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Design and Build the Exhaust Gas Energy-Utilizing-Heat Exchanger for Diesel Engines

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Abstract
Vietnam shipbuilding industry is developing strongly. For ships with a large tonnage of 50 to 100,000 tons, moreover the main engine installed on board is a diesel engine with a large capacity of tens of thousands of horsepower. Emissions generated by the main engine have a large flow, pressure and temperature are still quite high at about 0.35Mpa and 400oC, bringing large energy sources to the outside. This energy source accounts for about 20 to 25% of the burning heat generated in the combustion chamber. If you make full use of this energy source, it will contribute to saving fuel and increasing the efficiency of the ship power system. In addition to bringing high economic benefits due to a significant reduction in input fuel costs, reducing costs for handling waste and reducing environmental pollution, boilers that utilize exhaust heat do not consume fuel. It also contributes to the supply of saturated steam for heavy oil heating, fresh water distillation, oil and water separation, blowing sea valves, serving the crew's activities and cooking. For some large and modern ships that have used superheated steam due to boiler to operate generators, serving air conditioner cooling, food preservation.

Keywords: heating system, exhaust gas, diesel engine

1. Introduction
Up to now, many new and renewable energy resources are found in order to satisfy the ever-increasing energy demands of the human, increase dramatically about the prices and the depletion of mineral fuel, reduce the environmental pollution. Hence, finding out more energy efficient technologies such as the techniques of the exhaust gas energy recovery of internal combustion engine is pushing continually by many researchers. The combination between utilizing the exhaust gas of diesel engine and heating up pure vegetable oil to improve the disadvantages such as high viscosity, high density, high surface tension and use heated pure vegetable oil as the alternative fuel in diesel engine will reduce not only the dependence on fossil fuels but also the release of greenhouse gases and contribute the energy efficient recovery. Recent tendency about using the energy sources in order to reduce the rate of consumption of fossil fuel as well as pollution. The internal combustion engines are the major consumer of fossil fuel, however about 30 - 40% is converted into useful mechanical work. Besides, the heat is expelled to the environment through exhaust gases and engine cooling systems are approximately 25 – 35%, therefore it results in being serious environmental pollution, hence it is required and necessary to utilize the waste heat to increase the heat efficiency of internal combustion engines. The waste heat recovery and utilization not only saves fuel but also reduces the amount of greenhouse gases. Engine manufacturers have implemented the techniques such as enhanced fuel-air mixing, turbo-charging, and variable valve timing in order to increase thermal efficiency. However, around 65-75% of the fuel energy is still lost as waste heat through the coolant or the exhaust gases. As the most widely used source of primary power for machinery critical to the transportation, construction and agricultural sectors, engine has consumed more than 60% of fossil oil so it is able to result in exhausting the fossil fuel.
Many researchers recognize that waste heat recovery from engine exhaust has the potential to decrease fuel consumption without increasing emissions. Utilizing the exhaust gas energy to heat up pure vegetable oil and use as the alternative fuel in diesel engines not only increases

the heat efficiency of engines but also reduces the pollution emission. This paper gives a method of calculating and designing the exhaust energy recovery system to heat up pure coconut oil and use heated pure coconut oil as fuel in diesel engines.

2. Design and manufacturing the heating system

Waste heat is heat generated in a process by way of fuel combustion or chemical reaction. It depends on the temperature of the waste heat gases and mass flow rate of exhaust gas of diesel engines. Exhaust gases temperature of diesel engines after leaving the engine are as high as 450 - 600°C. Consequently, the hihger the exhaust gas temperature is, the higher the heat content is. Hence, it is necessary to design a better heat transfer and lower exhaust temperatures; however, the temperature of exhaust gases are limited by the laws of thermodynamics. Total energy from diesel engines is shown in the Fig. 1.

