Experimental Analysis of Falling Film Evaporator Applied in Centrifugal Chillers

Hua Liu, Dongbing Hu, Sheng Wang, Ying Zhang
State Key Laboratory of Air-conditioning Equipment and System Energy Conservations, China

A new type of evaporator, falling film, was tested, allowing low refrigerant charges. Under certain conditions, the heat transfer performance was better than a for traditional flooded evaporator. The effects of different refrigerant charges, tube pass arrangements and refrigerant types on the falling film evaporator were analyzed. The results showed that with the increase of refrigerant charge, the heat transfer performance was improved gradually, but the trend was gradually slower. The bottom-to-top tube pass arrangement provided a better performance than the top-to-bottom tube pass arrangement. The falling film evaporation centrifugal chiller with R1233zd (E) provided a higher COP when the refrigerant charge reached a certain amount.

Introduction

With the increasingly serious environmental problems, refrigerant replacement and reduction continuation technologies have become important concerns of the current air conditioning industry. Compared to traditional flooded evaporators, the horizontal tube falling film evaporator not only has higher heat exchange performance, but also has the advantages of less refrigerant charge, smaller heat transfer temperature difference, and reliable oil return. With the promotion of new refrigerants, in large or medium-sized chillers, the falling film evaporator may gradually replace the flooded evaporator. At present, many studies have been published on the falling film evaporator and new refrigerants, but most of them focus on the parameters of the liquid distributor, the distribution of the liquid film outside the tube, the flow pattern between the tubes, and single tube experiments [1-6]. There are few studies on the research of the whole unit.

This paper analyzes the performance of the falling film evaporation centrifugal chiller through unit testing. It can provide a background for design, production and promotion of falling film evaporator in chillers.

Experimental setup

Structural description of evaporator

As shown in Figure 1, the internal tube bundle arrangements of the flooded evaporator and that of the falling film evaporator are very different. For the flooded evaporator, the position of the top tubes is at about the center of the shell, and the tube bundles are arranged symmetrically from the left to the right. The refrigerant inlet is arranged at the bottom of the shell, and the gas outlet is at the top. In the falling film evaporator, the falling film distributor is at the top of the evaporator, and the tube bundles under the distributor are arranged

