Available online at www.sciencedirect.com

ScienceDirect

Procedia Social and Behavioral Sciences 20 (2011) 761–766

Procedia
Social and Behavioral Sciences

14th EWGT & 26th MEC & 1st RH

Thermal damage to the load in cold chain transport

Wiesław Zwierzycki[a], Krzysztof Bieńczak[a], Maciej Bieńczak[a,*], Arkadiusz Stachowiak[a] , Przemysław Tyczewski[a] and Tomasz Rochatka[a]

[a]*Poznan University of Technology, Piotrowo 3, Poznan 60-965, Poland*

Abstract

The article deals with the issues of cold chain transport. One of the most important criteria of the process' efficiency is temperature stabilization. At the Institute of Machines and Motor Vehicles of Poznan University of Technology, original computer software for heat exchange simulation was created. The software makes it possible to forecast temperature changes at the time of transport depending on the vehicle itself as well as the exploitation conditions. In the article, verification results of the computer software are also presented. The verification involved the comparison of the results (changes in the temperature of the goods) with the research results. The experiment involved cooling the load and monitoring its temperature. The verification covered five different states of enforcement. In the tests, such parameters as thermal insulation of the body, the original temperature of the load, cooling efficiency of the unit as well as ambient temperature were examined. In all of the cases it was found that the results of computations were within the range of variability of results registered during the research. The computer software under discussion may therefore be used to point to probable causes of significant temperature increase of transported goods in real-life situations. In the second part of the article, analyses of simulations of two such cases were presented. In each of the situations, the decisive factor resulting from the numerical forecast was confirmed by the results of insurance company's investigations. Therefore the simulation software might constitute an efficient tool supporting the decision making process with respect to the organization of cold chain transport.

Selection and/or peer-review under responsibility of the Organizing Committee.
Keywords: cold chain transport, simulation, heat transfer

1. Introduction

Specialized cooling transport constitutes challenges unknown in any other types of transport. From the logistics point of view, a cold chain calls for a specialized fleet. The choice of vehicles is a very complex task and so is fleet management and composition. Fleet manager needs to make the right decision and take numerous factors into consideration. Both the vehicle and the load must be properly prepared for the transport. Neglecting good transport practice might lead to damaging the load and be dangerous for the consumer who is the final link in the supply chain.

* Maciej Bieńczak. Tel.: +48-61-665-2716; fax: +48-61-665-2129.
E-mail address: mbienczak@wp.pl.

Selection and/or peer-review under responsibility of the Organizing Committee
doi:10.1016/j.sbspro.2011.08.084

One of the most important criteria of the process' efficiency is temperature stabilization. In order to meet this requirement, the following factors need to be accounted for:

- the choice of the vehicle with good thermal insulation properties and appropriate capacity,
- good organization of loading/unloading process (especially the preparation of the load) considering the distribution schedule as well as the weather.

Following the discussions presented in the work by James (1996), the temperature is the parameter which influences maintaining the quality features of the transported food. Flores (2003) expresses the opinion that in case of fresh cut vegetables the departures from the optimum temperature during their storage and transport are the measure of danger for consumers. It is well-founded to extend the opinion to any perishable food that is transported. For this reason, it seemed necessary to prepare calculation tools enabling to determine the temperature of the transported food. Before starting to build the computer code, the work carried out in other research centres in the world was analysed. The analysis of air flow and heat reception from the body filled with goods placed on pallets carried out by means of computer fluid dynamic methods and the experimental methods is presented in the paper by Moureh and Derens (2000). The results of the numerical experiments were compared with the ones of the physical experiments. Having built a model stand and created calculation procedures, the above authors assumed a very strongly simplified presumption that there was no heat transfer between the load and air circulating in the body. They assumed that the heat transfer took place only between the body walls and air transporting heat entering to the evaporator.

The presumption is not met:

- after loading, as the temperature of air and load can be different (the temperature difference causes the heat transfer),
- when fresh fruit and vegetables are transported.

Fresh fruit and vegetables generate heat of respiration. The value of this heat for many fruit and vegetables is of the same order as the heat transfer from the body walls through conduction. It should be pointed out here that from the point of view of equations describing the heat transfer, the heat of respiration should be treated as "a product" of internal heat sources.

