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SIMULATED PERFORMANCE ANALYSIS OF A GT-MCFC HYBRID SYSTEM FED WITH NATURAL GAS

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ABSTRACT

Fuel cells are electrochemical devices that convert chemical energy contained in fuels directly into electrical energy, providing power generation with high efficiency and low environmental impact. From the point of view of power generation, high temperature fuel cells are more preferable compared to low temperature fuel cells because of their greater fuel flexibility towards available fuels. A hybrid system based on high temperature fuel cells coupled to a gas turbine cycle allows high efficiency and low environmental pollution. Such hybrid system can also be employed as a combined heat and power (CHP) system producing both heat and electricity. The overall efficiency of such a CHP system could reach very high value (more than 85%) including the contribution due to heat recovery. In this paper, simulated performance analysis of a hybrid CHP system containing gas-turbine (GT) block and an externally reformed molten carbonate fuel cell (MCFC) (at downstream of gas turbine), fed with natural gas, is presented. The simulation of this system is carried out using Cycle-tempo. The proposed system is capable of reaching net electrical efficiency of 46% while the total thermal efficiency (including electricity and heat both) of this system is more than 85%.

Keywords: Molten Carbonate Fuel Cell, Hybrid System, Combined Heat and Power.

1. INTRODUCTION

Demand for energy is rising continuously, largely driven by the increasing energy needs of developing countries. International Energy Agency (IEA) suggests that global demand for energy will grow at a rate of 1.5% a year to 2030. During this period, China and India alone will be responsible for over 50% of total increase [1]. To meet this growing energy demand, the available oil reserves as well as other sources of traditional energy will not be sufficient; as they are diminishing continuously. Moreover fossil fuels emit both greenhouse gasses and other pollutants.

Therefore enormous attention has been given to reduce greenhouse gasses and other pollutants into the atmosphere by developing some suitable technologies for the efficient conversion of traditional as well as renewable sources. Fuel cells are high efficiency energy conversion devices as they are not "Carnot limited". In fuel cells, energy is obtained from direct electrochemical reaction of fuel oxidation with very small amount of exergy losses with respect to conventional combustion systems. Moreover, fuel cells have several potential benefits including flexibility in sizing, quiet operation and near zero emissions. From the point of view of power generation, high temperature fuel cells are more preferable compared to low temperature fuel cells because of their greater fuel flexibility towards available fuels.

Besides hydrogen, carbon monoxide and methane can be used in case of high temperature fuel cells. High temperature fuel cells can also use syngas, which is produced from gasification of coal or biomass, as a fuel if it is sufficiently clean. One type of high temperature fuel cells is molten carbonate fuel cell (MCFC) with an operating temperature between 600°C and 700°C [2]. The other type is the solid oxide fuel cell (SOFC) with an operating temperature between 600°C and 1000°C [2].

A hybrid System based on high temperature fuel cells coupled to a gas turbine cycle allows high efficiency and low environmental pollution. Such hybrid system can also be employed as a combined heat and power (CHP) system producing heat and electricity both. The overall efficiency of such a CHP system could reach very high value. Many studies have been conducted on integration of MCFC with gas turbine systems for power generation [3-7]. As MCFC requires CO_2 at the cathode during operation, researchers have proposed MCFC section at the downstream of GT section, in a lot of studies, to utilize the CO_2 present at the GT exhaust. S. Ghosh et al. [3] have analyzed a GT-MCFC hybrid plant producing power as well as utility heat where MCFC has been placed at the downstream of GT. In their scheme, they have used a CO_2 separator in order to separate the CO_2 from anode exhaust stream. CO_2 separated has been sent back to the cathode of MCFC for better operation.

