A Simulation Technique for the Refrigerating Cycle of Canned Drink Vending Machines

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1. Introduction

Fuji Electric is one of the leading manufacturers worldwide of vending machines, especially canned drinks vending machine. These vending machines are equipped with more than fifty different types of refrigeration systems.

Refrigeration is one of the fundamental functions of canned drink vending machines. Cold drinks are stored at temperatures below 4°C. In addition to cold drinks, hot canned drinks such as coffee and tea are also popular in Japan. Cold and hot drinks are both served from the same vending machines in Japan. During the winter, both cold and hot drinks are sold together in one vending machine. To achieve this functionality, the storage space inside vending machines is separated into to several compartments. During the winter, some compartments are kept hot (over 70°C in the heating mode), while the rest are kept cold (cooling mode). During the summer, all compartments are operated in the cooling mode. This type of canned drink vending machine is most common in Japan. However, separate storage compartments have to be refrigerated individually.

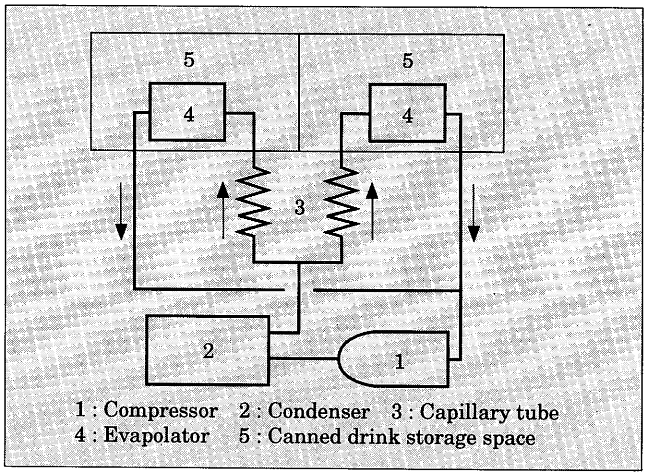
Recently, the refrigerant used in vending machines has been replaced with one that does not harm the ozone layer. The reduction of electric power consumption and shortened design time are also goals of refrigeration system design. Required development items are listed below.

(1) Individual refrigeration systems for each separate storage compartment
(2) Refrigeration systems that operate with CFC (chlorofluorocarbon) alternatives
(3) Electric energy saving
(4) Shortened design time

To develop a refrigeration system that meets these requirements, Fuji Electric has developed a simulation technique for the refrigeration cycle. This simulation technique has enabled a high quality refrigeration system to be designed easily.

Applying this simulation technique, we can estimate the steady state refrigerating cycle and optimum values for the amount of refrigerant, length and diameter of the capillary tube, etc can be estimated.

Fig.1 Typical refrigerating system for canned drink vending machine



In this paper, the calculation method of the simulation technique is introduced, and calculated results are compared with experimental ones. Application of this technique to practical vending machine design is also explained.

2. How This Simulation Technique Helps our Design of Refrigerating Cycles

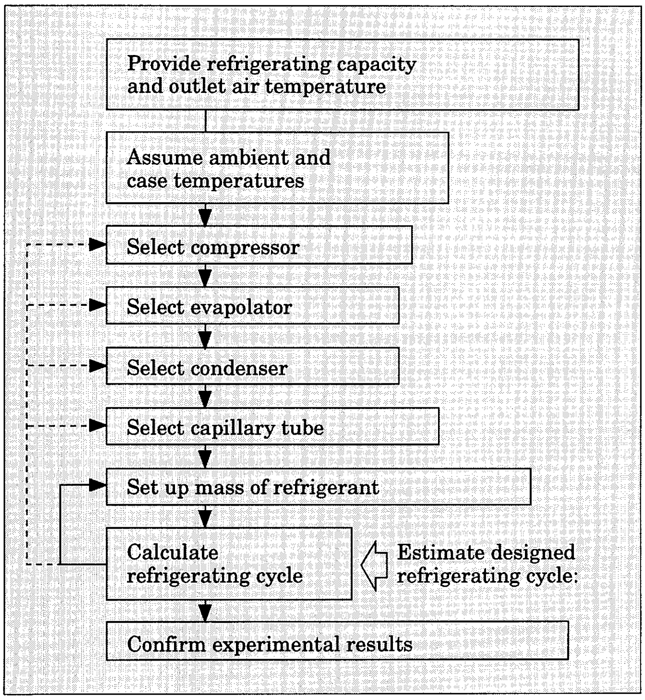
Refrigerating systems consist of four main components; a compressor, condenser, capillary tube and evaporator. Because the vending machines in Japan are equipped with separate storage compartments as mentioned above, each compartment is provided with its own evaporator and capillary tube, so that the compartments can be operated in either heating or cooling modes by turning on or off the electromagnetic valves.

