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Investigation of Rotary Compressor Heat Dissipation Model

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ABSTRACT

This paper presented a model of rotary compressor heat dissipation, which can be used to calculate heat dissipation under forced-convective/natural-convective and heat radiation mode respectively. The comparison, between calculated and experimental result for both constant speed compressor and variable speed one, shows that the average heat dissipation error is below 20% and discharge temperature deflection is less than 4 ℃。

1. INTRODUCTION

As shown in figure1, compressor energy conservation model is listed in equation (1):

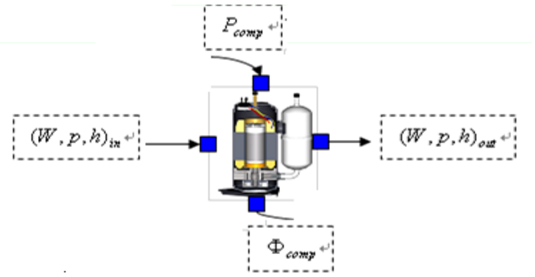

Figure 1 Compressor energy conservation model

$$W \cdot h_{in}(p_s, T_s / x_s) + P = W \cdot h_{out}(p_d, T_d) + \phi \tag{1}$$

$$W = f_W(p_s, p_d)$$

$$P = f_P(p_s, p_d)$$

$$\phi = f_\phi(T_d, T_{amb})$$

Mass flow rate W and input power P are a function of suction pressure p_s and discharge pressure p_d .Heat dissipation φ is a function of discharge temperature T_d and ambient temperature T_{amb} .

Equation 1 represents the energy conservation equation of rotary compressor based on the first law of thermodynamics. There are two methods to estimate heat dissipation φ in the equation (1).

The first method is indirectly measured heat dissipation φ through the experiment. Suction pressure p_s , suction temperature T_s , discharge pressure p_d , discharge temperature T_d , mass flow rate W and input power P can be measured in experiment. Based on these data, heat dissipation φ can be indirectly calculated by using equation (1). The second method is directly calculated heat dissipation φ. Sun and Sun (2010) estimated the natural convection heat transfer coefficient as 8 ~ 10W / (m^2·k) and the forced convection heat transfer coefficient as 20 ~ 25W / (m^2·k) Xie and Su (2009) used semi-empirical-theoretical model to estimate heat dissipation, the model is expressed by equation (2):

$$\phi = A \cdot [\alpha_{sh} \cdot (T_{sh} - T_{amb}) + \varepsilon \cdot \sigma (T_{sh}^4 - T_{amb}^4)] \tag{2}$$

A model of rotary compressor heat dissipation, which can be used to estimate heat dissipation and discharge temperature based on the performance of compressor and a comparison of heat dissipation and discharge temperature between model result and indirectly experiment result are given in this paper.

2. ROTARY COMPRESSOR HEAT DISSIPATION MODEL

When the compressor is in a state of balance in a certain condition, the heat transfer process of the compressor is considered as a steady state process. The heat transfer process is generally described by three aspects: (1) heat transfer from the refrigerant to shell wall inside; (2) heat transfer from shell wall inside to shell wall outside (3) heat transfer from shell wall outside to ambient air. Heat flow φ of each stage should be the same due to the steady state process. The heat transfer coefficient k can be expressed in equation (3):

$$\frac{1}{k} = \frac{1}{h_{ref}} + \frac{\delta}{\lambda} + \frac{1}{h_{amb}} \tag{3}$$

$\frac{1}{h_{ref}}$, $\frac{\delta}{\lambda}$, $\frac{1}{h_{amb}}$ are similar to the Ohm's law of the resistance, known as the thermal resistance of the heat transfer process. The principle of thermal resistance is: in a series of heat transfer process, if the heat flow through each link is the same, the entire thermal resistance is equal to the total value of each thermal resistance. According to this theory, each thermal resistance accounts for a different contribution to the total thermal resistance $\frac{1}{k}$, the smaller heat transfer coefficient is, and the bigger thermal resistance and contribution to the total thermal resistance is.

