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Johnson Thermoelectric EnergyConverter andApplication For Clean Energy Production

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Abstract:- *Fossil fuel utilization efficiency has virtually reached its limit. Therefore use of waste heat energy is only means of achieving further increase in energy use efficiency with this type of fuel.This work presents a study of Johnson's thermoelectric energy converter a type of heat engine which converts heat directly into electric power by decomposition of hydrogen.The mechanism and factors considered for design of engine is explained .The Ericsson's cycle used in Johnson's thermoelectric energy converter is also explained.This paper discusses the use of Johnson's thermoelectric energy converter as a clean energy production device. This paper also emphasizes on ambient heat engine, Johnson's thermoelectric cell used in cars, and use of Johnson's thermoelectric energy converter for energy management.It also discusses the trends of converting waste heat into electricity using Johnson's thermoelectric energy converter.This paper gives the outline of green energy production by use of jtec*

Keywords- *Johnson thermoelectric energy converter, JTEC system, membrane electrode system*

I.INTRODUCTION

The JTEC is a breakthrough technology that directly converts thermal energy into electrical energy Thermodynamic engines have inherent difficulties in achieving high compression ratios and in achieving the near constant temperature compression and expansion processes needed to approximate Carnot equivalent cycles. Solid-state thermoelectric converters that utilize semiconductor materials have only been able to achieve single digit conversion efficiency. Alkali Metal Thermoelectric Converters (AMTEC), which operate on a modified Rankine cycle and the Stirling engine, have inherent limitations and these systems have not achieved performance levels as envisioned**.**
Unlike traditional multi-step engines, the JTEC device converts heat directly into electricity in a single step with unrivaled efficiency. It has long been a goal to develop an engine that operates on thermal energy that is freely available. Until now, thermodynamic engines that use compressible working fluids have generally been mechanical devices. These devices have inherent difficulties in achieving high compression ratios and in achieving the near constant temperature compression and expansion processes needed to approximate Carnot equivalent cycles. Solid-state thermoelectric converters that utilize semiconductor materials have only been able to achieve single digit conversion efficiency. It uses the photodecomposition and recombination of hydrogen in a fuel cell via an approximate Ericsson cycle**.** A need remains for an electrochemical conversion system that does not require a continuous source of reactant, which does not require an electrolyte which may be plugged over time and which may be operate at relatively low temperatures The JTEC converts heat into electrical energy by compressing and expanding hydrogen gas.
Until now, thermodynamic engines that use compressible working fluids have generally been mechanical devices. These devices have inherent difficulties in achieving high compression ratios and in achieving the near constant temperature compression and expansion processes needed to approximate Carnot equivalent cycles.Solidstate thermoelectric converters that utilize semiconductor materials have only been able to achieve single digit conversion efficiency. Extensive resources have been applied toward Alkali Metal Thermoelectric Converters (AMTEC), which operate on a modified Rankine cycle and on the Stirling engine. However, because of inherent limitations, these systems have not achieved envisioned performance levels.
The JTEC is an all solidstate engine that operates on the Ericsson cycle. Equivalent to Carnot, the Ericsson cycle offers the maximum theoretical efficiency available from an engine operating between two temperatures. The JTEC system utilizes the electrochemical potential of hydrogen pressure applied across a proton conductive membrane (PCM). The membrane and a pair of electrodes form a Membrane Electrode Assembly (MEA) similar to those used in fuel cells. On the high pressure side of the MEA, hydrogen gas is oxidized resulting in the creation of protons and electrons. The pressure differential forces protons through the membrane causing the electrodes to conduct electrons through an external load.

II.TECHNOLOGY

The JTEC system utilizes the electro-chemical potential of hydrogen pressure applied across a proton conductive membrane (PCM). The membrane and a pair of electrodes form a Membrane Electrode Assembly (MEA) similar to those used in fuel cells. On the high-pressure side of the MEA, hydrogen gas is oxidized resulting in the creation of protons and electrons. The pressure differential forces protons through the membrane causing the electrodes to conduct electrons through an external load. On the low-pressure side, the protons are reduced with the electrons to reform hydrogen gas. This process can also operate in reverse. If current is passed through the MEA a low-pressure gas can be "pumped" to a higher pressure. The JTEC uses two membrane electrode assembly (MEA) stacks. One stack is coupled to a high temperature heat source and the other to a low temperature heat sink. Hydrogen circulates within the engine between the two MEA stacks via a counter flow regenerative heat exchanger. The engine does not require oxygen or a continuous fuel supply, only heat. This feature coupled with the use of a regenerative counter flow heat exchanger will allow the engine to approximate the Ericsson cycle.