For this plant, they have achieved electrical efficiency exceeding 40% with CO_2 emission reduction by 30%. P. Lunghi et al. [4] has carried out a parametric performance evaluation of a hybrid molten carbonate fuel cell (MCFC) with indirect heated gas turbine by varying the fuel utilization coefficient. In their analysis maximum electrical efficiency, up to 58% has been found for fuel utilization more than 0.7. Also they have observed less irreversible losses with less fuel utilization. In an another study, optimization of a biogas fuelled GT-MCFC hybrid system with hydrogen production has been performed by Verda and Nicolin [5]. From their results they have observed that efficiency and cost of this plant are largely affected by variations of MCFC temperature and reformer temperature. They have found minimum cost of electricity at 0.036/kwh for electrical efficiency of about 0.46; while for maximum electrical efficiency of about 0.62, the cost of electricity is 0.055/kwh. D. Sanchez et al. [6] carried out a comparative analysis between MCFC based hybrid systems using air and supercritical carbon dioxide (SCO_2) brayton cycles. From the results, they had observed that MCFC–SCO_2 achieve 60% efficiency, an almost 10% increase in efficiency with respect to conventional systems using hot air turbines. The energetic and exergetic performances of a biogas-based integrated MCFC-GT system have been investigated by R. S. E. Emam and I. Dincer [7]. From their investigation they had achieved overall energy and exergy efficiencies of 42.89% and 37.75% respectively.

In this paper, a simulated performance analysis of a GT-MCFC hybrid system, which produces power as well as utility heat, is presented. MCFC, operating at atmospheric pressure, is placed at the downstream of the GT section to utilize the CO_2 present at the GT exhaust. Natural gas is fed as a fuel to the GT-section as well as to the external reformer of MCFC. The simulation of this hybrid system is carried out using Cycle-tempo [8].

2. PLANT LAYOUT

Fig. 1 shows the schematic of the proposed system. The GT section consists of a compressor, a combustor and a turbine (represented by units 2, 3 and 4 respectively). The MCFC (unit 7) operates at atmospheric pressure. An external reformer (unit 11) is used at the upstream of MCFC to convert CH_4 into H_2. The reformer operates at pressure 4.3 bar. Natural gas is heated in a heat exchanger (unit 10) using the hot anode exhaust stream of MCFC, before being fed to the reformer. Steam required for the reforming reaction is produced, using the hot streams leaving the reformer and cathode of MCFC, in heat exchangers 12 and 13 respectively. A combustor (unit 16) is used, at the downstream of MCFC, where the remaining fuel in the anode exhaust stream is combusted. The resulting flue gas is then fed to the reformer which supplies the heat required for the endothermic reactions occurred inside the reformer.

During operation CO_2 is concentrated at the anode of MCFC. The anode exhaust stream is therefore rich in CO_2 but also it has a large amount of steam. A moisture separator (unit 18) is used at the downstream of MCFC to further enrich the anode exhaust stream in CO_2 by condensing some steam in it. The moisture separator supplies the heat, extracted from the anode exhaust stream, to a stream of recirculated cold water. The recirculated water leaving the moisture separator is again heated in a heat exchanger (unit 19) using the hot cathode exhaust stream. This recirculated hot water is then used for cogeneration. The CO_2 enriched anode exhaust stream leaving the moisture separator is heated in a heat exchanger (unit 9) using the hot cathode exhaust stream, before being recycled back to the cathode.

3. PLANT DEVELOPMENT AND SIMULATIONS

The development and numerical simulation of this proposed hybrid system is carried out using flow-sheeting program Cycle-Tempo. All the apparatus of this hybrid system (i.e. gas turbine, compressor, MCFC unit, heat exchanger etc.) are provided by the software. Some general assumptions have been made regarding all the apparatus:

(a) The apparatus are operated in steady state
(b) The heat exchangers are operating in counter current flow
(c) The processes are adiabatic.

