/kWh

Tests at Oulu University	OxTube DN100 Stainless Steel AISI304			J. Pylkkänen	July 21, 2015
Diameter in the end of the pipe systems (mm)	Feed pipe	Test 6	Test 10	Test 14	Test 20*)
	110	110	110	110	110
Efficient length of feed pipe / OxTube (m)	6 / 0	6 / 2,6	6 / 2,6	6 / 2,6	6 / 2,6
Volume flow in the pipe systems (m^3/s)	0,0385	0,0250	0,0263	0,0286	0,0118
Flow speed in OxTube (m/s)	4,047	2,630	2,769	3,006	1,238
Kinematic energy after OxTube (kWh/m^3)	0,00227	0,00096	0,00106	0,00126	0,00021
Net loss or energy used (kWh/m^3)	0,01190	0,01321	0,01311	0,01291	0,00460
Gas flow (l/min), etd=ejected, csd=compressed	N/A	etd air 26,0	etd air 34,7	csd air 30,0	O_2 15,0
Mass Flow (m^3/h)	138,46	90,00	94,74	102,86	42,35
SOTR (kgO_2/h)	0,44	1,03	1,21	1,83	0,59
SAE (kgO_2/kWh)	0,27	2,48	3,09	5,36	4,36

*) Throttle before OxTube

Table 2: Aeration efficiency of OxTube dissolving measured as difference of kinetic energy in and out. In many cases the pumping energy available can be used without additional power.

MODULES OF THE OXTUBE

A typical OxTube installation that ensure fast mixing and dissolving process consists of the following modules in sequence: Vortex ccw, Ejection, Vortex cw, Impulse, and Micro Bubbling. The water is treated continuously within 0,5 to 10 seconds depending on water type and process needs. In the most cases OxTube is able to intake gases and chemicals by feed and/or suction, mix them efficiently and evenly, and dissolve ingredients in the flowing liquid.

SansOx has developed two Ejector Modules, types throttle and forward spiral. The spiral type makes a strong axial suction in centre of the liquid spiral flow. The both types mix liquid, gas and ingredients evenly when the Vortex Modules are used.

The Vortex makes the liquid flow forward spiral in the manner that pressure on the tube surface increases and in the centre line decreases. This means less turbulences on the surface area and mixing suction in the flow centre area.

Impulse Module makes dissolving happen just after the liquid, fed gases and ingredients are efficiently and evenly mixed in Vortex Module. The maximum dissolving performance is achieved when these three processes feed, mixing and dissolving are integrated. In the OxTube dissolving, kinetic energy of the flow is used in order to press molecules close together against oblique surfaces of the Impulse Module.

Micro Bubbling Module consists of a tube and guiding plates made of hole patterned stainless steel plate. The micro bubbling makes dissolving finished and provides time for chemicals reactions in the treated liquid.

EXAMPLE IMAGES AND DEMONSTRATIONS

The gas is directed in middle of the vortex liquid flow as illustrated in Fig. 6. The air bubbles are micron sized and evenly distributed after suction without any diffusor. The OxTube aerated water is homogenously milky all around even in low flow speed, and milkier in high flow speed. The same flow condition without air suction, i.e. without OxTube treatment is seen in Fig. 7. Micro fine bubbles produced without a diffuser can be seen in vertical Fig. 8.

Horizontal flow with reasonable high speed is presented in Fig. 9. The bubbles just after the gas ejector module are micron size all the way and evenly distributed on the cross section, and mass flow increased over 15 percent with the same pumping pressure.