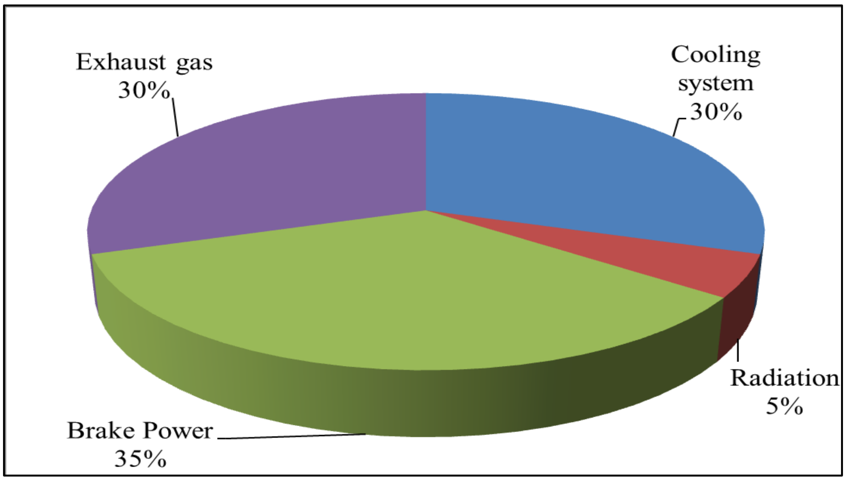

Fig. 1: Total energy in diesel engines

The waste heat energy contained in the exhaust gas depends on both the temperature and the mass flow rate of the exhaust gas. The funtion of heat loss for exhaust gas in diesel engines is given:

$$Q_{exhaust} = C_p.m_e.\Delta T \qquad (1)$$

Where,
$Q_{exhaust}$ is the heat loss (kJ/min);
m is the exhaust gas mass flow rate (kg/min);
C_p is the specific heat of exhaust gas (kJ/kg.K);
ΔT is temperature gradient (K).

For diesel engines in the ships that is bigger than 3000 hp of the power, the utilizing of exhaust gas energy is much more interested due to the space of engine room is large and exhaust gas heat energy is big. The exhaust gas energy of these engines can be recovered through the system of auxiliary – exhaust gas boiler or turbo - compressor aimed to heat up heavy fuel or turbochargers. However, small capacity engines, especially the diesel engines with less than 100HP of power, it is not occasional to arrange the devices utilizing the exhaust gas energy. In automobile diesel engines, significant amount of heat energy of exhaust gas is released into the environment. About 35% of the thermal energy generated from the combustion in the automotive engines is lost to the environment through exhaust gas and other losses. The amount of such losses, they are recoverable at least partly or greatly and depend on the engine load. Among various advanced methods, exhaust energy recovery for automobile diesel engines are proved to improve fuel consumption, further reducing CO_2 and other harmful exhaust emissions correspondingly.

The ASTM D1298 standard procedures were used to measure density, the ASTM D 445 standard was used to measure kinematic viscosity and Du Nouy ring method with a tension meter based on the ASTM D971 standard was used to measure surface tension of the CO100. The physical and chemical properties of the CO100 are given in the Table 1.

Table 1: Physical and chemical properties of the CO100 at room temperature

Properties	Methods	Unit	Result
Higher heating value	ASTM D 240	kJ/kg	39.000
Water content	ASTM E 203-01	ppm	432
Sunfat ash	ASTM D 874	%wt	0.03
Sulfur content	ASTM D 5453	ppm	170
Cetan number	ASTM D 976	-	39
Cloud point	ASTM D 97	ºC	21
Flash point	ASTM D 93	ºC	200
Density	ASTM D 1298	g/cm^3	0.9103
Kinematic viscosity	ASTM D 445	cSt	49.3
Surface tension	ASTM D 971	N/m	0.0322

It is observed that, higher heating value of CO100 is 5 – 8% smaller than that of diesel fuel. However, the kinematic viscosity of the CO100 is 7 – 10 times higher than that of diesel fuel. Therefore, it is necessary to heat CO100 up to the suitable temperature in order to the CO100 kinematic viscosity be close to diesel fuel' one. The experimental test result about the relationship between the CO100 kinematic viscosity and temperature shows that, CO100 heated up 100ºC – 110ºC (CO100_t100) will satisfy the requirements of diesel fuel based on TCVN5689-2005 and QCVN 1:2009.

3. Experimental results and discussion

3.1 Heat loss through the exhaust in diesel engine

The diesel engine D245 is used to calculate and design the heating system by utilizing the exhaust gas energy in order to heat up CO100 from room temperature to 100^0C. The specifications of diesel engine D245 can be briefly described in Table 2.

