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THE INFLUENCE OF STEAM COLD TRAP IN THE VACUUM CHAMBER INSTALLATION ON THE ICE SUBLIMATION SPEED[1]

Jarosław Diakun, Kamil Dolik, Adam Kopeć*

Department of Processes and Devices of the Food Industry, Koszalin University of Technology
* *Corresponding author: e-mail: adam.kopec@tu.koszalin.pl*

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ABSTRACT

This work is a continuation of research on the differences in the sublimation speed of free ice and ice contained in the porous material. The results of previous research were published in Technica Agraria 12(1-2)/2013 (Diakun, Dolik, Kopec "The sublimation speed of free ice and ice in the sprat carcass"). A test stand used in studies was supplemented by a cold trap to prevent the steam flow into the vacuum pump and for the intensification of the ice sublimation process. The comparative tests: with the cold trap and without were performed. The research material (samples) was in the form of ice nugget, frozen sprat carcasses and ice frozen within the sponge (porous material model). The aim of the study was to examine the cold trap impact on the conditions within the vacuum chamber during sublimation and the speed of the process. The differences in the sublimation speed for the free ice, the ice from the frozen sprat and from the model were rated. The results showed a significant increase in the sublimation speed during the process with the active cold trap.

Introduction

Sublimation is a phenomenon of ice transition into water steam with omission of the liquid phase, which takes place below the triple water point, described with parameters of saturate vapour pressure p_0=610,483 Pa and temperature T_0=0.0099ºC (Gujgo et al., 1968; Lewicki et al., 1999). In the food industry, this phenomenon is used for drying thermolabile products and products which require fast and total rehydration (Rząca and Witrowa-Rajchert, 2007; Witrowa-Rajchert, 2008). Thus, fast reproductive food is obtained (Kramkowski et al., 2003). In case of some food products (e.g. sea cucumber *Stichopus japonicus*) it is more effective than other methods (e.g. than drying in air) and allows obtaining a final product with a higher quality (Duan et al., 2010), which has a low volumetric density, high porosity and sustainability to dehydration (Huang et al., 2011).

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The authors try to use the sublimation phenomenon for defrosting fish carcasses. The sublimation-vacuum-vapour method developed by them is a modification of the classical vacuum-vapour method, where an initial stage of ice sublimation was introduced (Kopeć, 2008; Kopeć and Diakun, 2005; 2007). This stage aims at formation of the porous structure inside the block by vaporisation of a part of ice which fills in the spaces between fish carcasses. Introduction of vapour inside the formed fissures in the next stage of defrosting will allow defrosting of the remaining part of ice and separating a block into single fish with the temperature below 0ºC. In his publication titled "Sublimation time of free ice and ice of sprat carcasses" (Diakun et al., 2013) he proved that there is a clear difference in the free ice sublimation intensity and in case of ice inside fish. There is a need to carry out further research in order to verify the possibility of intensification of the sublimation phenomenon through the use of a steam cold trap.

Objective and scope of research

The objective of the research was to verify the impact of the steam cold trap on the stability of pressure conditions in the chamber and the intensity of ice sublimation from the sprat carcasses, a model of the porous material and free ice.

Methods and materials

General scheme of the research stand was presented in figure 1.

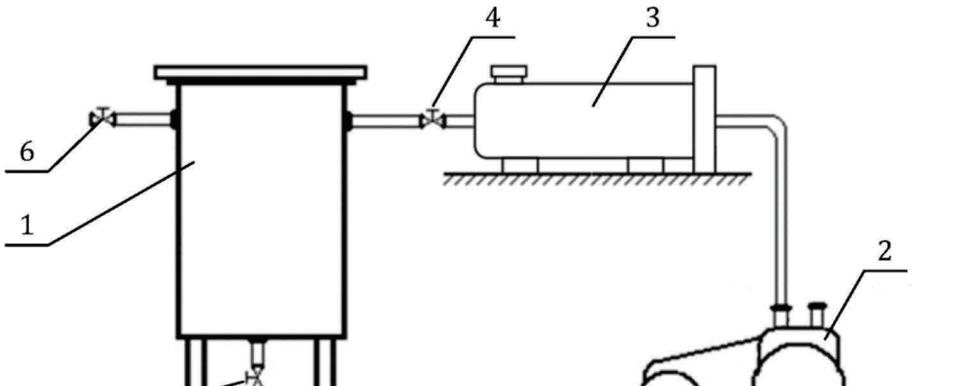

Figure. 1. Schematic diagram of the research stand. 1 – vacuum chamber, 2 – BL-15 vacuum pump, 3 – steam freezer, 4 – pump and freezer valve, 5 – steam generator valve, 6 – air inlet valve

