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A. Marchenko, D. Samoilenko, A.A. Hamzah, O.A. Hamzah

WAYS OF USING WASTE ENERGY FROM I.C. ENGINES EXHAUST GASES

In present study the power conversion methods was investigated which could be applied as a bottoming cycle in combination with the WHR systems of diesel and gas engines to produce additional electrical power from the excess heat. It has been identified that there are large potentials of energy savings through the use of waste heat recovery technologies. Waste heat recovery defines capturing and reusing the waste heat from internal combustion engine for heating, generating mechanical or electrical work and refrigeration system.

Introduction

Out of all the available sources, the internal combustion engines are the major consumer of fossil fuel around the globe. Out of the total heat supplied to the engine in the form of fuel, approximately, 30 to 40% is converted into useful mechanical work.

The remaining heat is expelled to the environment through exhaust gases and engine cooling systems, resulting in to entropy rise and serious environmental pollution, so it is required to utilized waste heat into useful work. The recovery and utilization of waste heat not only conserves fuel, usually fossil fuel but also reduces the amount of waste heat and greenhouse gases damped to environment. It is imperative that serious and concrete effort should be launched for conserving this energy through exhaust heat recovery techniques. Such a waste heat recovery would ultimately reduce the overall energy requirement and also the impact on global warming.

Presently, high fuel costs and concerns about foreign oil dependence have resulted in increasingly complex engine designs to decrease fuel consumption. For example, engine manufacturers have implemented techniques such as enhanced fuel-air mixing, turbocharging, and variable valve timing in order to increase thermal efficiency. However, around 60-70% of the fuel energy is still lost as waste heat through the coolant or the exhaust. On the other hand, legislation of exhaust emission levels has focused on carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM).

Energy conservation on engine is one of best ways to deal with these problems since it can improve the energy utilization efficiency of engine and reduces emissions [1] . Given the importance of increasing energy conversion efficiency for reducing both the fuel consumption and emissions of engine, scientists and engineers have done lots of successful research aimed to improve engine thermal efficiency, including supercharge, lean mixture combustion, etc.

However, in all the energy saving technologies studied. Engine exhaust heat recovery is considered to be one of the most effective. Many researchers recognize that Waste Heat Recovery from engine exhaust has the potential to decrease fuel consumption without increasing emissions, and recent technological advancements have made these systems viable and cost effective [2].

Possibility of heat recovery from internal combustion engines

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. This heat depends in part on the temperature of the waste heat gases and mass flow rate of exhaust gas. Waste heat losses arise both from equipment inefficiencies and from thermodynamic limitations on equipment and processes. For example, consider internal combustion engine approximately 30 to 40% is converted into useful mechanical work. The remaining heat is expelled to the environment through exhaust gases and engine cooling systems [3]. It means approximately 60 to 70% energy losses as a waste heat through exhaust (30% as engine cooling system and 30 to 40% as environment through exhaust gas).

Exhaust gases immediately leaving the engine can have temperatures as high as [450-600°C]. Consequently, these gases have high heat content, carrying away as exhaust emission. Efforts can be made to design more energy efficient reverberatory engine with better heat transfer and lower exhaust temperatures; however, the laws of thermodynamics place a lower limit on the temperature of exhaust gases [4]. Total energy distributions from internal combustion engines is shown on Fig.1

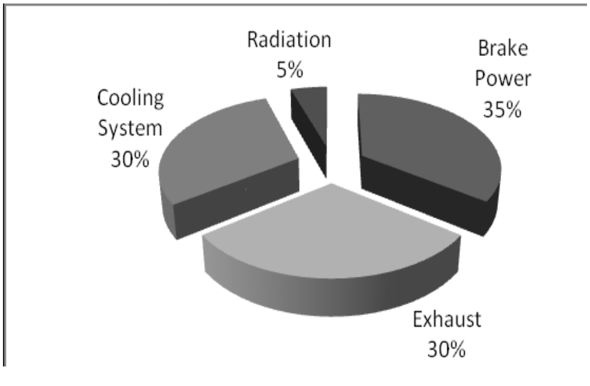

Fig. 1. Total energy distributions from internal combustion engines

Benefits of 'waste heat recovery'are:

1. Direct Benefits:

Recovery of waste heat has a direct effect on the combustion process efficiency. This is reflected by reduction in the utility consumption and process cost.

2. Indirect Benefits:

a) Reduction in pollution: A number of toxic combustible wastes such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM) etc, releasing to atmosphere. Recovering of heat reduces the environmental pollution levels.

b) Reduction in equipment sizes: Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes.

c) Reduction in auxiliary energy consumption: Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption [5].

