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Exploitation of Electrical Generator Waste Energy for House Heating and Hot Water Supply

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Abstract— *Energy demand is increasing worldwide, Iraqi people severe of power shortages from long years ago. Refrigeration and heating of homes consume the bulk of energy. In this study, a proposed system leads to use small electrical power generators for generating electricity and use the exhaust gas thermal energy for heating hot water that can be supplied for Iraqi houses. This system will satisfy more than 90% of the fuel used for heating water in winter.*

In fact this system is applied in many modern countries from long time ago, but for huge units not applied for small units. Small electrical generators have maximum thermodynamic efficiency about 27%, and there is about 73% of the fuel energy go to ambient as waist energy. The aim of this research is to verify the ability of thermal energy utilization of 5kw benzene electrical generator for the purposes of heating and hot water supply in winter to an Iraqi house.

Keywords— *Waste heat recovery, internal combustion engine, heat exchanger, Iraq.*

I. INTRODUCTION

Iraq suffered from a 40-year period of successive wars that destroyed its infrastructure and halted its development plans [1]. Among these destructive structures, electricity has the largest share, as power plants were destroyed by more than 98% [2]. Because of the unjust siege imposed on Iraq at that time, these power plants were not fully reconstructed and even after the US occupation of Iraq in 2003 did not exceed the crisis of electricity line of embarkation [3]. The Iraqi citizen is still suffering from a break for long hours of national electricity, especially in the summer, which rises temperatures to reach a peak of more than 50°C in the day [4]. As a solution to spare the citizen power outage, most Iraqis relied on small generators working with gasoline or diesel. These generators are divided from capacities ranging from 0.9 kW to several hundred kW [5]. These diesel and gasoline (which can be described as the world's most fuel-intensive source of sulfur) cause significant pollution to air and the environment and affect human health, but the use of it in generators is a must [6, 7].

In general the overall efficiency of gasoline or diesel engine is not exceed thin 30%, so about 70% of the fuel energy is gone as a waste heat [8]. The efficient way for new combined heat and power generation focuses on technologies that can recover engine waste heat to useful energy, to improve the overall efficiency of house small electrical generator [9]. Recovery of energy from the engine exhaust represents a potential for at least 100% improvement in the overall engine thermal efficiency. Most of exhaust heat can utilizes to boiling water, or to provide comfortable air for heating operation in winter or by using high technique to generate excess electrical power by thermoelectric generators which is a semiconductor thermoelectric devices or by turbocharger electrical generator [10]. Fig. 1 shows the distribution of fuel energy in the small electrical generator of internal combustion engine.

In general, the waste energy in electrical generator, can be classify according to the way of power transition, exhaust gasses it consist of about 40% of the fuel input energy, and the second is the coolant waste heat, it is about 30%. Of fuel input energy [11]. Heat recovery is a complex system; many parameters must be considered. The exit temperature of the waste heat and the applications of the regenerated waste heat are key factors in heat recovery systems [12].

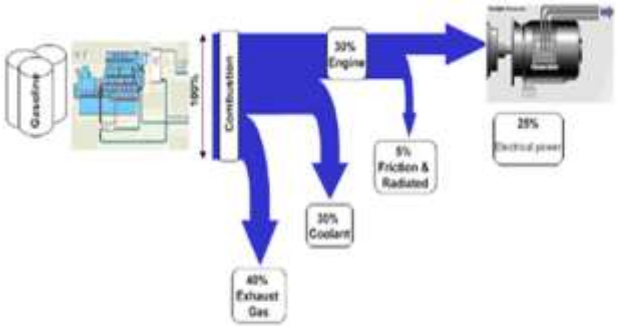

Fig. 1. The distribution of fuel energy of an electrical generator operates using internal combustion engine.

There are three temperature ranges of heat recovery, from liquids or gases, at low temperatures below 230°C, the second range is temperature recoverable heat between 230°C to 650°C, high temperature recoverable heat above 650°C is usually available only in exhaust gases [13].

1-History of Heat Recovers

Historically Combined heat and power (CHP), has been around since the beginning days of central power plants. Thomas Edison used (CHP) as early as 1882 in America's first power plant, selling both electricity and the waste heat produced as a byproduct [14]. Although electricity generated by regeneration was common applied at time, these systems soon were replaced by central power as this became more readily available and easy to apply [15]. Engineers have always appreciated the high efficiency opportunity of combining electricity generation with thermal loads in buildings and factories. Interest in combined heat and power has fluctuated over the years because of changes in the price of fuel and the system construction cost, and the ability to drive and use these systems. Combined heat and power has evolved differently in Europe than in the United States [16].

