

Advanced High Current Density Compact Electrolyser for Small Capacity Applications

S. K. Mitra, P. Raghunathan and V. K. Tangri

Heavy Water Division, Bhabha Atomic Research Centre, Mumbai, India-400085

skmitra@apsara.barc.ernet.in; pragvn@magnum.barc.ernet.in; vktangri@magnum.barc.ernet.in

ABSTRACT

Bhabha Atomic Research Centre, India has been working on the development of high efficiency advanced electrolysis cell modules capable of high current density operation for the production of hydrogen. Use of indigenously developed porous nickel electrodes in filter press type electrolytic modules has been a major innovative design aspect of the electrolyser development programme. A compact electrolyser, developed recently, has been designed and demonstrated in a prototype model on continuous round-the-clock operation for more than two months. Being a compact high current density electrolyser, it is suitable for remote and mobile applications. The electrolyser has a nominal capacity of 10 Nm³ of hydrogen/hr working at a temperature of 60°C and pressure of 1.6 Kg.Cm². The compact electrolyser module (weighing 1 ton approx.) consists of 40 cells incorporating porous nickel electrodes both as anode and cathode of the cell and the cells are connected electrically in series. The cell module operates at a current density of about 4500 ASM and consumes about of 56 kW electric power at operating conditions. The design, construction and operation of this low temperature and high current density compact electrolyser and operating characteristics of the cell module are presented.

Keywords: Compact electrolyser, porous nickel electrode, advanced cell module, high current density, hydrogen production.

1. INTRODUCTION

Water electrolyzers operating at a high current density result in a compact cell module size and also require less floor space making them suitable for remote and mobile applications. Bhabha Atomic Research Centre (BARC) has developed a highly compact electrolyser prototype incorporating porous nickel electrodes in the cell module construction. This Compact Electrolyser has been designed for operation at near atmospheric pressure from safety considerations, especially in remote and non-industrial environments. Portable units should have reduced specific weight and volume needs and ruggedness suitable for operation by minimum skilled operator available at the site-specific installations like remote area hydrogen source or in oxygen need for special applications. In addition, conventional applications like under water hydrogen welder, for fine jobs like gem cutting etc. also need small electrolyzers.

2. WATER ELECTROLYSER DEVELOPMENT PROGRAMME AT BARC

Bhabha Atomic Research Centre has worked on porous nickel electrodes capable of high current density operation and developed the techniques for cell module components fabrication and the technology for complete electrolyser up to pilot scale. Electrolyzers with advanced cell modules were constructed and operated to develop expertise and experience to make the technology available indigenously. The cell module features were updated to make a rugged and robust electrolyser system for hydrogen production by electrolysis process.

Over the years the porous plaques making techniques and mounting arrangement for the finished electrodes were modified and multi-cell modules were studied for gas generation characteristics in

water electrolysis test setups. Earlier test modules were constructed with a cell design where the porous electrode was held tightly between two concentric flat rings fitting one into another and operated very successfully in our test studies at high current densities of up to 10,000 ASM and 90°C with a cell voltage of 2.04 volts (Nayar M.G. et al. 1980). Large modules having 70 cm² area porous nickel electrodes and 30 cells in series were tested in a portable electrolyser unit. Operating on two cell modules of 2 X 30 cells, it generated 1.45 Nm³/hr of hydrogen at working conditions of up to 100°C and 15 Kg/cm² pressure (Ragunathan et. al., 1985). It was also operated up to 10,000 ASM (Amperes per Square Metre) with a cell voltage of 1.8 - 2.1 Volts per cell. The unit was run more than 250 hours to gain operational data and testing of the cells. The double concentric ring fixing of the porous plaques was found suitable for small test electrodes. In the pilot plant study, 390 mm dia. porous plaques were directly spot-welded onto a single plain ring were used. However this type of resistance welded electrodes showed detachment of the porous plaques after some time of operation. Hence, subsequently Electron Beam (EB) welded electrode assemblies were developed to make stable and functionally more effective cells (Saha T.K. et. al.2004).

The compact electrolyser incorporates the improved features in the design and construction of both cell module and the complete electrolyser plant. This prototype electrolyser has demonstrated high current density operation even at low temperatures of about 60°C. Small electrolysers can be made based on this prototype test electrolyser study suitable for skid mounting and mobile uses meeting the user requirements.