Heat recovery in diesel engines

In general, diesel engines have an efficiency of about 35% and thus the rest of the input energy is wasted. Despite recent improvements of diesel engine efficiency, a considerable amount of energy is still expelled to the ambient with the exhaust gas. In a water-cooled engine about 35 kW and 30-40% of the input energy is wasted in the coolant and exhaust gases respectively.

The amount of such loss, recoverable at least partly, greatly depends on the engine load [6]. the wasted energy represents about two-thirds of the input energy and for the sake of a better fuel economy, exhaust gas from Internal Combustion engines can provide an important heat source that may be used in a number of ways to provide additional power and improve overall engine efficiency. These technical possibilities are currently under investigation by research institutes and engine manufacturers. For the heavy duty diesel engines, one of the most promising technical solutions for exhaust gas waste heat utilization appears to be the use of a useful work.

Availability of Waste Heat from I.C. Engine The quantity of waste heat contained in a exhaust gas is a function of both the temperature and the mass flow rate of the exhaust gas:

$$\dot{Q} = \dot{m} \times C_p \times \Delta T\,, \qquad (1)$$

where, Q is the heat loss (kJ/min); m is the exhaust gas mass flow rate (kg/min); Cp is the specific heat of exhaust gas (kJ/kg°K); and ΔT is temperature gradient in °K. In order to enable heat transfer and recovery, it is necessary that the waste heat source temperature is higher than the heat sink temperature. Moreover, the magnitude of the temperature difference between the heat source and sink is an important determinant of waste heat‟s utility or "quality".

The source and sink temperature difference influences the rate at which heat is transferred per unit surface area of recovery system, and the maximum theoretical efficiency of converting thermal from the heat source to another form of energy (i.e., mechanical or electrical). Finally, the temperature range has important function for the selection of waste heat recovery system designs [7-8].

Types of recovery system for internal combustion engines

Large quantity of hot flue gases is generated from internal combustion engine etc. If same of this waste heat could be recovered, a considerable amount of primary fuel could be saved. It is depends upon mass flow rate of exhaust gas and temperature of exhaust gas. The internal combustion engine energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and losses be minimized by adopting certain measures. There are different methods of the exhaust gas heat recovery namely for space heating, refrigeration and power generation. The mass flow rate of exhaust gas is the function of the engine size and speed, hence larger the engine size and higher the speed the exhaust gas heat is larger. So heat recovery system will be beneficial to the large engines comparatively to smaller engines. The heat recovery from exhaust gas and conversion in to mechanical power is possible with the help of Rankine, Stirling and Brayton thermodynamic cycles, vapour absorption cycle.

These cycles are proved for low temperature heat conversion in to the useful power. Engine exhaust heat recovery is considered to be one of the most effective means and it has become a research hotspot recently.

For example, Doyle and Patel [9] have designed a device for recovering exhaust gas heat based on Rankine cycle on a truck engine. The commissioning experiment of 450 kilometers showed that this device could save fuel consumption by 12.5%. Cummins Company has also done some research on waste heat recovery on truck engines, and the results showed that engine thermal efficiency could improve by 5.4% through exhaust heat recovery. James C. Conklin and James P. Szybist [10] have designed a six-stroke internal combustion engine cycle with water injection for in-cylinder exhaust heat recovery which has the potential to significantly improve the engine efficiency and fuel economy. R. Saidur et al [11] Rankine bottoming cycle technique to maximize energy efficiency, reduce fuel consumption and green house gas emissions.

Recovering engine waste heat can be achieved via numerous methods. The heat can either be reused with-in the same process or transferred to another thermal, electrical, or mechanical process.

Waste heat can be utilized for some useful works and it is reduces pollution. The diesel engine exhaust gas waste heat recovery rate increase with increasing diesel engine exhaust gas emission rate.

The increasing fuel costs and diminishing petroleum supplies are forcing governments and industries to increase the power efficiency of engines. A cursory look at the internal combustion engine heat balance indicates that the input energy is divided into roughly three equal parts: energy converted to useful work, energy transferred to coolant and energy lost with the exhaust gases. There are several technologies for recovering this energy on a internal combustion engine, where as the dominating ones are: Waste heat can utilized for heating purpose, power generation purpose, refrigeration purpose, etc.

Using of exhaust gas for heating purpose

Waste heat can be utilized for the heating purpose like space heating, Preheating intake air and fuel, dryer etc. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water etc. waste heat recovery system can utilized for pre heating intake air and intake fuel.[12]

Heat energy is recovered from the exhaust gases, which causes lower heat addition, thus improving engine thermal efficiency. Low grade fuel, such as, kerosene can be used in diesel engine by blending with conventional diesel fuel. Using the air preheating system and 10% kerosene blend as fuel, the thermal efficiency is improved and exhaust emissions (NOx and CO) is reduced as compared to neat diesel fuel without using air preheating system [13].

Waste heat recovery is useful for preheating alternative fuel so reduce viscosity of fuel, better fuel atomization and low volatility of fuel.

