Index UDC: 621.5

A Refrigerator Defrosting Device Based on A Single Adsorption Bed Driven by Waste Heat

Yinsheng Yu, Yuqing Tang, Xiuqi Hu, Chuanhang Wang

***Abstract*—The refrigerator frosting have increased the cooling load, the consumption of power, and have affected the quality of the contains. This device uses methanol stored in the liquid storage tank as a vector to recover waste heat of the compressor. And the adsorption bed is driven by the waste heat. The absorption and the desorption process of adsorbent-adsorbate (activated carbon-methanol) can recovery waste heat. Then through convective heat transferring, the heated methanol steam defrost the frost condensed on the evaporator. Thus the energy conservation is realizable. This device has the following advantages: 1.Using the waste heat as the source of the power, so it can reduce the energy consumption caused by the process of defrosting. 2.This device solves the problem that the temperature of the box might rise to such an extent that may decay the contains after defrosting. 3.Compressor's working condition has been improved after the device recovering the waste-heat of compressor. 4.This device have the characters of innovative design, simple structure and low manufacturing cost.**

Keywords: Refrigerator Defrosting, Adsorption Bed, Waste Heat, Heat Transfer, Energy Saving

I. Introduction

A. Background

At present, with the rapid development of industry, the problems of energy shortage and environmental disruption are increasingly severe. At the same time, along with the progress of material civilization, the consumers' awareness of energy conservation and environmental protection are also enhanced. Except considering the safety of products, the requirements for the products' energy conservation more than before.

Since the 21th century, the development of refrigerators has been increasingly improved. However, there are still the frosting phenomenon on the evaporator. According to the statistics in Figure 1, the quantity of household refrigerators has reached 93.37 million by 2014. According to the users' feedback of Chongqing Midea Limited Company and the data which was investigated from 300 residents in Chongqing, the results have revealed that 78.5% of the users are facing the problem of defrosting, and the consumption of defrosting device is the main energy consumption of refrigerators.

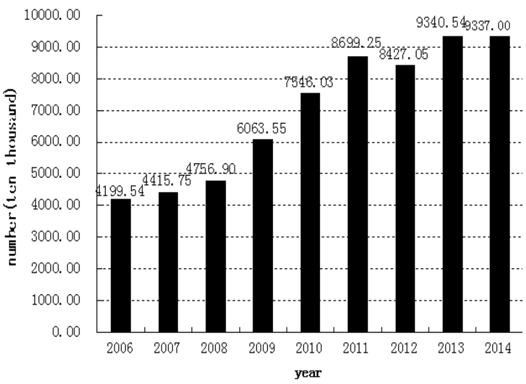


Figure 1. The yearly number of household refrigerators production in China from 2006 to 2014.

B. Significance

The frequent open of the refrigerator door and the aqueous contains are the mainly reasons result in defrosting.The average heat transfer resistance is 0.58w/(m·□), and the value is lower than the copper [372.16W/(m·□)] obviously. According to the data, the energy consumption increase 10% times and 3% times. The average value is 0.0132kw·h/ per day[1,2].

The electricity charge from electric power company is 0.58yuan/kw·h.Thus, the average increasing electricity charge that is due to the power consumption of defrosting is approximately 714840.7yuan yearly in China. As a result, developing the novel device for defrosting is full of market potential and energy efficiency.

C. Status of similar researches

The defrosting problem has plagued the refrigeration industry for a long time, and numerous attempts have been made to solve this problem. The general ways of defrosting at present are manual defrosting, electric heating defrosting and micro hydrophobic materials defrosting [3,5]. There are some disadvantages of ways above. Firstly, for manual defrosting, we need cut off the power and fetch out the box. Except the huge input of labor, time and materials, the contents would be spoiled, or an unsafe temperature condition would exist in the box. Secondly, the heater not only has added extra energy consumption but also has led to potential danger of electric leakage. Thirdly, the manufacturing cost of micro hydrophobic materials is high.

Great importance has been attached to the frost free refrigerator in recent years. Some frost-free refrigerators are not really frost-free. The accumulation of frost on the evaporator is invisible, and refrigerator also has been added heater for defrosting. Some frost-free refrigerators do not install heaters for defrosting, but this kind of refrigerators are in large quantities, and the additional fan increases the manufacturing cost [6,7].

