THERMODYNAMIC AND ENVIRONMENTAL ANALYSIS OF A FUEL CELL POWER SYSTEM USED IN A BUILDING IN AHVAZ

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ABSTRACT

Herein, a fuel cell power system that works in CHP mode has been considered to provide electrical, heating, cooling and domestic hot water loads of buildings. The buildings tolerate hot summers and mild winters during their operation life. In previous research, the PEM fuel cell system was designed and number of fuel cell stacks to provide the required energy of the building was estimated. As a complementary investigation, the thermodynamic and environmental analysis of the mentioned system has been conducted in this research. Results have shown that for a 12 fuel cell stacks at a nominal capacity of 8.5 kW, the mass production of monoxide carbon, monoxide nitrogen and dioxide carbon are equal to 1272.621 (kg/year), 1609.056 (kg/year) and 26107.23 (kg/year), respectively. The mass production values are acceptable since it is within limitation ranges mentioned by many environmental protocols.

Keywords: fuel cell power system, CHP mode, environmental analysis, mass production.

INTRODUCTION

With the huge growth of energy demands in the beginning of the 21st century, the environmental considerations have become the center of interest for many energy engineers. A large effort has been conducted on generating clean energy without substantial environmental pollution or hazardous mass products. These difficulties, far from finding effective solutions, are continuously increasing, which suggests the need of new technological alternatives to guarantee the reliability and robustness of the technology.

In this regard, one of these technological alternatives is named on-site generation or distributed generation. It is well-established that many developed countries provide most portion of their energy by large centralized power plants. Interestingly these plants negatively affect environment and pollutions (Rosen *et al.*, 2005). In this regard, cogeneration heat and power (CHP) systems are considered as an important issue in the field of non-Renewable sources.

Among several well-known cogeneration systems which are commonly employed in resilience buildings, the fuel cell systems are of the most important ones due to their benefits such as cost effectiveness (Rosen *et al.*, 2005; Silveira *et al.*, 1997). The use of fuel cells, micro gas turbines and internal combustion engines for OS-CHP, or on-site combined heat and power production in residential building, has been studied by several researchers ((Ehyaei and Bahadori, 2006; Ehyaei and Mozafari, 2010; Saidi *et al*., 2005a; 2005b; Renedo *et al.*, 2006; Khan *et al*., 2004; Dentice *et al*., 2003; Miguez *et al*., 2004a; 2004b; Gigliucci *et al.*, 2004; Kong *et al.*, 2004; Maribu *et al*., 2007; Maidment and Tozer, 2002; Ziher and Poredos, 2006; Cardona *et al*., 2000)

In the previous research, authors has considered the design and operating conditions of a CHP fuel cell system emphasis on entropy production (Pourmahmoud *et al*., 2014). The schematic diagram of the proposed system is illustrated in Figure-1. As seen in this schematic figure, the configuration of the designed system includes the fuel cell stacks, the burner, the steam reformer, the heat exchanger, the battery. In this system, the water heater was suggested to produce the electrical power of the building as well as some parts of the power required by the heat pump. The mechanical refrigerator needed for heating, cooling and DHW systems. The remaining part of the power for heat pump and mechanical refrigerator is provided by the exhaust gases. It should be mentioned that the consuming fuel of the burner and the reformer is natural gas.

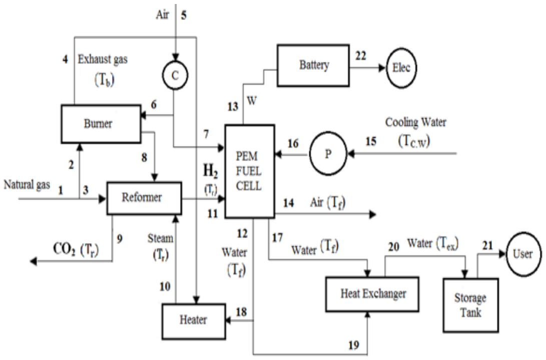

Figure-1. Configuration of CHP fuel cell system.

The present research is aimed to shed light on the other aspects of the proposed CHP fuel cell (Pourmahmoud *et al*., 2014). As a complementary investigation, in this paper the environmental analysis of the mentioned system has been conducted.

System characteristics

The operation of the CHP fuel cell system which is presented in Figure-1 can be described as the following:

first, the natural gas is fed through line (1) to the burner and the reformer sections. In the burner, natural gas is reacted with the air and burns. This generated heat is used to provide energy needs for the reformer section. In the reformer unite; the natural gas is reacted with the produced steam in the heater. In this stage, the produced hydrogen gas (H_2) by reformer, is fed to PEM fuel cell (line 11). This hydrogen is reacted with air (line 7), to produce electrical power and hot water. Remaining part of air is discharged to atmosphere. For cooling of fuel cell, water is pumped to fuel cell (line 16), which is warmed up and fed to heat exchanger. In heat exchanger, this water is mixed with a part of hot water which produced in PEM (line 19) and is fed to storage tank through. Remaining part of produced water by PEM fuel cell, change to steam in heater, and is used in reformer.

