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Temperature Monitoring in the Transportation of Meat Products

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Abstract

This paper analyses air temperature changes inside a cooling chamber of a vehicle carrying meat products, depending on the monitoring system in terms of maintaining the cold chain. The research was carried out in the years 2014-2015 in Małopolska region. The object of the research was a food business whose main specialty is the purchase, slaughter of pigs and butchering pig carcasses, and then transport of the meat products. The research was focused on the product transportation as the critical process determining health safety of the foodstuffs being carried. Performance of the air temperature monitoring system was analysed during three rides inside cooling chambers of three vehicles. Air temperature monitoring inside the cargo hold was performed using certified, wireless and autonomous meters with data loggers at measuring steps of 60 s. Inside the cooling chambers of vehicles systems for monitoring temperature changes, based on thermocouple sensors (K and J type) and the Pt-1000 thermistors, were installed. One of the monitoring systems was provided with 4 temperature sensors located in the cooling chamber (middle of chamber, air inlet and outlet from the evaporator and product temperature), and 4 bistable signals (opening the side and rear doors, defreezing and operation of the cooling unit). According to the results of the tests, in none of the experimental combinations analysed (taking into account the vehicle, route and monitoring system) the recorded temperatures were found to have caused interruption to the cold chain. A significant difference was found in the values of measured temperatures recorded by the monitoring system with the Pt-1000 thermistor, in relation to the monitoring systems based on K and J type thermocouples.

Keywords: Temperature; Meat; Transport; Cold chain HACCP

Nomenclature

T_z: Temperature outside the insulated body (°C)

t_p : Time of ride (min.)

R_L: Number of unloading operations

S_d: Standard deviation

W_z: Coefficient of variation (%)

min., max., av.: Respectively, minimum, maximum and average value

Introduction

Meat products belong to the group of perishable foodstuffs. Meat is prone to natural, continuous and irreversible bio-physiochemical changes (high water content, the presence of protein, carbohydrates and fat promote the processes of oxidation and rancidity) [1,2]. To ensure the health safety of meat products, it is required to use suitable raw material, appropriately selected cooling methods (freezing), the storage and distribution conditions and a continuous monitoring and control, in accordance with the applicable quality assurance systems [3,4]. The regulations (EC) No 853/2004 of 29 April 2004 laying down hygiene rules for food of animal origin (Journal of Laws L139 / 55 dated 30 April 2004) requires that the transport of this product be carried out according to the following criteria: fresh meat (red)-below +7°C, poultry (white)-below +4°C, meat offal-below +3°C, minced meat products-below +2°C. The above legislation allows for the so-called "Limited periods", in which the temperature does not have to be controlled, and which are associated with the necessary logistic processes (shipment preparation, loading and unloading of goods) [5,6]. The above-mentioned products are transported in various types of refrigerated vehicles. Transportation in deep-freezer vehicles (of frozen products) is based on similar rules to the requirements for the transport of chilled products, however, the temperature should not exceed -18°C (with acceptable short-term upward fluctuations of not more than +3°C). In both forms of transportation discussed, it is required to document the temperature conditions during the shipping process [7]. The process of transport, especially of meat products, is subject to a special surveillance system in accordance with the applicable system for hazard analysis and determination of critical control points (HACCP) (Sperber). Chilled or deep-frozen foodstuffs are subject to the procedure of maintaining unchanged conditions in which they have to be kept (cold chain). This means that from production, transport and distribution until the consumption by consumers, both the chilled and frozen products should be stored at an appropriate temperature [8]. Exposing the product to conditions outside the range of recommended temperatures, in either of the links of the cold chain, can result in lowering the quality, as well as changes which may impact the health security. In the cold chain, there are many critical points at which its continuity can be interrupted [9]. For this reason, mechanical or electronic temperature monitoring systems are in use. To meet the sanitary requirements for food safety, entrepreneurs carrying animal products, are obliged to provide this service using appropriate means of transport. The carriers, for carriage of perishable foodstuffs, use such means of transport as insulated truck bodies (with limited exchange of heat between the environment and the interior), cold storage (using e.g. ice with the ability to keep the temperature low), as well as refrigerator and freezer trucks (equipped with special refrigerating units). In road transport, the most common cooling methods include mechanical cooling, cooling with liquid nitrogen and with eutectic plates [10]. As the practice shows [11] the most common reasons for exceeding the temperature (and humidity) limits of the carried foodstuffs include

