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Cavitation Technology Development: A Paradigm Shift in Mining Effluent Treatment

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Québec Mines 2016

Objective

Canada's mining industry is increasingly challenged with stringent environmental regulations and is seeking ***novel barrier-free technologies*** for ***selective removal*** of hard-to-remove contaminants <u>without</u> chemical addition.

Introduction to Cavitation

Background

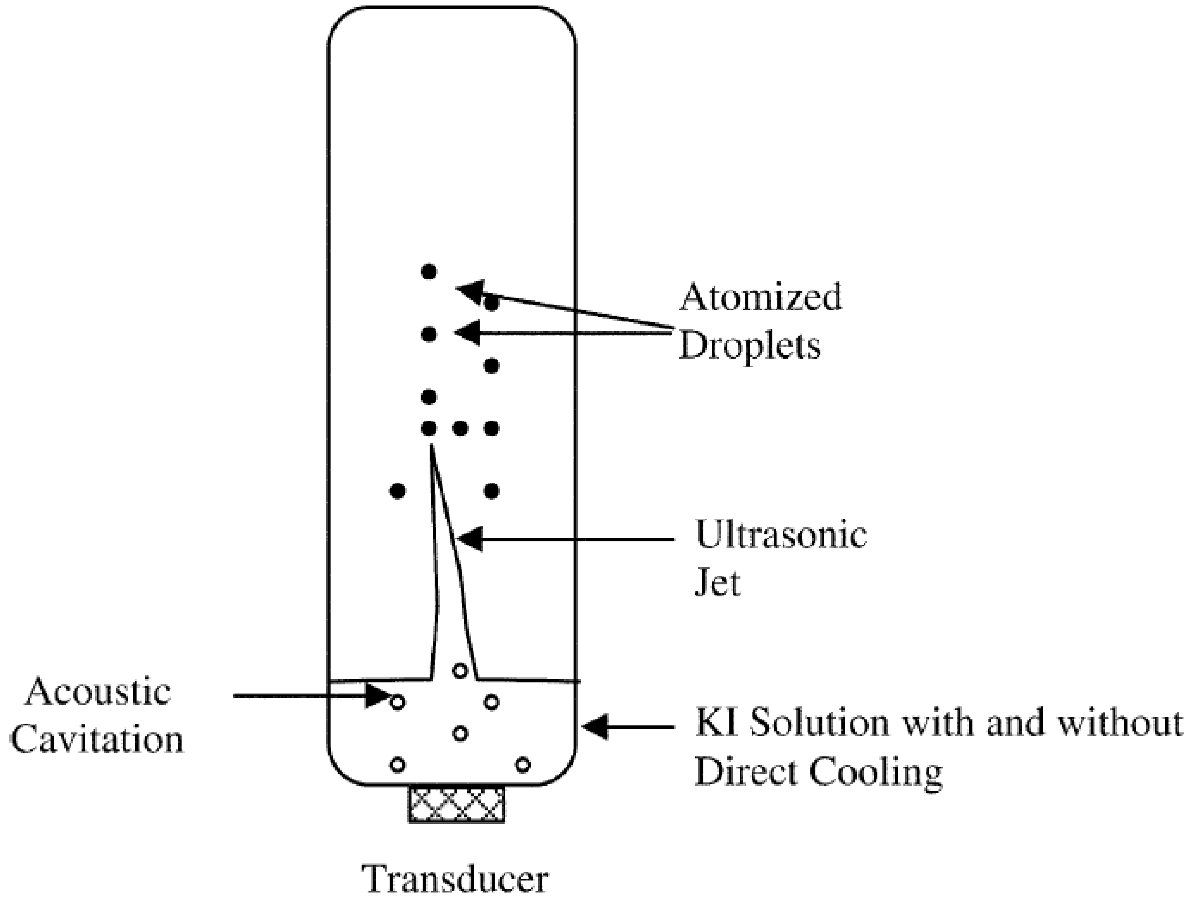
- Localized pressure reduction below vaporization pressure generate cavitation microbubbles
- Be characterized by the formation, growth and collapse of bubbles within a liquid
- Ultrasonic Cavitation introduces strong acoustic field in aqueous solution.
- By Hydrodynamic Cavitation, geometry of the system causes velocity fluctuation and drop the pressure.
- Produces high localized pressures and temperatures
- Energy harnessed to generate highly reactive free radicals, enhancing chemical processing Applied as an advanced oxidation process (AOP) in wastewater treatment

Application Issues

- Limited understanding of effects and control of cavitation process currently exists
- Process scale up from bench to commercial is not well understood

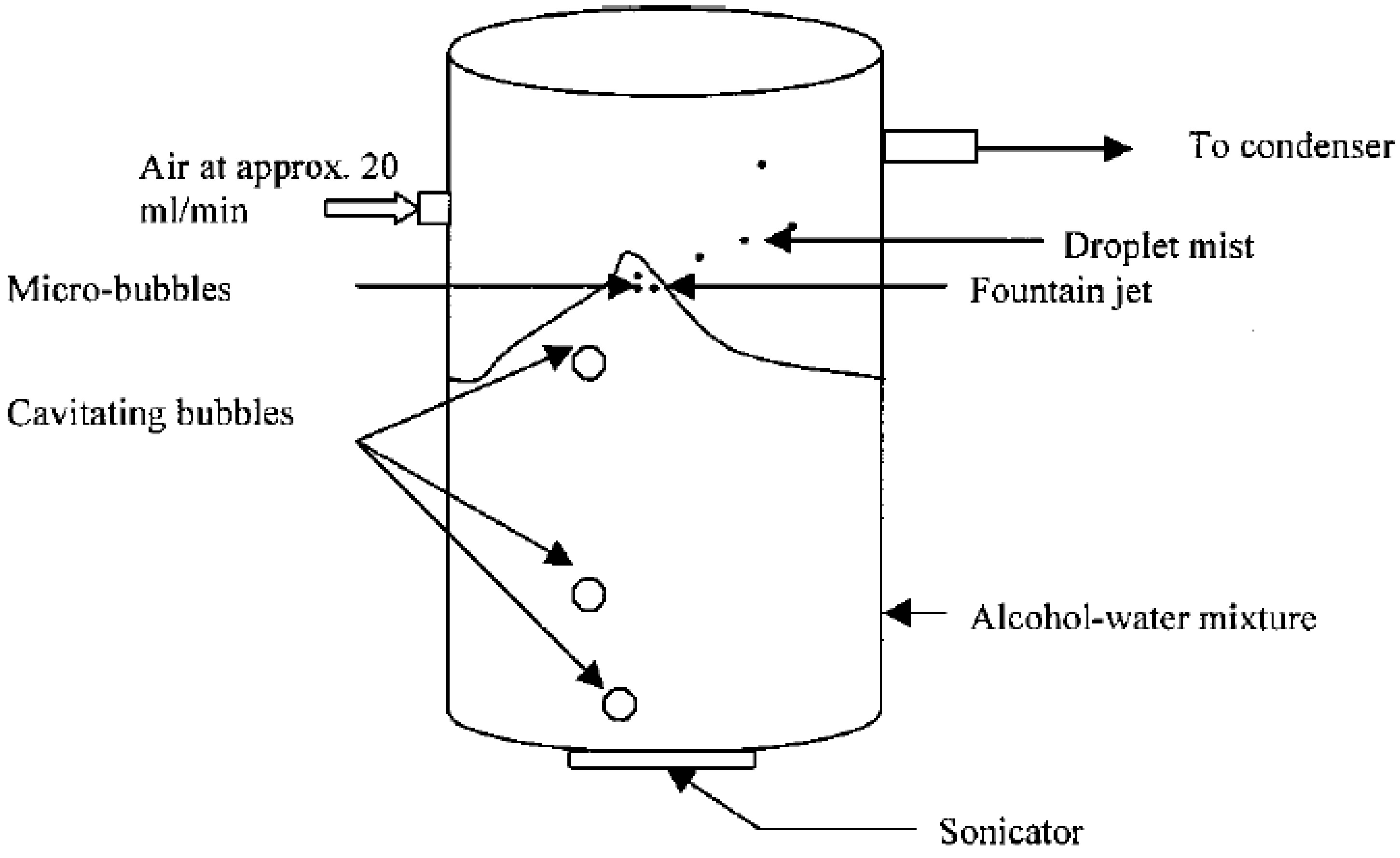
Ozonek J., (2012) Taylor & Francis Group, London.

Theory of Acoustic Cavitation Process (2002)



Kirpalani D.M. and McQuinn K.J., (2006). Ultrasonics Chemistry, 13.

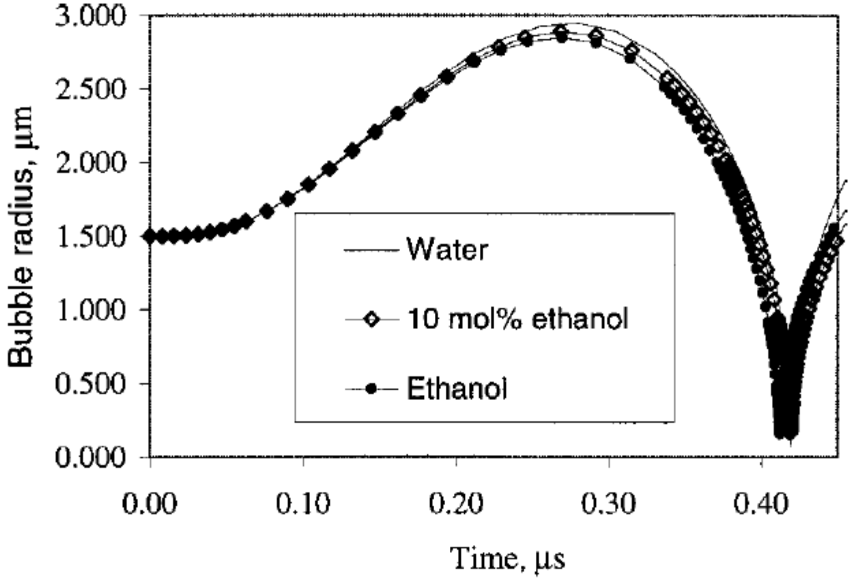
Process Beneficial Cavitation: Ultrasonic Separation of Alcohol–water Mixtures



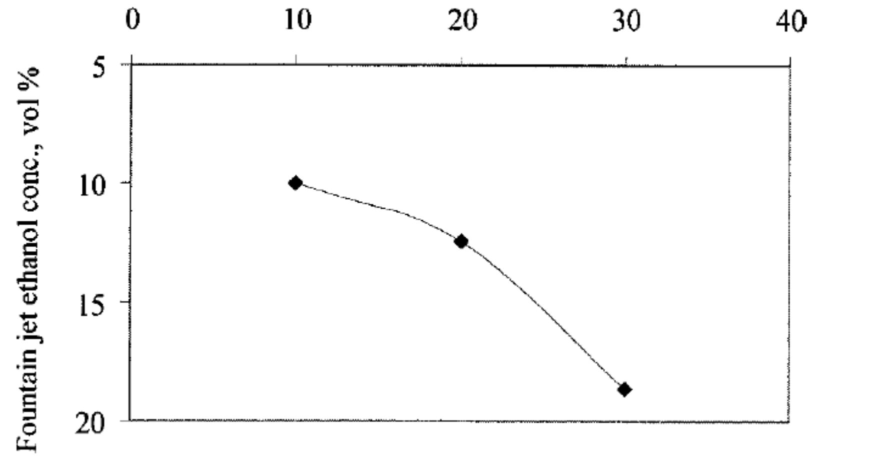
Kirpalani D.M. and Toll F., (2002). Journal of Chemical Physics, 117.

