СБОРНИК

ДОКЛАДИ
ОТ ГОДИШНА УНИВЕРСИТЕТСКА НАУЧНА КОНФЕРЕНЦИЯ

28-29 МАЙ 2020 ГОДИНА

Електронно издание

Велико Търново
2020 г.

Електронно издание

Редакционен съвет: Свилен Евтимов Стефанов, Ваня Куздова Банабакова, Георги Атанасов Георгиев, Илиян Цветанов Ангелов, Събин Иванов Събев

Технически редактор:
майор Иванка Георгиева

Издателски комплекс на НВУ „Васил Левски”
ISSN 2367-7481

ANALYSIS OF THE OPERATION OF EXPERIMENTAL COGENERATION INSTALLATION BASED ON INTERNAL COMBUSTION ENGINE

Konstantin Kostov

Abstract
The purpose of this study is to comprehensively investigate the extraction of heat and electricity, of an experimental cogeneration unit based on an internal combustion engine. The losses of the system and the possibilities for increasing the overall efficiency of the installation are analysed.

Keywords: *cogeneration unit, efficiency, heat and power generation, internal combustion engine.*

Introduction

The combined heat and power generation belongs to the high technologies in the energy sector and allows to significantly improve energy efficiency, while ensuring higher reliability and continuity of energy supply.

The state of the energy market and scarce local energy sources force us, both in the short and medium term, to meet the energy needs predominantly of using conventional energy carriers - oil, natural gas and coal, striving for maximum efficiency in the production of electricity and heat. One good solution in this direction is to use their decentral technology or their production by implementing local cogeneration systems.

Directive 2012/27 / EU of the European Parliament and of the Council on energy efficiency addresses the need to increase energy efficiency in the Union by 2020 at 20% savings in primary energy consumption in the European Union, compared to projections. The legal framework put in place is intended to accelerate the development and diffusion of innovative technological solutions in order to improve the competitiveness of Union industry and conservation the environment.

As a waste heat recovery system, cogeneration is a technology that can reduce the cost of energy conversion. A number of authors [5, 7, 10, 12] examine and analyse the applicability of cogeneration in various fields of industry, energy and agriculture.

Cogeneration, as a system, includes - a basic module, a heat recovery system, an electricity generator, electrical and mechanical connections and a control system.

Cogeneration systems using an internal combustion engine have found their greatest use because of their many advantages over other modules for combined production of electricity and heat. This type of cogeneration unit is suitable for providing independent heat and electrical supply to single or group of sites. Their advantages include high productivity, relatively low initial investment, the ability to use a wide range of fuels, and more. Their main disadvantages are the high emissions of harmful substances released into the atmosphere, significant levels of low frequency noise.

For to achieve maximum thermal efficiency, heat is absorbed by the cooling system of the internal combustion engine - in the order of 30% ÷ 35% and of the combustion products - 15% ÷ 20%, which is largely true for modules with relatively low power [4]. For large cogeneration systems, heat recovery can also be achieved by the engine oil temperature maintenance system [14, 15, 16, 17].

Recuperative surface heat exchangers are used to recover heat from cogeneration units based on internal combustion engines. The choice of a particular construction depends on the individual and specific features of the system, the heat losses of the apparatus, the ability to clean the heat exchange surface from dirt, the installation site, and the required power of the heat exchanger [2].

Characteristics of the object and methodology of the study

The object of analysis is presented in figure 1 and represents experimental installation of an cogenerator based on internal combustion engine. The installation consists of the following units and components:

- an internal combustion engine with a rated output of 45,6 kW converted to run on gas;
- sectional heat exchanger for heat absorption by the engine;
- shell and tube heat exchanger for heat recovery from engine combustion products;
- permanent, reversible, braking electric brake;
- pipe and electrical connections;
- management system.

In order to carry out the balance tests, a stand for complex tests of an internal combustion engine was essentially used, which was reconstructed and supplemented with heat exchangers and measuring instruments.

The stationary engine (1) coupled to the clutch and the gearbox is secured to a solid base mounted on elastic elements. The connection of the gearbox output shaft (respectively, the crankshaft of the engine) to the brake shaft (2) is made by a shaft drive with an elastic unit which, in addition to damping out the shocks and torsional vibrations, assumes the permissible misalignment between the two shafts. The internal combustion engine is connected to the two heat exchangers (3) and (4) for heat recovery.