After 1980 (CHP) shows a rapid growth of capacity in the United States. Installed capacity increased from less than 10 gig watts electric (GWe) in 1980 to almost 44 GWe by 1993 see Fig. 2. Most of these electrical power plants were installed near the large industrial units, such as paper, petroleum, and petrochemical plants. These plants gate a thermal energy from the electrical plants [17].

While on average, the European Union countries obtain about the same amount of their electricity from CHP, as the United States (9%), the market interest in CHP has gained in strength in many European countries. The United Kingdom has seen CHP share of electricity power production double, in the last decade. Installed CHP capacity has risen to 3.7 GWe in 1997, with projections of increases to 5 GWe by the year 2000. Similarly, Denmark and the Netherlands have seen tremendous growth in CHP since 1980, with these countries now obtaining more than 30 percent of their electricity from CHP, fig.(3) shows the percentage of national power production generated by CHP systems in 1999 [18].

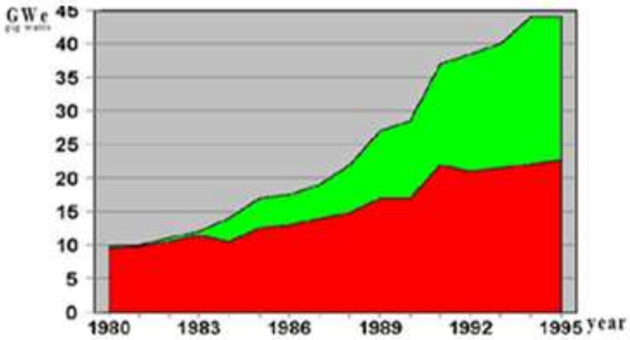

Fig. 2. The growth of combined heat and power system application.

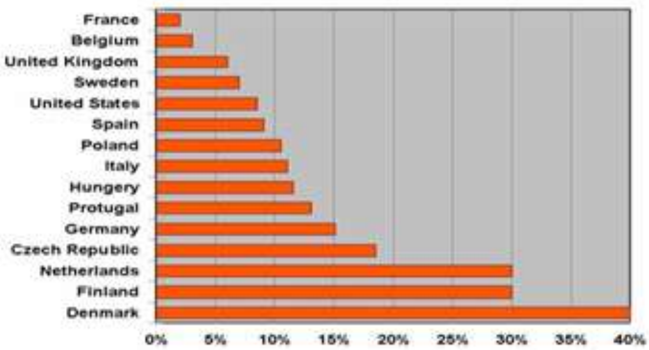

Fig. 3. The percentage of national power generated by (CHP) in many European countries in 2012.

2-Heat Recovery

Heat recovery equipment is used to capture thermal energy, which rejected from thermal engines, to make the recovered heat available for useful purposes. By extracting thermal energy from exhaust gas streams and liquid coolant circuits, heat-recovery units reduce fuel consumption and thereby increase overall energy efficiency. Thermal energy available from this source can be recovered as either hot water or low-pressure steam [19].

In general, the minimum amount of heat rejected in the ICE of electrical generator is about 30% of input energy, by means of engine jacket water. The engine cooling jacket commonly provides heat at around 95°C. In addition, about 40% by the exhaust gasses, the exhaust provides heat at around 650°C. So, the total heat rejected is about 70% of input energy [20]. Generally, engine jacket water is available as hot water so it can be used directly, or by main of simple heat exchanger, it is a very low cost option, it may be used for heating air conditioning just by a water-to-air radiator system, but hot water supply is the most common for domestic use [21]. Exhaust heat recovery can easily produce high temperature hot water up to 100°C or low-pressure steam up to about 15 psi on large engines, but is much more expensive to install. Therefore, if considering exhaust heat recovery, the capital cost of the heat exchanger must also be considered [22].

3-Design a Small Compound Heat and Power Unit

There are two basic types of reciprocating engines for power generation—spark ignition (SI) and compression ignition (CI). Reciprocating engines are used for a variety of stationary power generation applications, including, base-load power, emergency power, and peaking service. These engines are available for smaller power generation applications in sizes ranging from a few kilowatts to about five MW [23].

As mentioned before the amount of rejected heat in the internal combustion engine is more then 70% of input fuel energy, there are many types of (ICE) as two or four stock and medium or large engine with jacket water engine cooling or small engine without jacket water engine cooling the engine cooling is perform by air ventilation. Maximum heat rejected efficiency up to 70% of fuel input energy [24].