Ultrasonic Separation of Alcohol–water Mixtures

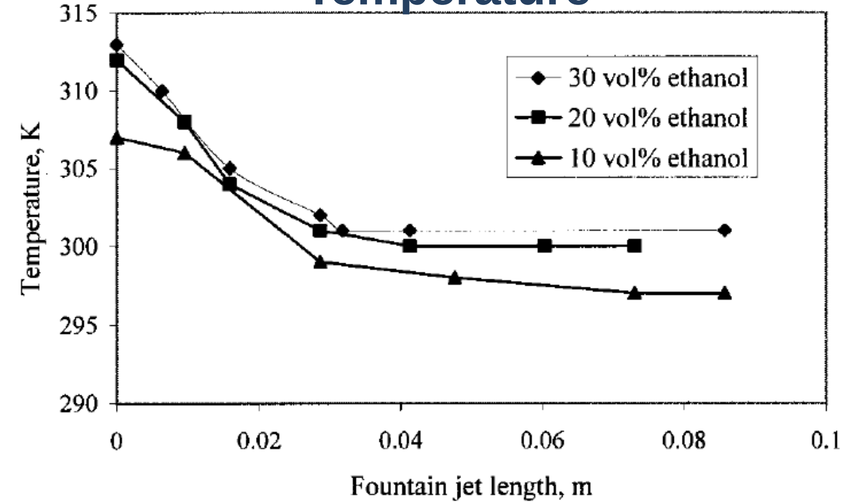
Bubble radius



Initial ethanol solution concentration



Temperature



Kirpalani D.M. and Toll F., (2002). Journal of Chemical Physics, 117.

Hydrodynamic Cavitation

Hydrodynamic Cavitation:

Quickly emerging as *barrier-free* water treatment solution for recycling process water and downstream effluent treatment before discharge

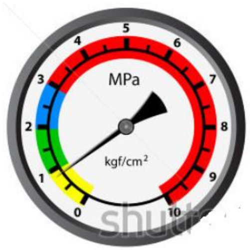
Advantages:

- Ease in process integration
- Modularity
- Scale up feasibility
- Suitable to remove contaminants
- Less energy consumption to provide localized high temperature and pressure
- Enhance chemical reaction rate

Ozonek J., (2012) Taylor & Francis Group, London.

Physico-chemical Effects Produced During The Cavitation Process

Pressure increase



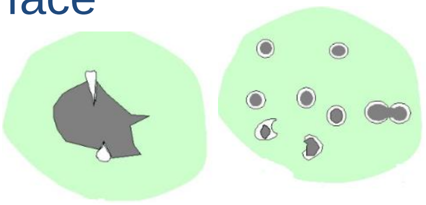
Temperature increase

Thermal effect

Mechanical effect

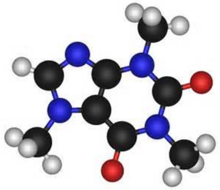
Chemical effect

Increase the phase transition boundary surface



Interfacial tensile forces and turbulence generation

Chemical reaction



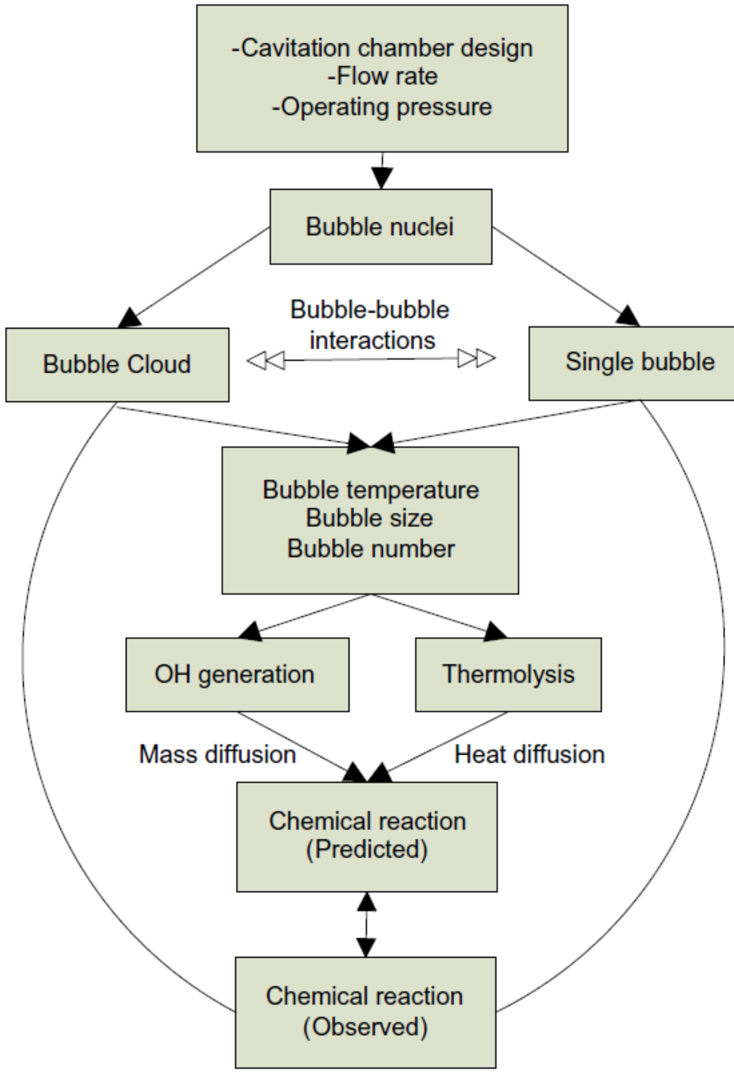
Ozone (O_3)

Hydroxyl radicals generation

($^{\bullet}OH$)

Dindar, E. (2016). *Innovative Energy & Research*, *5* (1), 1–7.

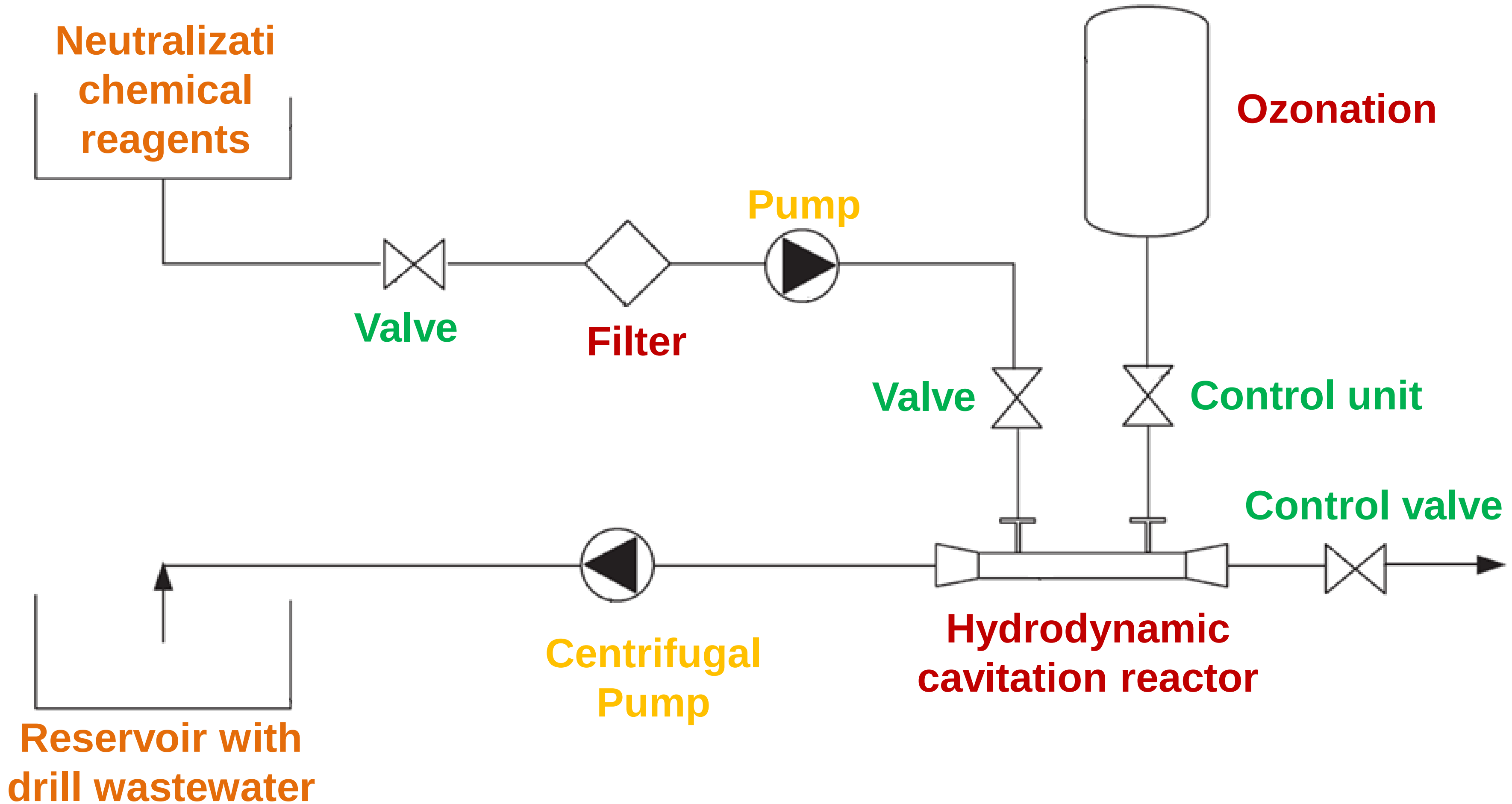
Hydrodynamic Cavitation- A Scale up Technology as an AOP



 Arrojo, S. & Benito, Y. (2008). *Ultrason Sonochem*, *15*(3), 203–11.

Neutralization- Drill Wastewater Treatment

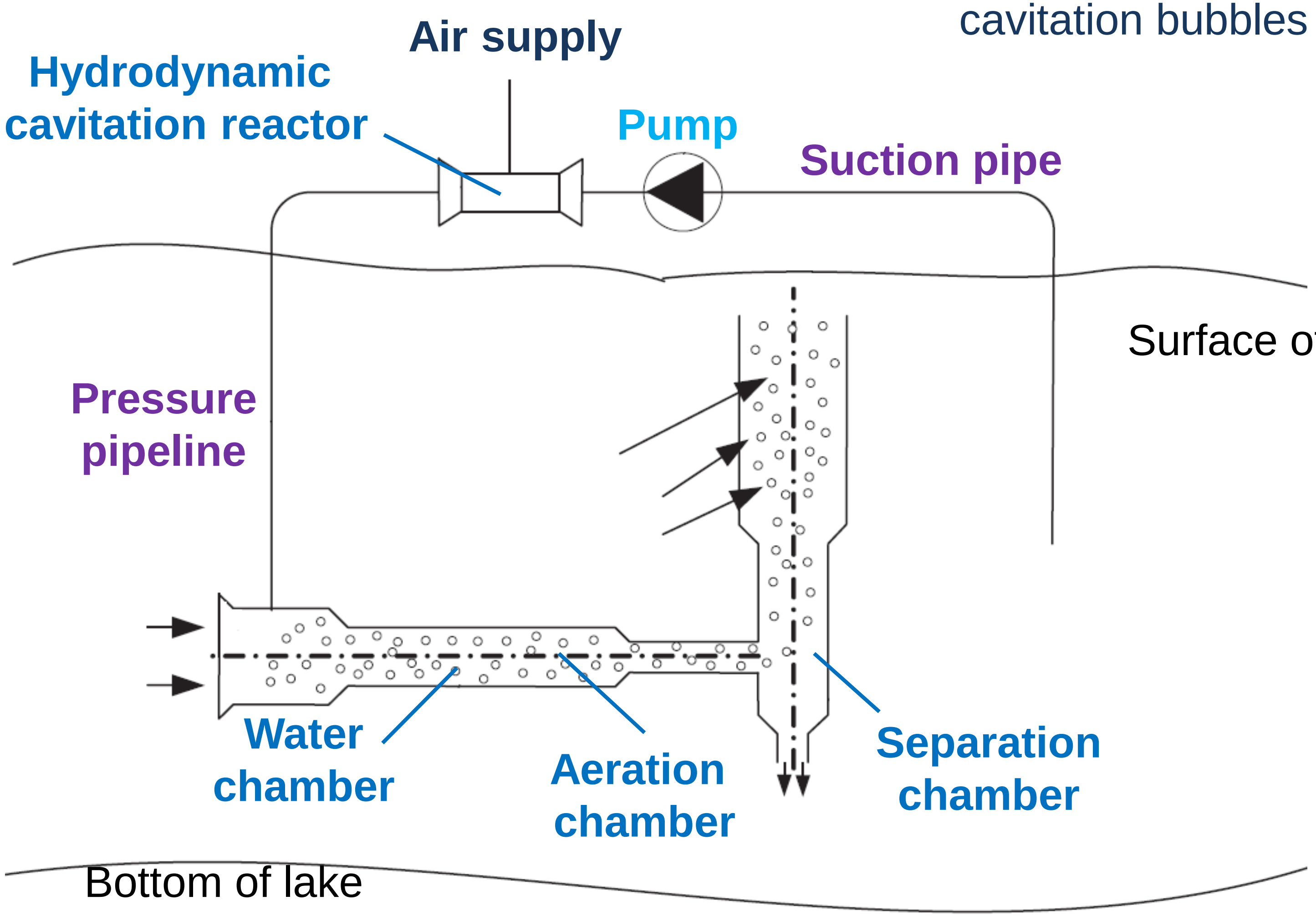
Q= 20 m^3/h



 Ozonek J., Taylor & Francis Group, London, 2012. (Litwinienko A., et al. (2005). Lublin Sci. Society.)

