Recovering energy from liquid sanitary waste for Direct Alcohol Fuel Cell

V. Pelillo & D. Laforgia
Department of Engineering for Innovation, University of Salento, Italy

Abstract

The evolution of energy systems can take place through different ways and, sometimes, by using processes already known but to be improved by the evolution of continuous research. That is the case of DAFC (Direct Alcohol Fuel Cell), known for a century, but whose operating mode consists of employing alcohol (at determined conditions). The objective of this work is not only to show the sustainability of these devices but mainly their application for supplying re-cycled ethanol and glycol, recovered from sanitary liquid waste, to be used for biomedical apparatus and plant located inside hospital pavilions, such as Neonatology, Resuscitation and Surgery rooms, where, the electric energy, must not be interruptible for safety reason because the DAFC must always be working. The proposed solution is supported by the U.E. Act (Directive 2006/12/CE) that allows waste recovery in order to produce energy. It is an innovating and alternative manner to provide a good use of sanitary liquid waste instead of sending them to common and regular disposal.

Keywords: sanitary waste, cell fuel, disposal, waste recovery, waste legislation.

1 Introduction

Hospital or clinical or sanitary waste requires more particular management procedures than general waste. There are specific classifications according to each western country’s legislation. They include not only the so-called conventional waste but also the so-called unconventional ones, that is, radioactive waste. To dispose of this waste, the main technique consists of using appropriate incineration plants capable of achieving the task in such a way that the environment is protected. Different studies suggest that as much as 50% of waste sent for incineration as clinical waste is in fact general waste, leading to
Table 1: European Waste Catalogue (2002) categorization of some sanitary waste.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 01</td>
<td>Wastes from human and animal health care and/or related research (except kitchen and restaurant wastes not arising from immediate health care)</td>
</tr>
<tr>
<td>18 01 01</td>
<td>Wastes from natal care, diagnosis, treatment or prevention of disease in humans</td>
</tr>
<tr>
<td>18 01 02</td>
<td>Sharps (except 18 01 03)</td>
</tr>
<tr>
<td>18 01 03*</td>
<td>Wastes whose collection and disposal is subject to special requirements in order to prevent infection</td>
</tr>
<tr>
<td>18 01 04</td>
<td>Wastes whose collection and disposal is not subject to special requirements in order to prevent infection (e.g. dressings, plaster casts, linen, disposable clothing, nappies)</td>
</tr>
<tr>
<td>18 01 06*</td>
<td>Chemicals consisting of or containing dangerous substances</td>
</tr>
<tr>
<td>18 01 07</td>
<td>Chemicals other than those mentioned in 18 01 06</td>
</tr>
<tr>
<td>18 01 08*</td>
<td>Cytotoxic and cytostatic medicines</td>
</tr>
<tr>
<td>18 01 09</td>
<td>Medicines other than those mentioned in 18 01 08</td>
</tr>
<tr>
<td>18 01 10*</td>
<td>Amalgam waste from dental care</td>
</tr>
</tbody>
</table>

Any waste whose six-digit code is marked with an asterisk (*) is a hazardous waste. Classification may be absolute (A), defining waste as hazardous regardless of the concentration of any ‘dangerous substance’ within it, or a ‘mirror entry’ (M), covering wastes having the potential to be hazardous or non-hazardous depending on their composition and the concentration of ‘dangerous substances’ within them. The hazard potential is determined by reference to published threshold limits or, for infection hazards, on risk assessment.