3.1 Molten Carbonate Fuel Cell

The MCFC unit used in this hybrid system is reformed externally. The reformer, placed at the upstream of the fuel cell system, is used to convert methane and higher hydrocarbons into hydrogen rich stream. Steam is used in the reformer and the heat required for the reforming reaction is extracted from the anode exhaust stream which is combusted before its entry to the reformer. It is assumed that the reforming reactions occur at the constant temperature. The MCFC model is used to calculate the performance of the fuel cell as function of parameters that are controlled by fuel cell operators. These control parameters are the total fuel utilization, which is the degree of conversion of fuel that is fed into the cell, and the current density. General characteristics of this available MCFC model are [8]:

(a)This model can be used for modeling stacks of both tubular and flat plate cells.
(b)This model is isothermal, i.e. the calculated chemical balances on the active cell area and the current density are based on the average cell temperature.
(c)The MCFC stack consists of a number of cells connected in series, with identical performance.

The processes occurring inside the fuel cell are modeled as shown below [8]:

The mass balance over the apparatus is:

$$\emptyset_{m,a,in} + \emptyset_{m,c,in} - \emptyset_{m,a,out} - \emptyset_{m,c,out} = 0 \qquad (1)$$

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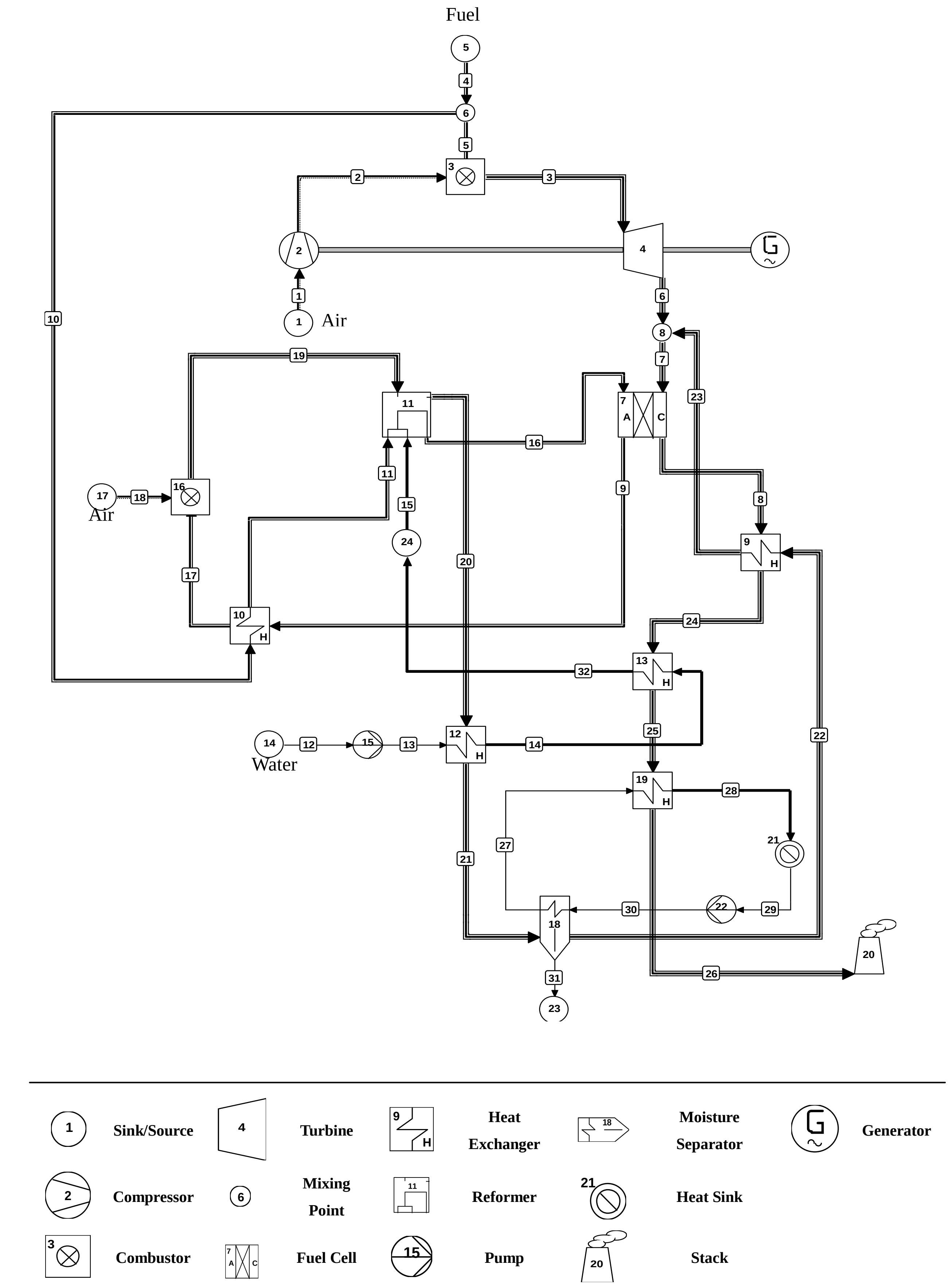