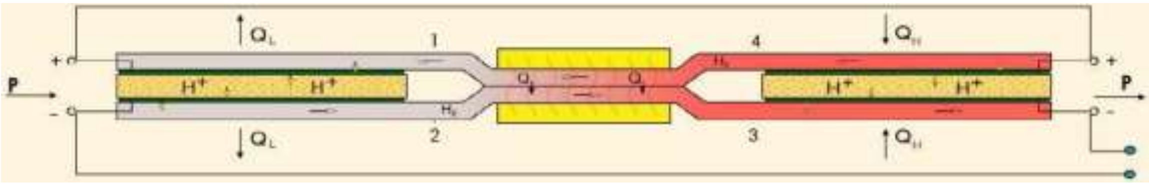


Fig 2.1 JTEC system

The Johnson Thermo-Electrochemical Convertor (JTEC) is an all solid-state device that operates on the Ericsson cycle. Equivalent to Carnot, the Ericsson Cycle offers the maximum theoretical efficiency available from a converter operating between two temperatures. The JTEC uses two membrane electrode assembly (MEA) stacks. One stack is coupled to a high temperature heat source and the other to a low temperature heat sink. Hydrogen circulates within the engine between the two MEA stacks via a counter flow regenerative heat exchanger. For some applications the engine does not require oxygen or a continuous fuel supply, only a temperature difference of at least10% between two areas. Like a gas turbine engine, the low temperature MEA stack is the compressor stage and the high temperature MEA is the power stage. The MEA stacks will be designed for sufficient heat transfer with the heat source and sink to allow near constant temperature expansion and compression processes.

VOC= RT/2F ln(PHi/PLow).

Where VOC is open circuit voltage, R is the universal gas constant, T is the cell absolute temperature in degrees Kelvin, F is Faraday's constant, PHi is the hydrogen pressure side and P Low is the hydrogen pressure on the low-pressure side.

III.CONSTRUCTION

JTECconsists of two electrochemical cells with proton conducting membrane. There are four electrodes (22, 23, 28, and 29) with two polymer proton conducting membrane made up of nafion. There are two conduits 11 and 12.Conduit 12 is a high pressure conduit, and conduit 11 is a low pressure conduit. The working fluid is hydrogen.

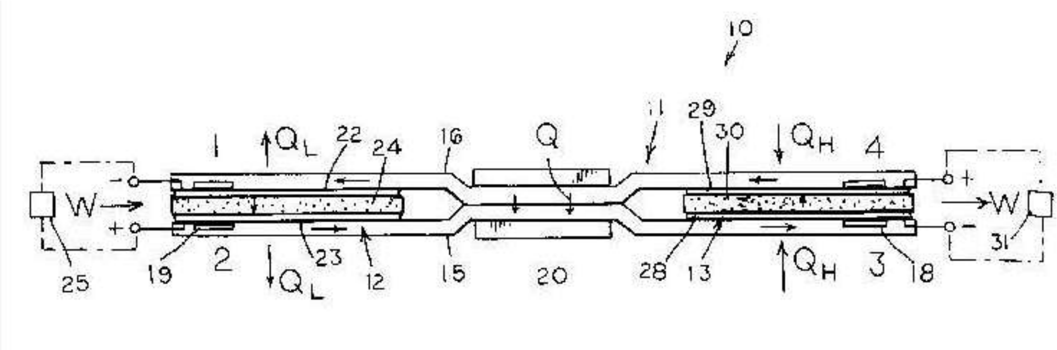


Fig 3.1 Construction of JTEC

A regenerative counter flow heat exchanger (20) is used to maintain an isothermal process.25 indicates source of voltage.31 is a load through which current flows.QL and QH indicates process where heat is added and released from the system. This process uses transfer of ions for conducting electricity.So the main components of JTEC are -

1. Membrane Electrode Assembly
2. Regenerative heat exchange
3. Proton conductingMembrane
4. Two conduits made up of non-reactive stainlesssteel

The conduit system 11 consists of Hydrogen gas. When an electronic voltage source is applied across electrode 22 the hydrogen gets ionized and gets converted into H+ ions.This H+ ions are generated due to voltage supplied. This ions are conducted by membrane electrode assembly .This H+ ions are reduced at electrode 23.The reaction is as follows

