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A Review on Waste Heat Recovery and Reused of Exhaust Gases from Diesel Engines

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I. INTRODUCTION

1.1 Motivation

The increasingly worldwide problem regarding rapid economy development and a relative shortage of energy, the internal combustion engine exhaust waste heat and environmental pollution has been more emphasized heavily recently. 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 (fossil fuel) but also reduces the amount of waste heat and greenhouse gases damped to environment. The study shows the availability and possibility of waste heat from internal combustion engine, also describe loss of exhaust gas energy of an internal combustion engine. Possible methods to recover the waste heat from internal combustion engine and performance and emissions of the internal combustion engine. Waste heat recovery system is the best way to recover waste heat and saving the fuel. Modern research and development efforts relating to combustion engines and vehicle design are largely driven by the pressing need to reduce the global consumption of fossil energy carriers and the resulting emissions of the greenhouse gas carbon dioxide. The limited supply of fossil fuels is one of the most important factors underpinning these efforts. Oil and natural gas are currently the most important energy carriers used in transportation, with oil accounting for 93% of the energy used in this sector in 2013 [1]. At current rates of production, the world's proven oil reserves will expire in approximately 52 years, while the prognosis for natural gas is 54 years [2]. However, an even more important factor is that as production rates start to decline, the limited supply of fossil fuels will become increasingly problematic. Global oil production is expected to peak before 2030 and may do so before 2020 [3]. A second, possibly even more important, factor underpinning the desire to develop energy efficient vehicles relates to emissions of greenhouse gases. The combustion of fossil fuels generates CO2 emissions, which absorb re-radiated heat from the earth's surface and thereby contribute to global warming. This anthropogenic greenhouse effect alters natural marine and terrestrial carbon cycles, reducing the environment's capacity for CO2 storage [4]. In the year 2005, the transport sector was responsible for slightly more than 23% of the world's CO2 emissions, with road transport accounting for 17%. The largest share of the globe's CO2 emissions (45%) originated from fossil fuels burned for energy generation. Overall CO2 emissions have increased by 80% since 1970 (and those from the transportation sector have increased by more than 100%), contributing to an average atmospheric temperature increase of around 0.8 °Cover the same period [5]. While this may sound small in absolute terms, the long term effects of this trend are predicted to be devastating for life on earth [6].Diesel emissions and control are still very much in theforefront. Interest in the diesel powertrain for LD applications is continuing, and may be increasing as a result of tightening vehicular CO2 regulations. Also, California is planning a nominal 70% tightening of criteria pollutant standards, so efforts are accelerating to continue emissions parity with gasoline vehicles. In the HD truck market, criteria pollutant regulations will not tighten until 2013 in Europe, but the US is proposing the first CO2 regulations for 2014. The combination of criteria pollutant and efficiency mandates will push diesel technologies in both sectors. The non-road market is implementing technologies to meet new 2011-12 emissions tightening, and technologies are moving into development for the 2014 step. Large locomotive and marine engines are also coming under emissions pressure (but will not specifically be covered here).[29]

As a result, a lot of research has been devoted to increasing combustion engine efficiency by reducing these losses. This can be done in various ways, including reducing losses due to mechanical friction, optimizing the engine to increase the efficiency of the combustion process, and creating superior gas exchange paths.

Hydrocarbon and CarbonMonoxide Control

Diesel oxidation catalysts (DOC) have been applied to engines for more than 20 years, yet we are still improving them and learning fundamentals. They serve two primary purposes to oxidize hydrocarbons (HC) and CO that is innate in the exhaust or added to provide fuel for regenerating a DPF, and to generate NO2, which is used to oxidize soot on a continuous basis or for improving the low temperature performance of SCR catalysts. On the latter point, Spurk, investigated NO2 coming from a catalyzed DPF for use in a downstream SCR system. Surprisingly, they found the NO2 coming out of the DOC and going into the DPF is not as important as the HCs coming from the DOC. Essentially, the HCs going into the DPF can interfere with the NO2 formation in the DPF. The Pt/Pd ratio is much more important to NO2 formation than precious metal loading on the DPF [29]

1.2 Scope of the work

This work focuses on the Rankine cycle as the most promising existing technology for engine waste heat recovery in terms of recuperation efficiency. While it is a comparatively mature technology and is widely used in power generation, its use in vehicles presents new challenges in system design. These stem from environmental and packaging issues, as well as difficulties relating to the quality and quantity of the available heat and its transient availability. It is not yet clear which working fluid and expansion device are optimal for use in a Rankinecycle-based system for vehicular applications. However, previous studies have indicated that these components are among the most important factors for the system’s performance.