Flotation- Rivers And Reservoirs' Water Aeration

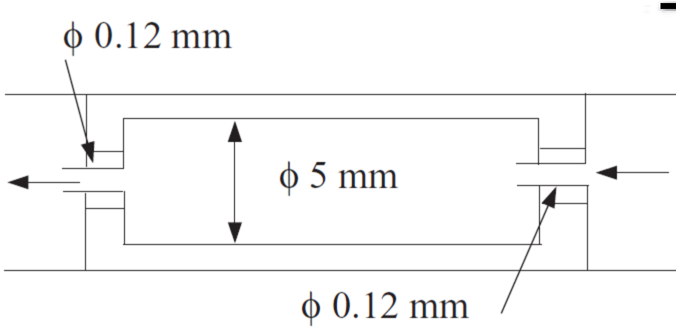
cavitation bubbles ($10^{10}/m^3$)



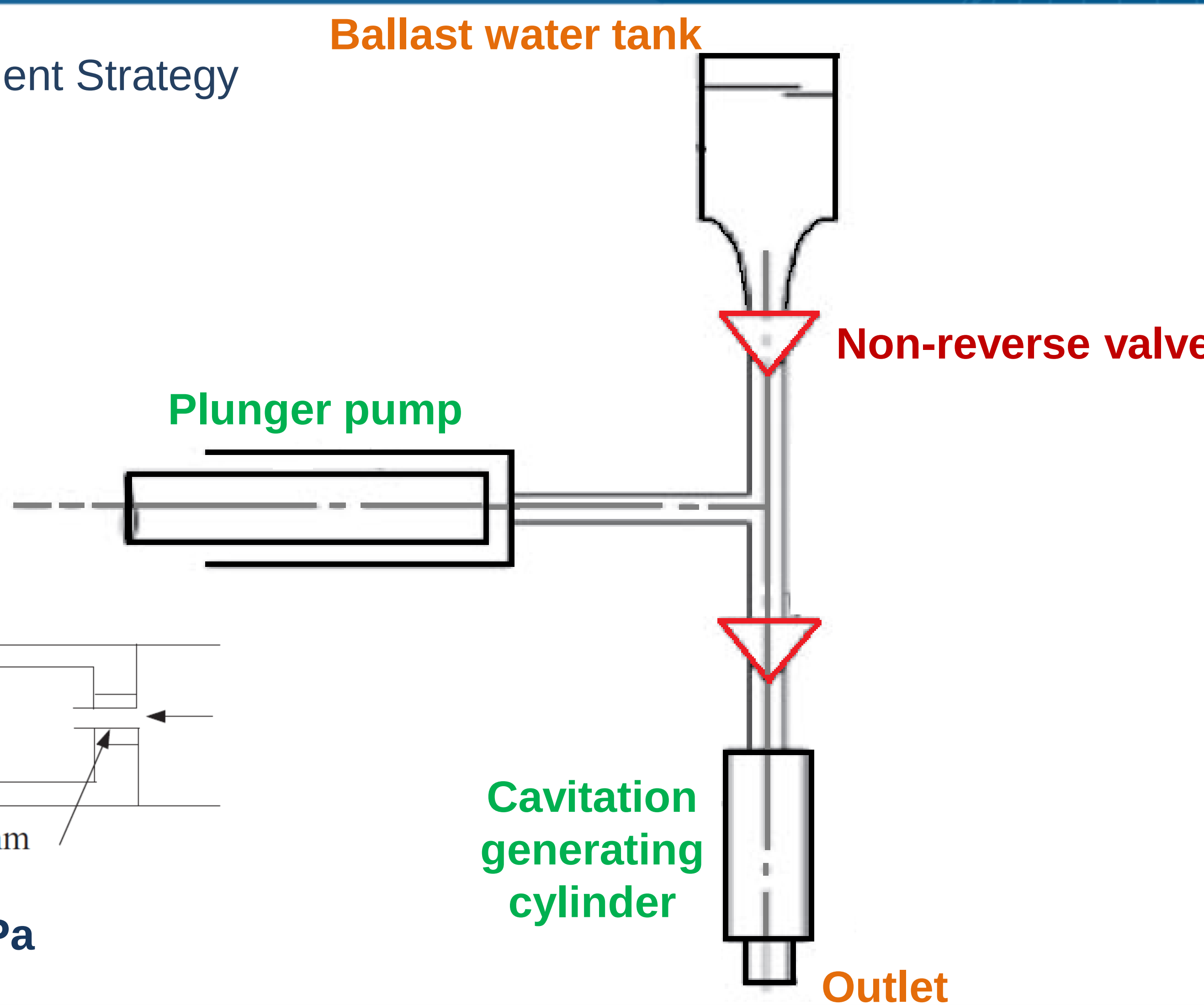
 Litwinienko A., Nekroz, K. Łukasik, K. Lublin (2005) Scientific Society.

Particle Size Reduction-Ballast Water Treatment

Ballast Fluid Treatment Strategy

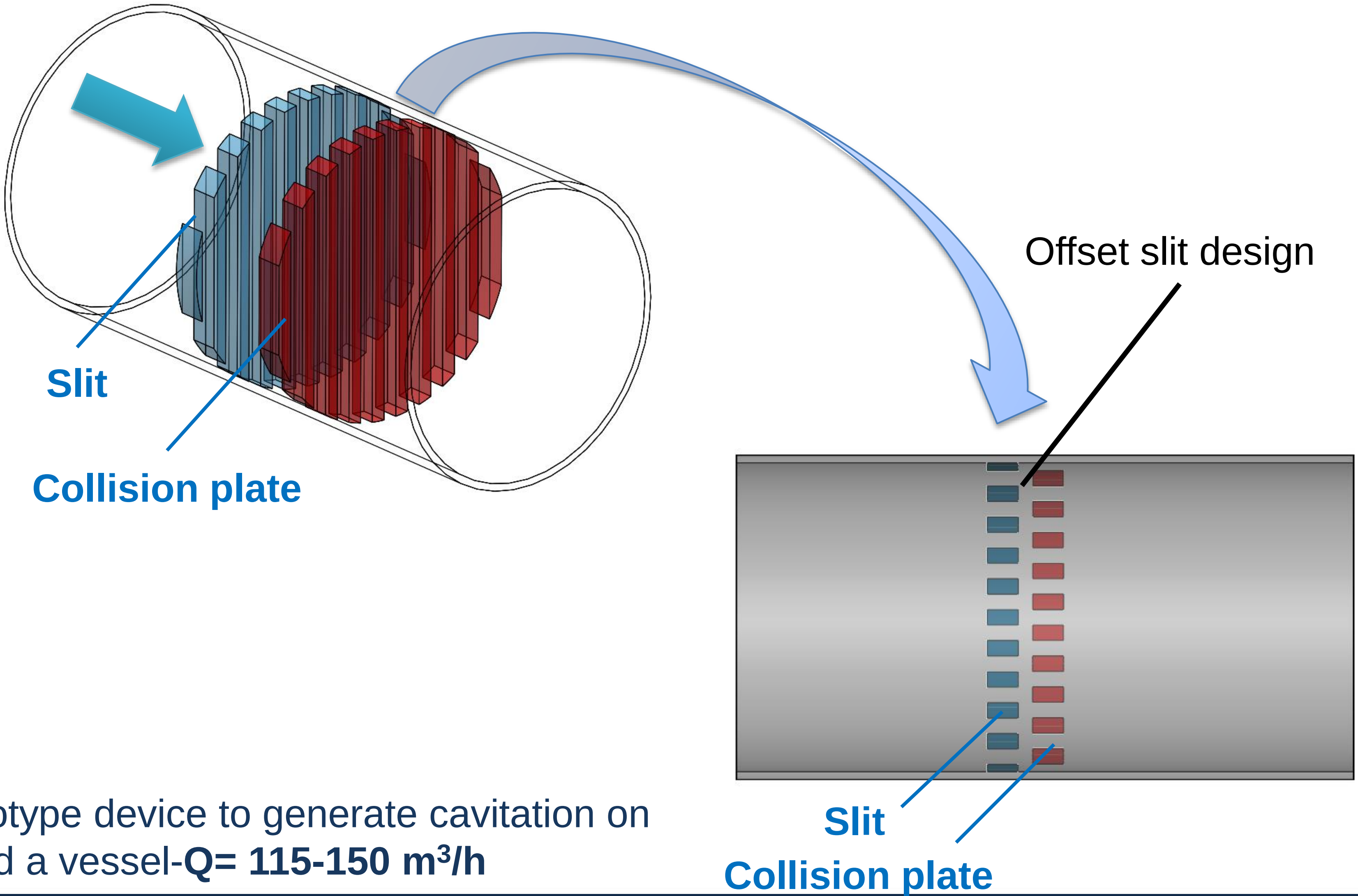


P= 150 MPa



Kato H., (2003) Fifth international symposium on cavitation, Osaka, Japan.