Figure 2 shows the outline of the design process for a refrigeration system.

The first step in designing a vending machine refrigeration system is to determine the compressor, condenser and capillary tube sizes necessary to realize the required refrigeration for cooling canned drinks in the storage compartments.

Next, the amount of refrigerant is estimated.

Fig.2 Refrigerating system design method



Applying the refrigerating cycle simulation technique, the refrigerating capacity is calculated. The amount of refrigerant is varied until the refrigerating capacity is maximized under the selected conditions.

If the combination of the selected compressor, condenser and capillary tube does not satisfied the required refrigerating capacity, new values of these refrigeration components are selected. Same processes are repeated until the most suitable combination of components is achieved.

3. Advantages of Applying this Simulation Technique

The advantages of application of this simulation technique are summarized below.

(1) Optimum selection of refrigeration components

The best combination of refrigerating system components that meets the required refrigerating capacity for cooling canned drinks can be determined.

(2) Calculation of steady state operating condition

The steady state operating condition of the refrigerating cycle can be calculated. The refrigerating capacity, electric power consumption, etc., for the vending machine operating conditions can be obtained.

(3) Determination of optimum amount of refrigerant

In refrigerating system with capillary tubes, the capacity of the system varies widely for different amounts of refrigerant. By applying simulation technique, the optimum amount of refrigerant can be determined.

(4) Design of new system that operates with new fluorocarbons

A refrigeration system can be designed that operates with CFC alternatives (HCFC-22 , HFC-134a).

(5) Design of a refrigeration system with dual evaporators

The refrigerating capacity of each evaporator can be calculated.

Table 1 Experimental compressor data

Evapolation pressure P_e (MPa)	Condension pressure P_c (MPa)	Ambient temp. T_a (°C)	Flow rate G_m (g / s)	Outlet temp. T_m (°C)
0.16	1.02	25.0	1.10	58.9
0.23	1.02	25.0	1.63	62.6
0.35	1.02	30.0	2.71	62.9
0.16	1.02	30.0	1.04	62.5

4. Simulation Method

4.1 Calculation of compressor data

The compressor capacity is estimated based on the experimental data shown in Table 1. Selecting the pressures in evaporator *Pe* and in compressor *Pc*, and the ambient temperature *Ta* as independent valuables, we can obtain the flow rate of refrigerant (*Gm*) , outlet temperature (*Tm*), and refrigerating capacity (*Q*) according to formulas (4.1) through (4.3), determined through regression analysis.

$$Gm = C_1+C_2Pe+C_3PePc+C_4Pe_2 \quad \cdots\cdots\cdots(4.1)$$

$$Q = C_5+C_6Pe+C_7PePc+C_8Pe_2 \quad \cdots\cdots\cdots(4.2)$$

$$Tm = (C_9+C_{10}Ta)\,(C_{11}+C_2Pe+C_{13}Pc) \quad \cdots\cdots\cdots(4.3)$$

C_1, C_2..., C_{13} are constants determined from the data in Table 1.

4.2 Calculation of condenser and evaporator data

The flow rate and inlet temperature from compressor to condenser are obtained from the calculated results of compressor data. The heat transfer rate inside the condenser can be calculated from the fin to air heat transfer coefficient and the condensation heat transfer coefficient inside the tube. As a result, the refrigerant temperature at the condenser outlet can be obtained.

We can execute all calculations in evaporator in same manner.

