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Strategy research on ship speed down and exploit high-viscosity fuel

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ABSTRACT

Ships to save fuel oil are focused in the field of marine energy efficiency and emission reduction. To reduce shipping costs, improve economic operation and increase shipping profits, shipping companies take measures to slow down main engine and burn high-viscosity fuel oil. The main engines, auxiliary engines and boilers of COSCO container vessel loading 10000 containers combust the inferior fuel oil with the high viscosity at 700cst, it is analyzed and calculated in this paper. The results show that, steam consumption to heat the inferior high viscosity fuel oil is increased. When the main engine mean speed is reduced to 50-55RPM, the ship's actual speed is 11-12kn, navigational speed of container vessel is very low, it's save fuel oil is very significant, fuel-efficient reaches to limit.

Key words: Marine energy efficiency; emission reduction; ship slow down; high viscosity fuel

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INTRODUCTION

With the prices of marine fuel oil rising more and more [1], fuel consumption is the most important part of the shipping costs [2], This brings forth more difficulties for the shipping companies. To reduce the fuel cost and the environmental pollution caused by burning fuel oil for the ship, the most effective measures is to save fuel, the less fuel consumption, the better ship energy saving and emission reduction, the lower ship operating cost [3]. An important strategy is to slow down and combust high viscosity fuel oil of main engine, auxiliary engines and boiler.

In the world environment of low shipping index, COSCO exploits high viscosity fuel oil to reduce the operational cost, and increase enterprise benefit. But the problem is the high viscosity fuel oil must be heated by steam of fuel oil fired marine boiler to reduce its viscosities to meet the requirements of main engines [4]. The project must be analyzed and calculated to determine whether it is economic and reasonable.

To reduce the fuel cost, as a vessel of COSCO adopts the fuel oil with the 700cst viscosities instead of 380cst and 500cst. In order to control fuel oil viscosity, which can meet combustion requirements of main engines; it needs steam generated by oil fired boilers to heat high viscosity fuel oil. The steam consumption is different because there are different fuel oil viscosities and different main engine speeds. In this process, it's a variable for steam consumption to heat high viscosity fuel oil, but the variable is difficult to be calculated. The economic entities must be evaluated for steam consumption with different viscosities of fuel oil.

This paper is focused on reducing fuel consumption and ship costs by the main engine slow down and using 700cst fuel oil. The main contributions are the analysis of the balance between slowing navigation speed and saving fuel oil, and the presentation of steadystate of the main engine waste heat utilization and steam consumption used to heat high-viscosity fuel oil. Experimental results in 10000 containers vessel demonstrate the benefits of ship energy saving and emission reduction. The paper is organized as follows; analysis and numerical calculation of the ship steam consumption, specifications and treatment of heavy fuel, effect of the main engine slow down. The conclusions are given finally.

ANALYSIS OF THE SHIP STEAM CONSUMPTION

The temperatures of fuel oil with various viscosities are different in fuel oil settling tanks, service tanks and purifiers, it is necessary to heat different viscosity or flow of fuel oil by different steam consumptions. So the steam consumption in fuel oil heaters should be calculated and analyzed. In the course of vessel design, steam heating system is adopted to heat fuel oil in tanks, purifiers and boosters. Because the steam pressure is mostly 0.4~0.8 MPa, the saturated steam with less 0.4 MPa is unable to heat heavy fuel oil in boosters, the steam generated by exhaust gas boiler can't get enough to heat high viscosity fuel oil when the main engine speed is less than a certain speed. At this time, fuel oil in boosters must be heated via the steam generated by fuel fired boiler. The pressure, temperature, specific volume, enthalpy, latent heat of vaporization and quality entropy of saturated water and steam [5] are shown in Table 1.

