Design of electric water heater based on piston pressure regulation

Baoming Huang

International Education College, North China Electric Power University (BaoDing), Baoding, Hebei, 071000

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Abstract: Our team has reviewed a large number of documents on the operating principles of current domestic electric water heaters and found that the current domestic electric water heaters have low utilization rates of hot water, and most of the improved methods are focused on improving the structure of the water inlet pipe, Did not start from the root cause. Our group summarized the improvement methods of traditional domestic electric water heaters and combined with its operating principles, and came up with a plan to improve the hot water output rate of electric water heaters from the source-using piston pressure regulation instead of the original "passing cold water to produce heat" Water" mode.

1. Development background and significance

With the development of society, the awareness of energy conservation in the world has become stronger and stronger, and energy conservation and emission reduction have become one of the themes of this era. Among them, energy saving and consumption reduction are the foundation of the survival of the enterprise. The hot water output rate is the main indicator to measure the water-saving and energy-saving capacity of storage electric water heaters. Increasing the hot water output rate is conducive to energy saving and consumption reduction. The hot water output rate of current storage-type household electric water heaters is generally 70% to 85%, and most of them are based on the "cold water in and hot water out" mode. This mode also limits the hot water output rate. The upper limit is theoretically impossible to reach 100%.

The storage-type electric water heater that uses the principle of piston pressure regulation is changed from the mode. Instead of adopting the traditional electric water heater "cold water in and hot water out" mode, it adopts the piston pressure regulation method to ensure that the internal air pressure of the water heater is maintained at a fixed value. All the hot water in the water heater can flow out, so that in theory, the hot water output rate can reach 100%, and the piston-type pressure regulation only needs to use the outside atmospheric pressure without additional power consumption, so as to achieve the goal of energy saving and consumption reduction.

Our project adjusts the pressure inside the electric water heater by adding an air chamber, so that hot water can flow out continuously. The external air chamber is composed of a cylinder with an open top and a freely movable circular baffle. The top of the cylinder is equipped with fixed pulleys along the four directions, and one end of each fixed pulley is equipped with a certain mass of weight. The other end is connected with the circular baffle, so as to achieve the purpose of adjusting the influence of the gravity of the circular baffle. This circular baffle is equivalent to a piston structure. One end is in direct contact with the outside atmosphere, and the other end is in contact with the gas in the gas chamber. From the principle of pressure balance, it can be known that the pressure in the gas chamber is equal to the sum of the outside atmospheric pressure and the equivalent pressure of the baffle. . The air chamber is connected to the water heater through a pipe, so that the air pressure in the water heater is always consistent with the air pressure in the air chamber, so that all the hot water in the water heater flows down smoothly. This greatly improves the hot water output rate, and theoretically can reach 100%.

Most of the current household electric water heaters heat the water in the water heater. After the heating is completed, cold water is continuously supplied to the water heater to press out hot water

during use. The heated hot water is continuously mixed with cold water, which naturally generates heat. The utilization rate decreases, which is also the root cause of the low hot water output rate.

Let's use an example to illustrate this problem. Suppose there is an electric water heater with a rated capacity of 60L, which is heated to 70°C and the water temperature of the water pipe is 20°C.

$$Q_l = c\rho C_p \Delta T$$

Where c is the specific heat capacity of water, c=4.2x10^3J/kg, is the density of water, $\rho = 1 \times 10^3 kg/m^3$, Cp is the rated volume of the electric water heater, C_p=60L and △T is the temperature change, where △T=50℃.

The calculated heat absorbed is:$Q_l = 1.26 \times 10^7$J.

The change of water temperature is a continuous process. In order to facilitate the analysis and calculation period, we decided to adopt a discretization method to convert it into a difference problem.

The water output process is equivalent to a uniform speed process, assuming that the temperature is constant when 1L of water is output each time

Assumption: Treat 1L of water as a whole, Choose a suitable temperature of 40℃,□ Between 0~100℃, the density of water is constant at 1g/cm3.

