Feasibility of Urine as Fuel

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Content

1. Background

Development of alternate energy sources over the recent years has gained a lot of importance for the very fact that the world's demand for energy has been at an all-time high and at the same time exhaustion of the non-renewable resources is predictably near. This paper makes an attempt to explore about various renewable sources of energy and specifically focus on the feasibility of extracting energy from urine. Also, through this report, we will evaluate various claims made on the internet as well as in other sources of scientific literature about the Urine Fuel Cell.
Urine is an abundantly found waste resource in the cities. The main component of urine is urea. Governments around the globe spend lot of money and energy to remove urea from sewage, so implementing a Urea fuel cell to harness electricity from Urine is one option that could be thought of.
According to Discovery channel [1], claims have been made that, a Urine-powered vehicle can travel up to 90 miles per gallon of Urine or a refrigerator sized unit can produce one kilo watt of power. Gerardine Botte, Russ College, Ohio State University [2] further investigated, and found out that electrolysis of Urea with the help of Nickel based catalyst for producing Hydrogen requires only 0.37 volts to produce Hydrogen, whereas for water 1.23 volts are needed. Botte also claims that urine from office building of 200-300 workers produces as much as 2 KW of energy. She also stated that the U. S. Army's need for power consumption could be met by this technology [2].
Dr. Shanwen Tao [3] and his research partner Dr. Rong Lan of Heriot-Watt University, U.K. are working on the same subject, and have developed prototype of such a cell, known as the Carbamide Power System. Dr. Tao, also stated that an average adult human produces enough urine each year to drive a car 2,700 kilometers on energy from the Urea it contains.

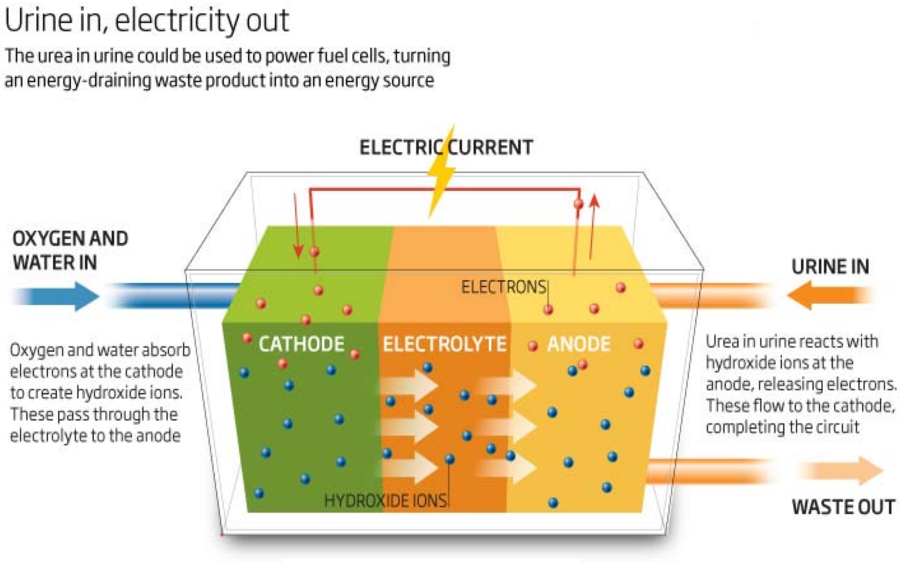

Figure I: Urine Fuel Cell [3]

2. Introduction

The most important technological impact of this project arises from the utilization of Urine, to produce cheap electricity. Apart from being a significant source of Hydrogen production, this technology can also be used to denitrify wastewater, thus saving expenditure on waste water remediation.
To start with, the concept of generating energy from urine involves using urea, which is a carrier of Hydrogen. As in one molecule of Urea (Carbamide) [4], a major component of urine, contains four atoms of Hydrogen bonded to two atoms of Nitrogen, this Hydrogen can be easily be released to give energy [1]. Urine as compared to Hydrogen is easy to store and transport, and is much less expensive as a fuel and is abundantly available. Urine is undoubtedly lesser expensive in regards to storage

conditions, like in Hydrogen storage, the special material vessel and high pressure and low temperature conditions are required. Also, for producing energy from Urine, less expensive membranes are installed in a fuel cell as compared to complex burners for hydrogen. Thus, Urine in a fuel cell offers promising route to renewable energy if the past literature claims are true.