Table 2: Specifications of diesel engine D245

Description	Unit	Quantity
Rated power, Ne	HP	80
Revolution, N	rpm	1500
Bore, D	mm	110
Stroke, S	mm	125
Compression ratio, r	-	16.7:1
CO100 fuel consumption, sfc	g/HP.h	210

Exhaust heat loss of diesel engine D245

Compression ratio (V_r)

$$V_r = \frac{V_c + V_s}{V_c}$$

so

$$V_c = \frac{V_s}{V_r - 1} \quad (2)$$

Where

$V_r = 16.7V_c$

and

$$V_s = \frac{\pi D^2}{4} S \quad (3)$$

Therefore $V_c = 7.56.10^{-5}$ m^3

Total volume $V_T = V_c + V_s = 12.63.10^{-4}$ m^3

Mass flow rate of CO100_t100 fuel:

$m_f = sfc.N_e = 4.67$ g/sec.

Volume rate $v = V_s \times N = 21.75.10^{-3}$ m^3/sec

Volume efficiency

$$\eta_v = \frac{m_a}{\rho_a.N.V_s} \quad (4)$$

Where:

Volumetric efficiency η_v is 0.8 to 0.9;

Density of CO100_t100 fuel ρ_f is 0.8639 g/cm^3; Calorific value of CO100 is 38 MJ/kg;

Density air fuel ρ_a is 1.167 kg/m^3;

Specific heat of exhaust gas C_P is 1.1-1.25 KJ/kg.K.

Therefore $m_a = \eta_v \rho_a N V_s = 1.24$ kg/min = 20.67 g/sec

Mass flow rate of exhaust gas $m_e = m_f + m_a = 25.34$ g/sec

Heat loss in exhaust gas of diesel engine D245 following (1) is: $Q_{exhaust} = 10.59$ kJ/sec = 10.59 kW.

3.2 Biofuel heating system by utilizing exhaust gas energy

It is found from the review Table 3 that, biofuels are the fuel rapidly growing in use, and it should have good fluidity, low viscosity and good atomization which can only possible by preheating.

Table 3: Review of preheating of different biofuel

Authors	Vegetable oil /Biofuel	Remarks
Acharya, Mishra, Rath, & Nayak (2011)	Kusum and Karanja oil's	Viscosity is close to diesel's by preheating to 100–130ºC.
P. P. Sonune (2012)	Mahua oil	At the temperature above 100 ºC the viscosity reaches to ASTM limits.
ER Ram Rattan (2012)	Mustard oil	Preheating upto 130°C to attain the same density as that of diesel
R. Raghu,et.al (2011)	Rice bran oil(RBME)	Raised to 158°C to bring its viscosity closer to diesel
Ahanasios (2011)	Sunflower, rapeseed and cottonseed oil	The alternative fuel passing through heat exchanger and its temperature in the range of 65-75°C
Somu Chokraborthy (2009)	Watse vegitable oil	Blends preheated to 100 °C become close to that of diesel.
Chauhan etal. (2010)	Jatropha	Optimal fuel inlet temperature was found to be 80°C
M.Nematullah Nasim	Neat jatropha oil	The preheating of the neat Jatropha oil is from 30°C to 100°C
Hevandro Colonhese Delalibera1	Soybean oil	Preheated 65 °C with 50% of soybean oil in diesel fuel
Oza Nityam P.	Karanj, Jatropha and Neem	Preheating the fuel to overcome higher viscosity and lower volatility associated with biodiesel.
Hazar and Aydin (2010)	Raw rapeseed oil (RRO)	Preheating to 100°C lowered viscosity and provided smooth fuel flow

Direct CO100 heating system by utilizing the exhaust gas energy can be applied in small ship. The advantages of this method include high thermal performance and simple. However, the reliability is low, this heating system only works when the main engine run, causing the hydraulic impedance in the exhaust line and installation difficulties. Further, it is necessary to ensure the exhaust gas temperature out of the heat exchanger higher than 200°C in order to avoid the dew point corrosive phenomenon. The exhaust gas energy of diesel engine D245 depending on load of engine is shown in Fig 2, the model of smooth pipe heater is shown in Fig 3.

