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Energy Modeling and Optimization Analysis of High Temperature Fuel Cells (MCFCs) A Review

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Abstract—*This paper review the already work done in last fifteen years focusing the energy modeling and optimization analysis of high temperature fuel cell that is Molten Carbonate Fuel Cells (MCFCs).The work include the research work published in various journals and conferences, articles, magazine, available in open literature. The literature review serves the various goals. first is focus on the work that has been done on the development of different model of MCFC using specific objective functions during these recent years and optimization solution of developed model using deferent optimization techniques/ algorithms. The review work is also summarized year wise development in the proposed field. The present work are focused the current sonorous and application of the MCFC. The review work will help the researcher to find the existing research gap on this issue and outline the future direction for the researcher through this review analysis.*

Keywords*: High Temperature Fuel Cell, Modeling, Simulation, Optimization.*

1. INTRODUCTION:

Sir William Grove developed the first fuel cell in England in 1839.His experiments during this time on electrolysis, the use of electricity to split water into hydrogen and oxygen-led to the first mention of a device that would later be termed the "fuel cell." Fuel cells are electrochemical devices that convert chemical energy in fuels into electrical energy directly, promising power generation with high efficiency and low environmental impact. The demand for electric energy in the world is increasing and public opinion of today yearns to reduce the usage of fossil fuels. Alternatives to fossil fuels are wind power, solar power, wave power and power from energy conversion systems using renewable fuels such as water-hydrogen cycle, biomass- gasification, ethanol etc. [1]. The increased need of energy will require enormous growth in energy generation capacity, more secure and diversified energy sources, and a successful strategy to control and to reduce greenhouse gases emission [02].

2. FUEL CELL APPLICATION

There are several types of fuel cells that are being developed for application as small as a cellular phone (0.5 watts) to as large as small power plant for an industrial facility or a small town (10 Megawatts).The fuel cells may be classified according to what kind of electrolyte and what type of fuel they use. Today there are six major different types; Direct Methanol Fuel Cell , Polymer Electrolyte Fuel Cell (PEFC), Phosphoric Acid Fuel Cell(PAFC), Alkaline Fuel Cell (AFC), Molten Carbonate Fuel Cell (MCFC) and Solid Oxide Fuel Cell (SOFC). Fuel cells may also be categorised into low temperature fuel cells and high temperature fuel cells. MCFC and SOFC are the two most common high temperature fuel cells .The advantages of using high temperature fuel cells are that the electrochemical reactions are fast and have low activation over potential and that no noble catalyst materials are needed.

3. MCFC IS SOURCES FOR THE CLEAN POWER GENERATION

The NO_x and SO_x emission are greatly reduced in comparison with fossil fuel based generation system [8, 9]. Presently MCFC is used for commercially, due to high operating temperature ranging is about 600-70 ^oC in which the good ionic conductivity [10]. A variety of fuel gas can be used i.e. Gas from biomass fermentation, gasified coal or waste gases & landfill gas [10]. The gas has to be reformed before it is use for electrochemical conversion [11]. The reforming (formation of hydrogen from methane) can be done either in an external reformer(ER), or in direct internal reforming special reforming unit attached to the cell P.Heidebrecht [12]. The MCFC process does not need to refine synthesis gases, including co & co_2 because co react with carbonate ions, putting electron out and CO_2 recycle to the cathode inlet to produce carbonate ions [13]. High temperature fuel cell are strongly effected energy losses due to heat exchange N. Woudstra [14, 15]. Economic assessment of an innovative system which integrates absorption enhanced reforming (AER) of lignite with MCFC for electricity generation is used by Y.D. wage[28]. Produce hydrogen form lignite to MCFC cell has its environmental advantages over the conventional coal power plants, this would like attractive option for zero green house gas emission

Y.Mugikura et.al & high thermal efficiency and lower pollutant emissions [20]. The current MCFC performance , compared with performance and cost of other fuel cell, improvement in the power density and life time as well as cost reduction are indentified as key priorities to accelerate the commercialization of the MCFC [16]. The technical, economic assessment of an innovative system which integrates absorption enhanced reforming (AER) of lignite with MCFC for electricity generation is used by Y.D. wage Produce hydrogen form lignite to MCFC cell has its environmental advantages over the conventional coal power plants, this would like attractive option for zero green house gas emission Y. Mugikura et.al & high thermal efficiency and lower pollutant emissions P. BTarman [17,18]. The MCFC is attractive in stationary, combined heat & power (CHP) generation system, the optimization of the cell shape for industrial MCFC stacks Arato E . Joseph daly et al. invested, MCFC operation with dual fuel flexibility, ability to operate high efficient& pollution free using natural gas or (HD-5 grade) propane A.R.Shrivakumar et.al [19].

Status of MCFC in global context

Molten Carbonate Fuel Cells (MCFC) are currently being uses in various capacity different purpose. The high temperature fuel cell also use for small power generation station like in MW capacities range. And hundred KWs, however, a 40-125 kW MCFC system for mid size commercial, industrial and municipal applications was developed by Gen Cell Corporation, and multi-MW systems are going to be demonstrated in Europe [47,48], USA and Japan [16,49]. Due to certain limitations like durability is limited by corrosion within the cell components, electrolyte loss as well as dissolution of the cathode into the cell matrix, eventually resulting in nickel shorting of the two electrodes. These include increasing power density and exploring less expensive manufacturing processes [51]. The total life of the cell and running cost is also major issue in the present. The researchers are keep in mind doing the work in that direction.

Molten Carbonate Fuel Cells state of the art in the world MCFC technology are under development in Italy, Japan, Korea, USA and Germany. The high number of MCFC installations is mainly due to the strong role played by the American company, Fuel Cell Energy (FCE) and the German CFC Solutions (formerly MTU CFC Solutions) in putting their products in operation [50, 52].

