УДК 621.43

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Increasing the efficiency of marine diesel engine by deep waste heat recovery along the route line

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Abstact

One of the promising ways in environmentalizing marine internal combustion engines (ICE) is the neutralization of harmful substances in exhaust gas through engine gas recirculation (EGR) technology. However, the use of such techniques conflicts with the engine's energy efficiency and leads to increasing fuel consumption. It is promising to use technologies that would increase fuel and energy efficiency of ICE with EGR systems and combine high environmental efficiency with engine fuel efficiency. The technology of precooling intake air at the suction of turbocharger by waste heat using chiller (WHUCh) was developed for ICE with EGR system. The advantage of this solution is the possibility of using the waste heat of recirculation gases to reduce the heat load on the scrubber recycling system and fuel consumption. The scheme-design solution of the EGR system with using the heat of recirculation gas by an ejector chiller (ECh) for cooling the air at the intake of main ship engine is proposed. The effect of using the heat of recirculation gas for cooling engine intake air is analyzed taking into account the changing climatic conditions on a vessel's route line. It is shown that using the heat of recirculation gas for cooling engine intake air by ejector refrigeration machine reduces the air temperature at the entrance of the main engine by 5-15 °C, which decreases the specific fuel consumption by 0.5-1.4 g/(kW·h). This reduces emissions of harmful substances (NOx by 26-38%; SOx by 9-14%) when the engine is running with recirculation of gas.

Keywords: Harmful Emissions, Exhaust Gas Recirculation, Ejector Chiller, Specific Fuel Consumption, Ecology

Introduction

The most sensitive environmental impact comes from ship power plants, in which the main source of energy (thermal, mechanical, electrical) is internal combustion engines. During the operation of internal combustion engines the greatest harm is caused by toxic substances contained in the exhaust gas. The formation of harmful gases, such as carbon dioxide CO_2, nitrogen oxides NOx, carbon monoxide CO, sulfur oxides SOx, etc., depends on the organization of work processes in the internal combustion engine.

A very effective way of greening marine internal combustion engines is the artificial neutralization of harmful substances in exhaust gases, for example, by exhaust gas recirculation (EGR technology). However, the use of such technology is in conflict with the energy efficiency of the internal combustion engine and causes increasing fuel consumption compared with conventional engine operation without exhaust gas recirculation.

So it is reasonable to use the technologies that would ensure an increase in fuel and energy efficiency of internal combustion engines with EGR systems, that is, would combine high environmental efficiency with engine fuel efficiency. These technologies would provide fuel saving due to pre-cooling air at the suction of the turbocharger of diesel engines by waste heat using chillers (WHUCh) as an example.

Research Methodology

The effectiveness of the application of proposed technical solution was analyzed on the basis of EGR system typical for MAN low-speed two-stroke diesel engines in accordance with the Tier III environmental conditions. Recirculation is provided by bypassing part of the exhaust gases purified from harmful gases in the scrubber after cooling in the heat exchanger-gas cooler. The EGR system comprises scrubber, chilling unit, condensate trap, the fan and the system is cleaned from the solution of NaOH.

Circuit solution with the use of the heat-using circuit of the ECh is considered for the ship's low-speed two-stroke diesel engine MAN B&W 6G50ME-C9.6. To analyze the parameters of the recirculation system, as well as the characteristics of the main engine, the CEAS software package of the leading manufacturer MAN was used [1]. The calculation was made for the following initial data: the performance characteristics of the main engine (under ISO conditions) – engine load – NMCR = 90 %; power – N_e = 9288 kW; speed – n_e = 96.5 rpm; specific fuel oil consumption (SFOC) – g_e = 166.0 g/(kWh); exhaust gas recirculation system (EGR) – as bypass with scrubber and gas cooler, responsible for Tier III environmental conditions.

The calculation of the characteristics of the engine was carried out on the operating mode during the voyage of the dry-cargo ship from Odessa to Yokohama. The variation of climatic conditions (ambient air temperature t_a, absolute humidity d_a and relative humidity φ_a, temperature of sea water t_w) during the vessel's voyage is presented.

The operating parameters of the heat-recovery contour based on the ECh were calculated using the well known equations, applied in the software complex developed at the Department of Conditioning and Refrigeration.

The following characteristics of the ECh for cooling the ship engine intake air were chosen: refrigerant – R142b; refrigerant evaporation temperature in the evaporator-air cooler t_0 = 5 °C and in the generator t_g = 80–120 °C, refrigerant condensing temperature in the condenser t_c = 25–45 °C.

The values of coefficient of performance for WHUCh: ζ= 0.30; 0.35.

Results

The solution with using the ECh was developed and analyzed. The bypassing recirculation system runs as follows: exhaust gases from 10 to 40 % in quantity are fed to the scrubber, where they are partially cooled and cleaned by spraying water with special nozzles. Then the exhaust gases are cooled in the heat exchanger - gas cooler (heater of water for refrigerant generator of ECh), condensed vapor from exhaust gases is drained through condensate trap and cooled gases are fed by the fan to the scavenge air receiver, where gases are mixed with the scavenge air coming from the turbocharger.