The Rankine cycle is a promising technique torecover waste heat. This additional amount of heat recovered implies impacts on aerodynamic of the truck and/or on the existing cooling system. A simple Rankine cycle based on exhaust gas has been preferred as it is today a heat source that exists on all existing engines on the market (EGR or non EGR engines). By recovering on engine exhaust gases, the Rankine cycle will affect the engine fuel consumption because of higher pressure losses on the exhaust line. The challenge for waste heat recovery techniques remains the heat rejection as Rankine cycle system efficiencies are quite low (10-15 %). Lots of working fluids exist and have been reported in the literature. Among them, the R245fa seems promising for the operating conditions described in this paper mainly due to its non flammablebehaviour and thermodynamic performance that could fit the commercial truck on road usage. The thermodynamic 0-D simulation remains a first tool to evaluate the maximum potential of such systems. In practice and depending on the assumptions used, various conclusions could be taken from those simulations [19]

1.3 Heat Recovery Chances in Engine

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 [4]. 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 842-1112°F [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 [5]. Fig. 1.1 show total energy distributions from internal combustion engine.

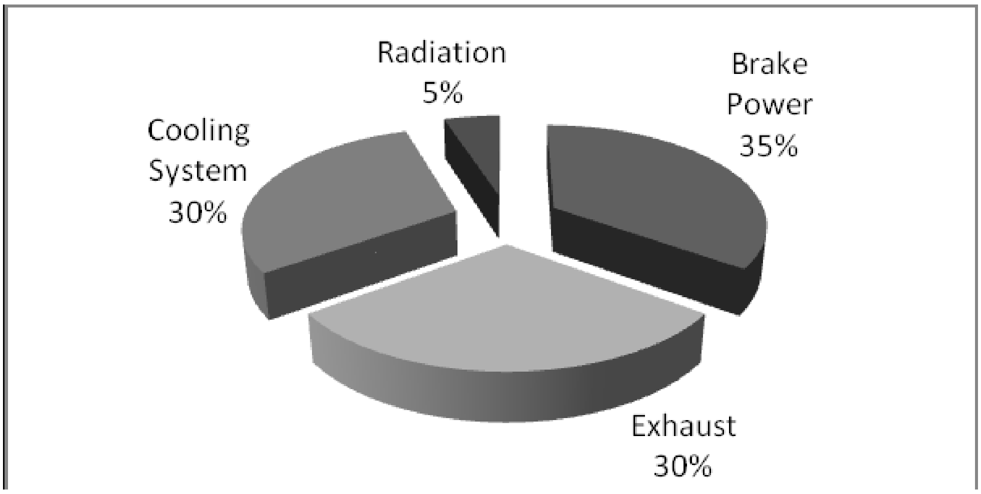

Fig 1.1: Total Fuel Energy Content in I. C. Engine

1.4 Heat Recovery System For Engine Heat Recovery

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 [47]. 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 [14] 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 [15] 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 [16] 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 within the same process or transferred to another thermal, electrical, or mechanical process. Hauxuewjun et al [17] has studied the analysis of exhaust gas waste heat recovery and pollution processing for diesel engine. They analyzed total effect of waste heat on pollution or environment. 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

1.5 Rankine Cycle

The Rankine cycle is a thermodynamic cycle that converts heat into work [6]. The Rankine cycle system consists of a turbine, pump, condenser and boiler. Figure 1.2 shows the ideal Rankine cycle and its characteristics in a temperature-entropy.

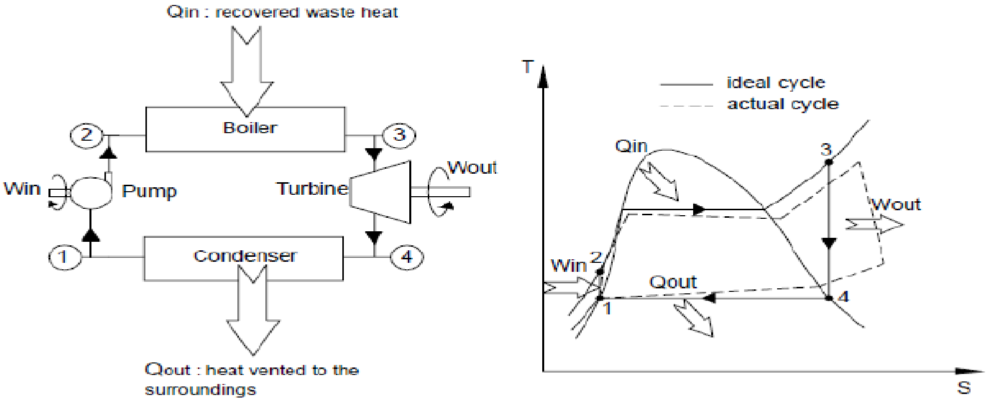

Fig 1.2: Rankine cycle schematic and its characteristics

The ideal Rankine cycle consists of the following four processes:

1 – 2: compression via pump

2 – 3: heat delivery at constant pressure in a boiler
3 – 4: isentropic expansion via turbine
4 – 1: heat rejection at constant pressure in a condenser

The efficiency of the Rankine cycle is limited by the use of the working fluid. In a Rankine cycle system, the working fluid is reused continuously and follows a closed loop. Water is a commonly used working fluid but becomes inefficient for WHR at temperatures below 370℃[9, 10]. For temperatures below 370℃, the use of organic fluids increases the Rankine cycle efficiency [9, 10, 12]. An Organic Rankine Cycle (ORC) is a Rankine cycle that uses organic fluid. Figure 1.2 shows the efficiencies of different working fluids versus turbine inlet temperatures. Note there can be an issue of formation of liquid droplets on the turbine blades during the expansion process. To eliminate this possibility, an Organic Rankine Cycle (ORC) is used.

II. LITERATURE REVIEW

2.1 Energy balance in combustion engines

This chapter discusses energy balances in Diesel engines for heavy duty vehicles and gasoline engines for light duty passenger cars. Because these engine types have very different applications, discussing them together makes it possible to clearly show how fuel energy is lost in different types of vehicle. In both cases, the engines are assumed to be operating under conditions that produce near-maximal brake-power efficiency.

Pradip G. Karale1 Dr. J.A Hole2 [1]In many applications I.C engine is used as primary power source. Out of the total heat supplied to the I.C engine in the form of fuel 30-40% heat is converted into useful work and remaining 60-70 % as a part of waste heat as friction, exhausts gas and engine cooling system. Through the exhaust of engine 30-40 % of heat is lost to the environment. Rapid economy development results in increasing energy demand, consequently fuel consumption and fuel prices which results in environmental pollution. This attracts the researchers to find more energy efficient techniques and concentrates on hard work on investigation of suitable waste heat recovery system. Waste heat utilization reduces the fuel (fossil fuel) consumption and reduces the amount of waste heat and greenhouse gases. A significant waste heat recovery systems or methods have been developed to recover the heat from exhaust gas of I.C engine. This article shows the Benefits of waste heat recovery, the available waste heat from I.C engine, Amount of heat carried away by exhaust gas and possible techniques to recover the heat from exhaust gas of I.C. engine. Waste heat recovery system is the best solution to recover waste heat to reduce waste heat, fuel consumption and pollution.

J. S. Jadhao, D. G. Thombare[2]The increasingly worldwide problem regarding rapid economy development and a relative shortage of energy, the internal combustion engine exhaust waste heat and environmental pollution has been more emphasized heavily recently. 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 (fossil fuel) but also reduces the amount of waste heat and greenhouse gases damped to environment. The study shows the availability and possibility of waste heat from internal combustion engine, also describe loss of exhaust gas energy of an internal combustion engine. Possible methods to recover the waste heat from internal combustion engine and performance and emissions of the internal combustion engine. Waste heat recovery system is the best way to recover waste heat and saving the fuel.

P. P. Sonune, H. S. Farkade[3] The research on alternative fuels for compression ignition engine has become essential due to depletion of petroleum products and its major contribution for pollutants, where vegetable oil promises best alternative fuel. Vegetable oils, due to their agricultural origin, are able to reduce net CO2 emissions to the atmosphere. But major disadvantage of vegetable oil is its viscosity, which is higher than that of mineral diesel. Hence neat vegetable oil does not give better performance. In the present paper preheated mahua oil and its blend with diesel has been introduced as an alternative fuel to overcome the above problems. Various fuel inlet temperatures, blending ratio, viscosity and various loading conditions are some of the parameters that need to be analyzed for better engine performance and reduced emissions. In this study, a review of research papers on various operating parameters have been prepared for better understanding of operating conditions and constrains for preheated mahua oil and its blends fuelled compression ignition engine. Only experimental study is not sufficient to understand the best combination of parameters improving the performance, hence analysis is carried out using mathematical relations available from the literature.

