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Research on the Control Mechanism and Simulation of Safety Conditions of Perishable Foods Transportation and Logistics

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1. Summary

1.1 Purpose and Mission

The present goal is to study Food Logistics Technical Conditions.

Cold-chain is a system engineering to ensure the quality and reduce the loss of foods during production, storage, transportation, distribution and retailing of perishable goods under certain low temperature environment. It is a part of cool logistics and transport technology. Because of the complicated environment and long transport duration, the refrigerated transportation is the key to keep the quality in the whole cold chain.

The world population is growing. It has increased from 5.3 billion in 1990 to 6.4 billion in 2000. It is predicted to be 11.2 billion by the year of 2010. In order to meet the food demands, an efficient refrigerated transportation is necessary. According to the statistics, there are at least 1 million refrigerated trucks and 400,000 refrigerated containers in use in the world. The retail value of the products transported can be estimated more than 1200 billion US dollars.

In China, fresh and live produces and other perishable goods need refrigerated transportation urgently. According to interrelated statistics, there are more than 7000 refrigerated railway cars, 30,000 refrigerated trucks, 100,000 tonnes water refrigerated vessels and 10000 refrigerated containers in use. However, the number is still deficient. Today, more than 120 million tonnes perishable goods need refrigerated transportation, but only half of them have been transported because of the restrict of condition and ability of refrigerated transport. More than 15% of foodstuff transported has decayed in the course of transport.

Low temperature is the key to keep the quality of perishable goods, but it is not the only necessary and sufficient condition. The excellent transport quality of perishable goods depends on the suitable control of temperature and humidity and the integrated use of multi-exercise. For example, Excessive low temperature would cause food frostbite and nutrition loss, on the other hand, excessive high temperature would result in rot. Excessive low humidity would cause serious weight-loss of food. On the other hand, excessive high humidity would result in mouldy. Moreover, temperature and humidity are only two main factors affecting quality of food transport.

This research aims to find the best control technology and method, which would keep the quality and reduce the weight-loss of perishable goods, and guarantee the edible safety of food, based on the character of perishable goods transportation.

1.2 Research course

In order to achieve the object, we conducted a study to simulate the factors and find the principle of food. In the first, by means of refrigerated transportation experiment platform, we tested the best reference point under actual transport conditions by adjusting and controlling temperature, humidity, airflow and air composition, etc. In the second, we will set up heat and mass transfer models by computed simulation based on experiment data. Furthermore, the real transportation has been simulated and investigated such as banana, milk, vegetable, pork, etc. The optimal control method would provide guidance for refrigerated transportation of perishable goods. The safety reliability models of food cold chain were builds up to design, assess and optimize food cold chain logistics system. Some key dates were shown as follow.

Date	Proceeding	Remark
2007.7	Group meeting	Study on the development of refrigerated transportation unit all over the world
2007.8	Group meeting	Study on the simulating test-bed of refrigerated transportation condition
2007.11	Group meeting	The International Cooperative Research Activity scheme
2008.4	Group meeting	Investigation summary and experimentation plan
2008.7	Group meeting	Experimentation plan and summary
2009.1	Group meeting	Plan and summary
2009.7	Group meeting	Plan and summary
2009.10	Group meeting	The International Cooperative Research Activity summary
2007.8	International Congress of Refrigeration	Study on the refrigerated transportation of perishable goods all over the world, Guangzhou
2007.9	7th EASTS 2007	Summary about IRG 08-2005, Dalian
2007.11	The 6th National Conference of Logistics	Shenzhen
2007.11	The 19th National Conference of Refrigeration	Hangzhou

2007.12	The National Conference of Refrigerated Transportation	Shanghai
2008.1	The National Symposium of Cold Chain Standard	Guangzhou
2008.4	The National Symposium of Cold Chain	Shanghai
2008.6	The National Institute Conference of Refrigeration	Beijing
2008.6	Proc. of the 4th international conference on the food factory for the future	Laval, France
2008.9	The 15th International Conference on Industrial Engineering & Engineering Management	Zhengzhou
2008.11	The 7th National Conference of Logistics	Wuhan
2008.12	The National Conference of Refrigerated Transportation	Shanghai
2008.12	The National Symposium of Cold Chain Standard	Hangzhou
2009.1	The National Symposium of Cold Chain Education	Guangzhou
2009.4	2009 International Symposium on Traffic Control and Safe	Zhangjiajie
2009.5	Proceedings of Second International Conference on Modelling and Simulation	Manchester
2009.11	The 20th National Conference of Refrigeration	Tianjing
2009.11	Proceedings of the Eastern Asia Society for Transportation Studies	Surabaya

1.3 Findings and conclusions

- The status investigation of refrigerated transportation

The status of refrigerated transportation and refrigerated transportation unit were investigated all over the world by document retrieval, conference, discussion, survey, questionnaire, etc. The equipment development, management status and energy consumption of railway refrigerated transportation were emphasized.

It showed that the sale and output of perishable food is increased rapidly all over the world. In China, the energy consumption was large and the quality of perishable food was not good because the old refrigerated transportation equipment and incomplete cold chain. The solution of the question is mending management system, improving technology and operation, optimizing transportation equipment, especially holding the mechanism of energy consumption in refrigerated transportation.

- Design and test on simulating test-bed of refrigerated transportation conditions

A simulating test-bed for refrigerated transportation condition was built and consisted of two parts. The first part is for exterior environment simulation. The exterior temperature can be adjusted from -20 to 50℃, humidity from 0~100%, and velocity from 0~30m/s by control system. At the same time, these parameters can be adjusted and assembled discretionarily. Most climate conditions can be simulated by this part. The second part is a standard refrigerated container. It can adjust the location and size of the entrance and exit of cold air tunnel, change the direction and volume of air discretionarily. The interior temperature can be adjusted from -25 to 20℃, humidity from 0~100% and atmosphere components (including O_2, CO_2, N_2, C_2H_4). It can deal with many problems such as multi compartments and multi temperature systems, different goods and different loading methods, etc. Furthermore, apparatus and instruments with high precision are equipped for detecting and controlling parameters such as temperature, humidity, velocity, and atmosphere component. Biologic and chemical instruments are outfitted for analyzing and detecting the quality of samples. The test-bed has been operated for one year after debugged. The performance is good and all parameters accord with standards related.

- The analysis of energy consumption of refrigerated transportation

An analytic system was set up to simulating the heat condition and energy consumption of refrigerated transportation. In this system, heat balance model (HBM) was chosen as the analyzed tool. It includes climate model outdoors, heat balance model of insulated layer (heat transfer model of the insulated layer, exterior and interior surface heat balance model of insulated layer), heat balance model of the air in the vehicle, etc. In this dissertation, a special climate model of refrigerated transportation was established, exterior surface heat balance model of insulated layer was completed, the response factor method was introduced in the unsteady heat transfer of refrigerated transportation, and the mechanism of air infiltration was studied. The model properly reflects the dynamic pattern of energy consumption of refrigerated transportation and provides a basis for holistic evaluation and optimum controlling on energy conservation. It was validated by ANSI/ASHRAE Standard 140-2004. At the same time, a simulating test-bed of refrigerated transportation condition was designed. Based on the model and test-bed, the parameters such as the category of perishable food, season, the climate outside the door, velocity, respiration heat, air tightness, heat leak performance, precooling, control strategy, etc were analyzed by this model linking to energy consumption of refrigerated transportation. The measures of energy conservation were advised.

- The optimal design of refrigerated transportation unit

Based on investigated, simulation and experimentation, the optimal design has been done on the refrigerated transportation unit. The airflow distribution of B10 type railway refrigerated car has been ameliorated. Furthermore, the application of energy conservation technology such as air curtain, foaming technology, air supply pattern, new refrigeration, air-air exchanger, etc was discussed.

- Safety reliability models of food cold chain

It puts forward the concept of safety reliability of food cold chain, and constructs the safety reliability models of cold chain logistics unit ($R = R_0 - d\Delta T^2 t$) and cold chain logistics system ($R_i = R_0 - d\sum_{j=1}^{i}\Delta T_j^2 t_j$), based on microbial growth model and dose – response curve. These models show that the failure rate of cold chain unit is proportional to the time and the square of temperature; the safety reliability of cold chain units are mutually independent, it only relats to their respective time and temperature yet unrelated to initial state of system and the other units. The system model also reveals that the safety reliability of cold chain system reduces gradually and irreveribly. Finally, it verifies the models by pasteurized milk cold chain experiment; the results indicate that this model can represent the safety of food cold chain.

- The allocation design of safety reliability of food cold chain system

Non-cost constrained optimization model and cost constrained optimization model have been built on the basis of safety reliability model and the function of temperature and energy consumption. Moreover, a new heuristic algorithm has been designed to find the solution. Further, it studies the reallocation decision of safety reliability of system. Safety factors of cold chain units are in accordance with their component importance.

- Safety analysis and assessment of cold chain system based on safety reliability

The concept and model of safety reliability can be applied to determine the key unit of cold chain, shelf life and use-by date of food. It also can assess the safety of cold chain logistics system based on GO-FLOW method. With the sensitivity analysis of safety factors of food cold chain system, it draws a conclusion that the unit having maximum safety factor is just the key unit of cold chain. The safety reliability model also provides a new method to predict the shelf life and use-by date of food. Based on pasteurized milk cold chain experiment, it is known that use-by date of food is quickly shortened with the temperature rising and the sale is the key safety unit. It is necessary to control the temperature of refrigerated display cabinet not exceed 10℃ and outer milk and inner milk should change position every day.

- Food distribution optimization based on safety reliability

Through a comparative analysis of fixed quantity distribution and fixed time distribution, some intensive distribution operation strategies have been provided. Fixed time distribution model is better than fixed quantity distribution model for those foods that require high service level; however, fixed quantity distribution model is better than fixed time distribution model for those foods with low timeliness. A model of vehicle route problem with time window based on safety reliability has been built, and solved using max-min ant colony optimization algorithms. Used the safety reliability model and date of pasteurized milk experiment; it studies distribution time, distribution temperature, stacked and reception of food. The results show that the milk temperature at the doorway and in the middle of carriage is lower than the milk temperature in the innermost of carriage. So, milk should not be stacked in the innermost of carriage but loaded at the doorway and the middle of carriage; distribution time of milk should be limited to no more than 12 hours; reception time should be shorten as possible and cold chain breaking must be avoided.

- Food inventory optimization based on safety reliability

By means of safety reliability of fresh food, a food ordering model integrated with penalty function of expiration is put forward to study the ordering policies. A. The higher food safety requirement is , the shorter food ordering cycle needed. Perishables require the shortest ordering cycle under same storing condition. B. The larger food demand rate is, the shorter ordering cycle needed. Fresh food at high demand rate must take high frequency ordering rule. Yet, it is proper to prolong ordering cycle for those at low demand rate. C. The better food storing condition is the longer ordering cycle could be. As regards out-stock strategy, the safety of two rules, which are first in first out (FIFO) rule and minimum safety reliability first out(MRFO) rule, have been compared by the means of simulation. The conclusion shows that minimum safety reliability first out rule is much safer than first in first out rule.

- The safety risks assessment, controlling mechanism and fast detection technology on fresh pork supply chain

The assessing model of safety risks of FPSC has been built with interval-valued fuzzy comprehensive evaluation, and general safety risks from each link of the supply chain in China are assessed based on investigation. Then the influence degree of each risk source is also analyzed. The assessing results show that the general safety risk is moderate in pig-breeding, pig-transportation and cold storage, but relatively higher in slaughter-process and pork distribution, and very high in pork selling.

The internal controlling measures of safety risks in each link are suggested based on assessing results, as well as the internal controll of slaughter-process, pork distribution and pork selling are emphasized. Then the controlling and coordinating mechanism for the safety risks between the supply chain subjects are analyzed in terms of the static game and dynamic evolution game theory. Moreover, in terms of the cortrolling cost, linear programming and fuzzy chance-constrained programming are used to optimize the purchasing costs of fresh pork in chain supermarkets based on safety costs under the mode of supply chain.

The detection principle and application of computer vision and artifical olfaction on the controlling of safety risks of fresh pork logistics are elucidated. Then, a new kind of fast quantitative detection technology based on chromatic aberration to the logistics quality of pork is developed by experimental research. Moreover, this technology is used to detect the changes of pork quality in different logistics modes, as well as safety risks in these modes are evaluated. The results show that safety risks are higher in the logistics of warm fresh pork, while lower in the logistics of chilling pork, and more lower in the logistics of chilled pork with vacuum package. The logistics mode of low temperature is proposed to reduce the safety risks.

1.4 Achievements

National Standard

Xie Ruhe, Liu Guanghai, etc. GB/T 22918-2008. Technical requirements for temperature-controlled transportation of perishable food. 2009.8.1

Degree thesises:

1. Liu Guanghai. Study on analysis of energy consumption and optimization of refrigerated transportation equipment [Doctor Thesis]. Tutor: Xie Ruhe. Changsha: Central South University. 2007.11
2. Qiu Zhuqiang. Study on the optimization of logistics network and logistics safety for fresh agricultural products based on cold chain [Doctor Thesis]. Tutor: Xie Ruhe. Changsha: Central South University. 2007.11
3. Lin Chaopeng. Study on the safety risks and controlling of fresh pork supply chain [Doctor Thesis]. Tutor: Xie Ruhe. Changsha: Central South University. 2009.6
4. Zou Yifeng. Study on the safety reliability of food cold chain logistic [Doctor Thesis]. Tutor: Xie Ruhe. Changsha: Central South University. 2009.11
5. Huang Chengzhou. Refrigerating system simulation and experiment of temperature-controlled transportation [Master Thesis]. Tutor: Xie Ruhe. Guangzhou: Guangzhou University. 2008.6
6. Fu Wei. Study on the impact of temperature field by air supply in refrigerated containers [Master Thesis]. Tutor: Xie Ruhe. Guangzhou: Guangzhou University. 2009.6

Papers:

1. Liu Guanghai, Xie Ruhe. Simulation and experimentation on the heat status of refrigerated car. Journal of Wuhan University of Technology (Transportation Science & Engineering). 2009.8
2. Zou Yifeng, Lin Chaopeng, Fu Wei. Temperature and quality change of pasteurized milk during refrigerated distribution. Science and Technology of Food Industry. 2009.4
3. Liu Guanghai, Xie Ruhe. Study on standard system of food cold chain. Storage Transportation & Preservation of Commodities. 2009.7
4. Liu Guanghai, Xie Ruhe. Study on the status and current of refrigerated transportation unit. Guangxi Journal of Light Industry. 2009.8
5. Huang Xiangrong, Xie Ruhe. The emergent deliver decision model based on ant colony optimization algorithm and RBF neural network. Stat. and decision. 2009.8
6. Lin Chaopeng, Xie Ruhe. Study on the quality changes of fresh pork under the

logistics modes. Logistics Engineering and Management. 2009.3

7. Xiao Wenzhong, Qiu Zhuqiang, Xie Ruhe. Evaluation of the Safety of Sale Logistics of Regional Fresh Agricultural Products. Industrial Engineering Journal.2009.1
8. Liu Guanghai, Xie Ruhe. The investigation of energy consumption of refrigerated transportation based on season and class. Guangxi Journal of Light Industry. 2009.7
9. Lin Chaopeng, Xie Ruhe, Xu Xiaochun, Zhang Xianghua. Study on the attention grade about pork accommodate risk and information channel based on the research on Shaoguan. Guangdong Agricultural Sciences.2008.3
10. Chen Baoxing, Xie Ruhe, Zhu Yuancheng. Towards the fram ework and construction of food logistics Security and Safety for the 2010 Guangzhou Asian Games. Journal of Guangzhou University（Social Science Edition）.2008.1
11. Liu Guanghai, Xie Ruhe. Heat Condition and Energy Consumption Model and Experiment on Refrigerator Car. Journal of Refrigeration.2008.03
12. Lin Chaopeng, Xie Ruhe,Xu Xiaochun. Study on quality changes of fresh-cut potato during refrigerated transportation and the selection of the antistaling agents. Southwest China Journal of Agricultural Sciences. 2008.3
13. Qiu Zhuqiang, Xie Ruhe, Gui Shouping. Discussion on the control mechanism of logistics safety of fresh agriculture products. Logistics Technology.2008.9
14. Zou Yifeng, Xie Ruhe, Qiu Zhuqiang. Safety assesment of lichee cold chain logistics system based on go-flow methodology. Industrial Engineering Journal.2008.6
15. Liu Guanghai, Xie Ruhe. Study and analysis on response factor method in unsteady heat transfer of railway refrigerator car. China Railway Science. 2007.1
16. Zhao Bo, Xie Ruhe.Application framework of GIS based simulation technology in food logistics safety management. Agriculture Network Information. 2007.5
17. Qiu Zhuqiang, Xie Ruhe,Lin Chaopeng. The status analysi on safety of primary products distribution logistics in Guangzhou. Guangdong Agricultural Sciences.2007.7
18. Liu Guanghai, Xie Ruhe, Qu Ruigui. Study on outdoor high temperature parameter by Pearsorr III distribution model. Journal of Chongqing Jianzhu University. 2007.4
19. Huang Chengzhou, Xie Ruhe. Development and countermeasure of food cold

chain logistics in China. Storage Transportation & Preservation of Commodities. 2007.4

20. Zhang Yanping, Xie Ruhe, Pan Siying.On Strengthening the legislation construction of food transportation Safety Management. China Market,.2007.45
21. Foster, AM, Swain, MJ, Barrett, R, D'Agaro, P, Ketteringham, LP & James, SJ. Three-dimensional effects of an air curtain used to restrict cold room infiltration. Applied Mathematical Modelling. 2007, 31(6)
22. Xu Xiaochun, Lin Chaopeng. Study on fresh-keeping technology of fresh-cut taro in the simulation system of refrigerated transportation. Beijing: The 22nd International Congress of Refrigeration. 2007.8
23. Xie Ruhe, Liu Guanghai, Qu Ruigui. Heat balance model for refrigerated car and simulation and experimentation on the temperature field. Beijing: The 22nd International Congress of Refrigeration. 2007.8
24. Xie Ruhe, Liu Guanghai. Design and test on the simulating test-bed of refrigerated transportation condition. Beijing: The 22nd International Congress of Refrigeration. 2007.8
25. Foster, AM, Evans, JA. Advanced techniques to understand and improve open-fronted vertical refrigerated display cabinets (keynote). Beijing: The 22nd International Congress of Refrigeration. 2007.8
26. Foster, AM, Swain, MJ. & James, SJ. Two and three dimensional CFD models of the effectiveness of an air curtain used to restrict cold room infiltration (keynote). Beijing: The 22nd International Congress of Refrigeration. 2007.8
27. James, C, James, S, Vincent, C, Andrade Lima, TI & Foster, AM. Air chilling of chicken carcasses. Beijing: The 22nd International Congress of Refrigeration. 2007.8
28. James, C, Palpacelli, S, James, S & Foster, AM. Mathematically optimising the crust freezing of pork loins. Beijing: The 22nd International Congress of Refrigeration. 2007.8
29. Evans, JA, Gigiel, A, Foster, AM & Brown, T. Air cycle combined heating and cooling. Beijing: The 22nd International Congress of Refrigeration. 2007.8
30. Foster, AM, Brown, T & Evans, JA, Air cycle combined heating and cooling. Food Factory 2008, Proc. of the 4th international conference on the food factory for the future, Laval, France. 4-5 June 2008
31. Liu Guanghai, Xie Ruhe. Management and innovation of railway refrigerated

transportation in cold chain logistics. Zhengzhou: The 15th International Conference on Industrial Engineering & Engineering Management. 2008.9

