A Review on optimization of shell and tube heat exchanger used in Rankine cycle of Exhaust gas waste heat recovery system

P. Sai Chaitanya*, T.V.S. Siva**, B. Suneela Rani
* Assistant Professor, Department of Mechanical Engineering, GMRIT, Rajam
** PG Student, Department of Mechanical Engineering, GMRIT, Rajam

Abstract: Most of the heat from automobiles (mostly diesel engines) is being wasted in different forms. This waste heat if recovered can be used for various other applications. So in the present paper, review of different waste heat recovery technologies for diesel engine exhaust gas was studied and in that context it was found that heat exchanger is commonly used. So this review ephasises the different ways by which heat transfer in a heat exchanger can be enhanced. Based on the review an optimized design of a shell and tube heat exchanger that can be effectively used for waster heat recovery from automobile exhaust gas using organic rankine cycle was proposed.

Index Terms— Automobile exhaust gas, Heat Exchanger, Optimized, Organic Rankine cycle, Waste heat recovery

1. Introduction

The transfer of thermal energy between fluids is one of the most important and frequently used processes in engineering. The transfer of heat is usually accomplished by means of a device known as a heat exchanger. According to a SAE survey about 60-70% of heat that is produced in an IC engine is wasted in different forms such as heat carried away by cooling water, Frictional losses and heat carried away by the exhaust gases. So there is a great thrust to recover this energy and use this energy for different applications.

Many researchers had focused on different techniques to recover waste heat that is generated by the IC engine exhaust gas. This has led to integrate advanced technologies to recover heat from IC engines. Such technologies are exhaust gas recirculation (EGR), Turbo charging, Thermo electric generator (TEG), and Organic rankine cycle (ORC). Out of these techniques ORC was found to be most suitable technique recover heat from IC engines.

When these techniques was closely studied all these techniques utlize heat exchanger to carry the heat from exhaust gases of IC engines. So for effective utilization of these techniques there was a need to design and optimize of heat exchanger. So in the present paper a review was done on heat exchanger design and optimization that can be used in ORC rankine cycle waste heat recovery system.

2. Review On Optimization Of Heat Exchanger Design Used In Exhaust Heat Recovery System

M. Hatami, D.D.Ganji, M.Gorji-Bandpy [1] A short review of the technologies that increase the heat transfer in HEXs is introduced and the availability of using them in the exhaust of engines is evaluated and finally a complete review of different HEXs which previously were designed for increasing the exhaust waste heat recovery is presented. Also, future view points for next HEXs designs are proposed to increase heat recovery from the exhaust of diesel engines.

It seems that in most of these technologies (ORC, TEG, EGR, HEXs and turbocharging), heat exchangers have an important role to transfer heat for recovering process, so a suitable design for heat exchanger should be applied in accordance with this fact that heat transfer increases when pressure drop is in the allowable limit. It can be concluded that using fins is more applicable and appropriate than foams and porous materials due to the lower pressure drop and higher heat transfer rate.

M. Hatami, D.D.Ganji, M.Gorji-Bandpy [2] In their research two cases of HEXs (an optimized Fig. 1 and a non-optimized) are produced experimentally and mounted on the exhaust of an OM314 diesel engine to compare their results in heat and exergy recovery. All experiments are done for five engine loads (0%, 20%, 40%, 60% and 80% of full load) and four water mass flow rates (50, 40, 30 and 20 g/s).

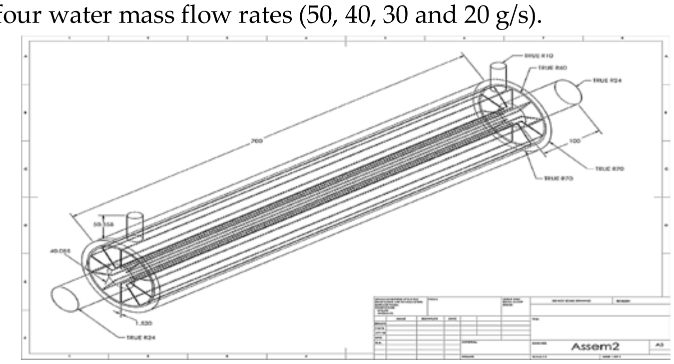

Fig. 1. Optimized Heat Exchanger.

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Results confirm that a new design of heat exchanger (HEX) called optimized finned-tube HEX optimized case widely increased the recovered heat.

V. Pandiyarajan, M. Chinna Pandian, E. Malan, R. Velraj, R.V. Seeniraj [3] In their present work a finned shell and tube heat exchanger and TES tank Fig. 2 of capacity 20 MJ were designed and fabricated and tested by integrating them with a diesel engine of capacity 7.4 kW. Nearly 10–15% of total heat (that would otherwise be gone as waste) is recovered with this system. The maximum heat extracted using the heat exchanger at full load condition is around 3.6 kW.