In previous research, the fuel cell stack with a nominal power of 8.4 kW is considered here, employing natural gas as fuel. Based on previous findings (Pourmahmoud *et al.*, 2014), we understand that the maximum electrical power requirement is 32.96 kW, occurring between the hours of 7 and 8 p.m. in July. It is found that the maximum heating load is 1590 kW, occurring at 5 a.m. in January (Pourmahmoud *et al.*, 2014). However, the maximum cooling load is 2028 kW, occurring at 3 p.m. in July (Pourmahmoud *et al.*, 2014). Furthermore, the maximum domestic hot water energy requirement is 0.926 kW, occurring between 5 a.m. and 11 p.m. in January (Pourmahmoud *et al*., 2014).

A method to meet the energy needs of the residential building under consideration is to employ a number of fuel cell stacks to produce electricity to meet the electrical energy needs of the building, and to provide some part of the heating and cooling energy needs through a heat pump (Pourmahmoud *et al*., 2014). Results show that all the energy needs of the building can be met with 12 fuel cell stacks at a nominal capacity of 8.4 kW (Pourmahmoud *et al*., 2014).

RESULTS AND DISCUSSIONS

The variation of carbon monoxide and nitrogen monoxide mass production of the proposed CHP fuel cell system with respect to the variation of the ambient air temperature is illustrated in Figure-2.

From this figure, it can be observed that when the ambient temperature increases from 1^oC to 40^oC, the carbon monoxide mass production by each fuel cell stack increases from 0.0277(kg/sec) to 0.0316(kg/sec). In addition mass production of monoxide nitrogen increases from 0.0518(kg/sec) to 0.0557(kg/sec). Monoxide carbon and monoxide nitrogen mass production due to number of fuel cell stacks to meet the energy loads during the hours is shown in Tables 5-6 and 7-8, respectively. Maximum monoxide carbon and maximum monoxide nitrogen mass production occurs at 15 hour in 15 July and is equal to 0.378 (kg/sec) and 0.6672 (kg/sec), respectively.

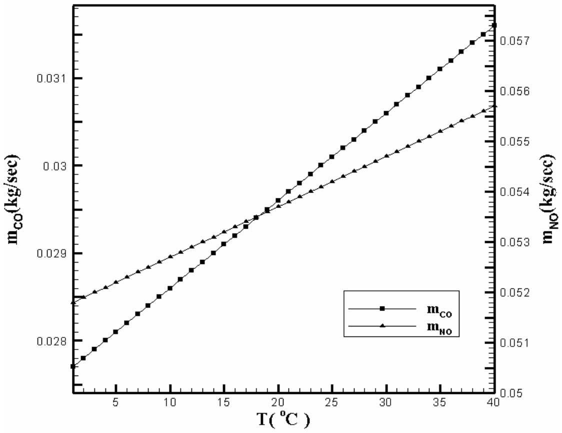

Figure-2. variation of mass production with respect air temperature in one unit of CHP fuel cell stack.

Table-1. Carbon monoxide mass production from fuel cell stacks which operate in the residential building in kg/sec (January-June).

Hour	Jan	Feb	Mar	Apr	May	Jun
2	0.196	0.168	0.1132	0.0584	0.0294	0.0596
4	0.196	0.196	0.1132	0.0582	0.0293	0.0594
6	0.196	0.196	0.1132	0.0582	0.0293	0.0594
8	0.1686	0.168	0.0849	0.0292	0.0295	0.0598
10	0.1128	0.1128	0.0286	0.0297	0.0891	0.1208
12	0.0852	0.0566	0.0287	0.0604	0.151	0.1836
14	0.0286	0.0285	0.0582	0.0912	0.2128	0.2772
15	0.0286	0.0286	0.0582	0.122	0.2121	0.31
16	0.0286	0.0285	0.0582	0.0912	0.1812	0.2772
18	0.0852	0.0568	0.0288	0.0912	0.15	0.1842
20	0.1132	0.1132	0.0287	0.0596	0.0894	0.152
22	0.1686	0.1405	0.0568	0.0295	0.0592	0.09
24	0.168	0.168	0.0849	0.0292	0.0294	0.0596

Table-2. Carbon monoxide mass production from fuel cell stacks which operate in the residential building in kg/sec (July-December).