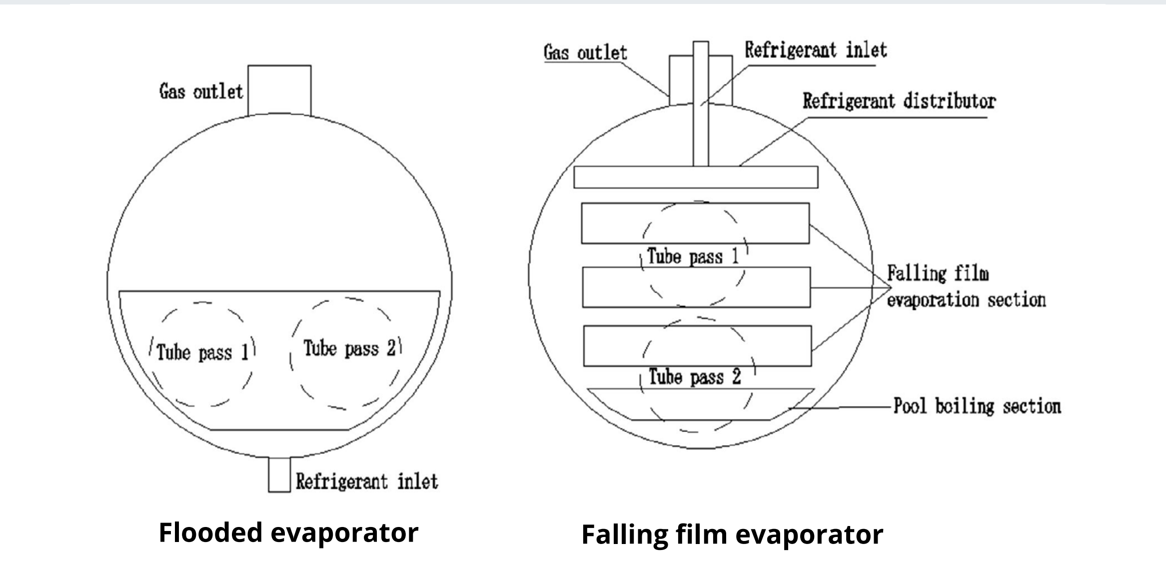

Fig. 1: Schematic diagram of tube bundle layout

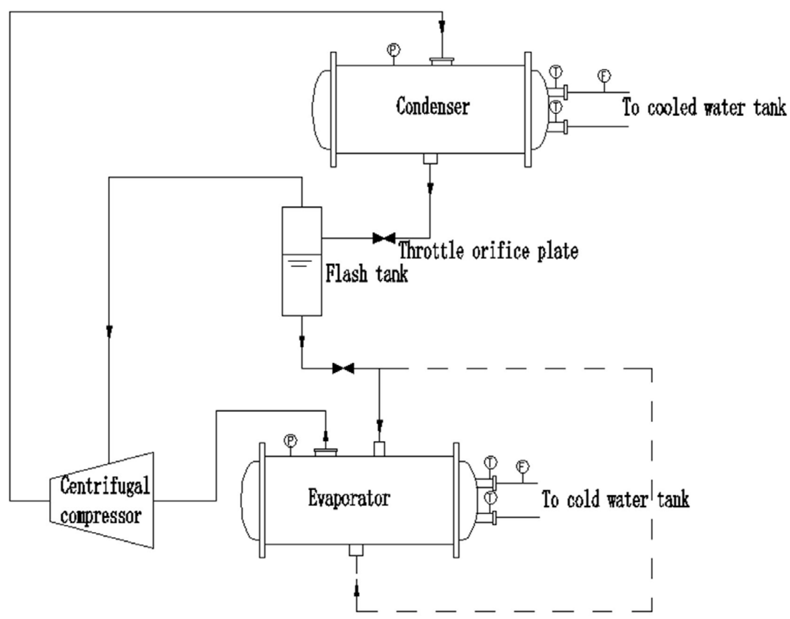

Fig. 1: Schematic diagram of tube bundle layout

symmetrically from top to bottom. The refrigerant inlet and gas outlet are both at the top of the shell.

Experimental apparatus

The sample unit was tested on a 600 RT chiller test bench, as shown in Figure 2. For the falling film evaporator, the refrigerant inlet is at the top, while for the flooded evaporator, the refrigerant inlet is at the bottom (as shown by dashed lines).

Testing conditions

The testing conditions of the evaporator are shown in Table 1.

Enhanced tubes with the same specification and type have been used in all experimental evaporators. The enhanced tubes have a diameter of 19 mm and total heat exchange area of 47.11 m^2. The testing conditions of the unit under nominal conditions based on GB/T 18430.1-2007 are shown as Table 2.

Test sequence	Type of centrifugal Chiller	Refrigerant charge	Tube pass arrangement
1	R134a, flooded evaporator	350kg	left in and right out
2	R134a, falling film evaporator	variable refrigerant charge	Top in and bottom out (top-to-bottom)
3	R134a, falling film evaporator	variable refrigerant charge	Bottom in and top out (bottom-to-top)
4	R1233zd(E), falling film evaporator	variable refrigerant charge	Bottom in and top out (bottom-to-top)

Table 1: Testing conditions of the evaporator

Type of centrifugal Chiller	Evaporator		Condenser	
	Volume flow rate (m^3/h)	Outlet Temperature (°C)	Volume flow rate (m^3/h)	Inlet temperature (°C)
Flooded evaporator (R134a)	211.0	7.0	264.5	30.0
Falling film evaporator (R134a)	211.0	7.0	264.5	30.0
Falling film evaporator (R13233zd(E))	211.0	7.0	264.5	30.0

Table 2: Testing conditions of the unit under GB nominal conditions

Device	Type	Precision
Digital power meter	WT230	±0.1%
Temperature measuring element	Pt100	±0.1 °C
Electromagnetic flow meter	AXF200G	±0.35%
Pressure sensor	AKS33	±0.5%

Table 3: Main testing devices used in the experiments

Cooling capacity (kW)	COP	Evaporation temperature (°C)
1148.0	5.92	5.6

Table 4: Experimental results of flooded refrigeration chiller

Experimental equipment

The main testing devices used in the experiments are shown in Table 3.

