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Temperature Sensitive Medium of New-Type Automotive Thermostat Based on Acetone Solution

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In order to study the temperature sensitive medium of a new-type thermostat, this paper designs a special experimental device to measure the thrust force generated by the volume expansion of various temperature sensitive media at different temperatures, and selects a temperature sensitive medium acetone solution that meets the requirements of the thermostat; at the same time, the response time of thermostat valve opening caused by volume expansion of heated acetone solution is measured, the experimental results show that the response speed is faster than that of the paraffin medium commonly used in the current thermostats. The new-type thermostat with acetone solution as the temperature sensitive medium has the characteristics of stable, reliable and fast response.

1. Introduction

Thermostat is an important component in the engine cooling system of vehicles. Its function is to open or close the passage of the cooling water to the radiator according to the temperature of the cooling water, adjust the cooling strength of the cooling system, and keep the engine in a suitable operating temperature, thereby reducing the consumption of gasoline and improving fuel utilization (Luo et al., 2004). At present, the paraffin thermostats are widely used, but they have the disadvantages of complicated structure, slow response speed, high requirement of temperature-sensitive paraffin wax, and it's difficult to prolong their service life (Chen et al., 2002).

Based on the current status of the thermostats, the research team designs a new type of thermostat, the thermostat valve is opened by the volume expansion of the temperature sensitive medium when it is heated and gasified. When the temperature is lowered to a certain level, the temperature sensitive medium is liquefied, and the valve is closed to control the operating temperature of the engine, so that the temperature of the cooling water is always maintained between 85°C and 90°C, thereby the engine can work under the most suitable temperature. Compared with previous thermostats, the proposed new-type thermostat has reliable operation, long service life, cheaper, and other advantages. In the devised new thermostat, the temperature characteristics of the temperature sensitive medium are directly related to the working performance of the thermostat. Therefore, selecting appropriate temperature sensitive medium for the thermostat by experiment is of important significance for the new-type thermostat.

2. Working principle and types of temperature sensitive media

There are many types of temperature sensitive media, which are classified into non-phase-transition type temperature sensitive media and phase-transition type temperature sensitive media according to whether the state changes after heating. There are three kinds of non-phase-transition type temperature sensitive media, the first kind is liquid-heated-expansion type temperature sensitive media, such as methanol, glycerin, and silicone oil; the second kind is gas-heated-expansion type temperature sensitive media, such as chlorine gas; and the third kind is solid-heated-expansion type temperature sensitive media, such as bimetallic strip. The phase-transition type temperature sensitive media include two types: the solid-liquid phase-transition type temperature sensitive media and liquid-gas phase-transition type temperature sensitive media. For the solid-liquid phase-transition type temperature sensitive medium, there is a kind of n-alkane, a rectified paraffin wax

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of 40-50°C, which is processed into temperature-sensitive wax, and it's characterized by a volume expansion of 13%-15% when it is converted from solid to liquid after being heated. This kind of temperature-sensitive wax is widely used in the automatic control of various thermostatic devices. For the liquid-gas phase-transition type temperature sensitive media, after the temperature sensitive medium is heated, it is transformed from liquid to gas, and the volume expansion amount is quite large, which can reach about 70%. At the same temperature, the liquid-gas phase-transition type temperature sensitive medium can obtain greater force, the boiling point of the liquid temperature sensitive medium is generally lower than the boiling point of the solid, and the liquid-gas phase-transition type temperature sensitive medium has a faster response speed than the solid-liquid phase-transition type temperature sensitive medium (Galeano et al., 2018). Common temperature sensitive media of this type include ether, acetone and ethanol, etc.

Although there are many types of temperature sensitive media, their mechanism of action is basically the same, that is, the volume of the temperature sensitive medium expands when heated, and the generated thrust opens the valve of the thermostat; and when the temperature drops, the volume of the temperature sensitive medium shrinks, and the valve is closed.