Using of exhaust gas for Power Generation Purpose

Waste heat can also be utilized indirectly for the power generation using rankine cycle. Bryton cycle, Stirling cycle and directly used for thermoelectric generator etc

Comparisons between steam Rankine, ORC, Kalina and TFC cycles

The differences between Kalina-type bottoming cycle configurations designed for different gas engine and gas diesel enginetypes have studied in [13]. One of their key focuses was to demonstrate the potential of the Kalina cycle to produce more power than the Rankine cycle as an engine bottoming cycle. Four different power plant configurations were studied, all based on Wärtsilä engines with gas engine models 16V25SG and 18V34SG and gas diesel engine models 18V32GD and 18V46GD.

The characteristics of the heat sources differ for the four engine models and the optimal Kalina cycle configuration is unique to the engine. Cycle configurations that use all engine heat sources are complex and include many heat exchangers. Low heat source temperatures should be to the advantage of the Kalina cycle relative to the Rankine cycle. In most cases the gas engine with a Kalina bottoming cycle produces more power compared to the Rankine cycles than the gas diesel engine. The Kalina cycle can use more of the heat in the exhaust gas stream than the Rankine cycle.

In [14] has compared the Kalina and ORC cycles. The OCR model is based on a system without regeneration. Isopenthane is assumed as the working fluid. A saturated vapor Kalina cycle is used. As a result, the maximum power generated for a given source is greater for the Kalina cycle. The Kalina cycle is well positioned against an ORC for a base load application. The Kalina is better than the ORC when the heat source stream has finite heat capacity, but similar when the source is condensing steam (constant temperature). In [14] compared the thermodynamic performance of the Kalina cycle and ORC (hexamethyldisiloxane as working fluid) in the case of heat recovery from two Wärtsilä 20V32 8.9 MW diesel engines with exhaust gas mass flow of 35 kg/s for both engines, at 346ºC. In order to facilitate the comparison, only the heat recovery from the exhaust gases was considered. An almost equal net electric power of 1615 kW (with a cycle efficiency of 19.7 %) and of 1603 kW (with cycle efficiency of 21.5 %) for the Kalina and ORC cycles was calculated, respectively. In this case, the Kalina cycle requires a very high maximum pressure in order to obtain high thermodynamic performances: 100 bar against the about 10 bar of the ORC cycle. The turbine design also favours the ORC cycle, as the isentropic enthalpy drop is definitely higher for the Kalina (575 kJ) than for the ORC (92 kJ). For the Kalina cycle, the required turbine rotational speed is very high (> 60000 rpm) thus requiring a gear box, and therefore adding gearbox losses. The use of the Kalina cycle for medium and high temperature thermal sources seems unjustified because there is no gain in performance instead, a complicated plant scheme, large surface heat exchangers and corrosion resistant materials, such as titanium in the turbine, result.

In [15] have compared the TFC, four ORCs and a Kalina cycle, all operating under the same conditions in the both heat sink and source. The same flow rate and temperature at source inlet and an isentropic efficiency of 70 % for the expander were assumed. Cycle pressures were selected to maximize exergy efficiency for each fluid. The cycle efficiencies (η), power outputs (P) and heat inputs (Q) are listed in Table 1[115].

Table 1. Comparison of TFC, four ORCs and a Kalina cycle

Cycle (fluid)	η (%)	P (kW)	Q (kW)
ORC (R141b)	10	13	132
ORC (R123)	9	17	179
ORC (R245ca)	9	18	189
ORC (R21)	9	18	198
Kalina (NH_3–H_2O)	3	13	373
TFC (NH_3–H_2O)	8	38	477

An ORC with R141b has the highest efficiency of 10 %, but extracts the least heat from the source, while the trilateral flash cycle receives the most, i.e., 3.6 times more. The TFC uses the most of the source's exergy because both the source fluid (water) and the working fluid (ammonia–water) are in liquid state and have similar specific heats, and thus the temperature difference in the heat exchanger is minimized. Since the source stream exergy is fixed, the cycle that converts the most of it into work (or useful exergy) is the best. The TFC recovers the most of the source's exergy (93 %), the Kalina cycle being the second best (76 %).

Conclusions

In present study the power conversion methods was investigated which could be applied as a bottoming cycle in combination with the WHR systems of diesel and gas engines to produce additional electrical power from the excess heat. Next crucial conclusions were made:

1. The steam Rankine cycle is a well-known, and the most developed and widespread bottoming cycle, typically combined with a gas turbine. It is most suitable for plant sizes of several hundreds of megawatts of electrical power. The steam Rankine cycle can also be applied with diesel engines, however, with less efficiently due to the lower exhaust gas temperature and flow.

3. Ranking cycle is offered in present study as waste heat utilisation unit to get more electricity from Hyundai power plant of total power output 2.7 mW.