32. Huang Xin, Xie Ruhe. Liu Guanghai. Analysis on Temperature Field of Refrigerated Car in Cold Chain Logistics. Zhangjiajie: 2009 International Symposium on Traffic Control and Safe. 2009.4
33. Liu Guanghai, Xie Ruhe, Qu Ruigui. Simulation and experimentation on quality and energy consumption in banana transportation. Manchester: Proceedings of Second International Conference on Modelling and Simulation. 2009.5
34. Liu Guanghai, Xie Ruhe, Qu Ruigui. Study on the consumption forecast model of perishable food distribution. Manchester: Proceedings of Second International Conference on Modelling and Simulation. 2009.5
35. Huang Xin, Xie Ruhe. The Simulation and analysis on integrated temperature used in energy consumption of refrigerated transport. Manchester: Proceedings of Second International Conference on Modelling and Simulation. 2009.5
36. Lin Chaopeng, Xie Ruhe. The quality changes and safety risks evaluation of fresh pork under the logistics modes. Tianjing: The 20th National Conference of Refrigeration, 2009.11
37. Xie Ruhe, Liu Guanghai, Huang Chengzhou. Refrigerating system simulation and experiment of temperature-controlled transportation. Tianjing: The 20th National Conference of Refrigeration, 2009.11
38. Liu Guanghai, Xie Ruhe. The analysis on infiltrated model of refrigerated transportation unit. Tianjing: The 20th National Conference of Refrigeration, 2009.11
39. Xie Ruhe, Liu Guanghai, Fu Wei. Study and simulation to the impact of temperature feld by air supply inside refrigerated container. Tianjing: The 20th National Conference of Refrigeration, 2009.11
40. Alan Foster, Xie Ruhe, Laurence Ketteringham, Andrew Gigiel, Judith Evans. Development of an empirical model of air infiltration into refrigerated multi-drop delivery vehicles. Tianjing: The 20th National Conference of Refrigeration, 2009.11
41. Liu Guanghai, Xie Ruhe, Chen Baoxing. Study on quality test method of banana during transportation. Surabaya: Proceedings of the Eastern Asia Society for Transportation Studies. 2009.11
42. Xie Ruhe, Zou Yifeng, Lin Chaopeng, Wang Lei. Temperature and quality

changes of pasteurized milk during refrigerated distribution. Surabaya: Proceedings of the Eastern Asia Society for Transportation Studies. 2009.11

43. Huang Xiangrong, Xie Ruhe, Chen Baoxing. Performance evaluation of food cold chain logistics enterprise and its application to supplier selection decision. Surabaya: Proceedings of the Eastern Asia Society for Transportation Studies. 2009.11
44. Xie Ruhe, Lin Chaopeng. Quality changes of fresh pork during logistics. Surabaya: Proceedings of the Eastern Asia Society for Transportation Studies. 2009.11

Books:

1. Foster AM. Improving performance of a chilled multi-deck retail display cabinet by CFD. In: Computational Fluid Dynamics in Food Processing. Ed. Sun DW. CRC Press 2007, Chapter 4, 103-138.
2. Foster AM. CFD optimisation of air movement through doorways in refrigerated rooms. In: Computational Fluid Dynamics in Food Processing. Ed. Sun DW. CRC Press 2007, Chapter 7, 167-194.

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2 Representative Achievement 1: Design and test on simulating test-bed of refrigerated transportation conditions

2.1 Abstract

A simulating test-bed for refrigerated transportation condition was built and consisted of two parts. The first part is for exterior environment simulation. The exterior temperature can be adjusted from -20 to 50℃, humidity from 0~100%, and velocity from 0~30m/s by control system. At the same time, these parameters can be adjusted and assembled discretionarily. Most climate conditions can be simulated by this part. The second part is a standard refrigerated container. It can adjust the location and size of the entrance and exit of cold air tunnel, change the direction and volume of air discretionarily. The interior temperature can be adjusted from -25 to 20℃, humidity from 0~100% and atmosphere components (including O_2, CO_2, N_2, C_2H_4). It can deal with many problems such as multi compartments and multi temperature systems, different goods and different loading methods, etc. Furthermore, apparatus and instruments with high precision are equipped for detecting and controlling parameters such as temperature, humidity, velocity, and atmosphere component. Biologic and chemical instruments are outfitted for analyzing and detecting the quality of samples. The test-bed has been operated for one year after debugged. The performance is good and all parameters accord with standards related.

2.2 Introduction

The higher the standard of living is, the higher the demand of quality of foods becomes. According to a statistics and estimation, the demanded volume of perishable goods transported in China is 210 million tons or more (Xie, 2003). The theory analysis and experimentation about refrigerated transportation have been researched since 1960s. The main categories as follows:

First of all, the research was focus on refrigerated food in the process of transportation, including the weight loss, the heat and mass transfer of food, the food safety and quality etc.

Next problem was how to simulate and optimize the refrigerated unit. In this category, the scholars emphasized particularly on the control of the unit temperature and humidity, the simulation and experiment of unit air distribution, and optimizing the unit from the consideration of energy conservation and food safety.

In addition, with the development of the new technology, scholars from different countries did lots of work on energy conservation, optimization design, CA device in refrigerated unit, the new substitute of the refrigerant, the design and application of the multi-stage temperature unit, refrigerated goods quality and sanitation, application of the new technology in cold chain, and so on.

Owing to the effort of scholars, the technology of the refrigerated transportation was developed rapidly. But problem exists inevitably. On one side, refrigerated transportation is a domain involving multi-subject and adopting various techniques, including mechanism manufacture, the technology of refrigeration, the technology of food processing, transportation engineering, economic and management, etc. Scholars often merely study the sub-subject; rarely research it as integration. For instance, the united control of the temperature, humidity, air distribution and air composition. On the other side, with the development of computer, larger sized soft of heat and mass transfer, flow-field analysis were applied, which had the advantage of speed, convenience, low-cost. So, more and more studies were done by the numerical calculation method instead of the experimental method. Through the numerical calculation method can elementary analyze the real circumstance of the refrigerated transportation, determine the main direction of the research, but because of the indefiniteness of the simulation parameters, the result is not so credibility. Furthermore, the research is reasonable only when study is made by combining numerical calculation and experiment. Therefore, a test-bed for simulating refrigerated transportation condition is a key and basis for further study. Its performance and precision will influence the dependability and accuracy of experiment and research.

2.3 The design of simulating test-bed

The optimization of refrigerated transportation means the optimization of parameters and control strategy in different condition. In order to meet this goal, the performance and indices of the test-bed must be designed reasonably.

2.3.1 Simulation of exterior environment

The temperature of exterior insulated layer is changed with time and place when refrigerated transportation unit (RTU) is running. The quantity of heat conducted into the unit through insulated layer will influence the temperature of perishable goods. This is a key factor for designing refrigerated system. In order to simulate the change of exterior environment temperature, an insulated room is built. The air temperature inside the room can be adjusted from -20 to 50□ by controlling refrigeration and heat equipment.

The airflow velocity is for simulating the running speed of RTU. It influences temperature distribution, energy consumption and atmosphere component inside the unit. Six big fans (45kW each) installed in front of RTU can provide airflow with velocity of 0~30m/s by controlling the frequency conversion.

2.3.2 Simulation of the RTU

- Size

RTU is the basis of refrigerated transportation. Small scale simulation may reflect refrigerated transportation condition in some extent. But a big warp is inevitable. In order to guarantee the dependability and accuracy of experiment, the size of RTU is designed as same as a 20 feet refrigerated container (6058mm×2438mm×2590mm). The temperature, humidity, atmosphere component, multi temperature and multi compartments system can be controlled and studied in this RTU. And the change of parameters can really recur.

- Design of multi-temperature and multi-compartment system

Insulated clapboard can divide the interior space into two parts with different size. This clapboard can be taken off. Two cooling systems are installed on both sides of the clapboard. So, the two partial spaces can run independently with different temperature at the same time.

- Control of temperature, humidity and atmosphere components

Heating, cooling and humidity adjusting apparatus are equipped. The interior temperature can be changed from -25 to 20□ and humidity can be changed from 0 to 100%. The concentration of N_2, O_2, and CO_2 can be inspected, recorded and adjusted; the concentration of ethylene can be controlled from 0 to 100ppm.

- Design of airflow

The design of airflow includes two aspects. The first is the airflow entrance and exit position. Many entrance and exit position are placed in the unit and controlled by valve. The position can be adjusted, taken off and moved. The second is airflow velocity and direction. The velocity is adjusted according to the fan’s frequency conversion (the volume of airflow can be changed from 0 to $2m^3/s$) and the dimension of entrance. The direction of airflow is changed by flow deflector.

- Inspecting system

The inspecting system of test-bed includes temperature and humidity sensors, anemoscope, atmosphere component detector, manometer, vidicon shoot, etc. There are

50 sensors of temperature, 10 of these are fixed and 40 are removable. These sensors are linked to computer with standard RS-485 serial interface. Data can be displayed and recorded every one second. The anemoscope includes several velocity sensors and portable anemoscope. Interior atmosphere components detector can measure the concentration of N_2, O_2, CO_2 and C_2H_4 simultaneously at any time. The data can be displayed, saved and printed. Manometer and vidicon give can monitor the state and process of experiment. Instruments such as torrefaction fan, saccharimeter, and acidity meter are outfitted for analyzing and detecting the quality of samples.

The layout of simulating test-bed for refrigerated transportation condition is shown as figure 2-1.

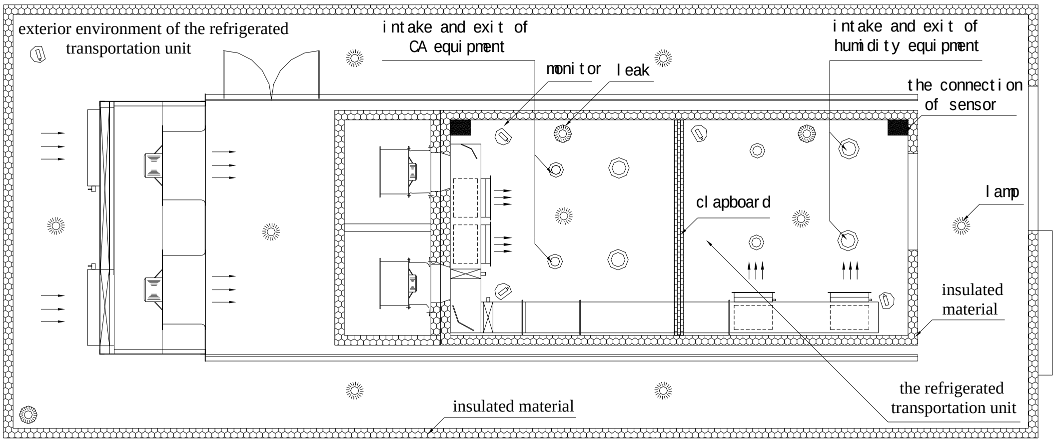

Fig. 2-1 The simulating test-bed of refrigerated transportation condition

2.4 Performance test

2.4.1 Standards and items of test

Three related standards are implemented. They are ISO1496-2 (Series 1 container — specification and test — part 2: thermal container), GB7392 (Thermal container --- specification and test) and ATP Agreement (Agreement on the international carriage of perishable foodstuffs and on the special equipment to be used for such carriage). Comprehensive and strict testing to the test-bed must be carried out. The performance test to RTU includes air tightness, heat leaking, cooling distribution and variation of temperature and humidity testing. The above standards are used for references and criterion (Chatzidakis and Rouvas, 2003; Liu, 2000; Chatzidakis and Chatzidaki, 2005; Moureh and Flick, 2004; Liu, 1998). Each sensor is calibrated (the precision of temperature sensor is ±0.15□, that of humidity sensor is ±0.3%, that of velocity sensor is ±0.3m/s, that of press difference sensor is ±0.5%, that of air flowmeter and wattmeter is

±1%).

2.4.2 Air tightness test for the test-bed

Test system for air tightness is shown in figure 2-2. The air leakage of this test-bed is between 3.6m3/h to 3.9m3/h less than 16m3/h of standard for 20' refrigerated container, so the air tightness of the test-bed is eligible.

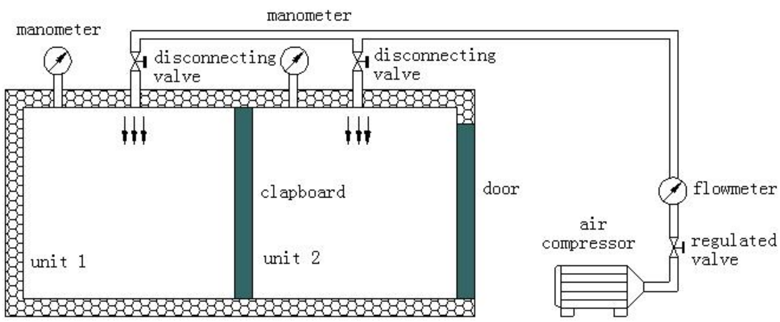

Fig. 2-2 Test system for air tightness

2.4.3 Heat leak test

There are two methods for heat leak test, i.e., cold-source and heat-source method. In this test, heat source method is used.

The coefficient (K) of thermal conduction and thermal leakage (L) can be calculated according to temperature difference and power consumption. The coefficient of thermal conduction is $0.32 W \cdot m^{-2} \cdot K^{-1}$ less than $0.47 W \cdot m^{-2} \cdot K^{-1}$ of standard and thermal leakage is $26 W \cdot K^{-1}$ equal to $26 W \cdot K^{-1}$ of standard. The curve of test is shown as figure 2-3 and figure 2-4.

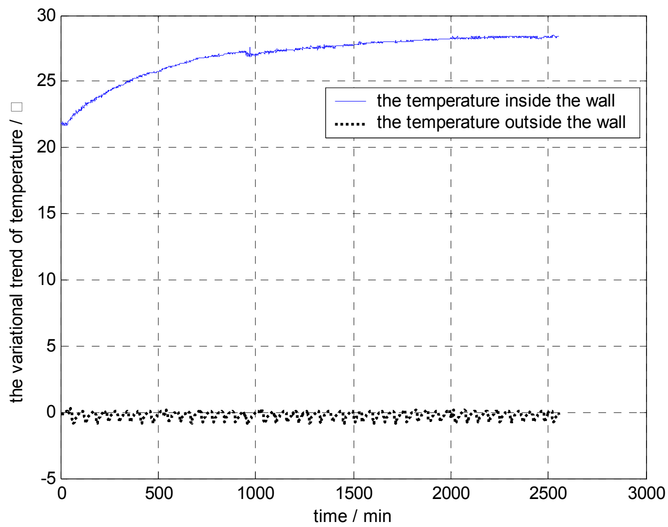

Fig. 2-3 Curve of temperature in the interior wall surface

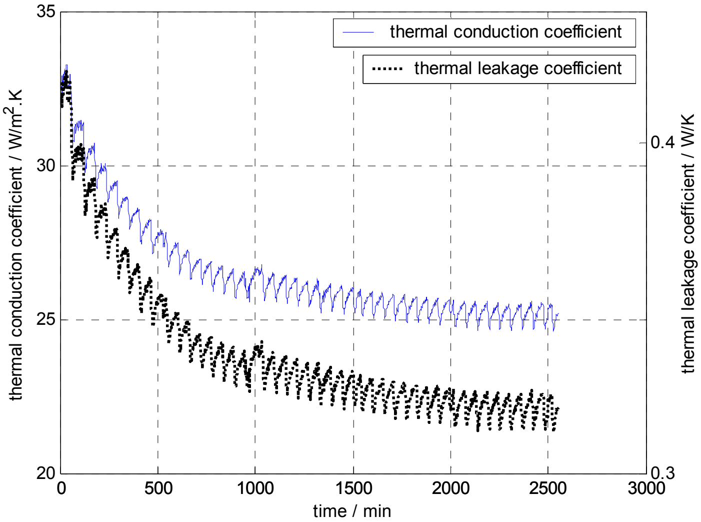

Fig. 2-4 Curve of *K* and *L*

2.4.4 Temperature test

The temperature of exterior ambient of RTU can be dropped from 50℃ to -20℃ slowly and steadily. The curve is shown as figure 2-5. Temperature of interior ambient of RTU is controlled while the temperature of exterior environment is set at 38℃. The temperature fluctuant range can be controlled from ±0.1 to ±5K to reflect the influence of different condition to the quality of perishable goods. Figure 2-6 shows that the difference of temperature is less than 2K in different position at the same time; it is less than ±1.5K in the same position at different time.

2.4.5 Velocity test

The velocity of wind in 7 positions of exterior environment is tested. The velocity is adjusted by changing frequency of fans. The maximum velocity can reach up to 30m/s and the difference of velocity is less than 5% in different position at same frequency. The velocity of airflow of interior ambient can be changed from 0 to 10m/s and the difference of velocity is less than 5% in different entrance at same frequency. These are shown as in figure 2-8.

2.4.6 Other tests

Such as humidity, atmosphere components, multi compartments and multi temperature systems, etc. are tested one by one. The results show that every parameter is eligible.