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the human factor, technical defects of means of transport, damage of components in the systems for monitoring critical parameters. The manufacturers of temperature monitoring systems dedicated to refrigerated transport offer ready solutions based on various types of sensors to measure this parameter. Also the monitoring organization can be different. The systems offered usually have the certificates and approvals required by law. The use of various types of sensors (with different sensitivity, linearity, tolerance, resistance to external conditions etc.) may affect the measurement values obtained, which can have an effect on maintaining the cold chain (e.g. switching on a chiller early enough) [12]. This paper analyses air temperature changes inside a cooling chamber of a vehicle carrying meat products, depending on the monitoring system in terms of maintaining the cold chain.

Material and Research Methods

The research was carried out in the years 2014-2015 in Małopolska region. The object of the research was a food business whose main specialty is the purchase, slaughter of pigs and butchering pig carcasses, and then transport of the meat products. The research was focused on the product transportation as the critical process determining health safety of the foodstuffs being carried. The company is equipped with motor vehicles for the transport of meat products (in accordance with the requirements of the ATP Agreement on the International Carriage of Perishable Foodstuffs and on the special equipment used for such carriage). The transport vehicles have common features in line with current standards and regulations. They are equipped with specialized cargo holds adapted to transport of food and designed to allow the maintenance of proper hygienic conditions along with the refrigeration system, and the systems for monitoring thermal conditions [12-14]. Vehicle operators were trained on the applicable HACCP standards (also for monitoring thermal conditions of cargo holds during transport and keeping appropriate documentation in this regard). Performance of the air temperature monitoring system was analyzed during three rides inside cooling chambers of three vehicles. A single ride lasted from 240 to 270 minutes, including the time from loading and closing the cooling chamber door until unloading the last batch of product. The objects of research (refrigerated trucks) differed as to the payload, cooling method of the cargo hold, the number of breaks for unloading, ride time and distance covered (Table 1) The heat transfer coefficient of the insulated body walls was 0.4-0.6 $W \cdot (m^2 \cdot °K)^{-1}$ (according to the ATP classification of the heat transfer coefficient in the range 0.4-0-7 $W \cdot (m^2 \cdot °K)^{-1}$ is the so called normal insulation) [15]. Such differentiation was deliberate and purported to reflect the actual conditions in transit of foodstuffs. Air temperature monitoring inside the cargo hold was performed using certified, wireless and autonomous (powered with lithium battery) meters with data loggers. Measurement step of 60 s. was assumed. Inside the cooling chambers of the vehicles, 3 systems for temperature monitoring were installed: system I-K type thermocouple, system II-J type thermocouple (systems I and II based on a thermocouple sensor) and system III-based on Pt-1000 resistance sensor. System III comprised a thermo hygrometer based on a Pt-1000 termistor, with 4 temperature sensors located in the cooling chamber (in the middle-sensor 1, evaporator air inlet and outlet-sensors 2 and 3 and product temperature-sensor 4). The thermo hygrometer was additionally provided with 4 bistable signals (opening the rear and side doors, defreezing and operation of the refrigeration unit). Processing characteristics and tolerance limits of thermocouples are described in the standard PN-EN 60584-1, and those of resistance sensors in PN-EN 60751. Temperature sensors of the system I and II were located in the middle part of the body (near the cz1 sensor of the system III). Thermocouple is a component of electrical circuit that uses See beck effect (generating of electromotive force in a circuit containing two metals when their interfaces are in different temperatures) at the interface of two different materials. Thermocouple type K (sheet 06, NiCr-NiAl) in which the relationship between the emf and temperature is nearly linear and its sensitivity is 41 $\mu V \cdot °C^{-1}$, is used in the temperature range from -200 to +1,200°C. Thermocouple type J (sheet 04, Fe-CuNi) is used in the temperature range from -40 to +750°C, and its sensitivity is 55 $\mu\ V \cdot °C^{-1}$.