$$2\,H^{+} + 2\,e^{-} \rightarrow H$$

So excess hydrogen gas is generated in conduit 15.So a pressure differential is generated .High pressure is generated in conduit 15.The directions of arrow indicate the flow of hydrogen .So the hydrogen gas on electrode 23 moves to electrode 28 The passage of hydrogen gas H from the second conduit 16 to the first conduit 15 causes a pressure differential across the second electrochemical cell 13. As the hydrogen pressure differential between the first and second conduits 15 and 16 increases an electrical potential across the second electrochemical cell 13 is created and progressively increased. Hydrogen gas H at the higher pressure conduit 15 adjacent the second electrochemical cell third electrode 28 is oxidized into hydrogen protons. These hydrogen protons are forced by the hydrogen pressure differential through the sec and proton conductive membrane 30 to the fourth electrode 29 at the lower pressure second conduit 16. At the fourth electrode 29 the hydrogen protons are reduced into hydrogen gas. As such, the oxidation of the hydrogen gas causes the release of electrons which are passed to the third electrode 28.While the reduction of protons into hydrogen gas causes the acceptance or receiving of electrons from the fourth electrode29, thereby inducing an electric current through load.

IV.MEMBRANE ELECTRODE ASSEMBLY

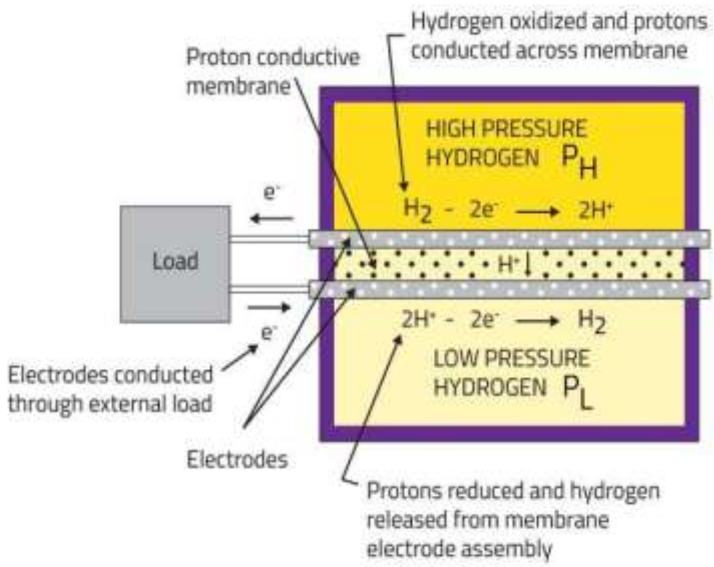


Fig 4.1 Membrane Electrode system

A membrane electrode assembly (MEA) is an assembled stack of proton exchange membranes (PEM) catalyst and flat plate electrode. The electrode is made up of copper. The membrane electrode assembly consists of two electrodes .At highpressure side of MEA hydrogen gas is decomposed to form hydrogen ions. These hydrogen ions are passed through nafion. This occurs due to the pressure differential. Then ions reduced at other end of assembly. The electrons flow to the electrode assembly through external load causing electric current. This can operate in reverse. If current is passed through MEA a low pressure gas can be pumped to a highpressure.

The PEM is a flouro polymer (PFSA) proton permeable but electrical barrier. This barrier allows the transport of the protons from the anode to the cathode through the membrane but forces the electrons to travel around a conductive path to the cathode. Companies such as DuPont and Dow produce PEMs. DuPont's PEM offering can be found under the trade name Nafion. The most commonly used Nafion PEMs are Nafion XL, 112, 115, 117, and 1110.Current service life is 7,300 hours under cyclingconditions, while at the same time reducing platinum group metal loading to0.2 mg/cm2.Commonly used materials for these electrodes are carbon cloth or carbon fiber papers. Many other different methods and procedures also exist for the production of MEAs which are quite similar between fuel cells and electrolyzes.

V.Regenerative Heatexchanger

A regenerative heat exchanger, or more commonly a regenerator, is a type of heat exchanger where heat from the hot fluid is intermittently stored in a thermal storage medium before it is transferred to the cold fluid. To accomplish this the hot fluid is brought into contact with the heat storage medium, then the fluid is displaced with the cold fluid, which absorbs the heat.

In regenerative heat exchangers, the fluid on either side of the heat exchanger can be the same fluid. The fluid may go through an external processing step, and then it is flowed back through the heat exchanger in the opposite direction for further processing. Usually the application will use this process cyclically or repetitively.

