Research on Marine Boiler’s Pressurized Combustion and Heat Transfer

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The effect of pressure on combustion and heat transfer is analyzed. The research is based on the basic combustion and heat transfer theorem. A correction for the heat calculation method for pressurized furnace is made on the basis of the normal pressure case. The correction takes the effect of pressurizing into account. The results show that the correction is reasonable and the method is applicable to combustion and heat transfer of the marine supercharged boiler.

Keywords: marine boiler, pressurized combustion, radiant heat transfer, heat calculation method.


Introduction

The research on supercharged boiler started in the 20th century. Firstly the supercharged boiler was made successfully in Switzerland. It had many advantages, such as light weight, small bulk and flexibility, thus it was applied on the battleship in 1963 and great profits was obtained. Some other countries like France and Russia also have done many researches on it. The advantages of the supercharged boiler cause extensive attentions. Owing to the research started very late in our country and lack of related information, it is critical to advance our research on supercharged boiler. The present paper has done some basic researches on the calculation method of the furnace combustion, which is the most difficult part of the computation. In the present paper, a heat calculation method of the supercharged boiler is provided, based on the influences caused by pressurized combustion and taken the theorem of heat transfer and experimental data into account.

Influence of the Pressurized Combustion

Effects on the combustion

In the process of combustion, the physical reaction couples with chemical reaction. The speed of chemical reaction is crucial. In order to analyze the combustion of the furnace, firstly the factors affecting the speed should be analyzed, so that the combustion can be described properly.

From the hard-sphere collision theory, the expressions below is derived. The reaction rate constant is the integration of the reaction rate constant of different velocity multiplying weight factor.

\[ k(T) = \int f(u_r, T) u_r \sigma_r(u_r) du_r \]  

(1)

where \( f(u_r, T) du_r \) is equivalent to weight factor, and \( u_r \sigma_r(u_r) \) is equivalent to reaction rate constant.

The relative velocity distribution is using the Maxwell-Boltzmann correlation.

\[ f(u_r, T) = 4\pi u_r^2 \left( \frac{m}{2pk_BT} \right)^{3/2} \exp \left( -\frac{mu_r^2}{2k_BT} \right) \]  

(2)

From eq. (1), eq. (2), the following expressions can be drawn. The details are discussed in reference [1].

\[ k(T) = \pi d_{ab}^2 N_A \sqrt{\frac{8k_BT}{\pi\mu}} \exp \frac{-E}{RT} \]  

(3)

The increasing temperature increases the reaction rate constant \( k(T) \). In supercharged boiler, the local temperature is much higher than the normal one, so the reaction rate is accelerated. Increasing pressure decreases the mean free path, so increases the reaction rate.

\[ k = k_0 e^{-E/RT} \]  

(4)

The reaction speed is related to the speed constant.
The physical characteristic is reflected by $k_0$, and chemical characteristic is $E$. The literature [1] shows that $k_0$ should include a probability factor (steric factor). The probability factor includes all the factors that decrease the effective collision. Increasing pressure in the furnace augments the number of the effective collision, thus $k_0$ increases. The activation energy is not sensitive to temperature. It is proposed to be constant in chemical process. The reaction speed constant has an exponential relationship with the temperature, which should influence the reaction speed constant intensively.

Chemical-dynamics law is:

$$w \propto p^n \quad [3]$$

(5)

At the given temperature and reactant concentration, the chemical reaction rate is proportional to $P^n$. The pressure has apparent influence on the chemical reaction rate, especially with a higher order of reaction. For the boiler, when the pressure increases from $1 \times 10^5$ Pa to $3 \times 10^5$ Pa, the concentration of the reactant will be three times the original value at constant temperature. According to eq. (5), the reaction rate will be three times the original value (in general, the reaction order of hydrocarbon combustion in air is $1.5 < n < 2$)\(^{[31]}\). By Dalton’s law, gas concentration is proportional to its partial pressure, so increasing pressure will concentrate the air and accelerate the chemical reaction rate. With the same volume, increasing the combustion pressure in the boiler, the reaction intensity is improved.

In fact, when reaction in the furnace is intensified, the average temperature is heightened, and the chemical reaction rate is further accelerated, which is beneficial to heat transfer.

### Effects on heat transfer

During pressurized combustion of the heavy oil in the furnace, deposition carbons are produced, which are similar to the gas fuel, beside the residual carbons. Because of the complexity of the carbon formation and influential factors, it is hard to describe with mathematical descriptions. The present paper only analyzes some dominant factors, such as pressure, temperature, and oxygen concentration.

Many researches have been done on the influence of pressure on carbon black formation, and confirmed that the influence of pressure on carbon formation has a unique form. In Fig.1, when the furnace pressure is less than 1 MPa, the capacity of the carbon black formation is improved linearly with pressure increase, while the pressure reaches 1 MPa, the trend is almost flattened. The pressure of the combustion system is commonly about 0.3 MPa, in this range the production of the carbon black is improved linearly with pressure, thus pressure is an essential factor to influence the carbon black formation.

Carbon black formation also has close relationship with temperature and oxygen concentration. Flame temperature or local flame temperature has an obvious

![Fig.1 Carbon black output versus pressure](image-url)