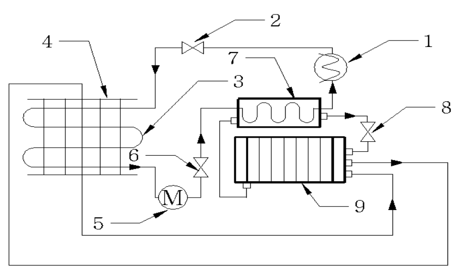
Baojun Mei [8] etc. prevented the refrigerators defrosting by changing the arc angle of groove on the walls of refrigerator. Jinqiang Lu[9]etc. constructed a super-hydrophobic surface which is capable of anti-condensation and anti-freezing. But the previous theoretical systems are not so mature, facing the problem of developing and reducing cost. In order to reduce the rise of the box temperature, Tiehuan Jing [10] etc. fixed storing cistern on the refrigerator. In order to reduce the energy consumption in the process of defrosting, domestic and foreign scholars came up with many novel means for defrosting the evaporator of a refrigerator unit, for example: double evaporator for defrosting, the device for saving energy of defrosting. Because of the high cost, the not ideal effect, and the complexity of the systems, these devices are not popularized.

Considering the problems of the previous studies, we make the use of the waste heat of compressor to drive a single adsorption bed. The absorption and the desorption process of adsorbent-adsorbate (activated carbon-methanol) can recycle waste heat. Then through convective heat transferring, defrosting the evaporator of a refrigerator unit is realizable. Thus we can solve the problem of defrosting energy consumption and achieve in energy conservation and emissions reduction.

II. Design Scheme

A. *The schematic of the system*

This device is designed for defrosting the evaporator of a refrigerator unit through convective heat transferring. The device is driven by the waste heat of compressor. The schematic of this system is shown in Figure 2:



1-condenser 2-throttle valve 3-evaporator 4-fin heat exchanger 5-compressor 6、8-solenoid valve 7-liquid storage tank 9-adsorption bed

Figure 2. Schematic diagram of the novel defrosting system

B. The design principle of this system

On the bases of the original refrigeration system, the added liquid storage tank recycles the waste heat of the compressor. When the compressor cumulative operation time accumulate to 20hs (this value can be reset according to different working conditions), the solenoid valve 6 is closed and the solenoid 8 is opened. The methanol in the 7 stared heat exchanges with adsorption bed. The adsorption starts to work driven by the waste heat. The heated adsorbate desorbs and flows to evaporator 5. Through the heat exchange, the frost melts away. After defrosting, the adsorbate flows back to the adsorption bed. When the defrosting is accomplished, the refrigerating cycle will be quickly restored. The novel device is structured when this cycle is repeated.

C. The Design of the Liquid Storage Tank

In order to increase the thermal storage effect, the heat dissipation of the liquid storage tank and the temperature distribution which is brought by the flowing of the working fluid is required to consider. Taking all the factors into account, the liquid storage tank was designed as Figure 3:

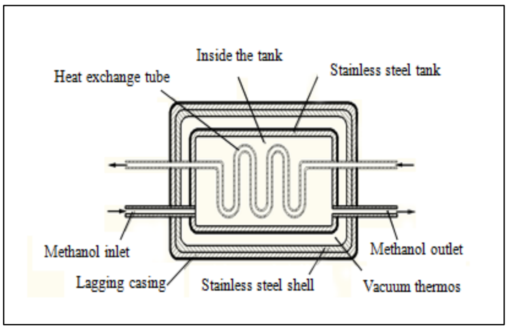
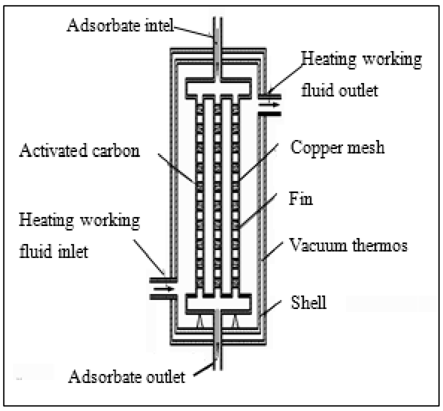


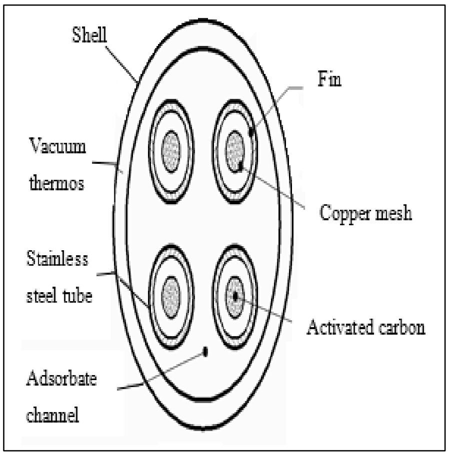
Figure 3. The profile of liquid storage tank

D. The Design of the Adsorption Bed

In order to enhance the heat transfer of the adsorption bed and increase its resistance to pressure, we designed the adsorption bed as the type of tube bank fin.