VI. Thermodynamic Analysis

The JTEC is an all solid state engine that operates on the Ericsson cycle. Equivalent to Carnot, the Ericsson cycle offers the maximum theoretical efficiency available from an engine operating between twotemperatures

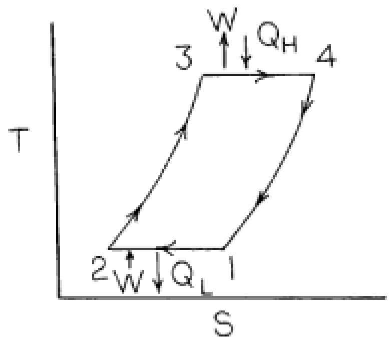


Fig 6.1 T-S plot

VII. Ericson Cycle

The following is a list of the four processes that occur between the four stages of the ideal Ericsson cycle:

1. Process 1 to 2: Isothermal compression. The compression space is assumed to be intercooled, so the gas undergoes isothermal compression. The compressed air flows into a storage tank at constant pressure. In the ideal cycle, there is no heat transfer across the tankwalls.
2. Process 2 to 3: Isobaric heat addition. From the tank, the compressed air flows through the regenerator and picks up heat at a high constant-pressure on the way to the heatedpower-cylinder.
3. Process 3 to 4: Isothermal expansion. The power-cylinder expansion-space is heated externally, and the gas undergoes isothermalexpansion.
4. Process 4 to 1: Isobaric heat removal. Before the air is released as exhaust, it is passed back through the regenerator, thus cooling the gas at a low constant pressure, and heating the regenerator for the nextcycle

The Ericsson engine is based on the Ericsson cycle, and is known as an "external combustion engine", because it is externally heated. To improve efficiency, the engine has a regenerator or recuperator between the compressor and the expander. The engine can be run open- or closed-cycle. Expansionoccurs simultaneously with compression, on opposite sides of the piston. The ideal Otto and Diesel cycles are not totally reversible because they involve heat transfer through a finite temperature difference during the irreversible isothermal heat- addition and heat-rejection processes. The aforementioned irreversibility renders the thermal efficiency of these cycles less than that of a Carnot engine operating within the same limits oftemperature.

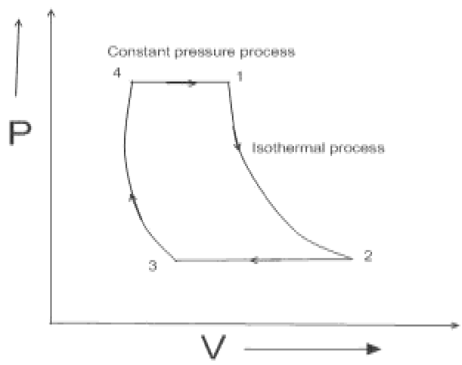


Fig 7.1 P-V plot

VIII. EFFICIENCY

An efficiency JTEC works on Ericsson cycle, which has a efficiencyin ideal conditions equal to Carnotcycle. Efficiency of jtec only depends on the temperature at both theends.

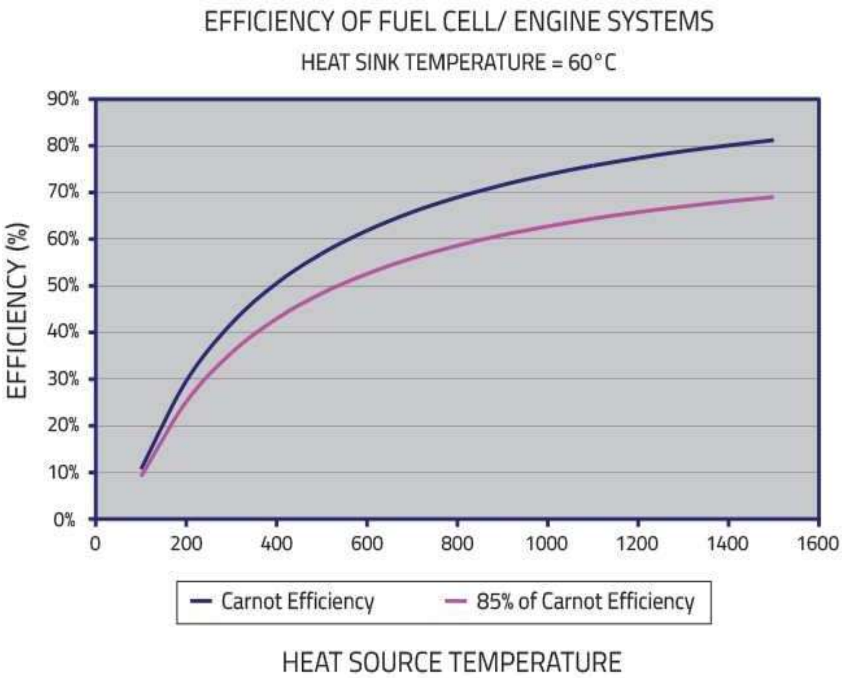


Fig 8.1 Efficiency of cell plot

The bigger the temperature differential, the higher the efficiency. With the help ofUniversity, Johnson hopes to have a low-temperature prototype (200-degree centigrade) completed within a year's time. The pair is experimenting with high-temperature membranes made of a novel ceramic material of micron-scale thickness. Johnson envisions a first-generation m capable of handling temperatures up to 600 degrees. (Currently, solar concentration using parabolic mirrors tops 800 degrees centigrade.) Based on the theoretical Carnot thermodynamic cycle, at 600 degrees efficiency rates approach 60 percent, twice those of today's solar Stirling engines.Jtec has efficiency almost double than Stirling engine.