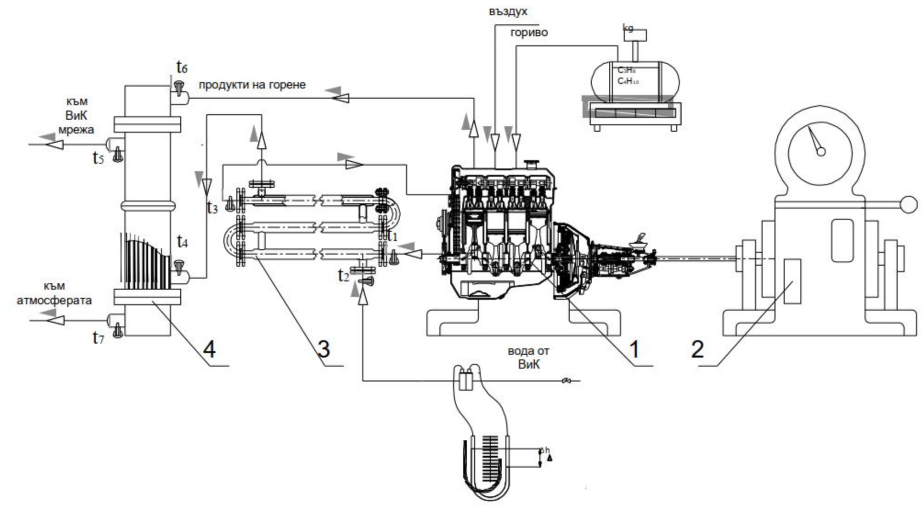

Figure 1. General view of the experimental system
1. Stationary internal combustion engine – 45,6kW;
2. Permanent, reversible, braking electric brake;
3. Three section heat exchanger;
4. Shell and tube heat exchanger "combustion products - water"

The use of a DC, reversible, deceleration electric brake allows accurate reading of the engine power at different loads while observing a synchronous speed of rotation $n=3000\ min^{-1}$.

This eliminates the need for an electric generator and the difficulty of creating and maintaining a constant load during the experiments.

The internal combustion engine is equipped with a propane-butane liquefied gas system. The use of liquefied gas propane-butane is justified by the high octane number of the gas, the easy regulation of the combustion process, the reduced toxicity of the exhaust gases, as well as the elimination of the need for the installation of filters along the gas path to purify and prevent contamination of the heat exchange surfaces, when the engine exhaust gas is recovered [8, 9].

The measurement of the amount of gas consumed during the operation of the installation is carried weight method out by an electronic balance on which the gas bottle is placed.

Two heat exchangers have been designed and installed to allow the heat from the internal combustion engine and the heat of the combustion products to be utilized accordingly. The first heat exchanger is a three section pipe to tube heat exchanger. It serves to remove heat from the engine's cooling system, the working fluids being water and ethylene glycol solution. The second heat exchanger is a shell tube heat exchanger. It is the transfer of heat from the exhaust gases of the engine to the liquid coolant (water) that comes from the previous heat exchanger.

The experiments are carried out in a sequence. The engine that receives fuel from the LPG evaporator is started. The combustion air required is without preheating, mixing with the fuel in the engine's intake system. After a certain period of time, the engine reaches operating temperature. The water tap from the water network opens. The heated water passes through the two heat exchangers in succession, raises the temperature, and then is supplied to the water sewage system. The gearbox is engaged in a fourth (direct) gear, the clutch engaged smoothly, and we gradually increase the engine speed until a synchronous speed is reached $n=3000min^{-1}$. The load on the engine is achieved by setting the corresponding operating mode of the brake. The values of the measured values are taken into account.

Two series of experiments were conducted. In the first series of tests, the engine was loaded to the maximum, changing the flow of water passing through the heat exchangers. The second series of experiments is with a constant flow of water, but with a reduction of load by 20% and 40% respectively.

Results and discussion

To analyse the operation of the installation, a heat balance has been drawn up, which is equal to:

$$Q_{over}=Q_{el.}+Q_{h.}+Q_{l.}\ ,\ [W] \quad (1)$$

where:

- Q_{over} - the amount of heat imported per unit time with the fuel-air mixture;
- $Q_{el.}$ - the electrical power read from the brake;
- $Q_{h.}$ - the utilized amount of heat from heat exchangers;
- $Q_{l.}$ - losses in the cogenerator.