The results presented in the discussed paper should be treated as approximate. Comini et al. (1995) presented a mathematical model describing the heat transfer in the load and in the body interload spaces and also in the refrigeration body walls. The air circulation in the body is enforced by fans which are the integral parts of the evaporator of the refrigeration unit. The authors used the finite elements method for solving the differential equations system. The simplified presumptions used when solving equations were the subject of the experimental verification. By solving the equations they defined the thermal fields in the load and interload spaces.

Modelling of the air flow in the refrigeration body was discussed in the paper by Zental-Menia et al. (2002). The authors tested the mentioned phenomenon on the physical model and with the use of a FLUENT computer programme. The performed experiments confirmed the effectiveness of the programme.

The effect of the refrigeration chamber design solutions on the temperature distribution and the air flow speed was analysed in the elaboration by Jing Xie et al. (2006). The analyses were done for a chamber that was not filled with any load. The process of heat transfer between the wall and the packed load is considered in the work by Laguerre et al. (2006). This problem is solved with the use calculation and experimental methods.

Temperature changes of frozen food placed on pallets in cardboard boxes influenced by ambient temperature were analysed in the work by Moureh and Derens. (2000) Calculations were carried out for ambient temperatures occurring in France in February and July. The heat transfer on the radiation path is taken into account in the calculation model. The calculation results are compared with the measurements values. The temperature differences between the calculation and measurement values do not exceed 1.5 ^{0}C.

2. Calculation model

At the Institute of Machines and Transportation of Poznań Technical University, original computer software for heat exchange simulation was created. The software makes it possible to forecast temperature changes at the time of transport depending on the vehicle itself as well as the exploitation conditions. The algorithms were prepared by means of the following:

- differential equations of temporary heating power exchanged between the load, the air inside the loading compartment, the cooling unit, the walls of the trailer and the ambience,
- the equation of undefined heat conductivity and the general equation of energy balance for the air flowing inside the channel (the finite elements method).

The mathematical formulation of calculation model was presented by Bieńczak (2011).

3. Verification of the models

Based on the aforementioned models, computer software was prepared and verified. The essential verification of the computer program was based on the comparison of simulation and research results. The research experiments were carried out for the body of a volume of about 8 m^3 and heat transfer coefficient 0.7 $W/(m^2K)$. The body was equipped with the refrigerated unit with the power of 2 kW. The load was composed of boxes of 1 dm^3 capacity filled with water. The boxes were placed in 600 × 400 × 230 mm cases. Three rows of cases were situated along the body. Each row contained five layers of packages. The cases were located on pallets. The width of the canal enabling air flow among the packages was about 60 mm. The tests included the temperature measurement of load and air during chilling. The initial load temperature was about 13^{o}C. The refrigeration unit operated at the thermostat setting at the level of 6^{o}C. During the tests, the temperature of the following elements was measured and recorded:

- load (in 40 points) – in the lower, middle and upper layer, in front and in the back of the body,
- air (in 16 points) – in the canals among the cases and between the cases and the wall of the body, at the air inlet and outlet of the refrigerated unit.

The verification covered four different states of enforcement (table 1). In the tests, such parameters as thermal insulation of the body, the original temperature of the load, cooling efficiency of the unit as well as ambient temperature were examined.

Table 1 Plan of the verification experiment

Test	Cooling unit		Load		Thermal insulation		Ambient temperature	
	nominal capacity	minimal capacity	not chilled before loading	chilled before loading	normal	heavy	26^{o}C	33^{o}C
1	X		X		X		X	
2		X	X		X		X	
3		X		X		X	X	
4		X		X		X		X

The comparison of the tests and calculations results concerned air temperature changes inside the load. In Fig. 1 and 2, extreme measurements obtained in subsequent tests (Table 1) were compared with the forecasted temporary values of air and load temperatures. For Model I average temperature was computed (Fig. 1). However, the other model (Fig. 2), allows for forecasting local temperature values measured at the points where selected thermometers were located (T_{min}, T_{max}). In the analyzed range, the calculations results were within the area of measurements results variability. Therefore, one might conclude that the analytic model applied in the computer program properly reflects general tendencies of the complex heat transfer process in real service conditions.

