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EXPERIMENTAL EVALUATION OF ELECTROLYTES PERFORMANCE INTO AN ALKALINE FUEL CELL (AFC)

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Abstract. Alkaline fuel cells (AFC) have impacted positively the automotive industry, by enrich gasoline and diesel engines with derivatives of electrolysis (H_2 , O_2 , and HHO) and consequently decreasing in combustion gases (CO , and CO_2). This paper presents the experimental validation of an electrolytic cell that produces oxyhydrogen gas, using two electrolytes (potassium hydroxide and sodium bicarbonate) with the objective of determining which is the most favorable in the operation of the device. The experimental results shown that the best electrolyte for the alkaline cells is the potassium hydroxide because it produces a flow rate of 0.39 ml / s with 6 g, sodium bicarbonate generates 0.29 ml / s with 20 g.

Keywords: Fuel cell, potassium hydroxide, sodium bicarbonate, electrolysis.

1. INTRODUCTION

Fossil fuels have remained for long time as the first option to satisfy energy demand worldwide, mainly due to the great variety of derivatives that could be obtained from it (gasoline, butane gas, asphalt, plastics, fertilizers, pesticides, drugs, among others). However different studies (Demeneix, 2020; Mukhopadhyay & Forssell, 2005; Perera et al., 2019; Petrov et al., 2017) have demonstrated the disadvantages of the long term use of fossil fuels as non-renewable energy source they are limited and highly polluting, generating damage to the environment and human health.

The Montreal Protocol, and the European Union have made restrictions and approved regulations to mitigate emissions of particulate matter, dioxide, and carbon monoxide, with this it seeks to gradually decrease the use of conventional energy sources to meet energy demands, because, for example, from oil, derivatives are obtained that in the medium or long term end up being pollutants (Norman et al., 2008).

In this sense, processes with efficient energy generation based on alternative energy sources has turned of great importance in scientific field (Talpone et al., 2012), especially in development of new fuels. For this purpose, fuel cells have proven to be the devices with the highest projection, taking into account the experimental results of the studies carried out on these devices. Their impact can be seen in industrial processes where combustion takes place (boilers, turbochargers and combustion engines. internal), they are also used to power cellular vehicles and laptops (Das & Gadde, 2015; Dhahad et al., 2019).

There are several types of fuel cells among which are the PEMFC, DMFC, PAFC, MCFC, SOFC (Inal & Deniz, 2020) and the versatility of fuel cells can be measured according to the research carried out on them and their impact or applicability in the industry, according to the power they supply, their availability is identified in transport systems,

mobile or stationary systems. In Tab. 1 are presented a classification of fuel cells in order to objectively identify their area of application and main advantages.

However, the application of expensive material (such as precious metals) in fabrication of PEM or SOFC electrolyzers along with their shorter operational lifetime make them relatively more expensive compared to the alkaline cells for small scale hydrogen production systems (Ursúa et al., 2012).

In the last decades the AFC have had great relevance due to a more favorable decrease in oxygen in the electrochemistry reaction, low cost, simplicity and high efficiency (> 70%), consequently, fuel cell technology has promoted the AFC study (Verma & Basu, 2007).

Table 1. Fuel cells applications and advantages.

Fuel Cell	Applications	Advantages
Alkaline Fuel Cells (AFC)	Space and military applications.	The alkaline electrolyte has a higher reaction rate at the cathode, causing a higher yield.
Proton exchange membrane fuel cells (PEMFC)	Transportation, portable power, small distributed generation.	Low corrosion, decrease due to management problems and low temperature.
Direct Methanol Fuel Cells (DMFC)	Cell phones, laptops and other portable devices.	Costs are low because you don't have a fuel reformer.
Phosphoric Acid Fuel Cells (PAFC)	Stationary power systems (residential and commercial).	It has high general efficiency with cogeneration, greater tolerance to impurities in hydrogen.
Molten Carbonate Fuel Cells (MCFC)	Stationary electric power systems (universities, hospitals, waste treatment plants and manufacturing companies).	High efficiency, allows the use of various catalysts, applicable in the combination of energy and heat.
Solid Oxide Fuel Cells (SOFC)	Distributed power generation (manufacturing companies).	Versatile in the use of catalysts, high efficiency and fuel flexibility.

From: (Das et al., 2017; Elmer et al., 2015; Sharaf & Orhan, 2014; Mekhilef et al., 2012)

In this article, the validation with experimental data of an AFC type electrolytic cell that produces oxyhydrogen as an alternative fuel will be carried out. Each sensor used to obtain the experimental data will be described, the devices that constitute the electrolysis test bench will be identified and the cell temperature and flow data.

