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PASSIVE LIQUID WATER RECOVERY FROM FUEL CELL EXHAUST

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Abstract: **Passive liquid water recovery from fuel cell effluent can be achieved by designing effective desiccant. Recovered water from desiccant is used for humidification of proton exchange membrane (PEM) to maintain at hydrated state. Proper membrane humidity is crucial to ensure optimal operation of a PEM to generate electricity. In this study a desiccant called water separator is designed, it works without consuming any external energy. The main aim of designing a component is to recover liquid water from hundred percent humidified air (vapour) which is coming out from cathode compartment of fuel stack and it is further used for humidifying the oxidant before entering the stack inlet. The self-sufficient water in vapour is investigated theoretically and experimentally. When the water separator temperature reached the critical point especially in large power applications or long time operation, recovered water was not sufficient for air humidification. On the contrary, it is sufficient while the temperature of water separator was below critical line. The temperature of separator is controlled by providing adequate heat transfer. The recovered amount of water by condensing the outlet gas or vapour to a proper temperature, easily satisfy required amount for humidification of oxidant at inlet of stack.**

Keywords: **cell stack, Proton exchange membrane, Humidification, Vapour, Liquid water recovery.**

I. INTRODUCTION

In hybrid vehicles the proton exchange membrane fuel cell (PEMFC) is used to convert hydrogen and oxygen to electricity from an electrochemical reaction, in which fuels combines to form water as a by-product. The fuel supplies to PEMFC should be humidified to get efficient performance

In this work an attempt have made for Water recovery and, in particular, to Water recovery for use in high temperature fuel cell systems. Reactant gases supplied to the fuel cell, and in particular, the reactant fuel gas supplied to the anode, must be sufficiently humidified to maintain a desired steam to carbon ratio in the fuel for proper and efficient fuel cell operation and to prevent carbon deposition in the fuel cell. The amount of Water consumed by fuel cell system for humidifying reactant gases is usually significant and requires a continuous supply of Water to the fuel cell system.

With rising prices of Hydrocarbon Fuels and the increasing costs of the environmental impact due to emissions it has become imperative to identify alternative energy sources. At present there are multiple competing sources of energy for automotive applications and Hydrogen is one of the most promising sources. In this regard there are two competing technologies as well.

- Internal Combustion
- Fuel Cell

Using Hydrogen in a regular Internal Combustion Engine is not easy, for instance, the flame velocity of Hydrogen is 300 m/s as opposed to 29 m/s of Petrol (Gasoline). In addition an enormous amount of work has already gone in to Fuel Cell technology development since the 1960s. If Hydrogen is indeed going to be the future fuel, Fuel Cells are the quickest way of creating the impetus for the creation of a Hydrogen infrastructure. With this in view, TATA Motors Limited (TML) decided to indigenously develop a Fuel Cell Bus. In order to complement the wide ranging experience of TATA Motors in Buses, for design of systems with Hydrogen and for overall consulting on Hydrogen Handling.

The energy conversion used in fuel cell technology provides several advantages over the combustion of fossil fuels. First, the only emission that arises directly from the fuel cell is pure water. Second, most fuel cells have higher design and off-design efficiencies than conventional energy conversion processes, which rely on combustion. Finally, the technology can be easily Additional emissions may arise from the production of hydrogen if the primary energy source is a fossil fuel. However, even with these considerations, fuel cells typically have lower emissions than traditional energy systems.

At the date of writing of this document it is envisaged that the Fuel Cell Stack will be procured from Ballard™, Inc of Canada. This Fuel Cell Stack has specifications supplied by Ballard and this specifications document (MK902 Fuel Cell Module Assembly – Product Assembly") is provided as an addendum to this document. The Balance of Plant exists to take care of the Fuel Cell Stack. This is the focus of the Design Work being undertaken by TML.