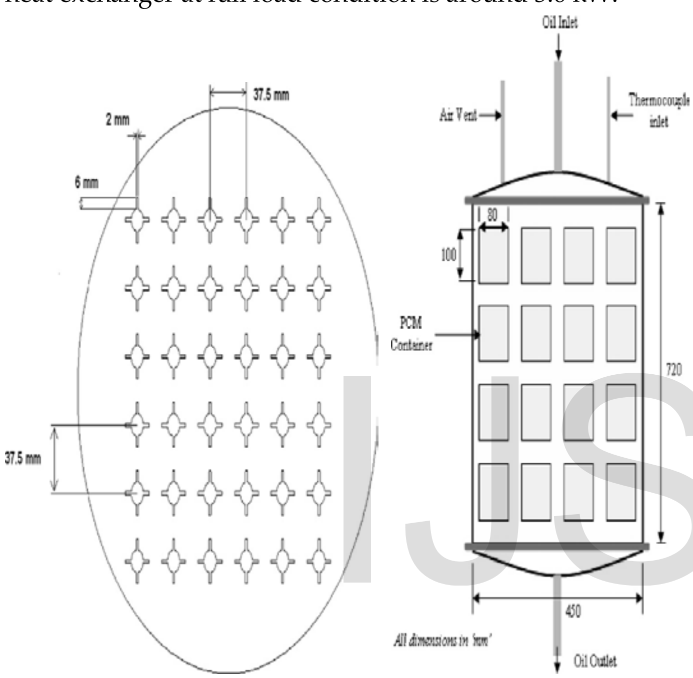

Fig. 2. Finned shell and tube heat exchanger and TES tank

Shengqiang Bai, HongliangLu, TingWu, XianglinYin, XunShi, Lidong Chen [4] Six different exhaust heat exchangers were designed within the same shell, and their computational fluid dynamics (CFD) models were developed to compare heat transfer and pressure drop in typical driving cycles for a vehicle with a 1.2 L gasoline engine. Serial plate structure enhanced heat transfer by 7 baffles and transferred the maximum heat of 1737W. It also produced a maximum pressure drop of 9.7 kPa in a suburban driving cycle. Under the maximum power output condition, only the inclined plate and empty cavity structure undergoes a pressure drop less than 80 kPa

Chien-Chou Weng, Mei-Jiau Huang [5] In their work, the influence of the number and the coverage rate on the heat-exchanger of the TEGs were explored via simulations. It was found that implementing more TE couples does not necessarily generate more power in total, and most of all the average power per TE couple decreases rapidly. For the heat exchanger investigated herein, the optimum length of the TEG cuboid is 80 mm for a heat exchanger of length 180 mm, and the optimum length of the heat exchanger is 120 mm for a TEG cuboid of length 50 mm.

Hongliang Lu, Ting Wu, Shengqiang Bai, Kangcong Xu, Yingjie Huang, Weimin Gao, Xianglin Yin, Lidong Chen [6] The present work tried to conceptually combine exhaust heat exchanger with muffler in the form of 1-inlet 2-outlet, 2-inlet 2-outlet and the baseline empty cavity Fig. 3. 1-Inlet 2-outlet increased hydraulic disturbance and enhanced heat transfer, resulting in the more uniform flow distribution and higher surface temperature than the other. The pressure drops of 1-inlet 2-outlet, 2-inlet 2-outlet were 165%, 318% more than that of empty cavity when inlet temperature was 100 _C and mass flow rate was 131 kg/h, and were 319%, 523% more than that of empty cavity when inlet temperature 400 _C and mass flow rate 156 kg/h. The structure geometry modification of heat exchanger in the next stage was the promotion of the variation of the velocity field and the uniformity of the temperature profile.

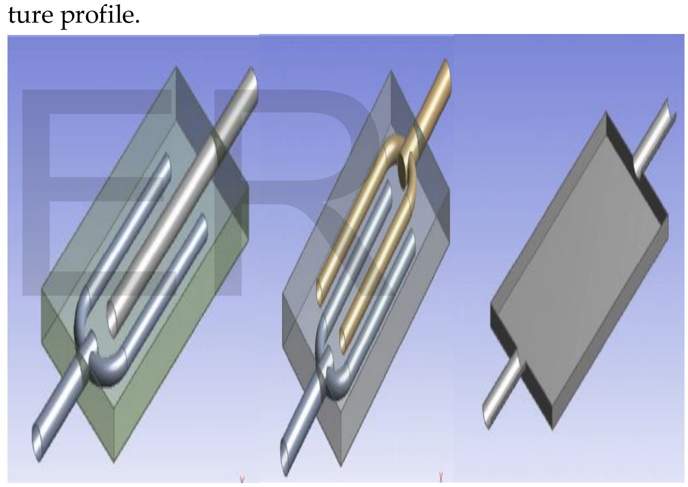

Fig. 3. 1-inlet 2-outlet, 2-inlet 2-outlet and empty cavity Heat Exchangers.