Turn heat utilization is equal to:

$$Q_h = Q_{cool} + Q_{smoke.} \quad [W] \quad (2)$$

where:

- Q_{cool} - amount of heat of the internal combustion engine cooling system;
- Q_{smoke} - the amount of heat obtained from the exhaust gases of the internal combustion engine;

Table 1 lists the balance sheet results obtained from the first series of experiments. Table 2 summarizes the results of the second series of experiments at constant water flow, but with a reduction of load of 20% and 40%, respectively.

After processing the experimental data, the dependencies shown in Figures 2 to 7 were constructed.

Table 1. Balance results of experiments performed

	Q_{over}	Q_{cool}	Q_{smoke}	$Q_{l.}$		Q_h		$Q_{el.}$		Q_h/Q_{el}
	kW	kW	kW	kW	%	kW	%	kW	%	
I	65,38	20,06	12,38	12,52	19,14	32,44	49,62	20,42	31,23	1,59
II	69,08	21,20	14,46	11,43	16,55	35,66	51,62	21,99	31,83	1,62
III	74,01	22,60	15,09	13,08	17,67	37,68	50,91	23,25	31,41	1,62

Table 2. Balance sheet results in load reduction

	load	Q_{over}	Q_{cool}	Q_{smoke}	$Q_{l.}$		Q_h		$Q_{el.}$		$Q_h/Q_{el.}$
	%	kW	kW	kW	kW	%	kW	%	kW	%	
I	60	42,19	9,1	6,07	13,82	32,76	15,17	35,96	13,20	31,28	1,15
II	80	56,25	15,24	9,53	13,89	24,7	24,77	44,04	17,59	31,27	1,41
III	100	69,08	21,20	14,46	11,43	16,55	35,66	51,62	21,99	31,83	1,61

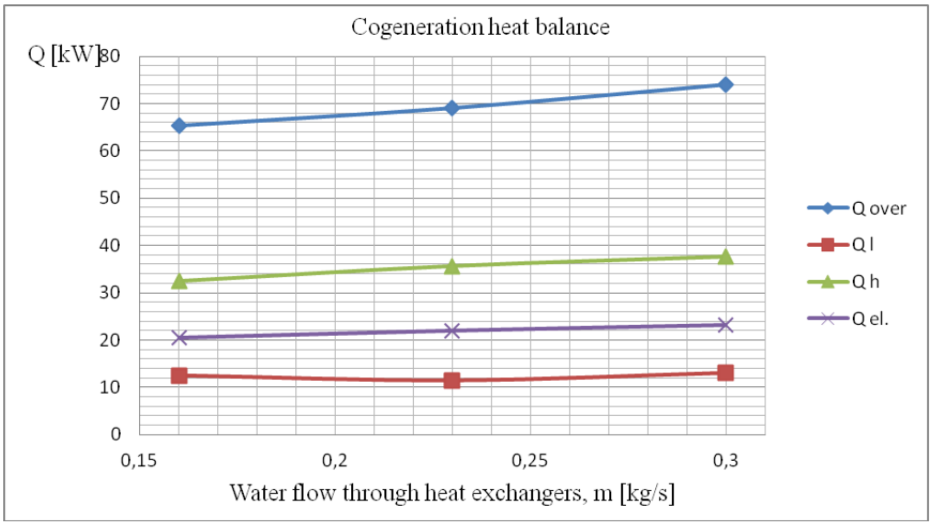

Figure 2. Thermal balance of the cogenerator as a function of the flow of water passing through the heat exchangers