The output of hot water is m_i , the cold water mixed into $m_i^{'}$, and finally the water of suitable temperature is obtained $m_i^{''}$. The relevant calculation formula is as follows:

$$m_i \cdot T_i + m_i^{'} \cdot T^{'} = m_i^{''} \cdot T^{''}$$
$$m_i^{''} = m_i^{'} + m_i$$
$$T^{'} = 20℃$$
$$T^{''} = 40℃$$

We can use this formula to calculate the actual water consumption $m_i^{''}$

For every hot water output from the water heaterm_i, the cold water will be mixed in m_i, and the temperature of the mixed hot water will change

$$(M - m_i) \cdot T_i + m_i \cdot T^{'} = M \cdot T_{i+1}$$
$$M = 60L$$
$$m_i = 1L$$
$$T^{'} = 20℃$$

We can get through MATLAB data analysis:

Up to the 55th iteration, the temperature in the water heater will drop below 40°C,The total amount of water available is: 90.4841 liters

In an ideal situation, the amount of water that can be mixed with 60 liters of hot water at 70°C burned by the water heater is 150 liters.It can be seen that the hot water output rate is lower in this mode.

By consulting the data, we found that most of the current improvements to electric water heaters are carried out on the improvement of the structure and position of the inlet pipe and heating pipe. The essence is to explore the impact of cold water in the water heater on the overall water temperature. The ideal situation is of course that the incoming cold water is at the bottom and does not exchange heat with the hot water above. This is obviously difficult to achieve. Therefore, although this type of improvement can increase the hot water output rate, it is difficult to greatly increase the hot water output. Rate, and theoretically cannot reach 100%.

2. Design

The structure of the piston pressure regulating electric water heater is shown in the figure.

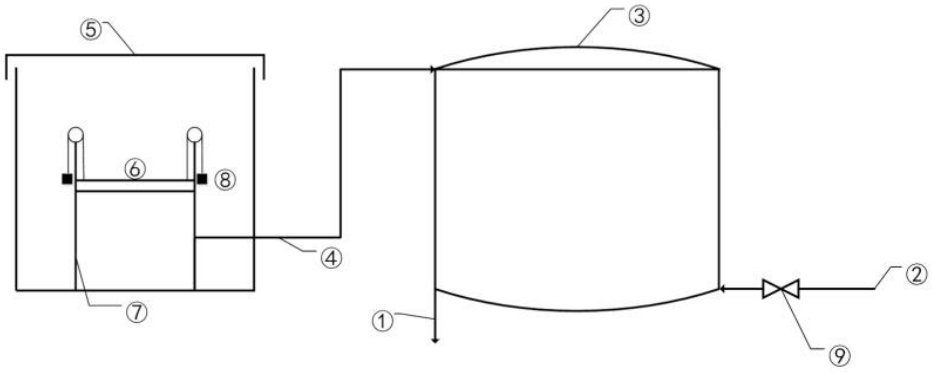

Figure 1. Design sketch

① is the water outlet, which is placed at the bottom of the electric water heater tank, and the temperature of the output water is the temperature of the water in the tank.

② is the water inlet, the channel through which cold water from outside enters.

③It is the heating box of the electric water heater, where the water is stored and heated.

④ is the ventilation channel, the channel connecting the air chamber and the electric water heater tank.

⑤It is a protective cover, which protects the air chamber to prevent dust from falling and rainwater from entering.

⑥ It is a stabilized piston, which isolates the internal and external environment, reduces the air flow in the electric water heater, thereby reducing heat loss; at the same time, it plays a role in balancing the internal and external ambient air pressure.

⑦ is the gas chamber, which stores gas, and is the main place to participate in pressure regulation.

⑧ is the balance weight, which offsets the influence of the gravity of the stabilized piston and the friction force between it and the air chamber.

⑨ is a solenoid valve, which controls the switch of the water inlet channel.

2.1. Regulating part

The outside atmospheric pressure uses the piston as a medium to adjust the air pressure inside the air chamber to stabilize the air pressure inside the air chamber at a certain value; the air chamber is connected to the electric water heater through a pipe, so that the internal air pressure of the electric water heater is equal to the air pressure inside the air chamber.

The process in which the outside atmospheric pressure adjusts the air pressure inside the chamber through the piston:

The piston is composed of a round baffle with a certain mass, a fixed pulley and a weight

The air chamber is a cylinder with an open top. A fixed pulley is fixed in the four positive directions at the top. A weight of a certain mass is placed on the outside of the air chamber through each fixed pulley, and the inside is connected with the baffle to change The influence of the pressure generated by the gravity of the baffle itself on the pressure in the air chamber can even be completely eliminated, so that the mass of the four weights is equal to the mass of the baffle.