unnecessarily high disposal costs [1]. Improved segregation can generate substantial savings. In an ideal world, segregation of waste should take place at the point of production, for example on the wards or in operating rooms. Encouraging segregation at production site may help to save money and provide a secure a correct way of disposing of hazardous materials in order to prevent irreversible damages on the environment. For the purposes of this research, we use the acceptance sanitary because it includes any waste produced by any structure where health activities are operated for the interest of humans and animals. While the acceptations hospital and clinical could generate a little bit confusing meaning. First of all, it is suitable to recall the origin of sanitary waste and its contents. Sanitary waste comes from the following sources: private and public hospitals, health centers, research facilities, health laboratories, veterinary surgeries, dental surgeries, etc. [2]. Instead, the contents consist wholly and partly of the following items: syringes, needles, glasses, human or animal tissue, swabs, dressings, excretions, blood, physiological fluids, pharmaceutical waste, incontinence bags, etc [3]. Sanitary liquids play a key role in hospitals, especially if they contain solvents that could be extracted in order to be regenerated for recycling in a new process. Improving the mechanism of waste segregation means money saving and keeping the environment safe. Different western countries, before the introduction of new regulations, namely EWC (European Waste Code) in its diverse versions, have faced the sanitary waste issue in many ways. The increasing costs and technology development may impose a new vision and a new approach for seeking to segregate waste in hospital facilities. This segregation must be enhanced especially by separating liquids from solids, hazardous from non-hazardous, flammable from inflammable. England [4], France [5] and Italy [6], for example regulated, in an
appropriate way, the matter in the 1990s by distinguishing the type of sanitary waste and the procedures for final disposal according to [7] the WHO too.

There has been an underlying disparity across Europe in the approach to the management of sanitary waste, both within hospitals [8] and in the commercial sector. Differences have been harmonized by the European Hazardous Waste Directive 91/689/EC (HWD), which seeks to provide a precise and uniform European-wide definition of hazardous waste, including clinical waste, and to ensure its regulation and correct management. The classification of a waste as hazardous has considerable impact in determining how that waste is regulated, and thereby on the care required at all stages from initial disposal to final destruction. A detailed classification of waste is set out in the European Waste Catalogue 2000/532/EC (EWC), an essential first step in the implementation of the HWD. EWC classification permits downregulation of some clinical waste. The EWC is pivotal to this legislation, enabling classification of waste based upon composition and hazard (Table 1). Non-hazardous waste escape stringent control in disposal that had previously been applied blanket fashion, permitting correspondingly lower disposal costs.

2 DAFC

Fuel cells generate electric power from an electrochemical process using fuels such as hydrogen or methanol. Compared with batteries, fuel cells typically have a higher energy density and a lower weight. In addition, fuel cells are environment-friendly (especially if the fuel is taken from a renewable resource) and can be recharged instantly. Fuel cells are being used in prototype applications to power vehicles, cellular telephones, homes, commercial properties, laptops, household appliances and industrial machinery. Direct Alcohol Fuel Cell (DAFC) uses liquid alcohols as a fuel and is very attractive as power sources for mobile, stationary and portable applications. However, alcohols are very difficult to electro-oxidize completely and up to now methanol has been considered the most promising organic fuel. Carbon-supported PtRu nanoparticles (PtRu/C) are the best electrocatalysts for Direct Methanol Fuel Cell (DMFC), however, the synthesis of highly dispersed carbon supported PtRu nanoparticles with high loading remains a challenger. The conventional methods of preparation, like wet impregnation and reduction, do not provide satisfactory control of the particle size and distribution.