As a major factor, thermal capacity and heat transfer of the heat exchanger affect the performance of TEG effectively. In order to achieve uniform temperature distribution and higher interface temperature, C.Q. Su, W.S.Wang, X.Liu, Y.D.Deng [7] the thermal characteristics of heat exchangers with various heat transfer enhancement features are studied, such as internal structure, material and surface area. Combining the computational fluid dynamics simulations and infrared test on a high- performance engine with a dynamometer, the thermal performance of the heat exchanger is evaluated.

A brass heat exchanger with accordion shape and surface area (660mm x 305 mm) is selected to form the hot side. It can reduce the thermal resistance (between the exchanger and the TEMs), and obtain a relatively high surface temperature and uniform temperature distribution to improve the efficiency of the TEG.

Shekh Nisar Hossain, Saiful Bari [8] in their research, experiments were conducted to measure the available exhaust heat from a 40 kW diesel generator using heat exchanger. The effectiveness of the heat exchangers using water as the working fluid was found to be 0.44 which seems to be lower. This lower performance of the existing heat exchangers indicates the necessity of optimization of the design of the heat exchangers for this particular application. With the available experimental data, computer simulations were carried out to optimize the design of the heat exchangers.

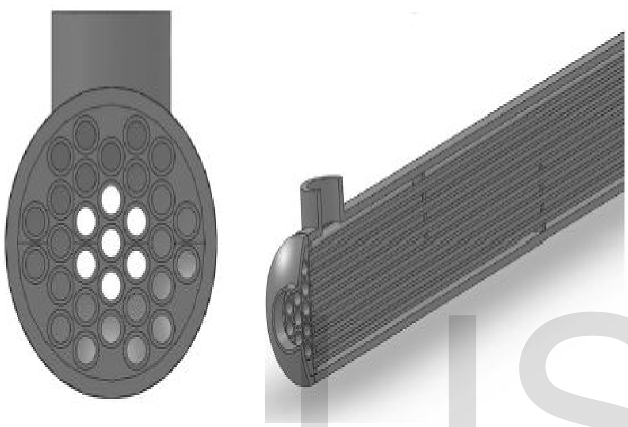

Fig. 4 Optomized Shell and tube Heat Exchanger.

Two heat exchangers were used to generate superheated steam to expand in the turbine using two orientations: series and parallel. The optimized heat exchangers were then used to estimate additional power considering actual turbine isentropic efficiency. The proposed heat exchanger Fig. 4 was able to produce 11% additional power using water as the working fluid at a pressure of 15 bar at rated engine load. This additional power resulted into 12% improvement in brake-specific fuel consumption (bsfc). The effects of the working fluid pressure were also investigated to maximize the additional power production.

The pressure was limited to 15 bar which was constrained by the exhaust gas temperature. However, higher pressure is possible for higher exhaust gas temperatures from higher capacity engines. This would yield more additional power with further improvements in bsfc. At 40% part load, the additional power developed was 3.4% which resulted in 3.3% reduction in bsfc. Heat exchanger type Shell and tube counter flow, hot fluid in tubes and cold fluid in the shell.The effectiveness of the non-optimized purchased heat exchangers was found to be 0.44 which is much lower than a well-designed heat exchanger. However, after optimization for this particular application the effectiveness of the heat exchangers was improved to 0.76. Maximum recovered additional power was found to be 2.9 kW at 15 bar working pressure at the rated load of the engine. Thus, an additional 11% power was achieved with the proposed shell and tube heat exchanger using water as the working fluid and this indicates 12% improvement in bsfc.

Mohsen Ghazikhani, Mohammad Hatami, Davood Domiri Ganji, Mofid Gorji-Bandpy, Ali Behravan, Gholamreza Shahi [9] In their experimental research, the exergy recovery from a DI Diesel engine is investigated where a turbocharged OM314 DIMLER diesel engine was tested at various engine speeds (1200, 1400, 1600, 1800 and 2000 rpm) and torques (20, 40, 60, 80 and 100 N m).

In this a double pipe heat exchanger with counter current flow is used in the exhaust of engine. As an important outcome, by increasing the load and engine speed, the recovered exergy increased. Furthermore, the reduction of brake specific fuel consumption (bsfc) due to the use of recovered exergy from exhaust has also been studied in the current study. The results show that by using recovered exergy, bsfc decreased approximately 10%.