R. Selvan Dr. K. Maniysundar[4]Transesterified vegetable oil, also called bio-diesel is becoming increasingly important as a fuel for diesel engine due to several reasons. Bio-diesel is a renewable, inexhaustible and a clean burning fuel. Many studies have shown that properties of bio-diesel are very close to petro diesel. Bio-diesel can be used in diesel engine without modification. Bio-diesel has no aromatic, no-sulfur and contains 10-12% oxygen by weight. These characteristics of bio-diesel reduce the harmful emissions of unburned hydrocarbons and CO, research has shown that NOx, emission is higher in case of bio-diesel fueled engine. Exhaust gas recirculation is an effective technique to reduce NOx [49]. The aim of present research work is to use B10,B20, B30, blend of jatropha methyl ester and cooled EGR in order to reduce pollutant from diesel engine emission of NOx, CO, HC,are recorded and compared with petro diesel. Various performance parameters was evaluated such as brake thermal efficiency, BSFC, SEC, TFC were calculated. Result indicates the reduction of NOx and brake thermal efficiency decreased with the application of EGR and Jatropha blends bio-diesel.

Charles Sprouse III *, Christopher Depcik[5]Escalating fuel prices and future carbon dioxide emission limits are creating a renewed interest in methods to increase the thermal efficiency of engines beyond the limit of in-cylinder techniques. One promising mechanism that accomplishes both objectives is the conversion of engine waste heat to a more useful form of energy, either mechanical or electrical. This paper reviews the history of internal combustion engine exhaust waste heat recovery focusing on Organic Rankine Cycles since this thermodynamic cycle works well with the medium-grade energy of the exhaust. Selection of the cycle expander and working fluid are the primary focus of the review, since they are regarded as having the largest impact on system performance. Results demonstrate a potential fuel economy improvement around 10% with modern refrigerants and advancements in expander technology.

S.L Nadaf*1, P.B Gangavati2 [6]Still, the diesel engine is far from perfection. Due to rising energy demands, consistently increasing of fuel prices since 1998 and environmental concerns. Researchers have continual push to find more energy efficient technologies have the great reasons for the investigation of waste heat recovery techniques, and are still working hard. In the context diesel engine exhaust heat utilization has the potential to reduce the consumption of fossil fuels and reduce the release of greenhouse gases, significant waste heat recovery technologies have been developed to recover exhaust heat and turn it into useful energy such as electricity. The current worldwide trends of increasing energy demand in transportation sector, extensive work and research have been focused on energy recovery in the automotive sector; therefore the main objective of this paper is to assess different waste heat recovery technologies based on current developments, research trends and its future in an automotive application. As a result, the article drew the conclusion that waste heat recovery and its utilization will remain a good prospect in future automotive engine application.

Jasdeep S. Condle[7]Typical internal combustion engines lose about 75% of the fuel energy throughthe engine coolant, exhaust and surface radiation [6]. Most of the heat generated comes from converting the chemical energy in the fuel to mechanical energy and in turn thermal energy is produced. In general, the thermal energy is unutilized and thus wasted. This report describes the analysis of a novel waste heat recovery (WHR) system that operates on a Rankine cycle. This novel WHR system consists of a second piston within the existing piston to reduce losses associated with compression and exhaust strokes in a four-cycle engine. The wasted thermal energy recovered from the coolant and exhaust systems generate a high temperature and high pressure working fluid which is used to power the modified piston assembly. Cycle simulation shows that a large, stationary natural gas spark ignition engine produces enough waste heat to operate the novel WHR system. With the use of this system, the stationary gas compression ignition engine running at 900 RPM and full load had a net increase of 177.03 kW (240.7 HP). This increase in power improved the brake fuel conversion efficiency by 4.53%.

Bertrand FankamTchanche *, George Papadakis, Gregory Lambrinos, AntoniosFrangoudakis [8] Theoretical performances as well as thermodynamic and environmental properties of few fluids havebeen comparatively assessed for use in low-temperature solar organic Rankine cycle systems. Efficiencies, volume flow rate, mass flow rate, pressure ratio, toxicity, flammability, ODP and GWP were used for comparison. Of 20 fluids investigated, R134a appears as the most suitable for small scale solar applications. R152a, R600a, R600 and R290 offer attractive performances but need safety precautions, owing to their flammability.

M. Nematullah Nasim1, RavindraBabu Yarasu2 and Jehad Yamin3 [9] Vegetable oil was being used as fuel in earlier days when the petroleum fuel supply was quite expensive and/or difficultto obtain. Later, with the ease of availability and supply of petroleum products, vegetable oil was replaced with the diesel which reduced the dependence on vegetable oil and the entire research efforts were directed towards improving the performance of CI engine using diesel fuel and the research efforts directed towards improving the performance of CI engines using vegetable oil as fuel for CI engines were reduced to very large extent. The present work describes thesimulated result of the performance of a four stroke, single cylinder, air-cooled, direct-injection compression ignition engine powered by neat jatropha oil. The preheating of the neat jatropha oil is done from 30oC to 100oC. The performance of the engine was studied for a speed range between 1500 to 4000 rpm, with the engine set at full throttle opening and hence the engine was operated under full load conditions. The parameters considered for comparing theperformance of neat jatropha oil with that of diesel fuel operation, were brake specific fuel consumption, thermal efficiency, brake power, NOX emission of the engine. The software established that i) the engine offers lower thermal efficiency when it is powered by preheated neat jatropha oil at higher speed ii) the power developed and Nox emission increase with the increase in the fuel inlet temperature iii) and the specific fuel consumption is higher than diesel fuel operation at all elevated fuel inlet temperature