Table1. Saturated water and steam

Pressure	Temperature	Specific volume		Enthalpy		Latent heat	Quality entropy	
		Liquid	Steam	Liquid	Steam		Liquid	Steam
10^5 Pa	℃	m3/kg	m3/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg·K	kJ/kg·K
4	143.62	0.0010839	0.46242	604.7	2738.5	2133.8	1.7764	6.8966
4.5	147.92	0.0010885	0.41392	623.2	2743.8	2120.6	1.8204	6.857
5	151.85	0.0010928	0.37481	640.1	2748.5	2108.4	1.8604	6.8215
6	158.84	0.0011009	0.31556	670.4	2756.4	2086	1.9308	6.7598

Because the temperature is all the same 75℃ for fuel with three different viscosities in fuel settling tanks, the separated temperature for different viscosities of fuel oil is about 95~98℃ in purifiers. The temperature of each viscosity of fuel oil is different in the fuel oil boosters. The heated temperatures of fuel oil with 380cst, 500cst and 700cst viscosities are respectively 142℃, 146℃ and 153℃in interpolation method, the latent heat of vaporization and enthalpy of saturated water and steam are shown in Table 2.

Table2. Saturated water and steam in three different temperatures

Fuel oil viscosity	Temperature	Latent heat of vaporization	Enthalpy	
			Liquid	Steam
cst	℃	kJ/kg	kJ/kg	kJ/kg
380	142	2133.8	604.7	2738.5
500	146	2126.494	623.2	2743.8
700	153	2104.83	640.1	2748.5

According to fuel oil system located in different vessel positions, the heating steam consumptions are different. The calculated formulas of steam consumption in different positions are respectively as following. The formula is suitable to calculate steam consumption of fuel oil service and settling tanks for keeping the temperatures [6].

Steam consumption of heater:

$$q_{m1} = \frac{\left[q_{m2} \cdot C_L \cdot (t_2 - t_1) \right]}{(i'' - i') \cdot \eta} \quad (1)$$

where, q_{m1}-steam consumption of heater (kg/h); q_{m2}-heated medium flow (kg/h); C_L-specific heat of heated medium(kJ/kg•K) (water C_L = 4.1868kJ/kg•K, oil C_L=1.884 kJ/kg•K); t_2-final temperature of heated medium (℃); t_1-first temperature of heated medium (℃); i''-enthalpy of heating steam (kJ/kg); i'-enthalpy of heating steam condensate water (kJ/kg); η-efficiency of heater.

Steam consumption of tank:

$$q_{m3} = \frac{m_1 \cdot C_L \cdot (t_2 - t_1)}{(i'' - i') \cdot T} + S_T \cdot h_T \cdot \left(\frac{t_2 + t_1}{2} - t_0 \right) \quad (2)$$

where, q_{m3}-steam consumption of tank (kg/h); m_1-liquid quality in tank (kg);C_L-specific heat of heated medium (kJ/kg•K); t_2-final temperature of heated medium (℃); t_1-first temperature of heated medium (℃); t_0-external temperature of tank (℃); S_T-surface square of tank (m^2); h_T-heat transfer coefficient of tank surface; T-heating time (h).

Steam consumption to keep tanks warm:

$$q_{m4} = \frac{S_T \cdot h_T \cdot (t_2 - t_0)}{(i'' - i')} \tag{3}$$

where, q_{m4}-steam consumption to keep tanks warm（kg/h）; S_T-heat transmission of tank surface (such as air, water, neighbor tanks) (m^2); h_T-coefficient of heat transmission (kJ / m^2•h•K); t_2-kept temperature (℃); t_0-external temperature of heat emission (℃).

Steam consumption of fuel pipe with steam tracer:

$$q_{m5} = (0.05 \sim 0.1) L_{FO} \tag{4}$$

where, q_{m5}-Steam consumption of fuel pipe with steam tracer (kg/h), L_{FO}-the fuel line length.

Auxiliary boiler steam production:

$$q_{mb} = \frac{g_b \cdot u_L \cdot \eta_b}{i'' - i'_w} \tag{5}$$

where, q_{mb}- auxiliary boiler steam production (kg/h), g_b- auxiliary boiler fuel consumption (kg/h), u_L-fuel low calorific value (kJ/kg), i''- steam enthalpy (kJ/kg), i'_w- enthalpy of feed water (kJ/kg).