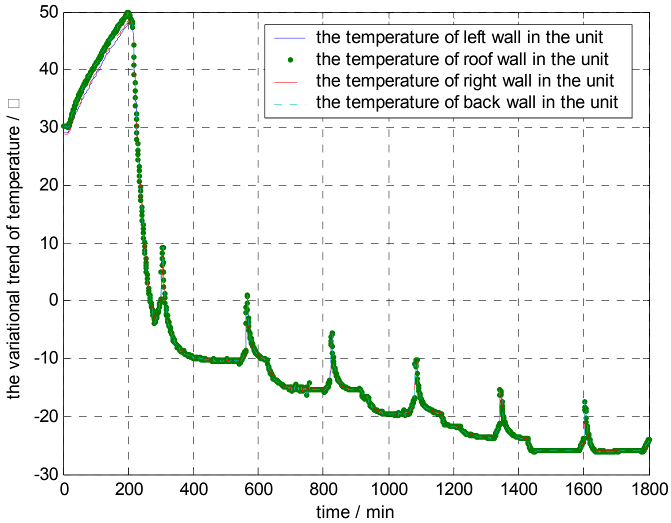

Fig. 2-5 Temperature of exterior environment

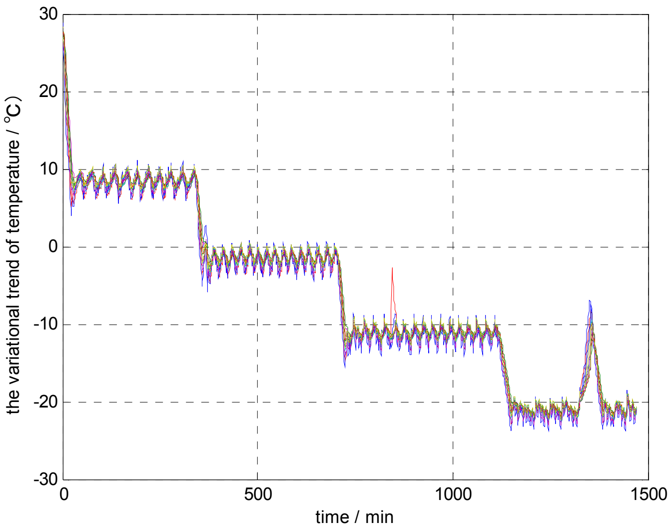

Fig. 2-6 Temperature of interior ambient

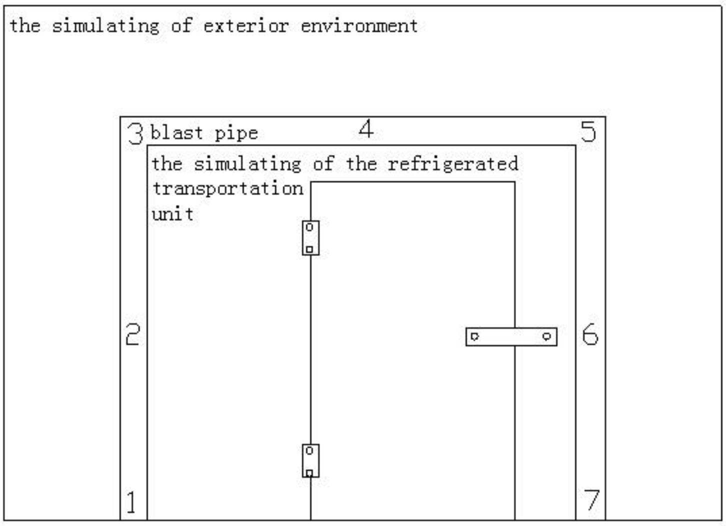

Fig. 2-7 Distribution of measuring positions of wind velocity of exterior environment

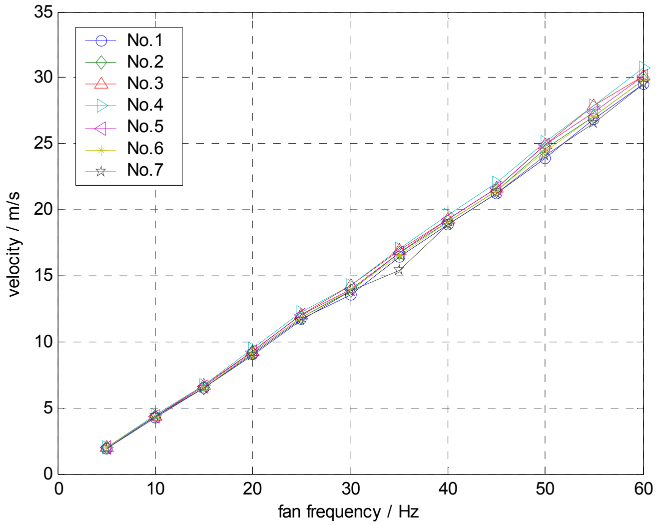

Fig. 2-8 Velocity of wind at different frequency of fan

2.5 Conclusion

The simulating test-bed of refrigerated transportation condition was designed by the Research Center for Logistics & Transportation of Guangzhou University. IIts whole indexes can meet the requirements of standards related (such as ISO1496-2, GB7392 and ATP agreement).

In virtue of the simulating test-bed for refrigerated transportation condition, the repeatability, maneuverability and accuracy of the experiment can be enhanced, and the experimental time and cost can be saved.

The factor affected the technical condition of the refrigerated transportation, for example, thermal status outside the vehicle, radiation, vehicle velocity, the thermal characteristics of vehicle, air infiltration, ventilation, the distribution of vehicle temperature and humidity, air distribution, forms of goods stack, packaging methods, pre-cooling time, etc, can be researched entirely on this test-bed.

Being designed, built and tested for more than one year, the performance index of this test-bed achieves the design requirement, offer a technology platform for the comprehensive research of refrigerated transportation, and will be made use of in the area of optimization design transportation equipment and food transportation safety, etc.

2.6 References

[1] Xie Ruhe, Wang Jun, Luo Rongwu, etc. Analysis of the market demands for the refrigeration

transport of the perishable goods. Railway Freight Transport. 2003, (1): 18~20
[2] Xie Ruhe, Hu Siji. Research on the problem of weight loss of perishable goods in refrigerated transportation. The 20th international congress of refrigeration, Sydney, Australia. 1999
[3] C.P. Tso , S.C.M. Yu , H.J. Poha, P.G. Jolly. Experimental study on the heat and mass transfer characteristics in a refrigerated truck. International Journal of Refrigeration, 2002 (25):340-350
[4] AntonõÂ n Ryska, Filip KraÂ, JirõÂ Ota. Method of determination of the active capacity of refrigeration and A/C units of variable speeds. International Journal of Refrigeration, 2000 (23):402-405
[5] Stephen W.T. Spence, W. John Doran, David W. Artt. Design, construction and testing of an air-cycle refrigeration system for road transport. International Journal of Refrigeration, 2004 (27):503–510
[6] Jean Moureh, Denis Flickb. Wall air–jet characteristics and airflow patterns within a slot ventilated enclosure. International Journal of Thermal Sciences, 2003 (42):703–711
[7] David J. Forkenbrock. Comparison of external costs of rail and truck freight transportation. Transportation Research Part A, 2001 (35):321-337
[8] Paul Spoonley. Technological and social changes into the third millennium and the impact on refrigeration. International Journal of Refrigeration, 2001 (24):593-601
[9] C.P. Tso, S.C.M. Yu, H.J. Poh, P.G. Jolly. Experimental study on the heat and mass transfer characteristics in a refrigerated truck. International Journal of Refrigeration, 2002 (25):340–350
[10] Londahl,G. How to maintain a sufficiently low temperature in frozen food distri -bution. Proceedings IIF. IIR commissions C1 and C2, Karlsruhe (West Germany). 1977
[11] Scott EP, Heldman DR. Prediction of frozen food quality during fluctuation temperature storage. ASAE paper No. 84-6570, 1984
[12] Dolan KD, Singh P, Heldman DR. Prediction of temperature in frozen foods exposed to solar radiation. Journal of Food Processing and Preservation, 1987 (11)
[13] Sergio, F.Almonacid-Merino, Antonio Torres. Mathematical models to evaluate temperature abuse effects during distribution of refrigerated solid foods. Journal of Food Engineering, 1993
[14] Oskam NA, Sillekens JJM, Ceton C. Validated models of the thermodynamic behaviour of perishables during flight. IIF-IIR-D1, D2/3 Cambridge(UK), 1998
[15] Eric Granryd. Hydrocarbons as refrigerants --- an overview. International Journal of Refrigeration, 1999
[16] Kidd F, West C A. Relation between the concentration of oxygen and carbon dioxide in the atmosphere, rate od respiration and length of storage of apples. Food Invention Board Report. London. 1927.

[17] Xie Ruhe, Liu Guanghai. Design and study on test-bed of refrigerated transportation. Kunming: The 18th National Conference of Refrigeration, 2005: 677~681

[18] ISO 1492-2. Series 1 container --- specification and testing --- part 2: thermal container

[19] GB 7392. Thermal container --- specification and testing

[20] ATP Agreement. Agreement on the international carriage of perishable foodstuffs and on the special equipment to be used for such carriage

[21] IIR. Basic Test Procedures for the Testing of Vehicles Freight Containers and Rail-Cars for the Transport of Perishable Products (BTP). IIR Bulletin 78-1039, 78-1733, 79-2074

[22] Chatzidakis S, Rouvas A, Chatzidakis K. Uncertainty and ATP tests—an approach for the calculation procedure of the k-value estimation. Report No. ATPTSM-2003, Austria, 2003

[23] Commission of the European Communities. Intercomparison of the determination of the k-coefficient of an insulated container as carried out by eleven European test stations. Report No. EUR 13285, Luxemburg, 1991

[24] Liu Xunhai. Development of thermal performance test facilities for refrigerated containers. J. University of Shanghai for Science and Technology. 2000, 22(4): 356~359

[25] Chatzidakis S, Chatzidakis K. A heat transfer simulation study of a multi-compartment isothermal liquid foodstuff tank tested according to the international ATP agreement. Energy Conversion and Management. 2005, 46(2): 197~221

[26] Moureh J, Flick D. Airflow pattern and temperature distribution in a typical refrigerated truck configuration loaded with pallets [J]. International Journal of Refrigeration. 2004, 27: 464~474

[27] Liu Dingming. International container and the standard. Beijing: People's Transportation Press. 1998, 225~229

3 Representative Achievement 2: The Model of Thermal Characteristic of Refrigerated Car

3.1 Abstract

This paper analyzed the simulating ways about heat system, such as heat balance model (HBM), weight factor model (WFM). HBM was chose as the analyzed tool of heat system. An analytic system was set up for simulating the heat condition and energy consumption of refrigerated car. The system includes climate model outdoors, heat transfer model of the insulated layer, exterior and interior surface heat balance model of insulated layer, heat balance model of the air in the vehicle, etc. Then, a real refrigerated car was simulated and analyzed from Beijing to Guangzhou, and verified by a real data of refrigerated car from Lianjiang (Guangdong Province) to Wulumuqi (Xinjiang Province). The results obtained from the model show good consistency with the experimental data. The model properly reflects the heat condition of car and provides a basis for holistic evaluation and optimum controlling on refrigerated car.

3.2 Introduction

Refrigerated transportation is a key of Cold-Chain. Condign transport condition is the basis for ensuring quality of perishable goods such as meat, fish, fruit, vegetable, egg, milk, etc. It also plays an important role for saving food resource, keeping food nutrition value, increasing sale income and decreasing energy consumption (Xie, et al., 2002). But the perishable foods would deteroprate or lose weight because of improper controlling in transportated condition. Solving the problem depends on proper simulation and analysis on transportated condition. This paper should focus on this question from the view of thermal characteristic.

3.3 The Choice of Analytic System

It is important to choose condign analytic method for improving the reliability and authenticity of the research. But correlative works are lack on refrigerated transportation. At the same time, the researches on thermal characteristic simulation and energy analysis of buildings have been increased rapidly since the second energy crisis in 1970s. The analytic method of thermal system such as heat balance model (HBM) and weight factor model (WFM) were used all over the world (Sowell and Hittle, 1995). Refrigerated transportation unit (RTU) can be seen as a moving building, so those methods would be used for reference in these researches (Tso, et al., 2002).

- The HBM is better than WFM in simulating the thermal condition of RTU accurately by analyzing both advantage and disadvantages of the models. The reasons are as follows.
- The accuracy of HBM is better than WFM, but the calculating time of HBM is longer than WFM. The problem of calculating time is solved by the development of computer technology step by step at present (Comini, et al., 1995).

The source of WFM is HBM. We can get weight factor of buildings, but the weight factor of RTU is unbeknown. So the accuracy of WFM is difficult to ensure.

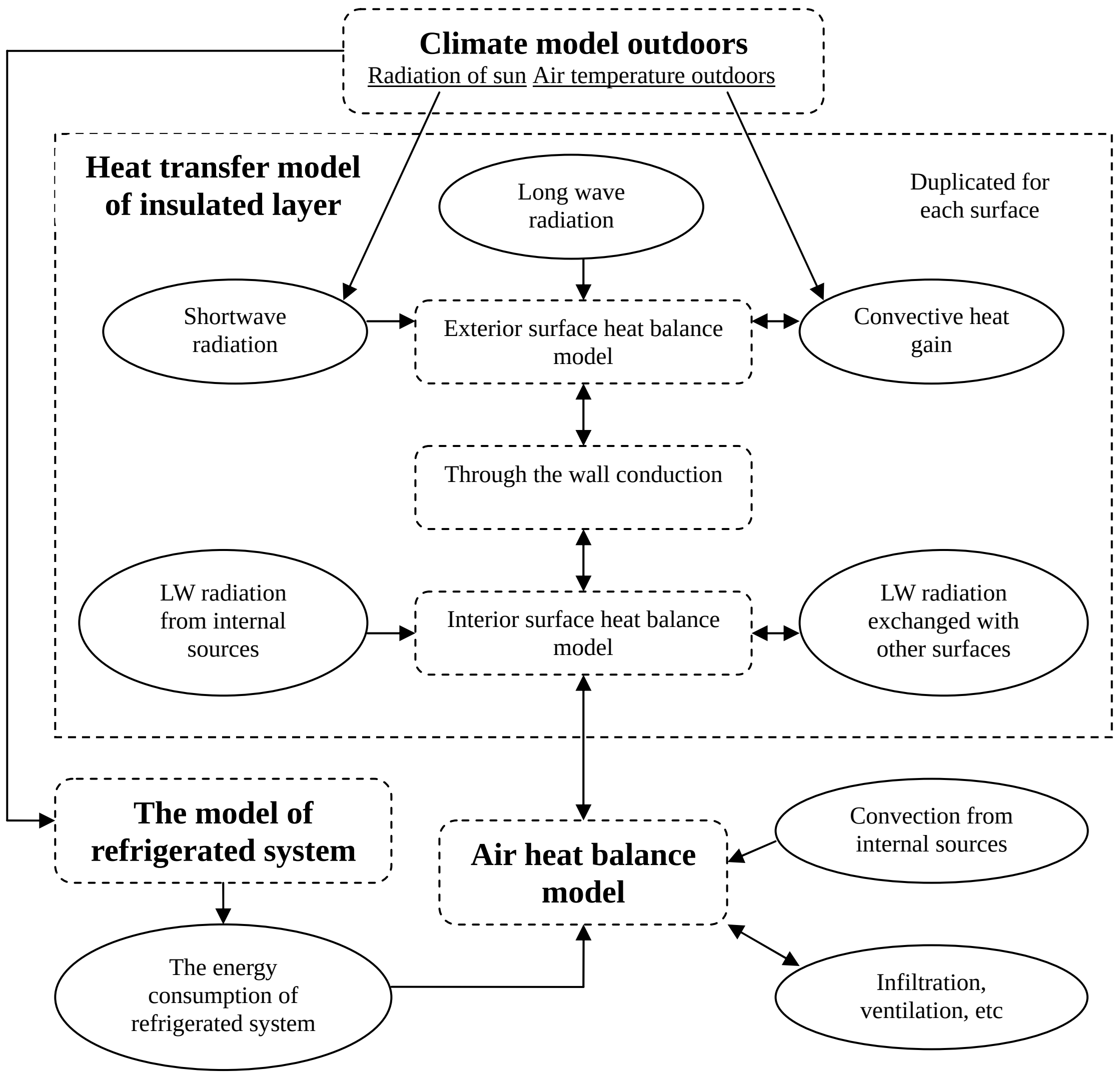

Fig 2-1. Schematic of heat balance processes in RTU

A system was set up for simulating the heat condition and energy consumption of railway refrigerated car when running by consulting the research productions all over the world (Pedersen, et al. 1997). The key parameters were conducted, which include the climate model outdoors, heat transfer model of the insulated layer (exterior and interior surface heat balance model, through insulated layer conduction), heat balance model of the air in the car, etc. These are shown in figure 3-1.

3.4 Mathematical Description of Heat Balance Model

3.4.1 The climate model outdoors

The climate data in air-conditioned building is a time series data because the building is static. But the climate data in RTU is a time-space series data for its running. So, the mathematical expression can be shown as follow (Liu and Xie, 2006).

$$t_e(\tau, x) = t_w(x) + \alpha_t(\tau) \cdot \Delta t(x) + \frac{\rho I_t(\tau, x)}{\alpha_w} - \frac{\zeta \Delta R}{\alpha_w}$$

Where, t_e is sol-air temperature, K; t_w is outdoor dry-bulb temperature, K; $\alpha_t(\tau)$ is module-scale coefficient; Δt is daily range, K; ρ is absorptance of exterior surface for shortwave solar radiation; I_t is total shortwave solar radiation flux incident on exterior surface of RTU, W·m^{-2}; ζ is long wave radiation coefficient of exterior surface; ΔR is exchange value of long wave radiation flux between exterior surface of RTU and sky, W·m^{-2}; x is variable of space, km; τ is variable of time, h; α_w is the convective heat transfer coefficient, W·m^{-2}·K^{-1}.

3.4.2 The exterior surface heat balance model

With some basic assumptions (ASHRAE, 2003), the heat balance on the exterior surface of an exterior insulated layer may be written as:

$$q_{ko} + q_{\alpha sol} + q_{conv} + q_{LWR} = 0$$

Where, q_{ko} is total heat flux conducted out of the exterior insulated layer surface, W·m^{-2}; $q_{\alpha sol}$ is absorbed direct, reflected and diffuse solar radiation flux, W·m^{-2}; q_{conv} is convective heat loss or gain from exterior air, W·m^{-2}; q_{LWR} is net long wave radiation exchange with the environment, W·m^{-2}.

Breaking these terms into individual components, the shortwave portion of the balance becomes:

$$q_{\alpha sol} = \alpha I_t$$

Where, α is absorpatance of exterior surface for shortwave solar radiation; I_t is total shortwave solar radiation flux incident on exterior surface of RTU, W·m^{-2}.

The convection term is:

$$q_{conv} = h_c(T_0 - T_{so})$$

Where, h_c is convective heat transfer coefficient, W·m^{-2}·K^{-1}; T_0 is outdoor dry-bulb temperature, K; T_{so} is exterior surface temperature, K.

The long wave portion of the balance may be written as:

$$q_{LWR} = \varepsilon\sigma[F_a(T_0{}^4 - T_{so}{}^4) + F_{sky}(T_{sky}{}^4 - T_{so}{}^4) + F_g(T_g{}^4 - T_{so}{}^4)]$$

Where, ε is long wave emittance of the exterior surface; σ_b is Stefan-Boltzmann constant, $\sigma_b = 5.67\times10^{-8}$ W·m^{-2}·K^{-4}; F_a is view factor of exterior surface to air temperature, K; F_{sky} is view factor of exterior surface to sky temperature, K; F_g is view factor of exterior insulated layer surface to ground surface temperature, K; T_{sky} is sky temperature, K; T_g is ground surface temperature, K.