RongfeiZhao HuiqingGuo Wei GaoGuohong Tong,[10] The heat produced from solid waste composting has stimulated great interest in heat recovery and utilization. This review presented advances in the composting heat recovery research in the last decade. Results of various experimental and theoretical studies on composting heat utilization are summarized. The results show great potentials for utilizing heat produced by composting process. Common problems experienced by the current methods are how to realize the maximum heat recovery without negatively impacting compost quality and the economics of heat recovery methods. This study also gives details of the problems and research gaps. Further advancement of these methods is currently receiving increased interest, both academically and commercially.

E.H. Wang a, H.G. Zhang a,*, B.Y. Fan a, M.G. Ouyangb, Y. Zhao c, Q.H.[11]MucOrganicRankine Cycle (ORC) could be used to recover low-grade waste heat. When a vehicle is running,

the engine exhaust gas states have a wide range of variance. Defining the operational conditions of the ORC that achieve the maximum utilization of waste heat is important. In this paper the performance of different working fluids operating in specific regions was analyzed using a thermodynamic model built in Matlab together with REFPROP. Nine different pure organic working fluids were selected according to their physical and chemical properties. The results were compared in the regions when net power outputs were fixed at 10 kW. Safety levels and environmental impacts were also evaluated. The outcomes indicate that R11, R141b, R113 and R123 manifest slightly higher thermodynamic performances than the others; however, R245fa and R245ca are the most environment-friendly working fluids for engine waste heat-recovery applications. The optimal control principle of ORC under the transient process is discussed

based on the analytical results.

Z.Q. Wang a,b,*, N.J. Zhou b, J. Guob, X.Y. Wang b [12]The paper presented a working fluid selection and parametric optimization using a multi-objectiveoptimization model by simulated annealing algorithm. The screening criteria considered included heat exchanger area per unit power output (A/Wnet) and heat recovery efficiency (V). The independent parameters are the evaporation and condensation pressures, working fluid and cooling water velocities in tubes. A comparison of optimized results for 13 working fluids shows that boiling temperature of

working fluids will greatly affect the optimal evaporating pressure. R123 is the best choice for the temperature range of 100e180_C and R141b is the optimal working fluid when the temperature higher than 180_C. When the exhaust temperature ranges from 100_C to 220_C, the optimal pinch point at evaporator is about 15_C. Economic characteristic of system decreases rapidly with heat source temperature decrease. When the heat source temperature is lower than 100_C, ORC technology is uneconomical.

Gunnar Latz[13]Department ofMost of the energy in the fuel burned in modern automotive internal combustion engines is lost as waste heat without contributing to the vehicle’s propulsion. In principle some of this lost energy could be captured and used to increase the vehicle’s fuel efficiency by fitting a waste heat recovery system to the engine. This thesis presents investigations into the design and functioning of waste heat recovery systems based on Rankine cycle technology for vehicular applications. To facilitate the design of such systems, the performance of different working fluids and expansion devices was investigated using a zero-dimensional model of the Rankine cycle. Simulations using this model indicated that water-based fluids should perform well when recovering waste heat from a high temperature source such as a combustion engine’s exhaust gas. In addition, evaluations based on similarity parameters indicated that displacement expanders are optimal in systems having low flow rates and high expansion pressure ratios, both of which are to be expected in vehicular systems using water as the working fluid. Organic working fluids allow higher flow rates in the cycle, making the efficient use of turbines possible.

