Generation of Alternate fuel Hydrogen From Waste (Urine)

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Abstract: For power generation currently mankind is highly dependent on fossil fuels. With reserves of fossil fuels declining at an exponential rate, there is a need for an alternative fuel for power generation. Hydrogen has tremendous potential to be used as clean & green fuel. There are several reported methods for hydrogen generation such as by using natural gas, oil reforming, coal gasification and electrolysis of water but all of them suffer from drawbacks such as massive emission of GHG, release of pollutant or high cost. A pollution free cost effective method of hydrogen generation is electrolysis of urine/urea rich water. This process can be carried out at much lower voltage (0.37 V) as compared to electrolysis of water which requires 1.23 Volts. This process can also be utilized on-board in an automotive to generate hydrogen on the go, hence solving the problem of hydrogen storage in hydrogen cars.

I. INTRODUCTION

A. Rise in demand of energy and the problem of pollution with increase in population and also advancement in technology, the demand for energy is increasing at an exponential rate. The shrinking oil reserves are expected to last only 42 years as of 1998[1]. Availability of fuel is not the only problem; simultaneously the problem of pollution needs to be addressed. Hence mankind is looking for an alternative fuel which is available in abundance to satisfy the needs of an ever increasing population and at the same time is green enough to not pollute the environment.

B. Hydrogen: the fuel of the future

Hydrogen has tremendous potential as fuel. Speaking about the abundance of hydrogen, it is the most abundant element on earth [3]. Also hydrogen is a green fuel that is on consumption of hydrogen there is no release of pollutants.

Hence hydrogen can be the abundant and green fuel mankind is searching for. But the processes by which this hydrogen is extracted are still either non-green or costly. The various available methods to produce hydrogen are Steam reforming of methane gas, Coal gasification, Electrolysis of water, Solar-Hydrogen system [3]. The first two processes are non-green and the latter two are very expensive processes. The detailed disadvantages are listed in **Table 1** [3]. Thus there is a need for a green process that could generate this green fuel hydrogen.

C. Urea electrolysis: A green and cheap method for hydrogen generation For large scale use of hydrogen as a fuel, a safe, efficient and ecofriendly method for its production is required. Electrochemical oxidation of urea to hydrogen in alkaline media is a comparatively new method for hydrogen generation. It has significant benefits over standard hydrogen production methods. Pure hydrogen (100%) is produced at low temperature, pressure and energy consumption along with other valuable products, such as nitrogen and clean water [2].

D. Raw material for the process and its sources

The raw material required for the process is Urea (a major constituent of urine) and an alkali like. NaOH, KOH etc. Major sources of Urea include domestic animal excreta, synthetic fertilizer, oceans, burning of biomass, crops, human excreta, agricultural runoff and industrial processes [1]. India being an agricultural country, agricultural runoff and urea rich waste water is available in abundance. Also large population of India will be boon if we develop this technology for generation of hydrogen from urine.

Table 1: Various techniques of hydrogen generation

Methods	Disadvantages
Steam reforming of methane gas	Resource is non renewable and also leads to emission of carbon dioxide gas
Gasification	Causes emission of carbon dioxide and has a very low efficiency of 45%
Electrolysis of water	Produces carbon dioxide emission if coal is used as source. Output energy may be less than input energy.
Solar-hydrogen system	Expensive

II. METHODOLOGY

A. Composition of Urine

Urine mainly consists of two components, namely, Urea and Water.

B. Electrolysis of Urea

Electrolysis is a process of breaking down a molecule or compound into its constituent elements, by passage of electric current. When Urea is electrolyzed, the reactions that take place are as follows:

Anode reaction:

$$CO(NH_2)_2(aq.) + 6OH^-(aq.) \Rightarrow N_2(g) + 5H_2O + CO_2(g) + 6e^-$$

(urea) (hydroxyl) (nitrogen) (water) (carbon dioxide)

Cathode reaction:

$$6H_2O\ (l) + 6e \Rightarrow 3H_2\ (g) + 6OH^-(aq.)$$

(hydrogen)

Overall reaction:

$$CO(NH_2)_2(aq.) + H_2O(l) \Rightarrow N_2(g) + 3H_2(g) + CO_2(g)$$

At anode urea is oxidized in the basic medium and there is generation of nitrogen gas and carbon dioxide. At cathode water undergoes reduction reaction and there is generation of hydrogen gas. These gases can be extracted from the electrodes with the help of simple tubes over them. Carbon dioxide produced reacts with the positive ion present in the electrolyte and leads to the formation of a compound like K_2CO_3 or Na_2CO_3, hence carbon dioxide is not released as a gas. The reactants required are urea and water as can be seen from the overall reaction and these two materials are the two major constituents of urine. Hence urine could serve the purpose of raw material for the process. The theoretical voltage required for the process is 0.37V at standard conditions [2].