Plankton Elimination- Ballast Water Treatment

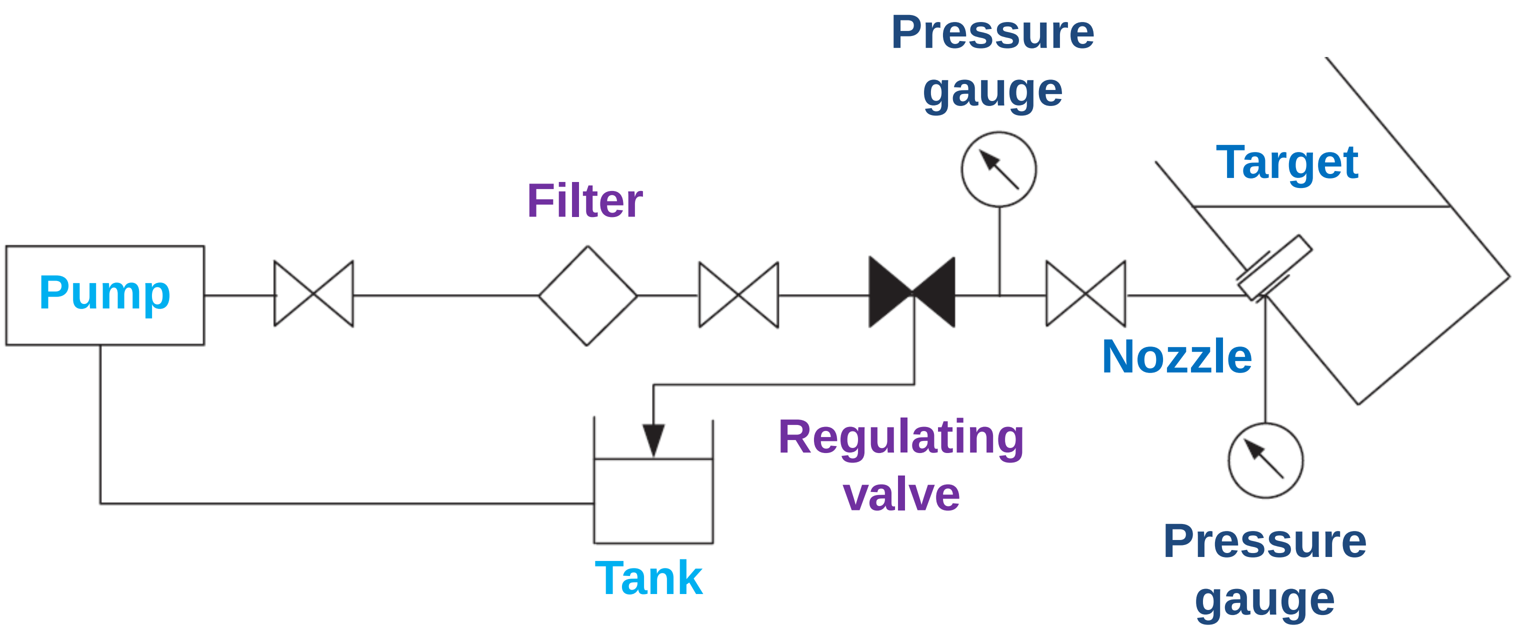


Prototype device to generate cavitation on board a vessel-**Q= 115-150 m³/h**

 Kato H., (2005) Department of Mechanical Engineering Japan.

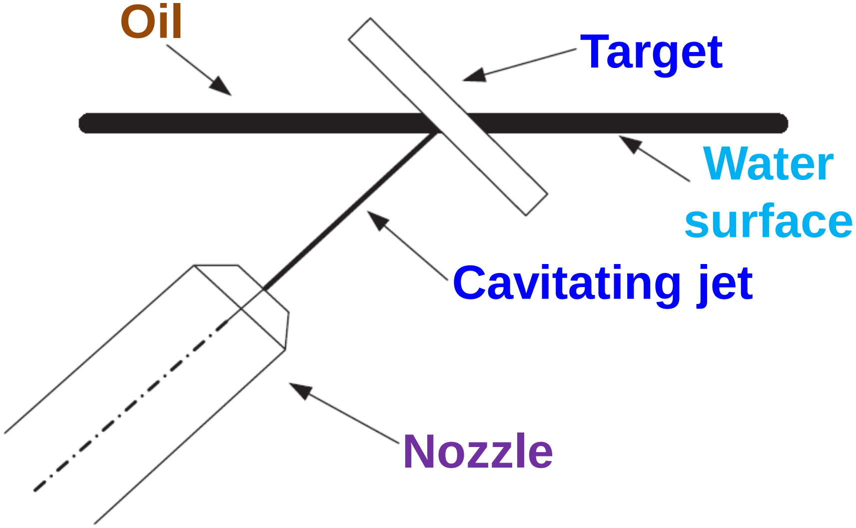
Oil Dispersion- Cavitating Jet Loop (Applied To Direct Shipping Ore)

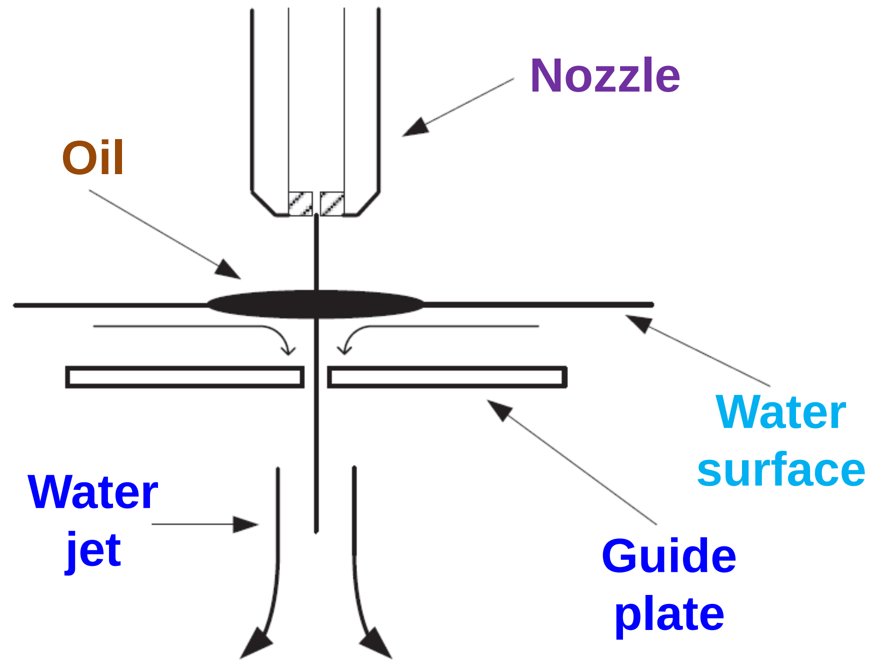
High speed water jet for dispersion of oil spills during ore shipping,
Q= 97 cm^3/s



Kato , H. Y., Honorki Oe, M., Mocniki T., Fukazawa T., (2006) J. of Marine Science and Technology, 11.

Reported Cavitation Nozzle Prototypes



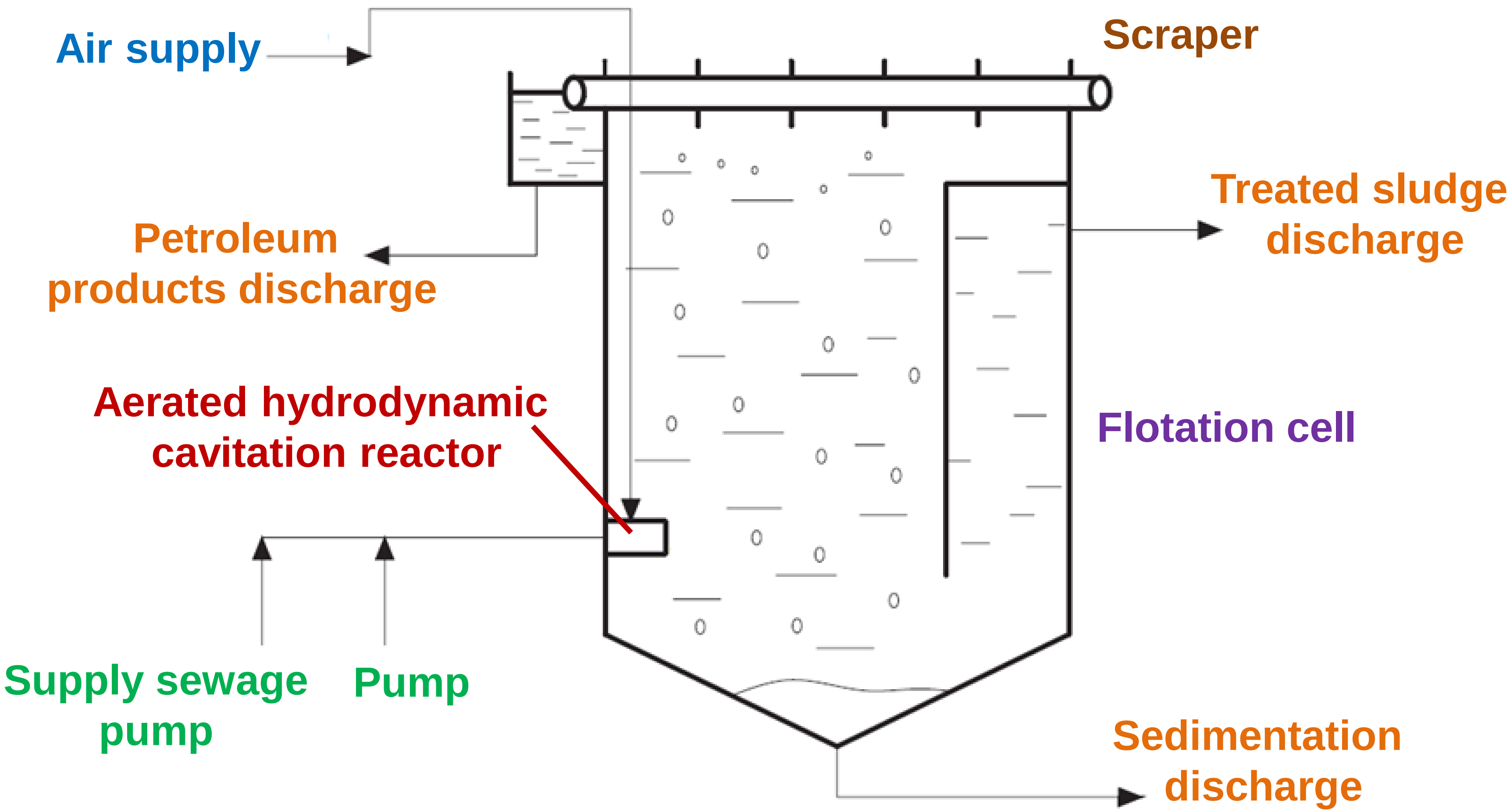


Submerged Cavitating Jet

In-Air Water Jet

Kato , H. Y., Honorki Oe, M., Mocniki T., Fukazawa T., (2006) J. of Marine Science and Technology, 11.

Aerated Hydrodynamic Cavitation Reactor- Wastewater Treatment



Q=28 m^3/h, P=0.3MP

Kolesnikow S.J., et al., (1998) Ekoinżynieria, 7.