Fig. 1: Flow sheet of GT-MCFC hybrid plant

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The equation that describes the mass exchange between cathode and anode is:

$$\phi_{m,a,in} - \phi_{m,a,out} = -\phi_{m,c\rightarrow a} \quad (2)$$

It is assumed that all the processes occur at constant temperature and pressure (P_{cell} and T_{cell}) which are the average cell pressure and temperature. For complete conversion of all the fuel components in the fuel cell, the current through the fuel cell is given as:

$$I_F = \frac{\emptyset_{m,a,in}}{M_{mol,a}} \times \left(y^0_{H_2} + y^0_{CO} + y^0_{CH_4}\right) \times 2F \quad (3)$$

Where '$\boldsymbol{y_i^0}$' are the concentrations at the inlet and 'M_{mol}' is the molecular mass of the anode gas. In reality, only part of the fuel in the fuel cell is converted. If the ratio between the real and the maximum conversion is specified by the utilization level '$\boldsymbol{U_F}$' then the real current through the cell is given as:

$$\mathrm{I} = I_F \times U_F \quad (4)$$

Total mass flow O_2 from cathode to anode is given by:

$$\emptyset_{m,O_2,c\rightarrow a} = M_{mol,O_2} \times \frac{I}{4F} \quad (5)$$

CO_2 transported from the cathode to the anode is given by:

$$\emptyset_{m,CO_2,c\rightarrow a} = M_{mol,CO_2} \times \frac{I}{2F} \quad (6)$$

From the mole balances for the components at the cathode, the composition at the cathode outlet are now calculated. Similarly, the quantities of H_2 and CO that are converted on the cell area are calculated from the current 'I'.

Here one-dimensional model is considered, i.e., the temperatures, pressures and compositions are supposed to be constant in a cross-section, perpendicular to the direction of the fuel cell flow. For the processes that occur without losses within the fuel cell, the cell voltage is identical to the reversible voltage or Nernst voltage 'E_x' and is given as:

$$E_x = E^0_T + \frac{RT_{cell}}{2F} ln\left\{\frac{y^{1/2}_{O_2,c} y_{H_2,a} y_{CO_2,c}}{y_{H_2O,a} y_{CO_2,a}} \times P^{1/2}_{cell}\right\} \quad (7)$$

Where 'E^0_T' is the standard reversible voltage for hydrogen, which only depends on the temperature, and is calculated from the change in the Gibbs energy 'ΔG' as:

$$E^0_T = +\frac{\Delta G^0_T}{2F} \quad (8)$$

In reality, the processes in the cell occur irreversibly, and hence the cell voltage 'V_x' is smaller than the reversible voltage. The difference between reversible and real voltage is indicated here with the voltage loss ΔV_x as:

$$V_x = E_x - \Delta V_x \quad (9)$$

In the model, it is assumed that the voltage losses on the level of the electrodes are negligible in the x-direction. This means that the cell voltage is supposed to be constant over the fuel cell. Hence the overall voltage is:

$$V = E_x - \Delta V_x \quad (10)$$

The voltage loss can be regarded as the driving force for the reactions in the fuel cell, and thus for the current density. Hence it can be assumed that the current density is proportional to the voltage loss. By analogy with Ohm's law, the proportionality constant is indicated with the equivalent cell resistance 'R_{eq}'. For cross section x, current density is:

$$i_x = \Delta V_x / R_{eq} \quad (11)$$

Finally, the velocity with which H_2 is converted in a cross-section x, can be calculated from the current density as:

$$\frac{dn_{H_2}}{dx} = \frac{i_x}{2F} \quad (12)$$

The changes in the concentrations of the components are calculated using this above equation, the mole balances for the components and the reaction balances for shift reactions. On the basis of the given equations, the voltage and current density are calculated in a cross-section with the help of numerical methods. The electrical output power of the fuel cell stack is given as:

$$P_e = V \times I \times \eta_{DCAC} \quad (13)$$

3.2 Combustor

In the combustor a chemical reaction takes place between the fuel and oxidant. Under ideal conditions, the flue gas composition, which results from the reaction, is same as the equilibrium composition of the reactants and reaction conditions. But, under actual conditions the reactions will not run to equilibrium. In the combustor model, the equilibrium composition is taken into account. It is however made possible to allow the flue gas composition to differ from the equilibrium composition by not letting part of the reactants take part in the reaction [8].

3.3 Turbo-machines

To model the turbines, data from General Electric and Stork Energy, Hengelo, the Netherlands are used [8]. Basically these data are used to calculate the isentropic efficiency. However there is provision to supply the isentropic efficiency by the user itself. To calculate the specific enthalpies at the extractions, straight expansion lines in the Mollier diagram are considered between inlet and outlet conditions. To model the compressors, similar method is used.

3.4 Heat Exchangers

Heat exchangers are modeled using the effectiveness-number of transfer units (ε-NTU) method [8]. Heat exchangers are modeled for both parallel as well as counter flow.

However, counter flow heat exchangers are used in this study. To model the compressors, similar method is used.

3.5 Moisture Separator

In the moisture separator, the incoming gas is cooled by a cooling medium flowing in the opposite direction, as a result of which water vapour condenses. The condensate formed is collected and discharged via a separate pipe. In the model it is assumed that the pressures of the moisture separated and the outgoing gas are equal and that the temperature of the moisture separated is 1°C lower than that of the outgoing gas. The gas leaves the separator saturated. Mass balance and energy balance equations are used to calculate the mass flow of moisture separated using the outlet pressure and temperature of the gas. However, there is provision to supply the mass flow of moisture separated, by the user itself.

4. ENERGY EFFICIENCY OF THE SYSTEM

The net electrical efficiency and the total thermal efficiency of the hybrid CHP system are calculated by using the following equations:

Net electrical efficiency, $\eta_{el}=\frac{P_{el,out}-P_{el,in}}{\Phi_{m,fuel}\times LHV_{fuel}}$ (14)

Total thermal efficiency, $\eta_{th,tot}=\frac{P_{el,out}+Q-P_{el,in}}{\Phi_{m,fuel}\times LHV_{fuel}}$ (15)

Where '$P_{el,out}$' is the total electrical power output of the system which is the sum of electrical power obtained from the GT section and MCFC section while '$P_{el,in}$' is the electrical power input to run the auxiliary components of the system. 'Q' is the useable heat produced by the system, '$\Phi_{m,fuel}$' is the combined mass flow of the fuel to the GT-unit as well as MCFC-unit and 'LHV_{fuel}' is lower heating value of the fuel.

