Analysis of Infrared Radiation Intensity by Water-Mist Spraying in Ship Exhaust System

Zhongke Sun\textsuperscript{1,2}, Zhen Wang\textsuperscript{3}, Zhongwei Chen\textsuperscript{2}, Zhihua Liu\textsuperscript{1}, Mo Liu\textsuperscript{2} and Shuai Zhang\textsuperscript{2}

\textsuperscript{1}College of Naval Architecture and Ocean Engineering, Naval University of Engineering, Wuhan, 430033, China
\textsuperscript{2}Academy of Naval Research, Beijing, 100161, China
\textsuperscript{3}China Ship Development and Design Center

\textbf{Abstract.} The infrared radiation intensity in 3–5μm of conventional ship exhaust system are so severe \cite{1} that can be easily captured by detector. Therefore, it’s necessary to take measure like spraying water mist to decrease temperature of exhaust system in order to decrease infrared radiation intensity. In this paper, the calculation of infrared radiation intensity of conventional ship exhaust system with water-mist spraying will be given. The results show that the average and maximum infrared radiation intensity of the exhaust system can be reduced by 90.3\% and 95.7\% after water mist cooling.

1. Introduction
In conventional ship exhaust system, multistage eductor equipment is added at the exhaust nozzle to cope with the tracking of infrared detector, as shown in Figure 1. Its working principle is to create a low-pressure environment with the help of the high speed of the exhaust flow, and the air outside can feel the pressure difference flowing into the pipe from the gap \cite{2}. The exhaust gas encounters the cooler air and its temperature decreases. However, The cooling effect of air is inadequate because of the limited specific heat capacity and flow rate. As a result, the infrared radiation intensity of the exhaust system can still be identified under the large detection zenith angle. So water-mist spraying is used for infrared suppression. The temperature reduction of spraying water mist has been tested by some institutes and and the final temperature less than 100\degree C \cite{3}. But the calculation and experimental results of infrared radiation intensity are not given.

In this paper, CFD software is used to simulate the flow field of the conventional ship exhaust system with water-mist spraying, and then calculate the infrared radiation intensity via the discrete transfer method. The spectral bands are mainly 3–5 μm in the middle infrared band. Malkmus model of statistical narrow band model was used to calculate plume radiation.

2. Flow Field Simulation of Conventional Ship Exhaust System

2.1. No Water-Mist Spraying
The calculation of flow field near the exhaust outlet is the key point because the infrared radiation intensity of ship exhaust system is concentrated at the exhaust outlet. The ejection model uses turbulence model standard k-ω model \cite{4}. In reference, the calculation results of k-ε model and k-ω model were compared in detail, and it was found that the calculation results of k-ω model were in better agreement with the experimental data of the ejector. The tail gas temperature is 733K, and the flow rate is 1.6kg/s.
Parameters of each component of tail gas are shown in table 1:

| ingredient | O\textsubscript{2} | N\textsubscript{2} | CO\textsubscript{2} | H\textsubscript{2}O(g) |
|------------|------------------|-----------------|----------------|------------------|
| Mass concentration | 0.17 | 0.76 | 0.05 | 0.02 |

**Figure 1.** Schematic of the Conventional Exhaust System Structure.

Contours of Temperature of the Conventional Ship Exhaust System is shown as figure 2. It’s the fundament to calculate infrared radiation intensity of ship exhaust system.

**Figure 2.** Contours of Temperature of the Conventional Ship Exhaust System.

2.2. *Water-mist Spraying*

The exhaust system relies on the atomizing nozzle installed on the inner wall of the pipe to spray water mist. The actual structure of the nozzle is not taken into account in calculation, since the nozzle structure has little influence on the flow field. So the atomizing nozzle model in the DPM model is adopted [6]. Only the parameterized nozzle model is used for analysis, which can simplify the analysis process of spraying water and cooling.
Figure 3. Contours of temperature of the Exhaust System by water-mist spraying in pipe.

Figure 3 shows the temperature diagram of the interaction between water mist and flue gas in the pipeline. It’s obvious that the temperature of gas can drop down to 100°C. The final temperature of gas is stable before arriving at the outlet.

3. Calculation of Infrared Radiation Intensity of Ship Exhaust System

The radiation calculation adopts the discrete transfer method [7]. This is a method to transform the three-dimensional radiation calculation problem into multiple one-dimensional radiation transfer calculation. The closed area of radiation calculation is decomposed into countless rays along a certain direction. The starting point and ending point of the rays correspond to the two intersection points of the envelope surface of the closed area respectively. The radiation is calculated from the boundary element at the starting point through the absorption and emission of the medium along the ray path to the end point. The detection Angle setting of zenith Angle $\theta$ calculated by infrared radiation is shown in Figure 3. Due to the shielding effect of the exhaust ejector, the inner wall of the nozzle and high temperature of the exhaust plume are not in the detection view under the small detection view, and the infrared radiation intensity of the ship exhaust system has little change under the small detection view. Small detection Angle of view has less variation. Therefore, the Angle interval of small detection Angle can be appropriately increased to 15°. The 60° to 90° view interval is reduced to 5° because visible high temperature area increases.

Figure 4. Distribution of calculating detection points on ship exhaust system.

The spectral transmittance of plume was calculated by Malkmus model [8]. The expression is as follows:

$$
\tau_\lambda = \exp\left\{-2 \frac{\bar{\gamma}}{d} \left[ \sqrt{1 + \kappa cpl \frac{d}{\bar{\gamma}}} - 1 \right] \right\}
$$

(1)
Where, $c$ is the mole fraction of plume; $p$ is the total pressure of mixed plume; $l$ is the length of propagation path; $\bar{\kappa}$ is the average absorption coefficient, $\bar{\gamma}$ is the average half-width of spectral line, $\bar{\delta}$ is the average space of spectral line [9]. The database HITEMP2010 was selected for spectral parameter calculation and the average spectral line half-width was given by empirical formula [10].

Figure 5. The infrared radiation intensity of the exhaust system cooled by water mist at different zenith angle.

From figure 5, it is not difficult to find that radiation intensity of exhaust system decreases at all angles after spraying water. The average infrared radiation intensity was reduced by 93 percent, the maximum radiation intensity at 85° was reduced by 97 percent. Figure 6 shows the distribution cloud diagram of infrared radiation intensity. Obviously, the radiation intensity near the exhaust axis is greater, while the radiation intensity value drops sharply after spraying water, and basically no longer appears in the distribution cloud diagram.

4. Conclusion
In view of conventional ship exhaust system, this paper has calculated the flow field and infrared radiation intensity of that. Based on the calculation, analysis of the influence of water-mist spraying in ship exhaust system for distribution characteristics of the infrared radiation intensity are done. Finally, we found water-mist spraying can reduced infrared radiation intensity of exhaust system on average for
93%, the largest value of infrared radiation intensity can decreased 97%. The distribution cloud map of infrared radiation intensity with or without water-mist spraying is given. Therefore, it can be concluded that the method of water-mist spraying has an impact on decreasing the infrared characteristic of ship exhaust system. The radiation intensity can drop too low to captured by detector.

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