II. THEORETICAL SCHEME

According to thermodynamics when the temperature of liquid at a specified pressure is raised to saturation temperature T_{sat} at that pressure, boiling occurs. Vice versa, when the temperature of a vapour is lowered to T_{sat}, condensation occurs. In this study the rates of heat transfer at the time of vapour-to-liquid phase transformations has been studied. Although condensation contests some unique features, like convection heat transfer since they involve fluid motion. condensation differ from other forms of convection in that they depend on the latent heat of vaporization h_{fg} of the fluid and the surface tension at the liquid–vapour interface, in addition to the properties of the fluid in each phase. Noting that under equilibrium conditions the temperature remains constant during a phase-change process at a fixed pressure, large amounts of heat (due to the large latent heat of vaporization released or absorbed) can be transferred during condensation essentially at constant temperature. In practice, however, it is necessary to maintain some difference between the surface temperature Ts and T_{sat} for effective heat transfer. Heat transfer coefficients h associated with condensation are typically much higher than those encountered in other forms of convection processes that involve a single phase. Here the physical mechanism of film condensation and discuss condensation heat transfer in geometrical arrangement and orientation. Finally, we introduce drop wise condensation and discuss ways of maintaining it. The theoretical calculations are carried out by assuming, process of condensation is occurring over number of components inside the water separator and heat transfer rate is increased by providing water jacket.