(a)

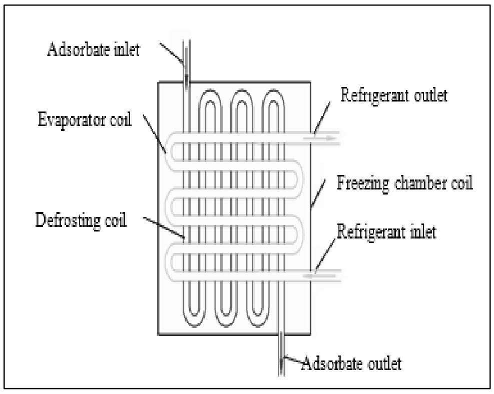


(b)

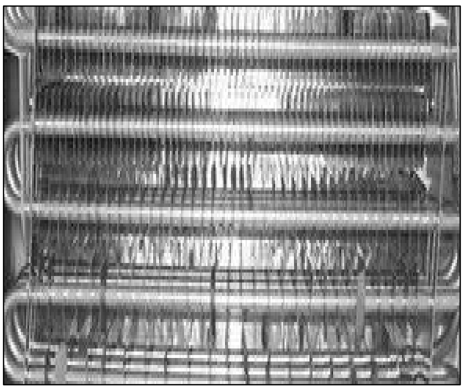
Figure 4. Internal structure of the adsorption bed (a)Front view (b)Top view

E. The Design of the Heat Changer

The heat changer was designed as finned heat exchanger and was put under the evaporator vertically.



(a)



(b)

Figure 5. Defrosting heat exchanger (a)Structure diagram (b)Model diagram

III. Theoretical Analyses

A. The Strength Check of Liquid Storage Tank

To ensure safe operation of the working device, now check the strength of the tank. Consult design specifications GB150-89 (steel pressure vessel). The calculation of steel tank strength check is listed as follows:

(NOTE: The maximum working pressure of Pc is 1.5 MPa; the maximum internal diameter of D_i is 80mm; the thickness of the tank is δ, and the value is 2mm. Considering twice corrosion allowance of C_2 in cycle, the annual thinning is 0.01mm.)

$$C_2 = 0.01mm \times 3 = 0.03mm;$$
$$C'_2 = 0.01mm \times 6 = 0.06mm;$$
$$C' = 2C'_2 = 2 \times 0.06mm = 0.12mm;$$

By the actual measured:

$$\delta_1 = 2.25mm$$

Under the setting temperature, the allowable stress of 16MnR is 163 MPa, and the yield point is 325 MPa.

(1)Check the thickness of the tank wall

According to the thickness checking formula:

$$\delta_2 = \delta + 2C'_2 \frac{P_c D_i}{2[\sigma]^t \phi - P_c} + C' \le \delta_1$$

Substituting data：

$$\delta_2 = \delta + 2C'_2 \frac{P_c D_i}{2[\sigma]^t \phi - P_c} + C'$$
$$= 2 + \frac{2\times 0.06 \times 1.5 \times 80}{2\times 170 \times 0.85 - 1.5} + 0.12 = 2.17mm$$
$$< \delta_1 = 2.25mm$$

The minimum thickness of the tank meets the strength requirements.