It is proposed to use the heat of the recirculating gases for high pressure liquid refrigerant evaporation in the generator of ECh with generation of high pressure refrigerant vapor as motive fluid for ejector to suck a low pressure refrigerant vapor from refrigerant evaporator - air cooler (AC-RE) at the intake of turbocharger. Thus, cooling capacity of ECh is used for cooling air at the intake of the engine turbocharger.

For MAN B & W 6G50ME-C9.6 engine considered, the specific fuel consumption decreases by about 0.5-1.6 g/(kWh) due to engine inlet air cooling during a voyage. With this the number of recirculation during a voyage is K_p = 14-20 %, the flow of recirculating flue gases is $G_{g.r}$ = 3-4 kg/s and a total exhaust gas flow G_g = 14-16 kg/s. The flow of "fresh" air to the engine turbocharger is $G_{a.egr}$ = 13-16 kg/s with exhaust gas recirculation and G_a = 17-19 kg/s - without recirculation of exhaust gases.

For the 6G50ME-C9.6 engine, according to the data of the MAN company (according to the calculations using the CEAS software package), when cooling intake air for every 10 °C a reduction in specific fuel consumption is 1.09 g/(kWh) or 0.109 g/(kWh·K) for every 1 °C air temperature drop.

The results of analyzing the operation efficiency of recirculation gas heat-recovery chiller with different coefficients of performance ζ = 0.30; 0.35 show the following cooling capacities received in chiller: $Q_{0(0,3)}$ = 160–280 kW (ζ= 0.30) and $Q_{0(0,35)}$ = 180–245 kW (ζ = 0,35). The heat load on the ECh generator (heat consumption of chiller) is Q_g = 520-820 kW with appropriate cooling of the recirculation gas in the gas cooler (before the scrubber) from the temperature t_{g2} = 370-440 °C to the temperature t_{g1} = 180 °C (limited taken into account the danger of corrosion) provides decrease in air temperature at the inlet of the engine turbocharger, respectively: $\Delta t_{a(0.3)}$ = 4.1–10.8 °C (ζ = 0.30); $\Delta t_{a(0.35)}$ = 4.8–12.6 °C (ζ = 0.35).

A decrease in the engine intake air temperature ensures a reduction in the specific fuel consumption in accordance with: $\Delta g_{e(0,3)}$ = 0.4–1.2 g/(kWh) (ζ= 0.30); $\Delta g_{e(0.35)}$ = 0.5–1.4 g/(kWh) (ζ = 0.35). The maximum efficiency of engine intake air cooling through recirculation exhaust gas heat-recovery corresponds to the coefficient of performance of the chiller ζ = 0.35 and is Δg_e = 0.8-2.2%, while the total specific fuel consumption will be $g_{e(0.35)}$ = 164-165 g/(kWh), and without engine intake air cooling - g_e = 163.7-164.4 g/(kWh).

Reduction of emissions due to lowering the engine intake air temperature when using the heat of recirculation gases is insignificant and amounts to no more than 0.2-0.3% for NOx and SOx, but for the system with gas recirculation and ζ = 0.35 is: $\Delta g_{NOx(0.6)}$ = 26–38 % (4.6–6.8 g/(kWh)); $\Delta g_{SOx(0.6)}$ = 9–14 % (1.1–1.5 g/(kWh)).

However, it should be noted that this enhance CO_2 emissions by $\Delta g_{CO2(0.6)}$ = 1.3–1.7 % (6.6–9.1 g/(kWh)).

The total of fuel economy $\sum B_f$ due to a decrease recirculation gas temperature for the variation of climatic conditions during the vessel route Odessa-Yokohama at different coefficients of performance of chiller is : $\Sigma B_f(0,3)$ = 14,8 t (ζ= 0,3); $\Sigma B_f(0,35)$ = 17,3 t (ζ= 0,35).

Conclusions

1. The technology of precooling intake air at the suction of turbocharger by waste heat using ejector chiller (ECh) is implemented in internal combustion engines with EGR system. The scheme solution of the ecological exhaust gas recirculation system with the use of its heat by an ejector refrigeration chiller for cooling the air at the intake of the ship's main engine is developed.
2. The effect of using the heat of recirculating gases for cooling air at the turbocharger intake was analyzed for the engine MAN 6G50ME-C9.6 with the account of changing climatic conditions on the vessel route line Odesa-Yokohama.
3. It is shown that the use of ecological recirculation gas heat in ejector refrigeration machine allows to reduce the air temperature at the intake of the ship's main engine by 5-15 °C, that provides a reduction of the specific fuel consumption by 0.5-1.4 g/(kW·h). With this the emissions of harmful substances are reduced due to recirculation of gases: of NOx by 26-38 %; SOx by 9-14 %.

References

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