Hydrogen Compressor Using PEM

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Abstract- *In the world of technology, after decades of development hydrogen is about to find its way into the automobile sector. Till date more than 30 hydrogen refuelling stations are installed in the America. The main component of these refuelling stations is hydrogen compressor. In 1998, the electrochemical hydrogen compressor was designed using PEM(Polymer electrolyte membrane) which gives CO as a by-product and hence is harmful to the environment but after that no more research was done on that. Hence, there is need to design the pollution free hydrogen compressor to ensure the future of hydrogen energy with optimum cost requirements. In this paper there is adscription of the electrochemical hydrogen compressor using eco-friendly reaction, which can compress the hydrogen fuel up to 40-43 bars with the help of electrolysis process. The abstract idea of this paper is to provide hydrogen compressor to future refuelling stations, which completes every requirement with considering the common people.*

Keywords- Electrochemical hydrogen compressor, Polymer electrolyte membrane, PEM-HYCO.

I. INTRODUCTION

Human have harnessed hydrogen for variety of applications from blasting rockets into space to making common household products like toothpaste. Now after decades of development hydrogen is about to find its way into the automobile sector. As we know it is very difficult to liquify the hydrogen gas as its liquification temperature can't be achieved easily and efficiency with our available technology. But instead of leaving the way of hydrogen energy we can look for other ways to use it. There are numbers of reactions available with us from that we can get a hydrogen gas. So, why not to use hydrogen as a future fuel? Everyone knows that there is a huge availability of hydrogen in the universe. Hence, we can use it in gaseous form instead of liquify it.

Now the main concern about using a hydrogen gas as a fuel is 'storage'. Till now, there are numerous methods available with us to store the hydrogen gas.

But now we have to think about filling it into the automobile engine. For that, we should design a hydrogen compressor which will compress the hydrogen gas considering the requirements of automobiles and their engines. There are number of Hydrogen compressors available in the market but they are available with a very high cost. Mechanical hydrogen compressors are also available but they are available with their moving parts. So, every compressor is available with their limitations. In country like India, it is not easy to use hydrogen compressor which requires lots of money. Hence we have to design a compressor with considering common people. So that in the future everyone should use hydrogen as a future fuel.

In 1998, electrochemical compressor was designed using PEM (Polymer Electrolyte Membrane OR Proton Exchange Membrane). This compressor is used for low power application like in the electrical fuel cell vehicle. Here, by combustion of methanol, Hydrogen gas is generated and is compressed with help of PEM using electrolysis process. But the major problem is about compressor is, it couldn't handle with the CO (Carbon Mono-oxide) which is generated by that combustion process as by-product.

Hence, In this paper, the ultimate goal is to modify that electrochemical compressor using cheapest reaction of Al (Aluminium) and Water to generate Hydrogen gas using NaOH as a catalyst so as to totally eliminate the harmful effect of CO and reducing the cost of compressor with modification based on new design so the common people can also afford the component.

II. LITERATURE REVIEW

Rohland et al. depicted new developments of the polymer electrolyte membrane (PEM) fuel cells make it possible to realize the electrochemical compression in a PEM-cell with high efficiency. A new cell design of PEM-cells for operation with a high pressure difference between anode side and cathode side was developed. The purification of hydrogen from carbon monoxide of the reformer gas can be integrated in the hydrogen compressor cell.[1]

Wang et al. studied AB_5 type and AB_5 type multicomponent hydrogen storage alloys for the purpose of high-pressure hydrogen compression. A single stage metal hydride hydrogen compressor with hydrogen compression rate of 40L/min and a double stage compressor with hydrogen compression rate of 20L/min were designed and built to produce high-pressure hydrogen.[2]

Lototekyy et al. explained about the hydrogen storage characteristics important for every solid H storage material (e.g. gravimetric and volumetric efficiency of hydrogen storage, hydrogen sorption kinetics and effective thermal conductivity), the thermodynamics of the metal hydrogen systems is of primary importance resulting in a temperature dependence of the absorption/desorption pressures). Several specific features should be optimised to govern the performance of the MH-compressors including synchronisation of the pressure plateaus for multi-stage compressors, reduction of slope of the isotherms and hysteresis, increase of cycling stability and life time, together with challenges in system design associated with volume expansion of the metal matrix during the hydrogenation.[3]