According to the principle of thermodynamics, for the temperature-sensitive materials of the same mass, the heat absorption at the phase transition point is much greater than the specific heat of the non-phase transition point, so the conversion efficiency of the phase-transition temperature-sensitive medium is relatively high (Wei et al., 2007). In the vicinity of the phase transition point, the temperature-sensitive material has a rapid volume-expansion process; while for non-phase-transition component, its heat conversion efficiency is relatively low, and its thermal expansion volume is small. To achieve a certain expansion volume, a larger temperature wrap is required, therefore, the temperature-sensitive medium selected by the author is a liquid-gas phase-transition temperature-sensitive medium with a low boiling point.

The liquid-gas phase-transition temperature sensitive media have the following advantages: when absorbing the heat, its volume expansion is large, the generated stroke and the thrust are large as well; the boiling point is low, and the response time is short. Since the suitable working temperature of the engine is between 80°C and 90°C, a liquid with a boiling point below 65°C is selected as the temperature sensitive medium of the new-type thermostat. The common liquid-gas phase-transition temperature-sensitive media with low boiling point include: ether, ethanol, acetone, etc., therefore, through the experiment, we need to select the temperature-sensitive medium that meets the temperature requirements of the thermostat from this type of temperature sensitive media.

3. Selection of temperature-sensitive medium

3.1 Temperature sensitive medium performance experiment

The temperature sensitive medium that meets the temperature requirements of the automobile thermostat should satisfy: first, in an environment in which the engine is in a suitable temperature, the volume changes obviously so that sufficient thrust force and displacement can be generated to open the thermostat valve; second, the response speed of the temperature sensitive medium should be faster, this makes the thermostat act more sensitive. The relationship between temperature, displacement and pressure of the temperature sensitive media such as ether, ethanol and acetone were determined experimentally, by combining the displacement amount required to open the valve of the thermostat, the optimal temperature sensitive medium can be determined.

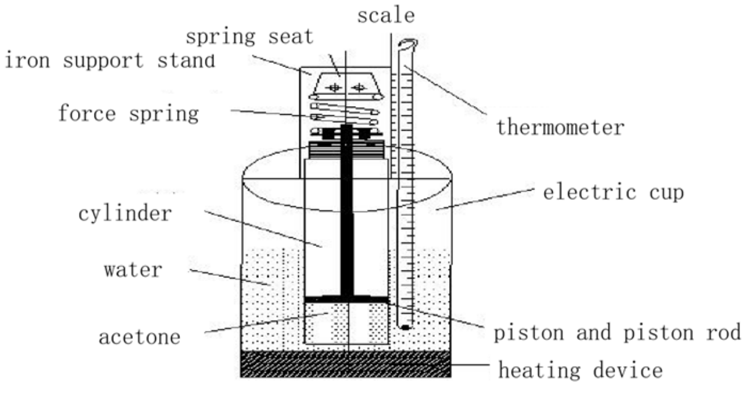

Figure 1: Experimental device

3.1.1 Experimental principle

Take a cylinder with a bottom diameter of 20mm, add a return spring to the piston of the cylinder and heat it in a water bath. Record the displacement of the return spring, according to the mechanical balance principle, the value of the saturated vapor pressure of the temperature-sensitive liquid can be obtained.

3.1.2 Experimental equipment

Acetone solution, ether solution, ethanol solution, an electric cup, a thermometer (accuracy 2°C), a graduated scale (accuracy 0.5 mm), an iron support stand, a cylinder with 20mm diameter (to simulate the thermostat), a vernier caliper, two springs with a stiffness of 1.3N/mm, thin wire, teflon seal tape, two medical syringes, and several rubber bands. The experimental device is shown in Figure 1.

3.1.3 Experimental conditions

1. Experimental environment: temperature 17°C, standard atmospheric pressure.
2. The stiffness of the springs is 1.3N/mm, the original length is 70mm, and the pre-compression amount is 13mm.
3. The ruler measurement accuracy is 0.5mm, and the thermometer accuracy is 2°C.

