THE COMPARATIVE ANALYSIS OF NATURAL GAS, LPG, AND GASOLINE IN GENERATING ON-SITE ELECTRICITY FOR RESIDENCES

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ABSTRACT

This study targets at examining electricity generation and the system parameters have been compared for household needs by on-site natural gas, LPG and gasoline generator as well as the heating of the residence by the released exit gas during the working of the system. In this study, the issue of individual electricity generation has been experimentally analysed by a sample application. Natural gas, LPG and gasoline have been converted into electrical energy by means of an internal combustible motor and an alternator. The system has functioned at full and low load. Working at full load, the generation of 1 kWh costs \$0.23 with natural gas, \$0.69 with LPG and \$1.07 with gasoline whereas at the low load, the costs of 1 kWh for the indicated fuels come out to be \$0.25, \$0.93 and \$1.55 respectively. The sufficiency of the waste heat, which is obtained through the burning of the indicated fuels, in residence heating and meeting the hot water need has been analysed. Depending on the working capacity of the system, it has been noted that the hot water obtained vary between 38°C and 50°C.

Keywords: Natural gas generator, Waste heat, LPG/Natural gas, Electricity generation, Cogeneration

1. INTRODUCTION

Energy is indispensable for the daily life of individuals, industrialization, and development of countries. There is a strong relationship between the countries' economies and the energy resources they have. Many countries develop energy policies to acquire sustainable development and to realize these policies they design strategies [1]. In line with this, especially the developing countries have been carrying out researches to increase energy efficiency and use energy resources properly. Furthermore, due to the increasing pollution in recent years; states, in accordance with the international law, have been designing programs which support types of energies that are cheap, sustainable, and least harmful to the environment.

When we look at the distribution of the types of the energies used worldwide, we come across with the following figures: 86% fossil fuels, 6% nuclear, 6% hydraulic, and 2% renewable energy [2]. It is already a known fact that Turkey lacks fossil fuel energy resources. While rate of local production to meet the needed energy demand was 47% in 1990, it decreased to 33% in 2000 and it is foreseen that it will stand at 23.6% in 2023 [3]. Moreover, despite the fact that Turkey lacks primary energy resources, the electrical energy losses, both technical and commercial come out to be 25.64% for the year 2012 [4]. It is a serious loss if a country cannot use ¼ of the electricity it generates. It is essential for Turkey's future that energy efficiency is increased by making use of energy resources effectively and minimizing energy losses.

In nowadays Turkey, natural gas is supplied to residences where its being used for purposes of meeting the need for heating and hot water. That is why, it is viable to generate electricity out of the already available gas in residences by burning it in a system comprised of an internally combustible motor coupled with an alternator. The exit heat obtained during the process is to meet the heating and hot water need, which is likely to result in a more efficient use of natural gas [5].

The system in this research is made to function by an internal combustible motor and a generator mechanism with an alternator connected to this motor, LPG and gasoline. Generating on-site electricity as well as making use of the waste heat obtained during the process for residence heating are to be researched in this paper. Besides, during this experimental research a comparison of natural gas, LPG, and gasoline fuels in terms of energy efficient, cost and usability is aimed.

2. MATERIALS AND METHODOLOGY

In this study, the experimental system was operated separately with gasoline, LPG, and natural gas and electricity was generated in the generator part and hot water was obtained from waste heat in the exhaust part. During the experiment, the variation of electricity and system parameters in relation with the amount of fuel consumed for each fuel is recorded according to the time.

As there are used three different fuels, instantaneous measurements of fuels are difficult. Therefore, the total fuel consumption for each fuel is considered. The schematic representation of the experimental system is given in Figure 1.