X. Liu, Y.D. Deng, K. Zhang, M. Xu, Y. Xu, C.Q. Su [10] A plate-shaped heat exchanger with chaos-shaped internal structure and thickness of 5 mm achieves a relatively ideal thermal performance, which is practically useful to enhance the thermal performance of the TEG, and larger total output power can be thus obtained. The maximum electrical power output of fishbone-shaped TEG is 160.21 W while the chaos-shaped is 183.24 W. In conclusion, the total output power is higher for the chaos-shaped heat exchanger, which is more ideal for TEG application.

Smaller inlet of exhaust channel enhances the heat transfer to TEG modules, but increases the flow resistance, and therefore a moderate channel size is needed. Based on the design and operating conditions in this study, the exhaust channel with the cross section of 60 mm * 40 mm might be optimal to balance the flow resistance and TEG power output. Placing bafflers at the channel inlet could increase the heat transfer coefficient for the whole channel; the near wall temperature downstream might decrease significantly. If bafflers can be placed properly according to the locations of the TEG modules, further increasing the number of bafflers may not improve the TEG performance significantly, but increase the pressure drop along channel.

To ensure effective utilization of the hot exhaust gas, the baffler angle needs to be sufficiently large, especially for the downstream locations. However, larger baffler angles increase the pressure drop significantly, therefore, Zhiqiang Niu, Hai Diao, Shuhai Yu, Kui Jiao , Qing Du, Gequn Shu [11] suggested that variable baffler angles, with the angle increasing along the flow direction, might be a middle course for balancing the heat transfer and pressure drop.

Hua Tian , Xiuxiu Sun , Qi Jia , Xingyu Liang , Gequn Shu , Xu Wang [12] proposes a segmented thermoelectric generator (TEG) that can be used to recover exhaust waste heat from a diesel engine (DE). The results showed that the segmented TEG is more suitable than the traditional TEG for a high-temperature heat source and for large temperature differences. Moreover, the maximum output power was inversely proportional to the thermocouple length; however, the maximum conversion Efficiency was directly proportional. The maximum output power increased with a decrease in the thermocouple length; however, the maximum conversion efficiency decreased with an increase in the thermocouple length. The advantages of the segmented TEG decreased with a decrease in the thermocouple length. The optimal performance depended on the ratio of the two materials. Segmented TEGs are reliable, feasible, and simple. The higher output power and conversion efficiency achieved compensate for the high cost of the thermoelectric material.

N.D. Love, J.P. Szybist and C.S. Sluder [13] conducted study in an effort to better understand and improve the performance of thermoelectric heat recovery systems for automotive use. For this purpose an experimental investigation of thermoelectric in contact with clean and fouled heat exchangers of different materials is performed. The thermoelectric devices are tested on a bench-scale thermoelectric heat recovery apparatus that simulates automotive exhaust. It is observed that for higher exhaust gas flow rates, thermoelectric power output increases from 2 to 3.8W while overall system efficiency decreases from 0.95% to 0.6%. Degradation of the effectiveness of the EGR-type heat exchangers over a period of driving is also simulated by exposing the heat exchangers to diesel engine exhaust under thermophoretic conditions to form a deposit layer. For the fouled EGR-type heat exchangers, power output and system efficiency is observed to be 5–10% lower for all conditions tested. A more optimally designed heat exchanger would likely be less sensitive to heat exchanger material. Heat exchangers fouled with diesel exhaust experience a degradation in performance of 5–10% compared to an unfouled heat exchanger of the same material.

Among the waste heat recovery methods, the bottoming Rankine cycle is the most promising. In this technique, the recovered heat is used to produce additional power using turbine. In order to maximise the additional power production, an effective heat exchanger design is necessary.

The main focus of the S Bari, S N Hossain [14] research was to design heat exchangers which needed to be pancake-shaped to be retrofitted into a vehicle. The heat exchanges chosen were shell and U-tube type. CFD simulations were carried out to optimize the design of the heat exchangers and calculate the additional power that could be achievable by using this optimized pancake-shaped heat exchangers Fig. 5.

The round-shaped heat exchangers were not suitable in vehicle operation because of the space limitations. However, round-shaped heat exchangers are easy to manufacture and relatively easy to clean. They can be used in diesel engine based generators.