In the first stage of research a stand consisting of the vacuum chamber connected directly with the vacuum pump BL-15 was used. The vacuum chamber was made of stainless steel and equipped with the vacuum passes which enable collection of electric signals from measuring devices. The cover of the chamber was made of glass which allows observation how samples behave during sublimation. In the second stage of research, to the installation between the chamber and the vacuum pump a steam cold trap was mounted. It was made at request as a part of the project "*Investment in knowledge as an incentive for the development of innovativeness in the region – 2nd edition"*. The steam cold trap consists of two chambers equipped with a cooling coil supplied from the cooling aggregate to R404a factor. The average temperature on the cooling coil was -12ºC. The cooling coil structure allows interchangeable operation of chambers – in case one of them will frost. This process takes place as a result of transmission of hot steam of the cooling factor through a coil pipe in the defrosted chamber.

A schematic representation of the measuring apparatus was presented in figure 2. The apparatus allows the measurement of such values as pressure changes in the chamber and changes in the samples weight. For the measurement of pressure Pirani gauge RG-10 type cooperating with the MP 211 pressure gauge was used. Changes in the samples weight were registered thanks to Tedea-Huntleigh 1022 cooperating with the weighting module PUE C31. Additionally, measurements of the changes of samples weight were carried out with the use of a laboratory scales WPS 210 type.

Measurement apparatus was served with the use of a computer working station on which LabView programme was installed. Specially created application in the LabView programme allowed constant recording of changes of measured values and recording results in the form of files, whose further processing was carried out in Microsoft Excel and Matlab programmes.

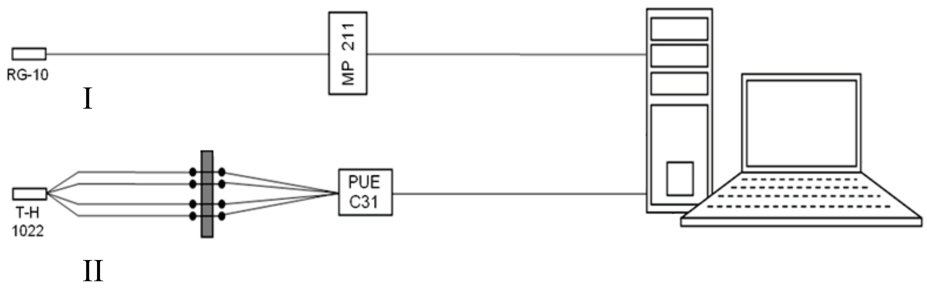

Figure. 2. Schematic diagram of measuring circuits: I – pressure measuring circuit, II – sample weight measuring circuit

The tests were carried out on sprat carcasses, models made of the porous material soaked with water (sponge) and samples of free ice.

Fresh sprat carcasses were purchased in the fish processing plant in Darłów. Non-damaged carcasses with the weight of 15 g each were selected for tests. Sprat carcasses were frozen with a convective method to the temperature of -30ºC.

Models of the porous material were made of sponge with a diameter of pores which is approx. 1-2 mm. Models were shaped as sprat carcasses saturated with water to the moment of achieving the weight corresponding to the weight of sprat carcasses and frozen with the convective method in the freezing chamber to the temperature of -30ºC.

Samples of free ice were prepared to resemble the investigated sprat carcasses with regard to shape and weight. Thus, forms in the shape of sprat carcasses were made. They were filled with water and placed in the freezing chamber, with the temperature of -30ºC.

During the research one sprat carcass, one model of porous material and free ice sample were placed in the vacuum chamber at the same time. The chamber was cleaned before each test and oil was replaced in the vacuum pump.

In the first stage of research after placing samples in the chamber the cover of the chamber was closed, the pump and the recording software were started. Then, the pump valve was opened and the changes in the pressure and temperature as well as changes in the samples weight were recorded in the chamber within 5 hours. After the sublimation ceased, the pump valve was closed and data were saved.