When Steam quantity of exhaust gas boiler is necessary to estimated, the exhaust gas parameters are modified according to the actual situation [7]. MAN B&W low speed engine as an example, power point selection relative to nominal power point to modify the amount of exhaust gas is given as (6a), part load power point to modify the amount of exhaust gas is given as (6b), environmental conditions to modify the amount of exhaust gas is given as (6c), as follows. Exhaust gas quantity is $q_{mg}= m_0+\triangle m_\delta+\triangle M_E$.

$$m_0\% = -14.9388\text{In}(n_0\%) + 14.9388\text{In}(p_0\%) + 100 \tag{6a}$$

$$\Delta m_\delta\% = 0.0055\times(p_\delta\%) - 1.15\times(p_\delta\%) + 60 \tag{6b}$$

$$\Delta M_E(\%) = -0.41(T_A - 25) - 0.03(P_A - 100) + 0.19(T_{CA} - 25) - 0.011(\Delta P_B - 3) \tag{6c}$$

where, n_0- nominal speed of main engine, p_0- nominal power of main engine, m_0-exhaust gas quantity of selected power; p_δ- part load power of main engine, $\triangle m_\delta$- exhaust gas modified quantity of part power of main engine; T_A-actual temperature (℃), P_A-atmosipheric pressure (kPa), T_{CA}- cooling water temperature of cooler inlet (℃), $\triangle P_B$-exhaust back pressure (kPa), $\triangle M_E$- exhaust gas modified quantity according to environmental conditions.

Exhaust gas boiler maximum steam production:

$$q_{mb} = q_{mg}\frac{C_g(t_{1E} - t_{2E})(1-\phi)}{i'' - i'_w} \tag{7}$$

where, q_{mb}- maximum steam production (kg/h), C_g=1.055 kJ/kg·K is exhaust gas specific heat, t_{1E}- exhaust gas inlet temperature of exhaust gas boiler, t_{2E}- exhaust gas outlet temperature of exhaust gas boiler,Φ = (4%～5%) is heat loss of exhaust gas boiler.

The formulas are suitable to calculate the heat transmission of fuel oil between tank wall and external medium in fuel oil storage tanks. Based on the formulas, the necessary steam consumption to heat the fuel oil and keep the temperatures can be determined. The temperatures in heater and tanks are respectively shown in Table 3 and Table 4.

Table3. Heated final temperature in heaters

Final heater of fuel oil					
Fuel oil viscosity (50℃)	180 mm²/s	380 mm²/s	460 mm²/s	600 mm²/s	700 mm²/s
t_2 (℃)	125	140	145	150	155
t_1 (℃)	90				

Table4. Heated temperature in fuel oil tank

Fuel oil viscosity (50℃)	**180 mm²/s**		**380 mm²/s**		**460 mm²/s**		**600 mm²/s**		**700 mm²/s**	
	t_1	t_2	t_1	t_2	t_1	t_2	t_1	t_2	t_1	t_2
F.O.Storage TK.(℃)	2	25	2	35	2	38	2	42	2	46
F.O.Setting TK.(℃)	25	60	35	60	38	60	42	60	46	60
F.O.Service TK.(℃)		90		90		90		90		90

NUMERICAL CALCULATION OF STEAM CONSUMPTION

Marine steam is produced by auxiliary boiler which is cylindrical and heavy fuel oil fired marine boiler and Exhaust gas boiler which is forced circulation and bare tube type, their evaporation is 4000kg/h, their steam condition is 0.6MPa saturated steam [8]. It is necessary to consume steam for the ship's heaters including main fuel oil heater, purifier fuel oil heater and aux. purifier fuel oil heater, heating coils including fuel oil storage TKs, fuel oil setting TKs and fuel oil service TKs. Because the heavy fuel viscosity at main engine which is two-stroke diesel engine inlet may be in the range 13-17cst, the necessary preheating temperature for a given nominal viscosity is taken from the viscosity-temperature diagram, to meet combustion requirements of the main engine, the temperature of 700cst fuel oil heated by steam is to 146-150℃. To ensure the heavy fuel treatment by purifier, the fuel oil temperature of purifier heater may be 90-98℃.

Given the thermal value of heavy oil is 9600kcal/ kg, 1kcal=4.184kJ, the steam consumption is calculated for fuel oil with 380cst, 500cst, and 700cst viscosities in different main engine speeds according to COSCO 10000 containers vessel. In the same time, the fuel oil consumption to generate steam is calculated to evaluate whether the project is reasonable and economic. According to the relevant design of fuel oil heating system, the consumptions of fuel oil and steam in boilers are calculated in fuel oil boosters. The results are shown in Table 5.