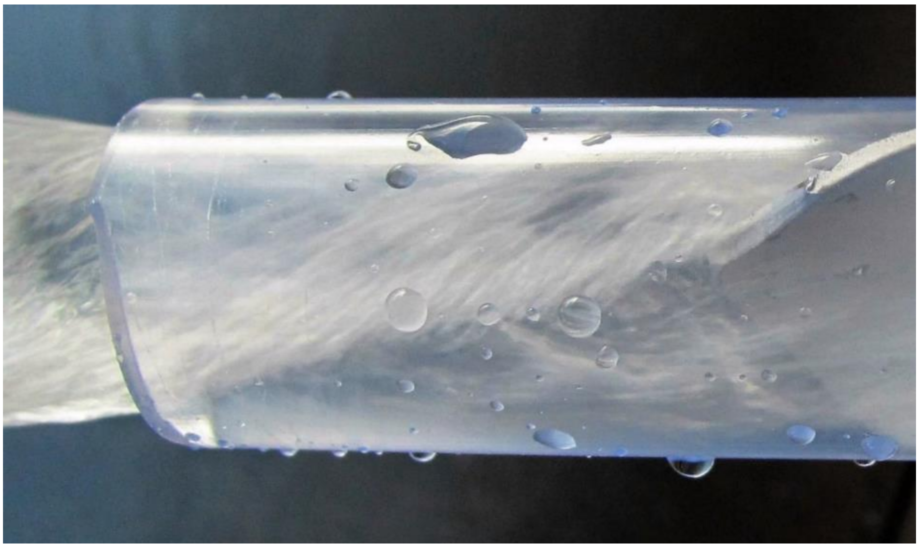


Fig. 6: Horizontal flow of 1.5 m/s with natural air suction. DO transfer efficiency is excellent due to air suction directly in middle of the vortex flow. The air bubbles are micron sized and evenly distributed after suction without any diffusor, which can be seen in left side of photo.

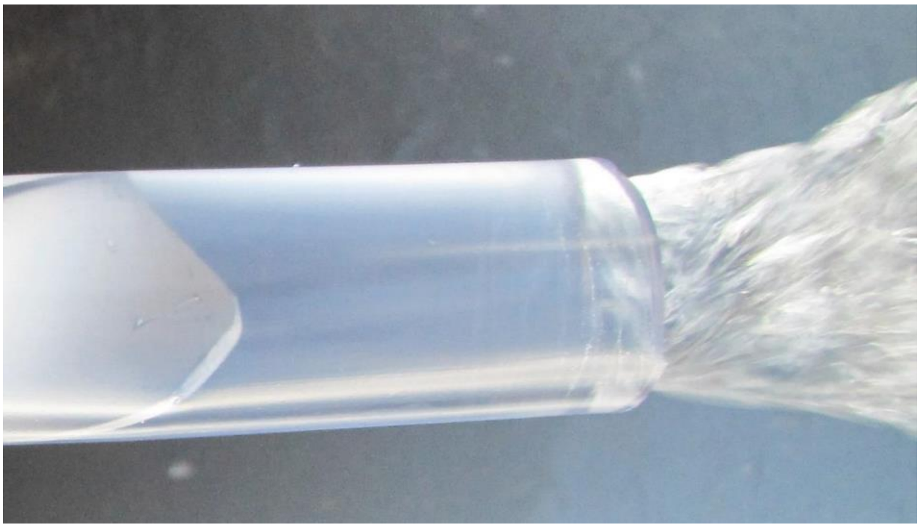


Fig. 7: Horizontal flow of speed of 1.4 m/s without air suction. No air bubbles, nor turbulences in pipe system, but many in outlet mouth. Mass flow of the water was about 10 % less than with air suction in figure 6.