8.1 Reasons for high efficiency

1. No moving parts. So no friction and no mechanicalfailure
2. Efficiency depends only upon Final and initialtemperatures
3. Efficiency is almost equal to Carnotefficiency

IX. Benefits over Electrochemical, Fuel cells

The conversion of heat energy or chemical energy to electrical energy, or visa-versa, may be accomplished in a varietyof Ways. It is known that electrochemical cells or batteries rely on redox reactions wherein electrons from a reactant being oxidized are transferred to a reactant being reduced. With the separation of the reactants from each other, it is possible to cause the electrons to W through an external circuit where they can be used to perform Work. Electrochemical cells however have had a problem of exhausting the reactants. Although cells can be designed to be recharged by applying a reverse polarity voltage across the electrodes, such recharging requires a separate electrical source. During the recharging of the cell the cell typically is notusable.

Fuel cells have been developed in an effort to overcome problems associated with electrochemical cells. Typically, fuel cells operate by passing an ionized species across a selective electrolyte which blocks the passage of the non-ionized species. By placing porous electrodes on either side of the electrolyte, a current may be induced in an external circuit connecting the electrodes. The most common type of fuel cell is a hydrogen-oxygen fuel cell which passes hydro gen through one of theelectrodes while oxygen is passed through the other electrode. The hydrogen and oxygen combine at the electrolyte-electrode interface to produce Water. By continuously removing the Water, a concentration gradient is maintained to induce the hydrogen and oxygen to the cell.

These types of fuel cells however suffer from a number ofdisadvantages. These cells must be continuously supplied with a reactant in order to produce electricity continuously. Additionally, these cells produce a continuous product stream which must be removed, the removal of which may pose a problem. The porous electrodes of these fuel cells must allow the passage of the reactant entering the cell. However, overtime these porous electrodes can become fouled or plugged to slow or even prevent the passage of the reactant. Such slowing of the reactant reduces the production of electricity. Lastly, the selection of an appropriate electrolyte is nodalWays easy. The electrolyte must rapidly transport the ionized species in order to increase the current production. Frequently, the limited migration of the ionized species through the electrolyte is a limiting factor on the amount of currentproduced.

X. ADVANTAGES

1. Unrivaled Efficiency- Unlike traditional multi-step energy conversion processes, the JTEC device converts heat directly into electricity in a single step. Operating on the Ericsson Cycle, the device has potential for significant efficiency improvements versus current technology

2. Cost-Savings - The JTEC is a solid-state heat engine with no moving parts, which offers a low maintenance alternative and reduces operating staff and related needs. It can convert otherwise wasted heat into electricity, which decreases both (a) fuel costs and (b) maintenance costs.

3. Clean Energy -The JTEC is able to harvest energy from ambient environments, meaning it has the potential to use solar heat or otherwise wasted heat, reducing our consumption of fossil fuels while producing clean energy.

4. Versatile -JTEC devices are scalable enough to be adapted for large-scale power plants and have the potential to be made small enough to convert body heat into power for personal electronics.

5. Reversible -The JTEC device has the ability to operate in reverse as a cooling device, for highly efficient air conditioning and refrigeration application