Comparing these three heat transfer coefficient, the heat transfer coefficient of process (3) is much smaller than the heat transfer coefficient of process (1) and process (2). As a result, the thermal resistance of air is far bigger than other two thermal resistances, and it accounts for the largest contribution to the total thermal resistance.

According to principle discussed above, when calculating the heat transfer coefficient k, the thermal coefficient of process (1) and process (2) can be ignored, only thermal coefficient of process (3) is used to calculate heat transfer coefficient k.

As the shell temperature is assumed to the discharge temperature, the following calculation takes the discharge temperature to represent the shell temperature.

In the heat dispersion model, the air-side heat transfer includes convective heat transfer and heat radiation, shown in equation (4)：

$$\phi = \phi_c + \phi_r \tag{4}$$

2.1 Convective heat transfer

Convective heat transfer can be divided into forced convective heat transfer and natural convective heat transfer. Both forced and natural convective heat transfer can be described as equation (5):

$$\phi_c = h \cdot A \cdot (T_d - T_{amb}) \tag{5}$$

Heat transfer coefficient can be calculated from equation (6)：

$$h = N\mathrm{u} \times \frac{\lambda}{d} \tag{6}$$

2.1.1 Forced convective heat transfer

In the test, the wind speed is 2m/s around compressor. The forced convection is described by equation (7):

$$N\mathrm{u} = C \,\mathrm{Re}^n \,\mathrm{Pr}^{1/3} \tag{7}$$

Pr is the Prandtl number, Renault number is listed in equation (8)

$$Re = \frac{ud}{\upsilon} \tag{8}$$

Re is about 10000. And in the equation (7), C=0.193，n=0.618。

2.1.2 Natural convective heat transfer

When the compressor is used in the air-conditioner, it is in the environment without wind. The empirical correlation of natural convection is shown in equation (9):

$$Nu_m = C(Gr\mathrm{Pr})_m^n \tag{9}$$

Here, C=0.59，n=0.25.

G_r is the Grashof number, shown in equation (10)：

$$G\mathrm{r} = \frac{g\alpha_V \Delta t d^3}{\nu^2} \tag{10}$$

2.2 Heat radiation

When calculating heat radiation between the compressor and environment, environment is assumed as the black body, emissivity and absorptivity ratio of paint is 0.95.

The actual heat radiation is shown in equation (11):

$$\phi_r = E_1 - E_2 \tag{11}$$

E_1 is heat radiation from compressor to environment, shown equation (12)：

$$E_1 = \varepsilon \cdot \sigma T_d^4 \tag{12}$$

σ is $5.67\times10^{-8} W/(m^2 \cdot K^4)$,T_d is discharge temperature (approximation for discharge temperature)

E_2 is heat radiation from environment to compressor, shown equation (13)

$$E_2 = \alpha \cdot \sigma T_{amb}^4 \tag{13}$$

3. COMPARISON RESULT AND UNCERTAINTY ANALYSIS

3.1 Comparison result

Table 1 showcases a comparison between calculating data and experiment data of 1.5 HP constant speed compressor in forced-convection environment and table 2 showcases the result under natural-convection environment. The model calculated heat radiation and forced/natural convective heat transfer. The results of Table 1 and Table 2 showcase a comparison with the measured data in the experiment. The suction gas superheat is 11.1k and ambient temperature is 35 ℃ in the experiment in both table 1 and table 2.

Figure 2 and Figure 3 is a comparison between radiation and convection in forced-convection/natural-convection.

Table 1 1.5HP constant speed rotary compressor data in forced-convection

Te(℃)	Tc(℃)	Measured discharge temp (℃)	Adiabatic discharge temp (℃)	Radiation(W)	Forced-convection heat transfer(W)	Model discharge temp(℃)	Measured heat dissipation(W)	Model heat dissipation(W)
10.4	65	113.1	124.9	78	123	113.1	201	201
7.2	54.4	97.2	107.6	58	97	97.7	163	156
-0.4	40	83.5	92.6	40	73	83	110	115
-4	30	73.2	81.2	31	57	72.8	84	88
1.5	40	81.6	89.9	40	70	81.3	106	110
7.2	45	83.6	90.7	42	74	83.3	112	116
10	45	81.3	87.4	40	70	81	106	110
1.5	30	68.4	74	27	49	68	70	76
10	40	74.4	79.5	33	59	74.1	87	92
10	30	60.8	64.2	20	38	60.8	58	58