In the second stage of research, before placing the samples in the chamber a cooling aggregate was turned on in order to obtain a respectively low temperature in the chamber of the steam cold trap. Then, analogous steps were carried out as in the first stage.

Tests for the first stage and the second stage were repeated three times and the measurement errors of the weight loss and duration of sublimation were determined based on the theory of interval estimation based on the t-Student distribution for the level of significance of α=0.05 (1).

$$\Delta = \pm\left(t_{\propto} \cdot \frac{\sigma}{\sqrt{n}}\right) \tag{1}$$

where:

σ – standard deviation,

t_{α} – Student's coefficient of distribution (for $\alpha = 0.05$ and $n = 3$),

n – number of measurements.

Results and discussion

Figure 3a presents the list of the results of measurements of samples weight changes during the process without the cold steam trap being active while figure 3b shows results of measurements of the changes of samples weight with the active cold steam trap. Calculations of the weight losses and the duration of sublimation of particular samples were carried out and their results were presented in figure 4a and 4b.

The presented plots and measurements, which were carried out, show that when the cold steam trap was working, a significant intensification of the ice sublimation process from the porous material model and free ice took place. When the cold steam trap was working the duration of ice sublimation from the model of capillary material increased by 0.48 $g \cdot h^{-1}$ and the weight loss was 2.44 g (16.44 %).

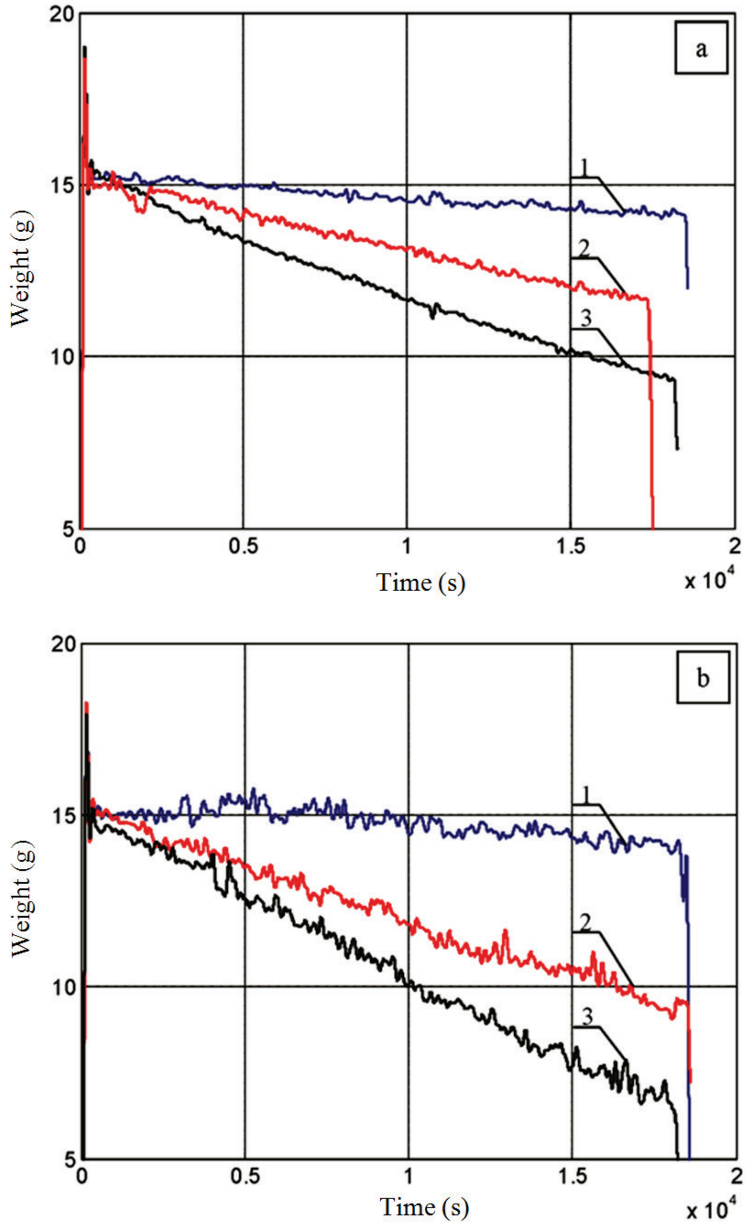

Figure. 3. Weight changes during the sublimation: a – without the cold trap, b – with the cold trap – for the samples of: 1 – sprat carcass, 2 – model of porous material, 3 – free ice