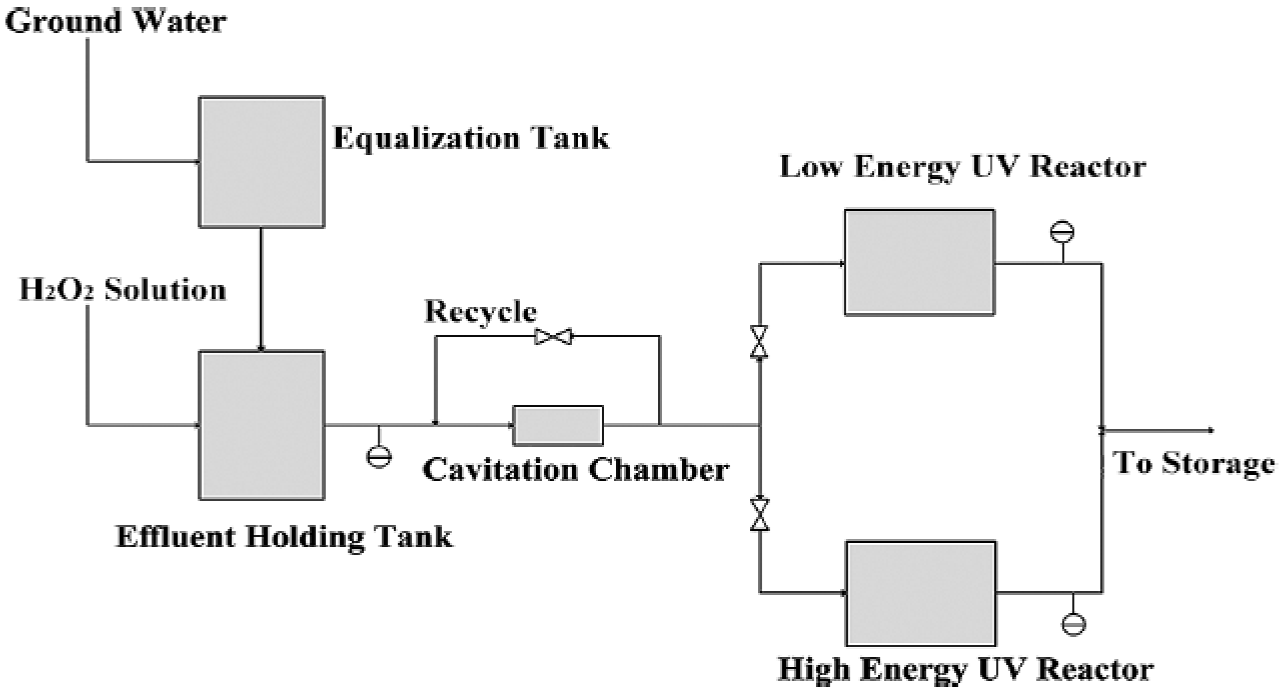
Separating Of Petroleum Products From Wastewater By Means Of Pressure Flotation - With Vs. Without The Use Of An Aerated Hydrodynamic Cavitation Reactor

		Purification using pressure flotation	
Parameter	Raw sewage	Only	With an aerated hydrodynamic cavitation reactor
Temperature, °C	10–30	10–30	10–30
Colour	dark-grey	light-grey	light
Suspension, mg/dm^3	300	30–60	5–12
Dry weight, mg/dm^3	3500	1200	800
COD, mg O^2/dm^3	180	110	30
Hydrocarbons in a hexane extract, mg/dm^3	300	30–60	0.5–3

Kolesnikow S.J., et al., (1998) Ekoinżynieria, 7.

New Developments - CAV-OX Process

- Combination of hydrodynamic cavitation, ultraviolet radiation, and hydrogen peroxide

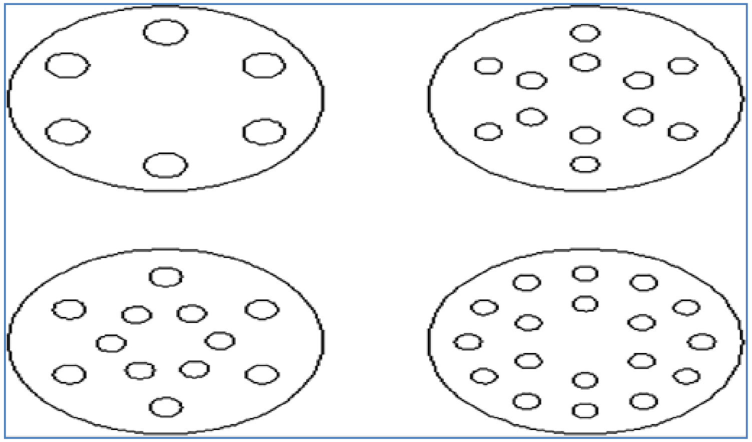


Contaminant (pentachlorophenol, benzene, toluene, ethyl benzene, xylenes, cyanide, phenol, and atrazine) removal 95-99.99%.

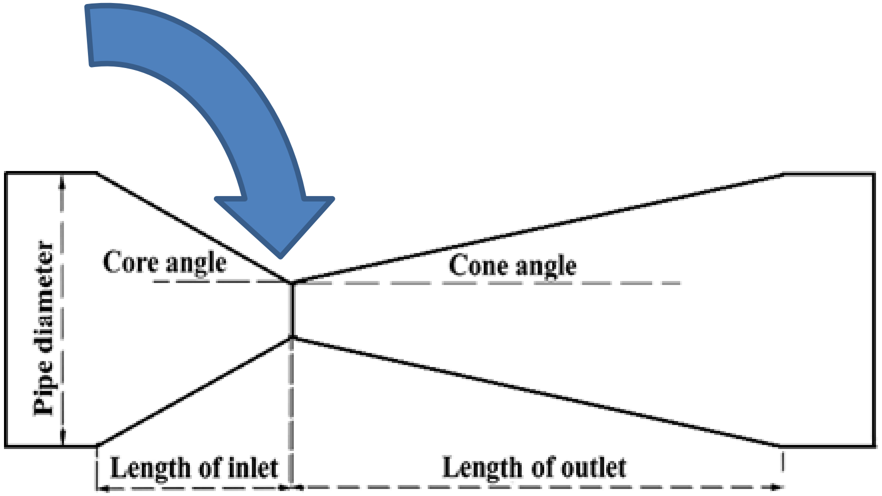
 Tao Y. et al. Chem. Eng. Technol. (2016), 39,1363–1376

Different Cavitation-based Techniques

Typical arrangements of orifice plates

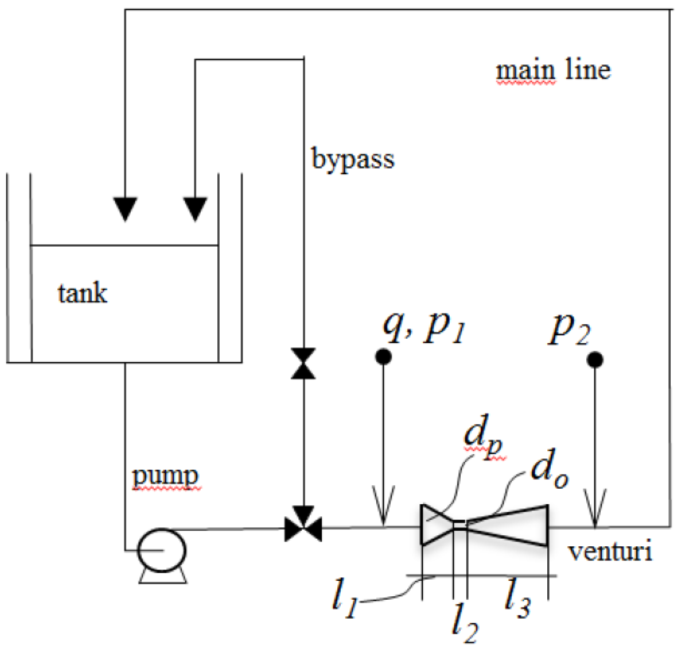


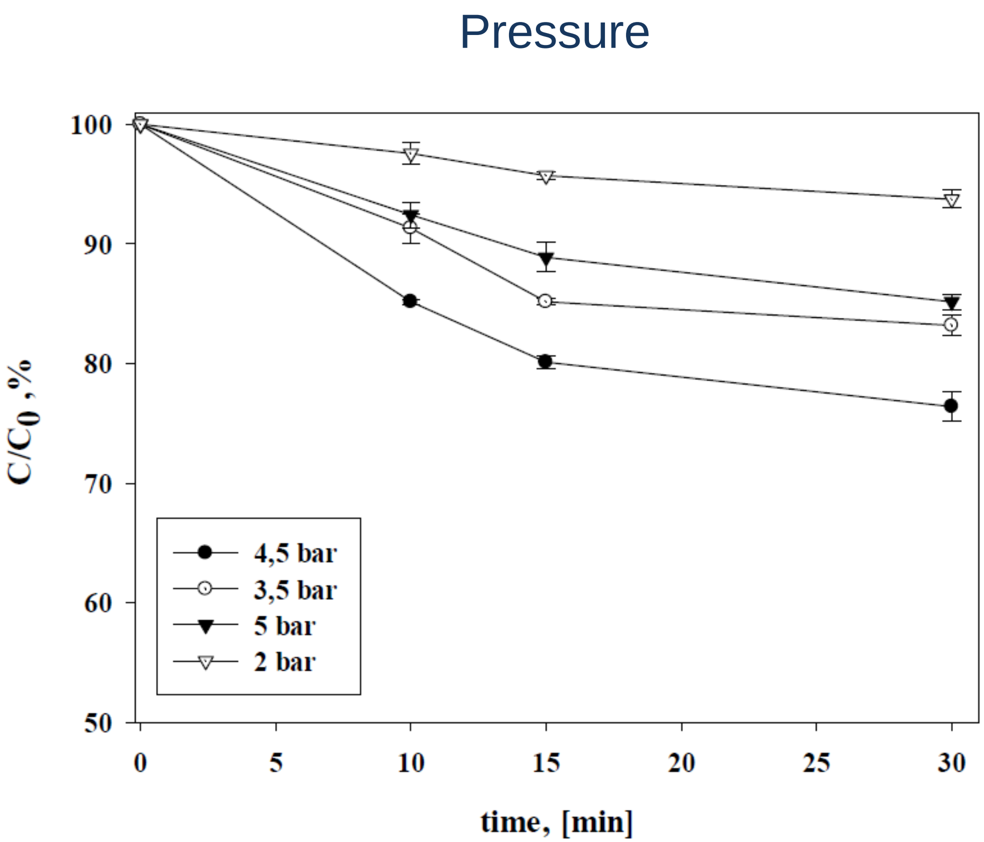
Venturi tube



 Tao Y. et al. Chem. Eng. Technol. (2016), 39,1363–1376

Advanced Oxidation in a Venturi Reactor

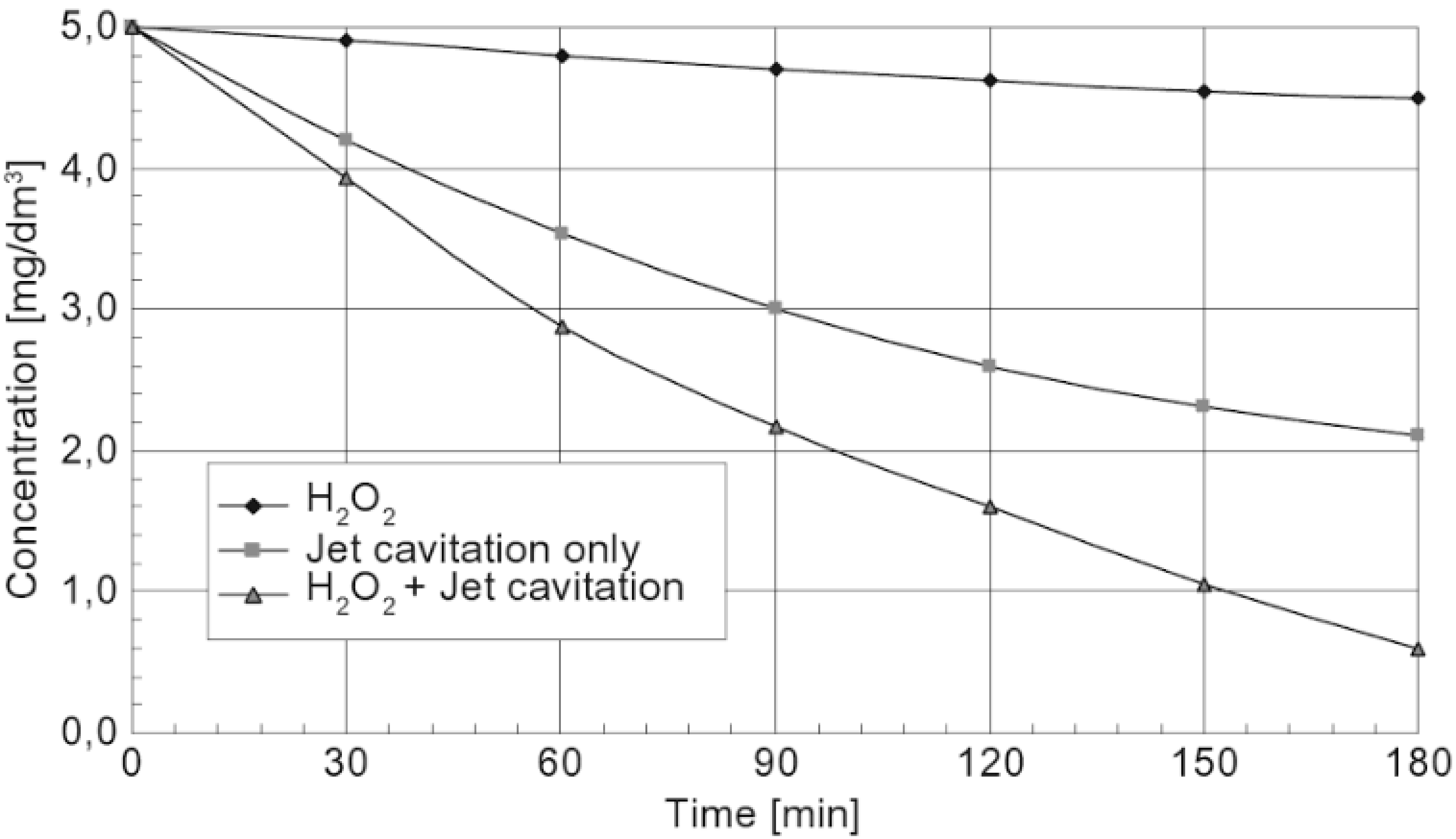




Q= 3.5-6 L/min

 Capocelli, M., et al. (2013). *Chem. Eng. Transactions*, *32*, 691–696.