4.3 Calculation of capillary tube data

Figure 3 shows a schematic model of the refrigerant flow in a capillary tube. Liquid refrigerant flows into the capillary tube and vaporizes. The refrigerant velocity increases and its temperature decreases as it flows downward. At the end of capillary tube, the velocity reaches the speed of sound. Figure 4 shows the flowchart used to calculate the refrigerant flow rate. The refrigerant temperature and pressure at the entrance of the capillary tube are obtained from the calculation results for condenser data. The refrigerant flow rate is determined such that the refrigerant velocity becomes equal to the speed of sound at the end of the capillary

Fig.3 Phase change of refrigerant in capillary tube

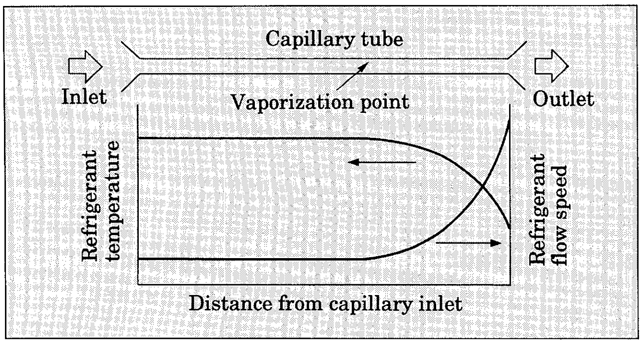
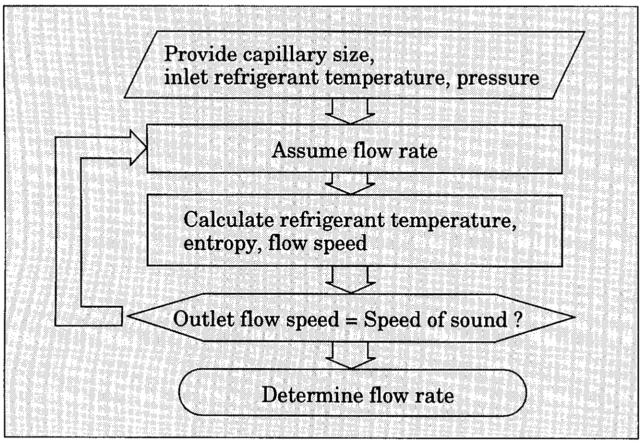


Fig.4 Flowchart of capillary tube calculation



tube.

5. Simulation Technique of Refrigeration Systems

The procedure to combine the calculated results for each component and to calculate the capacity of the refrigerating cycle is explained here. Figure 5 shows a flowchart of the simulation method. The operating conditions of component size, amount of refrigerant R0, ambient temperature and the temperature inside the compartments are given for working conditions.

First, initial values of capillary inlet temperature T0, pressure in evaporator P1 and pressure in condenser P2 are tentatively assumed. The values of these three variables are not given, and will vary according to the calculations below. Calculations of data for the capillary tube , evaporator, compressor and condenser are performed successively. As a result, the capillary inlet temperature T1, flow rate at capillary tube G1, flow rate at compressor G2, and calculated amount of refrigerant R1 are obtained. If the combination of selected values T0, P1 and P2 does not satisfy the required operation conditions, the calculated deviations T0-T1, G1-G2 and R0-R2 are not negligible.

If any calculated deviation exceeds the allowable tolerance, the values T0, P1 and P2 will be determined again by Newton's Method. Corrective calculations repeated until the relations T0=T1, G1=G2 and R0=R2 are satisfied. The calculation is finished when the deviation of each value is within the allowable tolerance.