3 Waste segregation and recovery for DAFC supply

Further segregation is proposed as an effective method of reducing costs in waste disposal, and to achieve compliance with the new legislative controls that prohibit mixing of waste [9]. Directed principally to the elimination of packaging waste from the more costly sanitary waste stream, space constraints in clinical areas can present practical problems that limit the options for additional segregation. Though attractive on environmental, ecological and administrative criteria, such complex and comprehensive waste management procedures are
likely to succeed only in new-build hospitals where sufficient space is devoted to these core functions at the design and construction stages. Since space is at a premium in the majority of existing building stock the elimination of packaging waste from clinical waste might best be achieved by removal at source, in the supply department, though this requires care to protect the integrity of sterile supplies. In circumstances where segregation of waste is undertaken solely at the point of arising, in the busy and often cramped hospital ward, the risks associated with incorrect segregation that might result in clinical waste entering a more general domestic waste stream cannot be dismissed. Efficient supply chain management may thus offer an effective response to demands for the improved segregation of waste, reducing costs without compromise of safety, and supporting effective risk reduction. However, based on the evidence reported here, it is apparent that there has been little if any improvement and that much still remains to be done to improve the standards of clinical waste management in hospitals. Amid the aforementioned sanitary waste, solvents containing alcohol are very interesting as fuel for DAFC. So, in hospital facilities, there is a need of creating specific areas for stocking waste in a segregated way, especially for solvents containing alcohol (ethanol and ethylene glycol). This procedure would be permitted by some legislation, for instance, European directive 2006/12/EC and Italian one [10]. Ethanol and ethylene glycol are used in hospital facilities and they are good energetic vectors of with respect to hydrogen and to hydrocarbons. They have a high solubility in water and energy density ($W_e$) like [11] gasoline (10-11 kWh kg$^{-1}$). Moreover, since energy efficiency ($\epsilon_r$) of DAFC is greater than (Table 2) that of hydrogen/oxygen-based cell fuel, that is, 83% at 25°C, this the interesting reason of recovering ethanol and ethylene glycol from sanitary liquids for energetic objectives. Ethanol and ethylene glycol are a good source of energy, even if it is necessary their electrochemical reaction entails the increasing of anode overvoltage towards high values with respect to those reached by hydrogen (Figure 1). This inconvenient could be overcome by allowing the reaction to be performed on binary or ternary catalyzer based on platinum which allow to obtain molecules with small dimensions that are easily oxidizable to CO$_2$ [12].

### Table 2: Thermodynamic data of related to electrochemical oxydation of some alcohols.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>$\Delta G$ /kJ mol$^{-1}$</th>
<th>$E^-$/V vs SHE</th>
<th>$E_{\text{metal}}$/V</th>
<th>$\Delta G$ /kJ mol$^{-1}$</th>
<th>$W_e$/kWh kg$^{-1}$</th>
<th>$\Delta H$ /kJ mol$^{-1}$</th>
<th>$\epsilon_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_3$OH</td>
<td>$-9.3$</td>
<td>0.016</td>
<td>1.213</td>
<td>$-702.7$</td>
<td>6.09</td>
<td>$-726.7$</td>
<td>0.967</td>
</tr>
<tr>
<td>C$_2$H$_5$OH</td>
<td>$-97.3$</td>
<td>0.084</td>
<td>1.145</td>
<td>$-1326.7$</td>
<td>8.01</td>
<td>$-1367.9$</td>
<td>0.970</td>
</tr>
<tr>
<td>C$_3$H$_7$OH-C$_2$H$_5$OH</td>
<td>$-4.8$</td>
<td>0.005</td>
<td>1.224</td>
<td>$-1811.5$</td>
<td>5.29</td>
<td>$-1902.2$</td>
<td>0.992</td>
</tr>
<tr>
<td>C$_2$H$_5$OH</td>
<td>$-168$</td>
<td>0.097</td>
<td>1.132</td>
<td>$-1965.3$</td>
<td>9.10</td>
<td>$-2023.2$</td>
<td>0.971</td>
</tr>
<tr>
<td>C$_2$H$_6$OH</td>
<td>$-243$</td>
<td>0.105</td>
<td>1.124</td>
<td>$-2602.1$</td>
<td>9.77</td>
<td>$-2676.8$</td>
<td>0.972</td>
</tr>
</tbody>
</table>
Figure 1: Comparison between voltage-current of an H₂/O₂-based cell fuel with platinum electrodes and DAFC ethanol with anodic ternary catalyzer (Pt-Sn-X).

Figure 2: Block scheme of proposed architecture.