3.1.4 Experimental steps

1. Pipette a proper amount of acetone solution (or ether solution or ethanol solution) into the hydraulic cylinder with a medical syringe, and then seal the hydraulic cylinder with screws wrapped with teflon tape.
2. Compress the spring with a free length of 70mm and install it on the washer of the push rod. Use the vernier caliper to measure the length L of the spring after compression. The pre-compression of the spring can be obtained with 70-L.
3. Install a piece of thin wire between the spring and the washer of the push rod, and the other end of the thin wire points to the side of the scale with the ruler, record the initial position of the thin wire, by measuring the upward displacement of the thin wire, we can get the upward displacement of the piston.
4. Add an appropriate amount of water to the electric cup, then turn on the power to heat the water.
5. Observe the upward displacement of the thin wire and the change of temperature, for every 2°C rise in temperature, record the upward displacement of the thin wire.

3.1.5 The experimental data is shown in Tables 1 to 3.

Table 1: Relationship between ethanol temperature, spring displacement, and gas pressure

Temperature (℃)	Displacement (mm)	Acting force of the gas (N)
56	0	<16.9
58	0	<16.9
60	0	<16.9
62	0	<16.9
64	0	<16.9
66	0	<16.9
68	1	18.2
70	1	18.2
72	1	18.2
74	2	19.5
76	2	19.5
78	3	20.8
80	3	20.8
82	4	22.1
84	4	22.1
86	5	23.4
88	6	24.7
90	7	26.0
92	8	27.3
94	10	29.9
96	11	31.2
98	13	33.8

As can be seen from Table 1 and the properties of ethanol, the boiling point is 78.3°C. During the experiment, at 68°C, the piston has been displaced but the displacement is not obvious, and the displacement is obvious from 78°C. At the same time, it can be seen from Table 1 that the displacement of the piston is only increased by 3 mm from 84°C to 90°C. This displacement is obviously insufficient for driving the valve of the thermostat to open.
As can be seen from Table 2 and the properties of acetone, the boiling point is 56.48°C. During the experiment, we found that the piston has a displacement from 56°C, and the displacement does not change at 60°C, it's because in the beginning, the pressure generated by the gasification of temperature sensitive liquid is not large enough to overcome the internal friction between the cylinder wall and the piston. As the pressure increases, from 80°C, the piston rises significantly, and the pressure generated by the gasification has increased significantly. At the same time, it can be seen from Table 2 that, from 84°C to 90°C, the displacement of the piston increased by 7.5 mm, which is sufficient for opening the valve of the thermostat.

Table 2: Relationship between acetone temperature, spring displacement, and gas pressure

Temperature (℃)	Displacement (mm)	Acting force of the gas (N)
56	2	19.5
58	2	19.5
60	2	19.5
62	3.5	21.5
64	4	22.1
66	4.5	22.8
68	5	23.4
70	6	24.7
72	7	26.0
74	8.5	28.0
76	10	29.9
78	11.5	31.9
80	12.5	33.2
82	14	35.1
84	16.5	38.4
86	19	41.6
88	22	45.5
90	24	48.1
92	27	52.0
94	30	55.9
96	33	59.8
98	35	62.4

As can be seen from Table 3 and the properties of ether, its boiling point is 34.5°C, according to the experimental test, the piston has a displacement from 34 °C, but the displacement has not been very obvious until 64 °C began to have a more obvious displacement, and the displacement is in line with the law. This is before the acetone began to have a significant shift time. This is because the ether has a low boiling point and vaporizes relatively early, so the pressure produced by vaporization is relatively high. From 84 °C to 90°C, the piston displacement is found to be 10 mm, which is obviously too large as the opening of the valve. Because of the strong anesthetic effect of ether, people must be very careful when they choose it. In combination with the above reasons, ether is not suitable as a thermostat medium.

3.2 Experimental conclusions

Through the above experimental analysis, this paper takes ethanol, ether and acetone as examples to study various common temperature-sensitive media. Within the suitable operating temperature range of the engine, the displacement generated by the gasification expansion of the acetone solution meets requirement of the opening of thermostat valve, it can generate enough thrust to reliably open the thermostat cooling valve. Therefore, we initially selected the acetone solution as the temperature sensitive medium for the new-type thermostat.

