Measurement of Specific Heat of Air at Constant Pressure

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I. Objective and requirement

Understand the basic principles in determining the specific heat of air.

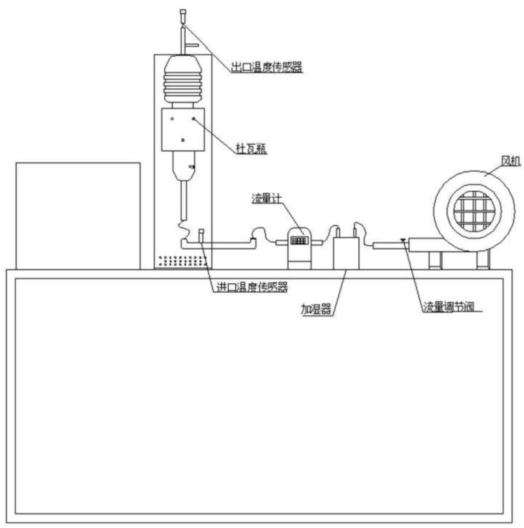
Familiar with this experiment's temperature, pressure, heat and flow measurement method.

Master the method of calculating the specific calorific value and obtaining the specific heat from the basic data.

Ⅱ.Equipment and principles

1.The whole device

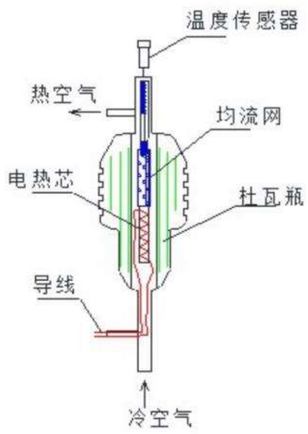
The device is composed of four parts: fan, flow meter, specific heat meter, electrical power regulation, measurement system, etc., and its specific schematic diagram is shown below.



2.The specific heat meter

The air is sent to the body of the specific heat meter by the fan through the flowmeter and then flows out after heating, swirling, mixing flow and temperature measurement.

The gas flow is controlled by the throttle valve, and the gas outlet temperature is regulated by the voltage input to the electric heater. A schematic diagram of the specific heat meter is shown below.



3.Dry and wet bulb thermometer

The dry and wet bulb thermometer is an instrument for measuring the humidity and temperature of the air. It consists of a dry-bulb thermometer and a wet-bulb thermometer. The dry-bulb thermometer shows the temperature of the air, and the wet bulb thermometer, whose bulb is wrapped with wet cambric, shows a temperature that is dependent on the amount of evaporation from the surface of its bulb. Because heat is used in evaporation, the drier the air whose humidity is being measured, the lower the reading of the wet bulb thermometer.

Thermal capacity is defined as the energy required to raise the temperature of a substance by one degree (1K or 1°C). It has the unit kJ/K. Specific heat is defined as the energy required to raise the temperature of per unit substance by one degree.

The specific heat at constant pressure can be viewed as the energy required to raise the temperature of a unit mass of a substance by one degree as the pressure is maintained constant.

The air with a certain volume flow is continuously fed into the specific heat meter under constant pressure. After being heated by the electric heater in the specific heat meter, the temperature rises continuously. When the system is stable, the specific heat capacity can be expressed as：

$$C_p = \frac{1}{q_m}(\frac{\partial \dot{Q}}{\partial T})_p \tag{1}$$

If the temperature rises from $T1$ to $T2$, the specific heat at constant pressure over this temperature range can be determined:

$$C_{pm}|_{T_1}^{T_2} = \frac{\dot{Q}}{q_m(T_2 - T_1)} \tag{2}$$

$q_m$is the mass flow rate

$\dot{Q}$ is the heat absorbed by the air in unit time

The air pressure in the specific heat meter is:

$$\mathrm{P} = P_a + P_f \tag{3}$$

the fan pressure P_f is 490Pa

the atmospheric pressure P_a outside is 101325Pa

The partial pressure of the water vapor and dry air are respectively:

$$P_w = \varphi \cdot P_s \tag{4}$$

$$P_d = P - \varphi \cdot P_s \tag{5}$$

φ is the measured relative humidity

P_s is the saturated steam vapor pressure of the water vapor at $T1$ temperature

As the air follows the ideal gas law, the mass flow rate of dry air and water vapor are respectively:

$$q_d = \frac{P_d V}{R_d T_1} \tag{6}$$

$$q_w = \frac{P_w V}{R_w T_1} \tag{7}$$

V is the volume flow rate of the air flow measured

R_d $= 287\mathrm{J}/(\mathrm{Kg}\cdot K)$ is the gas constant of dry air

$R_w = 486\mathrm{J}/(\mathrm{Kg}\cdot K)$ is the gas constant of water vapor

The heat absorption of water vapor can be approximately calculated by:

$$Q_w = q_w * (1850 * (T_2 - T_1)) \tag{8}$$

Then for dry air, we may get:

$$C_d = \frac{Q - Q_w}{q_d(T_2 - T_1)} \tag{9}$$

Q is the heat rate absorbed by the air (the heating power).

Ⅲ. Data processing and Analysis

1.Calculate the specific heat at constant pressure, and compare them with the standard values to calculate the relative error. Take one set of the data as an example, and write out the detailed calculation process.

	Heating Power (W)	Inlet Temp T1 (℃)	Outlet Temp T2(℃)	Relative Humidity	Volume Flow Rate (L/min)	Specific Heat Measured (J/(Kg*℃))	Specific Heat Standard Values (J/(Kg*℃))	Relative Error
1	5.43	27.12	46.60	69.16	12.93	1094	1015	7.250%
2	10.48	27.08	63.40	69.16	13.00	1127	1017	9.79%
3	15.56	27.00	72.20	69.56	12.88	1363	1017	25.37%
4	20.61	26.88	87.90	69.99	12.76	1349	1022	24.23%
5	25.70	26.92	102.2	69.84	12.77	1363	1022	25.00%

Take the first set of date as an example,

P=$P_a + P_f$=490+101325=101815Pa

P_s=3569Pa

$P_w = \varphi * P_s = 0.6916$ *3569=2468.3204 Pa

P_d=P-$\varphi * P_s$=101815-2468.3204=99346.6796 Pa

V=12.93*10^{-3}/60 m^3/s

$$q_d = \frac{P_d * V}{R_d * T1} = 99346.6796 * 2.155 * \frac{10^{-4}}{287 * (27.12 + 273.15)}$$

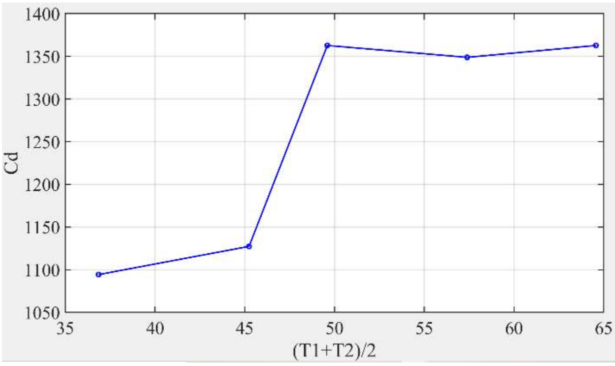
$$q_w = \frac{P_w * V}{R_w * T1} = 2468.3204 * 2.155 * \frac{10^{-4}}{486 * (27.12 + 273.15)}$$

$$Q_w = q_w * 1850 * (T2 - T1)$$

$$= 2468.3204 * 2.155 * \frac{10^{-4}}{486 * (27.12 + 273.15)} * 1850 * (46.6 - 27.12)$$

$$C_d = \frac{Q-Q_w}{q_d*(T2-T1)} = \frac{5.43-2468.3204*2.155*\frac{10^{-4}}{486*(27.12+273.15)}*1850*(46.6-27.12)}{99346.6796*2.155*\frac{10^{-4}}{287*(27.12+273.15)}*(46.6-27.12)} = 1094.34 \text{ J/(Kg*°C)}$$

2.Plot the specific heat Cd vs temperature $(T1 + T2)/2$



3.Discuss the result and make a conclusion.