Calculation formula

The overall heat transfer coefficient K is calculated as follows:

$$K = \frac{Q}{A \times \Delta T_m}$$

$$A = \pi \times d_o \times L \times N$$

$$\Delta T_m = \frac{T_{in} - T_{out}}{LN\left(\frac{T_{in} - T_o}{T_{out} - T_o}\right)}$$

Where:

Q Heat exchange rate, kW;

A Total heat exchange area, based on the outer surface area of the enhanced tube, m^2;

d_o Outer diameter of the enhanced tube, m;

L Effective length of the enhanced tube, m;

N Number of enhanced tubes;

ΔT_m Logarithmic mean temperature difference, °C;

T_{in} Inlet temperature of chilled water, °C;

T_{out} Outlet temperature of chilled water, °C;

T_o Evaporation temperature, °C.

Results and discussion

Experimental results of flooded evaporation chiller

Experimental results of the flooded evaporation chiller with 350 kg refrigerant charge are shown in Table 4.

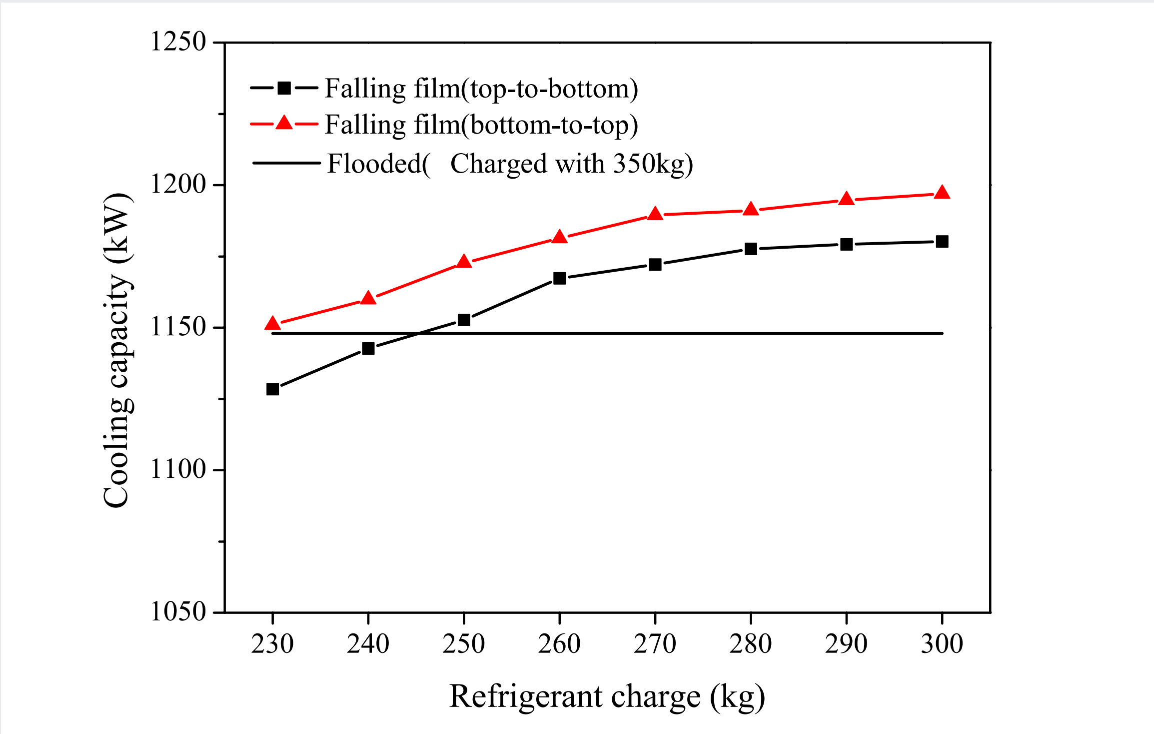

Fig. 3: Comparison of refrigeration capacity as a function of refrigerant charge

Experimental results of falling film evaporation chiller

The flooded and falling film evaporators were tested under the same conditions. The performance of the falling film evaporation chiller, with different tube pass arrangements, including top-to-bottom and bottom-to-top, and of the flooded evaporator, are shown in Figures 3-6.