Table 3: Relationship between ether temperature, spring displacement, and gas pressure

Temperature (℃)	Displacement (mm)	Acting force of the gas (N)
36	0.5	17.6
40	1	18.5
44	1	18.5
48	2	19.5
52	2	19.5
56	3	20.6
58	3	20.7
60	3	20.8
62	4	22.0
64	4	22.1
66	5	23.5
68	6	25.0
70	7	26.5
72	9	28.8
74	10	30.0
76	11.5	32.0
78	12.5	33.5
80	14.8	36.0
82	17.5	38.5
84	19.2	42.3
86	23.5	47.2
88	27	51.2
90	29	55.0
92	32	58.0
94	35.5	63.0
96	38.5	67.8
98	42.5	72.5

4. Response time analysis

The response time is an important parameter of the thermostat, which reflects how fast the thermostat can act with the change of temperature. The temperature sensitive medium is installed in the thermostat which appeared to be a cylindrical shape, and its heat conduction process is relatively complicated. In order to obtain the temperature change process and response time of the temperature sensitive medium, the author has tested a prototype of the new-type thermostat. The temperature sensing tank is a cylinder with a height of 70mm and a bottom surface diameter of 20mm. The material of the temperature sensing tank is brass and the wall thickness is 2mm. The temperature sensing tank is filled with acetone solution, and the thermostat is first placed in the ice cubes of 0°C, and then placed in a hot water environment of 95°C, the temperature of the central part of the acetone solution is measured by a specific thermometer, and the temperature changes with time as shown in Figure 2.

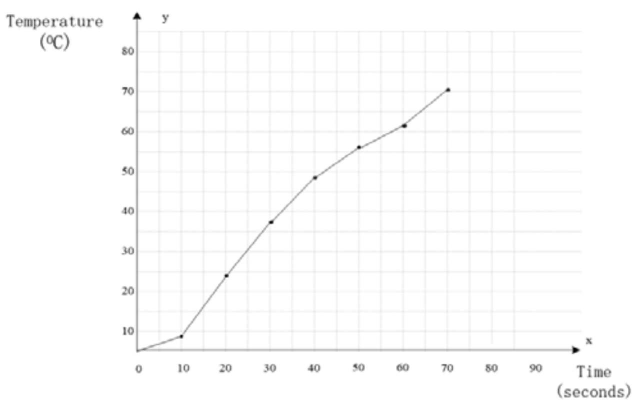

Figure 2: The relationship between the temperature of the central part of the acetone solution and time

It can be seen from Figure 2 that the 95°C load is applied to the 0°C acetone solution. The change of the temperature in the central part of the acetone solution is very fast at the beginning, and the temperature rises by 24.98°C in 20 seconds. After the temperature reaches 60°C, the temperature rises slowly and slowly (only 7.8°C/10 seconds), and this change is in line with the requirements of the thermostat, sensitive at low temperatures and stable at high temperatures. The temperature of the central part of the temperature sensing liquid in the thermostat takes about 70 seconds to change from 0°C to 70°C. It takes only about 95 seconds for the thermostat control valve to fully open, and this response time is faster than 184 seconds, which is the response time of most commonly used paraffin thermostats. Therefore, as a temperature sensitive medium of the new-type thermostat, the acetone solution can meet the requirements of fast response of the thermostats.

5. Conclusion

Through a simple experimental device, this paper studied the relationship between the thrust force generated by volume expansion during the gasification of the temperature-sensitive medium in the thermostat and the time, it measured the change process of the temperature-sensitive medium with time and determined the acetone solution as the temperature-sensitive medium for the new-type thermostat. In the new-type thermostat designed by our group, the acetone solution can generate enough displacement and thrust within the suitable operating temperature range of the engine, and the valve can be opened stably and reliably. Its response time is faster than the current widely used paraffin thermostats. This study provided data support for the structural improvement of the new-type thermostat. In the actual test of engine cooling performance, it’s found that the temperature characteristic analysis and experimental method for the temperature sensitive medium is effective.

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