Table 2 1.5HP constant speed rotary compressor data in natural-convection

Te(℃)	Tc(℃)	Measured discharge temp (℃)	Adiabatic discharge temp (℃)	Radiation(W)	Natural-convection heat transfer(W)	Model discharge temp（℃）	Measured heat dissipation (W)	Model heat dissipation(W)
10.4	65	113.1	124.9	83	56	116.7	201	139
7.2	54.4	97.2	107.6	62	42	100.9	163	105
-0.4	40	83.5	92.6	45	30	86.3	110	76
-4	30	73.2	81.2	34	23	75.8	84	57
1.5	40	81.6	89.9	43	29	84.3	106	72
7.2	45	83.6	90.7	45	30	85.9	112	75
10	45	81.3	87.4	42	28	83.3	106	70
1.5	30	68.4	74	29	19	70.2	70	48
10	40	74.4	79.5	35	23	76.1	87	58
10	30	60.8	64.2	21	13	62.2	58	35

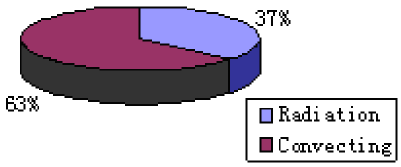

Figure 2 Comparison in Forced convection

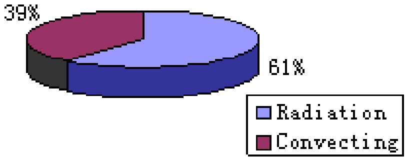

Figure 3 Comparison in natural convection

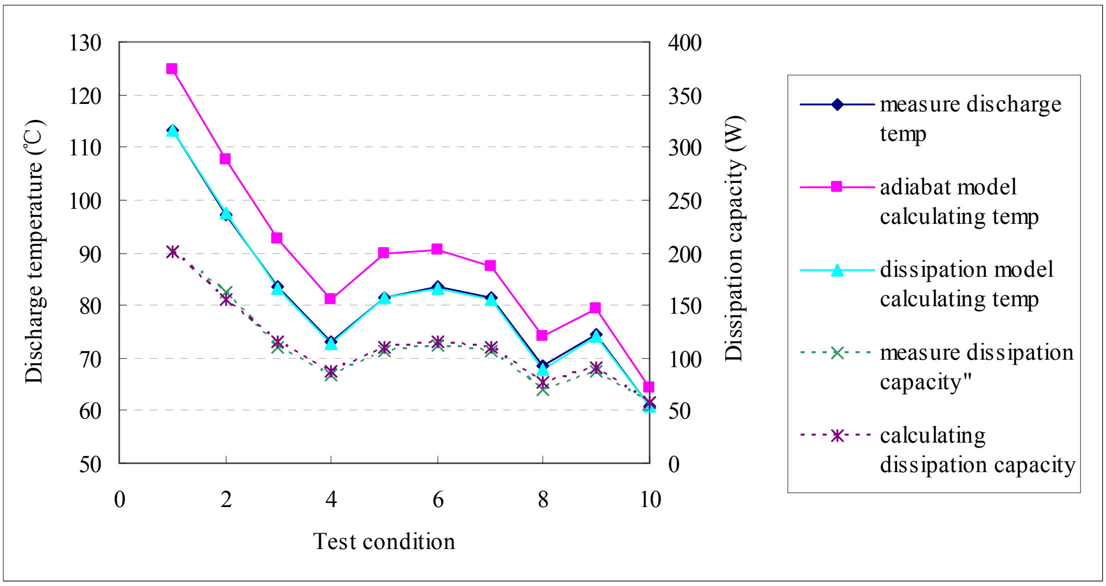

Figure 4 Comparison in discharge temperature and heat dissipation of 1.5HP constant speed compressor

Figure 4 is a comparison in discharge temperature and heat dissipation of 1.5HP constant speed compressor. It is found that the discharge temperature calculated by the model in forced-convection is very closed to the experimental discharge temperature, the deflection is less than 1℃. Therefore, the model can be applied to describe the compressor operation.