As shown in Figures 7-10, the cooling capacity, evaporation temperature, COP and overall heat transfer coefficient all increase with the increasing refrigerant charge. However, the cooling capacity and overall heat transfer coefficient of the chiller with R1233zd(E) under the same refrigerant charge are lower than those of the chiller with R134a over the full span of refrigerant charges studied, but they increase rapidly with the increasing refrigerant charge, and the differences between the two refrigerants gradually decrease. The evaporation temperature and COP of the chiller with R1233zd(E) are lower than those of the chiller with R134a when the refrigerant charge is small, but they exceed those of the chiller with R134a when the refrigerant charge reaches a certain value.

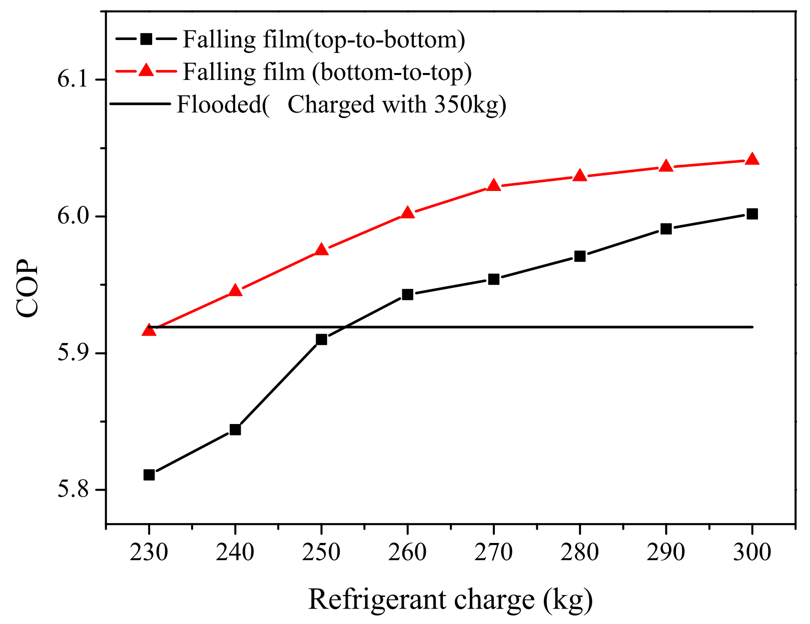

Fig. 4: Comparison of COP as a function of refrigerant charge

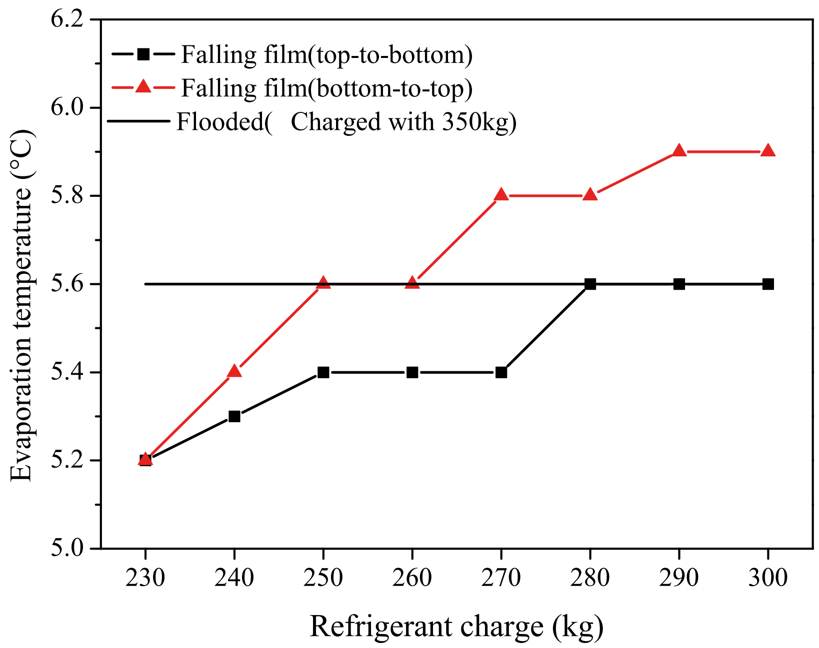

Fig. 5: Comparison of evaporation temperature as a function of refrigerant charge

