AVAILABILITY OF SMALL COMBINED HEAT AND POWER UNIT FED ON BIOGAS

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The paper addresses the calculations of the availability of the CHP unit fed on biogas. In the paper the authors present the results of exploitation investigations of two small biogas CHP units working in the waste-water treatment plant in Rzeszów. The investigation period is from January 2002 to December 2003. On the basis of these results the availability of biogas CHP units has been calculated. The results have been compared with the values of availability of small cogeneration systems based on a combustion engine or gas turbine fed on the non-renewable energy source - natural gas. The histograms of biogas CHP units have been presented. The function of occurrence of a specified time of disconnections has been obtained as a lognormal function.

Key words: CHP unit, biogas fuel, availability, disconnections time.

1. Introduction

A small CHP (combined heat and power) unit as a cogenerator based on a combustion engine or gas turbine can be an alternative energy source for a large energetic system. This system may be applied wherever the requirement for thermal and electric energy exists in relatively small amounts. Biogas fuel feeding presents an attractive option in applications for small CHP unit systems.

The exploitation of a small biogas CHP unit is related to its operating time. The system availability is a parameter which represents the possibilities of system worktime. It is a ratio of the real system worktime to the possible system worktime. It is an important quantity in the economic analysis of the work of a biogas CHP unit. Literature regarding CHP system availability refers to small cogeneration systems based on a combustion engine or gas turbine fed on the non-renewable energy source-natural gas. Example values of availabilities of small gas CHP systems are presented in Tab.1.

Table 1. Availability of small gas CHP systems (Skorek, 2002).

	Piston combustion engines			Gas turbines		
N	$< 60\,kW$	$80 - 800kW$	$> 800kW$	$0.5 - 5MW$	$5 - 25MW$	>25 MW
A	0.958	0.945	0.912	0.927	0.900	0.933

The results of the exploitation investigations of two small biogas CHP units are presented in this work. Each CHP unit consisted of a Diesel engine type SW680, driving the asynchronous generator. Technical parameters of the unit are characterized by Nowak and Wolańczyk (2002) and Wilk *et al.* (2004)

- rated electric power output – $95 - 97\,kW$;
- rated thermal power output – $128 - 130\,kW$;
- lower heating value of biogas – $LHV = 24.36\,kJ/m_n^3$ (Wilk and Wolańczyk, 2004);

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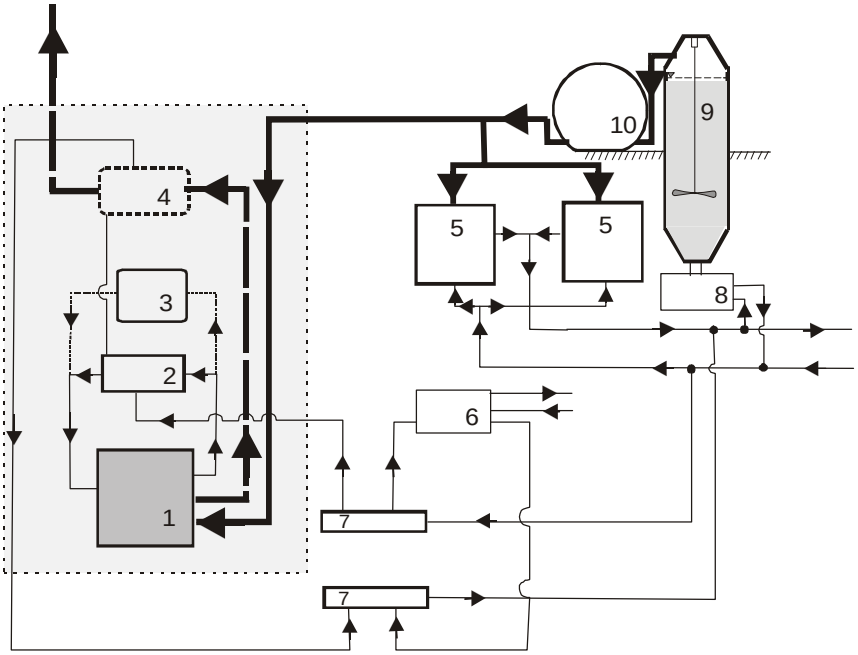
- biogas consumption – $V_{bg} = 50\, m_n^3/h$;
- maximum exhaust gas temperature – $480^0 C$.

Figure 1 presents the simplified scheme of electricity and heat production for the single cogeneration system based on the biogas in the waste-water treatment plant in Rzeszów. The graph of the monthly worktime of the units in the considered time interval is shown in Fig.2. The investigations concerned the time interval from January 2002 to December 2003.