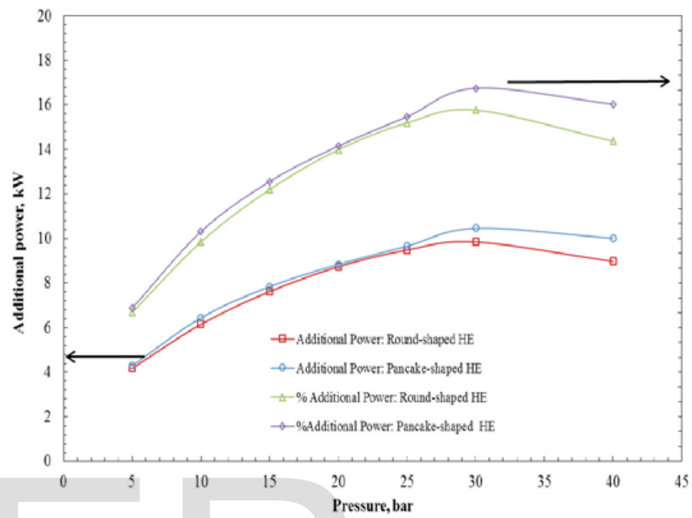

Fig. 5. Additional Power Generation at various pressures.

Tongcai Wang, Weiling Luan, Wei Wang, Shan-Tung Tu [15] a new type of open-cell metal foam-filled plate heat exchanger based thermoelectric generator system (HE-TEG) is proposed to utilize low grade waste heat. High heat exchange efficiency of 83.56% between heated air and cold water is achieved. The maximum open circuit voltage of 16 TE couple is 108.1 mV. The metal foams play an important role in enhancing the heat transfer process. The maximum temperature difference between two adjacent layers is 13.8^{0}C and the maximum open circuit voltage of 16 TE couple is 108.1 mV. By increasing the numbers of TE couples, the open circuit voltage is enlarged linearly. It is critical that the exhaust heat exchanger of the thermoelectric generator (TEG) that is used in automobile waste heat recovery provides a high heat transfer performance while maintaining a low pressure drop.

Chi Lu, Shixue Wang, Chen Chen, Yanzhe Li [16] in their study, incorporating net power output as part of a main comparative parameter, simulations are used to investigate two types of heat transfer enhancements for an exhaust heat exchanger, rectangular offset-strip fins and metal foams. The results for the rectangular offset-strip fins show that there are optimal values of the fin transverse spacing and the fin thickness maximizes the net power output. The use of metal foams can significantly increase the total power output and the efficiency of the TEG, especially foam with low porosity and small pore density (PPI). However, metal foams also produce a high pressure drop and a low net power output. This problem may be solved by using a TEG that combines thermoelectric generation with catalytic conversion.

Diesel engine exhaust contains 38% energy which can be used to produce extra power. Optimum pressure of fluid exists for maximum power which was 30bar for Shekh Nisar Hossain, Saiful Bari [17] study. The optimum pressure at 25%, 83%, 100% loads were 2, 20 and 30bar, respectively. Extra 24% power gained with optimized heat exchangers using water as working fluid. Parallel heat exchangers showed better performance than series up to 30bar. After optimization, the additional power increased from 16% to 23.7%. There existed an optimum pressure of the working fluid for the maximum additional power conceivable by EHR system for any particular application. For this 50 kW engine, the optimum pressure was found to be 30bar and the maximum recovered additional power was 9.85 kW. The design of the heat exchangers as well as their orientations was optimized for better performance of the EHR system. These resulted in an additional 23.7% power improvement using water as the working fluid. The additional power generation decreased at part loads. The pressure of the working fluid needed to be varied to maximize the additional power at part loads Fig. 6.

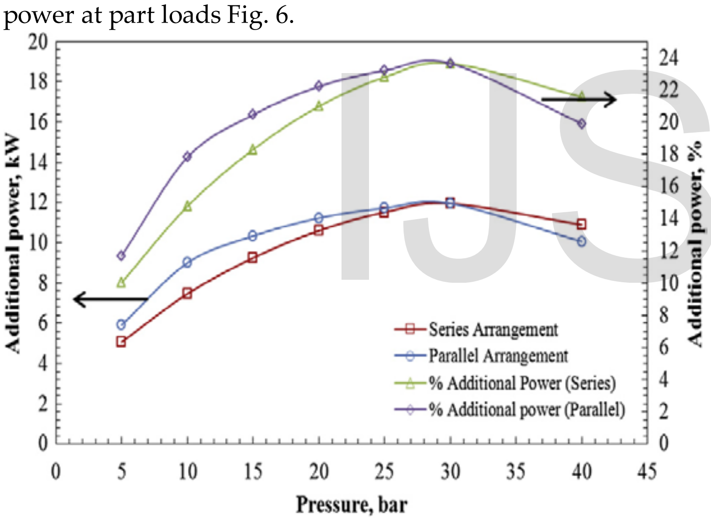

Fig. 6. Additional power output variation with working pressure.

