Utilizing Water Ice as Effective Temporary Cooling Storage in Aquaculture Systems Using Liquefied Gases

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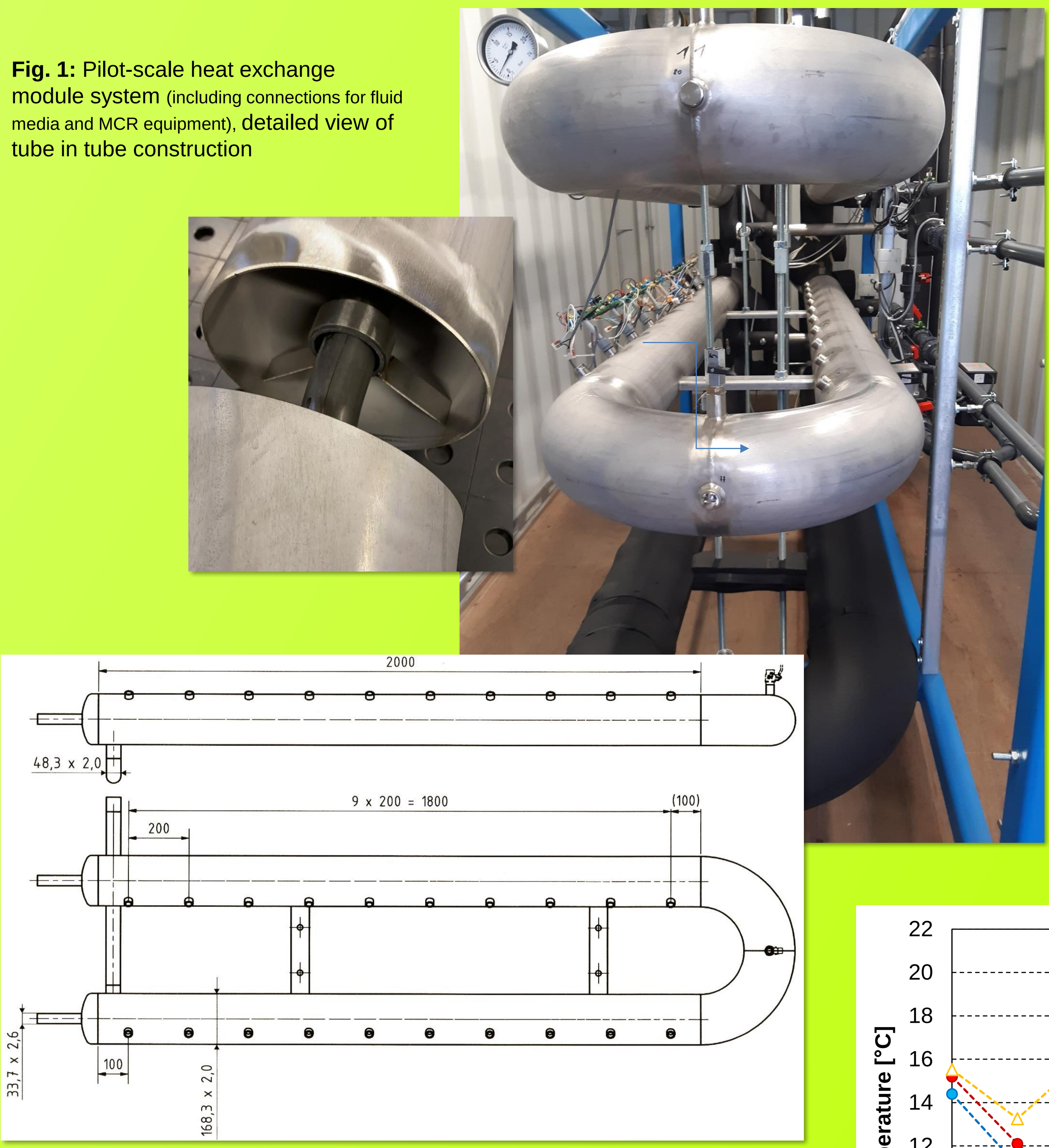
Introduction

Providing cold energy for fish farming/husbandry management (process water cooling, indoor air conditioning) as well as food processing and temporary storage of (intermediate) products is of growing importance in modern aquaculture systems. Same is true for the technical application of various gaseous media, as e.g. oxygen for oxygenation and disinfection (ozonation), nitrogen for cooling (flash freezing) and inertization, petroleum gas and natural gas for energy supply and cooling (e.g. in CCHP systems) and hydrogen in water treatment or – potentially in the future – also for energy supply. These gases are usually handled in liquid state at very low temperatures (-150…-250 °C) and enhanced pressure (up to 20 bar) – in order to minimize transport costs and storage tank capacities – and generally need to be regasified (i.e. vaporized) for final applications.