Table5. Steam consumption corresponding to different main engine speed

Parameters	**Medium parameters value**			**Unit**
Fuel oil viscosity	380	500	700	cst
Separated temperature	95	95	95	℃
Temperature of inlet	142	146	153	℃
Enthalpy of steam	2738.5	2741.433488	2749.799714	kJ/kg
Enthalpy of water	604.7	614.9395349	645.0849785	kJ/kg
Specific heat of fuel oil	1.884			kJ/kg·K
Steam consumption in 70 rpm	6.74339207	7.342437995	8.436630248	ton
Steam consumption in 65 rpm	5.705947137	6.21283215	7.138687133	ton
Steam consumption in 55 rpm	3.527312775	3.840659874	4.413006591	ton
Steam consumption in 50 rpm	2.904845815	3.162896367	3.634240722	ton
Steam consumption in 42 rpm	1.659911894	1.807369353	2.076708984	ton
Fuel consumption in 70 rpm	0.492490541	0.536911	0.61911967	ton
Fuel consumption in 65 rpm	0.416722765	0.454309308	0.52387049	ton
Fuel consumption in 55 rpm	0.257610437	0.280845754	0.323847212	ton
Fuel consumption in 50 rpm	0.212149771	0.231284738	0.266697704	ton
Fuel consumption in 42 rpm	0.121228441	0.132162708	0.152398688	ton

The calculated results in Table 5 show that the steam consumption is increased greatly with the increase of fuel oil viscosities. The steam consumption to heat different fuel oil viscosities in different main engine speeds is shown in Fig1. Fig.1 shows that the heating steam consumption increases with the rising of the main engine speeds. When the exhaust gas is not enough to generate steam to heat the fuel oil, the steam boiler should be started to produce steam. With the increase of the viscosities of fuel oil, the fuel oil consumption of boiler rises. The conclusion can be reached in Fig.1 that the fuel oil consumption to generate steam increases with the rising of the main engine speeds.

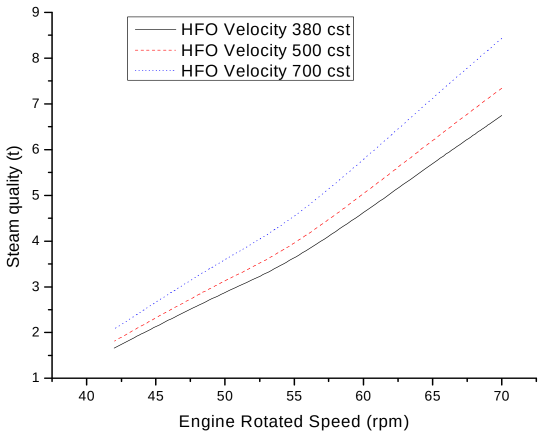

Fig.1. Steam consumption for heating fuel oil with different viscosities

QUALITIES AND TREATMENT OF HEAVY FUEL OIL

The qualities of the heavy fuel have a bearing on the frequency of overhauls and the effort required for the preparation of the heavy fuel, it is primarily economic considerations according to the type, size and speed of the main engines. Heavy fuel oil must be treated in the fuel oil purifier. The fuel must not have any corrosive effect on the combustion equipment of the main engine and must not contain used lubricating oil or any chemical wastes. Marine fuels are usually differentiated by viscosity, which is indicated in centistokes (cst) and measured at 50℃, the fuels are classified according to ISO8217, it is necessary to evaluate the quality and suitability of a fuel for use in a diesel engine. The use of fuel oils with properties approaching the maximum limits requires very good supervision and maintenance of the engine and the fuel treatment equipment. With fuels of poor quality and inadequate fuel preparation, improper overhauling and added maintenance costs have to be faced.