V. Dolz, R. Novella, A. García, J. Sanchez [18] study different bottoming Rankine cycles with water-steam and/or ORC configurations in classical and innovative setups such as a waste heat recovery system in a Heavy Duty Diesel (HDD) Engine. The waste energy sources are studied from the standpoint of energy analysis to determine which are the most appropriate for their application in bottoming cycles attending to minimizing external irreversibilities. Finally, two configurations are chosen as the most appropriate, in a balance between external irreversibilities and technological complexity, and they have been analyzed to determine global efficiencies, power increments and necessary modifications to implement these cycles in the HDD engine. The configuration with all heat sources includes waste energy recovery in two different cycles (binary cycle). The main problem of this solution is the big size of heat exchanger surface necessary. The configuration with high temperature heat sources uses only high temperature waste energy sources in a water Rankine cycle. This solution is more realistic, but reduces the energy recovery in comparison with the configuration with all heat sources. The external irreversibilities of this Rankine cycle have been extensively studied in the present work. The most important conclusion in the studied cases, with ideal processes and when the engine dissipates more heat energy is that it can only recover between 8% and 9% of the total energy dissipated by the engine once internal irreverisibilities are also considered.

António Domingues, Helder Santos, Mário Costa [19] evaluates the vehicle exhaust WHR (waste heat recovery) potential using a RC (Rankine cycle). The thermodynamic analysis was performed for water, R123 and R245fa and revealed the advantage of using water as the working fluid in applications of thermal recovery from exhaust gases of vehicles equipped with a spark-ignition engine. Moreover, the heat exchanger effectiveness for the organic working fluids R123 and R245fa is higher than that for the water and, consequently, they can also be considered appropriate for use in vehicle WHR applications through RCs when the exhaust gas temperatures are relatively low. For an ideal heat exchanger, the simulations revealed increases in the internal combustion engine thermal and vehicle mechanical efficiencies of 1.4%-3.52% and 10.16%-15.95%, respectively, while for a shell and tube heat exchanger, the simulations showed an increase of 0.85%-1.2% in the thermal efficiency and an increase of 2.64%e6.96% in the mechanical efficiency for an evaporating pressure of 2MPa. The vehicle exhaust WHR potential using a RC has been evaluated with the aid of both a RC thermodynamic model and a heat exchanger model. However, it is important to note that the thermal and mechanical efficiencies can be enhanced with the increase in the evaporating pressure of the working fluid. The present analysis confirms that RCs have high potential for vehicle exhaust waste heat recovery. However, improved evaporator designs and appropriate expander devices allowing for higher evaporating pressures are required to obtain the maximum WHR potential from vehicle RC systems.

C.O. Katsanos, D.T. Hountalas, E.G. Pariotis [20] A theoretical study is conducted to investigate the potential improvement of the overall efficiency of a heavy-duty truck diesel engine equipped with a Rankine bottoming cycle for recovering heat from the exhaust gas. To this scope, a newly developed thermodynamic simulation model has been used, considering two different working media: water and the refrigerant R245ca From the comparative evaluation between the two working media examined, using the optimum configuration of the cycle for each operating condition, it has been revealed that the brake specific fuel consumption improvement ranges from 10.2% (at 25% engine load) to 8.5% (at 100% engine load) for R245ca and 6.1% (at 25% engine load) to 7.5% (at 100% engine load) for water Fig. 7.

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The maximum power generated by Rankine cycle system at full engine load is 34 kW when using R245ca and 30 kW when using steam as working medium for the present application. Rankine cycle with R245ca as working fluid presents almost the same optimum peak pressure value at all engine loads. On the other hand, the optimum high pressure value of steam Rankine cycle increases with engine load. Organic Rankine cycle operates with 15 times higher mass flow rate of working fluid compared to the corresponding one when using steam. The optimum value of mass flow rate for both steam and organic media increases with engine load.

A promising technique for the recovery of energy from the exhaust gas is the use of a Rankine bottoming cycle. This technical solution has been examined in the past with

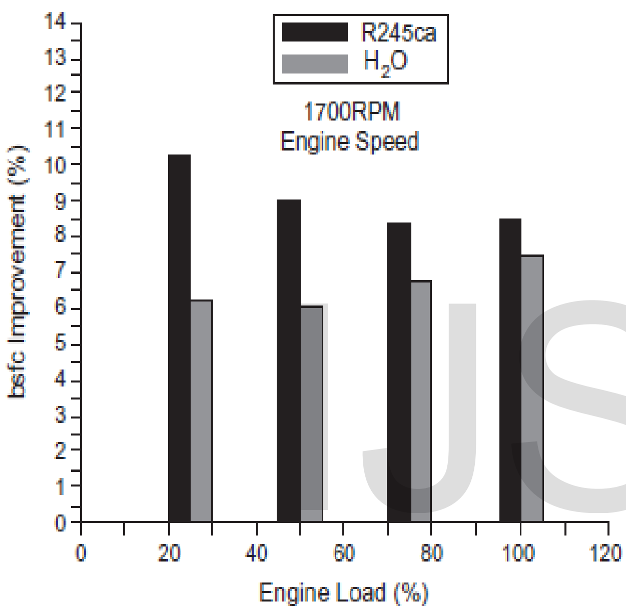

Fig. 7. Bsfc improvement vs engine load when using either steam or R245ca as Rankine cycle.