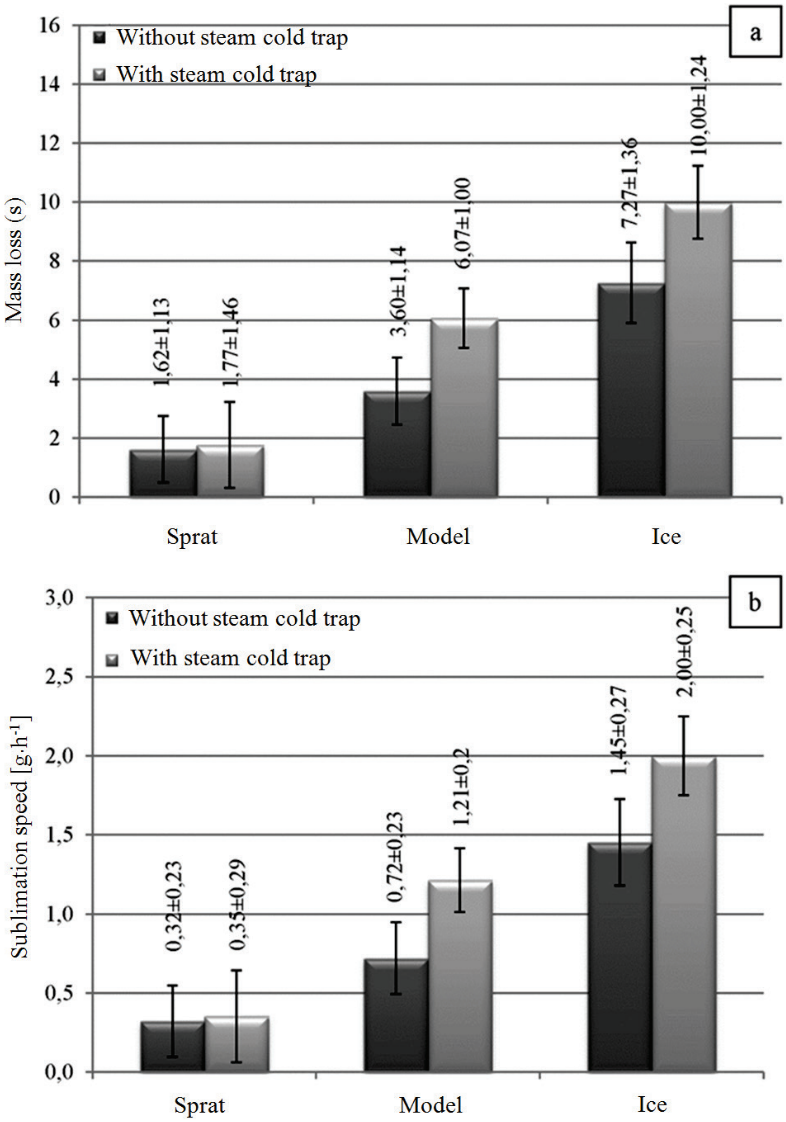

Figure. 4. Results of calculations: a – weight loss of sublimated samples, b – sublimation speed

On the other hand, for free ice samples the duration of sublimation towards the results obtained from samples without the cold steam trap increased by 0.57 $g \cdot h^{-1}$ and the weight loss by 2.83 g (18.22%). The cold steam trap work did not significantly influence the intensity of ice sublimation from the sprat carcasses. It could have resulted from the barrier nature of the sprat's external layer (skin), which limited the ice sublimation phenomenon from the inside of the sprat. The barrier nature of the skin also influenced the fact that both in case of tests without the working cold steam trap as in case of tests with the working cold steam trap – the slowest sublimation was in case of ice from sprat carcasses. The fastest was the free ice which was not limited by tissues and foreign structures.

Figure 5 presents the changes of pressure in the vacuum chamber during sublimation with and without the working cold steam trap. It is clear that with the use of the cold steam trap, the pressure in the vacuum chamber was by approx. 10 Pa lower and more stable (it does not grow considerably during the process) than at the process carried out without the cold steam trap. It is caused by the flowing out particles of steam through the cold steam trap as a result of which additional force, which causes steam particles movement from above the dried material towards the cold steam trap, is formed. This force influences the duration of ice sublimation and is proportional to the difference of pressures corresponding to the temperatures of material and the surface of freezing elements (Gujgo et al., 1968). The use of the cold steam trap also limits getting the steam particles to the vacuum pump which does not cause the decrease of efficiency and the obtained vacuum.