(2)Check the work stress of the tank pressure

According to the thickness checking formula:

$$\delta_T = \frac{P_T(D_i + \delta_e)}{2\delta_e} \le 0.9\sigma_s \phi$$

Substituting data：

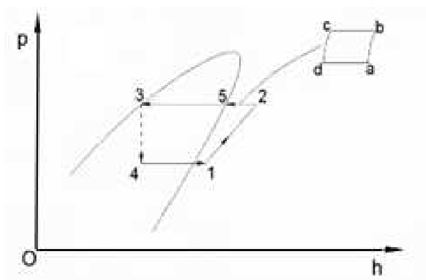
$$\sigma_T = \frac{1.25 \times 1.6 \times (80 + 2.25 - 2 \times 0.06)}{2 \times (2.25 - 2 \times 0.06) \times 0.85}$$
$$= 43.36MPa \le 0.9\sigma_s \phi$$

Calculation result shows that tank structure meets the strength requirement, and the design of main body is reasonable

In summary, the liquid storage tank meets the requirement in the conditions of methanol as the working fluid, the working pressure of 0.1-1.0MPa and the operating temperature is 20-80□.

B. Thermodynamic Analysis of The System

Consulting related documents, analyzing and studying on the thermodynamic process of defrosting, the p-h diagram of the refrigeration cycle which is based on this novel device can be drawn as follows:



1-2 The isentropic process of compressor
2-3 The isobaric process of condenser
3-4 The adiabatic process of throttle
4-1 The isobaric process of evaporator
2-5 The isobaric process of liquid storage tank
a-b-c-d The absorption and desorption process of

Consulting related documents about R134a refrigerant, have known in general case: The temperature of the evaporator is -35□; The temperature of the condenser temperature is 80□.

We combine the thermodynamic state of each point(1: slightly superheated steam; 2: superheated steam; 3: saturated liquid; 4: wet steam; 5: slightly superheated steam;), and the thermodynamic charts of R134a.

Set the compressor power P_1 as 200W. Then the mass flow rate of the refrigerant is Q_m:

$$Q_m = \frac{P_1}{h_2 - h_1}$$

As the analysis process above, the refrigerant had elevated temperature and pressure after flowing through the compressor. The heating power is P_2 :

$$P_2 = \frac{h_2 - h_5}{Q_m}$$

According to the refrigerator prospectus, it can be assumed that refrigerator run 30min per hour, then the amount of heat that changed between surge drum and refrigerant can be obtained as follows:

$$Q = t_1 \cdot P_2$$

Taking the actual restrictions of volume and materials into account, the radius R of the surge drum's bottom surface is 0.075m and the length of the surge drum is 0.2m. Then the volume of it is V:

$$V = \pi R^2 \cdot L = 0.0035 m^3$$

The physical parameters of methanol:

$$C_p = 2.5 \times 10^3 kJ / kg$$
$$\rho = 791 kg / m^3$$

The temperature rising at per hour of methanol in the surge drum is Δt.

$$\Delta t = \frac{Q}{C_p \cdot \rho \cdot V}$$

Using the methanol as the working fluid and substituting data, it can be concluded that the temperature rising at per hour of methanol in the surge drum is 5.44□. Considering the heat dissipation of the insulating layer and assuming the coefficient of heat emission, it can be concluded that the temperature rising at per hour of methanol in the surge drum is 4.63□.

Analysis shows that the system COP has no change before or after adding this defrosting device and the COP is 1.103.

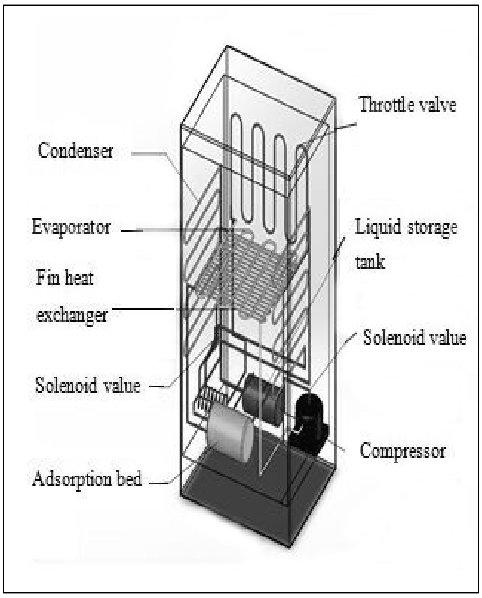
IV Experimental Programs

A. The Experimental Parameters and Computational Analysis

After the theoretical calculation of this device, taking the idea of comparative experiments, we did the experimental tests of electric heating defrosting and methanol defrosting respectively. The following is the basic parameters of the experiment: The freezer temperature is -18□; The dimension of the refrigerator is 56cm(L)×51cm(W)×110cm(H); The refrigerant is R134a.

