Theoretical analysis on combustion features of dimethyl ether and liquefied natural gas

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Abstract. In this paper, the combustion features of dimethyl ether (DME) and liquefied natural gas (LNG) have been investigated by theoretical analysis. For the fuel consumption, the heat loss of the waste gas and the NO emission, we find that these indexes of LNG are higher than that of DME. However, the thermal efficiency of DME is better than that of LNG. In addition, the combustion products of DME do not include SO_2.

Introduction

Nowadays, environment protection and energy sustainability have played essential roles in social development. However, with the development of economy, the primary energy consumption grows higher and higher. At the same time, the problems like environment pollution and resource shortage are taking seriously. Therefore, looking for new type of alternative energy has been one of the important tasks.

As an organic compound, DME is the simplest ether with the molecular formula C_2H_6O and it can be synthesized by two ways: direct or indirect. The physical properties of DME are similar to LPG, such as colorless, non-toxic, mildly anesthetic and inflammable. Besides, DME is not greenhouse gas but has a high cetane index [1,2,3,4,5]. DME as a new clean energy, it has high combustion efficiency, without smoke dust and particulate matter [6,7]. In addition, the emission of CO_2, SO_2 and NO_x is also lower than any other fuels [1,8,9]. Thus, DME has attracted attention as a new energy on its production, transportation, storage and utilization [7,10,11,12].

Recently, the combustion of DME has been explored at home and aboard. Lee et al. reported the combustion of DME in the scale of laboratory [13]. Subsequently, the interrelated studies about the combustion of DME have been investigated by Technical University of Denmark, AMOCO, NAVISTAR, AVL, AIST and etc. The results indicate that the nitrogen oxide is decreasing significantly when maintain the high heat efficient and dynamic property [10,14,15]. Because of the excellent performances of DME, Japan, Korea and many countries in Europe focus on the application of DME on engine and vehicle [7,8,16]. More recently, the plat flame micro combustor burning DME for thermoelectric power generation was researched [17].

In this paper, the combustion features of dimethyl ether (DME) will be studied by theoretical analysis. The results will be employed to compare with the combustion of LNG. On the foundation, we discuss the feasibility of DME replacing the LNG.

Theoretical Analysis

To facilitate comparison, a glass melting furnaces with the glass production of 1×10^3kg/h is use to calculate the relevant data of the combustion which uses the DME and LNG as fuel, respectively. The correlation parameters which are used in our theoretical analysis are given in Table 1.

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Table 1. Correlation parameters in theoretical analysis [18].

Title	Symbol	Value	Title	Symbol	Value
Empirical coefficient	C	1.1	Raw material quantity,[kg/h]	M_O	1.2×10^3
Air specific heat,[kJ/kg·K]	C_{air}	0.91	Glass temperature in exit,[˚C]	t_{GE}	1300
Specific feat of glass metal in 1300˚C	C_{GE}	1.4	Ambient temperature,[˚C]	t_{amb}	20
Specific heat of glass raw materials,[kJ/kg·K]	C_O	0.82	Exhaust gas temperature,[˚C]	t_{FS}	1300
Specific heat of fuel, [kJ/kg·K]	$C_{p,FUEL}$	DME:1.614, LNG:2.1	Air amount,[m^3/h]	V_{air}	DME:2278, LNG:2714
Specific heat of exhaust gas,[kJ/kg·K]	C_R	1.3	Volume fraction of NO	φ	0.08%
Specific heat of smoke,[kJ/kg·K]	C_S	DME:1.429, LNG:1.433	Fuel consumption,[m^3/h]	V_{FUEL}	DME:146, LNG:261
Sulfur content(calculate by H_2S),[mg/m^3]	G	DME: 0, LNG: 20	Volume of SO_2 in smoke,[m^3/h]	V_G	DME:0, LNG:3.439
Enthalpy of fuel, [kJ/m^3]	$h_{C,FUEL}$	DME:61700 LNG:37255	Volume of NO in smoke,[m^3/h]	V_{NO}	DME:2.056, LNG:2.38
Enthalpy of vapor,[kJ/kg]	$h_{f,water}$	4500	Smoke volume,[m^3/h]	V_s	DME:2570, LNG:2975
Melting heat in reaction,[kJ/kg·K]	I	630	Air density,[kg/m^3]	ρ_{air}	1.42
Melting rate	MC	4%	Fuel density,[kg/m^3]	ρ_{FUEL}	DME:1.95, LNG: 0.71
Glass output,[kg/h]	M_G	1.0×10^3	Smoke density,[kg/m^3]	ρ_s	DME:1.257, LNG:1.236

The related calculation equation is shown as follow.