2.1.1 Heavy duty Diesel engine

Figure 2-1 shows the energy balance for a 12.8 liter heavy duty Diesel engine, which was derived based on a validated simulation model for this engine. The engine has 6 cylinders, is turbo-charged to increase performance, and uses a short-route EGR system. This means that a controlled amount of exhaust gas is taken directly from the exhaust manifold and mixed with fresh air on the inlet side. The purpose of the EGR system is to reduce engine-out NOxemissions, which happens because the combustion temperature decreases as the proportion of recirculated exhaust gas in the cylinder increases. The recirculated exhaust gas must be cooled to maximize the efficiency of this process and avoid a negative impact on the engine’s volumetric efficiency. Potential waste heat sources in the heavy-duty engine are the charge air cooler (CAC) on the inlet side, the cooler for the EGR system, the post-turbine exhaust gas, and heat lost to the surroundingsvia the coolant and radiation. The analysis in this case focuses on the engine’s B75 operating point, which corresponds to an intermediate engine speed and 75% of the engine’s maximum torque at this speed [38]Under theseconditions, the engine operates at around its maximum brake-power efficiency of 42%. However, even under these optimal conditions, heat losses account for more than half of the energy in the fuel that is burned. The majority of this energy is lost from the coolant and by radiation. The radiative losses would be very difficult to reclaim using a system based on the Rankine cycle and are therefore not considered further in this work [42]. Heat losses via the exhaust gas account for 15% of the fuel energy, while losses from the post-compressor charge air and the exhaust gas entering the EGR cooler account for 11% each.The quality of the available waste heat from a given source is arguably more important than thesource’s contribution to the total waste heat when designing heat recovery systems. It can beassessed by considering the Carnot efficiency ηCarnot, which represents the maximum achievable efficiency for a heat engine operating under reversible conditions driven by a heat source at temperature Tsourceand a heat sink at temperature Tsink, **eq. (2.1)**.

$$\eta_{Carnot} = 1 - \frac{T_{Sink}}{T_{Source}}$$

eq. (2.1).

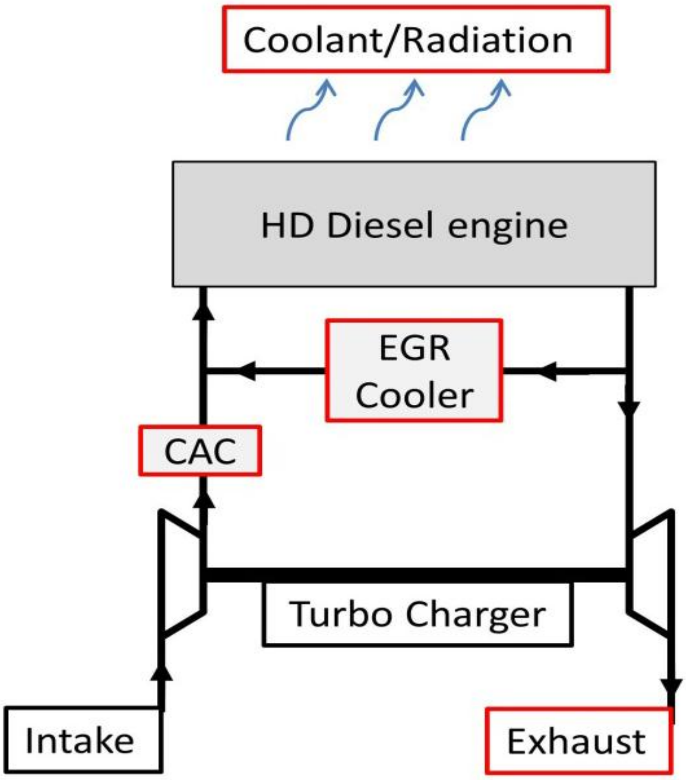

Figure 2-1: Energy balance for a heavy duty Diesel engine.

2.2 Heat Recovery Technologies

This chapter describes the three heat recovery technologies that are most commonly seen as viable options for combustion engines: turbocompound systems, thermoelectric converters, and
Rankine cycle systems.

2.2.1 Turbocompound Systems

The turbocompound system is a technology that recovers energy from the exhaust gas by using an additional turbine in the exhaust system, which is typically located downstream of the turbocharger turbine. The expansion of the exhaust gas in the turbine reduces the enthalpy of the exhaust gas [48]. When multiplied by the turbine's efficiency, this enthalpy decrease represents the maximum work that can be obtained from the device. In contrast to turbochargers, where the recovered energy is used to power a compressor, the turbocompound system's output is used to directly augment the vehicle's propulsion or to drive a generator that produces electricity for the vehicle. As such, there are two types of turbocompound systems: mechanical and electrical. ***Figure 2-2***shows one possible configuration for a combustion engine with a mechanical turbocompound system. In mechanical turbocompound systems, it is necessary to use gears to reduce the turbine's output speed such that it matches the engine's crankshaft speed. In addition, a fluid coupling must be used to separate the compound turbine from torsional crankshaft vibrations and thereby prevent damage to the turbine and the high-speed gear set [15-16]. Electrical turbocompound systems have the advantage of not being connected to the vehicle's propulsion system. Their speed can thus be controlled independently of the engine's speed, which avoids the risk of having to operate the turbine inefficiently under off-design conditions [16].