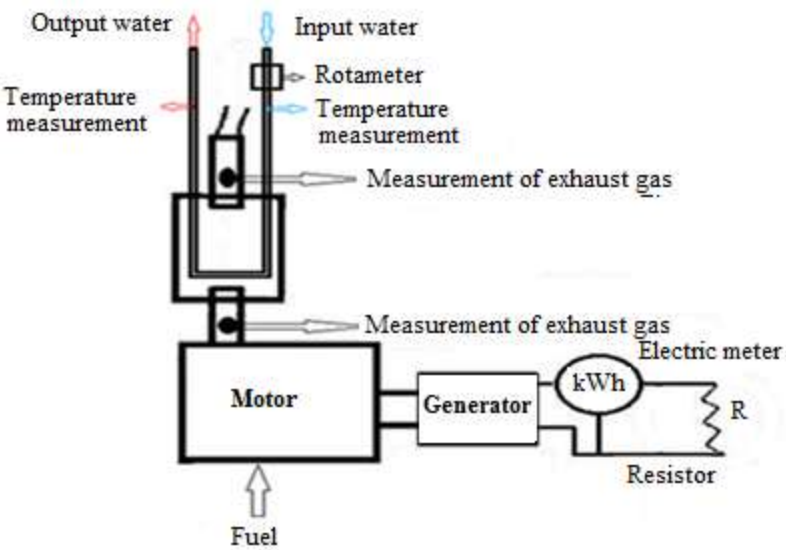


Figure 1. The view of the experimental system

During the experiment three different fuels have been used. Therefore, there have been made some alterations in the fuel system and exhaust of the generator. In order for the system to be able to function with LPG, a 30-bar resistant LPG tank was installed on the generator. Furthermore, in order to decrease the pressure to a usable level and to convert the liquid LPG to gas, a regulator (vaporizer) has been installed on the system. Since the multivalve on the system turn on and off by electricity, the multivalve were given electricity by accumulator and adapter. As there is high pressure between the LPG tank and the regulator, the connection between these two elements have been done by standardized copper pipes. An atomizing nozzle was installed on the carburettor. One end of the rubber pipe, on which there is a gas adjustment valve, is connected to the regulator while the other end is connected to the atomizing nozzle on the carburettor.

As the internally combustible motor is air cooled, the LPG, which comes to the vaporizer as liquid, is converted into gas by exhaust heat. Therefore, as shown in Figure 2, the copper pipe in the high pressure zone was put in contact with the exhaust, as a result of which the LPG in liquid form was converted into gas. Owing to the high pressure it has, the 4 bar liquid LPG moves and comes in contact with the exhaust heat via the copper pipe in the high pressure line and makes its way to the regulator in the form of gas. After the gas pressure is decreased to a usable level in the regulator, the motor is run by atomizing the LPG, which goes through the low pressure line where gas regulator valve is located, to the carburettor. In Figure 5 the LPG connections of the system are shown.

In order for the system to function with the natural gas, 21-bar gas used in residences has been utilized. The natural gas is connected to the system with a standardized flex hose. The atomizing nozzle and regulator valve used for LPG have been used for natural gas as well.

Figure 2. Water connection to the heat exchanger and preheating of the LPG on the exhaust

The dimensions of the exhaust, whose schematic view is shown in Figure 3, are as follows: length (A) 220 mm, height (B) 200 mm, and width (C) 120 mm. The copper pipe used as heat exchanger has a length of 5650 mm, an external diameter of 4826 mm, and an internal diameter of 4.826 mm and a thickness of 0.76 mm. In order to impede the accumulation of the particles, which come into being as a result of the burning in the exhaust, on the exchanger, vanes were not used on the copper pipe. Therefore, the copper pipe has been designed as 18-pass a spiral heat exchanger and was inserted in the exhaust. The temperature of the water and exhaust gas in the system have been measured with a K-type thermocouple. The design phases of the exhaust used in the experimental system are shown in Figure 4.