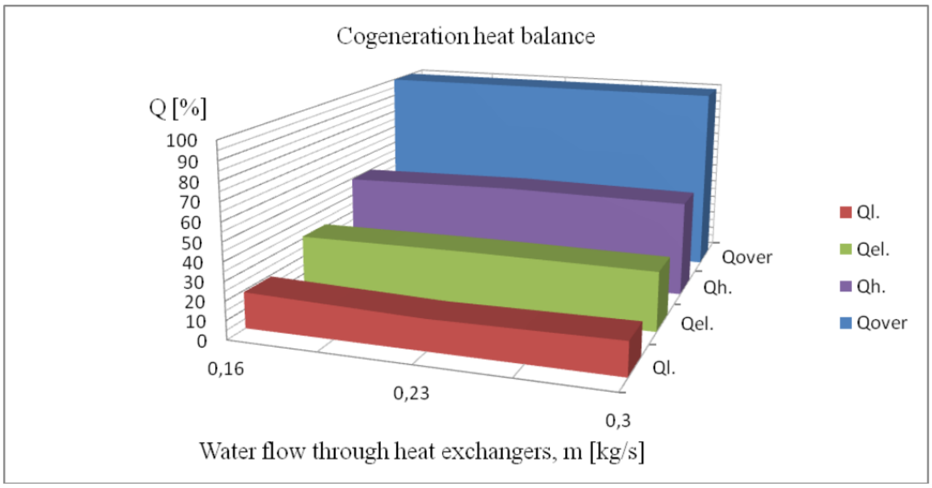

Figure 3. Percentage of extracted electricity and heat and losses in the cogenerator depending on the flow of water passing through the heat exchangers

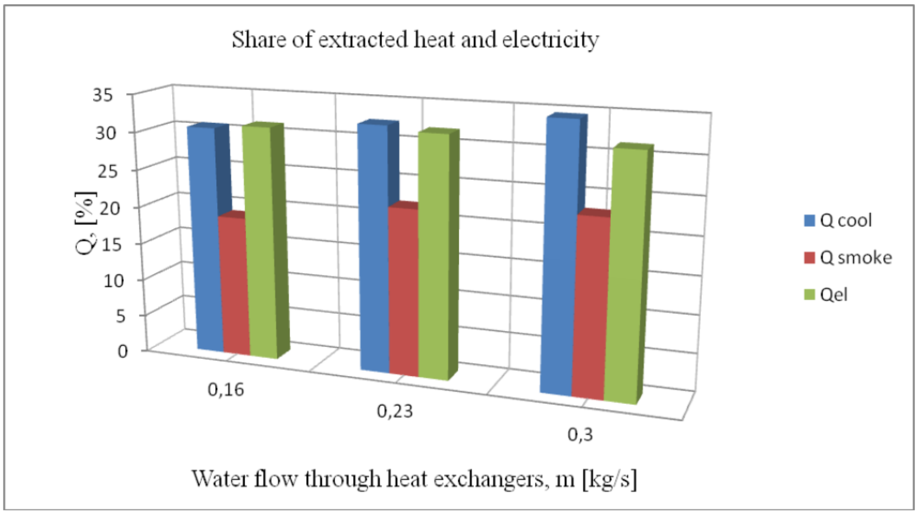

Figure 4. Percentage of extracted electricity and heat in the two heat exchangers of the cogenerator depending on the flow of water passing through the heat exchangers

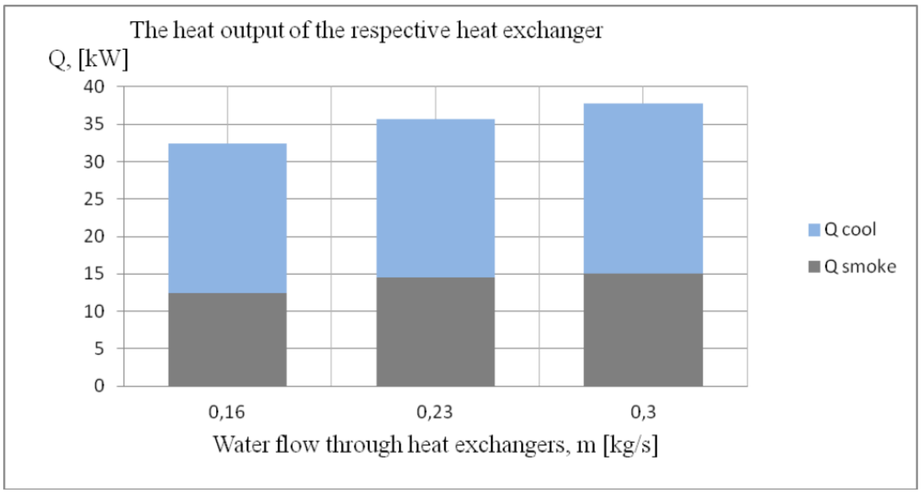

Figure 5. Comparison of the extracted heat in the two heat exchangers of the cogenerator depending on the flow of water passing through the heat exchangers