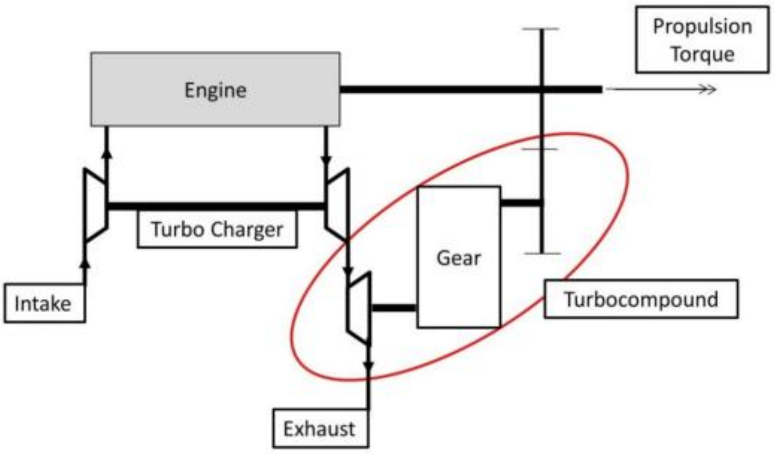

Figure 2-2: Configuration of a mechanical turbocompound system in a combustion engine

2.2.2 Thermoelectric converters

Thermoelectric materials rely on the Seebeck effect, i.e. the generation of an electrical potential when a temperature gradient is applied across the junctions of two dissimilar conductors [17]. This phenomenon was named after Thomas Johann Seebeck, who discovered it in 1823. ***Figure 2-3***shows how thermoelectric materials (TEM) can be used for exhaust heat recovery in passenger cars. TEM devices for power generation usually employ p- and n-type semiconductor elements as the dissimilar conductors because this increases the device’s potential output [18]. In heat recovery systems for combustion engines, the temperature gradient applied across the junction of the device originates from the difference between the temperature of the hot exhaust gas (*Tsource*) and that of a cooling fluid (*Tsink*). At equilibrium, the temperature of the hot side of the TEM is *Thot*and that of the cold side is *Tcold*.

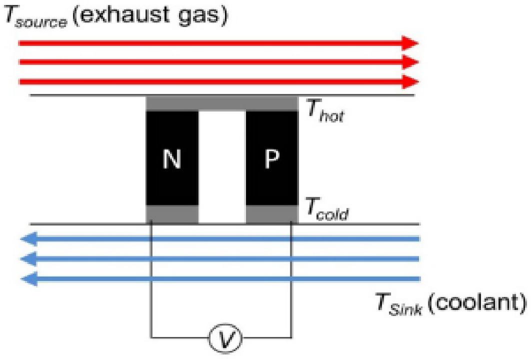

Figure 2-3: A thermoelectric generator for recovering waste heat from exhaust gases

2.3 Organic Rankine Cycle

The low-grade temperature heat from the exhaust cannot be efficiently converted to electrical power by using conventional methods as seen in industrial waste heat recovery systems. In this section, a study on converting these low-grade temperature heat sources using Rankine cycle is discussed. There are many other thermodynamic cycles proposed to generate electricity from exhaust heat [40]. These are Kalina, supercritical Rankine, organic Rankine, trilateral flash andGoswami cycles. Interestingly, organic Rankine cycles have been compared in many studies in the past few years (Saidur et al., 2012) [11]. In recent years, interests in a Rankine bottomingcycle have prompted various automotive manufacturers to investigate its potentials. Many researchers reported that they achieved a decrease in fuel consumption upto or more than 10% for their passenger cars. For commercial trucks, Nelson (2008) reported that Cummins improves 10% of fuel consumption for their trucks by utilizing ORC. One notably exciting new research is the one proposed by Miller et al. (2009) in which they explored the use of organic Rankine bottoming cycle integrated with TEG.