It is also found there is a considerable difference of heat transfer between forced convection environment and natural convection environment, natural convective heat transfer is much less than the forced convective heat transfer.

Table 3 below summarizes the comparison between calculating data and experimental data of 1.5 HP variable speed compressor.

Table 3 1.5HP variable speed rotary compressor data in forced-convection

Te (℃)	Tc (℃)	Frequency (Hz)	Measured discharge temp (℃)	Adiabatic discharge temp (℃)	Radiation (W)	Forced convection heat transfer(W)	Model discharge temp (℃)	Measured heat dissipation (W)	Model heat dissipation (W)
10	35	15	56.6	62.6	14	28	56	38	42
15	35	15	52.7	57.6	12	24	53.1	40	36
15	40	15	60.9	66	17	33	59.8	42	51
5	35	30	60.8	64.9	18	34	60.3	45	52
10	40	30	64.5	68.8	21	40	64.4	59	61
15	45	30	68.7	72.9	24	46	68.7	70	70
0	35	45	65.6	69.1	21	40	64.7	49	61
5	40	45	69	72.2	24	45	68.4	60	70
10	45	45	72.9	76.3	28	51	72.5	70	79
0	40	60	73.9	77.3	28	52	73.1	65	80
0	50	60	89.5	93.2	41	73	87.3	71	114
5	35	60	63.6	65.1	19	37	62.6	34	57
5	45	60	78	80.5	31	57	76.7	58	89
5	60	60	101.1	105.1	53	90	99	93	144
10	40	60	67.4	68.9	23	43	66.6	42	65
10	50	60	81.9	84.1	35	63	80.6	61	98
15	40	60	64.2	65.5	20	39	63.7	43	59
15	60	60	94.2	96.6	47	81	92.8	79	128
-5	45	75	82.4	91	40	70	85.4	170	1110
0	50	75	85.7	93.4	43	75	88.6	189	117
5	60	75	97.3	105.5	55	92	100.5	243	148
-5	50	90	91.9	100.6	49	84	95.1	214	134
-5	60	90	107.8	118.1	67	109	111	255	176
0	60	90	104.1	111.7	62	101	106.2	228	163

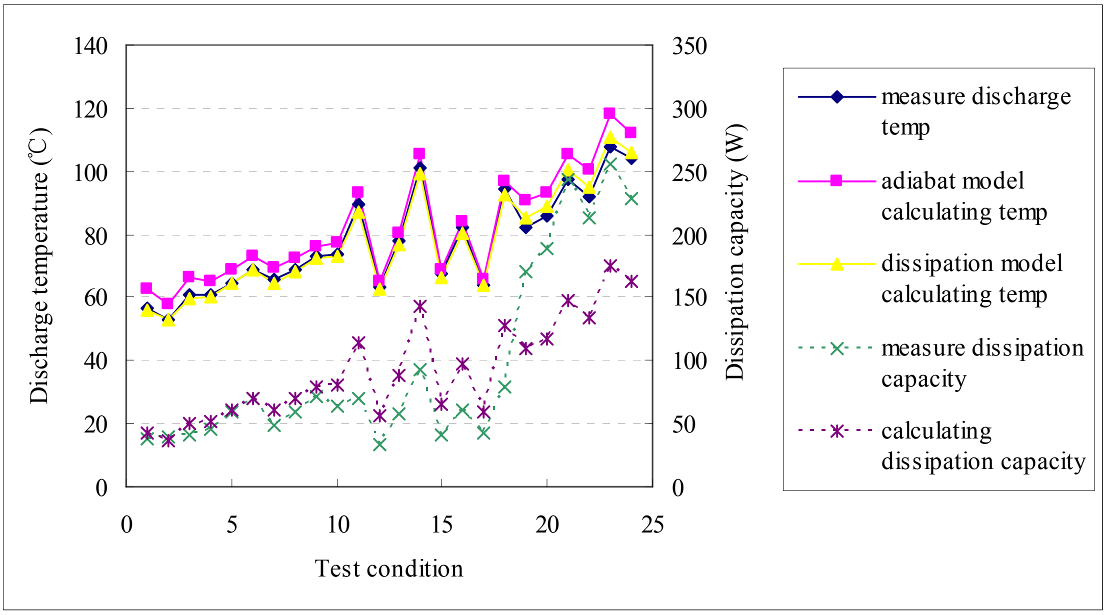

Figure 5 Comparison in discharge temperature and heat dissipation of 1.5HP variable speed compressor