None of the commercial regasification systems, like ambient air or (sea) water based vaporizers, refer to the (exergetic) cold potential, including enormous possibilities of the very interesting low-temperature levels and appreciable regasification (evaporation) enthalpies of the liquefied gases (approx. 200…500 kJ/kg, depending on pressure level). Combining the unit operations of cooling and gas supply is enabling completely new perspectives in energy efficient process design. However, especially considering discontinuous operational regimes matching the specific demands is a core issue in several application scenarios – resulting in the necessity of a cold storage option. Establishing an innovative operational regime of heat exchangers in regasification systems allows promising perspectives for low-cost energy efficient technical solution.

Fig. 1: Pilot-scale heat exchange module system (including connections for fluid media and MCR equipment), detailed view of tube in tube construction



Materials and Methods

For utilizing the cooling potential from regasification various heat transfer principles were compared and validated. Different heat exchanger designs were compared – whereby twisted coil type and double tube (tube-in-tube) heat exchangers (cf. Fig. 1) were selected for further investigations. Initially different synthetic thermofluids were investigated as cooling media (i.e. secondary or refrigerant media) in conventional operational regime.

An innovative approach was taking advantage of allowing phase change of the refrigerant within the technical system – using the solid phase (ice) for controlling thermal resistance of boundary layers as well as providing an integrated cold storage capacity. However, to prevent the heat exchanging systems from serious damage and optimize functionality as well as energy efficiency an advanced instrumentation, control and automation concept is essential. Hence, for controlling the thickness of the built-up ice layers different (non-)invasive measurement methods (based on mechanical, physico-chemical, optical and acoustic principles) were validated under process conditions. Based on the data obtained, process parameters (media flow rates, tolerable temperature ranges, intervals for (de-)freezing etc.) for optimized system operation were defined.