Table 1: Composition of the natural gas

Component	Mole %
Methane (CH_4)	81.29
Nitrogen (N_2)	14.32
Carbon dioxide (CO_2)	0.89
Oxygen (O_2)	0.01
Higher Hydrocarbons	3.49
LHV (KJ/Kg)	37998.9
HHV (KJ/Kg)	42107.3

5. INITIAL ASSUMPTIONS FOR SIMULATION

The simulation of this hybrid system is carried out by keeping the power output of the MCFC fixed at 1.206 MW. Other components of the system perform accordingly to deliver the MCFC's power output. The composition of the natural gas used in this hybrid plant is shown in Table 1. In Table 2, input parameters to the GT section are shown while input parameters to the MCFC section are shown in Table 3.

Table 2: Input Parameters to the GT-section

Parameter	Value
Air to fuel ratio combustor (Kg/Kg)	15
Isentropic efficiency compressor (%)	86
Mechanical efficiency compressor (%)	89
Pressure ratio	8
Isentropic efficiency turbine (%)	86
Mechanical efficiency turbine (%)	99
Generator efficiency (%)	96

Table 3: Input Parameters to the externally reformed MCFC section

Parameter	Value
Reaction pressure reformer (bar)	4.3
Reaction temperature reformer (°C)	700
Reaction pressure MCFC (bar)	1.013
Reaction temperature MCFC (°C)	700
Cell area (m^2)	700
Cell resistance (Ω m^2)	7e-5
DC/AC conversion efficiency (%)	96

6. SIMULATION RESULTS

Simulation of this hybrid system allows evaluating the mass flow-rate, power output, system efficiencies and energy values across the different components of the system. For the system, it is observed that net electrical efficiency of 46% is achieved when turbine inlet temperature for the GT-unit is kept at 1200°C with steam/fuel ratio of 2.59 for the reformer and fuel utilization of 77% for the MCFC. This is the base case performance for the system. To achieve this performance, air of mass flow 3.08 kg/sec is fed to the compressor while natural gas of mass flow 0.095 kg/sec is fed as a fuel to the combustion chamber of the GT-unit. To the external reformer of the MCFC, steam of mass flow 0.087 kg/sec and natural gas of mass flow 0.033 kg/sec are fed at temperature 480°C and at pressure 4.3 bar. The reformer delivers the fuel at 700°C to the anode of MCFC. To the cathode of MCFC, GT exhaust is fed along with the recycled anode exhaust stream after some enrichment of CO_2 in the moisture separator. Both the anode and cathode off-gasses leave the MCFC at 700°C.

The electrical power output from the GT-unit is 1.054 MW while the MCFC delivers 1.206 MW of electricity. Reforming reactions occurring in the reformer are endothermic. Therefore heat is required in the reformer. The reformer extract this heat from the anode exhaust stream which is combusted in a combustor (placed at the downstream of MCFC) to burn the remaining fuel.

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Now, using the anode as well as cathode exhaust streams, hot water is produced. This hot water is then used for cogeneration and utility heat around 2.07 MW can be produced. The base case performance for the hybrid system is shown in Table 4.

Table 4: Base case performance for the hybrid system

Parameter	**Value**
Fuel flow rate to the GT (kg/sec)	0.095
Fuel flow rate to the MCFC (kg/sec)	0.033
Turbine inlet temperature (K)	1473
Steam/fuel ratio for reformer	2.59
Fuel utilization for MCFC (%)	77
Power output generator (KW)	1053.97
Power output fuel cell (KW)	1206.02
Gross electric power (KW)	2259.99
Auxiliary power consumption (KW)	0.05
Net electrical power output (KW)	2259.94
Process heat (KW)	2070.93
Net electrical efficiency (%)	46.38
Total thermal efficiency (%)	88.8

In Fig. 2, it is represented how the total electrical efficiency of this hybrid system varies with turbine inlet temperature (TIT) for three different fuel utilizations 73%, 75% and 77% respectively. It is observed that with increase in TIT, efficiency of the system increases for all the three fuel utilizations. Also the system efficiency is found increasing with increasing fuel utilizations. With increase in TIT, the fuel flow rate as well as the power output of the GT section increases. But the rate of increase of GT power output is higher than the rate of increase of fuel flow rate. This is because the system efficiency increases with increase in TIT. With increase in fuel utilization, the fuel requirement decreases to supply the same amount of power in the MCFC section. This results in higher electrical efficiency with increase in fuel utilization. In Fig. 3, variation of total electric efficiency of the plant with increasing fuel utilization is plotted for turbine inlet temperature of 1200°C. For this system maximum electrical efficiency of 46% is achieved for 77% fuel utilization at turbine inlet temperature of 1200°C.