XI.JTEC FOR ENERGYMANAGEMENT

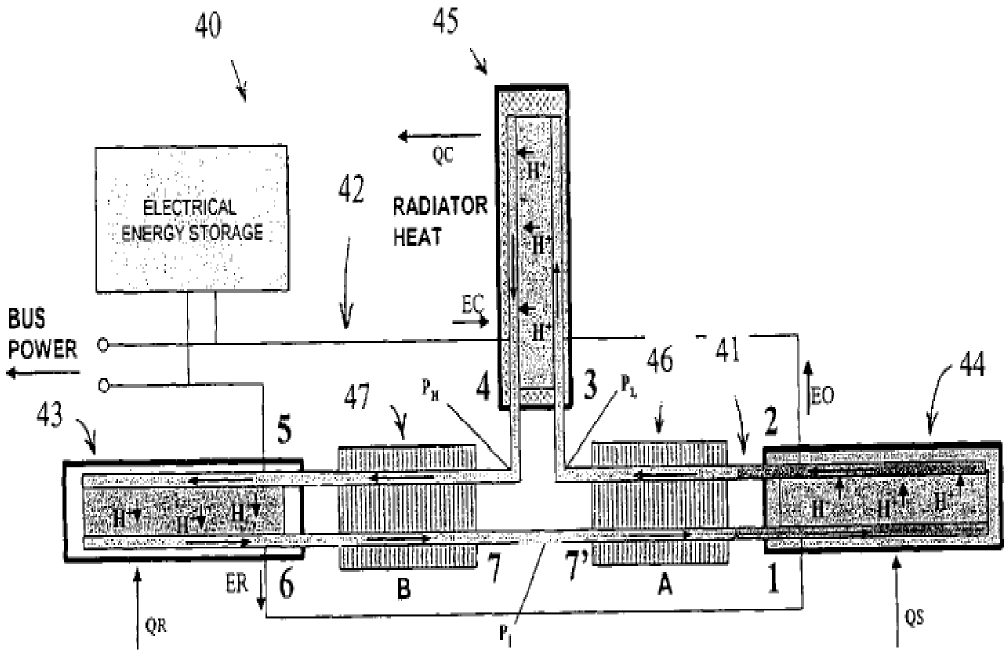


Fig 11.1 JTEC Energy management

In a preferred form of the invention an electrochemical conversion system for managing energy comprises a first electrochemical cell having a first ion conductive material, a first electrode mounted upon one side of the first ion conductive material, and a second electrode mounted upon one sideof the first ion conductive material opposite the first electrode, a second electrochemical cell having a second ion conductive material, a third electrode mounted upon one side of the second ion conductive material, and a fourth electrode mounted upon one side of the second ion conductive material opposite the third electrode, and a third electrochemical cell having a third ion conductive material, a fifth electrode mounted upon one side of the third ion conductive material, and a sixth electrode mounted upon one side of the third ion conductive material opposite the fifth electrode. The system also includes a conduit system having conduit, second conduit and third conduit. The first conduit is in fluid communication with the first electrochemical cell second electrode and the second electrochemical cell third electrode. The second conduit is in fluid communication with the second electrochemical cell fourth electrode and the third electrochemical cell fifth electrode. The third conduit is in fluid communication with the third electrochemical cell sixth electrode and the first electrochemical cell first electrode.

The system also includes a first heat exchanger for exchanging heat between the first conduit adjacent the first electrochemical cell and the third conduit adjacent the ?rst electro chemicalcell, and a second heat exchanger for exchanging heat between the first conduit adjacent the second electro chemical cell and the second conduit adjacent the second electrochemical cell. A supply of ionizable gas is contained within the conduit system and an electrical circuit coupled to the firstelectrode, the second electrode, the third electrode, the fourth electrode, the fifth electrode and the sixth electrode. The electrical circuit includes an electrical energy storage device.

XII. THERMODYNAMIC ANALYSIS

In order to carry out a thermodynamic analysis, the conservation laws of mass and energy have beenapplied to each component of the system. Every component has been considered as a control volumeexchanging heat, work and inflow and outflow streams with its surrounding. To simplify the theoreticalmodel, the following assumptions have been considered:
The analysis is carried out under steady state conditions and assuming thermodynamic equilibrium at allpoints of thecycle;The entropy diagram shown in FIG. 2 illustrates the theoretical change in entropy of the just described system during its operation in an ideal or perfect situation where in the heat exchanger is ideal or 100 percent efficient, i.e., wherein outside influences on the system are not considered.