1- CHP unit
2- heat exchanger coolant/water
3- coolant fan cooler
4- heat exchanger exhaust gas/water
5- water heater
6- emergency heat exchanger
7- water divider
8- sludge heat exchanger
9- sludge digester
10- biogas container

biogas

exhaust gas

Fig.1. Scheme of biogas cogeneration system.

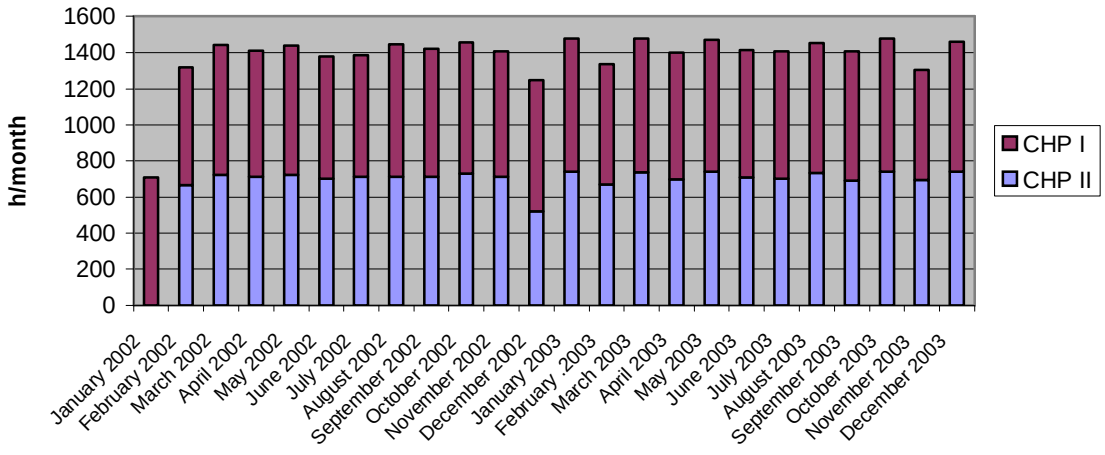


Fig.2. Monthly worktime of CHP units.

2. Causes of CHP system failures

Small CHP systems are liable to different failures during the worktime. The most often occurring causes of incidental disconnections of small CHP systems based on combustion engine or gas turbine are failures of: the control system, ignition system, lubrication system, heat system, heat exchanger, generator, exhaust system, engine, electric system, feed system and cooling system.

The failures time and the time to repair the system are the time of incidental disconnections. The time of planned disconnections is the time predicted mostly for routine maintenance.

The most frequent causes of incidental and planned disconnections of small cogenerated CHP systems are presented in Tab.2. The results of the investigated biogas CHP I unit refers to 135 cases of disconnections, the results of CHP II refers to 115 cases of disconnections and the literature results refer to 618 cases of disconnections of the CHP systems fed on natural gas.

Table 2. Main causes of disconnections of the small cogenerated CHP units.

The cause of disconnection	CHP I % (135 cases)	CHP II % (115 cases)	Skorek (2002) % (618 cases)
Engine	*39.4*	*37.5*	*9*
Electric system	*4.7*	*9.9*	*5*
Cooling engine system	*5.8*	*6.4*	*9*
Control system	*8.0*	*5.2*	*24*
Ignition system	*6.7*	-	*10*
Lubrication system	*2.2*	*17.5*	*9*
Routine maintenance	*16.1*	*11.3*	*10*
Heat system	-	*0.7*	*5*
Heat exchanger	-	*6.0*	*6*
Generator	-	*2.9*	*3*
Exhaust system	*3.7*	*0.3*	*2*
Feed system	*0.5*	-	-
Others	*12.8*	*2.2*	*8*

The time of disconnections of the investigated CHP systems is presented in Fig.3. The graph in Fig.3 refers to total worktime (2002 and 2003). It can be seen that the time of engine failures has the largest value in the case of both CHP systems.