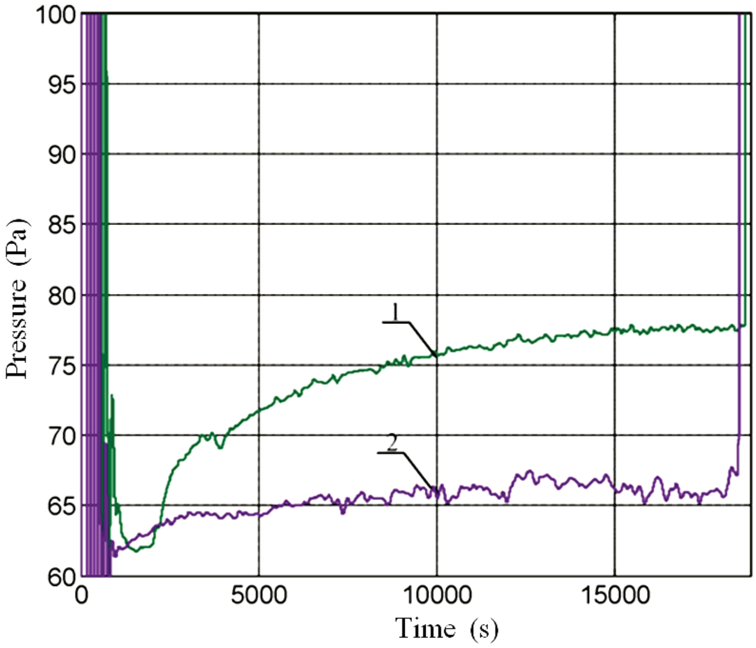

Figure. 5. Changes of the pressure within the vacuum chamber during sublimation of samples: 1 – without the cold trap, 2 – with the cold trap

Conclusions

The results of research show that the ice sublimation process in the installation equipped with the cold steam trap is reasonable. Its use allows shortening of the duration of the process. It also influences the more stable vacuum pump work. The results of the research also showed that the use of cold steam trap does not significantly influence the ice sublimation duration in the sprat carcasses. Acceleration of free ice sublimation with no impact on the duration of sublimation of ice from sprat carcasses may be significant for the process of sublime-vacuum-steam defrosting of sprat carcasses and may allow obtaining a desired effect of disintegration of the block into single, non-defrosted carcasses.

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WPŁYW ZASTOSOWANIA WYMRAŻACZA PARY WODNEJ W INSTALACJI KOMORY PRÓŻNIOWEJ NA SZYBKOŚĆ SUBLIMACJI LODU

Streszczenie. Praca stanowi kontynuację badań dotyczących różnic w szybkości sublimacji lodu czystego i zawartego w materiale porowatym, których wyniki opublikowano w Technica Agraria 12(1-2)/2013 (Diakun, Dolik, Kopeć „Szybkość sublimacji lodu swobodnego i lodu z tuszki szprota"). Wykorzystane w badaniach stanowisko pomiarowe uzupełniono o wymrażacz pary wodnej, który ma za zadanie zapobieganie przedostawaniu się wilgoci do pompy próżniowej oraz intensyfikację procesu sublimacji lodu. Wykonano porównawczo próby działania instalacji z wymrażaczem pary wodnej i bez wymrażacza. Materiałem badawczym (próbkami) były: bryłka lodu, zamrożone tuszki szprotów i lód zamrożony w gąbce (model materiału porowatego). Celem badań było sprawdzenie wpływu wymrażacza na warunki panujące w komorze podczas sublimacji oraz na szybkość procesu. Oceniono również różnice w szybkości sublimacji lodu: z powierzchni swobodnej, z tuszki ryby i zamrożonego w gąbce. Uzyskane wyniki wykazały znaczne zwiększenie szybkości sublimacji lodu podczas prowadzenia procesu z aktywnym wymrażaczem pary wodnej.

Słowa kluczowe: wymrażacz pary wodnej, sublimacja, lód swobodny, liofilizacja szprotów