6. Refrigerating Cycle with Dual Evaporators

Figure 6 shows a flowchart for calculating a dual

Fig.5 Flowchart of simulation technique 1 calculation

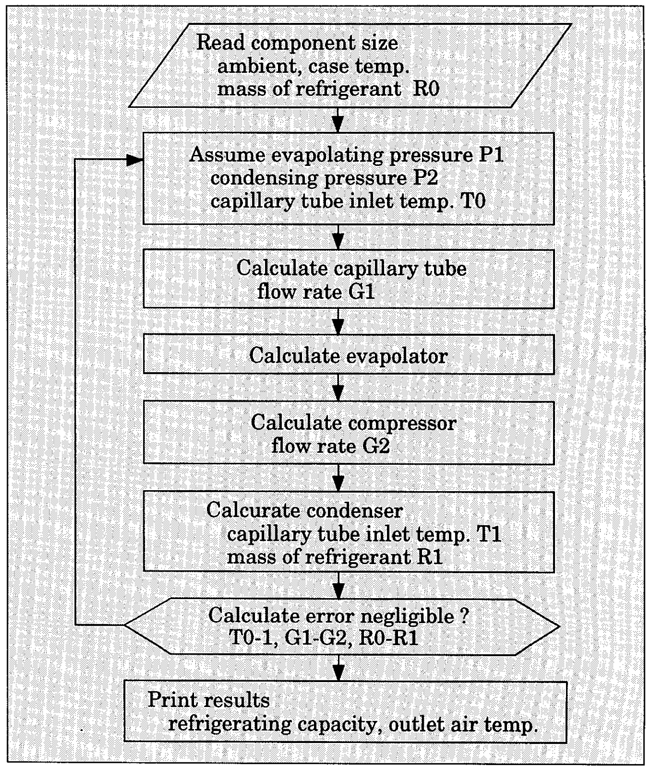


Fig.6 Flowchart of simulation technique 2 calculation (dual evaporators)

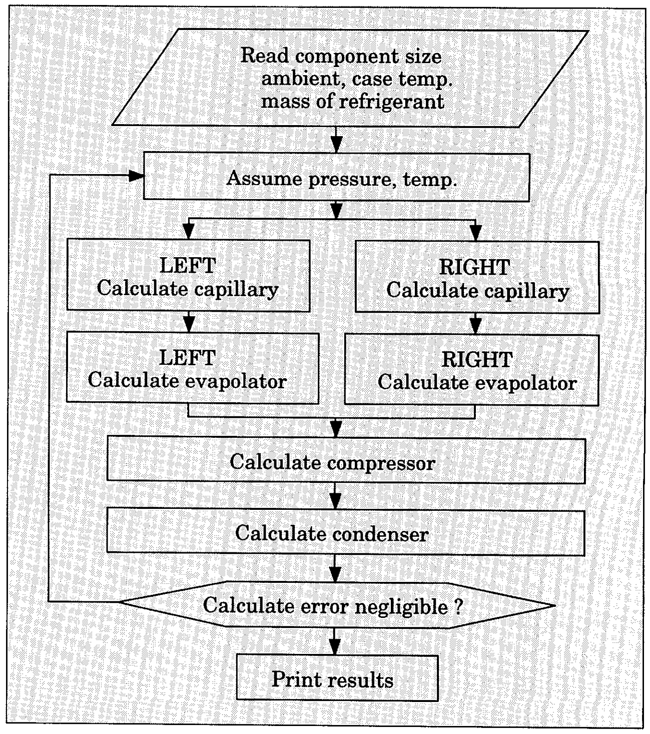
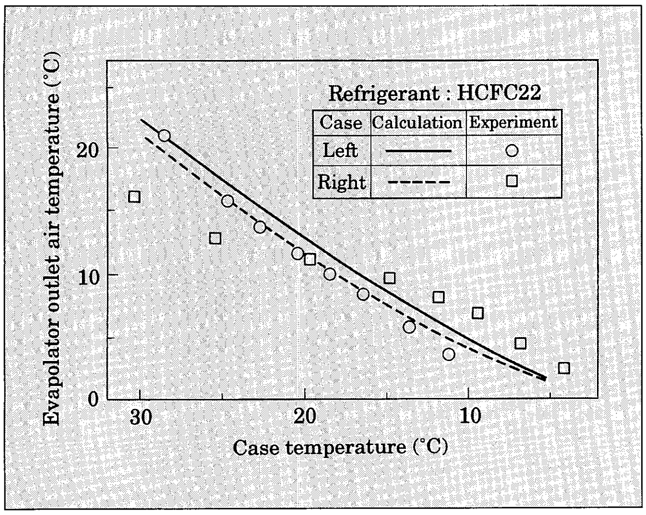


Table 2 Results of refrigeration simulation

Item		Experiment	Calculation
Condensing temp. (°C)		36	36
Evapolation temp. (°C)		−8.3	−8.3
Flow rate (g / s)		3.7	3.9
Condenser refrigerant condition (%)	Gas area	6	8
	Gas + liquid	95	92
	Liquid area	0	0
Left evapolator condition (%)	Gas + liquid	100	100
	Gas area	0	0
Right evapolator condition (%)	Gas + liquid	100	96
	Gas area	0	4
Evapolator outlet temp. (°C)	Left	2.5	3.2
	Right	5.2	2.9
Refrigerating capacity (W)	Left	267	274
	Right	266	265

Fig.7 Calculation results of evaporator outlet air temperature



evaporators system. Calculations of the refrigerating capacity and flow rate are performed for both right and left compartments individually.

