Study on the infrared radiation performance of Tourmaline composite and its effect on the diesel characteristic

Jian Bin LIAO¹²³,*; Hong Liang YU²³; Di SUN²³; Fong Yuan MA⁴

1. Marine Engineering College, Dalian Maritime University, Dalian 116026, China
2. Marine Engineering College, Jimei University, Xiamen 361021, China
3. Provincial Key Laboratory of Naval Architecture & Ocean Engineering, Xiamen 361021, China
4. National Taiwan Ocean University, Keelung City, Taiwan

a:ljb558@126.com; *Corresponding author: yu1202@hotmail.com

Abstract. The black tourmaline, magnesium tourmaline, and spinel were ground into powder, and the infrared radiation material was prepared by adding the ceramic powder, clay and the other material into the tourmaline powder according to a certain proportion. The infrared radiation property was tested and analyzed, the diesel was infrared radiation activated by the composite material, and the physicochemical property of fuel oil was analyzed pre-test and post-test. The result shows that the infrared absorption spectrum of the black tourmaline of different particle size is stable. After the diesel oil was infrared radiation activated by tourmaline composite materials, the physicochemical property of diesel oil was changed, the activation energy decreased, the viscosity and surface tension of fuel oil were reduced.

1. Introduction

The research of improving the combustion efficiency of diesel engine fuel, reducing the fuel consumption and the discharge of pollutants is quite wide range at present. Patents abroad show that it is feasible to activate fuel molecules, improve fuel combustion efficiency and the emission performance by using far infrared radiation. The current domestic research of infrared radiation materials mainly focus on agriculture, water treatment, air purification, biological medicine health industry, textile industry, etc. Infrared is part of the electromagnetic spectrum, and the infrared of 2.5 ~ 50 μm wavelength can enhance the vibration of groups and atoms of the molecules and strengthen the molecular rotation, thus the internal energy of the radiated molecules were increased.

Tourmaline is characterized by the electromagnetic field. When the environment temperature varies, tourmaline crystal would produce surface charge of the same number and opposite polarity on both ends of the symmetry axis of the third times, and the voltage is produced on both ends of the crystals and the far infrared radiation is released as the temperature changes [1]. Studies shows that the infrared radiant material can be used to activate engine fuel hence to improve the combustion efficiency of fuel and reduce the harmful gas emissions [2-5]. The research of the effect of tourmaline composite materials on boiler diesel combustion emissions has been carried out [6]. Research mainly focuses on the high radiation materials of 3–14μm band in Domestic, however, the infrared emissivity is low in 3–5μm wavelength [7].

In order to improve the activation efficiency of far infrared fuel, the research of far infrared radiation properties of the tourmaline, spinel and other composite material were studied. The nature tourmaline was composite modified by using the spinel material of high infrared emissivity in the
3–5µm band, and the activation of the far-infrared negative ions of tourmaline composite materials for the fuel and the changes of physical and chemical properties were analyzed.

2. Mechanism of infrared radiation
Infrared radiation, also known as infrared light, is firstly discovered by the British astronomer F.W. Herschel in 1800. Infrared light is an electromagnetic wave located in the out end of the visible red light and will radiate infrared radiation energy over absolute zero (-273 °C) [8, 9]. Infrared radiation can be divided into near infrared wavelength (0.76–1.5µm), infrared (1.5–5.6µm) and far infrared wave (8–14µm) and super infrared (15–1000µm).

The infrared radiation can be depicted by emissivity ε, namely

\[ \varepsilon = \frac{M}{Mb} \]  

Where M is the radiant exitance of objects, Mb is the radiant exitance of blackbodies, and ε reflects the radiation ability of objects. Blackbody emissivity (or absorption)is 1, namely ε=1, therefore, the α ratio of the other object whose temperature is more than absolute zero degree and the ideal blackbodies is less than 1. The emissivity changes over the material of permittivity, surface roughness, temperature, wavelength, observation direction, the radiant energy wavelength and observation angle. The infrared radiation of blackbody follows the below rule:

1. Stefan-Boltzmann's law

\[ M_b = \varepsilon \sigma T^4 \]  

Where, Mb is the total power of blackbody radiation, σ is Stefan-Boltzmann constant=5.699×10-8W·m-2K-4, ε is the blackbody radiation coefficient, T is the absolute temperature of blackbody. The Stefan - Boltzmann's law depicts that the total radiation power of various wavelengths is proportional to the four times of blackbody temperature (Kelvin) T.