2. EXPERIMENTAL PROCESS

The production of HHO gas is possible due to the electrolysis process of the water present inside the cell when an electrical work is supplied (through the voltage source) take place an electrochemical reaction that models the decomposition of the water molecule (H₂O). The experimental bench used to obtain the characteristic data with the production of oxyhydrogen gas (HHO) of the alkaline fuel cell is shown in Fig.1.

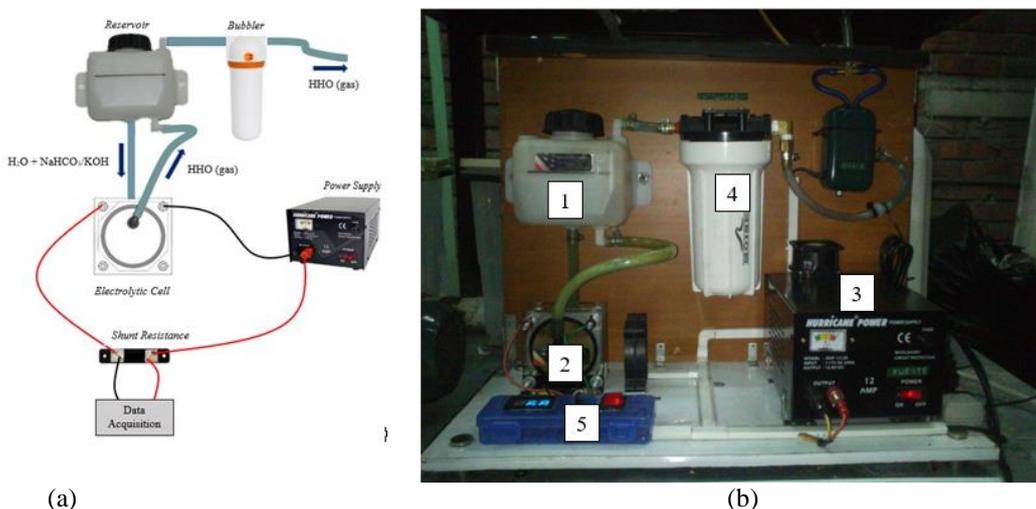


Figure 1. Test bench for HHO gas production: (a) Diagram (b) Photography.

The main components of the test bench in Fig. 1b are detailly described at next:

1. *Reservoir*: for store the distilled water solution and the electrolyte used (sodium bicarbonate or potassium hydroxide), has a capacity of up to 1000 g of the substances used. While tests were carried out the mass of the solution with sodium bicarbonate was 520 g and with potassium hydroxide was 506 g. Once the HHO gas is produced, it will also be stored in this reservoir until it is moved to the bubbler.

2. *Electrolytic cell*: allows the decomposition of the water molecule through the electrolysis process, transforming the electrical work supplied by the power supply into a non-spontaneous oxidation-reduction chemical reaction. It was manufactured by the company HydroClubUSA, his maximum production capacity of 2.25 L / min consuming 30 A at 12 V. The electrolyzer is a dry type cell where the working fluid (water) is inside the device to obtain the HHO gas. In Fig. 2 you can see the electrolytic cell, which consists of a stack of 9 316 stainless steel plates with the configuration + NNN - NNN +, where "-" represents the negative electrode (cathode), "+" represents the positive electrode (anode) and N the neutral plates according to the power; the separation between plates is made with PVC rings, it also has two acrylic plates to provide mechanical and thermal resistance, it also has two elbows, for the entrance of the solution and the exit of the biphasic flow (solution in liquid state mixed with HHO gas) (Waddell, 2011).

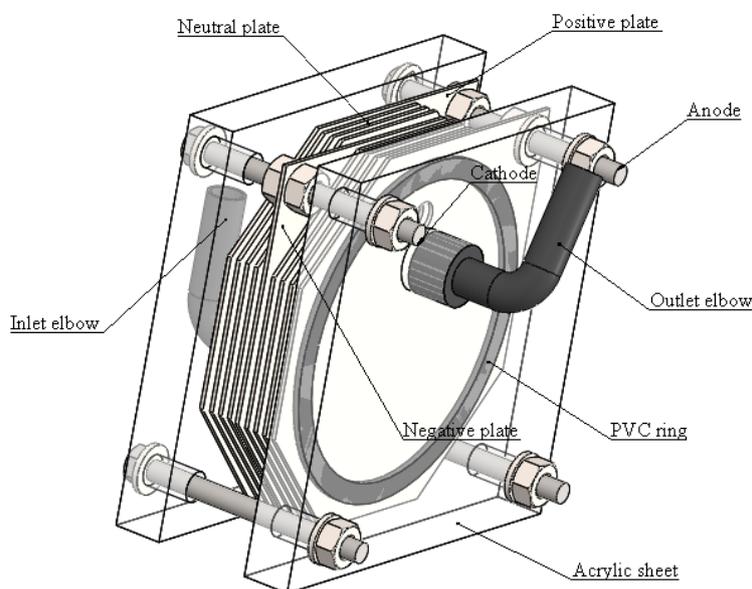


Figure 2. Dry type electrolytic cell.