In metropolitan cities where the population exceeds one crore, population of Mumbai alone crosses two crores. So, Mumbai produces approximately 20,000 Kl of urine per day. This if burnt with the help of fuel cell can generate ample amounts of energy besides alleviating the pollution problem. The resulting electricity produced can be used for various day-to-day applications. Simple chores like pumping water in a society (Housing Complex) to running a car, from operating streetlights to water heaters, all such electrical application can be undertaken by urine powered fuel cell. Having said this, it is very important to check the feasibility of this Project. Consumption of energy per day in city like Mumbai is high. Hence, even if basic energy requirements are quenched by this technology, energy consumption of the city will be substantially reduced.

3. Thermodynamics

Thermodynamic study of urea fuel cell is done in order to check the feasibility of the proposed Urine cell theoretically for its applications. The feed to the cell comprises of human Urine as a source of urea. Urine capacity of a person is approximately 800 ml – 2 litre per day. Urea content in urine is 9.32gram/liter [5]

Fuel Cell Reaction during combustion of Urea:

$$2CO(NH_2)_2 + 3O_2 \Leftrightarrow 2N_2 + 2CO_2 + 4H_2O \quad \text{(Equation 1)}$$

Molecular formula	CH_4N_2O
Molar mass	60.06 g/mol
Appearance	White solid
Density	1.32 g/cm^3
Melting point	133-135^{o}C
Solubility in water	107.9 g/100ml(20 ^{o}C) 167 g/100ml(40 ^{o}C) 251 g/100ml(60 ^{o}C) 400 g/100ml(80 ^{o}C)

Table I: Properties of Urea [6]

Table II: Thermodynamic Parameters of Urea and Urea Combustion Products [7]

Compounds	$CO(NH_2)_2$ (c)	O_2 (g)	N_2 (g)	CO_2 (g)	H_2O (l)
ΔG_f^o (kcals/mol)	-47.19	0	0	-94.254	-56.687
ΔH_f^o (kcals/mol)	-79.71	0	0	-94.051	-68.315
ΔS^o (cal/Kmol)	25.00	49.003	45.77	51.06	16.71
C_p^o (cal/Kmol)	22.26	7.016	6.961	8.87	17.995

Table III: Thermodynamic Value of Urea Dissolution in Water [7]

Compounds	Dissolved Urea at Infinite Dilution
ΔG_f^o (kJ/mol)	-6.86
ΔH_f^o (kJ/mol)	-14
ΔS^o (J/Kmol)	69.5
C_p^o (J/Kmol)	4.31*

*Assuming heat capacity of dilute urea solution equals to that of water.

From Equation (1) it can be calculated that per mole of Urea burned in the Fuel cell the free energy released is:

ΔGR = -320.9 Kcal/mol (Equation 2)

It is assumed that in the Fuel Cell Urea concentration reduces from 9.3 grams to 1 gram. The amount of Electricity released in this operation is limited by Free Energy of reaction as well as Free Energy of Urea dissolution. The first part is given by Equation (2) and the latter part can be calculated using van Laar Model.