4. STATUS OF MCFC IN INDIAN CONTEXT

Type Bharat Heavy Electricals Ltd. (R&D), Hyderabad. They are involved in the development of Phosphoric Acid Fuel Cells (PAFCs) and have developed a 50-kW stack, in current they have also generate power through a 200 kW fuel cell bases power plant. The fuel used is LPG and besides generation of electricity, it also produces hot water which is uses in their canteen. TATA Energy Resources Institute (TERI) is also ongoing research they demonstrated the use of digester gas (biogas) for generating electricity with co association of ERC (Energy Research Corporation), USA. The research is carrying on various university of India, work on developing a DMFC (direct methanol fuel cell) is underway at IISc (Indian Institute of Science). And also research on SOFC is being ongoing at IISc and CGCRI (Central Glass and Ceramic Research Institute). BHU (Banaras Hindu University) ongoing Research and development on metal hydride storage is The technologies wise status of the high temperature fuel cell. The table 5.1 shown status of fuel cell in global.

Table 5.1: Fuel Cell major technologies national & international status

Technology	International Status	National Status
Coal Gasification (IGCC)	Commercially purpose	set up pilot plant under going
Biological route for Hydrogen Production	Work progress for Commercial application	Work in progress set up plant
Metal Hydrides for Hydrogen storage	In this direction good development	Hydrides with for ambient conditions developed
Carbon nano structures for Hydrogen Storage	In R&D Stage	In R&D Stage, Further R&D efforts underway
IC Engine for Hydrogen	commercially available is poor	Work under progress
PEM Fuel Cells for Stationary applications and automobiles	Commercially available	Prototype Demonstrated stage.
Solid Oxide Fuel Cells	R&D Demonstration Stage	In early stages of R&D Status

5. MODELING ANALYSIS OF MCFC

Models Development of MCFC using different object functions/ parameters are shown in the Table 6.1 work summarized in the Table 6.2

Table 6.1: Models Development of MCFC using different object functions/ parameters

Reference	Used model	Objective function
W.He.Q.Chen [21]	Three dimensional	Parametric simulation
Ansaldo Ricerche[53]	Intergated system	MCFC Couple with Gasifire
H.S Zhang et al. [54]	Intergated system	MCFC Couple with,Turbine
J.H Koh et al.[10]	MCFC,Stack parameter	Temperature effect
M.Pfferodt et al. [12]	Symmetric stack model	Direct Reforming consider
P.Heidebrecht et al.[13]	Dynamic Model	Cross flow with Direct Internal Reforming

Masahiro et al. [29]	Simple,Porous Electode Model	Porousivity
Bosio B et al. [23]	Modeling, and experimentation	scale-up process
Park H. K et al. [24]	Mathematical Modeling	effects of the reformer
Standaert et al. [22]	Analytical	Non-isothermal fuel cells
Xianglin et al. [55]	Mathematical Model	Energy flow and energy utilization
VarbanovP et al. [30]	Intergated system	Efficiency
Ding,J,Patel etal. [44]	Computer Model	Direct Carbonate fuel Cells design
Heidebrecht etal. [43]	Model-Based Analysis of Cell Dynamics	Internal reforming consider
Zhiwen et al.[34]	Mathematical Modeling	High power internal reforming
Fan yang et al [32]	Model, predictive control	Vehicle power and propulsion
Brouwer,et al.[33,27]	Numerical Modeling	stack modeling are based on repeated cells
Sung-YoonLee, etal .[36]	Mathematical modeling	150-cell stack, all cells are connected in a series, obtained average current density
N. Subramanian et al.[25]	Mathematical Model	Current density

Table 6.2: Models Development of MCFC using different object functions/ parameters

Reference	Used model	Objective function
Aiguo Liu et al.[37]	One-dimensional mathematical model	Volume resistance characteristics
Amal Elleuch et al.[41]	Analytical modeling of electrochemicl mechanism in CO_2	polarizations calculation
Ding,J,Patel etal.[44]	Computer Model	Direct Carbonate fuel Cells design
Heidebrecht etal.[43]	Model-Based Analysis of Cell Dynamics	Internal reforming consider
Ding,J,Patel etal.[44]	Computer Model	Direct Carbonate fuel Cells design
Heidebrecht etal.[43]	Model-Based Analysis of Cell Dynamics	Internal reforming consider
Zhiwen et al.[34]	Mathematical Modeling	High power internal reforming
Fan yang et al.[32]	Model, predictive control	Vehicle power and propulsion
M.Mangold et al.[26]	Nonlinear model reduction of a two-dimensional	Internal Reforming, consider
Bengt Sundén et al.[35]	Modeling of Heat and Mass Transfer	Energy transfer
Brouwer, et al.[33,27]	Numerical Modeling	stack modeling are based on repeated cells
Sung-YoonLee, et al.[36]	Mathematical modeling	150-cell stack, obtained average current density
N.Subramanian et al.[52]	Mathematical Model	Current density
Aiguo Liu et al.[37]	One dimensional mathematical model	Volume resistance characteristic
Aiguo Liu et al.[37]	One-dimensional mathematical model	Volume resistance characteristics
Amal Elleuch et al.[41]	Analytical modeling of electrochemical mechanism in CO_2	polarizations calculation
Ding,J,Patel etal.[44]	Computer Model	Direct Carbonate fuel Cells design
Heidebrecht etal.[43]	Model-Based Analysis of Cell Dynamics	Internal reforming consider

6. CONCLUSION

The present work 51 numbers research papers were selected, categorised and analysis and gap in the work been identified to suggest for future analysis. The present work will be helpful for researchers, academicians and practitioners for better understanding in the field of energy modeling and optimization analysis of high temperature fuel cells (MCFCs).

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