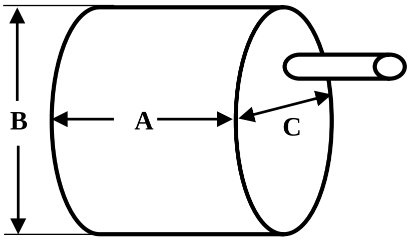


Figure 3. Schematic view of the exhaust in the experimental system

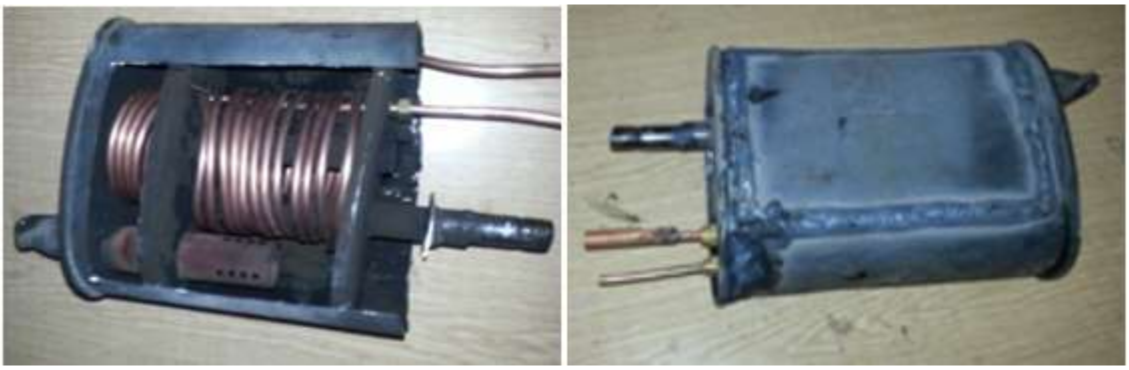


Figure 4. Design phases of the exhaust and heat exchanger

As seen in Figure 5 an air-cooled, four-cycle, single cylinder with a maximum output of 6.5/3000 HP/rpm internal combustible motor has been used. The generator coupled with motor has a 230 V output voltage, 50 Hz output frequency and 2.5 kWh nominal output power. For a maximum electrical power output, Rheostats of 2.8 kWh have been used.

The electrical output power generated by the system has been measured by an electricity meter. Temperature and power measurement are conducted when generator reaches a stable working condition at a certain load. At the same time, to determine the duration that it takes for the system to reach its regime, the measurement results have been constantly recorded.

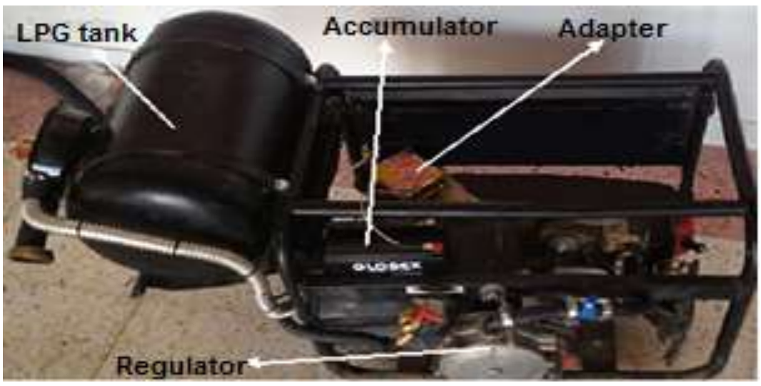


Figure 5. The generator and LPG connections used in the experimental study

3. RESEARCH FINDINGS

It was observed that the system reached the regime 10 minutes after it started to work. After it reached the regime, the system was put to work at both full and low loads for each one of the fuels and the results were recorded. While working at full load, the generation of 1 kWh electricity costs $0.23 with natural gas, $0.69 with LPG and $1.07 with gasoline. The data obtained during the working of the system at full load are shown in [Table 1]. As can be seen, at full load natural gas is 3 times more economical than LPG and 4.6 times more than gasoline.

Table 1. System run at full load for 1kWh electricity generation

Fuels	Natural gas (m^3/h)	LPG (lt/h)	Gasoline (lt/h)
Fuel consumption(fuel/kwh)	0.869	0.815	0.758
Fuel cost ($/kwh)	0.23	0.69	1.07

It is seen in [Table 2] that natural gas is doing better than the other two fuels in terms of cost when the system works at low load too. While working at low load, the generation of 1 kWh electricity costs $0.25 with natural gas, $0.93 with LPG and $1.55 with gasoline. In line with these data, it is seen that at low load natural gas is 3.7 times more economical than LPG and 6.2 times more than gasoline.

Gasoline sale unit rate = $1.42 fuel/litter [6]
LPG sale unit rate = $0.85 fuel/litter [7]
Natural gas sale unit rate = $0.27 fuel/$m^3$ [8]

Table 2. System's operation at low load for 1kWh electricity generation

Fuels	Natural gas (m^3/kWh)	LPG (lt/kWh)	Gasoline (lt/kWh)
Fuel consumption(fuel/kwh)	0.953	1.101	1.096
Fuel cost ($/kwh)	0.25	0.93	1.55

The findings have shown that natural gas is more cost-effective when the system works both at full and low load. Furthermore, it has been observed that when the system works at low load, the cost for all three fuels has increased. As can be seen from Figure 6, when the system works at low load, the costs for natural gas, LPG, and gasoline increase by 8%, 34%, and 44% respectively. Therefore, in terms of cost effectiveness, the best results can be obtained by the system working with natural gas and at full load.