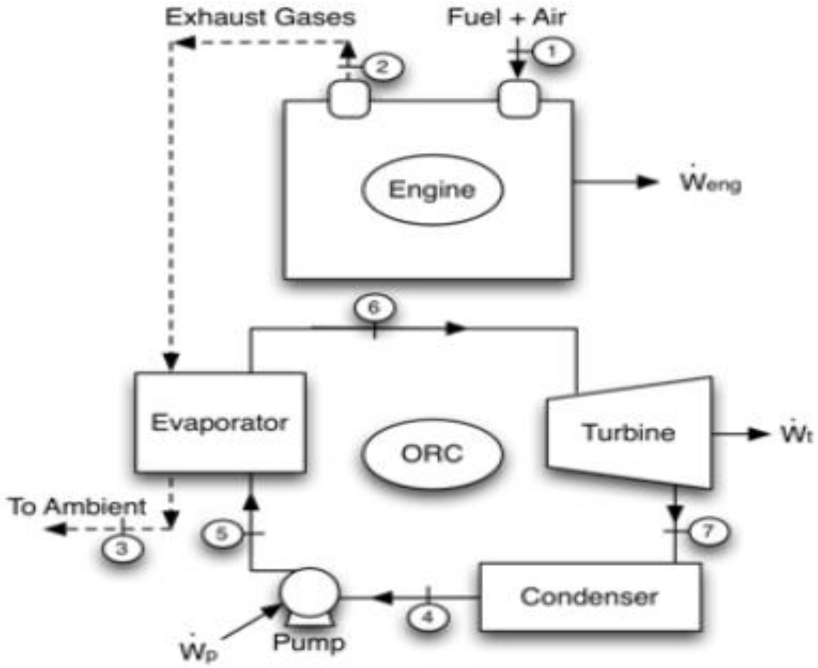

Figure 2.4: A typical waste heat energy recovery system with ORC

III. RESEARCH GAP

In many applications I.C engine is used as primary power source. Out of the total heat supplied to the I.C engine in the form of fuel 30-40% heat is converted into useful work and remaining 60-70 % as a part of waste heat as friction, exhausts gas and engine cooling system. Through the exhaust of engine 30-40 % of heat is lost to the environment. Rapid economy development results in increasing energy demand, consequently fuel consumption and fuel prices which results in environmental pollution. This attracts the researchers to find more energy efficient techniques and concentrates on hard work on investigation of suitable waste heat recovery system. Waste heat utilization reduces the fuel (fossil fuel) consumption and reduces the amount of waste heat and greenhouse gases. A significant waste heat recovery systems or methods have been developed to recover the heat from exhaust gas of I.C engine. This article shows the Benefits of waste heat recovery, the available waste heat from I.C engine, Amount of heat carried away by exhaust gas and possible techniques to recover the heat from exhaust gas of I.C. engine. Waste heat recovery system is the best solution to recover waste heat to reduce waste heat, fuel consumption and pollution.

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 [50]. It would also help to recognize the improvement in performance and emissions of the engine. If these technologies were adopted by the automotive manufacturers then it will be result in efficient engine performance and Low emission. The waste 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. For waste heat recovery thermoelectric generator is use low heat, which has low efficiency. It is helpful for the same amount of increases in thermal efficiency and reduction in emission. Typical internal combustion engines lose about 75% of the fuel energy throughthe engine coolant, exhaust and surface radiation [6]. Most of the heat generated comes from converting the chemical energy in the fuel to mechanical energy and in turn thermal energy is produced. In general, the thermal energy is unutilized and thus wasted. This report describes the analysis of a novel waste heat recovery (WHR) system that operates on a Rankine cycle [12]. This novel WHR system consists of a second piston within the existing piston to reduce losses associated with compression and exhaust strokes in a four-cycle engine. The wasted thermal energy recovered from the coolant and exhaust systems generate a high temperature and high pressure working fluid which is used to power the modified piston assembly. Cycle simulation shows that a large, stationary natural gas spark ignition engine produces enough waste heat to operate the novel WHR system. With the use of this system, the stationary gas compression ignition engine running at 900 RPM and full load had a net increase of 177.03 kW (240.7 HP). This increase in power improved the brake fuel conversion efficiency by 4.53%.

IV. CONCLUSION

The internal combustion (IC) engine is probably the most important heat engine nowadays butstill has a major drawback: most current engine designs reject more than half of the supplied fuel energy in the form of heat losses. There is a pressing need to improve the efficiency of IC engines because of the danger of climate change and the earth's diminishing fossil fuel reserves, making the use of waste heat recovery systems for IC engines increasingly attractive. Systems based on the Rankine cycle are considered to be among the most promising technologies forthis purpose because of their heat recovery efficiency [46]. It has been observed that there is a large amount heat is waste from the engine. Approximately heat lost by exhaust as is same to useful work produced by engine. It is identified that there is large potential of energy saving through the use of waste heat recovery technologies [21]. The recovery and utilization of waste heat not only conserves fuel but also reduces the greenhouse gases and waste heat by increasing efficiency of engine. This study shows the Benefits of waste heat recovery, Heat carried away by the exhaust gas, various possible methods for heat recovery. This also shows that the new concept of Heat wheel may be used for exhaust gas heat recovery for intake air preheating of Diesel engine.

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