very positive indications and a strong potential for significant improvement. However various technical challenges have to be solved among which most important are packaging and rejection of excess heat from the engine cooling system. For this reason Dimitrios T. Hountalas, Georgios C. Mavropoulos, Christos Katsanos, Walter Knecht [21] a simulation model which has been developed to describe the operation of a Rankine bottoming cycle is utilized to estimate the potential efficiency gain from its application on a heavy duty truck powered by a diesel engine.

Furthermore it is revealed that the utilization of both EGR cooler and CA cooler heat beyond its positive effect on bsfc reduction potential is also beneficial for overall system packaging allowing the serious reduction of primary heat exchanger dimensions. In the present investigation a comprehensive simulation model was used to analyze by detail the potential benefits in efficiency and power output when combining a Rankine cycle to an existing heavy duty diesel engine used in truck applications. Special emphasis was given to the benefits arising from the utilization of CAC and EGR cooler heat. The investigation covered two working medium i.e. steam and organic.

From the simulation results the main conclusions are

1) A 20% increase in the case of steam and a 30% increase in the case of R245ca of radiator heat rejection capacity are adequate to successfully fulfill the additional demand for heat rejection of the diesel.

2) Rankine power plant when both CAC and EGR heat is partially utilized. This is significantly lower compared to the case where EGR cooler and CAC heat is not utilized where the corresponding values are approximately double.

3) The maximum improvement in bsfc was observed in the case of the organic Rankine cycle and is _11.3% when both EGR and CAC heat amounts are utilized. The corresponding value for steam is _9%. Rankine cycle is a promising technological solution for heavy duty trucks considering present and future fuel prices that are expected to be high.

Seokhwan Lee, Choongsik Bae [22] a design of experiments (DOE) technique was used to design an exhaust heat exchanger to reduce the exhaust gas temperature under high load conditions in a spark-ignition engine. Through a limited number of experiments, the DOE evaluated the influence and the interaction of eight selected design parameters of the heat exchanger that affect the cooling performance of the exhaust gas. The heat exchanger was installed between the exhaust manifold and the inlet of the close-coupled catalytic converter (CCC) to avoid thermal aging. To maximize the heat transfer between the exhaust gas and coolant, fins were implemented at the inner surface of the heat exchanger.

The design parameters consisted of the fin geometry (i.e., length, thickness, arrangement, and number of fins), coolant direction, exchanger wall thickness, and the length of the heat exchanger. Design of experiment (DOE) was used to investigate the effect of geometrical parameters of 18 heat exchangers to clarify the effect of the fin shape to the heat exchanger cooling efficiency. The heat exchanger that has maximum effectiveness was not necessarily the optimum design. In comparison with the initial design (sample 1), the optimal sample showed that the cooling performance more than doubled. While EER (Exhaust Energy Recovery) has been widely pursued for improving the total efficiency and reducing CO2 emissions of internal combustion engines, the improvement on engine efficiency has been investigated with experimental work and numerical simulation based on a steam Rankine cycle EER system.

Tianyou Wang, Yajun Zhang, Jie Zhang, Gequn Shu, Zhijun Peng [23] test was conducted on a light-duty gasoline engine connected with a multi-coil helical heat exchanger. Combining those experimental and modelling results, it demonstrates that the flow rate of working fluid plays a very important and complex role for controlling the steam outlet pressure and overheats degree. For achieving required over-heat and steam pressure, the flow rate must be carefully regulated if the engine working condition changes. The flow rate has also significant influence on the heat exchanger efficiency. To achieving better heat transfer efficiency, the flow rate should be maintained as high as possible.

From the test, it is found the installation of heat exchanger can increase the exhaust back pressure slightly, the total fuel saving of the engine could be up to 34% under some operating condition. From the simulation, it is found the EER system based on the light-duty test engine could increase the engine fuel conversion efficiency up to 14%, though under general vehicle operating conditions it was just between 3% and 8%. Although the heat exchanger can increase the exhaust back pressure slightly, the total fuel saving could be up to 34% under 2000 rpm and 75 Nm.

Alberto A. Boretti [24] further explores the option to use Rankine cycle systems to improve the fuel economy of vehicles under normal driving conditions. A single Rankine cycle system is integrated here with the engine design. A latest turbocharged 1.6 L direct injection engine has the coolant circuit modified to serve as pre-heater for the Rankine cycle fluid. This fluid is then vaporised and superheated in the boiler/super heater coaxial to the exhaust pipe located downstream of the turbocharger turbine and the closed coupled catalytic converter. The exhaust ports are insulated to reduce the heat losses.