Calculation result of 1.5 HP variable speed compressor shows the discharge temperature of calculating model in forced convection is close to the experimental result, the deflection is less than 4℃. This model can also be applied to variable speed compressors.

3.2 Uncertainty Analysis

In this part, the experimental uncertainty is analyzed. Uncertainty of the main instrument is listed in Table 4.

Table 4 Main measure instrument

	Type	Producer	Range	Precision
Temp Sense	R040-32/Pt100	CHINO	Td=50~150 ℃,Tvi=33~63 ℃ Teo=10~42℃,Ts=10~42℃	0.20%
Pressure Sense	FP101A-Z21-L20	YOCOGAWA	Pd=1.10~3.00 MPa Ps=0.164~1.192 MPa	0.25%
Flow meter	CMF025	MicroMotion	0~300Kg/h	0.15%
Power meter（calorimeter）	WT130	YOCOGAWA	1000~10000W	0.10%
Power meter（compressor）	WT2030	YOCOGAWA	500~5000W	0.10%

The measured heat dissipation of this paper is calculated by compressor energy conservation model in equation (1) rather than directly measured in the experiment. Uncertainty results calculated by EES are listed in Table 5~8:

Table 5 Calculated results of uncertainty in rated condition

Name	value	error	percentage
Heat dissipationφ(W)	164.3	3.661	
Power(W)	936	0.936	6.54%
Condenser Pressure(MPa)	2.147	0.00537	8.62%
Evaporator Pressure(MPa)	0.6225	0.00156	1.99%
Discharge Temp(℃)	97.2	0.1944	71.09%
Suction Temp(℃)	18.3	0.0366	1.76%
Flow Rate(kg/h)	63.4	0.0951	10.00%

Table 6 Calculated results of uncertainty in other condition

Name	value	error	percentage
Heat dissipationφ(W)	201.3	4.57	
Power(W)	1140	1.14	6.22%
Condenser Pressure(MPa)	2.702	0.00676	8.16%
Evaporator Pressure(MPa)	0.6894	0.00172	1.66%
Discharge Temp(℃)	113.1	0.2262	72.71%
Suction Temp(℃)	21.5	0.043	1.75%
Flow Rate(kg/h)	66	0.099	9.50%

4. CONCLUSION

The paper presented a rotary compressor heat dissipation model, which calculates forced-convection/natural-convection and heat radiation from theory. Compared with the experimental data, the discharge temperature model deflection is less than 4 ℃, the average heat dissipating error is below 20%, which indicates a promising model for rotary compressor heat dissipation.

NOMENCLATURE

A	compressor surface area	(m^2)
d	compressor diameter	(m)
E	emissive power	(W/m^2)
Gr	Grashof number	
h	enthalpy	(kJ/kg)
h	surface heat transfer coefficient	($W/m^2 \cdot k$)

k	overall heat transfer coefficient	$(W/m^2 \cdot k)$
Nu	Nusselt number	
p	pressure	(MPa)
P	input power	(W)
Pr	Prandtl number	
Re	Reynolds number	
T	temperature	(℃)
u	wind speed	(m/s)
W	mass flow rate	(kg/h)
φ	heat dissipation	(W)
α	absorptivity	
α_v	expansion coefficient	(K^{-1})
ε	emissivity	
σ	black body radiation constant	
λ	thermal conductivity	$(W/ m \cdot k)$
δ	shell thickness	(m)
υ	kinematic viscosity	$(m^2 \cdot s)$
Δt	excess temperature	(℃)

Subscript

amb	ambient air
c	convection
D	discharge
r	radiation
ref	refrigerant
S	suction
sh	shell wall

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