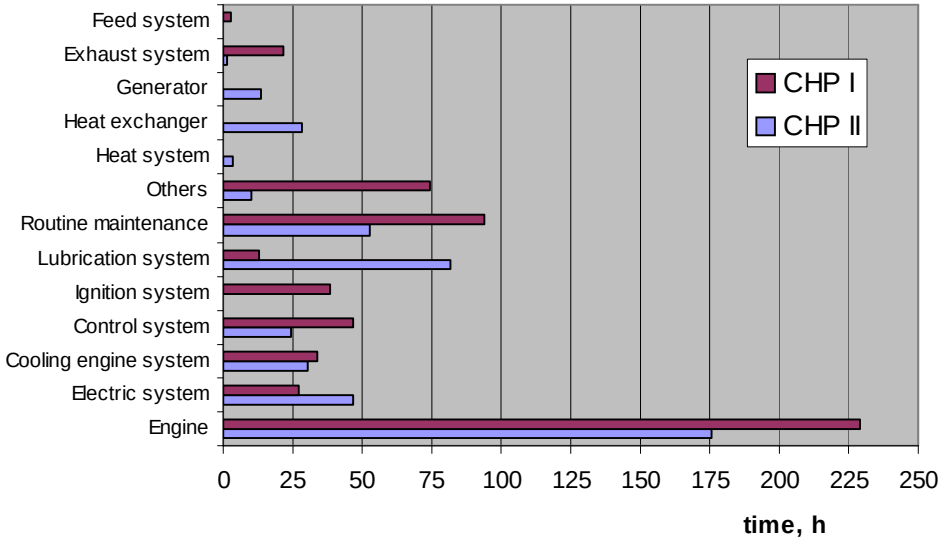


Fig.3. Disconnections time of biogas CHP units working in the waste-water treatment plant in Rzeszów (Wilk *et al.*, 2004). Investigation period is from January 2002 to December 2003.

3. Availability of small biogas chp unit system

3.1. Steady state availability

The steady state availability is a measure in determining the long term performance of a system which is to be operated continuously. The small biogas CHP unit is an example of this system. The steady state availability of a system is defined as Ananda and Gamage (2004)

$$A = \frac{\tau_y}{\tau_y + \tau_x} \tag{3.1}$$

where τ_x is the mean time to repair the system and τ_y is the mean time between failures. The possible worktime of the system τ_0 is the sum of τ_x and τ_y. The mean time to repair the system τ_x is the sum of the time of planned disconnections τ_p and the time of incidental disconnections τ_{np}. The definition of the system availability can be formulated as a ratio of the real system worktime to the possible system worktime

$$A = \frac{\tau_0 - (\tau_p + \tau_{np})}{\tau_0}. \tag{3.2}$$

It is known that the disconnection time of many repairable systems is well characterized by a normal distribution

$$f\left(x,\mu,\sigma^2\right)=\frac{\exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]}{(2\pi)^{1/2}\sigma}, \qquad x>0, \tag{3.3}$$

or lognormal distribution (Ananda and Gamage, 2004; Kumar and Knezevic, 1998)

$$f\left(x,\mu,\sigma^2\right)=\frac{\exp\left[-\frac{1}{2}\left(\frac{\ln x-\mu}{\sigma}\right)^2\right]}{(2\pi)^{1/2}\sigma x}, \qquad x>0. \tag{3.4}$$

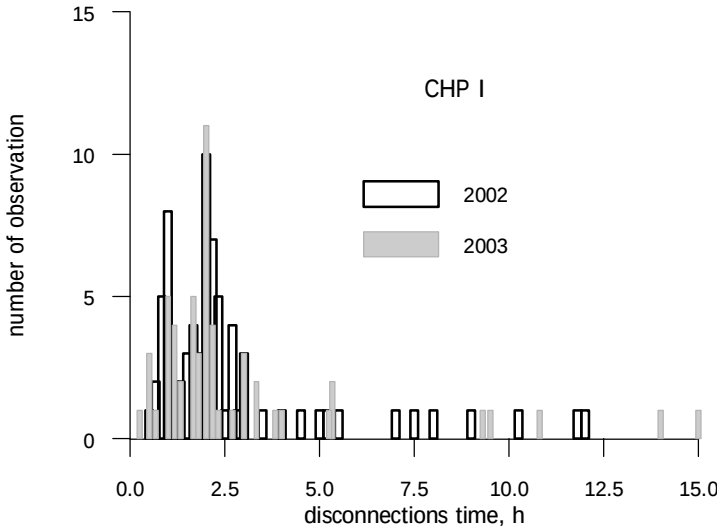
Ananda and Gamage (2004) in their paper present the example with simulated data. It deals with lognormal distribution of τ_x with the following population parameter configurations: $\alpha=5.0$, $\beta=0.1$, $\mu=1.0$, $\sigma=0.5$, where α and β are the parameters in the equations to the availability calculation

$$A=\left[1+\exp\left((\mu-\alpha)+\frac{\left(\sigma^2-\beta^2\right)}{2}\right)\right]^{-1}. \tag{3.5}$$

In this case, the actual availability of the system is *0.9798*.

3.2. Results of the investigation

The exploitation investigation of two small biogas CHP units made it possible to make a histograms of disconnection time duration observation. The histograms presented in Fig.4 reveal that the most durable observed disconnections time is 2 hours and was observed nearly 10 times in the case of CHP I, and 15 times in the case of CHP II.