According to the general condition of heating defrosting at present, when the cumulative working time of the compressor had upped to 8 hours, the refrigerator stared defrosting. The maximum time of defrosting is 30 minutes when the evaporator temperature rose to 14□, heating stopped[11]. In general, the power of the heating wire is150w to 230w, and the average heating time is 30 minutesThe ratio of the compressor running time to the stopping time is 1:1.5. So one defrosting time is 20 minutes. And the power consumption of the defrosting is 180·0.5=0.09 kw·h. Due to the heat quantity would offset some cooling capacity, the increment of refrigerator power consumption is 0.09·2·24/20=0.216kW·h. (Take performance factor of 1.0 to calculate) The calculation above did not take effect due to the perturbations of the freezing temperature.

B. Experimental System



(a)

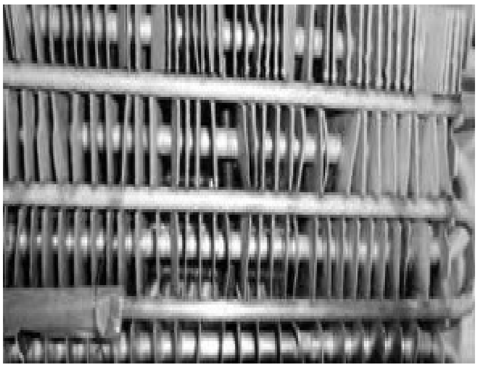
(b)

Figure 7. System diagram (a) 3D stereogram (b) Model diagram

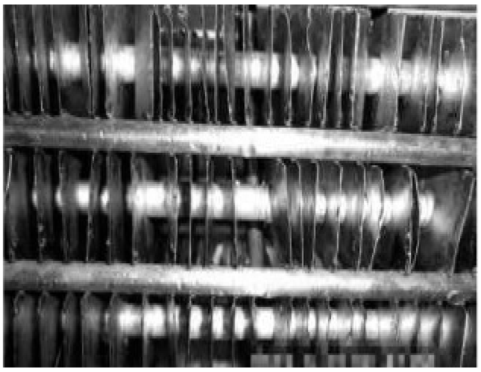
C. Experimental Results

After the system had run for a week, then we collected and analyzed the data by comparing between heat defrosting(The power of the heating wire is 180w) and methanol defrosting.

The effect of defrosting is shown as follows:



(a)Before



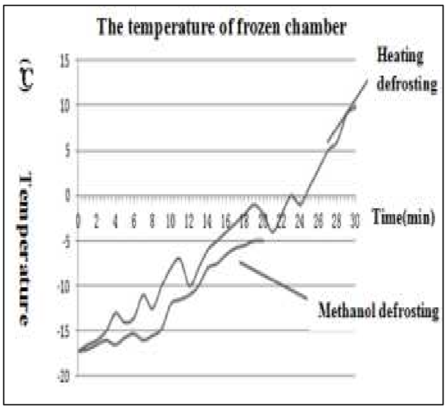
(b) After

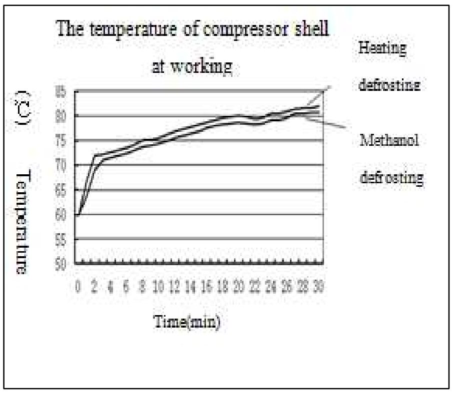
The experimental results are shown as the following Table1. and performance curve:

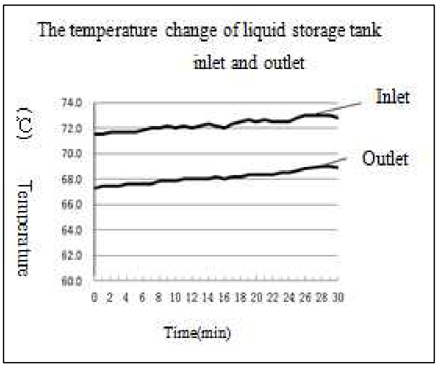
Table 1. The average values of each point after defrosting experiment