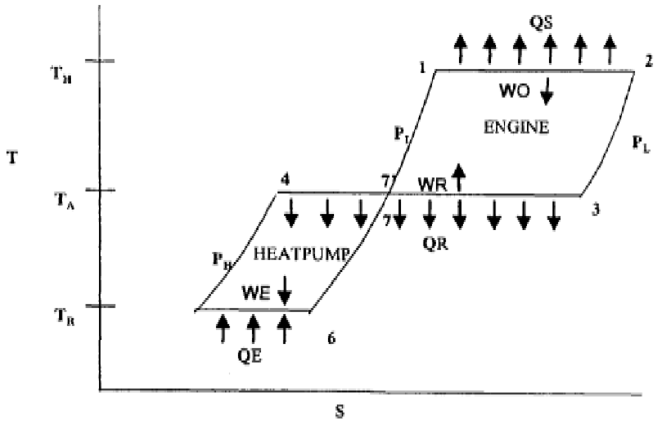


Fig 12.1 T-S plot

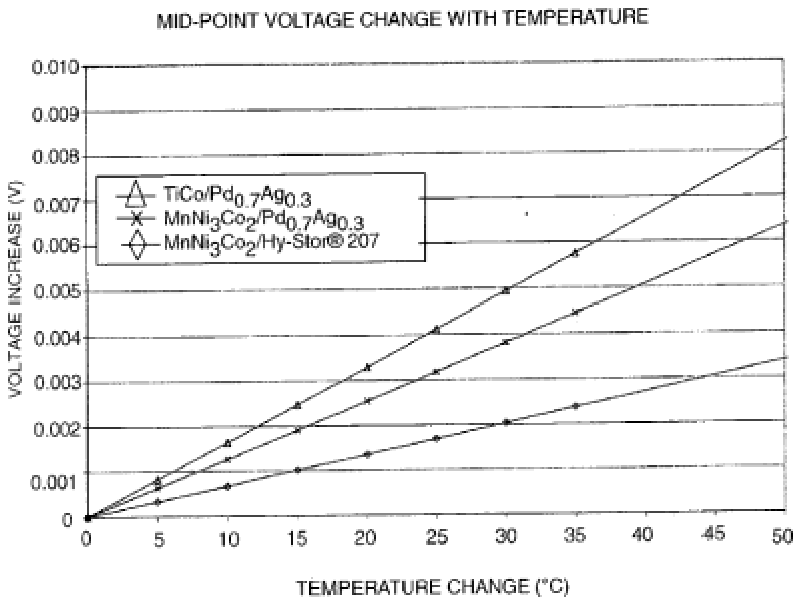
The system may also be operated in a reverse cycle as a heatpump, as shown in. Here, the second electrochemical cell 13 is coupled to an external power supply 25While the first electrochemical cell 12 is coupled to an external load 31. Also, the region adjacent the first electrochemical cell 12 is provided with heat energy (QL) by While heat energy is extracted (QH) from the region adjacent the second electrochemical cell 13. The operation of the device in thisconfiguration is the extraction of heat energy (QL) from a low temperature source and supply it as heat energy (QH) to a higher temperature source, as illustrated in FIG. 3. The principles of the invention however remain the same as those previously described, with the system here providing a change in the heat energy.

XIII. JOHNSON’S AMBIENT HEATENGINE

An ambient-heat engine has a substantially thermally-conductive housing whose interior is divided into a high-pressurechamber and a low-pressure chamber by a substantially gasimpermeable barrier. An ionically-conductive, electrical-energy- generating mechanism forms at least a portion of the barrier. First hydrogen- storage medium is disposed within the high-pressure chamber and second hydrogen-storagemedium is disposed within the low-pressure chamber. An electrical-energy storage device connected to the ironically conductive, electrical mechanism is operable between a charge condition and a discharge conditioning). The Johnson Ambient-Heat Engine (JANE) (an electrochemical conversion system) uses thermal transients that naturally occur in its ambient environment to generate electrical power. During selected periods of high temperature, the electrochemical conversion system naturally produces a high voltage output for a given pressure ratio between the high- pressure and low-pressure chambers. The electrical-energy storage device is charged by allowing hydrogen to expand from the high-pressure chamber into the low- pressure chamber during periods of high temperature and thereby high voltage.

Conversely, the electrochemical conversion system produces low voltage during periods of low temperature. The electrical-energy storage device is discharged during selected low voltage periods to compress hydrogen from the low-pressure chamber back into the high-pressure chamber. Given two electrons per hydrogen molecule, returning the hydrogen to the high-pressure chamber requires the same amount of current as that generated when it transitioned to the low-pressure chamber. However, less energy is required since the hydrogen is returned during periods when the voltage of the electrochemical conversion system is low. The difference in energy produced during high-temperature expansion versus low temperature-compression is retained within the electrical-energy storage device and is available for supply to an external load. The below figure is a data plot showing the voltage potential of proton-conductive Membrane-Electrode

Assembly (MEA)cell as a function of temperature for selected ranges of hydrogen pressure ratio



XIV. USE OF JTEC IN MILTARY AND AEROSPACE

1. The JTEC is especially suited to militaryapplication.
2. As a solid state device with no mechanical moving parts, it is designed to be low maintenance, with the ability to be left in the field unattended for extended periods oftime.
3. The JTEC is being designed to withstand harshenvironments.
4. It is possible to design formats of the JTEC with no metals, facilitating stealth operations.
5. No ongoing liquid fuel input is required, making the JTEC a costeffective technology

XV.JTEC AS A FUEL CELL IN CAR

1. Jtec can be used as a battery in acar. Once charged fully jtec can go 1000miles as that compared to 200 miles by current hydrogen fuelcell
2. It is made up ofceramic so it has greaterlife
3. Lessweight.