2. The organic Rankine cycle (ORC) applies the principle of the steam Rankine cycle but uses organic working fluids instead of water. Among low-grade heat bottoming cycles, the ORC is so far the most commercially developed one. It is simpler and economically more feasible than the steam Rankine cycle.

3. Kalina cycle is a 'modified' Rankine cycle using mixtures as the working fluid, typically water-ammonia. The use of a mixture having a varying boiling point results a good thermal match in the waste heat boiler, but requires a recuperator after the turbine and distillation condensation subsystem to avoid exergy loss at the heat sink. This makes the plant scheme more complex.

4. The Kalina Cycle is reported to achieve better performance and smaller plant size than a steam Rankine plant with equal output. Order of superiority between the Kalina Cycle and the ORC is contradictory. Ammonia is toxic and highly corrosive, which has to be taken into account in material selection.

5. The Kalina Cycle has some references in waste heat and geothermal power plants. In the trilateral flash cycle (TFC) the working fluid is heated under pressure to a temperature above boiling point. The expansion phase in the expander starts from saturated liquid state and flashes to the condenser pressure. The power recovery potential of the TFC highly depends on the two-phase expansion inside the expander. The lack of a suitable expander with high adiabatic efficiency is the main obstacle for the TFC in becoming reality. A twin screw expander is predicted to have sufficient adiabatic efficiency.

10. It has been identified that there are large potentials of energy savings through the use of waste heat recovery technologies. Waste heat recovery defines capturing and reusing the waste heat from internal combustion engine for heating, generating mechanical or electrical work and refrigeration system.

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Марченко Андрей Петрович – доктор техн. наук, профессор, заведующий кафедрой двигателей внутреннего сгорания Национального технического университета “Харьковский политехнический институт”, Харьков, Украина, e-mail: dvs@kpi.kharkov.ua

Али Адель Хамза – аспирант кафедры двигателей внутреннего сгорания Национального технического университета “Харьковский политехнический институт”, Харьков, Украина, e-mail: dvs@kpi.kharkov.ua

Омар Адель Хамза – аспирант кафедры двигателей внутреннего сгорания Национального технического университета “Харьковский политехнический институт”, Харьков, Украина, e-mail: dvs@kpi.kharkov.ua

Самойленко Дмитрий Евгеньевич – канд. техн. наук, с.н.с., докторант кафедры двигателей внутреннего сгорания Национального технического университета “Харьковский политехнический институт”, Харьков, Украина, e-mail: dvs@kpi.kharkov.ua

ОСНОВНЫЕ СПОСОБЫ ИСПОЛЬЗОВАНИЯ ЭНЕРГИИ ОТРАБОТАВШИХ ГАЗОВ ДВС

А. Марченко, Д. Самойленко, А.А. Хамзах, О.А. Хамзах

В статье рассмотрены основные способы использования энергии отработавших газов для генерации электрической энергии. Определено, что за счет применения полезной энергии отработавших газов возможно в значительной степени улучшить энергоэффективность установки на базе ДВС.

ОСНОВНІ СПОСОБИ ВИКОРИСТАННЯ ЕНЕРГІЇ ВІДПРАЦЬОВАНИХ ГАЗІВ ДВЗ

А. Марченко, Д. Самойленко, А.А. Хамзах, О.А. Хамзах

В статті розглянуті основні способи використання енергії відпрацьованих газів для виробництва електричної енергії. Визначено, що за рахунок використання корисної енергії відпрацьованих газів можливо значною мірою покращити енергоефективність установки на базі ДВЗ.

УДК 621.43

Т.М. Колеснікова

ТЕОРЕТИЧНІ ДОСЛІДЖЕННЯ РОБОЧОГО ПРОЦЕСУ БЕЗШАТУННОГО ДВИГУНА

Приведена математична модель робочого циклу бензинового чотиритактного двигуна з урахуванням кінематики силового механізму та змінного ступеня стискання на часткових режимах.

Модель впускної системи заснована на рівняннях втрат тиску в елементах впускної системи і дозволяє визначати температуру та тиск перед впускним клапаном в залежності від навантаження та частоти обертання колінчастого валу.

По точності розрахунків дана математична модель не поступається відомим програмам, але значно простіша, менш трудомістка й вимагає меншого машинного часу. Модель дозволяє оцінювати заходи, що направлені на оптимізацію конструкції двигуна й підвищення його паливної економічності.

Вступ

Сучасні автомобільні двигуни внутрішнього згоряння зберігають тенденцію до подальшого їх удосконалення для вирішення проблеми зниження витрати палива і зменшення токсичності відпрацьованих газів (ВГ). Однак існуючі на сьогодні методи вирішення цієї проблеми, з одного боку, значно ускладнюють конструкцію ДВЗ, а з іншого