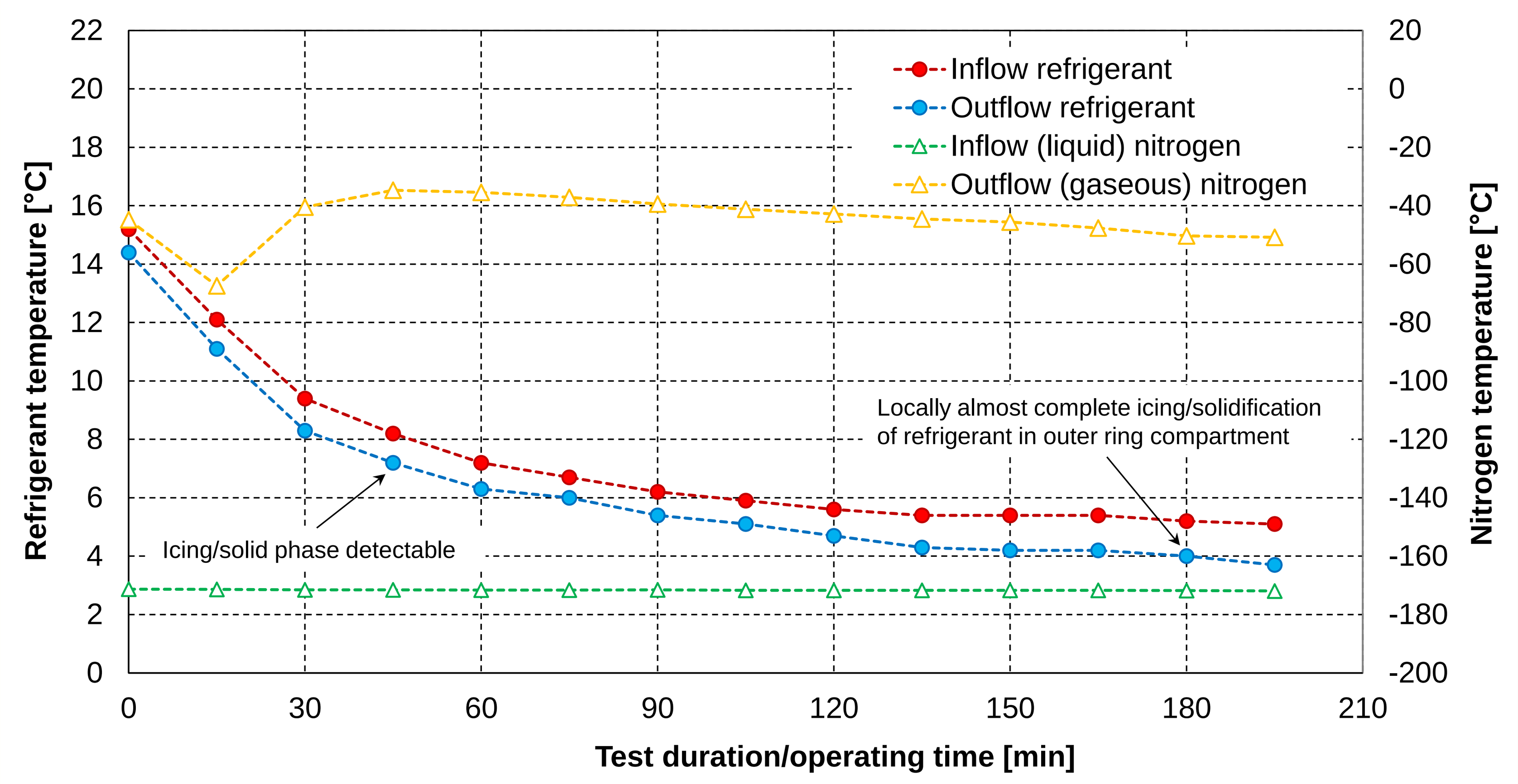


Fig. 2: Pilot-scale tests for cold supply in air conditioning applications (variable refrigerant return temperature) – temperatures of fluid media (refrigerant water, flow rate approx. 760 L/h; LN_2 storage tank pressure 8.1…8.5 bar)

Results and Discussion

Fig. 2 exemplarily shows results from pilot-scale test of the double tube heat exchange system providing cooling energy for air conditioning system. Water was used as refrigerant – allowing phase change (freezing) and using built-up ice layers as latent heat storage option (capacity up to 5 kWh).

Thickness of ice layer built up on the outside of the central tube in heat exchanging system was monitored by using an adapted temperature probe configuration (temperature gradient measurement; cf. Fig. 3) in comparison to data obtained by reference method (application of mechanical test probes).