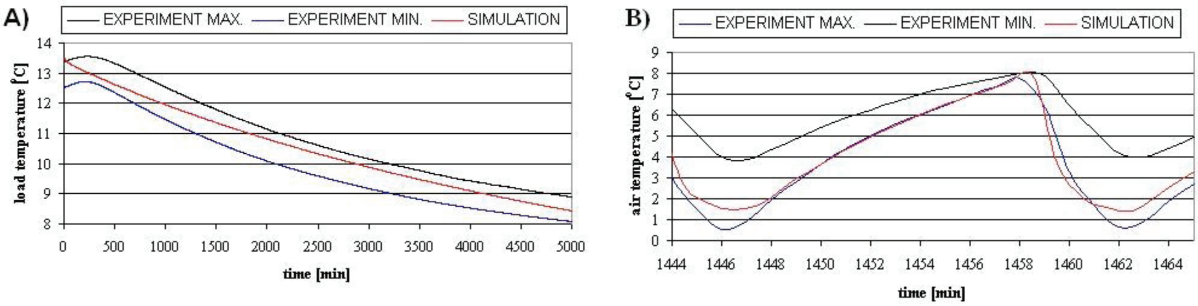

Figure 1 Comparison of simulation and research results (model I, test 1 – table 1) A) load temperature; B) air temperature

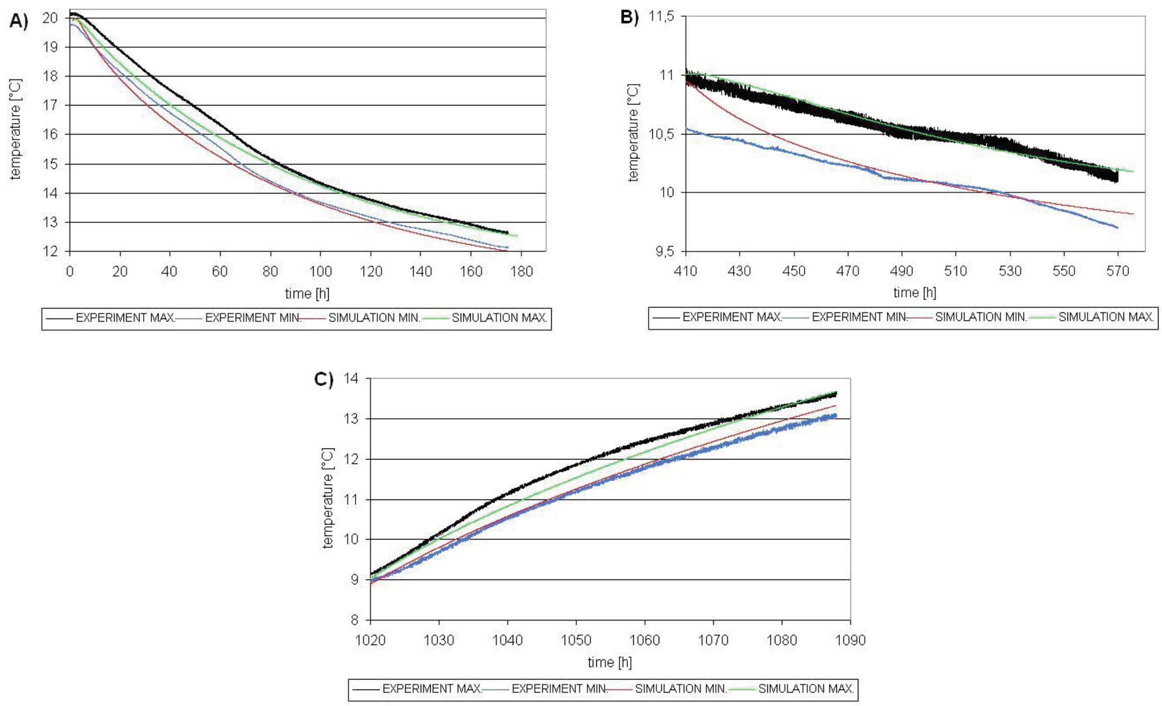

Figure 2 Comparison of simulation and research results (model II) A) load temperature – test 2 (table 1); B) load temperature – test 3; C) load temperature – test 4.