4. Calculations

Mole fraction of Urea in Saturated Solution (Point 1) can be calculated as
x1 = 251 / [60.06*(251/60.06+100/18)]= 0.4296
x1 =0.4296 (Equation 3)

so we can calculate, x2 = 0.5704

Table III At infinite dilution gives for Urea
ΔG_∞° =-6.86KJ/mol (Equation 4)

This is related to Activity Coefficient as follows[9]
ΔG_∞°=RT ln γ2 (Equation 5)

Substituting ΔG_∞°, R & T, we get,
-6.86=8.314*333 lnγ1
lnγ1=-6.86*[1000/(8.314*333)] = - 2.4778
lnγ1=B12
Hence, B12=-2.4778

For pure Urea in equilibrium with the saturated solution

Now van Laar Model is given as
lnγ1 = B12/ [1+ (B12* x1)/ (B21*x2)]2 (Equation 6)

lnγ2 = B21/ [1+ (B21* x2)/ (B12*x1)]2 (Equation 7)

At urea saturation:
Solubility of urea is 1

$\gamma 2$ x2 = 1 (Equation 8)
$\gamma 2$ = 1/0.4296 = 2.3277

Substituting values of $\gamma 2$, B12, x1, x2 in equation III we get,

ln 2.328 = B21/ [1+ (B21* 0.5704)/(-2.4778*0.4296)]2
B12 =aB212 + bB21+ c
0.246 B212- 1.9655 B21+ 0.845=0
B21=0.4712 & B21=7.3827

Since we are getting two values of B21, hence we consider two cases, case I and case II.

Mole fraction at cell conditions

IN FEED:
9.3 gpl of urea in urine
x1=9.3/(60.06*1.002)/[9.3/(60.06*1.002) + 992.7/(18*1.002)]
x1=2.8026*10-3
x2=1-x1
x2=0.9972

IN EFFLUENT:
1 gpl of urea in urine
x1 = 1/(60.06*1.002)/[1/(60.06*1.002+1.001/18*1.002)]
x1=2.996*10-4
x2=1-x1
x2=0.99972

Case I:
For B21=0.4717,
$\gamma 1$ =0.07787
$\mu 1$= $\gamma 1$*x1 (Equation 9)
$\mu 1$=2.1823*10-4 KJ/mol

Accordingly,
$\gamma 2$ =0.0832
$\mu 2$= $\gamma 2$*x2
$\mu 2$=2.4926*10-5KJ/mol

Case II:
For B21=7.3827
$\gamma 1$ =0.0835
$\mu 1$=2.3402*10-4 KJ/mol

Accordingly,
$\gamma 2$ =0.0838
$\mu 2$=2.51065*10-5 KJ/mol

Thus for B21=0.4717,
$\Delta\mu$=1.933*10-4KJ/mol and

For B21=7.3827, $\Delta\mu$=2.089135*10-4 KJ/mol.
We use smaller value of $\Delta\mu$=1.933*10-4KJ/mol.
ΔG°=-320.876Kcal/mol

Thus, $\Delta G_{cell} = \Delta G^{\circ} + \Delta\mu$ (Equation 10)
ΔG_{cell} = -320.8759Kcal/mol.

Solving for B12 and B21 using Equations (6 & 7) one can get,
$\Delta G_{Dissolution}$ = -.0001 Kcal/mol. (Equation 11)
which is negligibly small.

The value of Gibbs free energy thus calculated for cell is negative, and hence it suggests that extracting energy from fuel cell using is possible. But, having said this, it is also important to check its feasibility economically.

5. Modes of Fuel Cell operation

One may employ Distributed Operation as several small cells in the places such as public urinals or housing complexes to avoid transport of Urine or a large centralized facility using advantage of scale may be created. However, it would require transport through tankers for Urine collection. Distributed Operation would require high capital cost, whereas for Centralized Operation transportation cost would be more. One may evaluate both the options as follows:

5.1. Distributed Fuel Cell

Distributed fuel cell is used for sufficient electric supply for domestic purposes in a given area of people. Consider a Housing Complex with 100 people residing in it. Assuming that Urine collected per person is 1 litre per day, Urea collection would be 100 lit per day, and the calculations can be done as follows:

Power generated per 100 people = -320.9/860= 1.3 KWH assuming 100% Efficiency of the cell (since 1 KWH = 860 Kcal) (Equation 12)

Surprisingly the energy generated by Urine collected from society of 100 people is not sufficient to run a single motor of 0.5kw for 6 hours (3KWH) for water supply. Neither would it be enough to light 200watt LED lamps to light up the building for 12 hours (2.4KWH). It therefore appears that distributed fuel cell concept is not feasible.