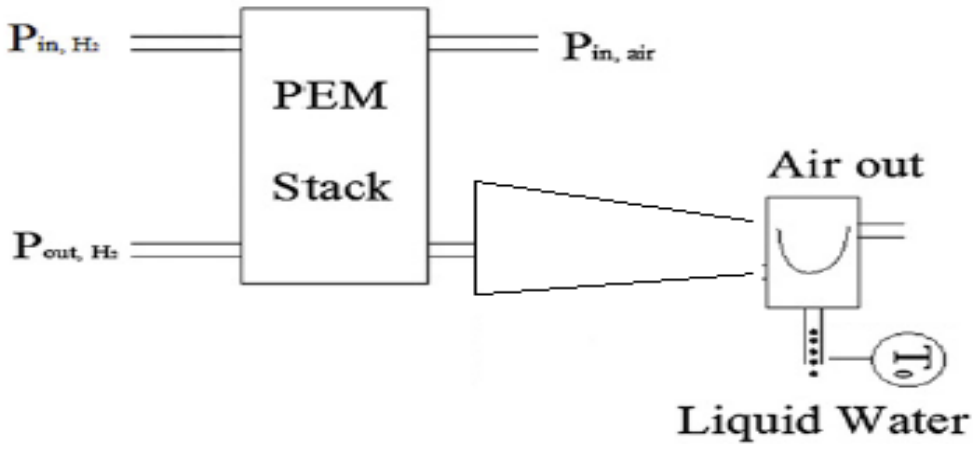


Fig. 1 Schematic of water Separator Fixed to Stack

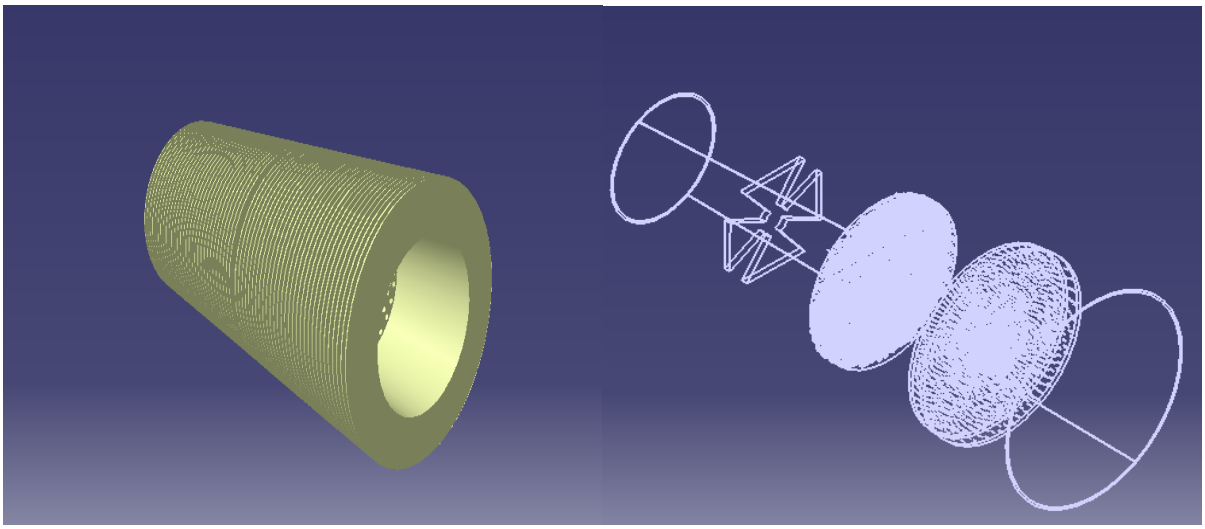


Fig.2 Model of Water Separator

Before the condensation the mass of liquid particles as to be find out in the air coming out of stack

III. THEORETICAL SEPARATION METHOD

This is a constant volume process. Since the work is zero, the first law reduces to

$$Q=u_2-u_1=m_{o2}c_{vo2}\,(T_2-T_1)+m_{n2}cv_{n2}\,(T_2-T_1)+(m_2u_2)_v+(m_2u_2)_L-(m_1u_1)_v \quad (1)$$

Where "m" and "u" are mass and internal energy of oxygen, nitrogen and water vapour in the system, oxygen and nitrogen are highest compositions in air. The mass of nitrogen can be calculated using ideal gas equation of state. The mass flow rate of air and water in the inlet could be expressed as.

$$\dot{m}_a=\frac{n\lambda I}{0.21*4*F}M_{air} \quad (2)$$

$$\dot{m}_{w,\,add,air}=\frac{M_{H_2o}\,P_{inH2o}}{M_{air}\,M_{pin}-P_{inH2o}}\dot{m}a=\frac{n\lambda I}{0.21*4*F}*\frac{RH.P_{sat}(T_{in})}{P_{in}-RH.P_{sat}(T_{in})}*M_{H_2}o \quad (3)$$

Where M_{air} and $\dot{m}_a$ were the molecular weight and mass flow rate of the air, respectively, λ was the stoichiometry, n was the cell number, I was the working current, and F was the Faraday constant. P_{in} and P_{inH2o} were the inlet total pressure and inlet water vapour Partial pressure, respectively, $P_{sat}(T_{in})$ was the saturated water vapour pressure with respect to the inlet temperature T_{in}, RH was the relative humidity, M_{H_2o} was the water molecular weight. The mass of nitrogen can be calculated using ideal gas equation of state

$$\dot{m}_n=\frac{PsV}{RT} \quad (4)$$

$\dot{m}_n$ is mass flow rate of nitrogen in vapour ,'P_s' is saturation pressure of water vapour, 'v' is velocity, 'R 'is real gas constant and' T' is temperature of vapour.

$$p_s=610.78*e^{\left[\frac{t}{t+238.3}\right]}*17.2694 \quad (5)$$

't' is the vapour temperature at inlet.