4. Practical applications

4.1. Example I

Frozen poultry was transported in summer, during a heat wave. The required transport temperature was –20°C. Due to multiple problems with crossing the Ukrainian and Moldavian border, the loaded semi-trailer was standing for some days at the border exposed to high temperature (about 46°C). After 20 hot days, the load came back to the country. After entering the Polish territory, it was found that there was a leakage from the transported meat. The temperature of the meat was –3 to 0°C. It was assumed that the main reason of the temperature rise was the transport duration (20 days instead of 3 days). Simulations of the load temperature changes within 20 days service were made. The obtained results are presented in Figure 8. The calculations were done for 3 variants:

- heat insulation properties of the body (k=0.4 W/(m^2K)) and the refrigerated unit power appropriate for the transport in the temperature –20°C; in this case no significant load temperature increase was found and the cooling unit was operative for about 80% of its service time,
- very poor heat insulation properties of the body (k=1.0 W/(m^2K); the change caused by a long term of service and wear; cooling capacity was typical for semi-trailers transporting frozen load – in this situation the load temperature increases (to about –15°C) and the refrigerating unit works continuously.
- very poor heat insulation properties of the body (k=1.0 W/(m^2K), it was additionally assumed that cooling capacity was lower by 30% (the change arising from a very high ambient temperature and hard operation of the machine) – in this case the load temperature increased to the level comparable with the description of the event (about –4°C).

The obtained results show that the main reason of the temperature rise of frozen poultry might have been caused by high ambient temperature and continuous operation of the refrigerating unit. The negative effect can also be connected with the deterioration of the body heat insulation properties (material wear effect). It should be pointed out that if the load reached the destination place according to the schedule (within 3 days), in none of the analysed cases defrosting would occur.

4.2. Example II

Another example illustrating the functionality of the software deals with substantial increase of temperature of meat transported from Poland to Hungary. At the time of loading, the temperature of the meat was 2.6°C. The transport lasted 35 hours and the maximum ambient temperature was approximately 22°C. At the time of unloading it was found that the temperature of meat (in the boxes located near the back door of the body) was over 6°C which exceeded the maximum allowed level by 2°C. Since the technical condition of the trailer and the cooling unit was correct, the increased temperature must have been caused by inappropriate preparation of the meat for transport (i.e. the meat had not been cooled well enough before it was loaded). After the slaughter, the meat must have been cooled in ice water and immediately loaded for transport on the cooling trailer. The procedure however, requires that the meat should be placed in a cooling warehouse to get its temperature stabilized.

Using Model II, the distribution of temperature after 35 hours was defined for two situations:

- the goods were correctly prepared for transport, the initial temperature throughout the load was 2.6°C, and
- the incorrectly prepared load when half of the goods (placed in the distant part of the trailer) were not cooled appropriately and thus the initial temperature was as high as 7°C.

The computation results presented in Fig. 4 point to the fact that in (b) it was impossible to cool down the incorrectly prepared goods to reach the required temperature of 4°C. Moreover, in the correctly prepared load, a substantial increase of temperature was observed. The example shows how important it is to prepare the goods (cool them down) prior to the transport.

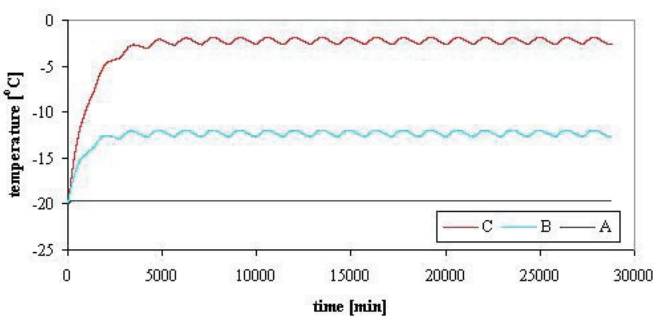

Figure 3 Temperature change in transport (example I) A) k=0,4 W/(m^2K), 7700 W B) k=1,0 W/(m^2K), 7700 W C) k=1,0 W/(m^2K), 5900 W