3. PROTOTYPE COMPACT ELECTROLYSER DESIGN FEATURES

For developing a compact high current density electrolyser suitable for remote and mobile applications operation at 60°C or below at near atmospheric pressure were chosen as design goals with some relaxation with respect to cell voltage with reduced floor space and working conditions. The gas liquid separator was made vertical to save space and cooling coils were installed inside the separator tanks to remove the waste heat from the system and also to cool the gases to recover the water vapour at the tank itself. The cell module was of bipolar filter press type and the end plate was incorporated in the end flange itself to facilitate central feeding of the module current. The electrode size was increased to keep the no. of cells to 40 per module. Electrolyte distribution was made effective in the cell chambers with distribution channels cut on the inner side of the electrode holder rings. Bubble coalescers are interspaced between the cell module and the separators for both the product gas lines to grow the gas bubbles released from the porous electrodes. All the instruments and controls are also mounted within the structure. The DM water tank is mounted at the top level providing sufficient head for gravity flow of the make-up water for the electrolysis process. Pressure at oxygen and differential pressure at hydrogen side are used to control the system pressure and gas flow rates. Chilled water/ services water is supplied to cool the electrolyte and the gases depending on the operating current density, heat load and operating temperature fixed. The electrolyser was designed to work up to 80°C and 5 Kg/cm²; however the operating points were limited to 60°C and 1.6 Kg/cm². A separate Rectifier cubicle supplies the DC power to the electrolyser module through multi core cables. Adequate interlocks are provided for steady and safe operation of the electrolyser.

The Compact Electrolyser plant comprises of the following sub-systems.

- i) Process plant including the cell module
- ii) DC power supply
- iii) Chilled water supply unit

The electrolyser process plant includes the prototype cell module, associated process equipments and instruments, gas analyzers and auxiliary systems for DM water, chilled Water, drain lines etc The process equipments of this prototype electrolyser layout has been made compact with suitable minimum interconnections and housed within the confines of the structural envelope taking into consideration the easy accessibility and maintainability. This also makes the installation layout

compact and skid mountable. The general features and the electrolyser design parameters are given in Table 1. The electrolyser and the prototype cell module are shown in the Fig. 1.

Table 1 Compact Electrolyser General Features

Design capacity	10 Nm ³ /hr of Hydrogen
Design temperature	80 ⁰ C
Design pressure	5 Kg/cm ²
Operating temperature	40 - 60 ⁰ C
Operating pressure	1.6 Kg/cm ² (abs.)
Module voltage	80-110 Volts
Module current	200-525 Amps
No. of cells per module	40
Electrode size, dia.	39 cm
Current density of operation	4400 ASM
Electrolyte used	30% KOH solution
Hydrogen purity	99.5%
Materials of construction	
Electrodes (Cathode& Anode)	Porous Nickel
Bipolar plate	SS 304 L
Electrode holder rings	SS 304 L
Diaphragm	Asbestos
Gasket	Teflon
Process equipment	SS 304 L

4. ELECTROLYSIS PROCESS FLOW DIAGRAM

Pure water being a very poor conductor of electricity, a 30 % KOH solution is used as the electrolyte. When DC electricity is passed through the electrolytic cell module, water is split into hydrogen and Oxygen gases. The rate of gas production is directly proportional to the quantity of current flowing between the electrodes; correspondingly water is consumed. Hence DM water is continuously added as makeup. Electrolysis is a highly endothermic process, requiring a minimum enthalpy of 68.3 Kcals /g-mole of hydrogen which corresponds to a minimum electrolysis voltage of 1.48 Volts at room temperature. However, in practice higher voltages have to be supplied to carry out the electrolysis at a reasonable rate of gas production i.e. at practical current densities.



Fig. 1 Compact Electrolyser

The excess energy supplied will result in the production of waste heat raising the temperature of the electrolyte and the gases. The waste heat has to be continuously removed to ensure constant operating conditions.

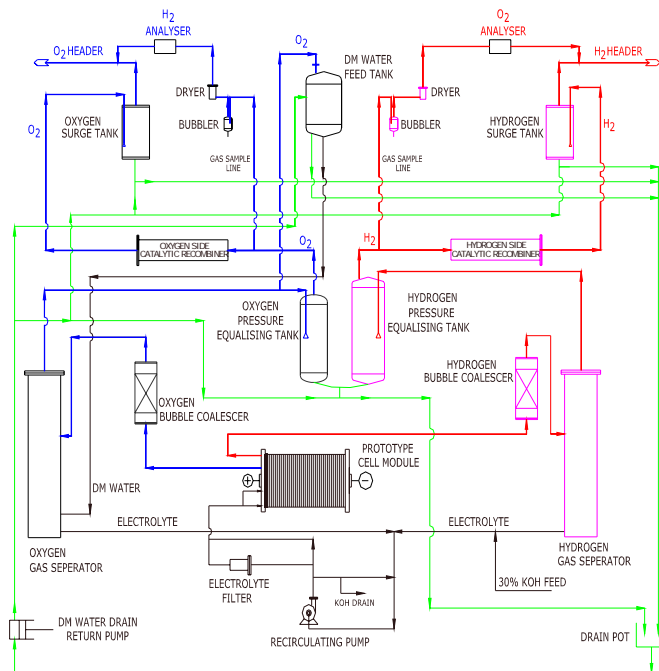


Fig. 2 Electrolysis process flow diagram

The electrolysis process flow diagram for the compact electrolyser is given in Fig. 2.