Combining these equations into equation 2, the heat balance on the exterior surface of a RTU may be written as:

$$q_{ko} = h_c(T_{so} - T_0) + \varepsilon\sigma[F_a(T_{so}{}^4 - T_0{}^4) + F_{sky}(T_{so}{}^4 - T_{sky}{}^4) + F_g(T_{so}{}^4 - T_g{}^4)] - \alpha I_t$$

Noting that the view factors must equal one, the following algebraic manipulation may be performed:

$$q_{ko} = [\frac{\varepsilon\sigma(T_0{}^4 - T_{so}{}^4)}{T_0 - T_{so}}](T_{so} - T_0) + \varepsilon\sigma[F_{sky}(T_0{}^4 - T_{sky}{}^4) + F_g(T_0{}^4 - T_g{}^4) - h_c] - \alpha I_t$$

By equation 2 and 7, we can see that solving heat balance equation on exterior surface is to calculate $q_{\alpha sol}$, q_{conv} and q_{LWR} at first, and calculating $q_{\alpha sol}$, q_{conv} and q_{LWR} is equal to calculate parameters such as I_t, h_c, T_0, T_{sky}, T_g, F_{sky} and F_g, etc (McClellan and Pedersen, 1997).

3.4.3 The interior surface heat balance model

The heat balance on interior surface of an exterior insulated layer may be written as (Liesen and Pedersen, 1997):

$$q_{kin} + q_{LWX} + q_{LWS} + q_{conv} = 0$$

Where, q_{kin} is conduction flux through the insulated layer, W/m^{-2}; q_{LWX} is net long wave radiation exchange flux between surfaces, W·m^{-2}; q_{LWS} is long wave radiation flux from internal sources such as goods and equipment, etc, W·m^{-2}; q_{conv} is convective heat flux to zone air, W·m^{-2}.

Breaking these terms into their individual components by the same principle, the shortwave portion of the balance becomes:

$$q_i(n) + \alpha_i^c[t_r(n) - t_i(n)] + \sum_{k=1}^{N_i} C_b\varepsilon_{ik}\varphi_{ik}[(\frac{T_k(n)}{100})^4 - (\frac{T_i(n)}{100})^4] + q_i^r(n) = 0$$

Where, $t_r(n)$ is temperature in the RTU, K; $t_i(n)$ and $t_k(n)$ is temperature of the i

and k interior insulated layer surface, K; α_i^c is convective heat transfer coefficient of the i interior insulated layer surface, W·m^{-2}·K^{-1}; C_b is black body constants, $C_b = 5.67\times10^{-8}$ W·m^{-2}·K^{-4}; ε_{ik} is systematical blackening between i and k interior insulated layer surface, the value is product of blackening of i and k interior insulated layer surface, $\varepsilon_{ik} = \varepsilon_i \varepsilon_k$; φ_{ik} is radiant view of factor of i interior insulated layer surface to k interior insulated layer surface; N_i is numbers of interior insulated layer surface of RTU; $q_i(n)$ is conduction flux of i interior insulated layer surface, W·m^{-2}; $q_i^r(n)$ is radiation flux of i interior insulated layer surface from internal sources, W·m^{-2}. A heat balance equation can be written as equation 10. In this equation, i means number of RTU's interior surface, i = 1, 2, 3, 4, 5, 6. 1 means the top insulated layer, 2 means the floor, 3~6 mean the east, west, front and rear insulated layer.

$$AT_i(n) = B$$

$$T_i(n) = [t_1(n), t_2(n), t_3(n), t_4(n), t_5(n), t_6(n)]$$

$$A=\begin{bmatrix} -[\alpha_1+Z_1(0)] & \alpha_{1,2}^r & \alpha_{1,3}^r & \alpha_{1,4}^r & \alpha_{1,5}^r & \alpha_{1,6}^r \\ \alpha_{2,1}^r & -[\alpha_2+Z_2(0)] & \alpha_{2,3}^r & \alpha_{2,4}^r & \alpha_{2,5}^r & \alpha_{2,6}^r \\ \alpha_{3,1}^r & \alpha_{3,2}^r & -[\alpha_3+Z_3(0)] & \alpha_{3,4}^r & \alpha_{3,5}^r & \alpha_{3,6}^r \\ \alpha_{4,1}^r & \alpha_{4,2}^r & \alpha_{4,3}^r & -[\alpha_4+Z_4(0)] & \alpha_{4,5}^r & \alpha_{4,6}^r \\ \alpha_{5,1}^r & \alpha_{5,2}^r & \alpha_{5,3}^r & \alpha_{5,4}^r & -[\alpha_5+Z_5(0)] & [\alpha_{5,6}^r+Y_5(0)] \\ \alpha_{6,1}^r & \alpha_{6,2}^r & \alpha_{6,3}^r & \alpha_{6,4}^r & [\alpha_{6,5}^r+Y_6(0)] & -[\alpha_6+Z_6(0)] \end{bmatrix}$$

$$B=\begin{bmatrix} -\sum_{j=0}^{N_s} Y_1(j)t_{Z1}(n-j)+\sum_{j=1}^{N_s} Z_1(j)t_1(n-j)-\alpha_1^c t_r \\ -\sum_{j=0}^{N_s} Y_2(j)t_{Z2}(n-j)+\sum_{j=1}^{N_s} Z_2(j)t_2(n-j)-\alpha_2^c t_r \\ -\sum_{j=0}^{N_s} Y_3(j)t_{Z3}(n-j)+\sum_{j=1}^{N_s} Z_3(j)t_3(n-j)-\alpha_3^c t_r \\ -\sum_{j=0}^{N_s} Y_4(j)t_{Z4}(n-j)+\sum_{j=1}^{N_s} Z_4(j)t_4(n-j)-\alpha_4^c t_r \\ -\sum_{j=0}^{N_s} Y_5(j)t_6(n-j)+\sum_{j=1}^{N_s} Z_5(j)t_5(n-j)-\alpha_5^c t_r \\ -\sum_{j=0}^{N_s} Y_6(j)t_5(n-j)+\sum_{j=1}^{N_s} Z_6(j)t_6(n-j)-\alpha_6^c t_r \end{bmatrix}$$

Where, A is coefficient matrix, it depends on the heat transfer performance of the insulated layer of RTU; B is constraint matrix, it lies on its performance and environment's heat condition; $T_i(n)$ is temperature vectors of interior insulated layer surface n.

The temperature of interior insulated layer surface at any time can be calculated by solving follow matrix:

$$T_i(n) = A^{-1}B$$

3.4.4 The insulated layer heat conduction model

There are probably more ways to formulate the insulated layer conduction process than any of the other processes. Among the possible ways for simulating this process are numerical finite difference, numerical finite element, transform methods and time series methods.

The heat conduction calculation of insulated layer includes temperature calculation and heat flux calculation. So, the solution technique must be able to deal with the simultaneous condition. From the view of computational method, two popular methods are finite difference procedure and time series method using conduction transfer function. Because of the advantage of less calculating time, the method of conduction transfer function formulation was selected for the heat balance procedure (Liu and Xie, 2007). The general expression is:

$$\left.\begin{aligned} X(0) &= K + \sum_{i=1}^{\infty} \frac{A_i}{\Delta\tau}(1 - e^{-a_i\Delta\tau}) & j = 0 \\ X(j) &= -\sum_{i=1}^{\infty} \frac{A_i}{\Delta\tau}(1 - e^{-a_i\Delta\tau})^2 e^{-(j-1)a_i\Delta\tau} & j \geq 1 \end{aligned}\right\}$$

$$\left.\begin{aligned} Y(0) &= K + \sum_{i=1}^{\infty} \frac{B_i}{\Delta\tau}(1 - e^{-a_i\Delta\tau}) & j = 0 \\ Y(j) &= -\sum_{i=1}^{\infty} \frac{B_i}{\Delta\tau}(1 - e^{-a_i\Delta\tau})^2 e^{-(j-1)a_i\Delta\tau} & j \geq 1 \end{aligned}\right\}$$

$$\left.\begin{aligned} Z(0) &= K + \sum_{i=1}^{\infty} \frac{C_i}{\Delta\tau}(1 - e^{-a_i\Delta\tau}) & j = 0 \\ Z(j) &= -\sum_{i=1}^{\infty} \frac{C_i}{\Delta\tau}(1 - e^{-a_i\Delta\tau})^2 e^{-(j-1)a_i\Delta\tau} & j \geq 1 \end{aligned}\right\}$$

Where, K is conduction coefficient, W·m-2·K-1; i is number of equation root; a_i is i root of $B(s) = 0$; $\Delta\tau$ is distant time, h; A_i, B_i, C_i is coefficient; $X(j)$ is exterior conduction transfer function; $Y(j)$ is cross conduction transfer function; $Z(j)$ is the interior conduction transfer function.

3.4.5 The performance model of refrigerated system

The performance of refrigerated system in RTU is changed with the change of climate and load. It can be gained through performance curve when the system is certain.

3.4.6 Air heat balance model

In heat balance formulations aimed at determining cooling loads, the capacitance of air in RTU is neglected and air heat balance is regard as a quasi-steady balance in each time interval. The mathematical expression can be shown as below (Crandall and Sieber, 1996):

$$q_{add} = q_{CE} + q_{IV} + q_{VE} + \sum q_{conv} + q_R$$

Where, q_{CE} is the convective part of internal loads, W; q_{IV} is load due to infiltration air, W; q_{VE} is load due to ventilation air, W; $\sum q_{conv}$ is convection heat transfer from surfaces, W; q_R is heat transfer to/from refrigerated system, W; q_{add} is the quantity of heat to/from air, W.

In the end, the heat condition of RTU can be obtained by calculating these mathematical models (ASHRAE, 2003).

3.5 The Simulation and Experimentation of Heat Condition of RTU

3.5.1 The simulation on heat condition of RTU

A refrigerated car of B23 type was simulated and analyzed from Beijing to Guangzhou on July 21st by the model on the assumption that he temperature in the car was 0℃ and the refrigerated system met the need of load all the time. Then the temperature field distribution of interior surfaces would be shown as figure 2-2 to figure 2-6. The fluctuation of temperature of interior surfaces depends on the temperature of the exterior surface, the conduction performance of the insulated layer, etc. For the refrigerated car of B23 type, the heat insulation performance of roof is much better than other insulated layers and that of 4 side insulated layers is little better than that of floor. The fact can be seen from the figures that the temperature on roof is the lowest though the disturbance is the strongest, but the temperature on floor is higher though the disturbance is the least. The temperature on east and west side insulated layers are higher than those on front and rear insulated layers because the difference of disturbance.

3.5.2 The experimentation

To validate the correctness of model, the simulated result was compared with test data. In this experiment, a refrigerated railway car (No.7060135) loaded with banana from Lianjiang(Guangdong Province) to Wulumuqi(Xinjiang Province) was chosen as the test object. The inner temperature is set to 13□ and kept by heat insulating, single & double set refrigerating or ventilating. The temperature data from simulation to east and west insulated layer surface were compared with those from experiment. The results and rules were accordant with the whole. The difference was from two sides. On the one hand, the cloudage and latitude were hard to simulated accurately; on the other hand, the temperature was different in different place because of the different velocity, ventilation mode, the packing of goods, etc. So, the difference was inevitable. But the result was acceptable.

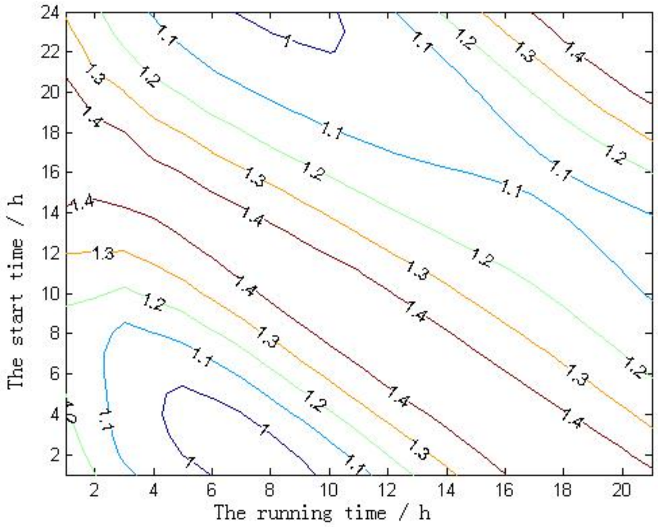

Fig 3-2. The temperature field on roof of B23

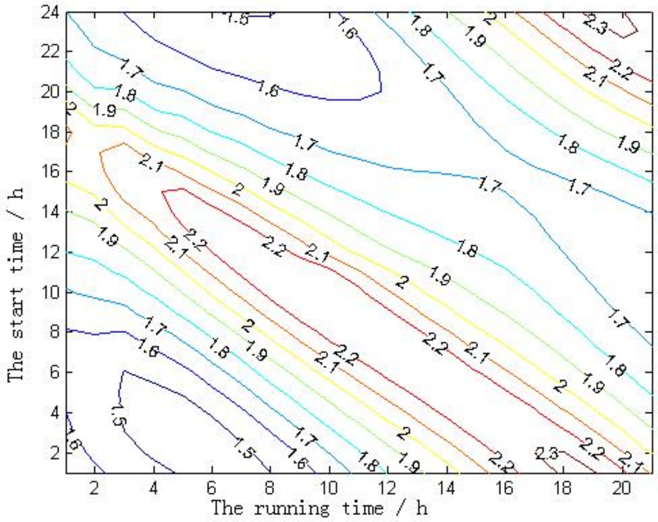

Fig 3-3. The temperature field on floor of B23

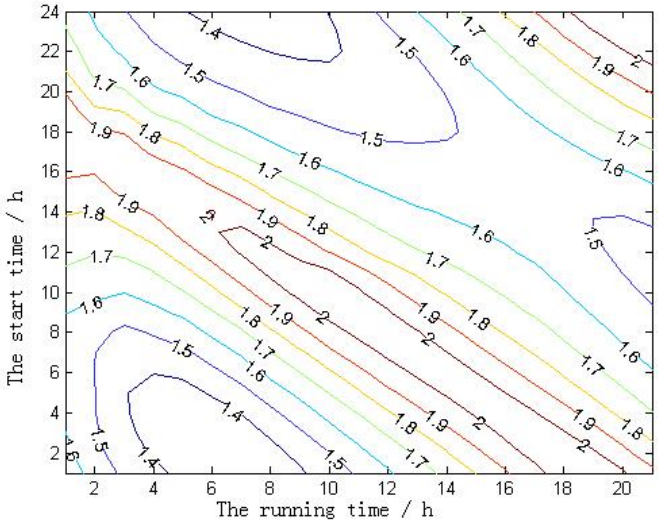

Fig 3-4. The temperature field on east insulated layer of B23

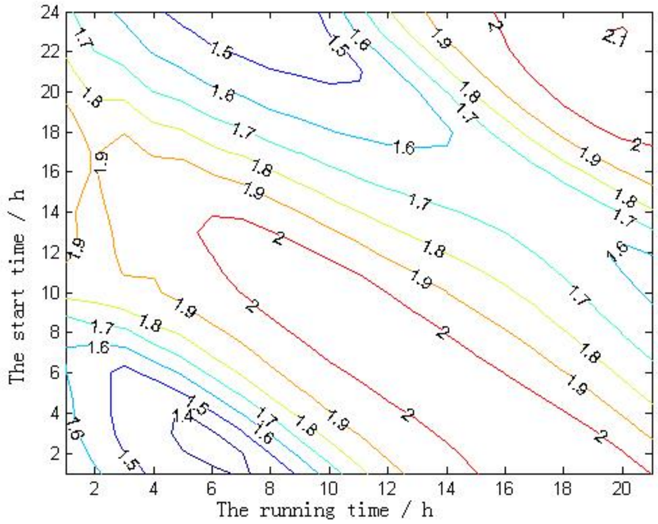

Fig 3-5. The temperature field on west insulated layer of B23

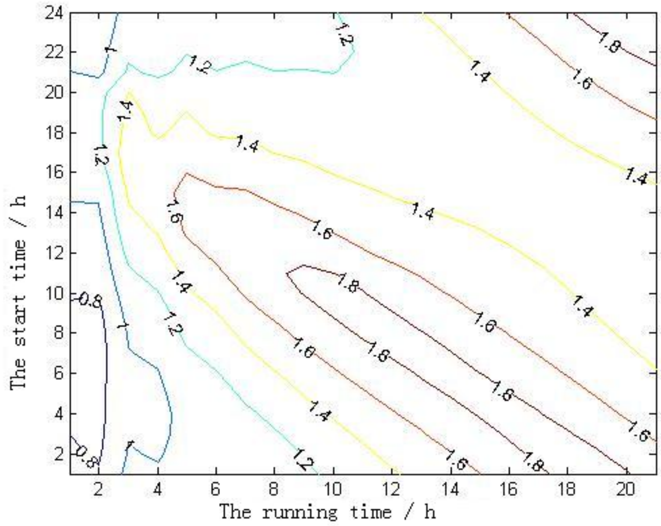

Fig 3-6. Temperature field on front and rear insulated layers

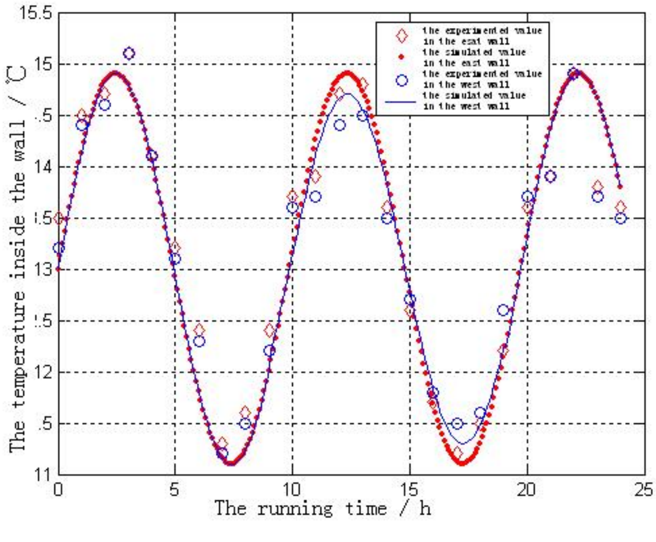

Fig 3-7. Comparison between simulation and experiment temperature

3.6 conclusions

Aiming at the refrigerated train specific characteristics, research indicated the heat balance method is more convenient in the simulation of the train thermal situation on the basis of the analysis of the present situation all over the world. On one side, this method analyzed the unsteady heat transfer between the insulated layers in non-linear weather condition outside the transported equipment. On the other side, owing to the development of the computer, especially the application of the mainframe computer, the problem of calculating time is solving step by step.