Li et al. produced hydrogen with pressure of over 70MPa by using a thermally driven hydride compressor. To reach this target, the hydrogen storage properties of La–Ce–Ca–Ni–Al family AB_5 type and Ti–Zr–Cr–Fe–V family AB_2 type multicomponent alloys have been investigated. $La_{0.35}Ce_{0.45}Ca_{0.2}Ni_{4.95}Al_{0.05}$ alloy was developed as the first stage hydrogen compression alloy, and $Ti_{0.8}Z\ _{0.2}Cr_{0.95}Fe\ _{0.95}V_{0.1}$ as the second stage hydrogen compression alloy. With these two alloys, a double-stage compressor with hydrogen compression capacity of around 2000 L/cycle was designed and built, oil was used as the cooling and heat medium. When hot oil of 423K is used as the heat source, product hydrogen with pressure of 74.5MPa can be obtained, and the hydrogen flow rate of the compressor reaches 34.6 L/min.[4]

Laurencelle et al. stated that, the metal hydride hydrogen compressor technology is feasible but remains at the prototype development phase. It offers great potential for special application niches due to some attractive characteristics: no moving parts, no vibration, no noise, safety, high purity, low maintenance. However, its capital cost and its efficiency need a breakthrough to compete with diaphragm compressors, still about two times more efficient. Moreover, some applications like electrolytic hydrogen production where compression is a secondary process and where low-grade heat is available would benefit of its thermodynamic operating mode.[5]

Wang et al. depicted about a hydrogen storage alloy pair, $Ml_{0.55}Mm_{0.2}Ca_{0.25}Ni_5$ and $(Ti_{0.97}Zr_{0.03})_{1.1}Cr_{1.6}Mn_{0.4}$, has been developed for the use in a double-stage metal hydride hydrogen compressor (MHHC). Only hot water is used as the heat source, the built MHHC can convert hydrogen from 2.0 to 45MPa and simultaneously the hydrogen is purified from industrial grade (98% pure) to ultrapure grade (99.9999%). It is an economical technique to refill hydrogen into high-pressure vessel for a fuel cell vehicle.[6]

Dehouche et al. explained the use of the metal hydride technology for thermal compressors implies a strategy to select reactive alloys adapted to the desired performance of the compression cycle. After selection, detailed characterization of thermal and sorption properties are required in order to optimise the compressor behaviour.[7]

Solovey et al. focused on the single stage metal hydride thermo sorption compressors (TSCs) with different gas deliveries: TSC-70, TSC-80, TSC-150 and TSC-300. These have delivery pressure from 7 to 30Mpa at the initial pressure of 0.3-1Mpa. These devices can work in continuous mode or in periodic mode. They are characterised with original design properties, caused by severe barometric working conditions. The technical parameters of these compressors as well as the results of their long term operation in the different energy- technological systems are also presented in this report.[8]

Muthukumar et al. tested a metal hydride based hydrogen compressor using MmNi4.6Al0.4 at both constant and variable delivery pressures. The effects of operating parameters such as supply pressure and heat source temperature on the compressor performance are investigated. The compressor yields a maximum isentropic efficiency of 7.3% at 95 ◦C heat source temperature at variable delivery pressure operation mode, and 14.2% at 85 ◦C heat source temperature at constant delivery pressure operation mode. At both the operation modes, the volumetric efficiency of the compressor is found to decrease at high heat source temperatures.[9]

III. PRINCIPLE

The operating principle of the PEM hydrogen compressor is shown in fig.1.

Anode- Pt/Ru/C
Cathode- Pt/C
PEM Type- Nafion 211

The equilibrium potential of such unit is given by the NERST equation-

$$U = U_0 + \frac{RT}{2F} ln \frac{p_{H_2}^{II}}{p_{H_2}^{I}} \qquad \text{… eq. 1}$$

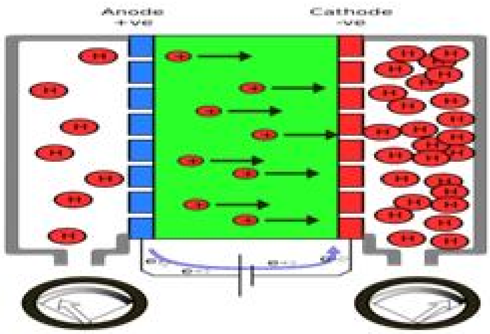

Fig. No. 1

When an external current is applied, hydrogen of pressure $p^{I}_{H_2}$ is oxidised at the anode to protons (H^{+}) which are transported across the PEM membrane and reduced at the cathode to hydrogen inert gas components can't cross the membrane , they are removed from the compressed hydrogen. According to Faradays Law, the amount of hydrogen transported to the cathode side of the cell is-

$$\frac{dn}{dt} = \frac{I}{zF}$$

With z = 2 follows

$$\frac{dn}{dt} = c * I$$

$$c = 6.95*10^{-3}\frac{Nl}{\min A}$$

The total cell voltage is given by the NERST equation (i.e. 29 mV for P^{II}/P^{I} ratio of 10), ohmic and polarization losses. The polarization resistance contribute only a small amount to the cell voltage, because of the highly reversible hydrogen oxidation and hydrogen evolution reaction. Typical values of the total cell voltage are 50-100 mV compared to mechanical compressor the irreversible part (I^2R) of the power consumption will be stable by increasing the pressure to the pressure limit determined by the mechanical construction.[1]