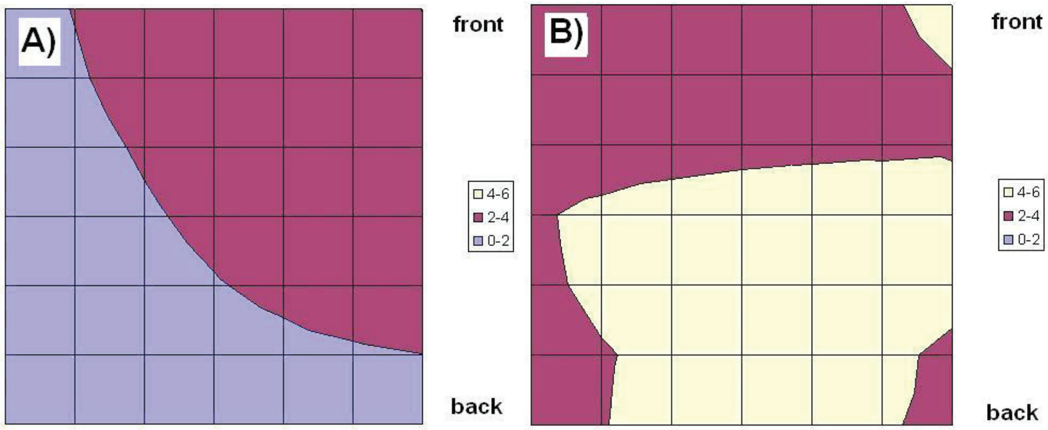

Figure 4. Distribution of temperature within the load after 35 hours of transport (example II) A) original temperature: 2.6°C throughout the load B) original temperature: 2.6°C in the front part of the trailer and 7°C in the further part of the trailer

5. Conclusion

In both analyzed cases, the decisive factor resulting from the numerical simulation was confirmed by the outcomes of insurance company's investigations. Therefore the simulation software might constitute an efficient tool supporting the decision making process with respect to the organization of cold chain transport.

Moreover the simulation tool is helpful during training of perishable foodstuff transport managers. It shows in a very user-friendly way the importance of good vehicle selection and the influence of temperature factor on the conditions of the transport process.

References

Bieńczak K. (2011). Providing safety for food consumer in transport link of refrigeration chain. *Maintenance and reliability*, 49, 16-27.

Comini G, Cortella G, Saro O. (1995). Finite element Analysis of coupled conduction and convection in refigerated transport. *International Journal of Refrigeration*, 18(2), 123-131.

Estradu-Flores S. (2003). Safe temperature regulations during the road transport of fresh cuts. *D.C: International Congress of Refrigeration*, Washington, 8.

James S. (1996). The Chill Chain from Caracass to Consumer. *Meat Science*, 43(8), 203-216.

Jing Xie, Xiao-Hua Qu, Jun-Ye Shi, Da-Wen Sun. (2006). Effects of design parameters on flow and temperature fields of a cold store by CFD simulation. *Journal of Food Engineering*, 77 (3), 355-363

Laguerre O, Ben Amara S, Flick D. (2006). Heat transfer between wall and packed bed crossed by low velocity airflow. *Applied Thermal Engineering*, 26 (16), 1951-1960.

Moureh J, Derens E. (2000). Numerical modelling of the temperature increase in frozen food packaged in pallets in the distribution chain. *International Journal of Refrigeration*, 23 (7), 540-552.

Moureh J, Flick D. (2004). Airflow pattern and temperature distribution inatriptical refrigerated truck with palets. *International Journal of Refrigeration*, 27 (5), 464-474.

Zertal-Menia N, Moureh J, Flick D. (2002). Modelisation simplifiee des coulements d'air dans un vehicule frigorifique. *International Journal of Refigeration*, 25(5), 660-672.