Pt-1000 is a resistance sensor reacting to temperature variations by changing resistance of an integrated resistor (with temperature, increases the vibration amplitude of atomic nuclei and the probability of collision of free electrons and ions which, due the inhibition of electron motion, causes the resistance increase). The microprocessor built in the thermo hygrometer calculated the current measurement results (knowledge of non-linear characteristics of sensors and digital calibration data saved during calibration of the instrument was used). The meter can create a histogram containing statistical information on the occurrence of measurement values recorded in the ranges specified. As a standard, the measuring range for temperature was divided to 63 parts, each with a span of 2°C. It was possible to set limit values of the parameter measured and to indicate its exceeding during the recording session. The monitoring system III was characterized by the following technical specifications: measuring range from -30 to +80°C, measurement uncertainty +/- 0.2°C, resolution 0.1°C. Such system is dedicated to refrigerated transport vehicles with individual refrigeration unit which, at an average ambient temperature +30°C, makes it possible to lower and hold temperature inside the body (cooling chamber) from +12 to 0°C inclusive-class A [10,15]. Recorder programming, reading, presentation and printing of the data saved was performed by means of a PC with installed dedicated software and a reader connected to the USB port. Data transmission between the recorder and USB reader connected to the PC was wireless in both systems with the use of an optical infra-red interface. The analysis of the temperatures measured included differences between the data sequences recorded. The differences were determined by the value of basic statistical measures and variance analysis. During each ride of a vehicle, the ambient temperature was also monitored immediately outside the insulated body. The test results were analyzed using STATISTICA 10 software at the significance level assumed α=0.05. In carrying out a preliminary analysis of the measuring series obtained during the tests (air temperature inside the refrigerated chamber), the λ^2 test was used to check the equality of groups. The distribution normality in tests was determined with Kolmogorov-Smirnov test, and homogeneity of variance with Brown-Forsythe test. Significance of differences was studied using the variance analysis with F-Snedecor test. For statistically significant quality predictors, multiple comparisons were performed to distinguish homogeneous variable groups (Tukey test).

Vehicle designation and description		Route description			Route designation
		T_z (°C)	t_p (min)	(R_L)	
P1	Refrigerated van, volume 8.9 m^3, compressor refrigeration unit, heat transfer coefficient 0.6 $W \cdot (m^2 \cdot °K)^{-1}$	24.1	241	4	T1
		2.4	255	5	T2
		11.0	253	4	T3
P2	Refrigerated container truck, volume 13.8 m^3, absorption refrigeration unit, heat transfer coefficient 0.6 $W \cdot (m^2 \cdot °K)^{-1}$	23.1	244	5	T1
		3.5	270	5	T2
		9.6	236	4	T3
P3	Hook refrigerator truck, volume 53.5 m^3, compressor refrigeration unit, heat transfer coefficient 0.4 $W \cdot (m^2 \cdot °K)^{-1}$	19.0	240	1	T1
		3.3	246	1	T2
		12.2	241	2	T3

Table 1: Description of the transport vehicles and routes covered.

Results and Discussion

The calculated values λ^2 of Kolmogorov-Smirnov and Brown-Forsythe tests were insignificant. Due to the fact that the test probability value p=0.057 for the statistics λ^2 was close to the limit value of the significance level assumed, for multiple comparisons Spjotvoll-Stoline procedure (generalisation of the HSD Tukey tests for samples of different sizes) was applied. Analysis of basic statistics (tab) characterising the relationships between the vehicle used and monitoring system and the temperature value measured inside the refrigerated body clearly points that in neither of the experimental combination was the average temperature exceeded during transport of meat. 10 to 15 minute interruptions (Figure 1) of the critical limit 7°C occurred (indicated in Table 2 as the maximum value). Such short-term temperature exceeding is acceptable, which is caused mainly by opening the cooling chamber doors and unloading [5]. The values of variability factor (W_z, the ratio of standard deviation and average value expressed in %) indicate that the variability within the measured temperature range was: 15.2% for system I, 13.7% for system II and 17.4% for system III. Such a great variability for system III was due to the fact that the system was based on measuring sensors placed in different points of the cooling chamber, thus recording extreme temperature values. The value of the variability factor within the measured temperature range, based exclusively on the transport vehicle, was: 15.9%-vehicle 1, 15.2%-vehicle 2 and 14.8% for vehicle 3 (maximum difference in the variability exceeded slightly 1%). For vehicle 3, the result obtained is justified as this was a hook refrigerator truck with large volume of the cooling chamber, which is one the reasons for reduced heat exchange (inertia) during transit and single unloading.

