Analysis on the determination of specific heat of air at constant pressure

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Abstract. Heat calculation is often encountered in industrial production and life. For example, the calculation of flue gas heat release or the heat absorption of working medium in thermal equipment in thermal power plant boiler is a common heat calculation. This paper mainly introduces the experimental principle and method of specific heat of gas, and measures the average specific heat of air at constant pressure. Through this experiment, we can be familiar with the basic measurement methods of temperature, pressure, heat and flow in the experiment. In this paper, we compare the experimental data with the actual data, and analyze the cause of the error.

1. Introduction
Based on daily experience and scientific experiments, the energy required to raise the temperature of different substance is different. 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. The specific heat is defined as the energy required to raise the temperature of per unit substance by one degree [1]. If the specific heat is based on a unit mass, it has the unit kJ/(kg▪K) or kJ/(kg▪℃). In general, specific heat is a path function and depends on how the process is executed. In thermodynamics, we are interested in two kinds of process specific heat: specific heat at constant volume and specific heat at constant pressure. The specific heat at constant volume can be viewed as the energy required to raise the temperature of a unit mass of a substance by one degree as the volume is maintained constant. It is \( c_v \). The energy required to do the same as pressure is maintained constant is the specific heat at constant pressure \( c_p \). In various thermal processes, \( c_v \) and \( c_p \) are the most commonly used, the most important.

2. Experiment

2.1. Experimental principle
The specific heat of gas can be measured by experiment. This paper analyzes the measurement and results of specific heat of air at constant pressure.

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 heat absorbed by the air in unit time is:

\[
Q = q_n c_p \int_{I_2}^{I_1} (I_1 - I_2)
\]
Then

$$c_{p,t}^{*} = \frac{Q}{q_m(t_2 - t_1)}$$

where $c_{p,t}^{*}$ is the average specific heat as the temperature changes from $t_1$ to $t_2$.

2.2. Experimental equipment

The experimental device is shown in Figure 1[2]. The whole device consists of fan, flowmeter, specific heat meter, electric power regulation and measurement system.

![Experimental device for measuring specific heat of air at constant pressure](image)

The air is sent to the body of the specific heat meter by the fan through the flowmeter, and then flows out after heating, current sharing, swirl, mixed flow and temperature measurement. The gas flow is controlled by the throttle valve; the gas outlet temperature is regulated by the voltage input to the electric heater.

The experimental principle of measuring the specific heat of air at constant pressure is shown in Figure 2.

First, connect the power supply and measuring instrument, select the required outlet thermometer to insert into the groove of the mixed flow tank. Then, start the fan and adjust the throttle valve to keep the flow near the rated value. Gradually increase the voltage to raise the outlet temperature to the expected temperature. After the outlet temperature is stable, read out the following measurement data: The temperature required for every 10 liters of gas passing through the flowmeter; Inlet temperature of specific heat meter, outlet temperature; Local atmospheric pressure; voltage and current of electric heater, etc.

![Experimental principle of measuring specific heat of air at constant pressure](image)

2.3. Experimental result

The three groups of measurement data and calculation results are shown in Table 1.
Table 1. Measurement data and calculation results

| Serial number | t₁ (℃) | t₂ (℃) | P (w) | \( q_v \) (m³/s) | \( p_b \) (p_a) | \( q_m \) (kg/s) | \( c_p \) (kJ/(kg▪K)) |
|---------------|--------|--------|-------|------------------|----------------|-----------------|------------------|
| 1             | 17.0   | 78.7   | 30    | 3.79 \times 10^{-4} | 1.01 \times 10^5 | 4.82 \times 10^{-4} | 1.0088           |
| 2             | 17.0   | 40.3   | 14    | 5 \times 10^{-4}   | 1.01 \times 10^5 | 6 \times 10^{-4}  | 1.014            |
| 3             | 17.0   | 63.0   | 25    | 5 \times 10^{-4}   | 1.01 \times 10^5 | 6.07 \times 10^{-4} | 1.005            |

The heat absorbed by the air in unit time is:

\[
Q = UI = PV \quad (3)
\]

Here \( Q \) is the heat absorption per unit time of air, equal to the heat release per unit time of electric heater \( P \), that is, the product of voltage and current.

where \( U \) is the voltage, \( V \); \( I \) is the electric current, A.

The mass flow is determined from the ideal-gas equation of state to be

\[
q_m = \frac{p_b P_v}{R_0 T_1} \quad (4)
\]

where \( R \) is a very important parameter. It is the gas constant, J/(kg▪K) and its value just depends on the variety of the gas but not related to the state of the gas. The universal gas constant \( R_0 \) is 8314J/(kmol▪K). It is the same for all kinds of ideal gases. Its value can be obtained at the standard condition \((p_0 = 1.01325 \times 10^5\text{ p}_a, T_0 = 273\text{ K})\) by using the equation of state. At this state, the molar specific volume of any gas \( V_0 = 22.4\text{ m}^3/\text{kmol} \).

Thus

\[
R = \frac{R_0 V_0}{M} = \frac{273}{28.97} = \frac{8314}{28.97} = 287 \quad \text{J / kg · K}
\]

where the molar mass \( M \) of air is 28.97.

3. Discussion

As the air is a wet air containing water vapor, when the wet air rises from the temperature \( t_1 \) to the temperature \( t_2 \), the water vapor in it must absorb part of the heat. Therefore, the heat absorbed by the air should be the difference between the heat released by the electric heater \( Q' \) and the heat absorbed by the water vapor \( Q_w \). Namely:

\[
c_p \frac{q_m}{(t_2 - t_1)} = \frac{Q - Q_w}{q_m(t_2 - t_1)} \quad (5)
\]

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

\[
Q_w = 1850(t_2 - t_1) \quad (6)
\]

where \( q_{mw} \) is the mass flow of water vapor.

\[
q_{mw} = \frac{p_u q_m}{R_w T_0} \quad (7)
\]

The gas constant of water vapor is 461.5 J/(kg▪K)[3]. It can be found from the gas constant table of common gases. \( p_u \) is partial pressure of water vapor, \( r_w \) is volume composition of water vapor, \( d \) is specific humidity, determined by psychrometric chart (h-d chart).

\[
p_u = r_w (p_b + \frac{\Delta h}{13.6}) \times 133.323 \quad (8)
\]

\[
r_w = \frac{d}{1 + d / 622} \quad (9)
\]

The partial pressure of the dry air \( p \) is

\[
p = (1 - r_w) p_u \quad (10)
\]
4. Conclusion
Experiments show that the analysis is correct. Based on the Vocational and Technical College, the heat absorption and flow rate of water vapor in wet air are not included in this experiment, which is the reason for the error. In addition, the accuracy of equipment and reading will cause errors. There is no further accurate calculation in this experiment, and the heat absorption of water vapor is not considered. There is a certain error in the experimental results. But through this experiment, students can be familiar with the experimental equipment, experience the experimental process, understand the experimental principle. We have achieved the goal of experiment.

References
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