It is recommended that the relevant specifications of diesel engines for the design of the fuel treatment plant, the minimum centrifuge capacity is 1.2×CMCR(kW)×BSFC(g/kWh) /1000(litres/hour), which correspond to 0.21 l/kW, where CMCR is the abbreviation of "Contract Maximum Continuous Rating", BSFC is the abbreviation of "Brake Specific Fuel Consumption". The fuel treatment has to remove sludge and reduce catalyst fines and water to the recommended engine inlet limits.

The maximum admissible viscosity of the fuel that can be used in an installation depends on the heating and fuel preparation facilities available. The throughput and the temperature of the fuel going through the centrifuges must be adjusted in relation to the viscosity to achieve good separation. Heating the fuel above 150℃ to reach the recommended viscosity at engine inlet is not recommended, because the fuel may start to decompose, form deposits and be dangerous as it will probably be well above the flash point.

To overcome the difficulty in burning fuel oil with 700cst viscosity in burner of steam boilers, the burner of boiler ignition system and fuel oil supply pump of boiler should be improved to be suitable for burning fuel oil with high viscosities. In the same way, the injecting oil system of diesel should be improved to burn fuel oil with high viscosities [6]. Simultaneously, fuel oil transferring system, fuel oil purifying system, fuel oil service system and fuel oil draining system should be improved either. By means of fuel oil treatment to separate water and impurities in fuel oil with high viscosities, fuel oil quality which is pumped into diesel burner is improved so that the fuel oil burns fully and reduces nitrogen oxide and sulfide emissions. The initial investment of each fuel oil treatment is 50,000 Euros, but the cost would be recovered after sailing 3~5 months. The fuel oil treatment improves fuel oil quality and reduces the harms for main engines, auxiliary engines and boilers.

RESULTS OF THE MAIN ENGINE SLOW DOWN

As fuel prices rise, fuel costs have accounted for more than vessel operating costs by 60%. The diesel engine running slow has become a measure of ship cost decreasing and benefits increasing. But the diesel engine slow down too much or too little can lead to loss of shipping profits [9]. If only considering the relationship between the diesel engine speed down and fuel-efficient, navigation speed reduced by 10%, the diesel engine power is reduced by 27.1%, fuel consumption reduced by 19%. If navigation speed reduced by 20%, the diesel engine power is reduced by 48.8%, fuel consumption reduced by 36%. 25 knots refer to 100% relative propulsion power of COSCO container vessel loading 10000 containers, a reduction of 25% (5 knots) will result in a reduction of 57% propulsion power. It is observed that the diesel engine speed down oil-saving effect is obvious significantly.

But excessive speed down the main engine is in bad conditions for a long time, it led to the deterioration of combustion, the moving parts wear and so forth. When the main engine running too low load, exhaust gas boiler produces steam insufficient, and scavenging pressure is not enough, therefore, auxiliary boiler and main engine auxiliary blower are started, to increase fuel and electric power consumption. Ship fuel-efficient exist limit point between main engine speed down and inoperation of auxiliary boiler and blower [10]. Maximum steam quantity of exhaust gas boiler depends on the main engine exhaust gas volume and temperature, which are with the changes of main engine service power, load size, environment condition exhaust back pressure and so on.

During the ship sailing, exhaust boiler which is exhaust gas economizer produces steam generated by main engine exhaust high temperature gas heating fresh water. When the main engine speed of 10000 containers vessel is less than 55 rpm, main engine exhaust gas decreases rapidly, the steam pressure is lower than 0.4 MPa. The heavy fuel is not satisfied with the required viscosity and fuel fired boiler which is auxiliary boiler must start. In terms of 10000 containers vessel, which is the case study of this paper, the fuel consumption of boiler is about 2.5 ~3 tons fuel per day. As there is some energy of exhaust gas when main engines are with 55 rpm, the fuel consumption is different. When the vessel is in harbor, the fuel consumption of steam boiler is about 4~5 tons per day. The 700cst fuel is exploited, 0.4 MPa steam pressure does not fulfill the required viscosity for main engine when its speed is 50-55 rpm. In this condition, the steam boiler must be ignited or the main engine speed must be improved. Therefore the main engine mean speed is reduced to 50-55RPM, fuel-efficient reaches to limit.