Glass heat in exit of furnace:

$$Q_1 = M_G \cdot C_{GE} \cdot (t_{GE} - t_{amb}) \tag{1}$$

Melting heat in reaction in furnace:

$$Q_2 = IM_G \tag{2}$$

Vaporization heat of water in raw material:

$$Q_3 = M_G \cdot MC \cdot h_{f,water} \tag{3}$$

Combustion heat of fuel:

$$Q_4 = V_{FUEL} \cdot h_{C,FUEL} \tag{4}$$

Combustion heat of organics (like antifoaming agents):

$$Q_5 = 17.5\times10^3 \mathrm{kJ/h} \tag{5}$$

Physical heat of raw material:

$$Q_{61} = M_O \cdot C_O \cdot t_{amb} \tag{6}$$

Physical heat of fuel:

$$Q_{62} = V_{FUEL} \cdot C_{p,FUEL} \cdot \rho_{FUEL} \cdot t_{amb} \tag{7}$$

Physical heat of air:

$$Q_{63} = V_{air} \cdot C_{air} \cdot \rho_{air} \cdot t_{amb} \tag{8}$$

Physical heat taken into furnace:

$$Q_6 = Q_{61} + Q_{62} + Q_{63} \tag{9}$$

Total heat taken into furnace:

$$Q_0 = Q_4 + Q_5 + Q_6 \tag{10}$$

Heat taken out by smoke:

$$Q_{71} = V_s \cdot \rho_s \cdot C_s \cdot t_{FS} \tag{11}$$

Heat taken out by exhaust gas in reaction:

$$Q_{72} = (M_O - M_G)\ C_R \cdot t_{FS} \tag{12}$$

Heat loss by waste gas:

$$Q_7 = C \cdot (Q_{71} + Q_{72}) \tag{13}$$

Thermal efficiency of furnace:

$$\eta = \frac{Q_1 + Q_2 + Q_3}{Q_0} \tag{14}$$

According to equation (1) - equation (14), the results of theoretical calculation is shown in Table 2.

Table 2. Results of theoretical calculation.

Title	Symbol	Value	
		DME	LNG
Glass heat in exit of furnace, [kJ/h]	Q_1	1792×10^3	1792×10^3
Melting heat in reaction in furnace, [kJ/h]	Q_2	756×10^3	756×10^3
Vaporization heat of water in raw material, [kJ/h]	Q_3	216×10^3	216×10^3
Combustion heat of fuel, [kJ/h]	Q_4	9008.2×10^3	9723.6×10^3
Combustion heat of organics(like antifoaming agents) , [kJ/h]	Q_5	17.5×10^3	17.5×10^3
Physical heat of raw material, [kJ/h]	Q_{61}	19.7×10^3	19.7×10^3
Physical heat of fuel, [kJ/h]	Q_{62}	9.2×10^3	7.8×10^3
Physical heat of air, [kJ/h]	Q_{63}	55.2×10^3	65.7×10^3
Physical heat taken into furnace, [kJ/h]	Q_6	84.1×10^3	93.2×10^3
Total heat taken into furnace, [kJ/h]	Q_0	9109.8×10^3	9834.3×10^3
Heat taken out by smoke, [kJ/h]	Q_{71}	6001.3×10^3	6850.1×10^3
Heat taken out by exhaust gas in reaction, [kJ/h]	Q_{72}	338×10^3	338×10^3
Heat loss by waste gas, [kJ/h]	Q_7	6339.3×10^3	7188.1×10^3
Thermal efficiency of furnace	η	30.3%	28.1%

Discussion

According to the above calculations, the thermal efficiency, heat loss by waste gas, fuel consumption and the emission volume of NO and SO_2 are illustrated in Fig. 1. The results show that the consumption volume and the heat loss by waste gas of DME are lower than that of LNG, as illustrated in Fig. 1 (a) and (b). It implies that the DME contains oxygen can reduce the requisite amount of the air, thus can decrease the volume of the waste gas emission. This result leads to the thermal efficiency of DME is higher than that of LNG, as shown in Fig. 1 (c). Since DME does not include the element S, the emission of SO_2 is zero, however, LNG is mixture and contains the element S, and thus SO_2 exist in combustion products of LNG, as given in Fig. 1 (d). For the same volume fraction of NO, the low volume of the waste gas emission will produce the low NO emission, as shown in Fig. 1 (e). Therefore, it is feasible that DME replacing LNG in industrial thermal system.