In addition to gravity, the baffle is also subject to friction from a chamber wall. The friction force can be completely balanced with a weight device, because leaving proper friction means that the baffle will be forced to move only when the air pressure difference between the air chamber and the outside reaches a certain threshold, which can avoid frequent piston sliding.

The pressure of the piston itself on the gas in the cylinder is adjusted by hanging weights. The pressure balance can be obtained. After the pressure of the gas in the cylinder is stabilized, it will be equal to the sum of the external atmospheric pressure and the equivalent pressure generated by the

piston itself. This value is also It is called the rated air pressure of the water heater. The air pressure rating in the cylinder can be adjusted by adjusting the weight of the weight.

It can be concluded from the force balance that the pressure generated by the equivalent piston itself = F2-F3-F1The equivalent pressure generated by the piston itself

This attribute will affect the water output rate of the nozzle. The larger the rated air pressure, the greater the water output rate, and the smaller the rated air pressure, the smaller the water output rate.

According to the principle of pressure balance:

Air pressure inside the air chamber = outside atmospheric pressure + piston equivalent pressure

The equivalent pressure of the piston is generally determined with the determination of the mass of the weight, and the external atmospheric pressure is generally stable around 1.013x105Pa.

The piston connects the inside and outside of the air chamber to keep the air pressure inside the air chamber at a certain value.

Connect the air chamber to the electric water heater through the air duct, the internal air pressure of the electric water heater is equal to the air pressure inside the air chamber, and the air pressure inside the air chamber is only related to the outside atmospheric pressure and the equivalent pressure of the piston. The air pressure is only related to the external atmospheric pressure and the equivalent pressure of the piston.

2.2. Water ingress detection part

The water level sensor in the container transmits the sensed water level signal to the controller. The computer in the controller compares the measured water level signal with the set signal to obtain the deviation, and then sends it to the water supply solenoid valve according to the nature of the deviation. The command of "open" and "close" ensures that the container reaches the set water level. After the water intake program is completed, the computer in the temperature control section sends an "open" command to the solenoid valve that supplies the heating medium, and the system starts to heat the water in the container. When the temperature is set. The controller issues the command to close the valve, cuts off the heat source, and the system enters the heat preservation state. In the process of programming, ensure that the electric regulating valve that controls the heat source does not open when the system does not reach the set water level, thereby avoiding heat loss and accidents.

After turning on the electric water heater and setting the water capacity, the system starts the solenoid valve, the water inlet opens, and the water level sensor technology measures the amount of water added to the set value. At this time, the system applies a closing command to the solenoid valve to stop the water intake.

3. Working principle

3.1. The principle of water in and out

1. The working principle of effluent

Hot water flows out of the water heater, causing the gas volume in the water heater to increase. According to Boyle's law, it can be concluded that the pressure inside the water heater will decrease to less than the rated pressure, and the piston will move downward, and the gas volume will decrease, which will re-balance.

2. The working principle of water inlet

After turning on the electric water heater and setting the water capacity, the system starts the solenoid valve, the water inlet is opened, and the water level sensor technology detects that the added water reaches the set value. At this time, the system applies a closing command to the solenoid valve to stop the water intake.

Water intake causes the volume of gas in the water heater to decrease. According to Boyle's law, it can be concluded that the pressure inside the water heater will increase, greater than the rated pressure, and the piston will move upwards, and the gas volume will increase, and it will regain balance.

3.2. Principles of the two heating modes

1. Normal temperature heating mode

For users whose water demand is lower than the rated capacity of the water heater, the normal temperature mode can be set to 37~41℃, (the optimal temperature for bathing the human body is 37~41℃), at this time users only need to directly use the hot water in the water heater to take a bath. , There is no need to mix with cold water, and it also has the effect of slowing down the loss of magnesium rods. The internal heating temperature of the water heater is reduced, and the scale is naturally reduced, which naturally delays the consumption of magnesium rods.

2. High temperature heating mode

For users with large water demand, the traditional method is used to calculate the required boiling water temperature through an internal program to achieve a balance between temperature and water volume.

According to the calculation formula for the hot water output rate of the storage electric water heater given in GB21519-2008 "Energy efficiency limit value and energy efficiency grade of the storage electric water heater"

$$\mu = 10^3 m_p \cdot \frac{\theta_p - \theta_c}{(\theta_{A1} - \theta_c) \cdot \rho \cdot C_R} \cdot 100\%$$

It can be known from the structure principle of the piston pressure regulating electric water heater that the water intake process is completed before heating, so it does not exist. The hot water output rate can be simplified as the ratio of the output water capacity to the rated capacity. Taking into account factors such as the air occupies a part of the volume and the heat absorption of this part of the air, it can be concluded that the hot water output rate is above 95%, and theoretically 100% can be obtained.