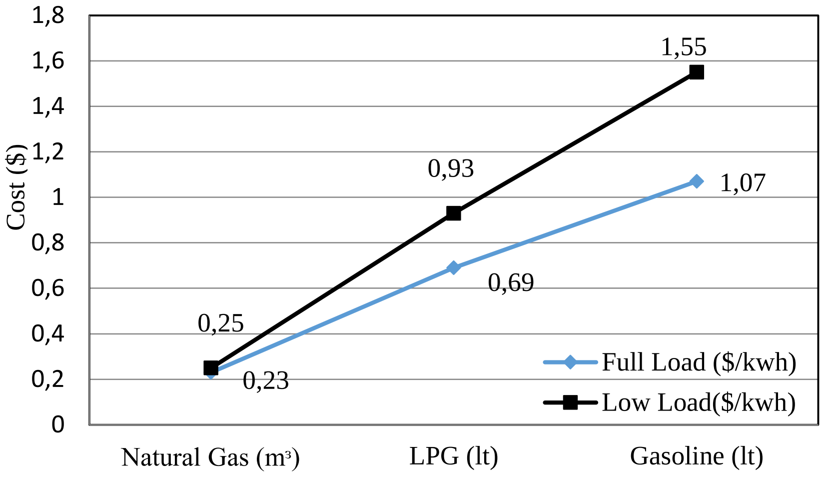


Figure 6. Comparison of system run at full and low load

In the second part of the research, the three fuels have been compared in terms of consumption, cost, and energy generation. The experiments have been carried out at full load and low load. The data obtained as a result of the system's one-hour at full load operation are given in [Table 3]. After system's one-hour working, the highest energy generation, 1.51 kWh, was recorded with gasoline, LPG following with 1.32 kWh and natural gas with 1.21 kWh. In terms of energy generation, natural gas has performed 9 % less than LPG and 24.7 % less than gasoline.

Table 3. System's one-hour operation at full load

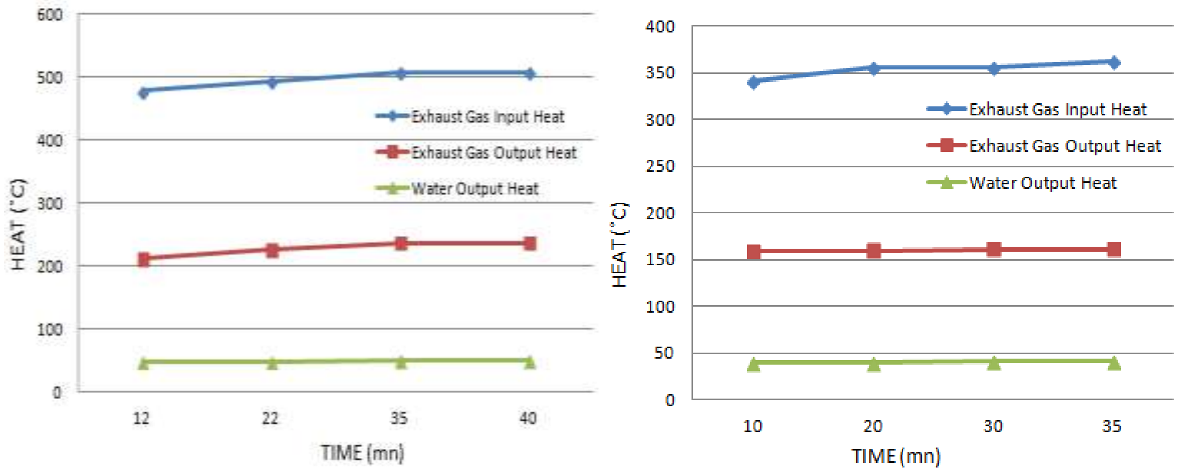
Fuels	Natural gas (m^3/h)	LPG (lt/h)	gasoline (lt/h)
Fuel consumption(fuel/h)	1.06	1.08	1.15
Fuel cost(€/h)	0.28	0.92	1.63
Energy generation(Kwh)	1.21	1.32	1.51