5.2. Centralized Fuel Cell

Considering centralized system one can focus on collecting Urine of 10KL and transporting it to 50Km by diesel driven tanker which runs 3.5Km/l of diesel. According to the Indian Oil 1 litre of diesel is Rupees 50[10] on the date 01 July 2011. For 50Km diesel driven tanker amount required is 714.28 Rupees. As calculated previously 1.3 KWH produced from 100 litres of urine. Thus from 10 KL of Urine we get 130KWH of energy. Amount of rupees produced for 130KWH is 650 Rupees assuming 5Rs per KWH. Thus the energy produced by the Urine is utilized in transporting itself. Hence, there will be no energy left for producing electricity. Thus, Urine Fuel Cell, is not feasible to develop centralized fuel cell as well.

6. Conclusions

The usability of cell can be checked by applying it to energy requirements in day-to-day life. In the case of Thermodynamic Feasibility, as we have assumed 100% cell efficiency, the cell is considered to be working to its maximum potential. Even though Thermodynamic limit is reached; this cell cannot be made feasible. As in case study, applied for Centralized as well as Distributed Fuel Cell, it can be inferred that, this technology produces very less amount of energy, with given amount of effluent. Also, considering the economic aspects, the fuel cell is not only costly, but maintenance of the same will be expensive too. The initial investment is high and the returns are comparatively low. It can be concluded that, Urine Fuel Cell is neither feasible on a commercial scale nor for small-scale applications, as the energy produced is neither sufficient nor economical. Although, it is a clean technology, yet, practically, the energy content of Urine is very low, and therefore not feasible to exploit in commercially.

7. Table of symbols

Symbols	Description
$\Delta G^{\circ}f$	Gibbs free energy change for formation
$\Delta H^{\circ}f$	Enthalpy change for formation
$C^{\circ}p$	Standard heat capacity
ΔS°	Standard Entropy change
ΔGR	Gibbs free energy change for reaction
$\Delta G\infty^{\circ}$	Gibbs free energy change at infinite dilution
x1	Mole fraction of urea
x2	Mole fraction of water
B12 ,B21	Van laar constant
R	Universal gas constant
T	Temperature
γ1, γ2	Activity coefficients of urea and water

8. References

1) Eric Bland, Urine A 'Clean' Energy Source, Discovery News, 2009, http://dsc.discovery.com/news/2009/07/08/urine-power.html
2) Gerardine G. Botte, Associate Professor of Chemical and Biomolecular Engineering, Ohio University, 2009, http://www.ohio.edu/ceer/news/index.cfm
3) Nothing goes to waste: urine as a new source of renewable energy, ZME science, http://www.zmescience.com/research/nothing-goes-to-waste-urine-as-a-new-source-of-renewable-energy-424155/
4) Alyssa Danigelis, Pee Power to the People, 2010, http://news.discovery.com/tech/pee-power-to-the-people.html
5) Urine properties, Wikipedia, http://en.wikipedia.org/wiki/Urine
6) Urea properties, Wikipedia, http://en.wikipedia.org/wiki/Urea
7) CRC Handbook of chemistry and Physics, Editor: R. C. Weast 63rd Edition. CRC press, Inc. Boca Raton, Florida. 1983.
8) Charles A. Liberko and Stephanie Terry, A simplified method for measuring the entropy change of urea dissolution, J. Chem. Edu., 78, 1087-1088 (2001)

9) Chemical And Process Thermodynamics B. G. Kyle, second edition, Easter Economy Edition, Prentice Hall, USA, 1992.
10) Diesel costing, http://www.iocl.com/Products/HighSpeedDiesel.aspx
11) Ohio Scientists Create Fuel from Water Art, Tempo Interaktif, http://www.tempointeraktif.com/hg/sains/2011/04/01/brk,20110401-324428,id.html