The variance analysis result presented in Table 3, relating to the differences in air temperature measurements inside the cooling chamber indicates clearly that only the monitoring systems used in the experiment influenced significantly the parameter being measured. Therefore, it has to be concluded that the means of transport (equipped with various cooling systems) assumed in the research and the following rides (with different distances, duration, ambient temperature and number of unloading) had no effect on the temperature changes inside the refrigerated body. The result of Spjotvoll-Stoline procedure (Table 4) proved existence of 2 homogeneous groups whose distribution indicates that temperature measurement values obtained by system 3 were different than those of systems 1 and 2. In this case, it can be concluded that the monitoring system based on the Pt-1000 thermistor provides significantly different temperature readings (about 8% greater) in relation to the systems based on the K and J thermocouples. To verify the result obtained, at the following stages, only the temperature data acquired by the monitoring system based on the Pt-1000 thermistor was analyzed. As already mentioned, the monitoring system using the Pt-1000 thermistor was based on 4 temperature sensors located in the cooling chamber space. Variance analysis performed in this respect, taking also into account the spacing of sensors, proved a significant effect of both, the route of the ride and location of sensors on the temperature values measured (Table 5). Multiple comparisons of differences in air temperatures obtained with the Pt-1000 thermo hygrometer inside the cooling chamber, depending on the route and sensor location (Tables 6 and 7) indicate that the differences achieved are determined mainly by the location of measuring sensors and also by the route covered by the vehicle (frequency of unloading, ride time and ambient temperature). Such a result of the analysis of variance and arrangement of homogeneous groups would indicate that not without significance is the type of temperature meter installed in the refrigerated vehicle. To verify this conclusion, the relationships

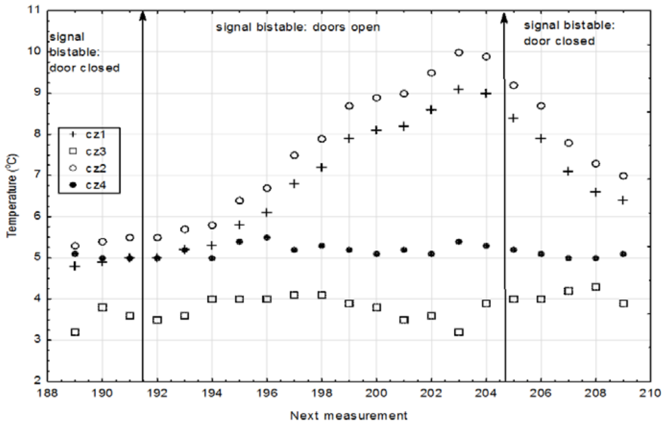

Figure 1: Temperature curve inside the refrigerated vehicel measured by sensores (cz1, cz2, cz3, cz4 - sesonrs 1-4 respectively) of the monitoring system equipped with Pt-1000 thermistor (selected example).

Vehicle	Route	System	T_w (°C)			Sd (°C)	Wz (%)
			min	max	av		
1	T1	I	4,1	8,1	6,1	0,9	14,8
		II	3,9	7,9	5,9	0,9	15,3
		III	3,4	8,4	5,9	1,1	18,8
	T2	I	4,2	8,8	6,5	1,0	15,4
		II	4,2	8,1	6,2	0,9	14,6
		III	3,5	7,9	5,7	1,0	17,5
	T3	I	3,8	7,7	5,8	0,9	15,1
		II	4,1	7,6	5,9	0,8	13,3
		III	3,4	8,4	5,9	1,1	18,6
2	T1	I	4,4	8,6	6,5	0,9	13,8
		II	4,1	7,9	6,0	0,8	13,3
		III	3,4	8,8	6,1	1,2	19,7
	T2	I	3,7	7,1	5,4	0,8	14,8
		II	3,9	8,1	6,0	0,9	15,0
		III	3,5	7,9	5,7	1,0	17,5
	T3	I	4,2	7,7	6,0	0,8	13,4
		II	4,2	7,4	5,8	0,7	12,1
		III	3,5	8,2	5,9	1,0	17,1
3	T1	I	4,1	7,9	6,0	0,8	14,1
		II	4,4	7,8	6,1	0,8	12,4
		III	4,0	8,5	6,3	1,0	16,0
	T2	I	3,5	8,2	5,9	1,0	17,1
		II	3,6	7,8	5,7	0,9	15,8
		III	3,8	8,2	6,0	1,0	16,7
	T3	I	4,2	8,1	6,2	0,9	14,6
		II	4,4	7,6	6,0	0,7	11,7
		III	4,0	7,9	6,0	0,9	15,1

Table 2: Basic statistics characterizing the relationships between the vehicle used, monitoring system and the measured temperature value inside the refrigerated body.