C. Advantages of this method over Water electrolysis

Table 2 shows the advantages of electrolysis of urea over electrolysis of water. It can be noted from the reactions involved in the two processes that only 1 mole of hydrogen is generated when 1 mole of water is electrolyzed, whereas on electrolysis of urea 3 moles of hydrogen are produced. Also electrolysis of urea takes place at 0.37V and electrolysis of water requires 1.23 V, which is nearly 3 times more. Hence in terms of both productions of hydrogen as well as input energy required, electrolysis of urea is advantageous over electrolysis of water.

D. Reaction Components

Reaction vessel: Reaction can be carried out in the light gauge iron, steel or other material like plastic [4].

Anode: Adsorption of urea takes place at the conducting component of the anode. Thus the conducting component at the anode can be one or more metals active towards electrochemical oxidation of urea. Active metals may include Nickel, Co, Fe, Cu, Pt, Ir, Ruthenium, Rhodium, and its alloys. [4].

Cathode: The conducting component of cathode may be copper, cobalt, iridium, iron, nickel, platinum, ruthenium, rhodium, palladium and mixtures and its alloys. [4].

Electrolyte: Solution containing urea and any of the following:

LiOH, KOH, NaOH, MgOH, $Ca(OH)_2$, Rubidium hydroxide, Cesium hydroxide, Barium hydroxide, Strontium hydroxide [4]. KOH is most widely used. Concentration of Hydroxide salt (KOH) usually ranges from 2M to 6M [4].

Voltage source range: Direct current supply source can be used as power source for the process. A voltage of 0.85 V to less than about 1.7 V is generally applied for the oxidation of urea. [4]. Best results are obtained between 1.4V to 1.6V [4].

Table 2: Comparison of Urea and water electrolysis

	Reaction of electrolysis	Production	Consumption
Water	H2O ⇨ H2 + ½ O2	1 mole of hydrogen	1.23 Volts
Urea	CO(NH2)2 + H2O ⇨ N2 + 3 H2 + CO2	3 moles of hydrogen	0.37 Volts
Conclusion		3 times more production	3 times less consumption

III. ADVANTAGES

A) Non-polluting nature of the process (Green Process)

On consumption of fossil fuels the byproducts obtained are nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon dioxide (CO_2) and sulphur dioxide (SO_2). These emissions include potential green house gases and leads to problem of global warming and acid rain. ThereMulticon paper finale.doc is no release of such pollutants in the process of electrolysis of urea. Hence it is a green process for the generation of a green fuel, i.e. Hydrogen.

B) Availability of raw materials

The raw material required for the process is available in abundance. In case of other fuels like fossil fuels, when population increases, the demand grows but the supply rate remains same. But in case of this process, if population grows it would increase the raw material too, and hence supply can increase simultaneously with the demand.

C) 100% Faradic efficiency

Ammonia electrolysis (which is very similar to urea electrolysis) has 100% Faradic efficiency [1] and hence calculations for current required for the process can be done very easily.

D) Reduces ammonia emissions

Urea is converted to ammonia over a period of time. Ammonia emissions contribute to the formation of ammonium nitrate and sulphate. These emissions can result in health problems. When urea produced is utilized for this process it leads to reduction in ammonia emissions.

E) Remediates denitrification of waste water

Current methods for waste water denitrification are expensive and time consuming. This process can remediate denitrification of waste water.

IV. IMPACTS

A) Could solve the problem of energy crisis

Since the raw material required for the process is available in abundance and would in fact grow if population grows, this process can solve the problem of energy crisis.

B) Could solve the problem of pollution

Since the process is entirely green, it can address the problem of pollution.

C) Health impacts

Urea rich waste water is widely abundant and currently purged into rivers and lakes where it undergoes a natural conversion to ammonia. Ammonia is then released in the gas phase to Earth's atmosphere leading to a variety of health problems including: asthma attacks, chronic bronchitis, and even premature mortality, resulting in billions of dollars in health costs each year [1,2]. This expenditure can be saved if urea is electrolyzed and not let to change to ammonia.

D) Waste water denitrification can become inexpensive

Unlike the current methods being used for waste water denitrification, this process could be a cheap and effective method for the purpose of denitrification of waste water.

V. CURRENT TRENDS

Current researches in Urea electrolysis focus on these developments to make the process more efficient and to optimize the output:

A) Most suitable electrode material and structure

Noble metals like Pt, Ir, Rh etc. have shown good electro catalytic activity in alkaline medium. But the use of noble metals increases the cost of the apparatus and hence hinders the commercialization of the process. To overcome this problem various metals were tested and it was found that inexpensive nickel gave higher electro catalytic activity as compared to the noble metals. Further research proved that a combination of nickel with noble metals for e.g. Ni-Pt, Ni-Ir etc gave better results however at the expense of an increased cost [6].