7. Simulation Results

Table 2 shows a comparison of simulation results with experimental data. The calculated condensing temperature, evaporating temperature and flow rate correspond closely to the experimental data. The data actually converged after repeating the calculations of 10 to 20 times.

Figure 7 shows the calculated results of air temperature at the outlet of the evaporator when the temperature in the storage compartment is lower than the ambient temperature.

Figure 8 and 9 indicate condensing temperature, evaporating temperature and flow rate. The amount of refrigerant is varied in Fig. 8 and the capillary tube length is varied in Fig. 9.

When the refrigerating cycle does not satisfied the

Fig.8 Refrigerating cycle characteristics 1
(Amount of refrigerant is varied)

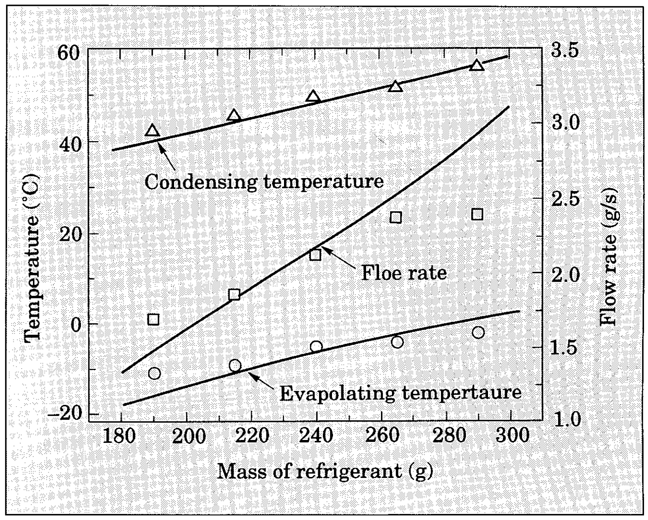
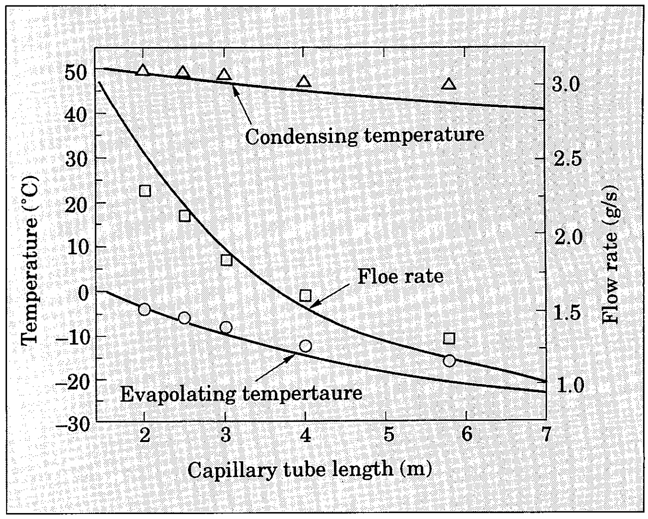


Fig.9 Refrigerating cycle characteristics 2
(Capillary tube length is varied)



required refrigerating capacity, the simulation technique can be applied by changing the amount of refrigerant or the capillary tube length as shown in Figs. 8 and 9, so that an optimum refrigerating system can be designed.

8. Conclusion

Fuji Electric has developed a simulation technique for the refrigerating cycle of automatic canned drink vending machines. By applying this simulation technique, the optimum refrigerating cycle for a specified automatic vending machine can be designed. Calculated results closely correspond to the experimental data. Not only can the best combination of components for the refrigeration system be determined, but the optimum mass of refrigerant, and operating conditions of the refrigerating cycle can also be realized. Further, it is also possible to estimate the capacity of the refrigerating cycle even from the design phase.