Exhaust gases from reciprocating engines can vary in temperature and composition. Consequently, heat exchanger and silencer box manufacturers need to be consulted to determine the minimum silencer exit temperature. This temperature, which may be 120Co or more, influences the amount of heat that can be recovered and used for process applications [25]. During operation, heat-recovery mufflers should not create excessive backpressure on the reciprocating engine because high backpressure reduces the engine efficiency and increases the exhaust gas temperature [26]. In selecting the location for a reciprocating engine, it is important to realize that sharp bends in the exhaust system piping can create excessive backpressure and should be avoided. Maintenance and cleaning of heat-recovery mufflers is important for effective heat recovery [27]. Cleanout plugs, drains, and bypasses are often included to make maintenance easier. When used with oil-fired reciprocating engines, the muffler should include a soot blower to allow periodic cleaning to avoid soot build-up on exhaust gas heat exchanger surfaces [28].

II. THE SYSTEM DESIGN ACCORDING TO THE ENGINE TYPE

A-The first design is to engine that have water jacket cooling; Fig. 5 shows a sketch diagram of compound heat and power system. The system is consist of the following unites.

1-Electrecal generator: The essential unit for this system is the small electrical generator of four stroke gasoline engine of 10-50 kW maximum power capacity, with jacket water cooling system.

2-Water to water heat exchanger: It is the first stage of waste heat recovery. Heat exchanger is the main device of the available waste heat will be recovered. Several different types of heat exchanger exists, each exchanger has its own unique operating specifications. Heat exchanger are designed with specific temperature ranges, therefore, different temperature ranges requiring different heat exchangers. Three main categories of flow are parallel, cross and counter flow. Of the three flow directions the most effective is counter flow as Refs. [29] & [30] clarified. Fig. 4 sketches the three types of heat exchanger.

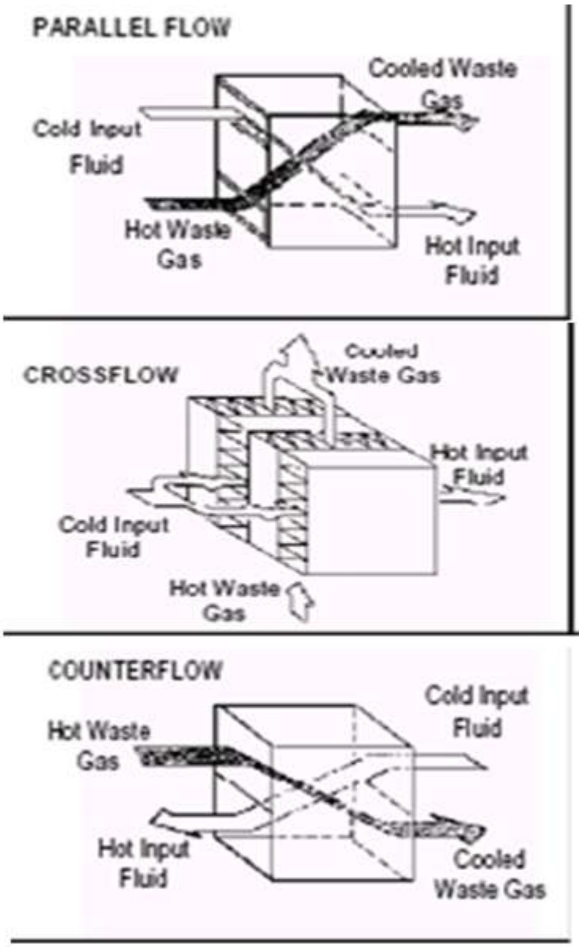

Fig. 4. Sketch for three types of heat exchanger.

3-Gas to water heat exchanger: Metallic counter flow heat exchanger is a gas to water heat exchanger, however the two streams of gas and water do not physically mix. Radiation exchangers are simple in design as shown in Fig. 5. For effective heat transfer, the temperature of the exhaust gases must remain above the temperature of the fluid to be heated. [31].

4-Hot water storage tank: A cylindrical metal tank of good insulation walls, capacity of 200 liters as storage heat tank. Safety valve or ventilation hole in upper seal is necessary to prevent over heating state.