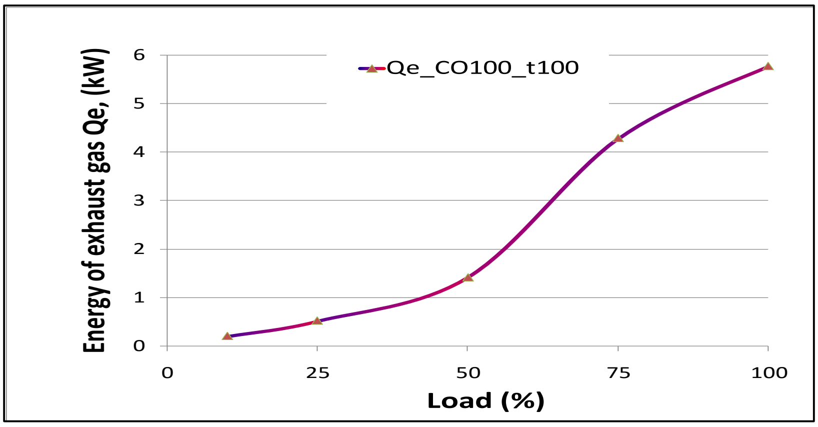

Fig.2: Exhaust gas energy of diesel engine

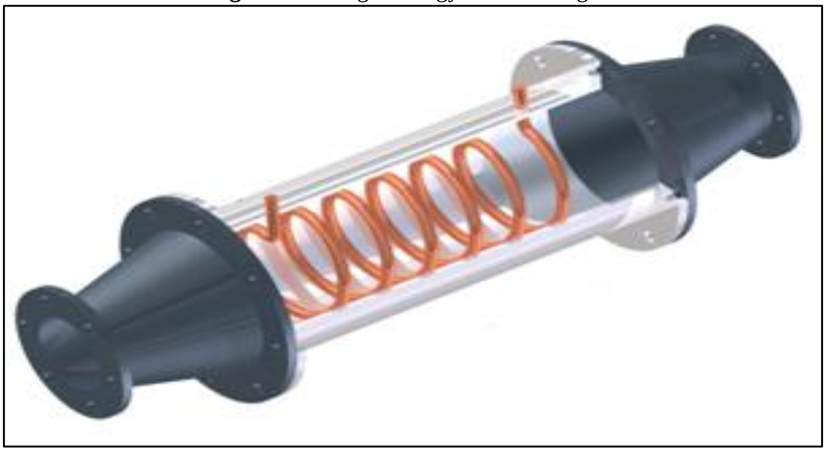

Fig.3: Model of smooth pipe heater

The device of utilizing exhaust gas energy is calculated and designed in case of the diesel engine working at 90% of load and 1500 rev/min of speed. The redundancy heat energy of exhaust gas will be adjusted to expel into the environment by the by/pass valve. The results about the heater between exhaust gas energy and CO100 in order to heat CO100 up to 100ºC based on the heat balance equation $Q_{expel} = Q_{absorb}$ are given in the Table 4.

Table 4. Design parameters of the heater

Parameter	Sign	Unit	Result
Diameter of CO100 pipes	d_2/d_1	mm/mm	12/8
Heat coefficient of CO100	α_2	W/m^2.K	25.3
Heat coefficient of exhaust gas	α_1	W/m^2.K	78.2
Thermal conductivity coefficient of pipes material	λ	W/m.K	35.5
Heat transfer coefficient	k	W/m^2.K	19.08
Heat transfer surface square	F	m^2	0.04
Height of heater	H_h	mm	415

Nitrogen oxides NO_x, carbon dioxides CO_2 and smoke emission of the engine D245 while using CO100_t100 are shown in Fig 4, Fig 5 and Fig 6.