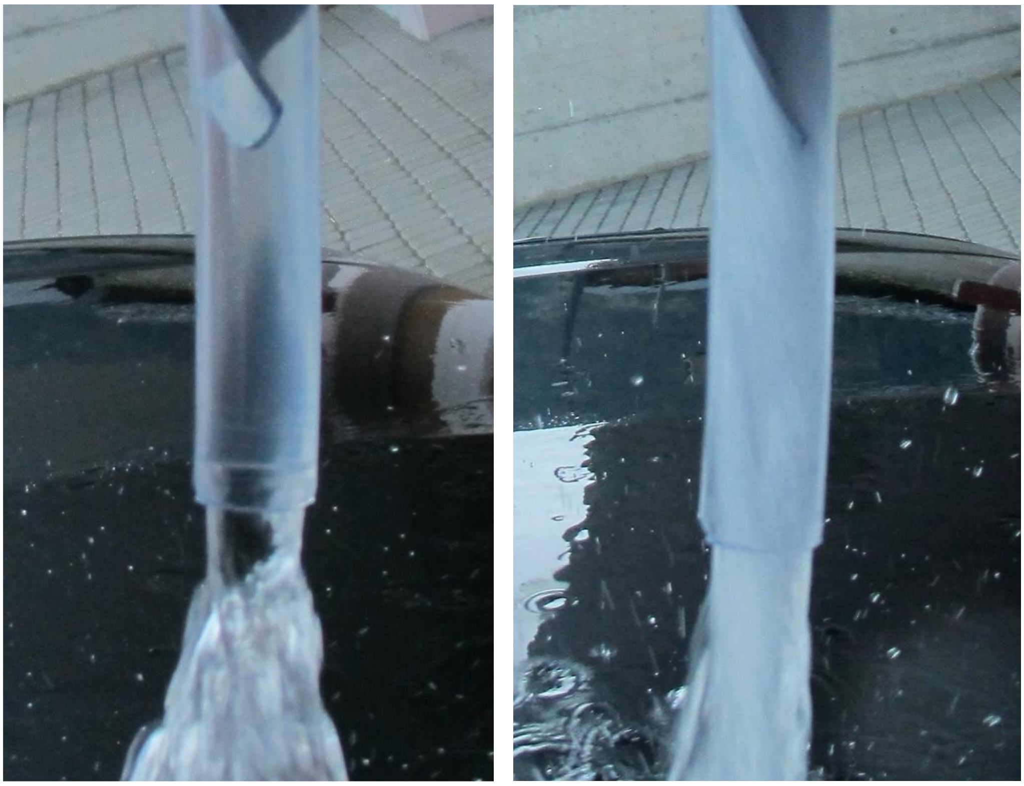


Fig. 8 Vertical down flow of speed of 2.2 left and the flow increased to 2.6 m/s right; left without air suction and right the flow switched to air suction. Air bubbles of micron sized are extremely even distributed in the vortex flow, mass flow is about 18 % greater with air suction.

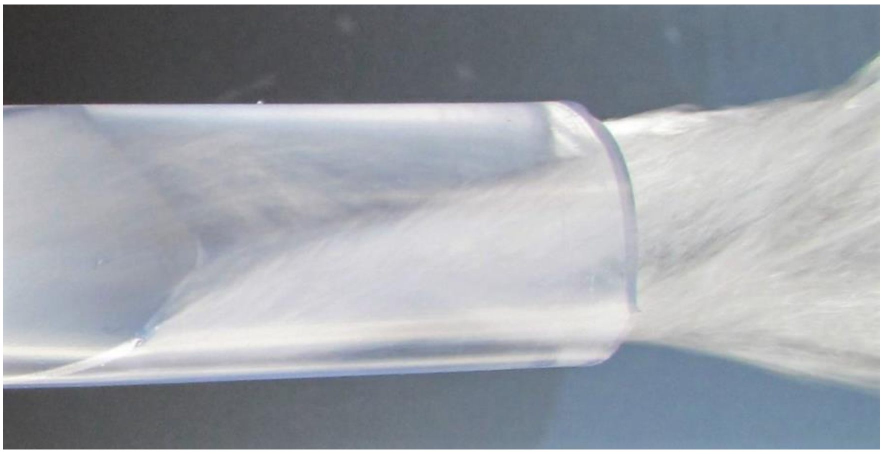


Fig. 9: Horizontal flow of high speed of 3 m/s in intake pipe with natural air suction. The flow is still smooth, and air bubble small and evenly distributed. Mass flow increased some 15 % of the flow without air suction.

Fig. 10: Here the vortex stream can be seen clearly and how it leads the air / gas stream in the middle of water stream. Increased pressure on the tube surface and reduced pressure in the center line make mixing more efficient and even, which secures high class dissolving.

HIGH PERFORMANCE GAS DISSOLVING

High Performance Gas Dissolving contents of OxTube with two Ejectors, gas remover GasRemox and Undissolved Gas Recycling, Fig. 11. Gas overdosing increases probability to fill all possible diffusion places, and gas consumption is reduced by recycling undissolved gas to the OxTube treatment. Gas dissolving rate of over 90 percent can be achieved by recycling up to the maximum concentrate level.