Hour	July	Aug	Sep	Oct	Nov	Dec
2	0.0602	0.0598	0.0594	0.0287	0.0849	0.168
4	0.06	0.0596	0.0295	0.0287	0.1132	0.168
6	0.06	0.0594	0.0295	0.0287	0.1132	0.1674
8	0.0909	0.09	0.0594	0.0287	0.0852	0.1405
10	0.153	0.1515	0.09	0.0582	0.0286	0.1128
12	0.2799	0.2763	0.1824	0.0885	0.0287	0.0283
14	0.3454	0.3421	0.2456	0.12	0.0584	0.0287
15	0.378	0.3732	0.2456	0.09	0.0584	0.0287
16	0.3454	0.3421	0.2448	0.12	0.0584	0.0286
18	0.2808	0.2772	0.183	0.0885	0.058	0.0568
20	0.1848	0.183	0.1204	0.0586	0.0287	0.0846
22	0.1216	0.1204	0.0894	0.0576	0.057	0.112
24	0.0906	0.06	0.0594	0.0287	0.0568	0.1395

Figure-3 shows that unlike monoxide nitrogen and monoxide carbon, mass production of dioxide carbon decreases when the inlet air temperature increases from 1^{o}C to 40^{o}C, it decreases from 0.802 (kg/sec) to 0.79843 (kg/sec). As we know, increasing ambient air temperature led to reduction heat rate burner and increasing mass flow rate of fuel. So mass production of dioxide carbon by burner increases. In the other hand, with increasing ambient air temperature, outlet pressure of compressor and power of compressor increase. So, net power of the system and outlet dioxide carbon of the reformer decrease. Increasing of mass production of dioxide carbon by burner is less than decreasing mass production of dioxide carbon by reformer. Therefore, total mass production of dioxide carbon by system decreases with increasing ambient air temperature. This variation is shown in Figure-3.

Furthermore, it should be noted that dioxide carbon mass production from fuel cell stacks which operate in the residential building is shown in Tables 1-5.

Table-3. Monoxide nitrogen mass production from fuel cell stacks which operate in the residential building in kg/sec (January-June).

Hour	Jan	Feb	Mar	Apr	May	Jun
2	0.3654	0.3132	0.2096	0.1066	0.0535	0.1076
4	0.3654	0.3605	0.2096	0.1064	0.0534	0.1074
6	0.3654	0.3647	0.2096	0.1064	0.0534	0.1074
8	0.2096	0.21	0.0527	0.0537	0.1611	0.2172
10	0.3132	0.3132	0.1572	0.0534	0.0536	0.108
12	0.1578	0.1052	0.0529	0.1086	0.2715	0.3282
14	0.1575	0.105	0.0529	0.1635	0.271	0.3282
15	0.0527	0.0527	0.1064	0.1635	0.3815	0.4923
16	0.0527	0.0527	0.1064	0.2184	0.3808	0.548
18	0.0527	0.0527	0.1064	0.1635	0.3258	0.4932
20	0.2096	0.2096	0.0528	0.108	0.1614	0.2725
22	0.3132	0.3132	0.1575	0.0533	0.0536	0.108
24	0.3132	0.261	0.105	0.0536	0.1072	0.1626

Table-4. Monoxide nitrogen mass production from fuel cell stacks which operate in the residential building in kg/sec (July-December).

Hour	July	Aug	Sep	Oct	Nov	Dec
2	0.1086	0.108	0.1074	0.0528	0.1575	0.3132
4	0.1084	0.1076	0.0536	0.0528	0.21	0.3132
6	0.1084	0.1074	0.0536	0.0528	0.21	0.3132
8	0.1632	0.1626	0.1074	0.0529	0.1575	0.2615
10	0.2735	0.273	0.1626	0.1064	0.0528	0.2096
12	0.4968	0.4941	0.3264	0.1605	0.0529	0.0525
14	0.6116	0.6028	0.4352	0.2164	0.1066	0.0528
15	0.6672	0.6576	0.436	0.1626	0.1066	0.0528
16	0.6105	0.6028	0.436	0.2168	0.1066	0.0528
18	0.4959	0.4941	0.3276	0.1608	0.1062	0.1052
20	0.3288	0.3276	0.2172	0.1068	0.0527	0.1572
22	0.1629	0.1084	0.1074	0.0529	0.105	0.261
24	0.218	0.2172	0.162	0.1058	0.1052	0.2092