The flow of vapour inside the tube is turbulent, because of some disturbance inside the tube At a Reynolds number of about 1800, the condensate flow becomes turbulent. Several empirical relations of varying degrees of complexity are proposed for the heat transfer coefficient for turbulent flow. Again assuming $\rho_v<<\rho_l$ for simplicity, Labuntsov proposed the following relation for the turbulent flow of condensate on vertical plates.

$$h_{vertical,turbulent} = \frac{Re K_l}{8750 + 58Pr^{-0.5}(Re^{0.75} - 235)} \left(\frac{g}{v_l^2}\right)^{\frac{1}{3}} \quad (6)$$

Where,

$$R_{vertical,turbulent} = \frac{0.0690 L K_l Pr^{0.5}(T_{sat} - T_s)}{8750 + 58Pr^{-0.5}(Re^{0.75} - 235)} \left(\frac{g}{v_l^2}\right)^{\frac{1}{3}} - 151pr0.5 + 253)^{\frac{1}{3}} \quad (7)$$

Then the heat transfer rate in the vertical components can be calculated by knowing heat transfer surface area

$$Q = hA(T_{sat}-T_s) \quad (8)$$

Totally the mass of condensed or separated water can be calculated by

$$m_{.condensation} = nfg/Q \quad (9)$$

Where $m_{.condensation}$ is mass of water is condensed or separated, h_{fg} is latent heat of vaporization and Q is the total rate of heat transfer by separator.

IV. EXPERIMENTATION

Experiment setup used as per below shown process and instrumentation diagram to carry out the practical testing. Fig 3 is the Process and Instrumentation Diagram with water separator system, the operating conditions are varies according to the various components, two partitions are made A and B, and same operating conditions are mentioned below.

A. Conditions

1. Air inlet Temp- 20 to 40 deg c
2. Air Humidity – depends on atmosphere

B. Conditions

1. Air inlet Temp- 40 to 180 deg c
2. Air Humidity – 100% humidified
3. Air mass flow rate- 0 to 120 gm/sec

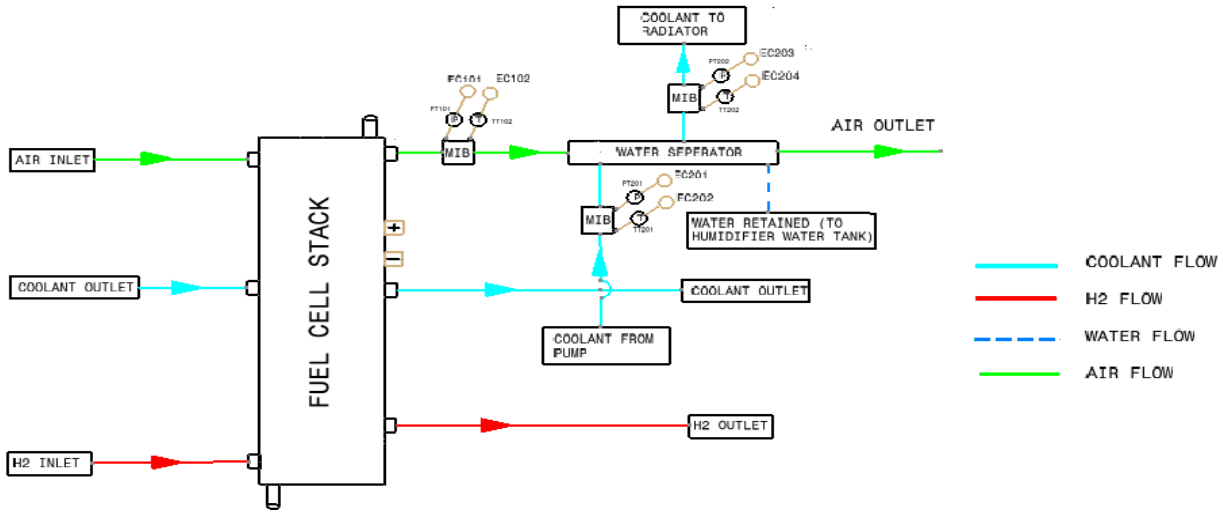


Fig. 3 P&ID of water separator

A - Boundary conditions are atmospheric operating conditions

B – Once Air compressor sucks air from atmosphere air need to be compressed up to 2 bar pressure under the flow rate of 120 gm/sec and Temperature of compressed air Maximum up to 180 ^{o}c.