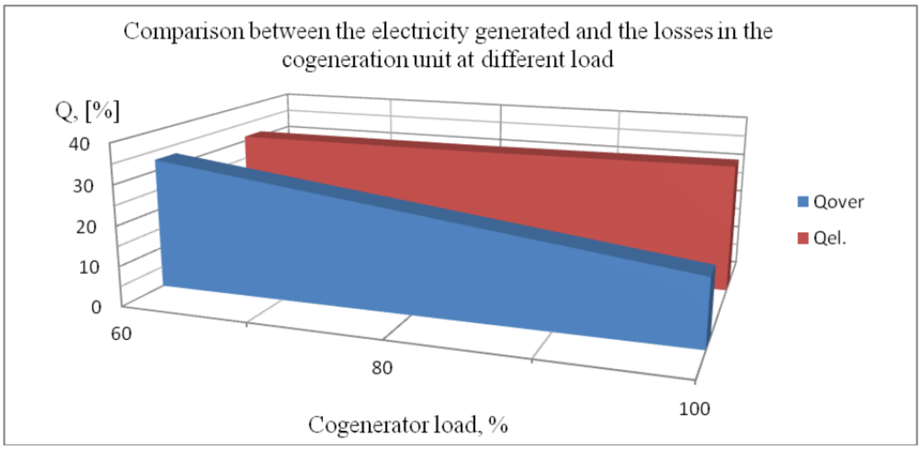

Figure 6. Comparison between the electricity generated and the losses in the cogeneration at reduction the load by 20% and 40%

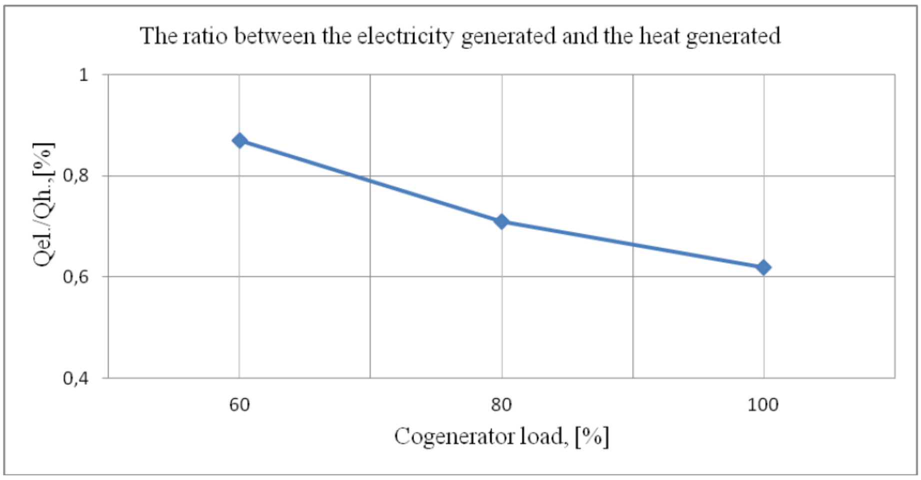

Figure 7. Ratio of generated electric power into heat generated at 20% and 40% load reduction

The following conclusions can be drawn from the results obtained:

- The total losses (the difference between the imported amount of energy with fuel and the obtained heat and electricity) of the cogenerator are in the range of 17-19%;
- The ratio of extracted heat to electricity is about 1,6 times;
- As the load decreases, the ratio of "electricity generated to heat" increases.

The cogenerator laboratory bench designed in this way is characterized by large losses, which are high relative to the total efficiency of the stand. The results obtained show that as the load of the engine decreases, the ratio of "generated electricity to heat" increases. This is mainly due to the reduced flow of combustion products in the gas-water heat exchanger and to the decreasing heat transfer coefficient on the gas side.

Conclusion

The losses are complex in nature and the possibilities for increasing the overall efficiency of the installation must be analysed.

Using design options to increase the thermal efficiency of an internal combustion engine is one option. The efficiency of the cogenerator can be increased by optimizing the operation of the internal combustion engine, by increasing the ε compression ratio. A number of authors [1, 3, 6, 11, 13] have worked in this direction and have shown that as the compression rate increases, the thermal efficiency - ηt increases intensively at small compression rates, after which ηt slowly increases with increasing compression. ε. Higher thermal efficiency leads to an increase in *Qel.* share at the expense of losses, case reduction *Qover*.