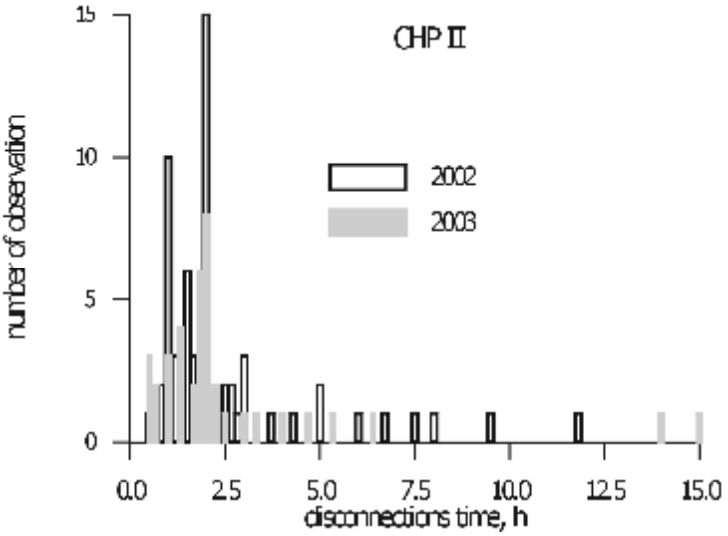


Fig.4. Histograms of disconnections time of biogas CHP units.

On the basis of the histograms the function of probability density of occurrence of specified disconnection time has been obtained as a lognormal function. The results are presented in Fig.5. The black points on the graph refer to the first system (CHP I) which has been working from the 1st of January 2002 to the 18th of December 2003. The white points refer to the second system (CHP II) which was started on the 11th of February 2002 and it was working to the end of December 2003. The solid line on the graph in Fig.5 represents lognormal distribution according to Eq.(3.4) with parameters: $\mu = 1.0$, $\sigma = 0.5$.

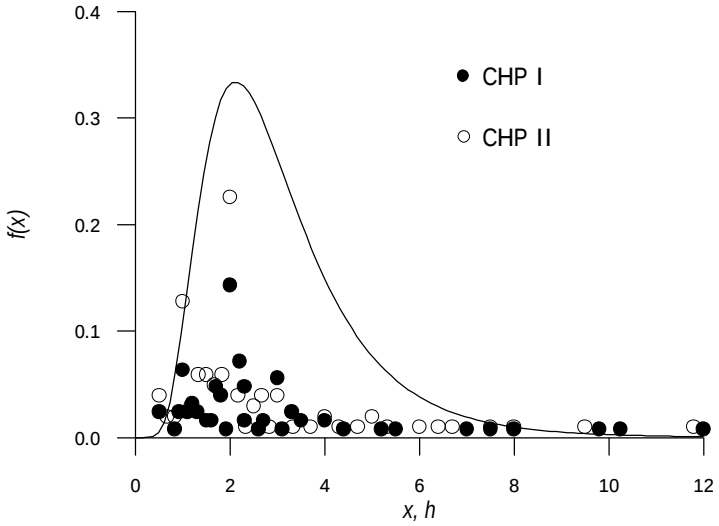


Fig.5. The time to repair the biogas CHP unit characterized by a lognormal distribution.

3.3. Calculations of availability

The availability of two small biogas CHP units working in the waste-water treatment plant in Rzeszów from January 2002 to December 2003 has been calculated according to Eq.(3.2) on the basis of the

exploitation investigation results. The calculated values of availability and the values of possible worktime, times of planned and incidental disconnections are shown in Tab.3.

Table 3. Availability of small biogas CHP unit system.

Biogas CHP unit system	Worktime	τ_0, h	τ_p, h	τ_{np}, h	A
CHP I	2002	*8760*	*154*	*160*	*0.964*
	2003	*8448*	*85*	*291*	*0.955*
	2002&2003	*17208*	*239*	*451*	*0.960*
CHP II	2002	*7783*	*143*	*160*	*0.961*
	2003	*8760*	*56*	*356*	*0.953*
	2002&2003	*16543*	*199*	*516*	*0.957*

4. Final remarks

The work presents the results of exploitation investigations of the small biogas cogeneration system working in the waste-water treatment plant. The availability of the CHP unit has been obtained on the basis of the investigations.

As a result of the exploitation investigations of the CHP units fed on biogas the following conclusions can be formulated:

- disconnection of the CHP unit caused by engine disconnection (planned and incidental) has the greatest influence on the CHP unit availability;
- the most often appearing disconnection time is similar for both the units and it is equal to about 2 hours;
- the probability density of occurrence of specified disconnection time has a lognormal function form;
- the availability of the investigated CHP units fed on biogas has a comparable value to the values of availability of conventional systems working under similar conditions.

Nomenclature

A – availability
CHP – combined heat and power
f – function of probability density
N – power, kW, MW
α, β – parameters in Eq.(3.5)
μ – location parameter
σ – scale parameter
τ – time, h
τ_0 – possible worktime, h
τ_p – time of planned disconnections, h
τ_{np} – time of incidental disconnections, h

Subscripts

x, y – variables representing the time to repair the system and the time between failures of the system

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