Increase in surface area of electrode increases the number of electro active sites and hence increases the current density and urea electrolysis efficiency. Various shapes of electrodes were tested which includes Ni deposited on Carbon sponge, hexagonal and hollow sphere electrodes. The onset voltage obtained by using hexagonal electrode was 0.300 V [7,11].

Also nickel electrodeposited nano composites have been used as electrodes, for e.g. nano cup three dimensional arrays , nanowires, nanotubes etc [6,7,8,9,10].

B) Use of gel electrolyte

Use of gel electrolyte instead of aqueous KOH results in a system that is comparatively inexpensive, leak proof, compact and hence more suitable in portable applications. PAA (Poly acrylic acid) is a gel electrolyte that has been found suitable for urea electrolysis.

C) Using the process for on-board hydrogen generation in automotives

VI. ON-BOARD HYDROGEN GENERATION IN AUTOMOTIVES

A hydrogen fuel cell vehicle (HFCV) converts 50-60% available energy in hydrogen as compared to an ICE that converts only 20-30% energy of gasoline.

Although automobile sector has made a move towards utilizing hydrogen as fuel, the problem that it faces is the storage of hydrogen.

Energy content of hydrogen is 2.7 times more than that of gasoline by weight. Although this seems like an advantage but at the same time carrying a large amount of hydrogen on board can prove fatal in case of an accident. Hence the automobile sector is looking for a method to generate hydrogen on board according to demand.

The process of urea electrolysis is now being considered as a solution to the problem.

A general layout of how this process can be used on board on a vehicle is depicted in **figure 1**. The components required are Urea storage tank, Urea electrolytic cell, Hydrogen drum, Compressor, PEMFC, Controller, Electric motor and a startup battery [1]. Urea being inflammable at all temperatures avoids the risk of fire in case of an accident.

The function of hydrogen drum is to store just 1 millimeter of hydrogen so that the fuel cell can be provided with a continuous flow of hydrogen [1]. A controller is proposed so that only the required amount of urea enters the electrolytic cell based on hydrogen requirement. PEMFC converts the hydrogen into electricity. Since urea electrolysis is 100% efficient, no unreacted urea will be left.

Considering 1 gm of hydrogen, the input required in the electrolytic cell is 1.55Wh and the output obtained from PEMFC is 33 Wh. If the system is made self sustainable by providing a portion of the output to the input, still a net energy of 31.45Wh will be available to drive the motor and hence the automobile [1].

For obtaining a refueling range of 483 km, according to calculations, there is a requirement of a 69.4 kW PEMFC. From the 69.4kW power obtained from the PEMFC, 41.6 kW is utilized as input to the electrolytic cell. Hence the net energy driving the automobile is 27.8 kW [1].

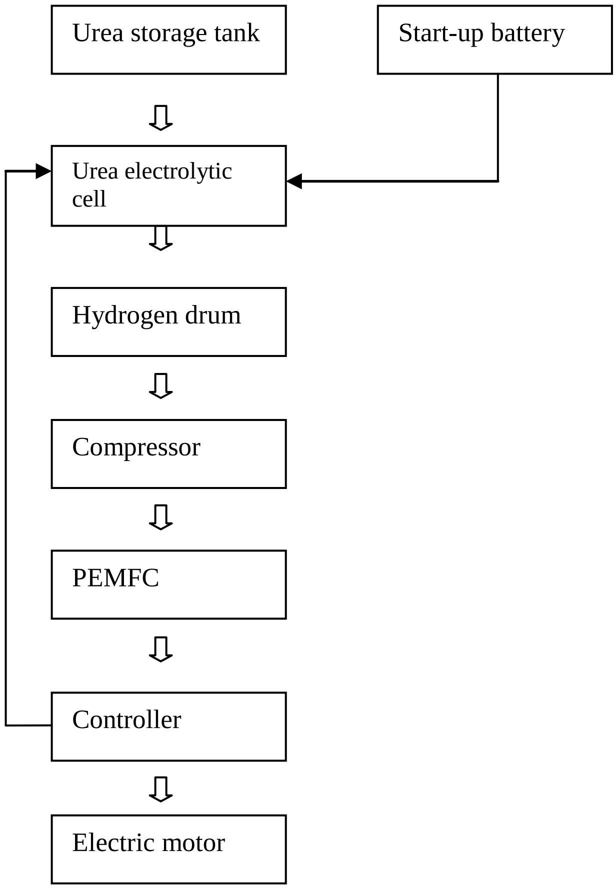

Fig. 1 : Proposed flow diagram for on-board hydrogen generation in automotives

CONCLUSION

Electrochemical oxidation of urea in an alkaline medium is a green, cheap and effective method for hydrogen generation from waste. If the process is further optimized it could one day be a major source of hydrogen for the world. This process can be utilized by the automotive industry to generate hydrogen on demand and hence can power the automotive industry to a whole new level bringing a major breakthrough in the field of automobile engineering.

VII. ACKNOWLEDGEMENT

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