The KOH electrolyte filled in the gas separators is fed into the electrolytic cell module by a can motor pump. The electrolyte enters the module in two separate individual streams flowing into anode and cathode chambers respectively of all the cells. After electrolysis the anolyte carrying the oxygen and catholyte carrying the hydrogen bubbles pass through respective bubble coalescers for growing the gas bubbles to bigger sizes to facilitate easy and effective gas – liquid separation at the gas separators. Waste heat is removed in the gas separators and the electrolyte is recirculated. The respective product gases pass through the manometric pressure equalizer tanks, which are provided with demister packs to remove electrolyte entrainment. The product gases are cooled in the catalytic recombiner cum cooler. Feed water is added from a DM water storage tank to the oxygen separator on demand through a solenoid valve actuated by set electrolyte level sensing. On line gas analyzers monitor the purity of the gases in both the gas streams.

5. CELL MODULE DESIGN FEATURES AND ASSEMBLY

The bipolar filter-press type cell module design has taken into account the high current density operation and the requirements for the removal of large heat and product gases from the individual cells. This calls for adequate and uniform electrolyte distribution over the electrode and effective removal of the waste heat generated inside the cell. Fig. 3 shows a disassembled view of the cell module components of the electrolyser. The stacking of the cell modules requires sub-assembly of the cellblocks, comprising the bipolar plate and the electrodes and stacking them vertically with gasket and diaphragms interspaced. The cells are held in position with end flange and tie rods. The design of bipolar plate and porous nickel electrode are specially modified to suit the compact electrolyser module characteristics.

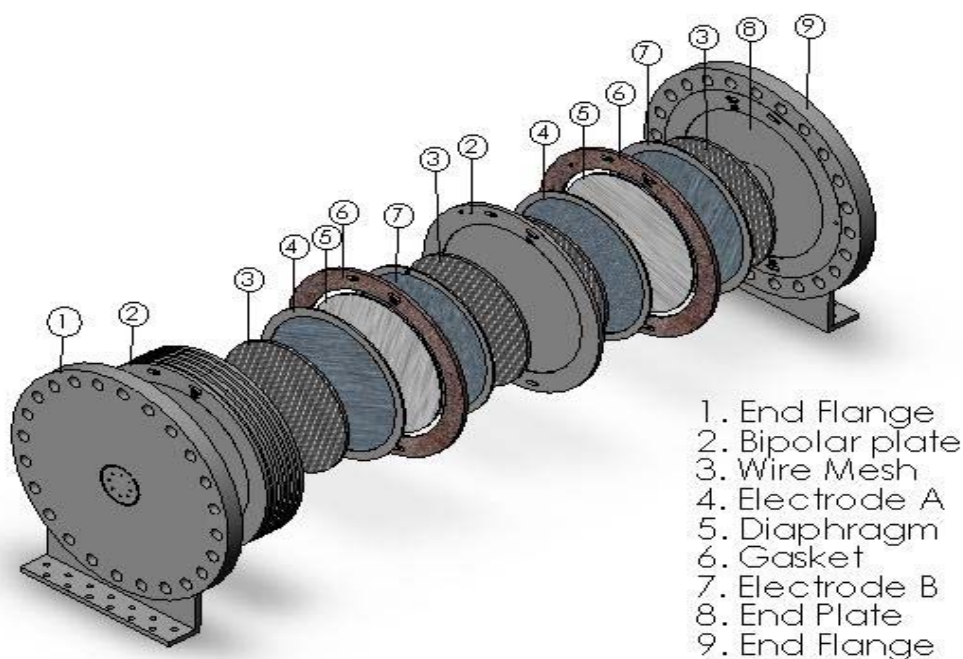


Fig. 3 Disassembled view of the compact electrolyser module

The bipolar plate is designed to incorporate

- i) The proper housing of the electrode holder rings into the anode and cathode chambers
- ii) A corrugated nickel wire mesh support to prevent the buckling of the thin porous electrodes and to give additional electrical contact between the plate and the electrode.
- iii) Concealed multiple port channels for electrolyte entry and electrolyte/gas exit for effective removal of the product gases into different streams from the cell space.
- iv) Separate and individual ducts for the removal of the gases from the cell module.

The Electrode holder rings have the following two functions.

- i) To hold the porous nickel plaques and provide effective electrical contact.
- ii) To distribute the electrolyte evenly through a semi-circular electrolyte channels made on the rear side.