The data obtained as a result of the system's one-hour operation at low load are given in [Table 4]. After the system's one-hour working, the highest energy generation is recorded with 0.99 kWh by natural gas, LPG following with 0.78 kWh and the lowest with 0.68 kWh by gasoline. The data obtained show that natural gas has the lowest cost while gasoline has the highest. In terms of energy generation, contrary to the results obtained at system's full load operation, natural gas performs 26.9% better than LPG and 45.5% better than gasoline at system's low-load operation.

Table 4. System's one-hour operation at low load

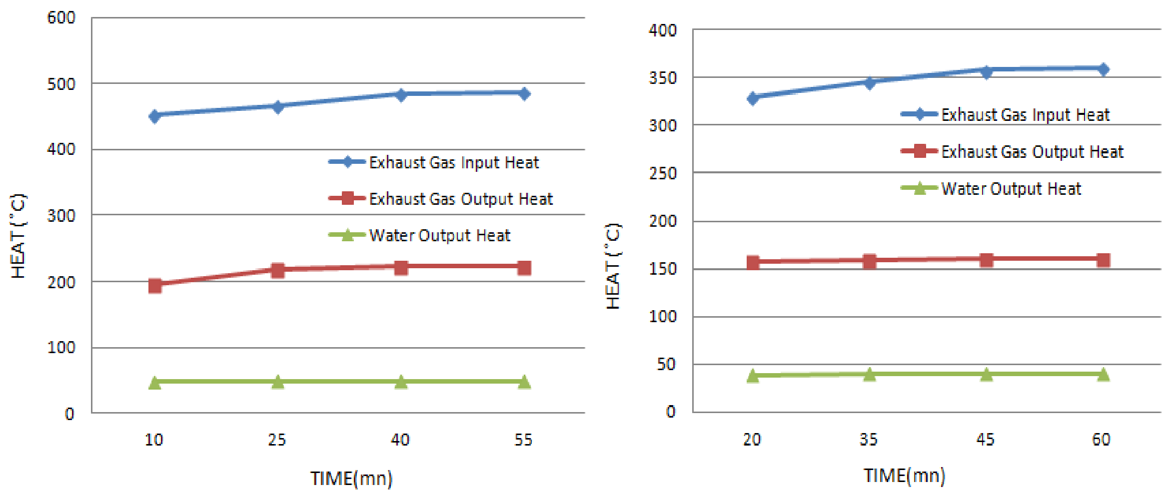
Fuels	Natural gas (m^3/h)	LPG (lt/h)	gasoline (lt/h)
Fuel consumption(fuel/h)	0.76	0.86	0.75
Fuel cost(€/h)	0.20	0.73	1.06
Energy generation(Kwh)	0.99	0.78	0.68

Another aspect of the research has been to measure exhaust gas temperature and produce hot water out of the waste heat by means of the heat exchanger inserted in the exhaust. The experiments were conducted at full and low load for the three fuels. At the system's full load operation, the exhaust gas input temperature was noted between 450°C and 507°C. At this temperature range, the water entering the heat exchanger in the exhaust at 23 ° C and at a rate of 0.015 kg /s, came out at a temperature range of 45 ° C to 50 ° C. The output temperatures of the exhaust gas stood between 190°C and 237°C. When the system works at low load exhaust gas input temperatures are noted as being between 320°C and 362°C while exhaust gas output temperatures are between 158°C and 161°C. Water entering the heat exchanger at a rate of 0.015 kg /s and at a temperature of 23 ° C was noted to be between 38 ° C and 41 ° C. It is seen that the results obtained for all three fuels in this experiment are quite close to each other. Values for the exhaust gas and heat exchanger for natural gas, LPG, and gasoline are given in Figures 7, 8 and 9 respectively.