Fig.2 shows the main engine change trend curves between mean power, fuel consumption, specific fuel oil consumption (SFOC) and mean speed, they are as the mean speed increases. In Fig.2, when main engine mean speed is 50.0 rpm, main engine fuel consumption (MEFC) is 345.5 kg/nmile and to achieve maximum value; when mean speed is more than 50.0 rpm or less than 50.0 rpm, MEFC are decreased. When main engine mean speed is 38.64 rpm and 62.99 rpm, SFOC is minimum and maximum respectively. Main engine mean power is as the mean speed increases, highest speed when maximum power. When mean speed is less than 31.9 rpm, mean power, fuel consumption and SFOC is the lowest, also leads the ship to the lowest cost.

Fig.3 shows quadratic function fitting of the main engine change trend curves, in Fig.3, ME-rpm is the main engine mean speed, ME-g/kwh is the main engine specific fuel oil consumption (SFOC), ME-kg/nmile is the main engine fuel consumption per nautical mile, ME-ton/day is the main engine fuel consumption per day, ME-kw is the main engine mean power. When ship's actual speed is increased, ME-kw is proportional to the third power of ship's actual speed. ME-rpm and ME-ton/day are proportional to the ship's actual speed. ME-g/kwh and ME-kg/nmile are increased little with the increase of the ship's actual speed. When ship's actual speed is 11-12kn, the two curves of ME-kg/nmile and ME-kw and the two curves of ME-ton/day and ME-g/kwh are intersected respectively, consequently, 11-12kn is the economic speed of 10000 containers vessel, its save fuel oil is very significant.

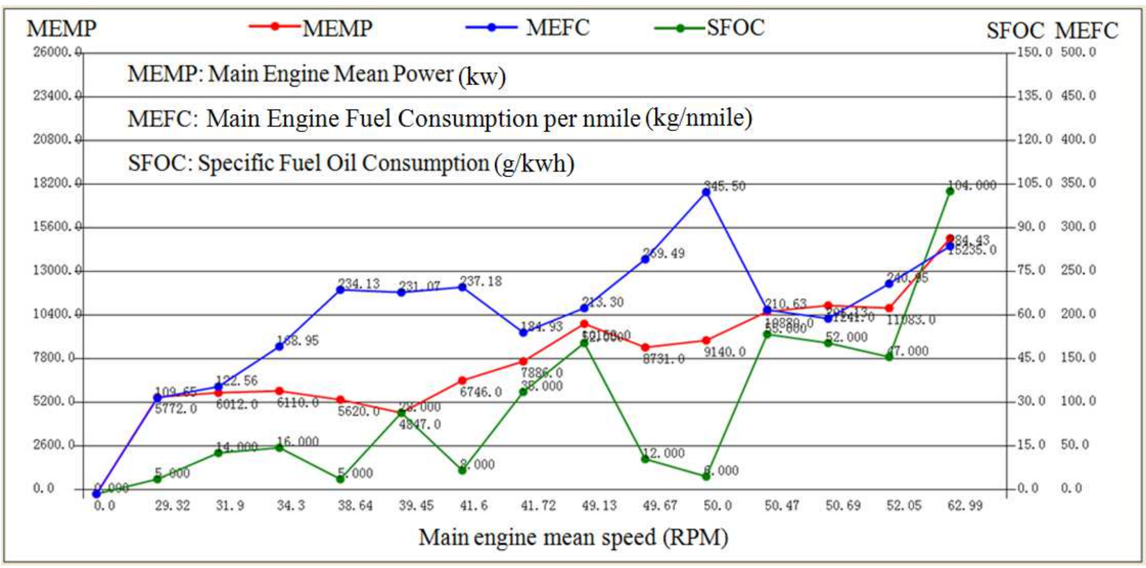

Fig.2. the main engine change trend curves of mean powers, fuel consumption and SFOC