Figure 2 illustrates the proposed architecture of processing segregated liquid waste extracted from sanitary waste and from sanitary decayed radioactive waste. Both types of waste, included other solvents that have not been segregated before, are stocked in a specific tank of figure 2. Afterwards, the liquids are treated in a fractionation unit according to the plant of figure 3.

Thanks to Antoine Equation [13], using the appropriate constants, it is possible to calculate the vapor tension of both alcohols (ethanol and ethylene glycol), then, their volatility and the relative one.
To calculate the number of steps necessary to obtain the desired separation, it is appropriate to use the FUG (Fenske-Underwood-Gilliland) method according to the following procedure:

\[
N_{min} = \frac{\log \left( \frac{x_{D_i}}{x_{B_j}} \cdot \frac{x_{B_i}}{x_{D_j}} \right)}{\log \alpha^*}
\]

(1)

\[
1 - q = \sum \frac{\alpha_i x_{F_i}}{\alpha_i - \Theta}
\]

(2)

\[
R_{min} + 1 = \sum \frac{a_i x_{D_i}}{a_i - Q}
\]

(3)

\[
\frac{N - N_{min}}{N + 1} = 1 - \exp \left[ \frac{(1 + 54.4X)(X - 1)}{(11 + 117.2X)\sqrt{X}} \right]
\]

(4)

where \( X \) is equal to

\[
X = \frac{R - R_{min}}{R + 1}
\]

(5)
Finally, to establish in which stage it is better to feed, Kirkbride Equation has been used in empirical way, that is,

\[
\frac{N_R}{N_S} = \left[ \frac{B}{D} \left( \frac{x_{F,HK}}{x_{F,LK}} \frac{x_{B,LK}}{x_{D,HK}} \right) \right]^{0.206}
\]  

(6)

The FUG method has allowed to get the following parameters for the design of the system:
\( N_{\text{min}} = 2, R_{\text{min}} = 0.24, N = 7, R = 0.31 \), number of feeding stage=5.

**Nomenclature**

- \( F_w \) Flow for fractionation tower in kg/h
- \( x_{Fw} \) Fraction in weight of ethanol
- \( x_{Dw} \) Fraction in weight of ethanol in the distilled
- \( F \) Flow for tower in kmol/h
- \( x_F \) Fraction in moles of ethanol in the feeding
- \( x_D \) Fraction in moles of ethanol in the distilled
- \( PM_{\text{ethanol}} \) Ethanol molecular weight
- \( PM_{\text{glycol}} \) Ethylene Glycol molecular weight
- \( PM_{\text{mix}} \) Mixed feeding molecular weight
- \( T_{eb} \) Ebullition temperature
- \( P \) Operating pressure
- \( B \) Residual flow in kmol/h
- \( D \) Residual flow in kmol/h
- \( x_B \) Fraction in moles of ethanol in residual
- \( p^* \) Vapor tension
- \( \alpha \) Viscosity
- \( \alpha^* \) Relative viscosity
- \( N_{\text{min}} \) Minimal number of necessary stages for separation
- \( R_{\text{min}} \) Minimal reflux
- \( N \) Effective number of stage for separation
- \( R \) Reflux
- \( N_R \) Number of stages over feeding
- \( N_S \) Number of stages under feeding
4 Summary and conclusions

This research has illustrated the opportunity of recovering alcohols from sanitary waste in order to use them for feeding a DAFC. In general, even if segregation is carried out in clinical and hospital facilities, solvents containing alcohols are used in these facilities for different reasons. But an oversegregation that allows for recovery of alcohols from conventional sanitary waste and decayed radioactive ones will produce great benefits for saving money and protecting environment. The use of DAFC fuelled by recovered alcohols is essential for hospital pavilions like Neonatology, Resuscitation and Surgery rooms, where, the electric energy must not be interruptible for health and safety reasons. The proposed research agrees with European and national legislations.

References

[10] Italian act Dlgs.152/06 Parte IV, art.179 s.m.i.