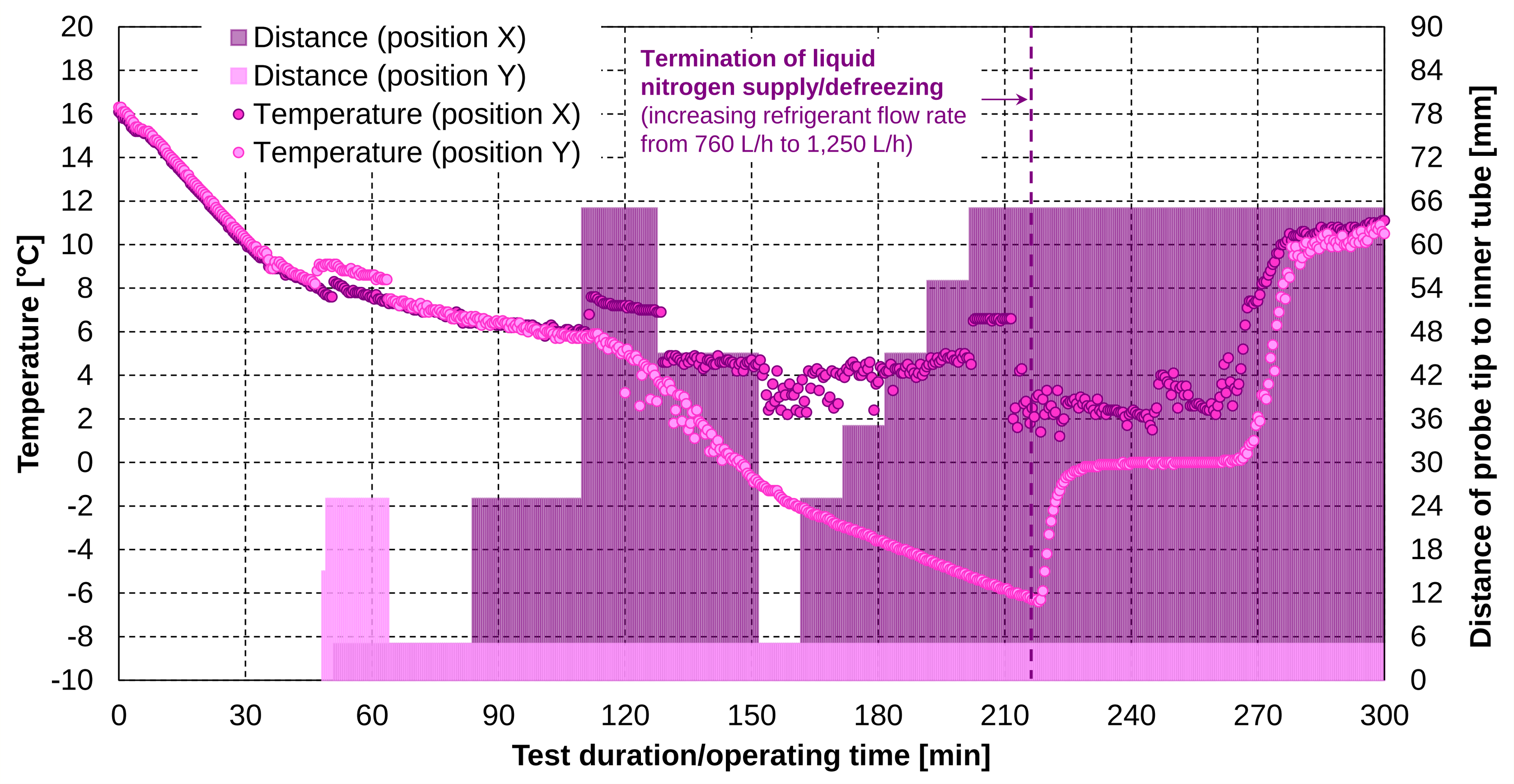
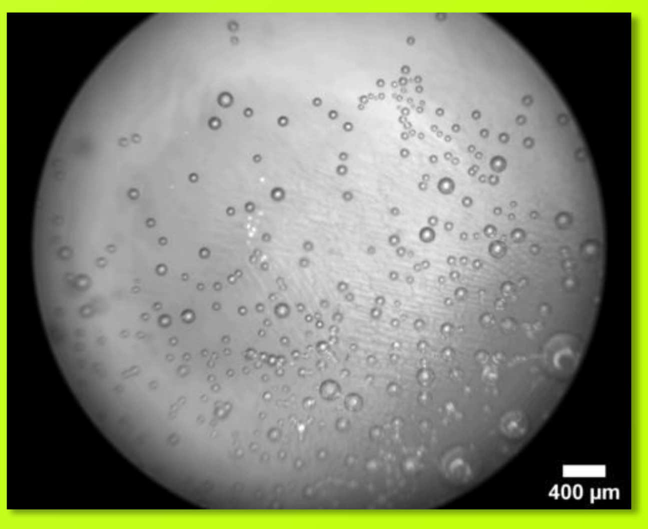


Fig. 3: Results from (indirect) measurement of ice layer thickness by temperature gradient measurements applying thermal elements (position X and Y allocated sequently in flow direction of refrigerant)

Fig. 4: Bubbles and cracks on the structured surface of built-up ice layer (microscopic view)



Established solid phase was carefully monitored – applying e.g. optical methods (endoscopic video microscopy, cf. Fig. 4) – in order to prevent dysfunctional state (complete blockage of cross section in outer compartment of heat exchanger) and controlled by defining intervals for defreezing the ice layer.

Summary and Outlook

Focusing fluctuations and/or probable mismatch of gas consumption and cooling demands a specially designed double tube heat exchanging system was successfully implemented for pilot scale application. Adapting process parameters and optimizing the operational regime (including phase change of the refrigerant) solid phase (water ice) was proven to be applicable as system internal temporary cold storage medium. Technical development and the results of respective investigations are currently transferred to a business case scenario – as part of a special RAS modernizing and energy efficiency project.

Acknowledgements

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