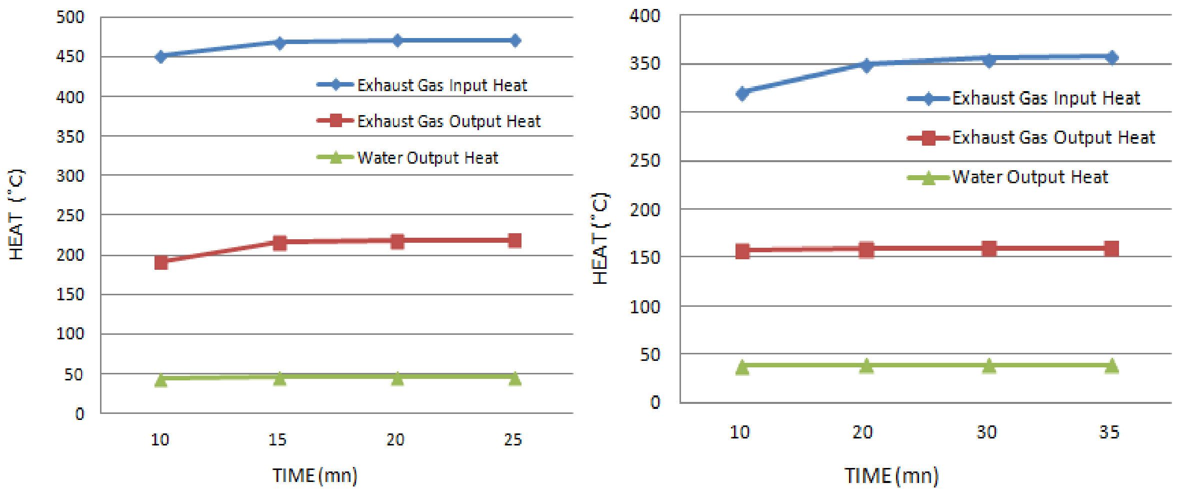
a) Full load b) Low load

Figure 7. Values obtained from exhaust gas and heat exchanger for natural gas at full and low load



a) Full load b) Low load

Figure 8. Values obtained from exhaust gas and heat exchanger for LPG at full and low load



a) Full load b) Low load

Figure 9. Values obtained from exhaust gas and heat exchanger for gasoline in full and low load

All measurements were made for 10 minutes after the system reached the stable condition. These measured values were obtained as a result of the system's operating at full and low load. After the flue gas inlet temperature rose for about 10 minutes at full and low load, it remained stationary. The flue gas outlet temperature rose for a short time at full load and then it turned stable. However, the flue gas outlet temperature remained stationary at low load. The outlet temperature values of the water heated by the waste heat rose for a short time and then continued at a constant value.

4. CONCLUSION

In this study, on-site electricity generation, which can be a model for future small scale cogeneration applications, is examined. Such a model could help minimize energy losses that occur during the transport of energy as well as the electrical energy transport costs. The results of the research have shown that natural gas is 3 times more economical than LPG and 4.6 times more than gasoline.

In addition, during the power generation, the system was able to heat the tap water at 23 ° C and 0.015 kg /s with the exhaust heat from the system up to a temperature range of 38 ° C to 50 ° C. In the light of this information, the waste heat, which is essential in terms of efficient use of energy, can be used for the heating of residences by being converted into usable energy. In such a system in houses, it is envisaged that by using more efficient equipment, necessary insulation and appropriate design of exhaust and heat exchanger, hot water and heating needs of residences can be met with waste heat.

By generating electricity in houses, it is possible to reduce the power losses of electricity and the transmission costs of electric energy. In addition, during the process of on-site electricity generation, it is highly probable that there will be occasional electricity surplus. If the surplus electricity is transferred to city network grids, both households and country's economy are to benefit. This contribution for the on-site electricity generator houses means that the energies (electricity, hot water) needed for daily use in these houses can be met with a lower cost and that by selling the surplus electricity, a profit making is possible.

On the other hand, on-site energy generation creates a potential for reducing countries' external dependency on energy. As a result, in today's Turkey, natural gas is used in many regions and in the near future, its use is planned to be spread to the whole country. In the regions where natural gas is already available, it’s observed that the vast majority of the houses make use of natural gas. Therefore, natural gas, which is cheaper than other fuels, easy to use, environmentally friendly, with no storage problem, can be used more effectively and efficiently in residences with such a system by making use of waste heat too.

Author Note: This article was presented as oral paper at the International Energy and Engineering Conference 2016 (UEMK 2016)

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