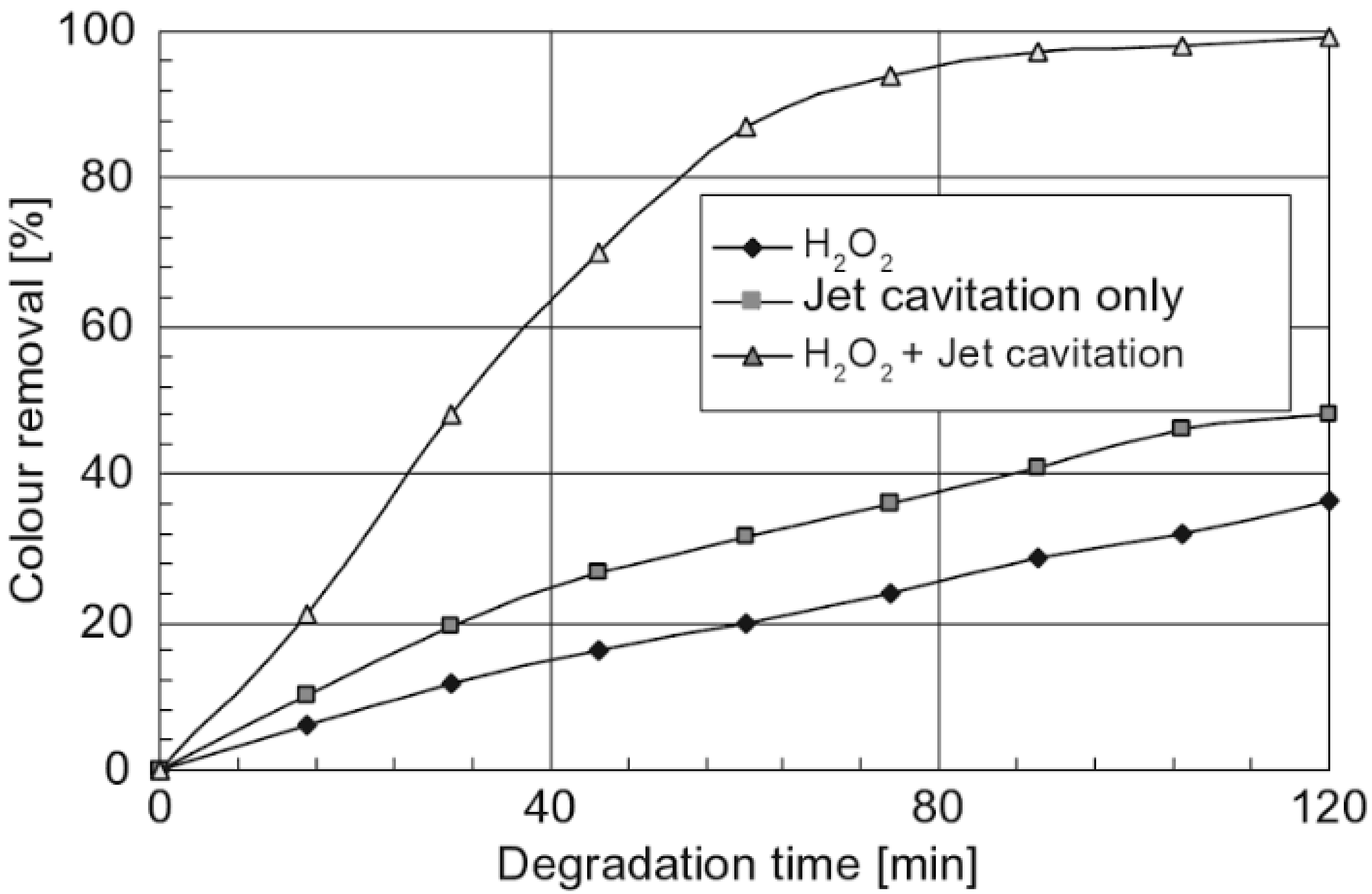
Benchmarking of AOP's -Degradation of Rhodamine B



P= 0.6 MPa, T= 40 ^{o}C, pH= 5.4, H_2O_2= 100 mg/dm^3

 Ozonek J., Taylor & Francis Group, London, 2012.- Wang i. in. 2008

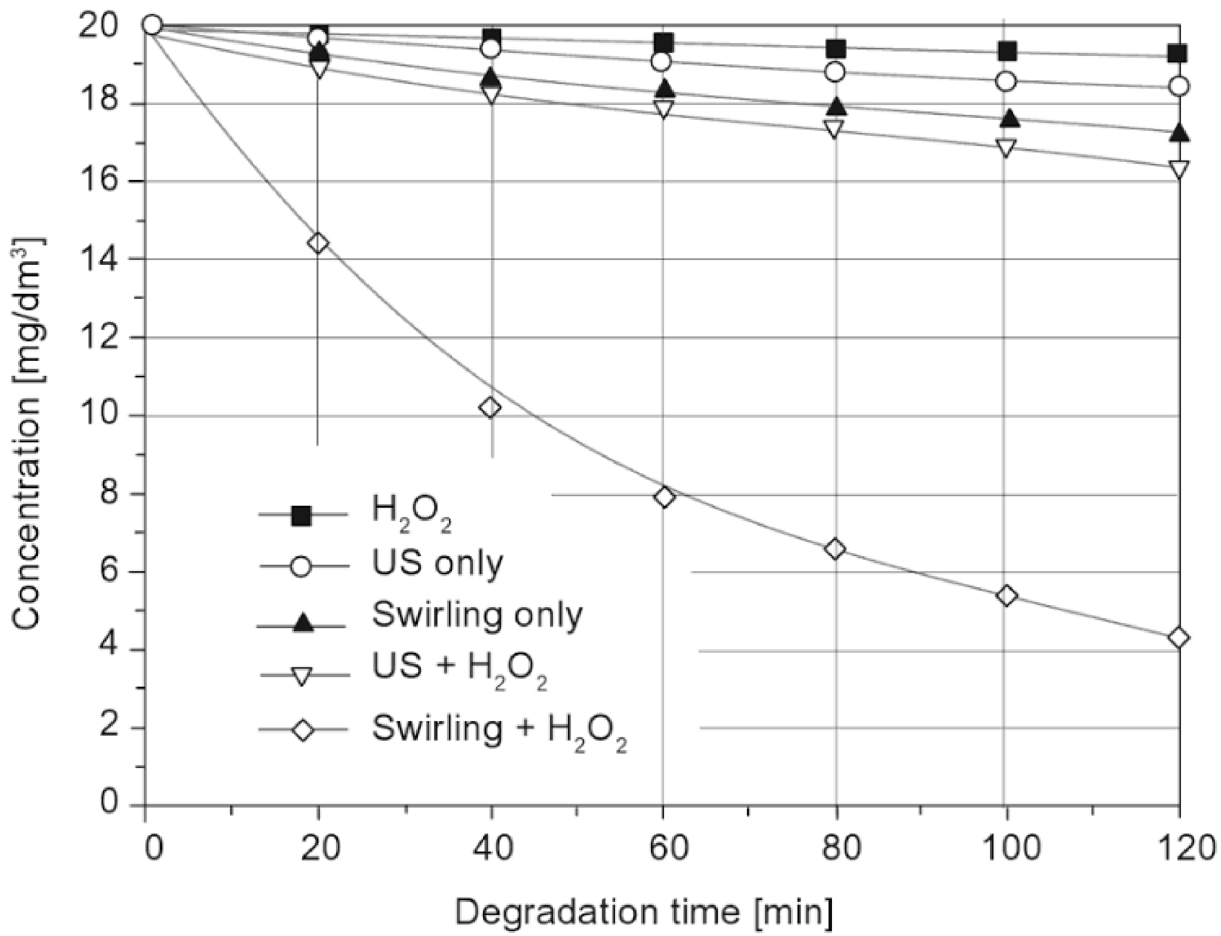
Benchmarking of AOP's - Color Removal



P= 0.6 MPa, T= 40 ^oC, pH= 5.4, H_2O_2= 100 mg/dm^3

Ozonek J., (2012) Taylor & Francis Group, London.

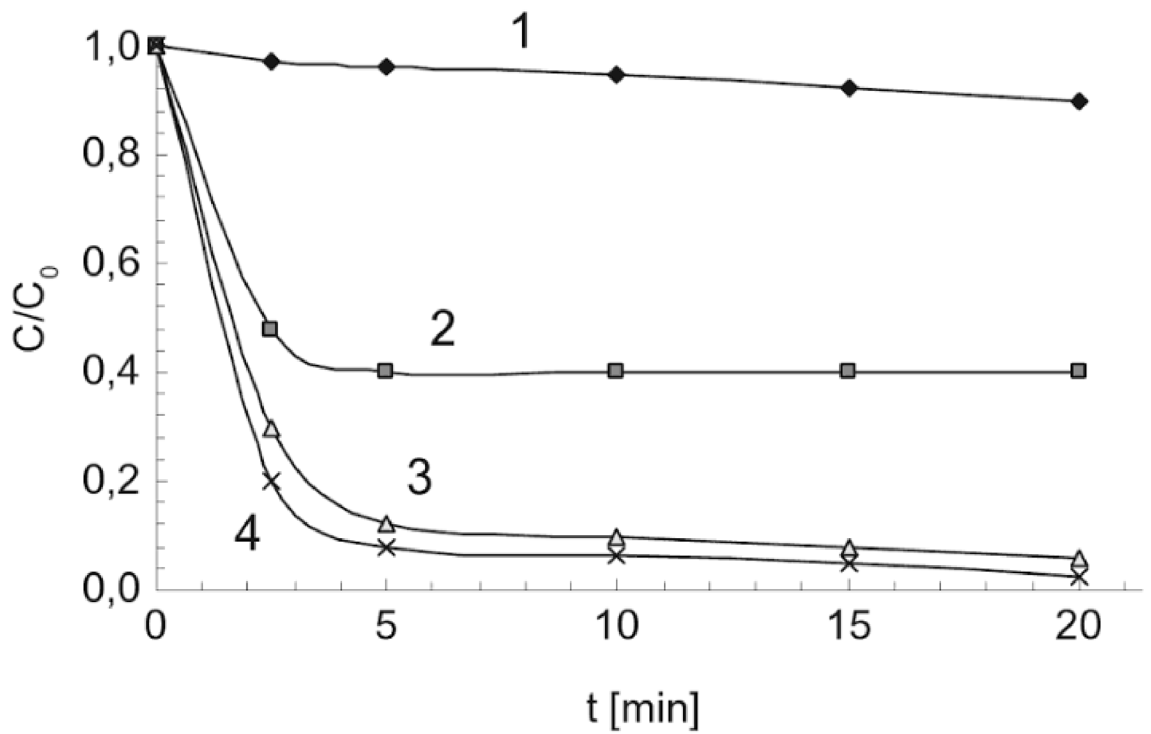
Benchmarking of AOP's -Reactive Brilliant Red K-2BP Concentration



P= 0.6 MPa, T= 40 ^oC, pH= 5.4, H_2O_2= 300 mg/dm^3

Ozonek J., (2012) Taylor & Francis Group, London.