The existing design for the fuel cell test stand was designed to control the operation of fuel cell stacks. All components in the system were selected based on mass flow rates corresponding to power, pressure ratings of at least 400 kPa, and operating temperatures of at least 100^{o}C. The test stand consisted of the following systems; air and hydrogen flow controllers, air and hydrogen heaters, liquid water injection humidifiers for air and hydrogen, water separator, coolant

water circulating loops with pump, and measurement and control devices. The design and configuration of this system did provide adequate humidification to operate a fuel cell stack by collecting water with the help of water separator.

In order to investigate the liquid water recovery amount, four cases are studied by experiment, As shown in Table 1, the investigation of water recovery amount from the stack by separator as done in four different cases . The fuel cell stack was reactivated with increasing current on the stack with fully humidified H2/air for about 8 h before the polarization curves were recorded. After the activation process, polarization curve was recorded to evaluate the initial performance of the fuel cell stack. The detailed experimental conditions of the fuel cell stack are shown in Table 1.

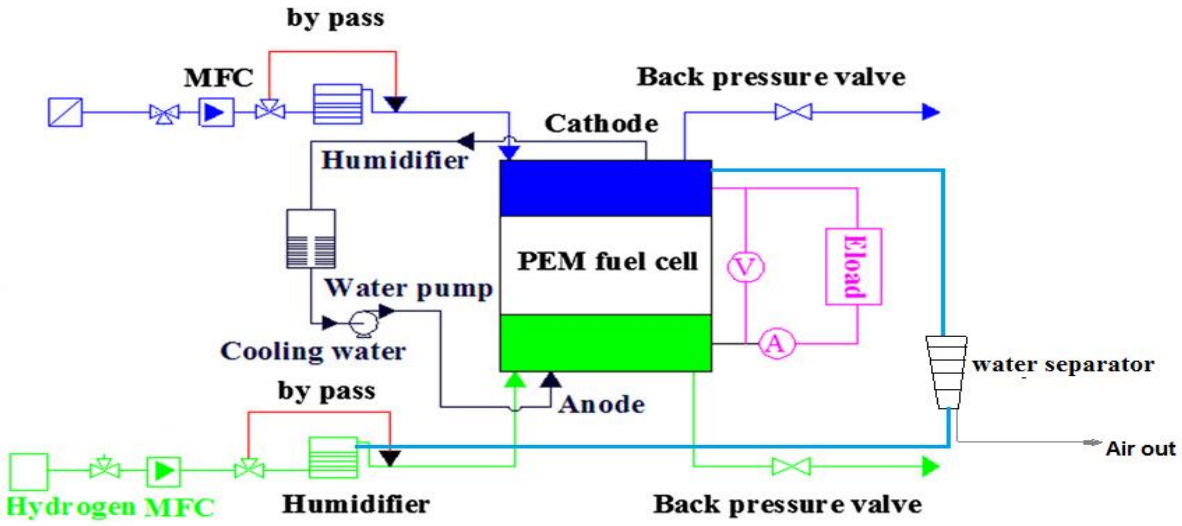


Fig. 4 Schematic diagram of the test system for PEM fuel cell stack.

SL NO	current	Pressure in @ water separator	Pressure out @ water separator	vapour mass flow rate	vapour temperature in @ water separator	vapour temperature out @ water separator
	Amp	kpa	kpa	gm/sec	^{0}c	^{0}c
1	440	211	194	120	64	41
2	400	200	183	110	61	38
3	340	186	169	100	58	35
4	300	170	153	80	55	32