Fig. 4 shows the variation of electric efficiency of the system with changes in steam/fuel ratio (SFRATI) for two different fuel utilizations 75% and 77% respectively. Maximum efficiency of 46% is achieved for SFRATI of 2.59 at 77% fuel utilization.

On increasing SFRATI, the amount of fuel fed to the system as well as the power output of the system increases. However, the rate of increase of fuel flow is higher than the rate of increase of power output of the system. That is why, electric efficiency of the system decreases with increase in SFRATI.

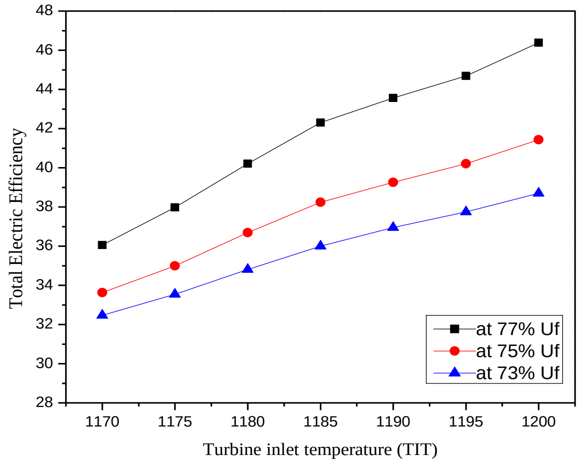

Fig. 2: Variation of total electric efficiency of the hybrid system with turbine inlet temperature for fuel utilizations 73%, 75% and 77% respectively

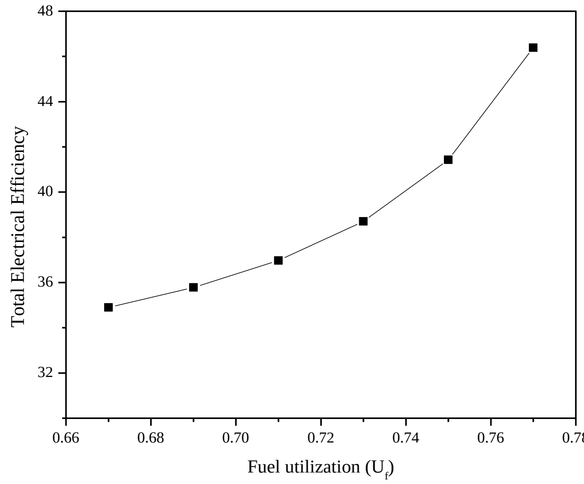

Fig. 3: Variation of total electric efficiency of the hybrid system with fuel utilization for turbine inlet temperature of 1200°C

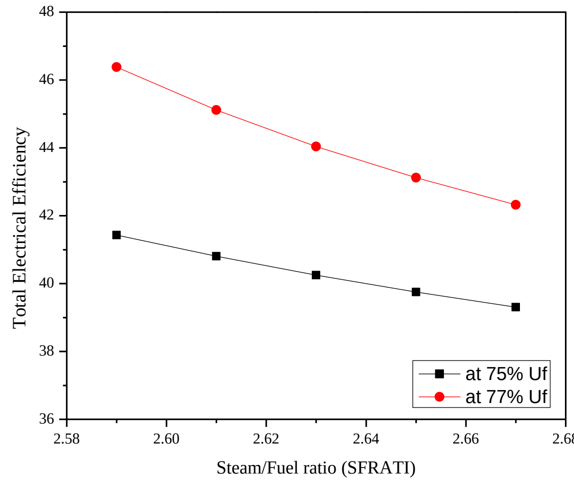

Fig. 4: Variation of total electric efficiency of the hybrid system with SFRATI for fuel utilizations 75% and 77% respectively