EB welding was used to join the porous plaques and the rings for efficient current supply to the porous electrodes at high current density operation.. The rings were fit tightly on to a circular slot in the bipolar plate ensuring electrical contact between the plate and the rings both on the face and the edges of the rings. This makes sufficient electrical contact between all the current communicating components like the bipolar backing plate, electrode holder rings and the porous plaques themselves in each cell. The two end plates of the cell module made in the end flanges themselves facilitate the central feeding of the module current. The module was properly insulated from the rest of the electrolyser and the structure. The features of the bipolar plate and the end flange are illustrated in the fig. 4 and Fig. 5.



Fig. 4 Bipolar Plate



Fig. 5 End flange

This electrolyser incorporates design modifications in the cell module components to ensure the required thermal and electrochemical performance at low temperature and pressure. Especially the gas-liquid separators have been designed to meet the thermal and process needs. Thus it performs the following multiple functions.

- i) To hold the total volume of the electrolyte solution, thus avoiding a separate hold-up tank.
- ii) Cooling coils are incorporated within both separators, to remove the excess process waste heat from the electrolyte and to cool the gases for recovering the water vapour formed in the hot gases. This prevents the unnecessary inter equipment moisture transfer and subsequent feed and bleed loads on the DM water lines.
- iii) All the primary controls and interlocks functions are incorporated in the gas-liquid separator itself for necessary functional and safety needs.

6. OPERATION AND PERFORMANCE

The compact electrolyser cell module was completely fabricated in-house, assembled and installed for operational tests and trials. The plant was continuously operated round the clock at different current densities and logged on more than 1500 hrs of operation time. The module current varied from 100 amperes to 525 amperes at corresponding module terminal voltages of 75 to 110 volts. Though cell module and the electrolyser were designed for 80°C and 5 kg/cm², normally the operation was carried out below 60°C and 1.6 kg/cm² only to meet the operating requirements of this prototype electrolyser. Both the electrolyte and the product gases were also kept cooled by chilled water/ service water supply to meet the user needs. The operation has established that porous electrodes can operate at higher current densities even at a low temperature of 60°C also. The average cell performance under module operating conditions is illustrated in fig. 6.

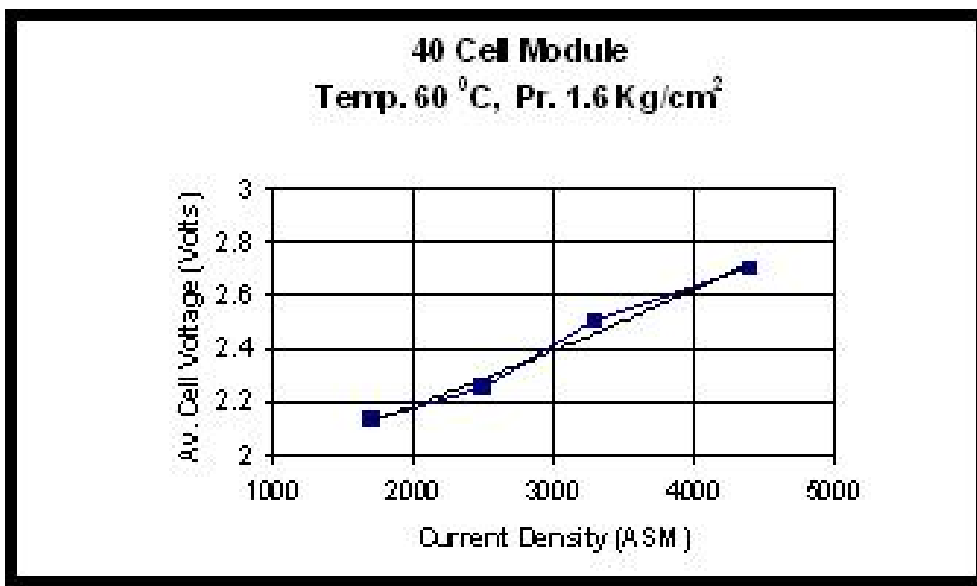


Fig. 6 Cell electrical performance in Compact Electrolyser module

7. FURTHER WORKS

The Compact electrolyser has been used as a prototype for developing portable and small capacity electrolyser plant construction using the high current density porous electrode incorporated cell modules. Presently, based on this prototype electrolyser, a 30 Nm³/hr hydrogen plant is being designed for operation at 85°C and 15 Kg/cm², having two cell modules capable of working at or beyond 5000ASM current density.

8. CONCLUSION

The design and operation of this compact electrolyser has demonstrated the suitability of using the advanced cell module design incorporating the porous nickel electrodes for making small

electrolysers capable of high current density operation at low temperature and pressure. The electrolyser design is being standardized for making ready built units of this capacity for higher pressures also. This size range can be easily adopted for various applications like generator cooling in large power stations, hydrogenation of oils, and future automotive fuel source as well as for oxygen use. Small-scale electrolysers (50-60 kW sizes) are very suitable for producing hydrogen fuel in automotive applications.

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