A system was set up for simulating the heat condition and energy consumption of refrigerated car when running by consulting the research productions all over the world. The key parameters were conducted, which include the climate model outdoors, heat transfer model of the insulated layer (exterior and interior surface heat balance model, through insulated layer conduction), heat balance model of the air in the vehicle, etc. The real heat condition of RTU was simulated by heat balance model. It provided a good description of real thermal condition of railway refrigerated car and was validated by experimentation.

By contrasting the simulation and experiment of mechanical refrigerator car in Jingguang line, it was considered that the simulation result was in good agreement with the experiment. With the analysis, the temperature hourly change of the internal surface is relative to not only the temperature outside surface but also the heat conduction capability of the insulated layers and the thermal inertia, etc. For the B23 type mechanical refrigerator car, the roof’s thermal insulation is better than others. The bottom is reversal and need to be improved. The other transported condition can be determined by the same way.

3.7 References

[1] Xie Ruhe, Luo Rongwu, Li Shaorong, etc. Current situation and developing trends of railway refrigerated transportation technology [J]. Refrigeration Journal. 2002, 23(2): 42-45.

[2] Sowell E F, Hittle D C. Evolution of building energy simulation methodology [J]. ASHRAE Trans. 1995, 101(1): 850-855.

[3] Comini G, Cortella G, Saro O. Finite element analysis of coupled conduction and convection in refrigerated transport [J]. Int. J. Refrig. 1995, 18(2):123-131.

[4] Pedersen C O, Fisher D E, Liesen R J. Development of a heat balance procedure for calculating

cooling loads. ASHRAE Trans. 1997, 103(1):459-466.

[5] McClellan T M, Pedersen C O. Investigation of outside heat balance models for use in a heat balance cooling load calculation procedure. ASHRAE Trans. 1997, 103(1):467-484.

[6] Liesen R J, Pedersen C O. An evaluation of inside surface heat balance models for cooling load calculations. ASHRAE Trans. 1997, 103(1):485-502.

[7] Liu Guanghai, Xie Ruhe, Ding Lixing. Study and discussion on the integrated temperature field in air-conditioned trains [J]. China Railway Science. 2006, 27(1): 99-103.

[8] ASHRAE. 2003 AHSRAE Handbook-Fundamentals [S]. 2003.

[9] Davies M G. Current methods to handle insulated layer conduction and room internal heat transfer [J]. ASHRAE Trans. 1999, 105(2):142-153.

[10] Liu Guanghai, Xie Ruhe. Study and analysis on response factor method in unsteady heat transfer of railway refrigerator car [J]. China Railway Science. 2007, 28(1): 86-92.

[11] Crandall M S, Sieber W K. The NIOSH indoor environmental evaluation experience. Part one: building environmental evaluation [J]. Appl. Occup. Environ. Hyg. 1996, 11(6): 533-539.

4 Representative Achievement 3: Development of an Empirical Model of Air Infiltration into Refrigerated Multi-Drop Delivery Vehicles

4.1 Abstract

Air infiltration into two refrigerated, multi-drop delivery vehicles was measured both as a function of road speed and of length of door opening, with various infiltration protection methods in place. Infiltration was found to be greatly dependant on the quality of the door seals and hinges. When the van was moving, the infiltration was found to be proportional to the vehicle speed. Keeping the refrigeration fan on was shown to have a significant effect in reducing infiltration. These infiltration rates have allowed new coefficients to be evaluated to use with an established analytical model to predict infiltration rates for different conditions (e.g. road speed, air temperature, door height and width).

4.2 Introduction

Regulations exist in most countries to control the temperature of chilled and frozen food. In Great Britain, the Food Safety (Temperature Control) Regulations 1995 implement part of EC Directive 93/43 and certain national provisions relating to food temperature control.

The Regulations state that perishable foods must be kept at or below 8ºC during transport, preparation and display for sale unless they are sold within four hours. Frozen foods must be maintained at, or below, -18 ºC. This regulation necessitates that such foods must be transported using refrigerated vehicles or insulated containers with eutectic packs.

Local delivery of chilled food is usually carried out in small to medium sized refrigerated vehicles (less than 7.5 tonnes). They are loaded with products in the morning and deliver to many retail outlets on a typical journey. At each outlet, the van will stop, and the door will be left open while foodstuffs are removed from the van. The difference in temperature between the refrigerated space and the ambient causes an exchange of air due to the stack effect and warm moist air enters. Gigiel (1995) showed that if the refrigeration plant does not operate whilst the vehicle is stationary and the period of time between deliveries is not long enough to provide an adequate pull down period; product temperature can increase to 12.3°C at the end of the journey.

Chen et al. (2002) showed that a major factor governing air-tightness in cold stores are the seals around the door. The driving force is the air pressure difference caused by temperature differences between the cold store and surroundings and wind pressure. Chen et al (2002) also showed that the condition of door seals could have a large effect on the level of infiltration. The same can be deduced for a refrigerated vehicle as it is essentially a cold store on wheels, however, much higher wind pressures can be obtained whilst the vehicles is moving.

A range of empirical models have been previously developed for predicting infiltration during door openings in refrigerated rooms. These models are described and the accuracies compared by Foster et al (2003). The Gosney and Olama (1975) model (equation 1) uses an empirical coefficient to adjust the model output to compensate for such effects as the vena contracta and turbulent mixing between incoming and outgoing streams that occur as the air passes through the door opening.

$$m = 0.221\,A\,(gh)^{0.5}\left[\frac{(\rho_i - \rho_o)}{\rho_i}\right]^{0.5}\left(\frac{2}{1+\left(\rho_i/\rho_o\right)^{0.333}}\right)^{1.5}\rho_i \qquad (1)$$

As this model was developed for cold storage rooms it is likely that the empirical derived coefficient would not be accurate for delivery vehicles that have smaller entrances and refrigerated spaces.

A mathematical modelling tool, CoolVan (Gigiel, 1995), was developed to predict the temperatures within foodstuffs inside the van throughout the delivery journey as well as the energy used by the refrigeration equipment. This model allows a complex set of journey parameters (number of stops, journey direction, vehicle speed, quantity delivered, etc) to be modelled and thus enable the user to assess whether food temperature problems would occur in reality.

To model air infiltration an analytical model was developed using the Gosney model with more appropriate empirical coefficients, for incorporation into the CoolVan model. Measurements of air infiltration were taken while moving with the door closed and while stationary with the door open or closed to provide data for the evaluation of the coefficients.

4.3 Materials and methods

4.3.1 Vehicles

Two insulated refrigerated vehicles were used for the experimental studies (Van A and B). Both vehicles were rigid chassis, multi-drop, intended for local delivery and had single hinged doors at the rear. The layouts of the vans are shown in Figure 4-1.

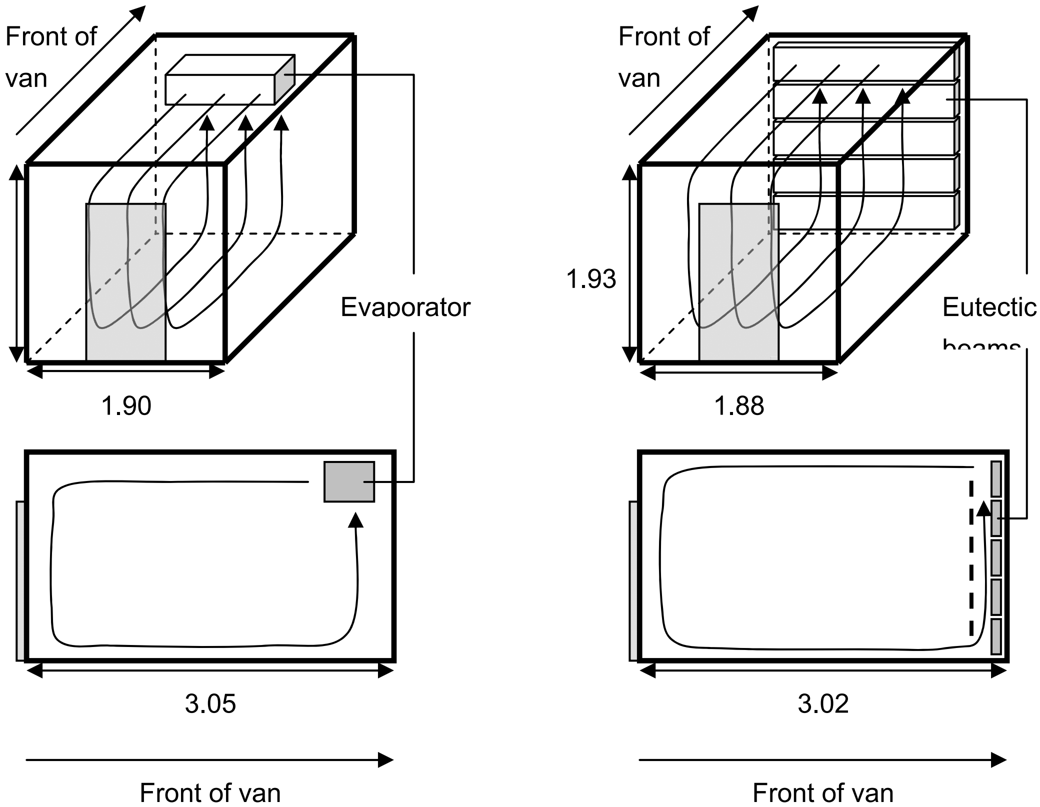

Figure 4-1. Layout of Van A (left) and B (right) refrigerated cells showing the refrigeration system and door positions and the approximate air circulation patterns. Dimensions in m.

Van A was a 7-year-old vehicle that was still in regular operation at the time of the experiments. The refrigerated space had internal dimensions of 1.90 x 1.92 x 3.05 m (width x height x depth), with a door that was 0.63 x 1.72 m (width x height). The door seals were in poor condition and the door did not fit snugly against the seals when shut. There were other gaps in the structure where the refrigeration pipes entered through the bulkhead above the drivers cab. Van A had a vapour-compression refrigeration system (nominally 2.8 kW) mounted on the front bulkhead of the vehicle over the drivers cab with an evaporator coil mounted at the top of the refrigerated space, at the cab end. Air was drawn through this and circulated around the load space by evaporator fans. Infiltration tests were carried out on Van A either with strip curtains protecting the entrance or without any infiltration protection.

Van B was a new vehicle at the time of the experiments. It had internal dimensions of 1.88 x 1.93 x 3.02 m (width x height x depth), with a door that was 0.65 x 1.74 m (width x height). The vehicle's door seals were in an excellent condition and less gaps were present in the structure than in Van A. Van B had a eutectic beam refrigeration system, with the beams running along the front wall of the inside of the load space. Air was circulated over these beams, to the back of the load space, by fans. Under normal conditions, the fans only circulated the air when there was demand for refrigeration from the thermostat, unlike the situation in Van A.

Infiltration tests were carried out on Van B either with strip curtains or with a lightweight sliding door, installed inside the main door, protecting the entrance. The sliding door was misshapen (bowed into the load space). This was because the sliding door had an outside handle which protruded towards the main door. When the main door was closed the door pushed the handle and this pushed the door inwards. This bowed shape had become fixed, such that it was evident even when the main door was open.

Figure 4-1 shows the refrigerated load spaces of both vans showing door and refrigeration positions with approximate air circulation patterns.

4.3.2 Measurement procedure

The exchange between the ambient air and the air in the load space was measured by recording the decline in concentration of CO_2 gas introduced into the load space through a tube. The air exchange was measured whilst the vans were in motion, with the door closed and stationary with the door either closed or open.

In each case, CO_2 was introduced into the load space until it reached a concentration close to, but not exceeding 5,000 ppm, a level which was not exceeded due to safety reasons. The refrigeration fans were left on for 5 minutes before the beginning of each test to ensure the CO_2 was well mixed in the load space. Defrosts were disabled during all experiments so as not to interfere with air flow or temperature control. The decline of the CO_2 concentration was monitored using a CO_2 infra-red analyser (Model ABPA-210, Horiba Ltd, Kyoto, Japan) (accuracy 250 ppm).

In the case of Van B, the eutectic beams gave maximum refrigeration load directly after being pre-cooled to a specified point by the built-in refrigeration system that was plugged into a mains electricity outlet. The eutectic beams were fully charged (pre-cooled) before each of the moving and door opening tests to ensure consistent operation.

Thermocouples (Type T) connected to a portable data logger were calibrated at 0°C and used for measuring temperatures inside and outside the vehicle. A thermocouple, located inside the van, measured the temperature of the air that was drawn onto the evaporator/beams. It was found from preliminary experiments that the temperature of the air onto the evaporator/beams was very close to the mean air temperature inside the van.

4.2.3 Measurements of infiltration with the van stationary and the door closed

The infiltration of air into the van was measured by recording the CO_2 concentration every 5 minutes while the van was stationary inside a large hall (floor dimensions, 24 m x 17 m), to remove external air movement effects, and with the load space door closed. The infiltration rate was calculated at each time interval using equation 1.

$$i = \frac{V}{t} \ln\left(\frac{C_1 - C_b}{C_2 - C_b} \right) \qquad (2)$$

This infiltration rate with no external air movement and the door closed was used as base data in the next two sets of experiments; as the zero speed condition for the moving van infiltration rates and as the 'background' infiltration rate for the door opening tests.

Since the seals on Van A were in a poor condition, these were replaced and further experiments carried out with these 'new seals'. An experiment was also carried out with tape over the door seals to establish what the infiltration would be if the doors were well sealed.

4.2.4 Measurements of infiltration with varying van speed

Roads were chosen where the speed of the vehicle could be safely maintained approximately constant and covering a range of 0 to 30 $m.s^{-1}$. The mean speed was calculated by dividing the distance covered (measured by the vehicle odometer) by the time taken. The CO_2 concentration was measured at intervals and the infiltration rate calculated using equation 1.

4.2.5 Measurements of infiltration during door opening

These tests were carried out in the same hall as the tests carried out with the van door closed.

The CO_2 concentration was recorded at the beginning and end of each test. Each test contained two or more door openings, which were carried out as follows.

1) The load space door was opened through 90°.
2) A person entered the load space, through the strip curtains or by opening the internal sliding door if either were present.
3) The person walked into the centre of the load space.

4) The person exited, through the strip curtains if present or closed the internal sliding door if fitted.

5) The person either closed the door on their way out or left it open for a fixed length of time before closing it.

The total time that the door was open, represented the door open duration quoted in the results. The door open durations measured, were between 7 and 300 s. This door opening procedure was repeated 2 to 4 times for each test.

Equation 2 was used to calculate the infiltration per door opening. It represents the relationship between the total infiltration during each experiment, the ‘background’ infiltration (with the door closed, measured in the first set of experiments), the infiltration per door opening and the duration and number of door openings.

$$M = \frac{(I_t - i_c t_c)}{n} \rho_o \tag{3}$$

- Experiments with Van A

Four trials were carried out in Van A, as described below (Table 4-1).

- Experiments with Van B

Two trials were carried out in Van B (Table 1). In both trials, the thermostat was set to control the internal temperature of the van at 4°C. The cooler fan would only run when the thermostat demanded refrigeration.

Table 4-1. Measurement conditions.

Van	Set	Fans	Door protection	□T
A	1	Continuous	None	15.5
A	2	Continuous	Strips	13.0
A	3	Off	Strips	12.0
A	4	Continuous	Strips	3.0
B	1	On demand	Strips	24.0
B	2	On demand	Sliding door	24.0

4.2.6 Infiltration model

- Door opening

New empirical coefficients were derived for the Gosney model, which fitted each set of experiments. These new coefficients allowed for the differences between vehicles and infiltration reducing devices.

- Moving vehicle

The driving force for infiltration when the load space door is closed and moving was dominated by the effects of dynamic pressure differences. This was due to the air flowing around the van (forced convection), rather than a density (temperature) differences between the air inside and outside the load space (natural convection) as occurs when the vehicle is stationary. For this reason, a separate model was created for the moving vehicle where infiltration was related to van speed rather than to temperature difference.

4.4 Results and Discussio/n

4.4.1 Van stationary and the door closed

The infiltration rates whilst stationary for Van A with poor seals, new seals and taped seals and Van B are shown in Table 4-2. The infiltration through Van A was reduced by a factor of 6 when the seals were replaced. Taping the seals reduced the infiltration further by a factor of 1.5. The infiltration through Van B was 9% less than through Van A with new seals. As there was still infiltration with the seals taped, this showed that infiltration occurred elsewhere in the load space, e.g. around pipework.

Table 4-2. Infiltration rate (g.s-1) for stationary vans. Infiltration rates for Van A are for 3 different conditions of sealing.

Van A			Van B
Poor seals	New seals	Taped seals	
3.19	0.554	0.365	0.509

4.4.2 Varying van speed

Figure 4-2 shows the mass infiltration rate versus vehicle speed for both Van A (with poor door seals) and B. A linear least squares fit was used to provide the variation of infiltration rate with van speed. The infiltration at zero speed was fixed by the results of the van stationary experiments.

The variation in mass infiltration rate (m) with van speed (v) for Van A was found to be

$$m = 0.785 \ v + 3.19$$

for Van B there was no significant correlation

The infiltration whilst moving at high speed (30 m.s^{-1}) was a factor of 8 times larger than whilst stationary for VanA. The likely reason that Van A gets comparably worse than Van B at speed was because the door hinges were in a poor condition. Consequently, the low pressure zone at the back of the vehicle when moving caused the door to move away from the poor fitting seals giving an even worse seal than whilst stationary.

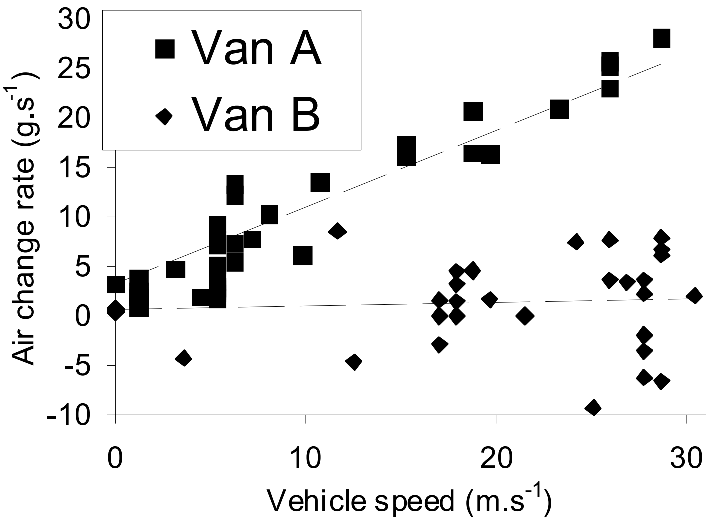

Figure 4-2. Mass infiltration rate versus vehicle speed for Van A (with poor door seals) and Van B.