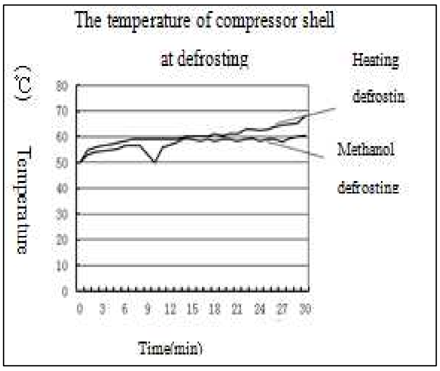
Test item / Experiment item	Heating defrosting	Methanol defrosting
t_1	25	25
t_2	-18	-18
t_3	-21	-21
t_4	80	50
t_5	24	20
t_6	80	80
t_7	9.8	-5

(NOTE t_1: Ambient temperature; t_2: Frozen chamber average temperature; t_3: Evaporator surface temperature; t_4: Compressor shell average temperature; t_5: Compressor inlet average temperature; t_6:Compressor outlet average temperature; t_7: Box temperature after defrosting)









V Benefit Analysis

A. Economic Benefit Analysis

According to the design and manufacture handbook of the refrigerators, the specification of each parts has been analyzed and calculated. The following Table 2. is the latest offer for the cost in the refrigeration equipment company website.

Table 2. The cost of the device

Device parts	Specification	Unit price/ yuan	number	Total price/yuan
Solenoid value	4V210-08	16/ind	2	32
Adsorption bed	304steel	30/ind	1	30
Liquid storage tank	H(25)*R(12)	40.5/ind	1	40.5
Thermos	Copper tube/ Aluminum tube Φ8X0.71	10/m	1.5 m	15
Methanol	Chemical material	19/L	1	19
Activated carbon	Brand of Kuai Huoling	34/kg	0.5	17
Fin heat exchanger	Brand of Shengqiang	30/ind	1	30
Total				183.5

Assuming the average power of defrosting is P_0. The unit price of power is β. The use time of refrigerator in one year is t_0. Compared to the widely used heating defrosting, this device can save the power consumption. Consulting document and design handbook, the calculation process of this device is shown as follows:

The value of P_0 is 0.216kw·h. According to the current published price of the power system in China, the value of β is 0.58yuan/kw·h. National Bureau of Statistics of the PRC in December 2014 statistics show that the national total number of refrigerator is 93.371 million that means n= 93371000.

As a result, the annual electricity fee can be saved by 4211.11 million yuan. ($E_0=n\cdot P_0\cdot t_0\cdot \beta=93371000\times0.216\times360\times0.58\approx4211.11$million)

The device is based on the waste heat of compressor. Under this condition, the operating load of compressor and the temperature of the refrigerator shell are reduced, as a result, the service life of the refrigerator is extended.

B. Environmental Benefit Analysis

This device is driven by waste heat without external power source. Zero discharge for this device is realizable. The analysis and discussion of its environmental benefits are shown as follows:

1. Assuming the value of carbon dioxide emission in producing 1kw/h electric is 'm'. Taking the average value of different kinds of power plants, the value of 'm' is 0.6kg/kw·h. Compared to the traditional heating defrosting, the carbon dioxide emission reduction is about $T=P_0 \cdot m \cdot t_0 \approx 4436989.92(T)$.

2. The device for the recovery of compressor waste heat can reduce the temperature of the refrigerator shell and improve indoor living environment.

VI Conclusion

On the basis analysis and discussion of the experimental results, the following conclusion can be made:

1.The defrosting refrigerator of such a structure is simple and flexible so that we can fix it on the original refrigerating system. The defrosting and energy-saving effects are impressive, and this device solves the problems that the temperature of the box might rise to such an extent after defrosting and the extra power consumption which caused by the process of defrosting. Compressor's working condition has been improved after the device recovering the waste-heat of compressor.

2.The extensive household refrigerators are either without defrosting device, or with device in high energy consumption. This novel device will be in great demand on the market because of its low cost and low energy consumption. It will satisfy the consumers and be more widely accepted over counterparts. By changing the parameters of this device, it also can be applied to large frozen storages, for example, the outdoor unit of air conditioner, the automobile condenser, etc.

REFERENCES

[1] Qi,Y. and Zhang, Y-J. A study for the power consumption measurement of defrosting refrigerators[J]. *Appliance Technology*. 2014, (20): 56-57.