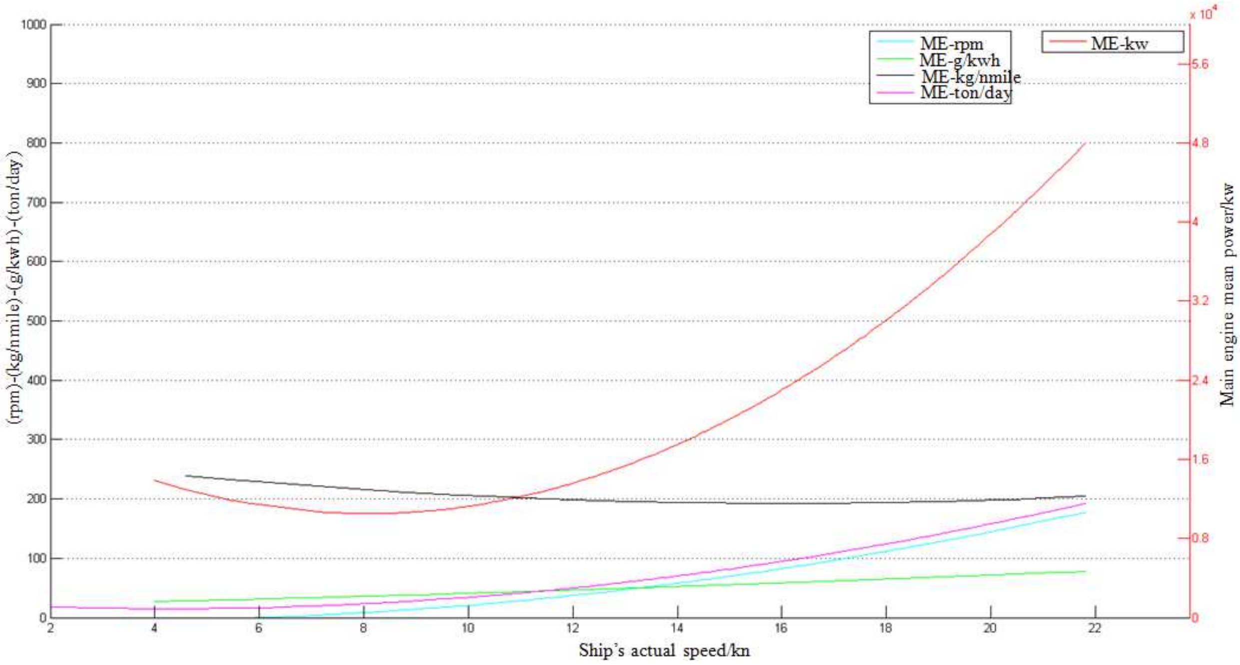

Fig.3. Quadratic function fitting of the main engine change trend curves

CONCLUSION

A slightly lower speed can be greatly save power, when the speed reduced by 20%, main engine power required can be reduced by 50%, this can greatly reduce the total fuel consumption of the main engine. Shipping companies take measures to slow down main engine and burn high-viscosity 700cst fuel oil. When the main engine mean speed is reduced to 50-55RPM, the ship's actual speed is 11-12kn, navigational speed of container vessel is very low, it's save fuel oil is very significant, fuel-efficient reaches to limit.

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REFERENCES

[1] Paskaleva K. *International Journal of Innovation and Regional Development*, **2009**, 1(4), 405-422.
[2] Arora A..*Traffic Engineering and Control*, **2012**, 53(10), 375-378.
[3] B. Chen and H. H. Cheng. *IEEE Trans. Intelligent Transportation Systems*, **2010**, 11(2), 485–497.
[4] Seng Dewen. *Applied Mechanics and Materials*, **2012**, 189, 482-485.
[5] SENG Dewen, LI Zhongxue. *Journal of Liaoning Technical University*, **2008**, 27(1), 9-12.
[6] Li Yuanzhang. *Energy for Metallurgical Industry*, **2004**, 23(2), 38-40.
[7] Hu Jun. Design and Research on Marine Fuel Oil Purifying System, Master Dissertation, Dalian Maritime University, Dalian, P.R. China, **2009**, 14-44.
[8] Di Lecce, V. Amato, A. IET *Intelligent Transport Systems*, **2011**, 5(3), 149-158.
[9] Yang Qiu-ping, Xie Xin-lian and Pei Guang-shi. *Journal of South China University of Technology (Natural Science Edition)*, **2011**, 39(10), 119-126.
[10] Xu Yanjun, *Wang Min. Navigation of China*, **2013**, 36(4), 135-138.