4.4.3 Door opening

The mass of air infiltrated per door opening against the door open duration for each case is shown in Figure 4-3. A linear least squares fit was used to provide the infiltration rate for each case.

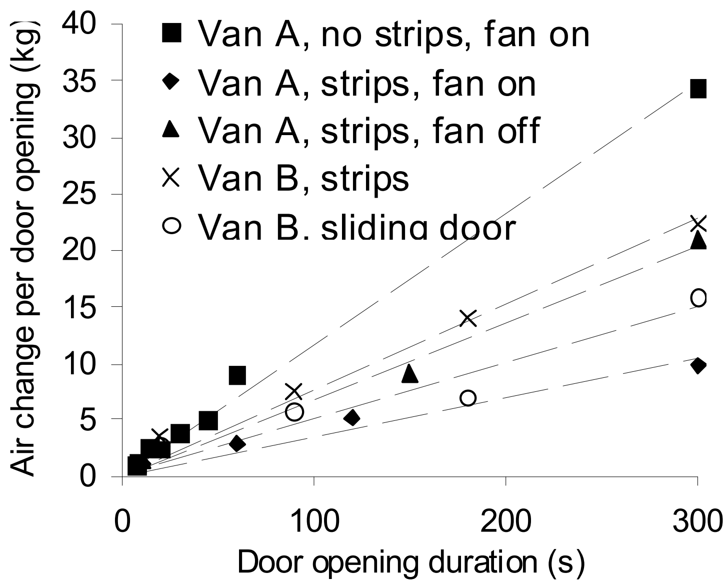

Figure 4-3. The mass of air infiltrated per door opening against the door open duration for each case.

It can be seen from these data that the infiltration per door opening follows a linear relationship, showing that the rate of infiltration does not change over the period of the door openings. This implies that the driving force (temperature difference between the air inside and outside the load space) remains constant over this time. For the driving force to remain constant, the air entering the room must be cooled to the same temperature as the air inside the room, which would mean that equal masses flow into and out of the room during door openings. For this reason the Gosney model was chosen to represent infiltration through door openings in the CoolVan model.

To calculate an adjusted empirical coefficient for the Gosney model, the measured mass infiltrated was divided by the value of mass infiltrated predicted by the Gosney model (without the empirical coefficient) for each condition (equation 3).

$$c = \frac{m}{A\,(gh)^{0.5}\left[\frac{(\rho_i - \rho_o)}{\rho_i}\right]^{0.5}\left(\frac{2}{1+\left(\rho_i/\rho_o\right)^{0.333}}\right)^{1.5}\rho_i} \quad (4)$$

Table 4-3 shows the infiltration rate for all of the conditions measured.

Table 4-3. Mass flow rates and derived empirical coefficients based on temperature difference during door opening for the two vans, for different door protection regimes.

	Van A			Van B	
	Fan on no strips	Fan on strips	Fan off strips	Strips	Sliding door
Mass flow rate ($g.s^{-1}$)	116.2	34.6	68.1	76.2	50.2
Temperature difference (K)	15.5± 1.5	13.0± 1.0	12.0± 1.5	24.0± 1.5	24.0± 1.5
Empirical coefficient	0.0968	0.0314	0.0643	0.0510	0.0336

The lowest empirical coefficient (lowest infiltration for a given temperature difference) was given by Van A when the fan was on and strips were in place. This value was 7% less than Van B with a sliding door. Since it was expected that the sliding door would be more effective at reducing infiltration than the strips, this was probably due to the sliding door being misshapen.

Having the evaporator fan on, reduced the coefficient significantly (51% reduction) with the strips in place. This was thought to be due to the re-circulating flow created by the fan. This flow pushes the strips out of the load space at the top and draws the strips in at the bottom. These are opposing forces to the natural convection.

Not surprisingly having the door open with no protection gave the greatest infiltration. The coefficient for this condition was 56% less than the coefficient derived by Gosney. It is expected that the coefficient would be lower than the Gosney coefficient due to the door being smaller than a normal cold store door (leading to a larger proportion of vena contracta and also the condition of fans on, which appears to have a positive effect of reducing infiltration.

These coefficients were used, as shown in equation 4, to predict infiltration during door opening.

$$m = c\,A\,(gh)^{0.5}\left[\frac{(\rho_i - \rho_o)}{\rho_i}\right]^{0.5}\left(\frac{2}{1+\left(\rho_i/\rho_o\right)^{0.333}}\right)^{1.5} \quad (5)$$

Figure 4-4 shows the measured and predicted air infiltration over a 120s door open duration with a variety of temperature differences between the air inside and outside the load space of Van A with fan on and strips. The measured values were derived from experiments at two temperature differences of 13°C and 3°C. The predicted data was created from the Gosney model, with an empirical coefficient derived from the best (least squares) fit to the infiltration data from the experiments carried out at a temperature difference of 13°C. Predicted values from this model were obtained for the same conditions as in the experiments, but with the temperature difference between the air inside and outside the load space varying between 0 to 30°C.

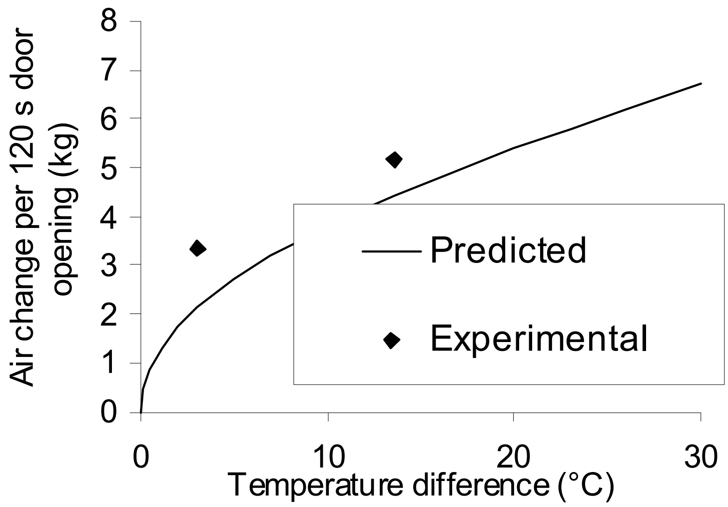

Figure 4-4. Measured and predicted mass of air infiltrated for two temperature differences (3 and 13°C) for the condition of Van A, fans running, strip curtains present.

Since the Gosney model was fitted to data over a number of door open durations, it can be seen that the predicted data does not fit exactly to the experimental data at 120 s door open duration. However, a similar trend can be seen to be occurring in the experimental and predicted data.

4.5 Conclusions

Infiltration of air into a stationary refrigerated multi drop vehicle when the door was closed was found to be greatly dependant on the quality of the door seals. Replacing the door seals can reduce infiltration by a factor of 6. However not all of the infiltration is through these seals, some comes through gaps around the refrigeration pipework where it enters the refrigerated load space.

For a vehicle with poor seals, the infiltration was found to be proportional to the vehicle speed. The effect of bad seals in an older vehicle can be compounded by worn door hinges. This work very much highlights the effect of poor maintenance on infiltration.

Keeping the refrigeration fan on was shown to have a significant effect in reducing infiltration. This was not found to be the case in other unpublished work by the authors on a cold storage room. The geometry of the refrigerated load space (fan pointing directly towards the top of the door, evaporator covering almost the full width of the load space), allows the dynamic pressure from the fan to effectively oppose the stack pressure.

These infiltration rates have allowed new coefficients to be evaluated to use with the Gosney model to predict infiltration rates for different conditions (e.g. air temperature, door height and width). These new coefficients and the relationship between vehicle speed and velocity allow a more accurate representation of infiltration for refrigerated multi drop vehicles.

4.6 Nomenclature

A	cross sectional area of the entrance, m^2
c	correction factor
C	concentration of CO_2, ppm
g	acceleration due to gravity, 9.81 $m.s^{-2}$
h	height of entrance, m
i	volume infiltration rate, $m^3.s^{-1}$
I	volume of infiltrated air, m^3
K	temperature correction factor
m	mass infiltrated rate, $g.s^{-1}$
M	mass of infiltrated air, g
n	Number of door openings

t time, s

V volume of air within the load space, m^3

Greek letters

i, o density inside and outside the cold store, $g.m^{-3}$

Subscripts

1 previous measurement time

2 current measurement time

b background

c for the whole of the time the door was closed

i inside cold store

o outside cold store

t for the whole of the experiment

4.7 References

[1] Chen, P., Cleland, D. J., Lovatt, S.J. and Bassett, M. R. (2002). An empirical model for predicting air infiltration into refrigerated stores through doors. International Journal of Refrigeration, Vol. 25, 799-812.

[2] Foster A. M., Swain M. J., Barrett R., James S. J. (2003). Experimental verification of analytical and CFD predictions of infiltration through cold store entrances. International Journal Of Refrigeration, Vol. 26, 918-25.

[3] Fritzsche, C. and Lilienblum, W. (1968). Neue messengun zur bestimmung der kalterluste an kuhlraumturen. Kaltetechnik-Klimatiserung, Vol. 20, 279-286.

[4] Gigiel, A. J. (1995). Predicting food temperatures in refrigerated transport. In Proceedings of the Institute of Refrigeration, Vol 7, No. 1.

[5] Gosney, W. B. & Olama H. A-L. (1975). Heat and enthalpy gains through cold room doorways. Refrigeration and Air Conditioning. Vol 79, No. 934, 35-

[6] The Food Safety (Temperature Control) Regulations 1995, The Stationery Office Limited, UK. ISBN 0110533836

5 Representative Achievement 4: Quality Changes of Fresh Pork during Logistics

5.1 Abstract

For pork meat was one of the highly corruptible products during logistics, the fast detection of total volatile basic nitrogen (TVBN) based on chromatic aberration method was researched and applied to observe the quality changes of warm fresh pork during logistics in winter and summer, as well as the quality changes of chilled pork and vacuum-package chilled pork during short-time and long-time logistics. The results show that the logistics quality of warm pork changes quickly, and the logistics quality of chilling pork changes slowly, while the logistics quality of chilling pork with vacuum package has least change. Low temperature logistics of fresh pork is recommended, and the quality would be best kept in the chilling pork logistics with vacuum package.

5.2 Introduction

Slaughter, storage, transportation, distribution and sale are composed of fresh pork logistics during which the factor of temperature plays an important role to the quality of pork. Akamittath et al. (1990) found an increase in Thiobarbituric acid reactive substances (TBARS) concomitant with a decrease in product redness, measured as the tristimulus parameter α*, for restructured pork during frozen storage at -10℃ for up to 8 weeks. Jensen et al. (1998) found increased lipid oxidation during chill storage of meat from a standard feeding regime compared to meat from pigs with high levels of α-tocopherol. Ultimate pH has previously been shown to be crucial for the quality of fresh pork chops during chill storage under retail conditions. (Juncher et al.,2001). The bacterial diversity and main flora of chilled meat under different storage conditions have been extensively studied according to traditional cultivation methods (Blixt and Borch, 2002; Borch et al., 1996; Gill, 1996; Jay et al., 2003). The bacterial composition and its change were complex, and the bacterial diversity reduced in chilled pork during storage whether by tray- or vacuum-packaging. (Dainty and Mackey, 1992; Olsson et al., 2003). The previous researches are mostly concentrated on the quality changes about fresh pork during storage, but the transportation and sale are also critical to keep pork fresh in the pork supply chain. Based on total volatile basic nitrogen (TVBN), one of the evaluation indexes to quality of fresh meat(Gómez-Estaca et al.,2007), the TVBN changes of fresh pork during transportation, storage and sale, in this paper, would be detected to expose the quality changes rules during logistics about fresh pork in contrast to vacuum-packaged pork.

5.3 Materials and Methods

5.3.1 Sampling

Pork hindquarter steaks (weight: 100-250g) were removed from pork carcasses in a commercial slaughterhouse. Of all the pork steaks, some were vacuum-packaged and the others were naked. At 28℃ external environment, the oscillating incubator with constant temperature and 2 Hz oscillatory frequency was used to simulate the refrigerated transportation, and the incubator was also used to simulate the storage and sale when the oscillator was shut off.

5.3.2 TVBN extraction

Ten grams of meat sample weighed accurately were dip in 50mL of distilled water with discontinuous stirring for 30 min, and 25mL of trichloroacetic acid (TCA) was added to precipitate the protein. Then the solution was filtrated and diluted to 100mL.

5.3.3 Detecting based on chromatic aberration method

Two tubes were prepared, one was used to load 10mL of extract and 2mL of chromogenetic reagent (0.4g of paradimethylaminobenzaldehyde, 10mL of 95% ethanol and 5mL of concentrated hydrochloric acid); the other was used to load 10mL of extract and 2mL of distilled water. After the reaction for 1~2min, the lightness (L*) and chromo (a*&b*) were detected by color difference meter. Then the color difference formula of CIE 1976 LAB was applied to converting according the standard curve from carbamide.

5.4 Results and Discussion

5.4.1 Standard curve and detection reliability

The regression equation of the standard curve (Fig 5-1) was $y = 4326.3x + 0.0499$ (R2=0.9978). Meanwhile, the precision and recovery of sample detection were 0.68% and 99~102% respectively, therefore, this method was accurate and feasible.

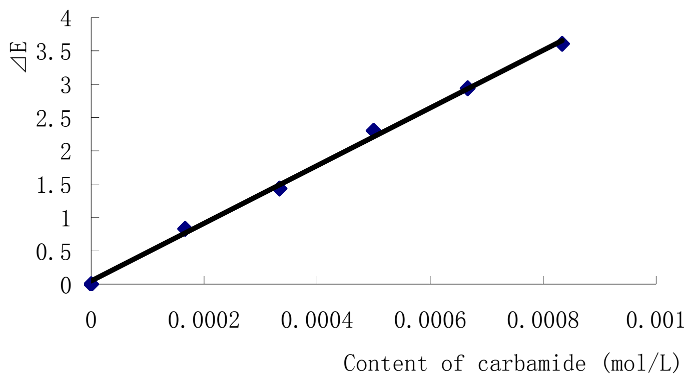

Fig 5-1 Standard curve

5.4.2 Quality changes of warm pork during logistics

Temperature of oscillating incubators was set at 10□ and 28□ to simulate the temperature of winter and summer respectively in Guangzhou. The meat samples were located on the oscillator in operation for 2h to simulate the transportation, and then the oscillator was shut off to simulate the process of retail, during which the TVBN contents were detected per hour (Fig 5-2). During transportation in winter, the content of TVBN could not exceed standard of 15mg/100g limited by GB 2707-2005 (Ministry of health, 2005), while exceed standard after 8h of retail. In contrast, TVBN could not exceed standard during transportation in summer, but exceed standard after only 1h of sale, and then rose steeply after retail display for a 3h period, which showed that the meat had been corrupting. Warm fresh pork logistics exists universally in villages and towns (Yuman, et al. 2003), which would bring high safety risk of meat, especially in summer.

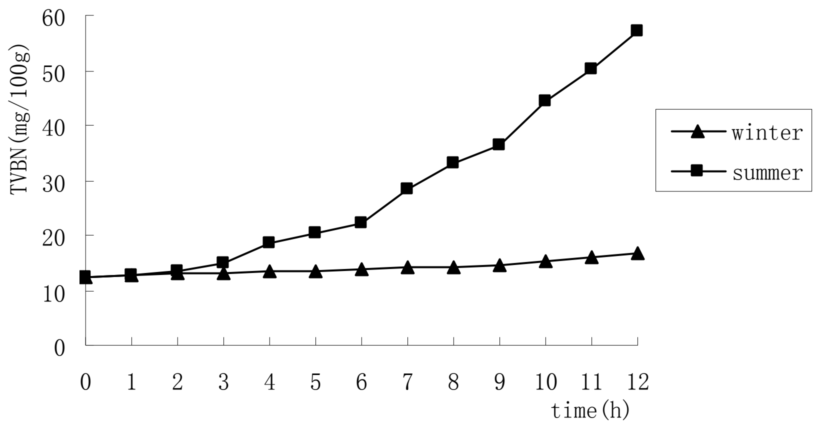

Fig 5-2 Quality changes of warm pork during logistics

5.4.3 Quality changes of chilled pork during short-time logistics

Three sample groups (standard groups, operation group and vacuum-package group) were simulated as short-time logistics which included transportation (3h), storage (2h) and retail. Based on the field survey of logistics temperature, standard group and vacuum-package group have been throughout at 4℃ during the whole logistics process, while operation group at 6℃ during transportation and 4℃ during storage and retail. The TVBN contents were detected per hour (Fig 5-3). TVBN contents of the three groups could not exceed standard after 10h of retail, which showed a less quality change under this logistics mode. The increase of TVBN contents of operation group were faster than that of standard group due to the temperature difference, which showed that the factor of temperature played an important role in chilled pork logistics and that strict temperature operation should be advocated. TVBN contents of vacuum-package group were lower than that of standard group at the same condition, which mostly originated from the more stable quality keeping (Jeremiah. et al. 1995).

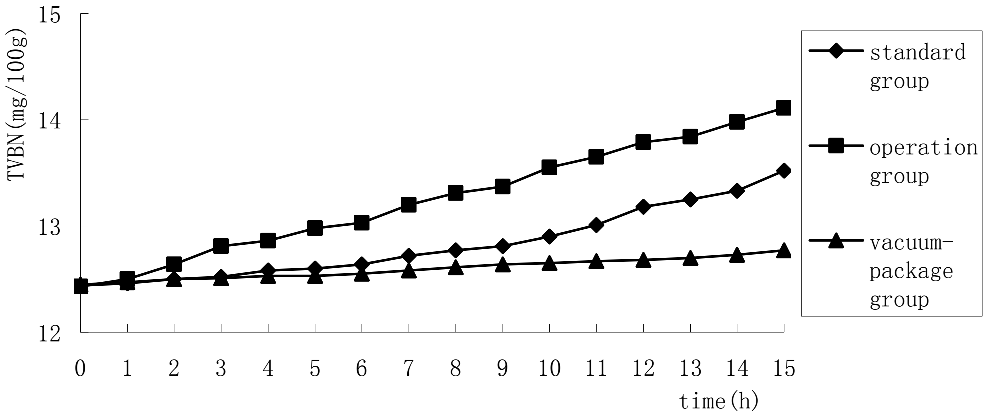

Fig 5-3 Quality changes of chilled pork during short-time logistics

5.4.4 Quality changes of chilled pork during long-time logistics

Three sample groups as the above were simulated as long-time logistics which included transportation (12h), storage (6h) and retail. The TVBN contents were detected per two hours (Fig 5-4). TVBN contents of the three groups could not exceed standard after 10h of retail, but close to the limit of 15mg/100g. The increase of TVBN contents of operation group was also faster than that of standard group due to the temperature difference. TVBN contents of vacuum-package group were also lower than that of standard group at the same condition.