The heating power is controlled by adjusting the voltage, which increases by about 5 W each time from 5.43 W, and a total of 5 sets of data are obtained. It can be seen from the data that the inlet temperature, relative humidity and volume flow rate are almost stable, while the outlet temperature and calculated specific heat capacity increases with the increase of the heating power. Using these 5 sets of data for calculation, the specific heat capacity of dry air at the temperature of about 27°C has a large relative error compared with the reference value.

Ⅳ.Questions

1.Why specific heat at constant pressure is greater than specific heat at constant volume?

Qualitative analysis: under the condition of constant pressure, the volume of system will expand when the temperature of the system rises. Compared with that under the condition of constant volume, the volume expansion process is the process of doing work to the outside, and this extra part leads to that the specific heat at constant pressure is greater than the specific heat at constant volume.

Theoretical derivation:

Define enthalpy as:

$$h = u + Pv$$

u is the internal energy

Consider ideal gas:

$$Pv = RT$$

So we obtain:

$$h = u + RT$$

From the definition of Cp and Cv:

$$du = c_v(T)\, dT$$

$$dh = c_p(T)\, dT$$

Then derivative the equation we obtained and combine the above equations:

$$\left.\begin{aligned} dh &= du + RdT \\ dh &= c_p dT \\ du &= c_v dT \end{aligned}\right\} c_p = c_v + R$$

It is obvious that Cp is large than Cv.

2.Acoording to the data measured and relevant resource, discuss how and why the specific heat of air changes with the temperature of the air.

According to the measured data, with the increase of air temperature, the calculated air specific heat capacity shows an increased trend.

The main factors affecting the specific heat of air at constant pressure are the work of isobaric expansion, the change of molecular potential energy and thermal motion.

At a low temperature, with the increase of temperature, the translational and rotational free energies of molecular thermal motion are gradually activated, which will lead to the increase of specific heat, while the expansion of gas will lead to the decrease of specific heat. The latter occupies a dominant position, so the

· It’s not quite right. At low temperature, there is attraction between molecules and need more heat. As temperature rises, the attraction gets week and heat capacity drops quickly.

increase of temperature will lead to a slight decrease of specific heat.

When the temperature is close to room temperature, air is approximately an ideal gas, and the change of molecular thermal motion is dominant. The translational and rotational degrees of freedom are fully activated, while the vibrational degrees of freedom are gradually activated. Therefore, the molar specific heat of air increases with the increase of temperature in a small range on 7R/2. When the temperature rises to the degree that the vibration degree of freedom is fully activated, the molar specific heat is basically stable at 9R/2.

3.Discuss the possible experimental errors and make improvement suggestions.

Experimental errors:

1)The experiment requires the stable outlet temperature, but in the actual experiment, the outlet temperature shows an increasing trend in a short time. The first and second sets of outlet temp data were obtained respectively after waiting for about 30 minutes after starting the experiment. Due to the time limit of the course, the waiting time of the third to fifth groups of data was about 15 minutes, so the relative error of the calculated specific heat capacity of the first and second groups was small, while the relative error of the third to fifth groups was large. Therefore, the reason for the large relative error is that the outlet temperature recorded in the experiment is not the stable outlet temperature, which is lower than the actual stable outlet temperature, so it leads to the larger calculated specific heat capacity.

2) Heat leakage occurred during the experiment, resulting in the heat absorbing power of dry air less than the given heating power. The given heating power was used in the calculation, which would lead to a larger calculated specific heat capacity.

Improvement suggestions

1)The measurement time of each group of power should be extended to obtain a more stable outlet temperature. According to the data processing of this experiment, the calculation results with relative error within 10% can be obtained when the measurement time is about 30 minutes.

2) Use the experimental instrument with better heat insulation effect to avoid the large errors in experimental results caused by heat leakage.

Experiment Data

Measurement of Specific Heat of Air at Constant Pressure Experiment Data Log Sheet

1. Basic Information

Name: 邹佳驹 Date: 10. 25

2. Data Record

Parameter: Fan pressure: 490pa, Local atmospheric pressure: 101325pa

	Heating Power (W)	Inlet Temp T_1 (°C)	Outlet Temp T_2 (°C)	Relative Humidity	Volume Flow Rate (L/min)
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