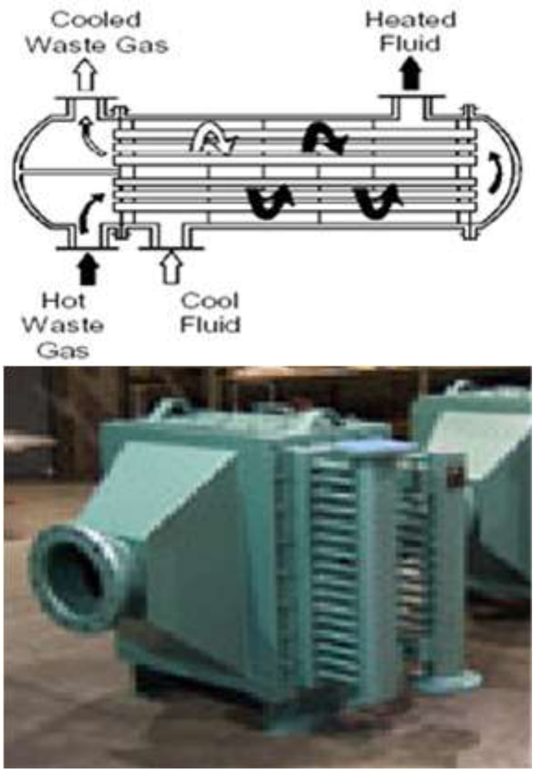

Fig. 5. Gas to water heat exchanger.

5-Emergency radiator: It is a normal radiator connecting with the system by a thermal safety valve, the function of this short cycle is to save the engine from over heat case.

6-Connecting pipes: Normally it made from high corrosion steel pipes with a good thermal insulation.

7-Indoor hot water radiator: It a metallic high corrosion resistance, consist of several layers of water jacket connected to other; it is available in market at low price.

B-The second design is for the small engine, of air cooling system, power up to 10 kW, the combined power and heat recovery system for this generator, is simple in design and has relatively lower efficiency than the first one. The maximum heat recovery is about 40% of the input fuel energy. Fig. 7 shows the sketch of this design, it consisting of the following:

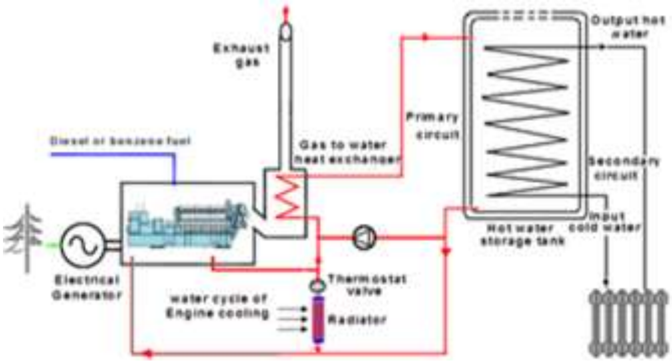

Fig. 6. Sketch diagram of compound heat and power system for water jacket cooling system.

B-The second design is for the small engine, of air cooling system, power up to 10 kW, the combined power and heat recovery system for this generator, is simple in design and has relatively lower efficiency than the first one. The maximum heat recovery is about 40% of the input fuel energy. Fig. 7 shows the sketch of this design, it consisting of the following:

1-Electrecal generator: In general the small electrical generator is gasoline fuelled engine, power generated of 0.5 up to 10 kW, it is either two stroke with engine speed of 3000rpm, or four stroke with engine speed of about 1500 rpm, these two types are without cooling water jacket, so the cooling of engine is perform with small fins on engine bloke. Maximum efficiency of these generators is less than 30% of input fuel energy, 30% of the rejected energy is ventilated with air by block engine fins. So, it cannot be recovered, the 40% of remaining rejected heat is as exhaust energy, which can be recovered.

2-Gas to water heat exchanger: It made from steel metal of high corrosion resistance, counter flow heat exchanger as shown in Fig. 7.

3-Indoor hot water radiator: it is a low cost simple type heat exchanger, use in house for heating.

4-Connecting pipes: It made of steel metal, with a good thermal insulation to prevent heat lost.

5-Hot water storage tank. A cylindrical tank of a good insulation walls, 100 liters capacity, with ventilator hole is necessary to prevent over heating state.

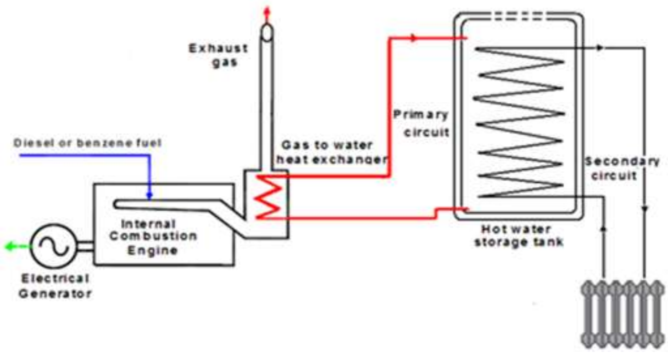

Fig. 7. Sketch diagram of combined heat and power for air cooling engine.