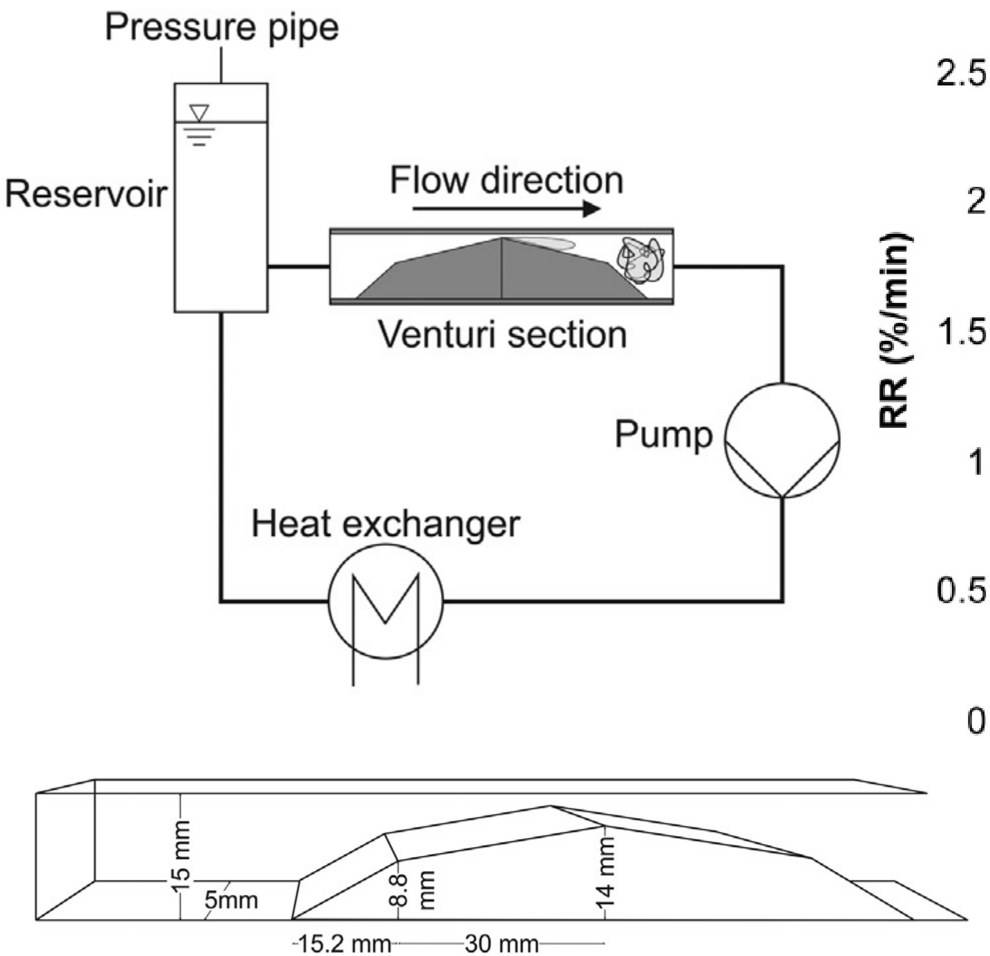
AOP's Benchmarking - 4-Nitrophen Removal

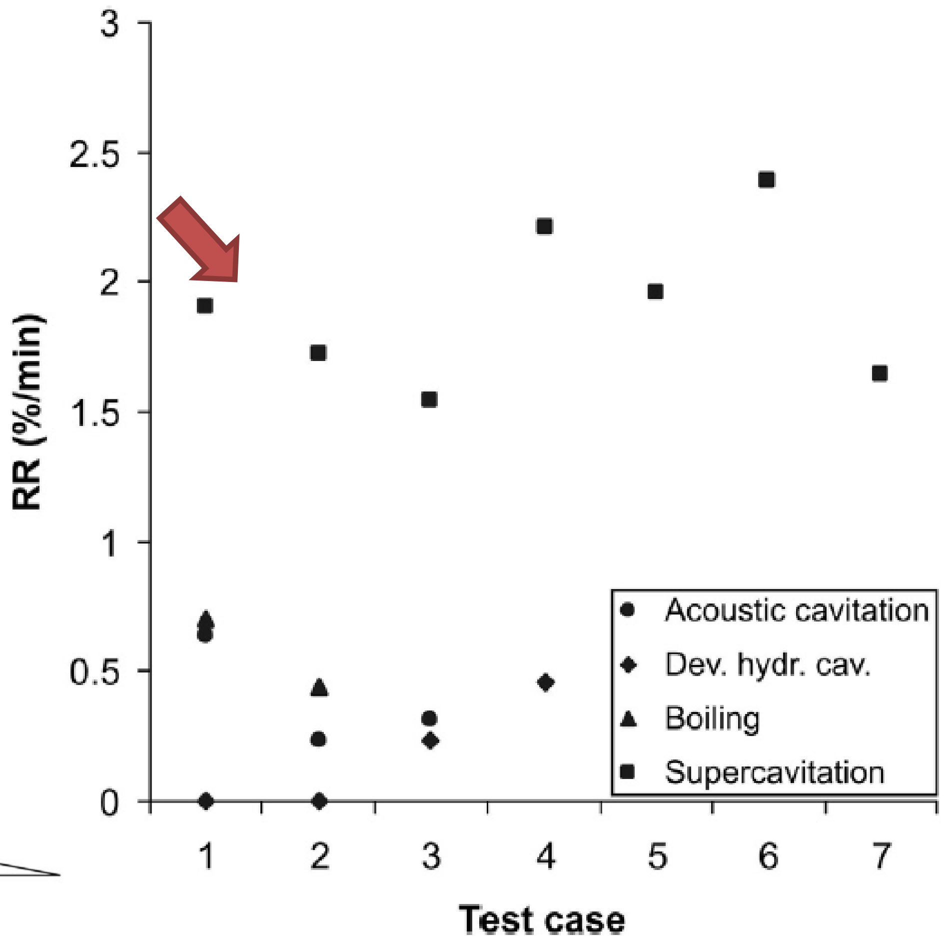


1- H_2O_2 + hydrodynamic cavitation
2- Fenton's reagent
3- H_2O_2 + hydrodynamic cavitation+ disspved Fe^0
4- Fenton's reagent + cavitation stream
T=20 ºC, pH= 3.4, [H_2O_2]= 4e-4, [Fe^{2+}]= 1.7e-4 mol/dm^3

Ozonek J., (2012) Taylor & Francis Group, London.

Advances in Hydrodynamic Cavitation - Removal of Microbes



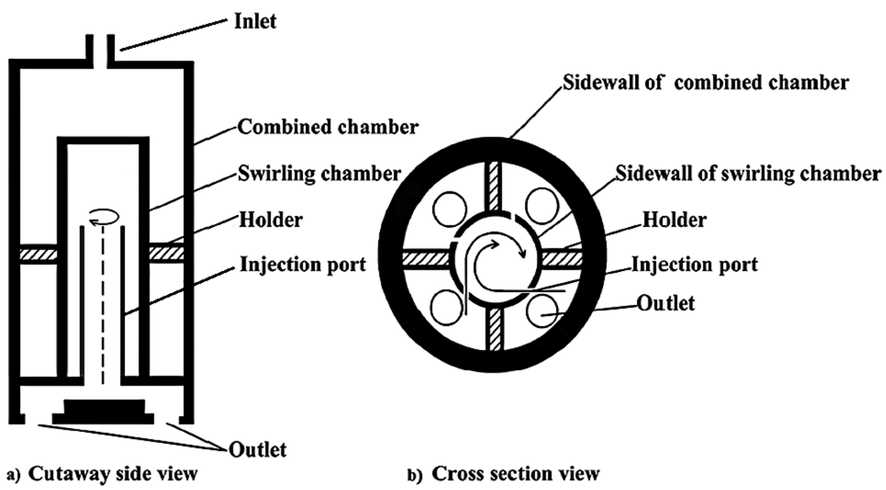


Removal rates (RR) of Legionella pneumophila

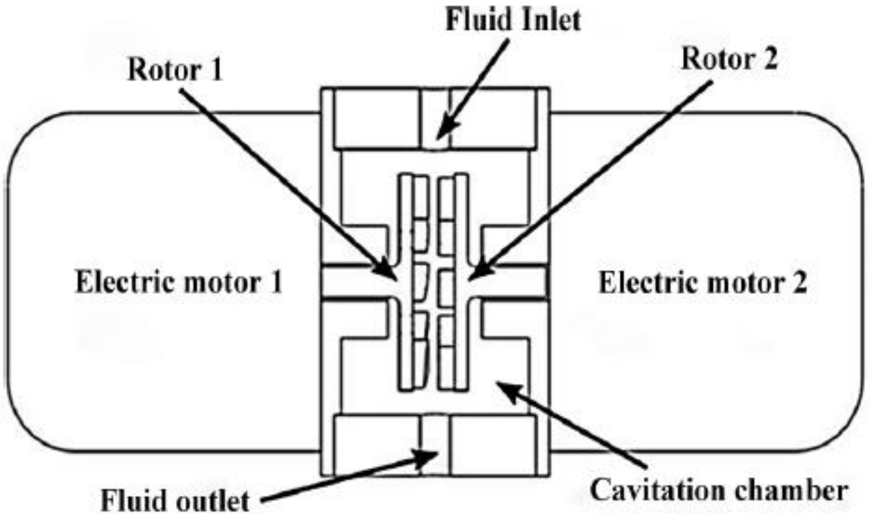
Dular, M., et al. (2016). *Ultrason. Sonochem.*, *29*, 577–88.