Improving the heat exchange equipment is another possibility to increase the overall efficiency of the installation. From the experimental studies performed, at nominal mode *(n=3000 min*$^{-1}$*)*, the heat absorbed by the combustion products in the tube-tube heat exchanger is approximately 1,5 times less than the heat absorbed by the three-section heat exchanger for engine cooling. This gives reason to take measures to improve the heat exchanger of combustion products - liquid coolant. It is necessary to increase the coefficient of heat transfer from the combustion products to the wall. Because, cogenerator based on internal combustion engine, they operate at a constant purity of crankshaft rotation (close to maximum torque), the amount of combustion products is relatively constant. This condition limits the application of some methods for intensifying heat transfer. For this reason, methods should be sought in this established mode of movement to intensify the heat transfer. From a technological and economic point of view, it seems most acceptable to apply methods of influencing the flow structure to reduce the thickness of the boundary layer. This can be achieved by placing additional walls and partitions or other poorly flowing elements in the duct.

References

1. Егорович Р., Возможность улучшения работы поршневого двигателя внутреннего сгорания, *Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета*, №6, 2004, 30-36
2. Разуваев А., Целесообразность применения систем утилизации теплоты ДВС, *Экспозиция*, №64, 2008, 112-114
3. Сакулин Р., И. Ахтямов, В. Шаяхметов, П. Яковлев, Расчетное исследование возможности реализации сверхвысокой степени сжатия в поршневом двигателе внутреннего сгорания, *Наука и образование*, №9, 2013, 117-124
4. Смирнов М.Н., Утилизация теплоты от судовой энергетической установки (СЭУ) на примере двигателя внутреннего сгорания (ДВС), *Международный научный журнал Молодой ученый*, №4, 38-41, 2017
5. Gambinia M., M. Vellinia High Efficiency Cogeneration: Electricity from cogeneration in CHP Plants, *Energy Procedia* 81, 2015, 430-439
6. Li T, Gao Y, Wang J, Chen Z. The Miller cycle effects on improvement of fuel economy in a highly boosted, high compression ratio, direct-injection gasoline engine: EIVC vs. LIVC. *Energy Convers Manage* 79, 2014, 59–65
7. Llamas A., O. Probst, On the role of efficient cogeneration for meeting Mexico's clean energy goals, *Energy Policy* 112, 2018, 173–183

8. Müller-Steinhagen H., M. Malayeri, A. Watkinson, Fouling heat exchanger – new approaches to solve an old problem, *Heat Transfer Engineering*, 26 (1): 2005, 1-4

9. Müller-Steinhagen H., M. Malayeri, A. Watkinson, Heat exchanger fouling: Environmental impacts, *Heat Transfer Engineering* 30 (10-11), 2009, 773-776

10. Rasul M.G., C. Ault, M. Sajjad. Bio-gas Mixed Fuel Micro Gas Turbine Co-Generation for Meeting Power Demand in Australian Remote Areas, *Energy Procedia* 75, 2015, 1065-1071

11. Shaik A, Moorthi NSV, Rudramoorthy R. Variable compression ratio engine: a future power plant for automobiles - an overview. *Proc Inst Mech Eng Part D* 221, 2007, 1159–68

12. Tian G., Y. Mao, J. Wang. Thermal efficiency analysis of small units of Co-generation of neat and power, *Procedia engineering* 205, 2017, 2184-2191

13. Wanga Z., H. Liua, R. Reitz, Knocking combustion in spark-ignition engines, *Progress in Energy and Combustion Science* 61, 2017, 78-112

14. http://sust-tour.webdevc.eu

15. http://tmmash.ru/oborudovanie/5-sistemy-utilizacii-tepla.html

16. http://www.deutz.com/

17. http://www.ge.com/power/resources/tools/product-comparison

For correspondence:
PhD eng. Konstantin Vasilev Kostov
Technical university of Sofia, Faculty of engineering and pedagogy of Sliven,
Sliven, 8800, Burgasko Shose Blvd 59,
e-mail: konstankostov@tu-sofia.bg