Wastewater Treatment by Natural Freeze Crystallization and Ice Separation (WINICE)

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- Arctic climate of Finland can contribute to treat wastewater by means of natural freezing.
- Ice layer formed by simulating natural freezing is found to be of high purity.
- Inclusion / purity level within the ice layer determines its strength.
- Verification of mathematical models and strength analysis through on site experiments.
- Energy efficient ice breaking and transportation system is required to make the integrated ice separation as a cost-effective process.

**Freezing of Waste Water**

- When waste water freezes, it is purified.
- Lower freezing rate provides almost pure ice.
- Freezing suitable natural conditions prevail in Finland.

**Modelling and optimization of natural ice growth**

- A growth rate model of ice layer from waters containing soluble salt by natural cooling will be developed.
- The model predicts dependences of heat and mass transfer on solute concentration.
- Crystal growth rates from various salts containing wastewaters will be modeled and verified empirically.
- There is an optimal moment to collect ice depending on different physical, economical, and environmental aspects.
- The process is optimized by developing a numerical tool based on a mathematical model of the growth of the ice layer.
- Evolutionary computation will be utilized in the optimization.
- As there are multiple criteria in the model, this will typically lead to multi-objective optimization.

**Ice breaking and transportation**

- Identification of low energy consuming and environmentally sound structural or non-structural methods to break the ice.
- New devices for icebreaking and ice collection by utilizing already established arctic technologies, e.g. icebreakers and mining conveyor systems.
- New transportation system that allows to extract the purified ice efficiently from wastewater.

**Ice strength and ice property study**

- Physical testing of ice properties at a frozen waste water site.
- The tests are conducted at the optimum ice thickness defined in the mathematical growth model. Furthermore, the ice properties are investigated in terms of inclusion to validate the growth model.
- The physical property tests will give insight on the required ice breaking forces and ice cusp sizes. This is an essential input for the design of ice-breaking and transportation equipment.

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*Temperature contour in Fig.1 was collected from Finnish Meteorological Institute.*

**Fig.1**: Adaptability of Natural freezing in mining industries*.

**Fig.2**: Freezing of NiSO₄ (aq) solution in winter simulator (LUT) and collected ice layer.

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[Image of temperature contour and map of Finland with a circle highlighting a region.]

[Image of NiSO₄ (aq) solution in a container and a collected ice layer.]

[Image of autonomous ice-skimmer and energy efficient ice breaking and transportation system.]

[Image of physical property testing equipment and verification of mathematical models and strength analysis through on site experiments.]

[Image of new devices for icebreaking by utilizing already established arctic technologies, e.g. icebreakers and mining conveyor systems.]

[Image of new transportation system that allows to extract the purified ice efficiently from wastewater.]