2. Wayne displacement law

\[ \lambda_\alpha T = C \]  

Where, λm is the radiation wavelength of peak, T is the blackbody absolute temperature, C is constant, the experimental measured value is about 2898µm·K. Wayne's law reflects the product of the peak wavelength and the blackbody temperature T is constant. This means that the short wave is the direction of motion as the T increases, on the contrary, long wave is the direction of motion as T drops.

3. Planck's law

Planck's radiation law, a basic thermal conduction rule between objects, describes that the radiation power per unit time and area is proportional to the four times of blackbody temperature, the mathematical expression is as follows

\[ M_b = \left(2\pi c^2/\lambda^5\right)\left(e^{hv/\lambda T} - 1\right) = \left(c_1/\lambda^5\right)\left(e^{c_1/\lambda T} - 1\right) \]  

Where, M_b is radiant exitance of spectrum; λ is the infrared radiation wavelength, µm; C is the light speed in vacuum; h is Planck's constant, h=6.625×10-34J·s; ν is infrared radiation frequency, k is the Boltzmann constant; T is the thermodynamics temperature of blackbody; c1 is the first radiation constant, c2 is the second radiation constant.

3. Mechanism of infrared radiation

3.1. Tourmaline and composite materials preparation and characterization
Tourmaline chemical general formula for NaR3Al6 [Si6O18] [BO3] 3 (OH, F) 4, is containing boron with additional anionic ring silicate minerals, the main chemical composition is SiO2, FeO, Fe2O3, B2O3, Al2O3, Na2O, MgO style, Li2O and MnO2 [10]; Belong to the trigonal system, the basic unit for (SiO4) 6 after the three ring [11]. Metallic elements such as sodium, calcium and magnesium after filling in the gaps between the three sides ring [12]. R on behalf of the metal cation in the chemical formula, and when R for Ca2 + magnesium 2 +, Fe2 +, or Li + Al3 +, respectively form calcium dravite, black tourmaline tourmaline and lithium mineral [13], tourmaline columnar crystals were
nearly triangle, its two side have positive and negative polarities of the natural, piezoelectric and pyroelectric property (focal electrical) [14].

Tourmaline, chemical general formula NaR3Al6[Si6O18][BO3]3(OH,F)4, is cycle silicate minerals containing boron and additional anionic. The chemical composition of tourmaline is SiO2, FeO, Fe2O3, B2O3, Al2O3, Na2O, MgO, Li2O, MnO2, etc. [10], belongs to the trigonal system, and is the composite three ring with basic unit (SiO4)6 [11]. The metallic elements such as sodium, calcium and magnesium fills in the gaps of the composite three ring [12]. In the chemical formula R represents the metal cation, and when R is Ca2+Mg2+,Fe2+,Li+,Al3+, and the tourmaline forms calcium tourmaline, dravite, black tourmaline and lithium tourmaline, respectively [13]. Tourmaline crystal is nearly triangle columnar, and its crystallization ends have natural positive and negative polarities, piezoelectric and pyroelectric property [14].

According to certain quality percentage, the black tourmaline, dravite and spinel material were ground into below 200 mesh by ball mill after broken. The far infrared radiation compound material was prepared by adding a percentage of the ceramic powder, clay, CaO and other composite materials into the tourmaline powder, and then sintered into the spherical composite particles A with diameter of 5 mm and B with diameter of 2 mm under 950 °C, and the particles are shown in Figure 1.

The microstructure of tourmaline and the composite material were observed with XL30W/TMP SEM of PHILIPS Company, and the microscopic structure of rough tourmaline and its powder are as shown in Figure 2 and Figure 3. Because of the tourmaline natural electric polarity, particles are adsorbed with each other, and small particles are chained connected to each other.