Mixed water volume = electric water heater liters × water heater output rate / hot water share of mixed water

Hot water share in mixed water = (mixed water temperature-cold water temperature) / (water heater heating temperature-cold water temperature)

By setting the required water volume (mixed water volume), suitable temperature (mixed water temperature), inlet water temperature (cold water temperature), and the hot water output rate calculated above, the required water heater heating temperature can be obtained to adjust the temperature The controller performs temperature adjustment to achieve the purpose of minimizing energy consumption.

4. Theoretical calculation test analysis

4.1. The effect of gas heat absorption

For the convenience of analysis, assume that the gas filled in the gas chamber is all nitrogen, the rated pressure is standard atmosphere, the starting temperature is 20°C, the rated volume of the electric water heater is 60L, and the molar volume of gas under this condition is 24.5L/mol.

The number of moles of nitrogen molecules: $N=\frac{C_p}{V_m}$, Substituting the relevant values to get, N=2.449mol.

This approximation regards the gas in the gas chamber as an ideal gas, which can be derived from the knowledge of thermodynamics, and its internal energy expression is as follows:

$$E = N \cdot \frac{i}{2} \cdot k \cdot T$$

Where E represents the internal energy in the gas chamber, the value of N can be obtained from the above as 2.449 mol, i is the degree of freedom of the gas molecule, where the degree of freedom

of the nitrogen molecule is 5, and k is the Boltzmann constant (k= 1.381x10-23J/K), T is the ambient temperature (in Kelvin).

When the ambient temperature changes from 20°C to 70°C, the amount of energy change in the body can be calculated as $\Delta E = 4.228 \cdot 10^{-21} J$.

It can be obtained from the second law of thermodynamics $Q_g = \Delta E$.

And the heat required for 60L of water is $Q_l = c\rho C_p \Delta T$, Where c is the specific heat capacity of water, c=4.2x10^{3}J/kg, ρ Is the density of water,$\rho = 1 \times 10^3 kg/m^3$, C_pIs the rated volume of the electric water heater, C_p=60L, $\triangle$TIs the amount of temperature change, which is known from the above as50℃, Calculated $Q_l = 1.26 \times 10^7$.

It can be seen from the order of magnitude that the heat absorbed by the gas is negligible relative to the heat absorbed by the water.

4.2. Calculation of hot water output rate

According to the calculation formula for the hot water output rate of the storage electric water heater given in GB21519-2008 "Energy efficiency limit value and energy efficiency grade of the storage electric water heater"

$$\mu = 10^3 m_p \cdot \frac{\theta_p - \theta_c}{(\theta_{A1} - \theta_c) \cdot \rho \cdot C_R} \cdot 100\%$$

It can be known from the structure principle of the piston pressure regulating electric water heater that the water intake process is completed before heating, so it does not existθ_c. The hot water output rate can be simplified as the ratio of the output water capacity to the rated capacity. In theory, it can reach 100%.

5. Innovation and application

The pressure regulating technology is used to adjust the internal air pressure of the electric water heater to make the hot water flow down smoothly. With the help of external atmospheric pressure for pressure regulation, no additional energy consumption is required.

5.1. advantage:

1. High hot water output rate, energy saving and consumption reduction.

Make full use of hot water to achieve the ideal state of "boiling as much hot water as you need".

With the help of the external atmospheric pressure, the internal pressure of the water heater is adjusted without additional energy consumption.

2. The noise is small and does not disturb the people.

5.2. Disadvantages:

1. The air chamber occupies a large volume.
2. Affected by the external environment.

5.3. Improvement direction:

1. Selection of Gas Type

Choose a certain gas or several combinations of gas or use compressed gas technology to achieve the effect of smaller gas chamber volume and less heat absorption.

2. Improvement of the protective cover

In special weather conditions, such as windy weather, in order to prevent frequent changes in the rated air pressure of the air chamber from causing frequent movement of the piston, the external interface of the protective cover can be improved.

3. The placement of the air chamber

Consider adopting a strategy similar to that of an outside air conditioner, placing the air chamber outdoors. Compared with the outdoor unit of the air conditioner, the air chamber is lighter in weight and can be easily hung outdoors in a hanging manner.

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