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7. CONCLUSIONS

Fuel cells are high efficiency energy conversion devices. From the point of view of power generation, high temperature fuel cells (MCFC and SOFC) are more preferable. Because they have greater fuel flexibility and also they allow recycle of the exhaust heat in a bottoming cycle, in order to realize a hybrid plant. Moreover, a hybrid System based on high Temperature fuel cells coupled to a gas turbine cycle allows low environmental pollution and they can be employed as a CHP system producing heat and electricity both.

In the present work, simulated performance analysis of a GT-MCFC hybrid system has been carried out. Optimum performance of the plant with electrical efficiency of 46% has been achieved at turbine inlet temperature of 1200°C with steam/fuel ratio of 2.59 and 77% fuel utilization. Utility heat around 2.07 MW can be obtained from this plant when operated at the optimum situation. The total thermal efficiency (electrical power and utility heat) of the plant is 88.8%.

REFERENCES

1. Survey Report-2010, "Survey of energy resources", World Energy Council, Regency House, Warwick Street, London, United Kingdom.
2. EG&G Technical Services, Inc, 2004, "Fuel Cell Handbook (7th Edition)", US Department of Energy, West Virginia, USA.
3. Ghosh S., De S., Saha S., 2006, "Improved performance and reduced emission from coal and gas fuelled GT-SOFC and GT-MCFC plants: Some Studies", *Proceedings of ASME Turbo Expo –Power for Land, Air and Sea, Barcelona, Spain, May 8-11, 2006*.
4. Lunghi P., Bove R., Desideri U., 2003, "Analysis and optimization of hybrid MCFC gas turbines plants", Journal of Power Sources, 118: 108-117.
5. Verda V., Nicolin F., 2010, "Thermodynamic and economic optimization of a MCFC-based hybrid system for the combined production of electricity and hydrogen", International Journal of Hydrogen Energy, 35: 794–806.
6. Sanchez D., Escalona J. M. M. D. E., Chacartegui R., Munoz A., Sanchez T., "A comparison between molten carbonate fuel cells based hybrid systems using air and supercritical carbon dioxide Brayton cycles with state of the art technology", Journal of Power Sources, 196: 4347-4354.
7. Emam R. S. E., Dincer I., "Energy and exergy analyses of a combined molten carbonate fuel cell-gas turbine system", International Journal of Hydrogen Energy, 36: 8927-8935.
8. Cycle-Tempo Manual, "Technical notes", Cycle Tempo Release 5.0-A program for thermodynamic modeling and optimization of energy conversion systems, TU Delft, Postbus, Delft, The Netherlands.

NOMENCLATURE

Symbol	Meaning	Unit
E_x	Nernst Voltage	V
E_T^0	Standard Reversible Voltage	V
ΔG_T^0	Standard Gibbs Energy Change	KJ/mol
F	Faraday Constant	C
R	Universal Gas Constant	KJ/mol-K
V_x	Cell Voltage	V
i_x	Current Density	$A.m^2$
I	Current	A
P	Power	KW
η_{DCAC}	efficiency of DC/AC-conversion	%
LHV	Lower Calorific Value	KJ/kg
ϕ_m	Mass Flow	Kg/sec
M_{mol}	Molecular Mass	Kg/mol
c→a	from cathode to anode	-

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Mihir Mouchum Hazarika was born on 1st March, 1988 in India. He obtained his bachelor degree in Mechanical Engineering from School of Engineering, Tezpur University, INDIA on 2010. His major field of study is Renewable Energy Systems like fuel cells, Combined Cycles fed with synthetic gas etc. Presently he is pursuing his Master of Engineering, with heat power as a specialization, in the Department of Mechanical Engineering, Bengal Engineering and Science University, Shibpur, India.

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