Figure 1. Particles A and B of composite

Figure 2. The SEM image of rough Tourmaline

Figure 3. The SEM image of Tourmaline powder

It can be seen that the rough tourmaline is characterized by compact structure and rough surface, however the powder is characterized by smooth surface and section lamellar structure. The composite material has obvious polymerization phenomenon, and the tourmaline particles distributed uniformly.
3.2. Infrared characteristic research of tourmaline and composite material
The black tourmaline from Xinjiang was taken as the sample and the infrared characteristics of different size tourmaline were researched. The sample 1 is rough tourmaline, the sample 2 is tourmaline powder, the sample 3 is tourmaline composite particles A with diameter of 5 mm, and the sample 4 is tourmaline composite particles B with diameter of 3 mm. These samples were infrared property tested, and its infrared spectrum diagram are as shown in Fig. 6.
Kirchhoff's law shows that the monochromatic radiation rate is equal to the monochromatic absorption values under the same temperature and corresponding wavelength for different objects. Therefore, the infrared radiation capacity is strong in absorption peak. It can be seen from Fig.6 that the absorption is not obvious in 4~7μm wavelength(2500-1429cm⁻¹)and the absorption peak is obvious in 2.8μm(3571cm⁻¹),7.5μm(1333cm⁻¹),9.0μm(1111cm⁻¹),19.4μm(515cm⁻¹). The infrared absorption spectrum of the black tourmaline of different size particle is stable, and the absorption spectrum column characteristics are the similar under the room temperature. The absorption peak is obvious near 9.0μm(1111cm⁻¹), according to Kirchhoff's law that the infrared absorption rate of A λ equals emissivity e λ , the normal emissivity near 9.0μm is strong. As is seen from Fig.6 that the infrared absorption effect for tourmaline composite materials with 5mm particle diameter in range of 2.83μm~21.89μm is better.

3.3. The effect of infrared radiation property on fuel oil physicochemical properties
The high-energy infrared in 2.5~22μm wavelength of infrared radiant material can be used to activate fuel oil, resonance excite fuel molecules bond energy, improve the fuel combustion efficiency, reduce harmful gas emissions, and eventually catalyze combustion. Take two same oil samples, the first sample is A and the second sample is B that was carried out radiation activation treatment by using the prepared infrared radiation composites above. The oil samples were observed with microscope respectively, and the results are as follows:

- The diagram of fuel unactivated with far-infrared radiation is as shown in Fig. 7
The diagram of fuel activated with far-infrared radiation is as shown in Fig. 8.

It can be seen from Fig. 7 and 8 that the particles in A sample appear scaly and the interface of oil and water is not obvious, however the particles in B sample appear broken, fuel gap structure is uniform, and the interface of oil and water is obvious. The structure characteristic of fuel oil in B sample contributes to the decrease of the fuel oil viscosity, which further increases the atomization effect and combustion efficiency. The physicochemical property of two oil samples were tested respectively, and the results are shown as table 1.

**Table 1. The test results of two sample**

| sample | closed flash point (℃) | Gross Calorific Value (MJ/kg) | Net Calorific Value (MJ/kg) | interfacial tension @25℃ (mN/m) | density @25℃ (Kg/m³) | viscosity @20℃ (mm²/s) |
|--------|------------------------|-------------------------------|----------------------------|---------------------------------|-----------------------|------------------------|
| A      | 79.5                   | 46.16                         | 43.03                      | 19.5                            | 836.8                 | 4.685                  |
| B      | 78.5                   | 45.96                         | 42.89                      | 17.0                            | 836.2                 | 4.629                  |

It is clear in table 1 that the interfacial tension changes obviously, drops from 19.5 to 17.0 mN/m after the diesel oil was activated by composite infrared radiation under room temperature, and the interfacial tension reduces 12.82%. Namely, the composite has significant influence on the interfacial tension of fuel oil. In fact, fuel oil is characterized by strong clustering and most of the fuel molecule are in the form of double dimer, trimer or polymer. Therefore, the oil droplets are bigger and atomization quality is poor, which leads to the incomplete combustion, the fuel consumption and flue gas emissions increase.

In addition, the interfacial tension of oil has close relationship with the diameter of the fuel jet [15]. When the interfacial tension of fuel oil reduces, the diameter of the oil droplets also decreases. Moreover, the infrared ray can be C-H and C-C key resonance absorbed, which makes it easier...
disconnect, restructure into carbon dioxide and water, and release energy [16]. Therefore, the reduction of the oil interfacial tension can achieve fuel sufficient burning, further energy conservation and emissions reduction.

Furthermore, the flash point drops by 1.26%, the gross calorific value and net calorific value reduce by 0.43% and 0.33% respectively after the diesel oil was activated by the infrared radiation of composite material. The results show that the safety of saving and transportation and the calorific value of sample are not significant damaged after infrared radiation activation.

4. Conclusion
(1) The infrared radiation properties of natural black tourmaline in different particle size were researched and analyzed, and the result shows that the infrared absorption spectrum of the black tourmaline is stable and the infrared radiation characteristic is similar under room temperature.

(2) The infrared radiation composite was prepared by a certain percentage of black tourmaline, tourmaline powder, drivate, spinel, ceramic powder, clay, and other composite materials, and then the diesel oil was activated with the infrared radiation composite. The result shows that the interfacial tension and the viscosity of diesel significantly reduce of and the flash point, gross calorific value and net calorific value of sample have no substantial change. The infrared radiation activation would not damage the oil sample and can effectively improve the physicochemical property of fuel oil.

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