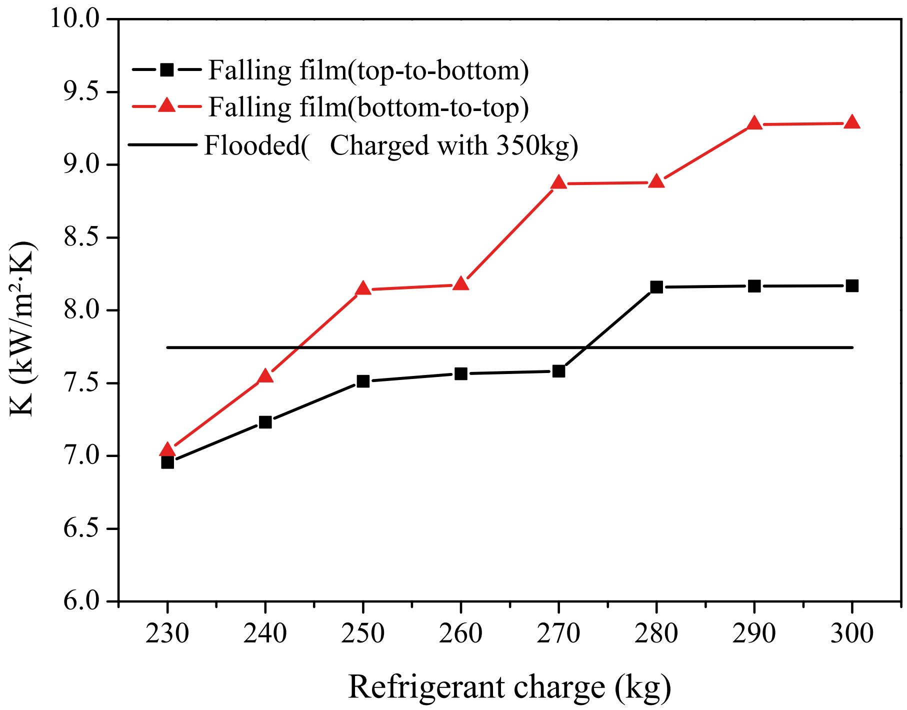

Fig. 6: Comparison of overall heat transfer coefficient as a function of refrigerant charge