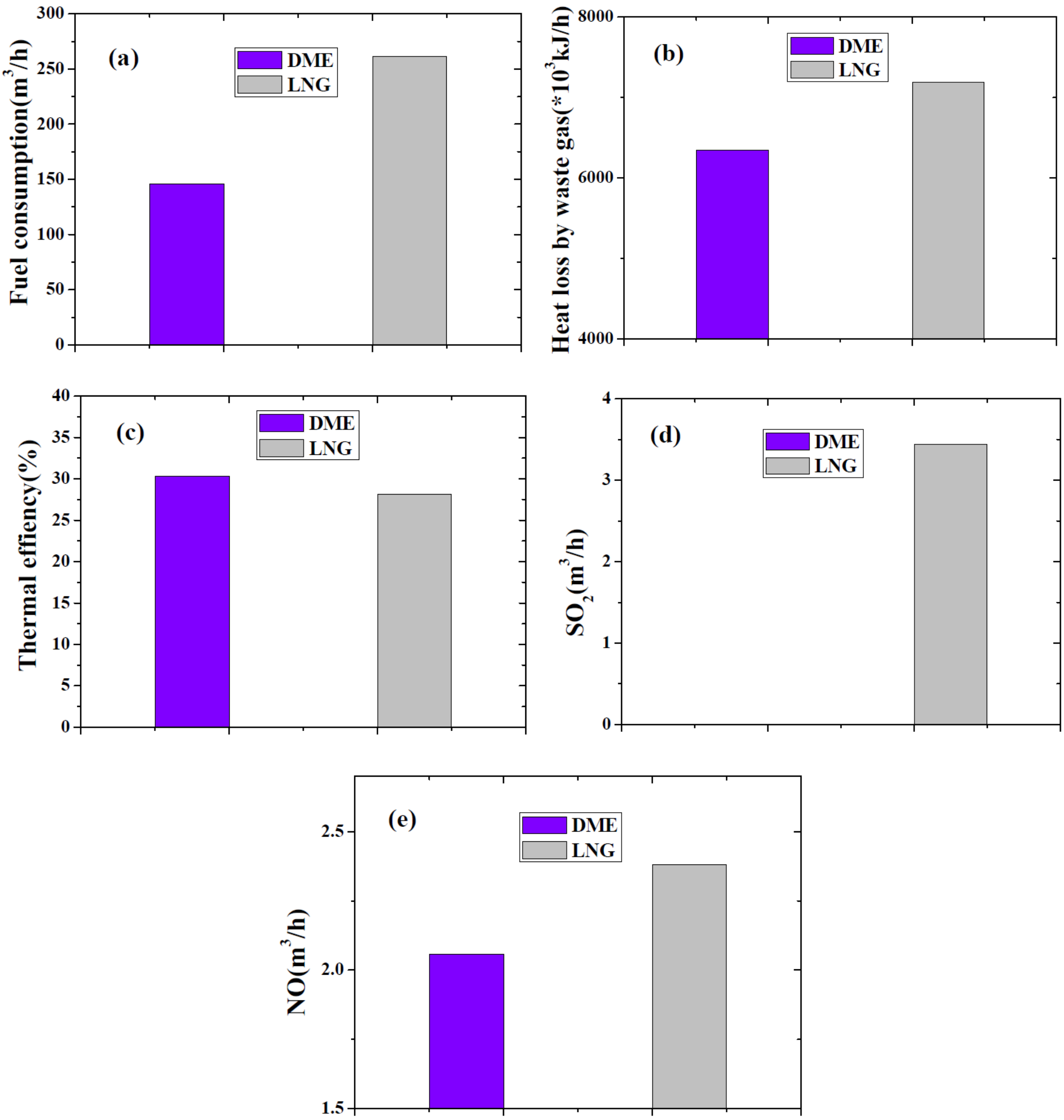

Fig.1. The comparisons diagrams with different parameters of DME and LNG.

Conclusions

(1) For the consumption volume, NO emission and the heat loss by waste gas of DME are lower than that of LNG.
(2) The thermal efficiency of DME is higher than that of LNG and the emission of SO_2 is zero for DME.

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