The recycling can be done by natural suction of the Ejector Module when liquid flow is high enough. It can be also powered by a gas pump or a compressor.

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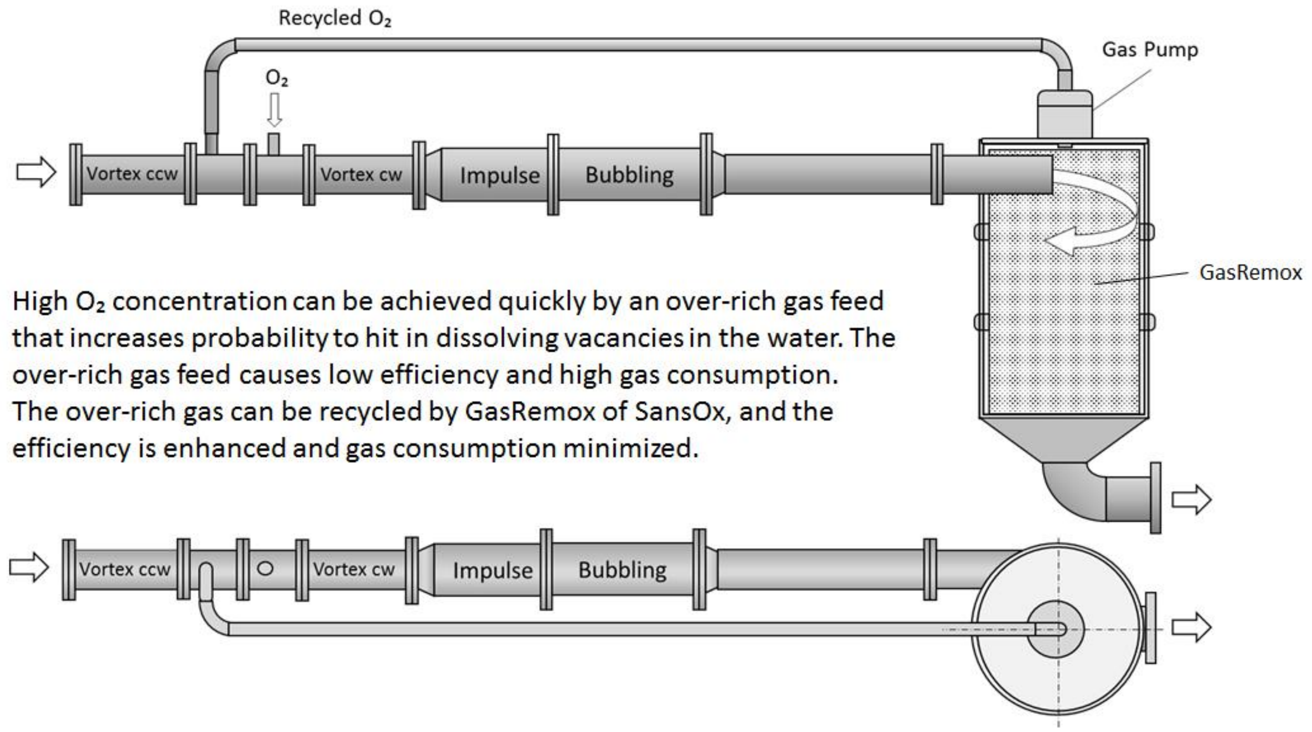

Fig. 11: High Performance Gas Dissolving contents of OxTube with two Ejectors, GasRemover and undissolved Gas Recycling.

CONCLUSIONS

The OxTube fulfils and even exceeds all the expectations and objectives set according to laboratory tests and practice. DO transfer efficiency is good even without impulse and micro bubbling modules, and excellent with a complete installation.

Amount of gas bubbles is great and bubble size small with potable water. The water just after air suction looks totally homogenous milky. This differs with various process and waste waters due to impurities and chemical reactions involved in treatment. Evenly dissolved oxygen speeds up significantly various chemical reactions depending on composition and concentration.

Oxygen dissolving can be performed up to the maximum theoretical concentration level within less than 10 seconds and with transfer efficiency of over 90 percent by using the undissolved gas recycling.

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