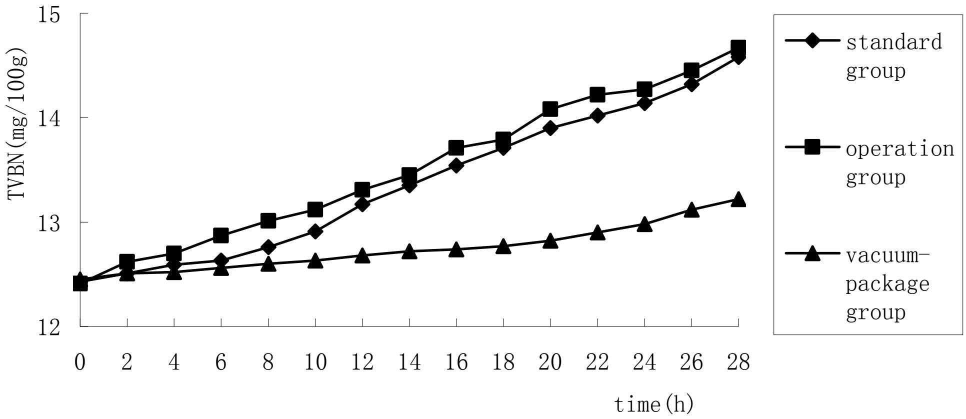

Fig 5-4 Quality changes of chilled pork during long-time logistics

5.5 Conclusions

In this study, the quality changes of fresh pork were observed in order to decrease damages during logistics. The paper found that the quality of warm pork meat become bad quickly, especially in summer, while slowly to those chilled meat during both short-time and long-time logistics. The result also shown that the process of vacuum-packaging to chilled pork could decrease the quality loss of food.

5.6 References

[1] Akamittath, J. G., Brekke, C. J., & Schanus, E. G. (1990). Lipid oxidation and color stability in restructured meat systems during frozen storage. Journal of Food Science, Vol. 55, No. 6, 1513–1517.

[2] Blixt, Y., Borch, E., (2002). Comparison of shelf life of vacuum-packed pork and beef. Meat Science. Vol. 60, No. 4, 371–378.

[3] Borch, E., Kant-Muemansb, M.L., Blixt, Y., (1996). Bacterial spoilage of meat products and cured meat. Int. J. Food Microbiol. Vol. 33, No. 1, 103–120.

[4] Dainty, R.H., Mackey, B.M., (1992). The relationship between the phenotypic properties of bacteria from chill-stored meat and spoilage processes. J. Appl. Microbiol. Suppl. Vol. 73, No. 21, 103S–114S.

[5] Gill, C.O., (1996). Extending the storage life of raw. Meat Science. Vol. 43, No. 1, 99–109.

[6] Gómez-Estaca. J, Gómez-Guillén. M.C, Montero. P, (2007). High pressure effects on the quality and preservation of cold-smoked dolphinfish (Coryphaena hippurus) fillets. Food Chemistry. Vol. 102, No. 4, 1250-1259.

[7] Jay, J.M., Vilai, J.P., Hughes, M.E., (2003). Profile and activity of the bacterial biota of ground beef

held from freshness to spoilage at 5 – 7℃. Int. J. Food Microbiol. Vol. 81, No. 2, 105 – 111.

[8] Jensen, C., Skibsted, L. H., & Bertelsen, G. (1998). Oxidative stability of frozen-stored raw pork chops, chill-stored pre-frozen raw pork chops, and frozen-stored pre-cooked sausages in relation to dietary CuSO4 rapeseed oil vitamin E. Zeitschrift fur Lebensmittel-Untersuchung und-Forschung A, Vol. 207, No. 5, 363 – 368.

[9] Juncher, D., Ronn, B., Mortensen, E. T., Henckel, P., Karlsson, A., Skibsted, L. H., & Bertelsen, G. (2001). Effect of pre-slaughter physiological conditions on the oxidative stability of colour and lipid during chill storage of pork. Meat Science, Vol. 58, No. 4, 347 – 357.

[10] Jeremiah. L.E, Gibson. L.L, Argnosa. G.C. (1995). The influence of controlled atmosphere and vacuum packageing upon chilled pork keeping quality. Meat Science, Vol. 40, No. 1, 79-92.

[11] Ministry of health of P.R.China, (2005). Higienic standard for fresh (frozen) meat of livestock. GB 2707-2005, 1-4.

[12] Olsson, C., Ahrne, S., Pettersson, B., Molina, G., (2003). The bacterial flora of fresh and chill-stored pork: analysis by cloning and sequencing of 16S rRNA genes. Int. J. Food Microbiol. Vol. 83, No. 3, 245 – 252.

[13] Yuman. Liu, Xiaoqing. Yin, Yintang. Du, (2003). Problems of food quality safety in pork supply chain. Chinese Journal of stockbreeding. Vol. 43, No. 2, 47-49.

6 Representative Achievement 5: Study on Quality Test Method of Banana during Transportation

6.1 Abstract

Nowadays, the quality of banana is evaluated by appearance during transportation in China. As a result of the strong subjectiveness and low accuracy of this method, disputes happen easily. The quality test method of banana is needed urgently during transportation. Experimentation was done for finding the fast method by “simulating test-bed for refrigerated transportation condition” in Guangzhou University. The result was found that it is better to use combinative approach of sensory evaluation and determination of pulp hardness when testing the quality of banana because this approach is feasible, time-saving and equipment requirement is simple and cheap.

6.2 Introduction

Banana is one of the four major fruits in the world and plays an important role in the international market of fresh fruit. However, due to a lot of factors such as breathing heat, transportation equipment, etc, it is difficult to control temperature in the process of transportation. And the problems such as chilling injury, softening and decaying often arise. At the same time, in the existing national standard and industry standard in China, the inspection of biochemical qualities of bananas mostly depends on laboratory test. This method takes time and required some equipments which are not easy to move. Therefore, in real operation, the quality of banana mostly relies on the subjective evaluation from the appearance. As a result of the strong subjectiveness and low accuracy of this method, disputes happen easily. So, the quality test method of banana is needed urgently during transportation. Experimentation was done for finding the fast method by “simulating test-bed for refrigerated transportation condition” in Guangzhou University.

6.3 The Experimentation of Banana

The experimentation lasts from loading banana to unloading banana. The time went on seven days from July 1 to July 7. The bananas product in the same place and have same quality. Some of the bananas are transported with refrigerated equipment (10~15℃), the others transported at normal temperature as contrast group In order to find the proper quality test method of banana during transportation, many indexes were tested such the sensory, weight, pH, sugar content, water content and hardness of the bananas.

6.3.1 Sensory Evaluation

According to the banana evaluation index system, bananas have reached excellent standard before loading. After transportation, bananas in refrigerated transportation remain excellent standard. While the banana (transport at normal temperature), some appear the excessive ripeness (10%), and the smell and the hardness of some bananas decrease, other part even appear the phenomena of split and viscous juice.

6.3.2 Hardness Test

TG-2 type meter of fruit hardness tester is used during the detection. It’s very small. Meter of fruit hardness measure direct the back of the fruit after ripping skin. When measuring, five samples are taken and each sample would be measured five times. The hardness of banana pulp is 11.2~11.3kg before the transportation and it has a slight decline to 10.3kg after unloading by refrigerated transportation. The hardness of banana pulp, which has nothing cooling treatment, is only 5.6kg after 7 days, even though the hardness of banana peel has no change. Some of them have been softening; the hardness of banana pulp is only 2.3kg. As the hardness of banana pulp is one of important indicators in maturity, the quality of bananas has been keeping by refrigerated transportation.

Figure 6-2 The hardness test of banana

6.3.3 PH Test

PH indicator paper is used during the detection. There is no change in the values of PH before and after the experimentation, both of which are 4.7. This shows that the PH value of the bananas can not be used as indicators in the evaluation of evaluation index. The result is proved by relevant reference, so it is reliable.

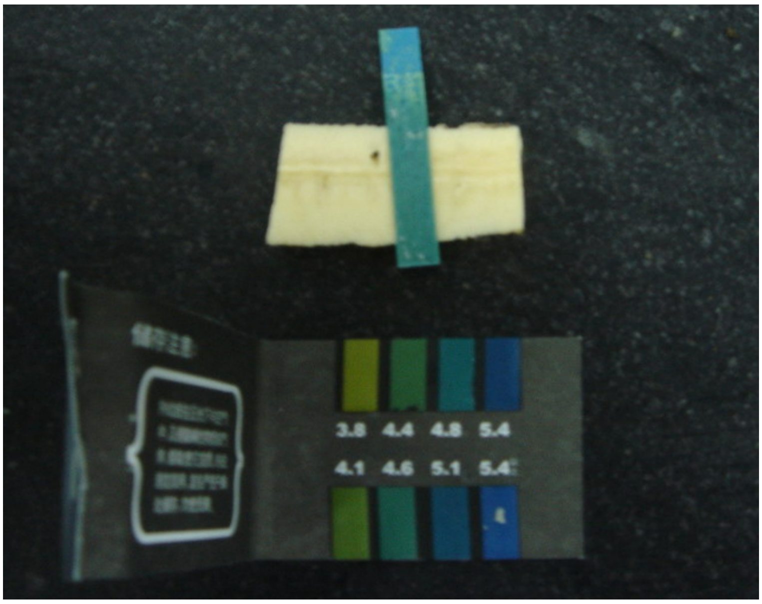

Figure 6-3 The PH test of banana

6.3.4 Water Content Test

The water contented of the banana should be tested by electronic balance and oven because the water in banana can be evaporated in high temperature. We can see that the bananas which have been transport in refrigerated transportation have been keeping a good quality and the water content basically has no change mostly (from 77% to 76%). The bananas which have been transport in no-protecting measures have bad performance in loss of moisture and the water content decreased significantlyfrom 77% to 71%, up to 1% per day.

Figure 6-4 The water content test of banana

6.3.5 Sugar Content Test

In the aspects of sugar content, it is difficult to get the juice for testing because of banana has been too much colloid. And it is also difficult to use any portable saccharimeter but only through laboratory titration method to determine the index of the sugar content. As a result, sugar content is not appropriate index of the quality testing parameters of banana during transportation.

6.4 Conclusions

The testing and analysis about the sensory evaluation, weight loss, pH value, sugar content, water content and hardness are carried out in the experiment. Through analysis of the various parameters and experimental methods, it's clear that the pH value of banana is steady during transport and the test method of weight loss, sugar content and water content need large-scale apparatus. So, the test method of weight loss, pH value, sugar content is difficult to be used in banana transport.

The fact can be found that it is better to use combinative approach of sensory evaluation and determination of pulp hardness when testing the quality of banana. Because this approach is feasible, time-saving and equipment requirement is simple and cheap, which is a good solution of the problems in the on-site inspection of quality.

6.5 References

[1] Xie R, Luo R, Li S. (2002) Current situation and developing trends of railway refrigerated transportation technology. Journal of Refrigeration, Vol.26, No.2, 52-58

[2] David J Forkenbrock. (2001) Comparison of external costs of rail and truck freight transportation. Transportation Research Part A, Vol.35, 321-337

[3] Commere B, Hautier J P. (2001) Transport: how to master the cold chain. Froid, FR. Vol.91, No.2, 79-83

[4] Xie R, Liu G, Guo C. (2006) Design and test on simulating test-bed of refrigerated transportation condition. Journal of Refrigeration, Vol.30, No.6, 52-58

[5] Chatzidakis S, Chatzidakis K. (2005) A heat transfer simulation study of a multi - compartment isothermal liquid foodstuff tank tested according to the international ATP Agreement. Energy Conversion and Management , Vol.46, No.2, 197-221

[6] Xie R, Hu S, Luo G. (1999) Research on the problem of weight loss of perishable goods in refrigerated transportation. Journal of Refrigeration, Vol.23, No.2, 42-49

[7] Xie R, Liu G. (2007) Heat balance model for refrigerated car and simulation and experimentation on the temperature field, Beijing: The 22nd International Congress of Refrigeration. ICR07-D2-992

7 Representative Achievement 6: Performance Evaluation of Food Cold Chain Logistics Enterprise and Its Application to Supplier Selection Decision

7.1 Abstract

The study establishes a performance evaluation index system of food cold chain logistics enterprise, and then proposes a relatively simple evaluation method on the basis of entropy weight method and grey relational grade analysis. Through the method the performance evaluation can be made on the premise of objectivity, efficiency and reliability. Finally, the paper verifies the applicability of the method with an application example on supplier selection decision problem.

7.2 Introduction

With the increasing attention to food safety and quality, the society and public have more and more demand on frozen foods. Most of frozen foods are agricultural and sideline products with strict seasonality or short preservation period, such as melons, fruits, fresh vegetables, meat, aquatic products, milk products, quick-frozen foods and so on (Zhijie and Yingjun, 2007). To reduce the perishable loss and guarantee the food safety and quality, each link of food cold chain logistics is always under regulated low-temperature environment, such as production, storage, transportation, distribution and sale (Jing et al., 2008).

In recent years, the performance evaluation of food cold chain logistics enterprise has become the research focus due to the high performance is the key to ensure food to be delivered safely, freshly and healthily (Yunling et al., 2008). Since there are various factors and they are interdependence, the performance evaluation of food cold chain logistics enterprise is a grey system. It's quite appropriate to utilize grey relational grade analysis to implement overall performance evaluation on food cold chain enterprises (Xiuyun, 2004). The difficulty in application of grey relational grade analysis is how to establish the suitable evaluation index system and how to determine the weights of indexes. There are some commonly-used methods, such as fuzzy comprehensive evaluation method (Chunyu and Xiaobo, 2006), BP neural network algorithm (Xinqing and Junmo, 2005) and analysis hierarchy process (Hongyan and Xuanxi, 2005), etc. These methods have certain applicability, but also have limitations. Some of them are too simple to lose lots of information, and some are too complex. In order to overcome those defects, the paper put forward the entropy method into the weight calculation of grey relational grade analysis method, which greatly improves the evaluation accuracy and applicability.

7.3 Performance Evaluation

7.3.1 Entropy Weight

The concept of entropy is particularly notable as it is applied across physics, information theory, mathematics, and many other branches of science and engineering. It is one kind of effective method with multi-objective decision nowadays. Entropy is mainly used to describe the uncertainty state of a system. In performance evaluation, entropy method can be used to determine the weight of each index, which calculation steps as follows.

Firstly construct a performance evaluation matrix O as follows:

$$O = (o_{ij})_{m \times n}, (i = 1,2,\cdots,m; j = 1,2,\cdots,n) \tag{1}$$

Where m is the number of candidate enterprises; n is the number of performance evaluation indexes; O denotes the performance evaluation matrix, and o_{ij} is the evaluation value of j-th index in i-th candidate enterprise.

Secondly the entropy of j-th index (i.e., s_j) can be calculated as follows:

$$s_j = -k \sum_{i=1}^{m} R_{ij} \ln R_{ij}, (j = 1,2,\cdots,n) \tag{2}$$

Where R_{ij} denotes the ratio of information density of j-th index in i-th enterprise to it in all enterprises; and $k = 1/\ln m$, $R_{ij} \ln R_{ij} = 0$ (if $R_{ij} = 0$).

Therefore the entropy weight of j-th index (i.e., w_j) can be calculated as follows:

$$w_j = (1 - s_j) \Big/ \sum_{j=1}^{n} (1 - s_j) \tag{3}$$

Then construct the entropy weight vector W as follows:

$$W = (w_1, w_2, \cdots, w_j), (j = 1,2,\cdots,n) \tag{4}$$

7.3.2 Grey Relational Analysis

The grey relational analysis uses information from the grey system to dynamically compare each factor quantitatively. This approach is based on the level of similarity and variability among all factors to establish their relation. This analytical method magnifies and clarifies the grey relation among all factors. It also provides data to support quantification and comparison analysis. In other words, the grey relational analysis is a method to analyze the relational grade for discrete sequences. This is unlike the traditional statistics analysis handling the relation between variables. The grey relational analysis requires less data and can analyze many interdependent factors. It can overcome the disadvantages of traditional statistics method, which calculation steps as follows:

Firstly experts are invited to give every evaluation value $o_i(j)$ (i.e., o_{ij}) of each performance evaluation index according to evaluation criteria, and then construct a performance evaluation vector O_i of i-th candidate enterprise as follows:

$$O_i = (o_i(1), o_i(2), \cdots, o_i(n)), (i = 1,2,\cdots,m) \tag{5}$$

Secondly evaluate the optimal performance value of each index according to the optimal performance criteria by experts, and then construct the optimal performance vector O_0 as follows:

$$O_0 = (o_0(1), o_0(2), \cdots, o_0(n)) \tag{6}$$

Subsequently, calculate the relational coefficient $\xi_{0,i}(k)$ between O_0 and O_i at the k-th index as following:

$$\xi_{0,i}(k) = \frac{\min_i \min_k |o_0(k) - o_i(k)| + \zeta \max_i \max_k |o_0(k) - o_i(k)|}{|o_0(k) - o_i(k)| + \zeta \max_i \max_k |o_0(k) - o_i(k)|} \tag{7}$$

Where ζ is the resolution coefficient, and its value varies from 0 to 1. In the paper, the value of ζ is equal to 0.5 fixedly.

Therefore the weighted relational grade value of i-th candidate enterprise (i.e., g_i) can be calculated as follows:

$$g_i = \sum_{j=1}^{n} \xi_{0,i}(k) \times w_j \tag{8}$$

Where w_j is the entropy weight of j-th index as shown in formula (3).

Then obtain the entropy weighted relational grade vector G as follows:

$$G = (g_1, g_2, \cdots, g_i), (i = 1,2,\cdots,m) \tag{9}$$

Eventually it is easy to decide the best one among all candidate enterprises according to its highest ranking of the relational grade on overall performance evaluation.

7.4 Application and Example

In order to illuminate the application of this method, an example is given below. A certain manufacturer wants to decide the best one among four candidate food cold chain logistics enterprises as long-term supplier according to overall performance. For that, the manufacturer applies the method mentioned above to supplier selection decision (Ruchun, 2007).

7.4.1 Performance Evaluation Index System

Considering the specialties of food and characteristics of cold chain logistics, the paper establishes a performance evaluation index system of food cold chain logistics enterprise, which includes eight operational indexes and eight cold chain indexes as shown in Table 7-1.

Table 7-1 The performance evaluation index system of food cold chain logistics enterprise

Operational Indexes	Evaluating Variables	Cold Chain Indexes	Evaluating Variables
Management Ability	u_1	Technical Equipment	u_9
Supply Flexibility	u_2	Cold Chain Network	u_{10}
Response Speed	u_3	Frozen Processing and Packaging	u_{11}
Product Diversity	u_4	Frozen Storage	u_{12}
Service Capacity	u_5	Frozen Transportation and Distribution	u_{13}
Informatization Degree	u_6	Raw Material Supervision	u_{14}
Financial Situation	u_7	Food Quality	u_{15}
Price level	u_8	Food Safety	u_{16}

7.4.2 Supplier Selection Decision

To describe the performance evaluation briefly and effectively, the 10-grade marking system can be used for evaluation value. Then experts are invited to give the evaluation values for all sixteen indexes $u_i (i = 1,2,\cdots,16)$ through Delphi method. After normalization, the performance evaluation value of each index for four candidate food cold chain logistics enterprises are listed in Table 7-2.