This work has shown the opportunity to recover the exhaust and the coolant waste heat in a hybrid passenger car covering a cold start driving cycle. The integrated Rankine cycle system permits a 4.2% better fuel economy over the full NEDC and a 6.4% better fuel economy when cruising at 120 km/h with the engine fully warmed-up. Other improvements of the vehicle fuel economy are permitted by the hybrid power train as presently neglected to focus on the waste heat recovery issues. The hybrid power train permits the recovery of the braking energy, the start/stop of the thermal engine and the optimum mix of thermal and electric motor power supply for much better fuel economies over driving cycles.

The sizing of a heat exchanger in bottoming rankine cycle Fig. 8 that can manage the heat load and still be of reasonable size and weight without excessive pressure drop is of significant importance especially for truck applications. This is the subject of the S. Mavridou, G.C. Mavropoulos, D. Bouris, D.T.Hountalas, G. Bergeles [25] work.

To approach the problem, a total of five different configurations are investigated and a comparison of conventional and state of the art heat transfer enhancement technologies is included.

Two groups of configurations are examined:

(a) A classical shell and tube heat exchanger using staggered cross-flow tube bundles with smooth circular tubes, finned tubes and tubes with dimpled surfaces and

(b) A cross flow plate heat exchanger, initially with finned surfaces on the exhaust gas side and then with 10 ppi and 40 ppi metal foam material substituting for the fins. Finally, the fact that future diesel engines are to be equipped with particulate traps makes the use of a heat exchanger more attractive because indications exist that heat exchanger fouling may not be so severe.

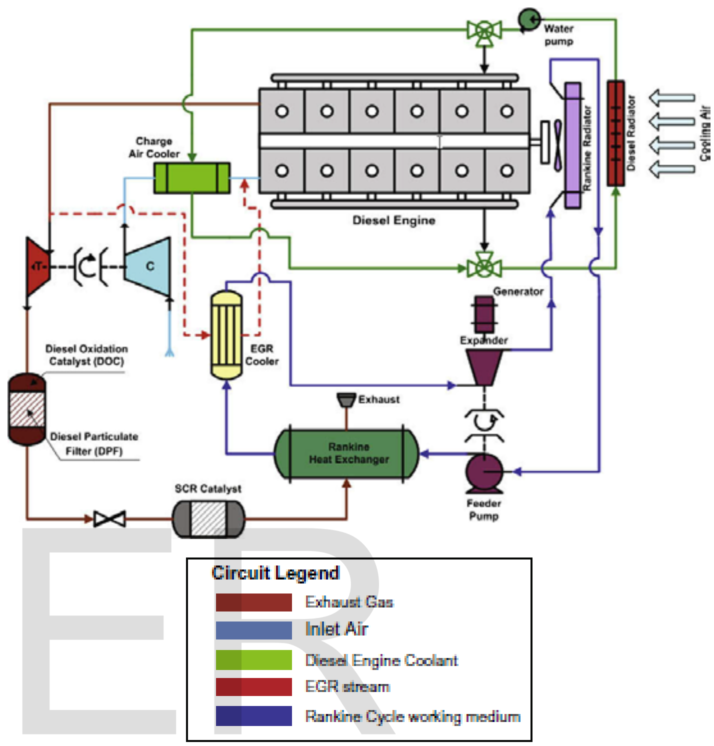

Fig. 8. Schematic view of the proposed layout of Rankine Cycle installation. Working media: steam

3. CONCLUSIONS:

Based on the present review following conclusions can be derived:

a. Out of all the waste heat recovery technologies such as Thermo electric generator (TEG), Organicc rankine cycle (ORC), Exhaust gas recirculation (EGR), Turbocharging etc, ORC is capable of extracting more amount of heat from exhaust gases of automobile.
b. All the above said waste heat recovery technologies use heat exchanger for heat recovery from exhaust gases of automobile.
c. Out of all the heat echangers shell and tube heat exchanger is found to be extracting more amount of heat and beat suited for waste heat recovery from automobile exhaust gases.
d. A Heat exchanger with following specification gives the following result: Shell and tube HE with counter flow, hot fluid in tubes and cold fluid in the shell.The effectiveness of the non-optimized purchased heat exchangers was

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found to be 0.44 which is much lower than a well-designed heat exchanger. However, after optimization (No. of tubes, Tube material, Baffle spacing) for this particular application the effectiveness of the heat exchangers was improved to 0.76. Maximum recovered additional power was found to be 2.9 kW at 15 bar working pressure at the rated load of the engine was found to be best heat exchanger design.

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