The electrochemical compressor is used in a fuel cell electric vehicle fuelled by methanol, which is converted to hydrogen gas in a gas processing unit consisting of a methanol reformer, shift converter and a cleaning unit for CO removal.[1]

Now, in this design the principle of compressor is same but instead of using methanol to generate H_2,it is generated by using a basic reaction of Al(scrap Al can be used) and water with NaOH as a catalyst. Hence from this reaction there is not any by product like CO which had seen in old PEM-HYCO. Hence there is elimination of CO-removal unit from the PEM-HYCO which ultimately leads to cost reduction also.

$2Al + 2NaOH + 2H_2O \rightarrow 2NaAl(OH)_4 + 3H_2$

In PEM-HYCO, metallic catalyst particles, oxide materials to support the catalyst (Au,Ru,Rh) are used in CO removal unit. Also there double layer of anode is used to reduce the sensitivity of the CO. Hence, here the total CO removal unit is eliminated and cheapest reaction is used to generate H_2 gas. So, the new compressor is the eco-friendly modification of the PEM-HYCO.

IV. EXPERIMENTAL SETUP

The cell design of the hydrogen compressor is similar to the fuel cell arrangement(see fig 1).Using this arrangement the total setup of H_2 gas to the compression of it.

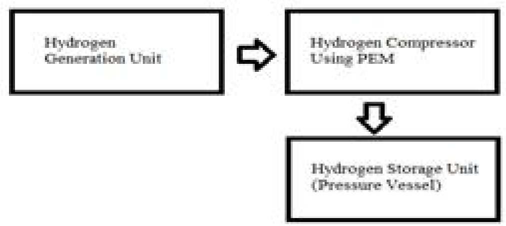

Fig. No. 2

As the whole principle of the modified design is based on the PEM-HYCO, there is no big modification in this compressor except the elimination of the CO removal unit and size of every component used. Here, every component is used with the different sizes than PEM-HYCO.

Hydrogen generation unit is required to generate hydrogen gas to use it in electric cell vehicle. From, the generated hydrogen gas, this unit is connected to H_2 compressor. In between these two units the pressure gauge is used to measure the pressure of generated H_2 gas which is $p^{I}_{H_2}$. After that the compressor compresses the hydrogen gas and gives out value of $p^{II}_{H_2}$ which is also measured by another pressure gauge.

The last unit of the experimental setup is storage unit, so pressure vessels can be used as a storage unit. To store the compressed hydrogen so, this can be used in refuelling stations anytime to fill hydrogen gas in automobile fuel tanks.

V. APPLICATIONS

As the PEM-HYCO is used in electric fuel cell vehicle, this compressor can be used for the same application as the cost of experimental setup is highly reduced and no harmful effect on environment as well as human.

Another very important application of this compressor is that, it can be used for future hydrogen refuelling station from where compressed hydrogen gas can be filled in automobile fuel tank. The main advantage of this system that the vessel are also used to store compressed hydrogen gas so, wherever there is a requirement of compressed hydrogen gas, this pressure vessels can be used instantly as per the application.

VI. RESULT AND DISCUSSION

Based on the electrochemical hydrogen compressor the result of modified hydrogen compressor can be obtained. The PEM-HYCO gives 40-43 bar output pressure after 18 min the point should be noted that as electrolysis process is used for this system. There are I^2R losses in system with increasing the current. Also there can be leakage losses between the membrane seals. As there is a pressure difference available in this system that will increase the hydrogen back diffusion. This back diffusion decreases the efficiency of hydrogen compressor. The rate of back diffusion is important to evaluate the efficiency of hydrogen compressor. The molecular hydrogen back diffusion can be obtained by the compensation current for constant pressure and the Faraday equation.

VII. CONCLUSION

The experimental data demonstrate that the compression of hydrogen with this new modified hydrogen compressor is promising option for refuelling stations as well as electric fuel cell vehicles because of its process efficiency, eco-friendly nature, low cost and noiseless operation.

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