[2] Cheng, Z-M et al. A study for the large capacity air-cooled refrigerators frosting and defrosting experiment[J]. *Appliance Technology*. 2009, (Z1): 52-53.

[3] Tang, X-L. A study for the control technology of BCD-350W air-cooled refrigerators[D]. HeFei University of technology. 2013.

[4] Yu, Y-Z. A study for the potential of reduction, governance efficiency, implementation way in China[J]. China Industrial Economy, 2011, (05): 58-68.

[5] Tang, X-D. A study for the air-cooled refrigerators feature and experiment of the rally of box temperature[J]. Xi`an Jiaotong University learned journal 2014, (11): 81-85+108.

[6] Evaluating the treatment of E-waste──a case study of discarded refrigerators[J]. Journal of China University of Mining & Technology,2008, (03): 454-458.

[7] Wang, X-M et al. Performance characteristics of an energy selective electron refrigerator with double resonances[J]. Chinese Physics B, 2009, (03): 984-991.

[8] Mei, B-J. A device for defrosting refrigerator[P]. An`hui: CN102564014A, 2012-07-11.

[9] Lu, J-Q. Through changing the wettability to improve the anti-freezing feature of the solid surface[D]. Zhe`Jiang University of technology, 2012.

[10] J, T-H et al. A device for defrosting refrigerator[P]. Tian`jin ： CN1474143, 2004-02-11.

[11] Guo, Q-T et al. Practical design hand book for refrigeration engineering[J]. China construction industry press, 1994.

Yinsheng Yu was born in Suizhou City, Hubei Province in 1993, now studying for bachelor's degree at the College of Power Engineering in Chongqing University. He was mainly engaged in microscale heat and mass transfer.hydrogen energy and solar energy utilization, energy saving and emission reduction in the research field of multiphase reaction. He participated in the Eighth College Students Energy Saving Social Practice and Technological Contest. He served as a leader of Chinese College Students' National Innovation Experiment (Solar jet-adsorption refrigeration combined cycle) in 2014-2015.

Mr. Yu's awards and honors include that he got the title of outstanding student of Chongqing University in 2013 and published a paper named Research progress of hydrogen production from organic wastes in MEC.

Address: College of Power Engineering, Chongqing University, No.174 Shazheng street, Shapingba District, Chongqing.

E-Mail: 20123858@cqu.edu.cn

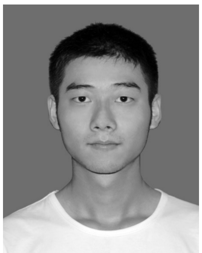
Tel: +86-133-9989-4503

Yuqing Tang was born in Wanzhou District, Chongqing in 1995, now studying for bachelor's degree at the College of Power Engineering in Chongqing University. She was mainly engaged in the research filed of refrigeration, cryogenic engineering and energy saving and emission reduction. She participated in the Eighth College Students Energy Saving Social Practice and Technological Contest.

Miss. Tang's awards and honors include the excellent league cadre of Power Engineering College in Chongqing University and the advanced individual at military training in Chongqing University.

E-Mail: 20133860@cqu.edu.cn

Tel: +86-132-9004-6657



Xiuqi Hu was born in Shiyan City, Hubei Province in 1994, now studying for bachelor's degree at the College of Mechanical Engineering in Chongqing University. He is Mainly enaged in machinery design, manufacture and automation. He participated in the Eighth College Students Energy Saving Social Practice and Technological Contest.

Mr. Hu's awards and honors include the Outstanding Student of Chongqing University in 2014 and the third prize comprehensive scholarship of Chongqing University.

E-Mail: 201235060@cqu.edu.cn

Tel: +86-156-8341-6417

Chuanhang Wang was born in Henan Province in 1990, now studying for master's degree at the College of Power Engineering in Chongqing University. The main research direction are adsorption refrigeration and microscale heat and mass transfer. He participated in the Fourteenth Session of the Postgraduate Debate Contest of Chongqing University on behalf of the College of Power Engineering in 2013. He served as a leader of Chinese College Students' National Innovation Experiment (Solar jet-adsorption refrigeration combined cycle) in 2014.

Mr. Wang's awards and honors include that he continuous gained Chongqing University scholarship twice, got the title of outstanding graduate of Chongqing University in 2014 and involved in editing "the Chongqing cold chain industry blue book in 2013".

E-Mail: 20133859@cqu.edu.cn

Tel: +86-188-7520-8228