Alternate Approaches For High Throughput Cavitation Systems

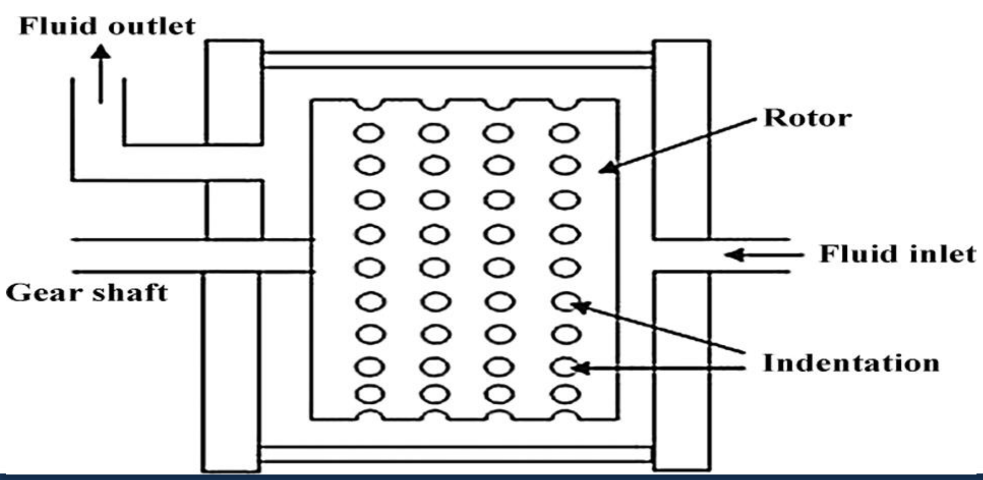
Rotating cavitation reactor



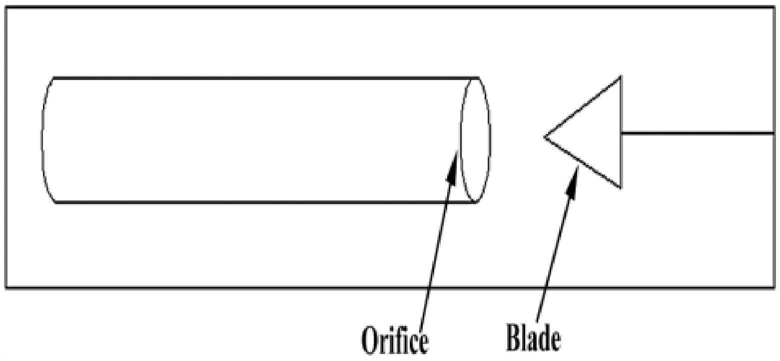
Two rotors



A rotor and a stator



Liquid whistle reactor



 Tao Y. et al. Chem. Eng. Technol. (2016), 39,1363–1376

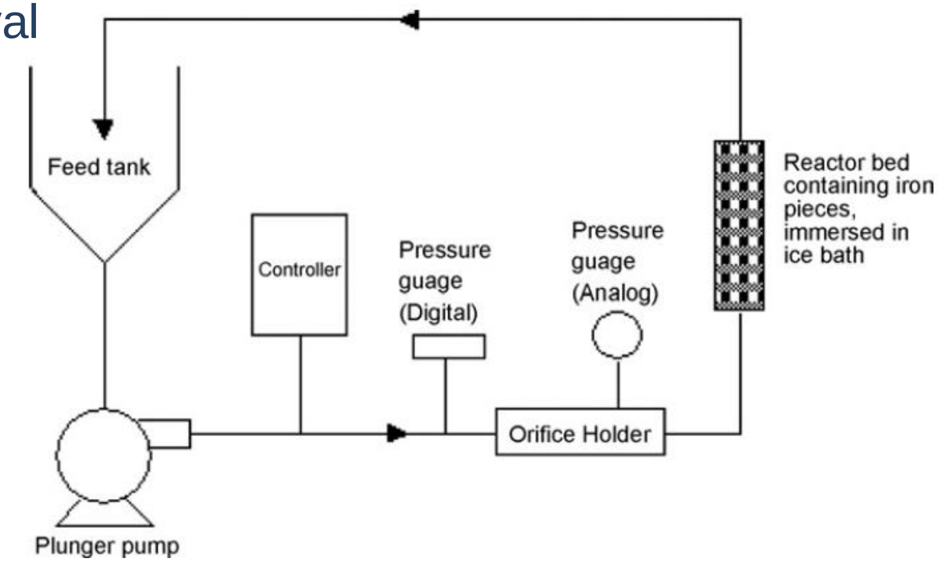
Comparison of Different Cavitation-based Techniques

Cavitation apparatus	Technique	Water volume [L]	Electricity power input [W]	Time of operation [min]	Pollutant removed [mg]	Maximum cavitation yield of unit energy input [mg L^{-1}]	Maximum cavitation yield of unit volume density energy input [mg L J^{-1}]
Swirling jet reactor [21]	HC	20	3500	180	187.2	4.95×10^{-6}	9.90×10^{-5}
Orifice plate [5]		50	5500	60	43.7	2.21×10^{-6}	1.10×10^{-4}
Orifice plate [22]		4	1100	120	9.2	1.16×10^{-6}	4.64×10^{-6}
Venturi [22]		4	1100	120	10.4	1.31×10^{-6}	5.25×10^{-6}
300-kHz ultrasonic generator [85]	AC	0.3	60	140	1.5	2.97×10^{-6}	8.93×10^{-7}
Multiple frequency (20 + 30 + 50 kHz) hexagonal cell [86]		7.5	900	30	2.2	1.36×10^{-6}	1.04×10^{-4}
Swirling jet reactor [64]	HC and H_2O_2	25	2500	180	247.8	9.18×10^{-6}	2.29×10^{-4}
Venturi [22]		4	1100	120	40.0	1.01×10^{-6}	2.02×10^{-5}
Orifice plate [87]	HC and Fe	30	5500	120	45.0	1.14×10^{-6}	3.41×10^{-5}
Venturi [22]	HC and Fenton	4	1100	45	40.0	1.35×10^{-5}	5.40×10^{-5}
Venturi [22]	HC and CCl_4	4	1100	120	32.8	4.14×10^{-6}	1.65×10^{-5}
24-kHz ultrasonic generator [88]	AC and H_2O_2	0.2	400	210	95.88	1.90×10^{-5}	3.80×10^{-5}
300-kHz ultrasonic generator [85]	AC and CCl_4	0.3	60	40	1.5	1.04×10^{-5}	3.13×10^{-6}

Tao Y. et al. Chem. Eng. Technol. (2016), 39,1363–1376

Hydrodynamic Cavitation and Heterogeneous Advanced Fenton Processing

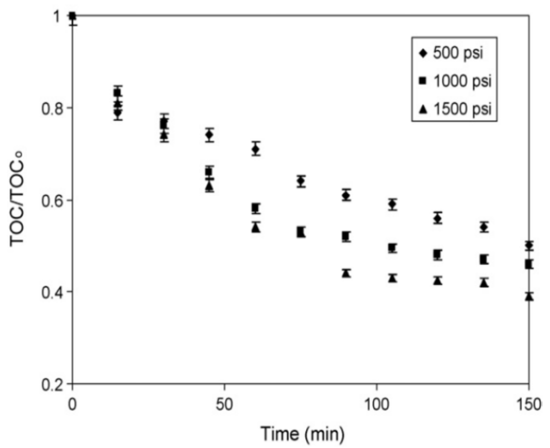
Industrial wastewater treatment- TOC removal



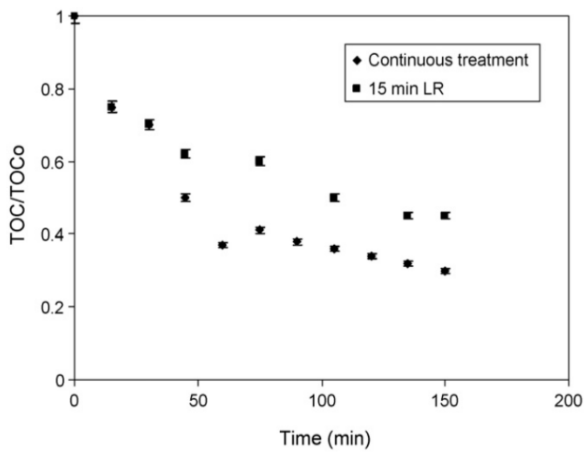
Operating parameters:

- Extent of dilution
- Operating pressure
- Oxidant loading
- Temperature
- Time
- Presence of copper winding

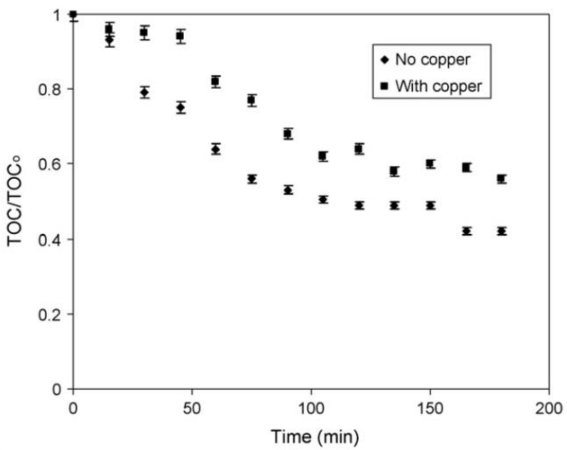
Inlet pressure



Treatment time

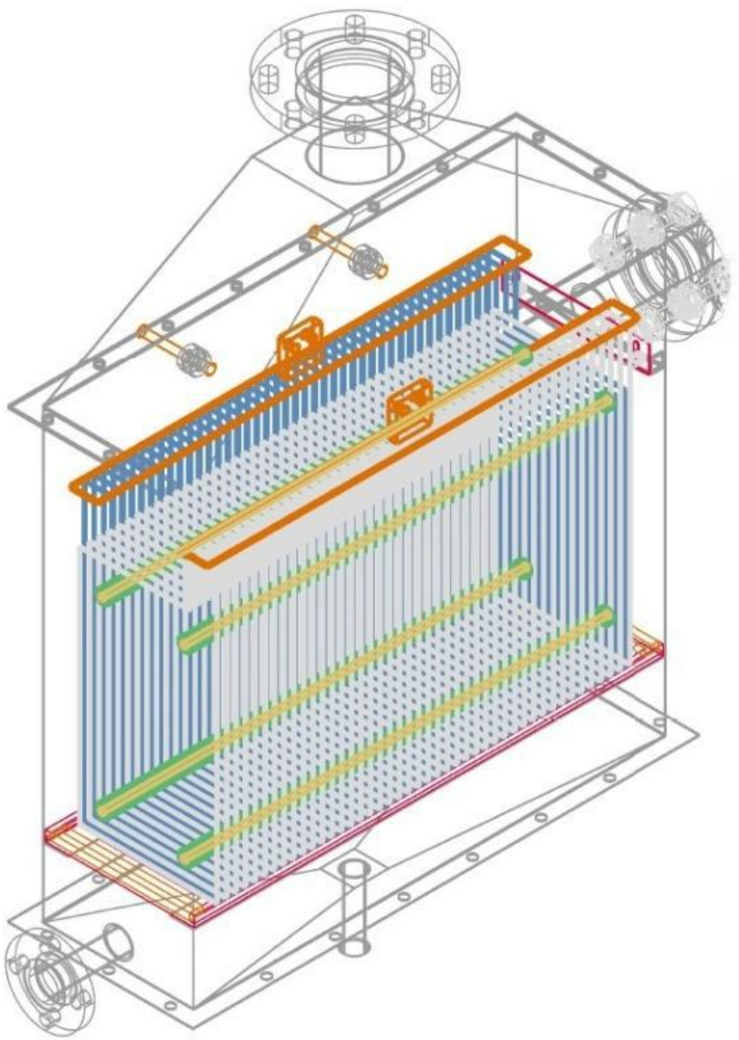


Presence of copper winding



Chakinala, A. G. et al. (2009). *Chem Eng J.*, *152* (2–3), 498–502. and (2008). *Ultrason. Sonochem.*, *15*(1), 49–54.

Hydrodynamic Cavitation and Electrocoagulation to the Contaminated Fluid Flow



System Advantages:

- ✓ Low CAPEX & OPEX
- ✓ Low power requirements
- ✓ No chemical additions
- ✓ Low maintenance
- ✓ Minimal operator attention
- ✓ Handles a wide variation in the waste stream
- ✓ Sludge minimization
- ✓ Treats multiple contaminants

- **System Capabilities**
- Removes heavy metals
- Removes suspended and colloidal solids
- Breaks oil emulsions in water
- Removes fats, oil, and grease
- Removes complex organics
- Destroys & removes bacteria, viruses, and cysts
- Processes multiple contaminants

 Gordon, R., et al (2010)., Patent appl. # **20110147231**.

Implementation in Mining Water Treatment

- In-situ generation of bubbles in flotation applications
- Increased fines and coarse particles recovery with reduced reagent consumption at Copper Cliff, Inco Ltd., Sudbury (Zhou, 2009)
- Neutralization of drill shaft wastewater streams (Litwinienko et *al*., 2005).

Cavitation Reactors: Potential Mine Water Treatment Solutions

Mine Wastewater	Non-Mine Wastewater
• Removal of oxyanions such as Arsenic and Selenium • Recovery of base and precious metals from effluents • Cyanide destruction • Ammonia removal	• Recovery of high value products from aqueous streams • Fermentation process water treatment • Removal of contaminants from oils

Thank you

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www.nrc-cnrc.gc.ca