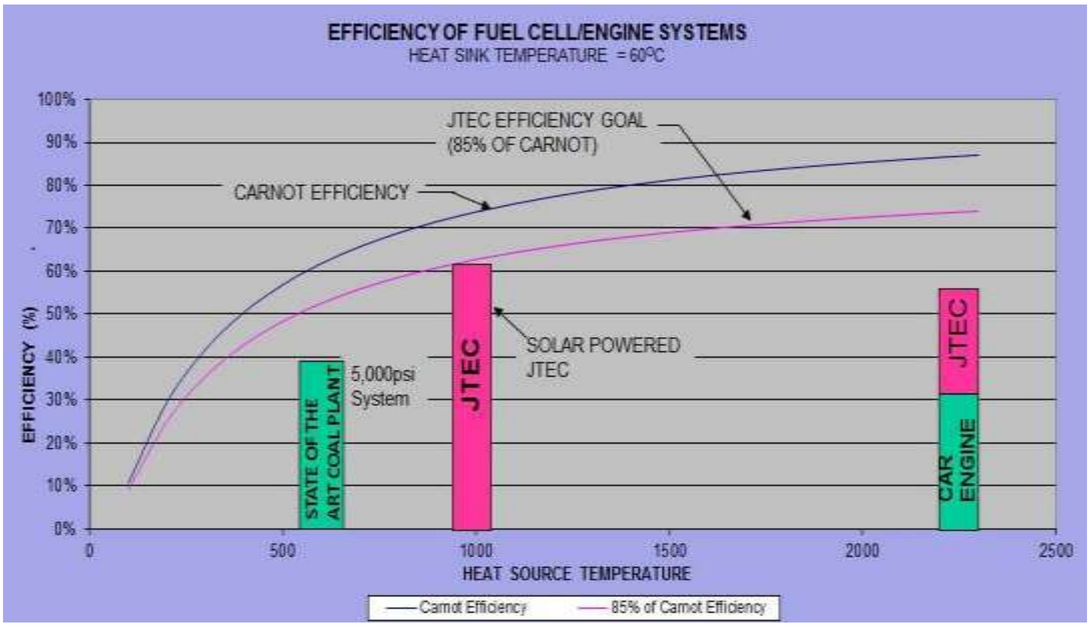


Fig 15.1 comparing efficiencies

XVI.USE OF JTEC IN WASTE HEAT RECOVERY

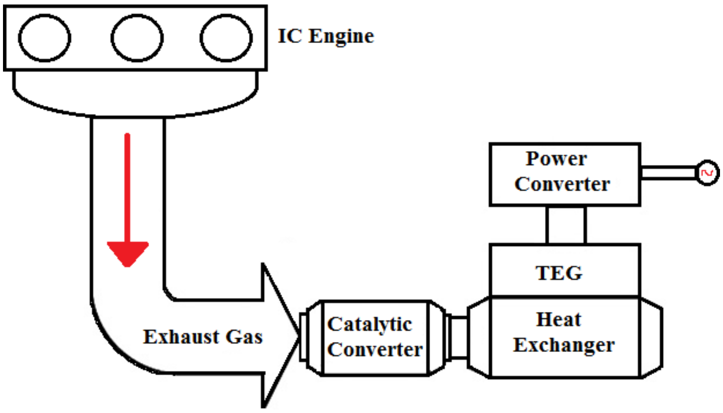


Fig 16.1 JTEC waste recovery system

JTECcan be used to recover waste heat from IC engine. The block indicating TEG is a thermoelectric energy converter. The efficiency of conversion of energy off jtec is double as that compared to any other energyconverter

XVII. JTEC FOR HARVESTING SOLAR ENERGY

Jtec can be used to harvest solar energy. JTEC could generate electricity from practically any heat source, from very small, just a few degrees, to very large temperature differences. JTEC approximates the Ericsson thermodynamic cycle which is Carnot equivalent. Research on this technology offers the potential for achieving solar power efficiency of 50% in the short-term and 80% in the long-term, far beyond what is expected from photovoltaic both in efficiency and in cost.

XVIII.CONCLUSIONS

1. The JTEC was confirmed as a potential heat engine for clean energy generation.
2. It can be used in many fields ranging from small scale memes to large nuclear powerplants.
3. The output of jtec is almost double as compared to other thermoelectric energy converters.
4. Nuclear power plants expend an enormous amount of energy on cooling the reactors. With the JTEC the heat created by the reactors could be absorbedand converted into clean energy in the form of electricity.
5. This represents dual cost savings: reduction in cooling costs and reduction in other electricity costs as the JTEC in the nuclear power plant now generates additionalelectricity.
6. JTEC is a viable source of converting solar energy to electricenergy.
7. This is the future of solar energyutilization.

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