6-Heat to power ratio (H/P):

In general, a good design 0f (CHP), have recovered heat to power ratios of between approximately 1:1 and 1:7.

Optimal design operates between the ranges of approximately 1:6 to 2:3.

For example, a small-scale (CHP) unit fuelled by natural gas has an electrical capacity (QE) of 1,027kWe and a thermal output (QH) of 1,325kWt. The heat (hot water) flow temperature is 80oC. The output heat to power (H/P) ratio.

H/P ratio

H/P= QH / QE = kWt / kWe = 1325/ 1027 = 1.29

7-System performance indicators:

To evaluate the (CHP) system, it is necessary to calculate some energy related indicators systems/components under examination. The useful heat (QH) is the heat produced in a combined process to satisfy an economically demand for heating or cooling. The calculation of electricity from combined (QE) can be made based on the power to heat ratio (PHR), that is, the ratio between electricity and useful heat from combined system.

$$Q_E = PHR \cdot Q_H$$

The electric efficiency (η_E) is the electrical generated in system divided by the fuel input energy (H_f). The fuel input should be calculated, based on the lower calorific values of fuels (LHV):

$$\eta_E = \frac{Q_E}{H_f} = \frac{Q_E}{\dot{m}_f \times LHV}$$

Thermal efficiency (ηq) is the useful heat recovered divided by the fuel input:

The overall efficiency (η_{all}) is the sum of electricity production and useful heat output divided by the fuel input used:

$$\eta_{all} = \frac{Q_E + Q_H}{H_f} = \frac{Q_E + Q_H}{\dot{m}_f \times LHV}$$

Calculation of primary energy savings (PES) due to the application of a CHP system can be obtained using the following expression:

$$PES = Q_E \left\{ \frac{1}{\eta_e} + \frac{1}{\eta_b PHR} - \frac{1}{\eta_E} \right\}$$

Where η_e is the electricity grid efficiency and η_b is the efficiency of the conventional boiler considered [32].

Capital cost: The cost of a reciprocating engine and generator set is generally lower than other types of electrical generator. Also reciprocating engines have higher efficiencies than gas turbines of comparable size. Also the maintenance can be performed by in-house staff or a local service provider. Installed costs for reciprocating engine CHP systems vary according to the system size, the cost of installation, fuel cost, and maintenance will reduces as system size increase, Fig. 8 shows the dffect of CHP system capacity on installed cost in UK [33] & [34].

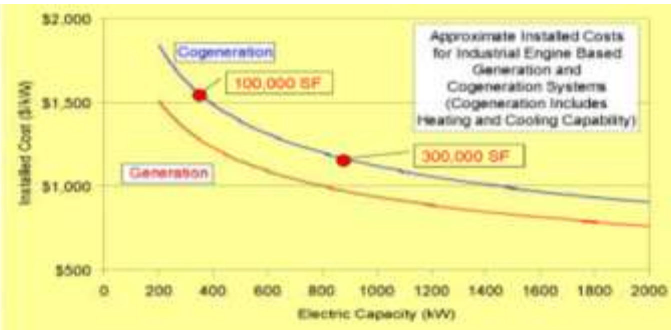

Fig. 8. Effect of engine-based CHP system capacity on installed.

III. Conclusion

To understand the advantages of this system, it is helpful first to think about the conservation of energy. National network power plant production electricity with efficiency about of 30 percent; 8 percent or so is lost along transmission

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lines. As much as 78 percent of the input fuel is lost heat energy. (Total Home Energy System) is a most efficient one, utilizing up to 80% of the fuel energy either in the form of electricity or heat. Because of their high-energy utilization, combined systems are seen as the energy systems of the future. The concept is not limited to homes, but can also be applied to greenhouses, dairies and any other application needing both forms of energy. So individual separated power plant unit with combined power and heat is the more efficient idea then the national Network of the electrical power supply. Especially for Iraq republic, that suffers damage actions for electrical transitions lines.

Symbols:

CHP	Combined heat and power system.
GWe	Gig watts electric.
Hf	Fuel input.
H/P	Hear to power ratio.
ICE	Internal combustion engine.
LHV	Lower calorific values of fuels.
MW	Mega-watt.
	Fuel flow rate.
PES	Primary energy savings.
PHR	Power to heat ratio.
Q_E	Electrical energy.
Q_H	Heat energy.
η_E	Electrical efficacy of the system.
Q_E	Electrical efficacy of the generator.
Q_H	Overall efficacy of the system.
η_H	Thermal efficiency.
η_b	Boiler efficiency.

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