Table 1: Experimental readings

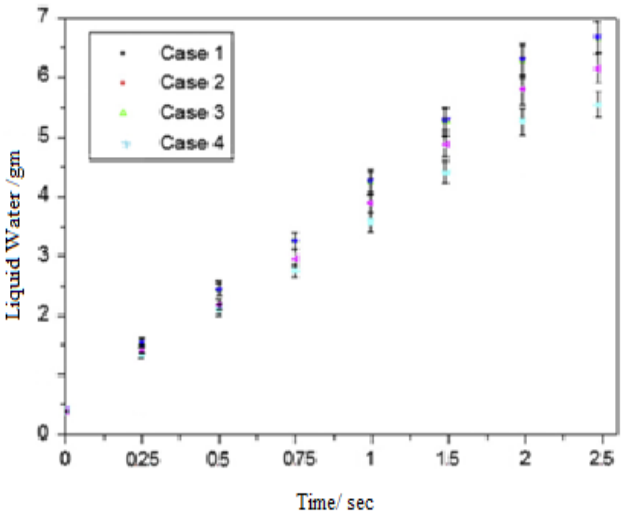
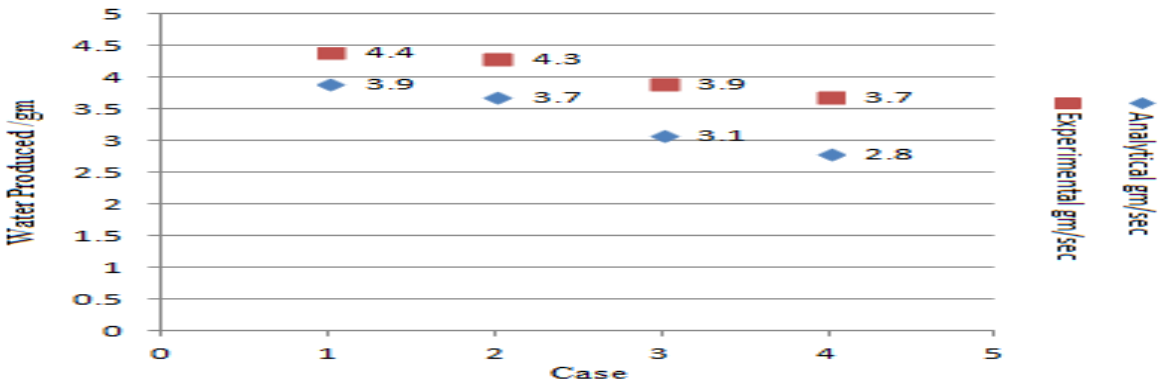


Fig. 5. Water recovery amount

The Fig. 5 displayed time evolutions of liquid water recovered from the outlet vapour at exit of stack. It can be seen, that amount of water increased almost linearly with the time for all cases. Where the maximum running condition of stack is at 440amps, It will be maximum when it is working at a condition of peak load. Moreover, the generation of water was about 4.4gm/sec is achieved by this separator experimentally and 3.9 gm/sec analytically. Consequently, most of liquid water could be separated from the higher temperature gas in the condenser when the gas was cooled by providing water jacket for efficient separation of liquid water from the outlet gases. On the other hand, as can be seen in Fig 6, water separation rate decreased with the drop in the gas temperature and mass flow rate in the condenser. At the end of the condensing process, there was almost no water could be separated from the gas.



. **Fig. 6** Comparisons of the Analytical and experimental data

V. CONCLUSION

The fuel cell system requires humid air to facilitate the chemical reaction. The reactants in the fuel cell are humidified to keep polymer membrane wet and saturated with the Water for sustained ionic conductivity. At Present Fuel Cell Power system is not implemented with water separator, the exhaust water vapour is vented directly to the atmosphere. In this work liquid water is separated from the exhaust water vapour and it is used for humidification in the fuel cell power system. Sufficient water can be recovered by condensing the high temperature exhaust of the stack, and the amount of recovered water can satisfy the humidification demand in the cathode easily by applying a high heat removal ability separator. In this work an economic and convenient way to a realize the water balance in the fuel cell, water in vapour can be separated for humidifying the inlet gas sufficiently. As a consequence, this method can be easily used for the air self humidification in large power and long time operating fuel cell stacks.

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