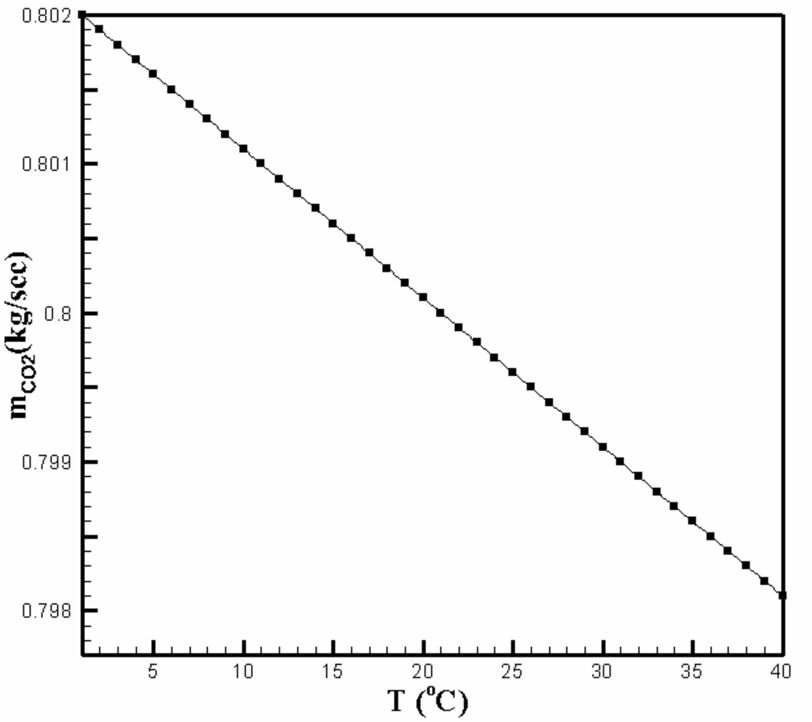

Figure-3. Variation of mass production of dioxide carbon with respect air temperature in one unit of CHP fuel cell stack.

Table-5. Dioxide carbon mass production from fuel cell stacks which operate in the residential building in kg/sec (January-June).

Hour	Jan	Feb	Mar	Apr	May	Jun
2	5.6119	4.8102	3.2056	1.601	0.8003	1.5998
4	5.6119	5.6119	3.2056	1.6012	0.8004	1.6
6	5.6119	5.6119	3.2056	1.6012	0.8004	1.6
8	4.8096	4.8102	2.4042	0.8005	0.8002	1.5996
10	3.206	3.206	0.8011	0.8	2.4	3.198
12	2.4039	1.6028	0.801	1.599	3.9975	4.7946
14	0.8011	0.8012	1.6012	2.3979	5.5951	7.1892
15	0.8011	0.8011	1.6012	3.1968	5.5958	7.987
16	0.8011	0.8012	1.6012	2.3979	4.797	7.1892
18	2.4039	1.6026	0.8008	2.3979	3.9985	4.794
20	3.2056	3.2056	0.801	1.5998	2.3997	3.9965
22	4.8096	4.008	1.6026	0.8002	1.6002	2.3991
24	4.8096	4.8102	2.4042	0.8005	0.8003	1.5998

Table-6. Dioxide carbon mass production from fuel cell stacks which operate in the residential building in kg/sec (July-December).

Hour	July	Aug	Sep	Oct	Nov	Dec
2	1.5992	1.5996	1.6	0.801	2.4042	4.8102
4	1.5994	1.5998	0.8002	0.801	3.2056	4.8102
6	1.5994	1.6	0.8002	0.801	3.2056	4.8102
8	2.3982	2.3991	1.6	0.8009	2.4039	4.008
10	3.9955	3.997	2.3991	1.6012	0.8011	3.206
12	7.1874	7.1901	4.7958	2.4009	0.801	0.8014
14	8.7813	8.7846	6.392	3.1988	1.601	0.8009
15	9.5784	9.5832	6.3912	2.3991	1.601	0.8009
16	8.7813	8.7846	6.3928	3.1988	1.601	0.8011
18	7.1865	7.1892	4.7952	2.4006	1.6014	1.6026
20	4.7934	4.7952	3.1984	1.6008	0.801	2.4045
22	3.1972	3.1984	2.3997	1.6018	1.6024	3.2068
24	2.3985	1.5994	1.6	0.801	1.6026	4.009

CONCLUSIONS

Herein, the environmental consideration of a polymer electrolyte membrane (PEM) fuel cell power system, which is proposed for domestic application, has been investigated. The system was proposed to meet the energy requirements of the building in Ahvaz. Environmental analysis of this CHP system shows that by increasing of ambient air temperature from 1^{o}C to 40^{o}C, production of nitrogen monoxide and carbon monoxide increases by 7.5% and 14.06%, respectively and production of carbon dioxide decreases by 0.48%. It has been found that mass production of monoxide carbon, nitrogen monoxide and carbon dioxide are equal to 1272.621 (kg/year), 1609.056 (kg/year) and 26107.23 (kg/year), respectively. This data is useful for design reliable systems that pass the environmental protocol limitations.

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