Independent variables	Number degrees of freedom	Value of F-Snedecor test	Value of test probabilisty
Free word	3	26568,63	0,0000
vehicle	6	0,02	0,9997
Route	6	0,13	0,9931
System	6	21,91	0,0000

Table 3: Variance analysis result - differences in air temperature measurements inside the cooling chamber depending on the vehicle, covered distance and monitoring system.

System	Temperature(°C)	Homogenous groups	
		1	2
System II	5,66	****	
System I	5,75	****	
System III	6,24		****

Table 4: Multiple comparisons for the differences in air temperature measurements inside the cooling chamber depending on the vehicle, covered distance and monitoring system.

Independent variables	Number degrees of freedom	Value of F-Snedecor test	Value of test Probability
Free word	1	14668,76	0,000000
Vehicle	2	3,83	0,4215
Route	2	33,46	0,000000
Sensor	2	31,31	0,000000

Table 5: Variance analysis result - differences in air temperature measurements made with the thermo hygrometer Pt-1000 inside the cooling chamber depending on the vehicle and covered distance.

Route	Temperature (°C)	Homogenous groups		
		1	2	3
route 1	4,88	****		
route 2	5,33		****	
route 3	5,94			****

Table 6: Multiple comparisons for differences in air temperature measurements made with the thermo hygrometer Pt-1000 inside the cooling chamber depending on the ride route.

Sensor	Temperature (°C)	Homogenous groups			
		1	2	3	4
sensor 3	4,85	****			
sensor 4	4,93		****		
sensor 1	5,3			****	
sensor 2	5,91				****

Table 7: Multiple comparisons for differences in air temperature measurements made with the thermo hygrometer Pt-1000 inside the cooling chamber depending on the sensor location.

Independent variables	Number degrees of freedom	Value of F-Snedecor test	Value of test probability
Free word	3	22381,02	0,0000
vehicle	6	1,12	0,3674
Route	6	1,29	0,3584
System (I, II, III cz1)	6	1,71	0,2954

Table 8: Variance analysis result - differences in air temperature measurements in the middle of the cooling chamber depending on the vehicle, covered distance and monitoring system (I, II, III cz1).

between readings of the sensors of three monitoring systems located in close vicinity would have to be studied either. Bearing in mind the above, the significances of differences in temperature readings from the monitoring systems I and II and the sensor 1 of the system III (middle part of the refrigerated body) were analyzed. The analysis of variance performed (Table 8) showed no significant differences between the grouping variables assumed in the experiment (insignificant values of F-Snedecor test). Therefore, there are no grounds to conclude that the monitoring systems used in the experiment could deliver different temperature readings and thereby disturb the function of the cold chain. The tests performed allow a conclusion that for an agricultural and food business transporting the foodstuffs, it is a less important issue to choose between the sensor with a thermocouple and thermistor, but more important is the number of sensors, their location and provision of the monitoring system with bistable indication system giving the information on the cold storage functioning (monitoring organization). The readings of the sensor no. 4 (system III), responsible for temperature measurement of the cargo being carried, are important for the safety of food and control of critical points. Temperature of the meat transported was around 5°C, even during unloading [16-18].

Conclusions

i. In none of the experimental combinations analyzed (taking into account the vehicle, route and monitoring system) the recorded temperatures were found to have caused interruption to the cold chain.

ii. In neither of the combinations studied did the temperature of cargo (meat) transported exceed the value 7°C.

iii. The means of transport used and distances covered (unloading frequency, ride time and ambient temperature) were found not to have negative impact on the temperature values measured inside the refrigerated bodies.

iv. A significant difference was found in the values of measured temperatures recorded by the monitoring system with the Pt-1000 thermistor, in relation to the monitoring systems based on K and J type thermocouples.

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