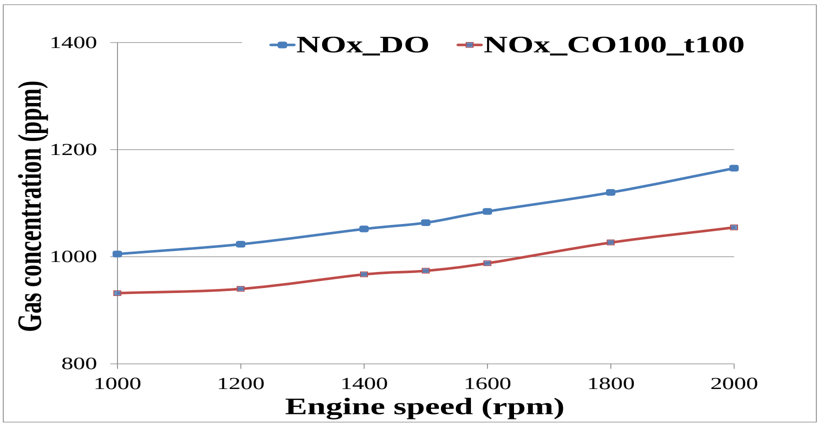

Fig.4: NO_x emission of the engine D245

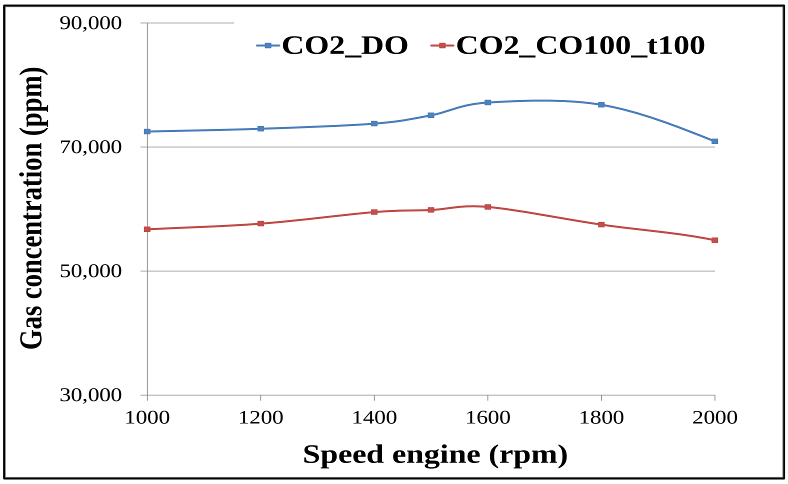

Fig.5: CO_2 emission of the engine D245

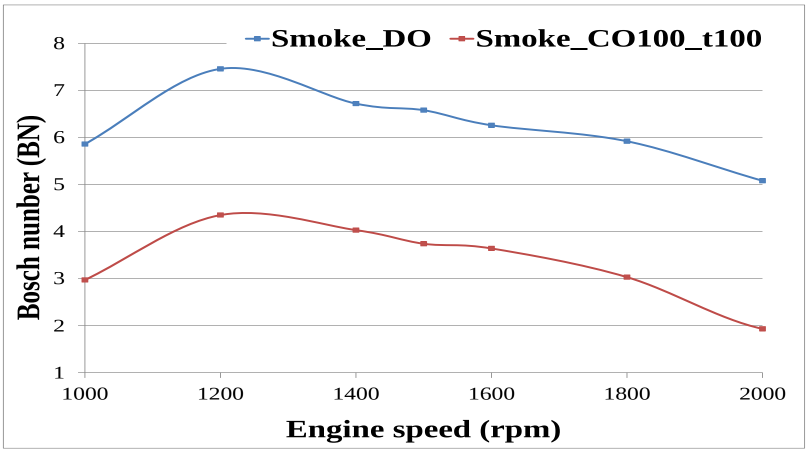

Fig.6: Smoke emission of the engine D245

From Fig 4, it can be seen that NO_x emissions of the engine D245 when fueled CO100_t100 is lower than that of diesel fuel, corresponding from 7.27%-10.35%; NO_x emissions is 8.81% of the average lower than that of diesel fuel. Whereas the emission smoke reduces 51.02% of the maximum, the emission CO_2 reduces 25.15% of the maximum.

Thus, it is able to prove and ensure that, utilizing the exhaust gas energy of diesel engine by heater in order to heat up CO100 to 100^{o}C and use heated CO100 as fuel in diesel engine not only saves the energy but also reduces the emission. These will improve the heat efficiency of diesel engine and restrict the dependence on the fossil fuel in the future.

4. Conclusions

Utilization of exhaust gas energy of diesel engine to improve the disadvantages of pure coconut oil and use heated pure coconut oil as fuel is necessary to improve the heat efficiency of diesel engine and reduce the environmental pollution. However, up to now, there is only exhaust gas energy of diesel engine in the ocean ship utilized. The results of this paper will orientate to calculate and design the heater to absorb the exhaust gas energy in small ship. Findings of this paper show that CO_2, NO_x and smoke are lower than that of diesel fuel. In next research, the effect of temperature on the heater strength will carry out. The paper presents the calculation, design and fabrication of the thermal oil heating system by direct utilizing exhaust gas energy of diesel engine to heat up pure coconut oil (CO100) that is a kind of pure vegetable oils, and use heated CO100 as fuel in diesel engines. The paper results show that, after installing the CO100 heating system in the engine D245 and using heated CO100 as fuel, the technical and economic indicators of heating system and engine D245 are maintained, the utilized exhaust gas energy is about 52%, the emission NO_x reduces 8.81% of the maximum, the emission smoke reduces 51.02% of the maximum, the emission CO_2 reduces 25.15% of the maximum.

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