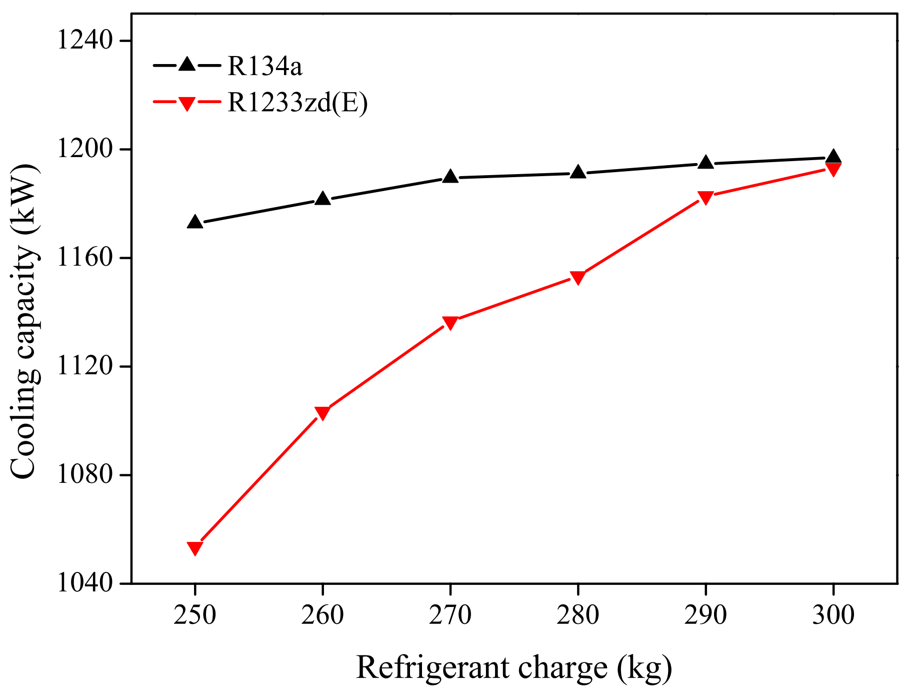

Fig. 7: Comparison of refrigeration capacity for different refrigerants

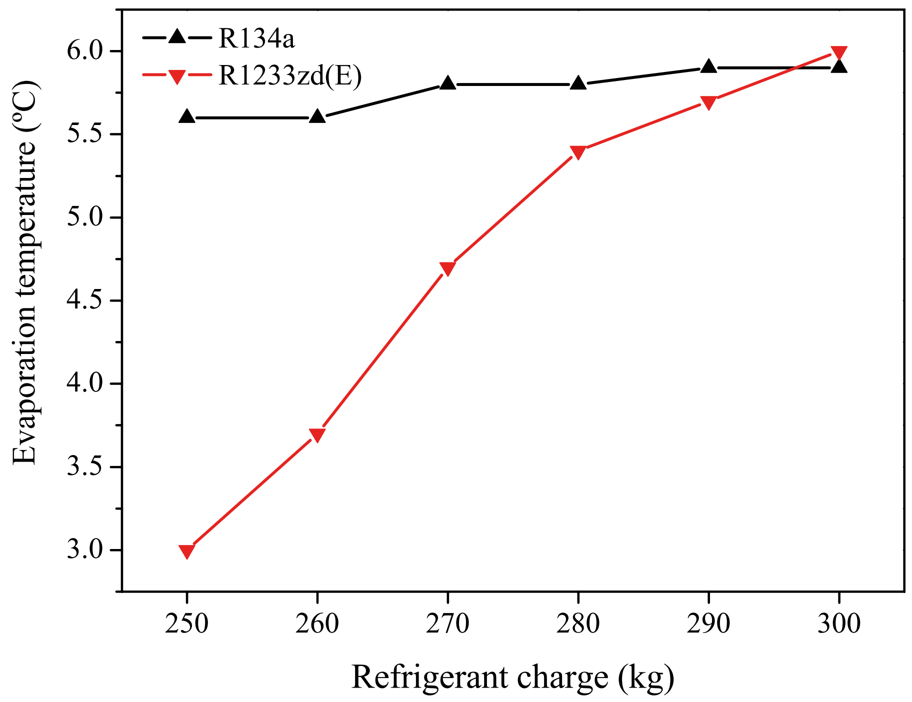

Fig. 8: Comparison of evaporation temperature for different refrigerants

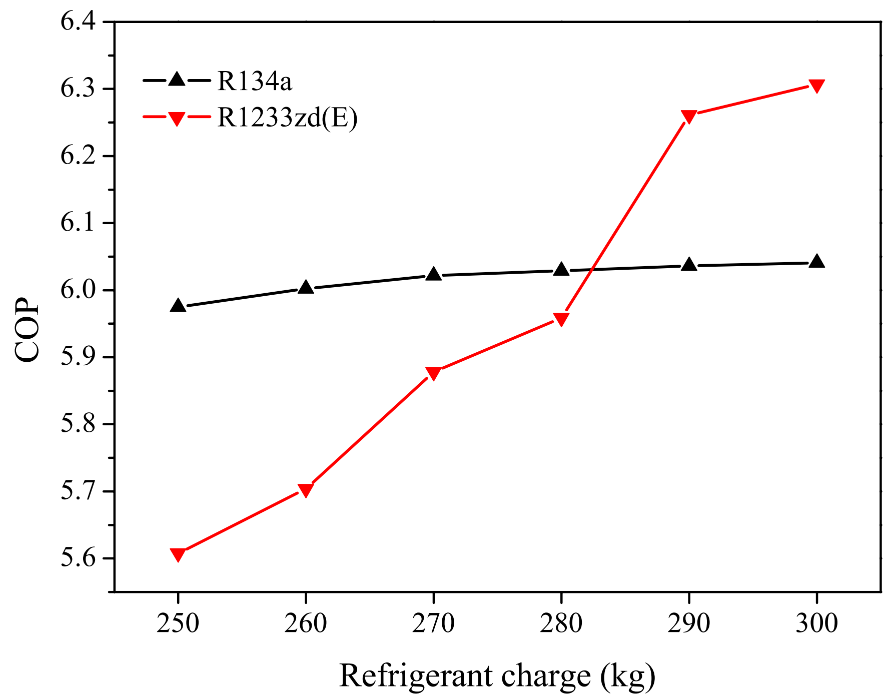

Fig. 9: Comparison of COP for different refrigerants

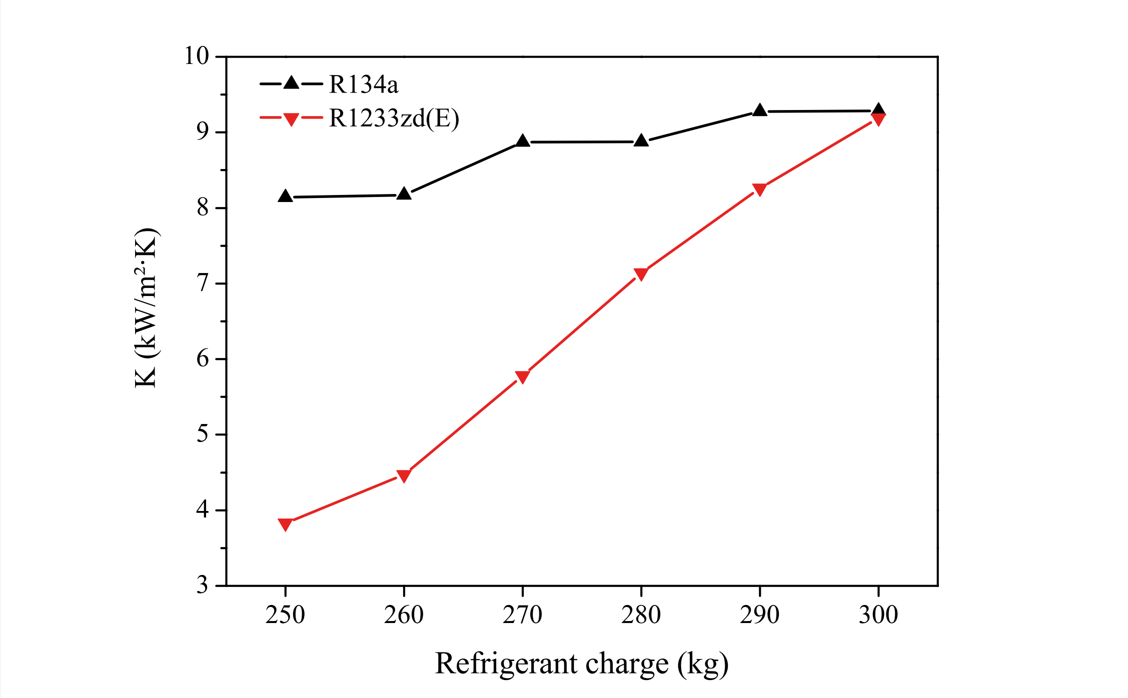

Fig.10: Comparison of overall heat transfer coefficient under different refrigerants

Conclusions

By experimental analysis on the falling film evaporation chillers, the following conclusions can be drawn:

1) As the refrigerant charge increases, the cooling capacity, COP and evaporation temperature of the falling film evaporation chiller gradually increase, but the growth trend decreases;

2) For the falling film evaporation chiller, the bottom-to-top tube pass arrangement gives better performance than the top-to-bottom tube pass arrangement;

3) Providing the same refrigeration capacity, the falling film evaporation chiller needs less refrigerant charge than the flooded evaporation chiller. When the tube pass arrangement of bottom-to-top is adopted, the refrigerant charge can be reduced by 34%;

4) The falling film evaporation chiller with R1233zd (E) has a lower cooling capacity than the chiller with R134a for the same refrigerant charge. And the evaporation temperature and COP of the chiller with R1233zd(E) exceeds the chiller with R134a when the refrigerant charge reaches a certain value.

HUA LIU
State Key Laboratory of Air-conditioning Equipment and System Energy Conservation
China
dgzxwang@163.com
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