Table 7-2 The performance evaluation value of each index for four candidate enterprises

Enterprise	The performance evaluation value of each index															
	u_1	u_2	u_3	u_4	u_5	u_6	u_7	u_8	u_9	u_{10}	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}	u_{16}
A	9	7	7	7	7	9	7	7	6	7	7	9	10	7	7	9
B	10	8	7	8	8	9	9	7	7	9	8	9	7	9	10	6
C	9	10	8	7	9	10	9	9	7	9	8	7	9	6	8	9
D	9	10	8	8	9	10	7	9	7	8	9	8	10	8	7	8

Hence, the performance evaluation matrix O can constructed according to the formula (1) as follows:

$$O = \begin{Bmatrix} 9 & 7 & 7 & 7 & 7 & 9 & 7 & 7 & 6 & 7 & 7 & 9 & 10 & 7 & 7 & 9 \\ 10 & 8 & 7 & 8 & 8 & 9 & 9 & 7 & 7 & 9 & 8 & 9 & 7 & 9 & 10 & 6 \\ 9 & 10 & 8 & 7 & 9 & 10 & 9 & 9 & 7 & 9 & 8 & 7 & 9 & 6 & 8 & 9 \\ 9 & 10 & 8 & 8 & 9 & 10 & 7 & 9 & 7 & 8 & 9 & 8 & 10 & 8 & 7 & 8 \end{Bmatrix}$$

Then the entropy weight vector can be obtained as follows:

$$W = (0.135, 0.089, 0.085, 0.084, 0.044, 0.034, 0.080, 0.082, 0.033, 0.081, 0.037, 0.043, 0.036, 0.042, 0.058, 0.037)$$

Subsequently, the optimal performance vector O_0 can be constructed by experts according to the optimal performance criteria as follows:

$$O_0 = (10,10,9,9,9,10,9,9,10,9,9,10,10,9,10,10)$$

Therefore the entropy weighted relational grade vector G can be obtained as follows:

$$G = (0.601, 0.776, 0.797, 0.775)$$

Eventually, it is easy for the manufacturer to decide that enterprise C is the best one among four candidate enterprises on performance evaluation due to its highest relational grade value.

7.5. Conclusion

The study investigates the performance evaluation of food cold chain logistics enterprise, and proposes a comprehensive evaluation method combined with the entropy weight method and grey relational analysis, and then applies it to supplier selection decision. The application example verifies the applicability and effectiveness of the proposed method. It makes relatively objective evaluation which helps to select and decide the highest performance supplier effectively. Future research will focus on continuous improvement of performance evaluation index system and various methods under more complicated conditions.

7.6 References

[1] Chunyu, R., and Xiaobo, W. (2006) Study on the third party logistics performance evaluation system based on FCE, Logistics Sci-tech, Vol.29, No.6, 40-42.

[2] Hongyan, S., and Xuanxi, N. (2005) The performance evaluation of 3PL enterprises based on the AHP model of multiplicative synthesis, Sci-Tech Progress and Policy, Vol.22, No.11, 94-96.

[3] Jing, X., Dongjie, Z. and Ziyu, L. (2008) Research on construction of our country food cold chain logistics management system, Journal of Agriculture Mechanization Research, No.7, 13-17.

[4] Ruchun, D. (2007) Cold Chain Logistics Operation Practice. China Logistics Publishing House, Beijing.

[5] Xinqing, X., Junmo, C. and Baoliang, Y. (2005) Study of choosing third party logistics serves based on BP neural network, East China Economic Management, Vol.19, No.9, 85-88.

[6] Xiuyun, G. (2004) Application of gray correlation method on regional competitiveness evaluation, Statistics and Decision, No.11, 55-56.

[7] Yunling, L., Jinghuan, L. and Ling, B. (2008) Study on integrated performance evaluation index system of food cold chain, Market Modernization, No.17, 156-157.

[8] Zhijie, L., and Yingjun, H. (2007) Research on constructing food stuff cold chain in china, Ecological Economy, No.11, 124-126.

8 Representative Achievement 7: Temperature and Quality Changes of Pasteurized Milk during Refrigerated Distribution

8.1 Abstract

To investigate temperature and quality changes of pasteurized milk during refrigerated distribution, parameters of distribution temperature and time were obtained by means of measuring the distribution vehicles. Then the total number of bacteria colony, acidity and protein content of pasteurized milk were investigated in the conditions of 8℃ and 10℃ with the control group of 2℃. The results showed that the temperature of at the doorway and in the center of carriage would be lower than that of innermost, as well as quality change would have been speeded up after 12 hours' distribution.

8.2 Introduction

The low-temperature sterilization technology used to pasteurized milk can prevent the nutritional content of milk from being washed away to the maximum extent. So, it is favored by more and more consumers and accounts for about 50 percent of the liquid milk sales. However, because pasteurization can not kill all of spores and high yeast in milk, cold-chain technology must be used in the process of storage, transportation and sales. If low temperature can not be maintained, the spores in milk will be the resumption of breeding. As a result, toxic substance is likely to produce and increase the poisoning risk to consumers. Distribution linking production with sale is an important part of milk Cold-chain. In the distribution process, interior temperature is very difficult to control accurately and increase the risk of the quality changes of pasteurized milk because of the larger changes in the external environment and continuing to open and close the door. In addition, interior temperature distribution and delivery time may also affect the quality of milk. At present, few related research is reported. In this paper, the temperature and quality changes of pasteurized milk are investigated in the actual distribution and some suggestions are presented for the pasteurized milk safe delivery.

8.3 Materials and methods

8.3.1 Experimental Materials

Pasteurized milk: Bagged, product label for the shelf life of 5d under 0~4 ℃.

8.3.2 Main Instruments and Equipments

- PetrifilmTM the total number of bacteria colony fast testing film;
- ZDR-20 intelligent temperature-recording instrument;
- SW-CJ-1F cleansed worktable;
- LRH-150 biochemical incubator;
- YX2808 vapor sterilization pot;
- JA2003 electronic analytical balance and 752 uv-visibal spectrophotometer.

8.3.3 Experimental Methods

- Tracking of temperature of distribution

The refrigerated distribution vehicles are detected following a larger-scale dairy production enterprise. There are nineteen distribution points. Four intelligent temperature-recording instruments are used. One is used to record the change of air temperature besides the door of the carriage and others are used to record milk temperature change of internal part, center part, and doorway of the carriage. Temperature-recording instrument is regulated with a mixture of ice water before measurement and time interval is 1 minute.

- Temperature changes simulation

Five samples of milk are random extracted to measure the total number of initial bacteria, acidity and protein content, and other samples are putted in the middle of three thermotank(the control group temperature setting 2□, the two experimental groups temperature setting according to 2.3.1 tracking records). Five random samples are extracted from every thermotank after 4 hours, 8 hours, 12 hours, 16 hours, 20 hours and 24 hours to measure the total number of bacteria colony, acidity and protein content.

8.3.4 Detection Method

The total number of bacteria colony is counted by PetrifilmTM total number of bacterial colony fast testing film method; the acidity is tested by titration method and protein content is measured by Coomassie Brilliant Blue G250 method.

8.4 Results and Discussion

8.4.1 Temperature Change during Distribution

According to the quality requirement of product, the distribution needs under 2 ~ 4 ℃, but in the actual distribution process, delivery personnel normally consider the time, the external environment temperature, energy consumption and other factors. This company sets distribution temperature to 8 ℃ according to the characteristics of the urban area of Guangzhou. When outside temperature reaches 25 ~ 32 ℃, the air temperature and the milk temperature changes at the doorway are shown in Figure 1, and the milk temperature changes in the innermost part and the center part of carriage are shown in Figure 2. As the door of carriage opens and shuts for discharge when the vehicle arrives at a distribution location, the time interval and temperature will affect the air temperature of carriage doorway and milk temperature. As shown in Figure 1, the temperature fluctuations of doorway of carriage are very frequent and extent of fluctuation is tremendous. The greatest range of fluctuation is more than 20 ℃. However, even if temperature fluctuations of carriage door are large, because of shorter unloading time (an average of 5 min), milk temperature still can be remained at about 8 ℃. From the Figure 2, milk temperature of carriage center part remained at about 8 ℃, yet the fluctuation of milk temperature is larger in the innermost part of carriage. With the unloading operation, the door is opened frequently, milk temperature in the innermost of carriage rises from around 8.5 ℃ to around 12 ℃ after 3 hours. while pasteurized milk heat exchange with the cold air increased with the reduction in cargo, the milk temperature drops and finally stabilized at around 10 ℃. Average milk temperature in the innermost of carriage remains around 10 ℃ during the whole distribution process. Such variation may be due to the top air supply means of refrigerated trucks. The temperature at the doorway and in the center of carriage is closer to the setting temperature 8 ℃, and the temperature is higher in the innermost of carriage where return air intake location.

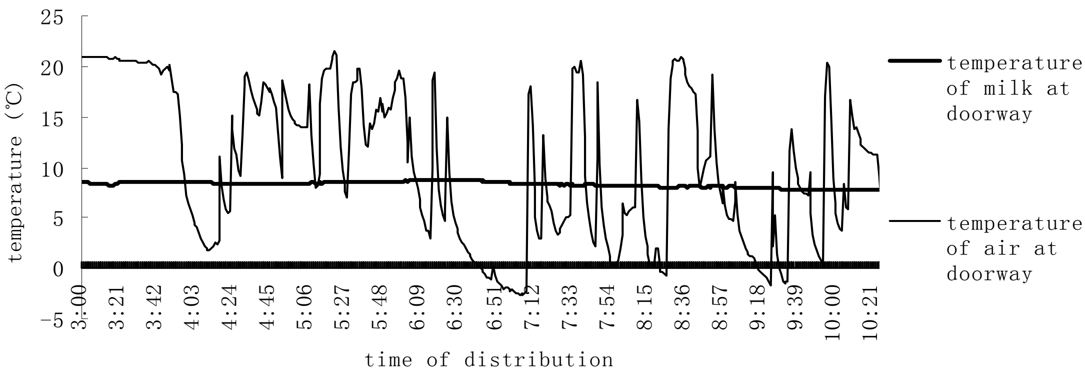

Figure 1 Changes of milk and air temperature at the doorway

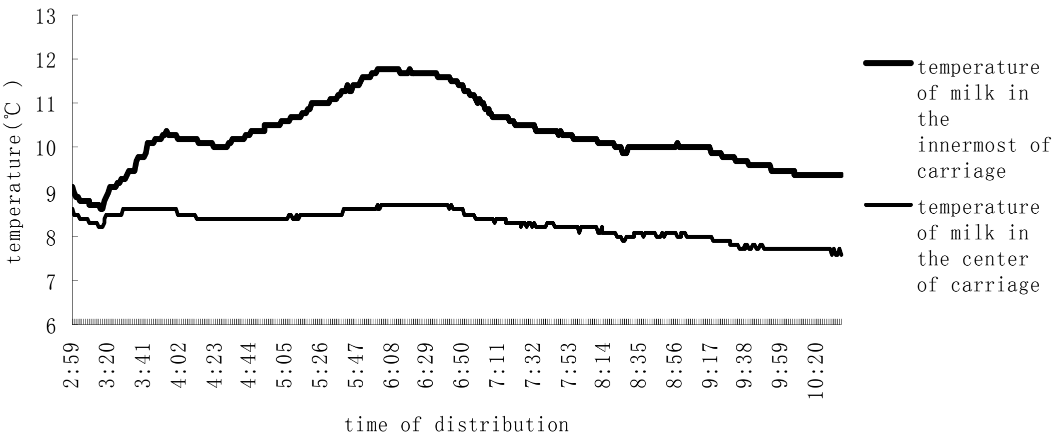

Figure 2 Changes of milk temperature in the center and in the innermost of carriage

8.4.2 Change of the Total Number of Bacteria Colony

Microbial in pasteurized milk keeps growing and reproduction during the frozen period and spoilage of milk mostly caused by the bacteria, the total number of bacteria colony can be used to evaluate the extent of microbial decomposition of the milk. The temperature of the two experimental groups were set to 8 ℃ (the milk temperature is simulated at the entrance and central part of carriage) and 10 ℃ (the milk temperature is simulated at the innermost part of carriage). The experimental results are shown in Figure 3, the total number of bacteria colony increases with the distribution time. As a control group (2 ℃) of milk samples, the total number of bacteria colony changes very little with prolongation of the distribution time. The total number of bacteria colony at the doorway and in the middle of carriage begins to substantially increase after 16h. However, the total number of bacteria colony in the innermost of carriage begins to substantially increase after 12h and the rate of increase is significantly higher than the milk samples at the doorway and in the middle of carriage. So, from the total number of bacteria colony stability point of view, the distribution time of pasteurized milk at 8 ℃ should be controlled in less than 12h.

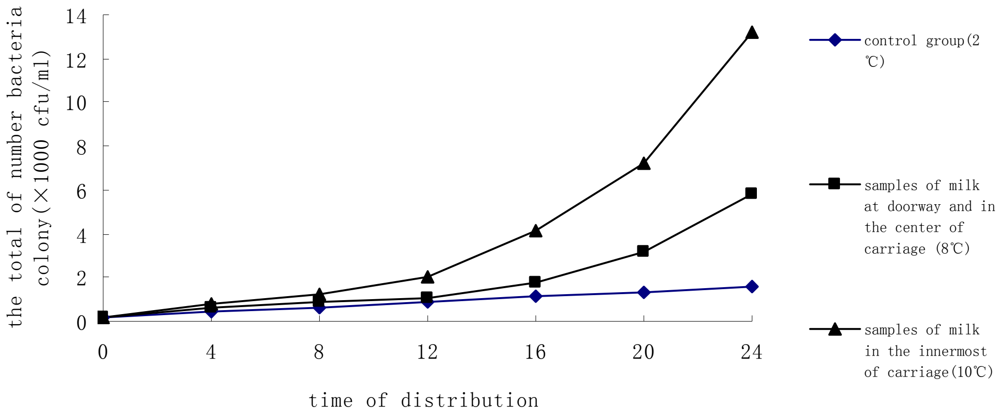

Figure 3 Change of the total number of bacteria colony in milk at different parts of carriage during distribution

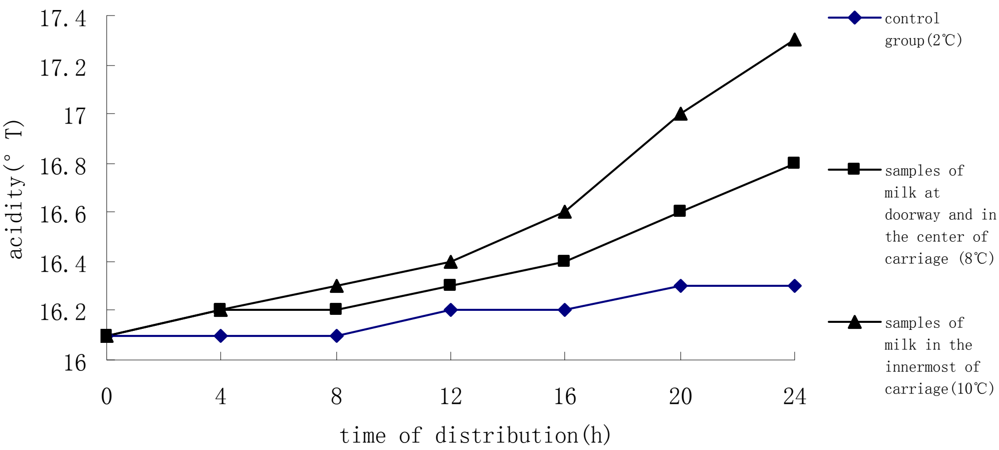

Figure 4 Change of acidity of milk samples in different parts of carriage during distribution

8.4.3 Change of Acidity during Distribution

Evaluation of milk acidity is the main indicator of quality of milk. After bacteria in milk grow and reproduce, it will break down the lactose in milk and produce lactic acid to increase the acidity of milk. The experimental results of changes of acidity in pasteurized milk during distribution are shown as Figure 4. As a control group (2 ℃) of milk samples, milk acidity increases slightly with the distribution time. The milk acidity at the doorway and in the center of carriage begins to substantially increase after 16h. However, the milk acidity in the benmost of carriage begins to substantially increase after 12h. The rate of increase was significantly higher than the milk samples at the doorway and in the center of carriage. So, from the milk acidity stability point of view, the distribution time of pasteurized milk at 8 ℃ should be controlled in less than 12h.

8.4.4 Change of Protein Content during Distribution

The protein content of the control group, doorway, center and innermost change little within 24h under the experimental conditions. It is maintained at around 2.95%. It is shown that the protein content is steady under the distribution conditions.

8.5 Conclusions

The total number of bacteria, acidity and protein content of pasteurized milk refrigerated under 2 ℃ remain the basic stability during the 24h. The result is basically coincided with document 6. The milk temperature of different parts of carriage with top air supply means are uneven during refrigerated distribution of pasteurized milk. The milk temperature at the doorway and in the center of carriage is lower than the milk temperature in the innermost of carriage. So, milk should be avoided to stack in the innermost of carriage but loaded at the doorway and in the middle of carriage. When Outside temperature is 25 ~ 32 ℃ and the temperature of refrigerated truck is set to 8 ℃ during refrigerated distribution of pasteurized milk, the acidity and the total number of bacteria colony of pasteurized milk begin to significantly change after 12h, but the protein content has little change all along. Also, due to different temperature at different parts of carriage, the quality of milk at the innermost parts of carriage varies quicker than that at the doorway and in the center of carriage, distribution time is appropriate to not more than 12h.

8.6 References

[1] Ding Ruchun, (2007). Cold chain logistics operations. China Material Press, Beijing.

[2] Chen Jinhan, Pang Jie, Gong Jiashun, (2007). Food logistics. China Light Industry Press, Beijing.

[3] Institute of light industry of Dalian, (1994). Food analysis. China Light Industry Press, Beijing.

[4] Chen Junhui, Tao Li, Li Jun, etc, (2003). Biochemistry experiments. Science Press, Beijing.

[5] M.H.Zwietering, J.C. de Wit, S. Notermans, (1996). Application of predicative microbiology to estimate the number of Bacillus cereus in pasteurized milk at the point of consumption. Int.J.Food Microbiology. Vol.130, 55-70.

[6] Gu Xuelian, Hua Zhao, (2005). Study on the quality effect of milk during refrigeration. Journal of Refrigeration. Vol.26, No.4, 48-50.