3. *Power supply*: It supplies the energy demand of the electrolysis process, DVP 1212D from HURRICANE POWER with a capacity of 13.8 V and up to 12 A (Fig. 1), representing the electrical power of a vehicle's battery, the latter being where the AFC are most applicable.

4. *Bubbler*: This element works as protection within the bank for the production of HHO gas, since it prevents the gas from returning to the tank described above, in turn it exercises the filter function to eliminate any particle or contaminant.

5. *Current measure*: it was used a shunt resistor to perform the current measurement. It has a resistivity value of approximately 1.5 m Ω , a differential mode voltage output that can deliver up to 75 mV that allows measured a maximum current of 50 A and an accuracy of 0.5%.

Additionally, the temperature of the electrochemical reaction in the electrolytic cell was measured using a LM35. The measurement was performed by putting the sensor in contact with a positive plate that leads to the anode and another on a negative plate that leads to the cathode to observe the variations in each electrode. The LM35 has a temperature measurement range of -55 to 150 $^{\circ}\text{C}$, precision of 0.5 $^{\circ}\text{C}$, and an analog output and linear scale factor + 10.0 mV / $^{\circ}\text{C}$.

In order to understand how the electrolytic cell produces the HHO gas by the effect of the electrolysis of water, a flowchart of the operation of the electrolyser with each one of the elements that influence the process is proposed in Fig. 3. The electrolytes selected to perform the validation of the temperature and flow of the fuel cell are sodium bicarbonate (NaHCO₃) and potassium hydroxide (KOH). This allows the analysis of the two electrolytes for determine which is the most favorable in the production of HHO.

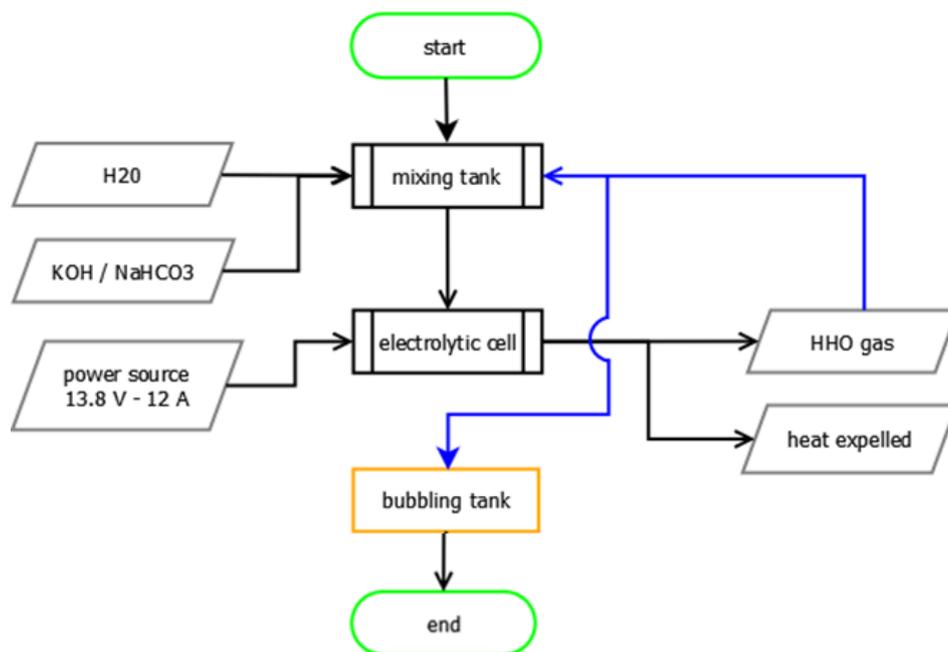


Figure 3. Flowchart of the electrolytic cell operation.

The electrolytes shown in Fig. 4, are described in detail below:

Sodium bicarbonate: this chemical substance is commercially accessible, for this reason it is considered in this research. It was used 500 g of NaHCO_3 in the validation and comparison. For the tests, the concentration was varied from 5 g to 20 g, the amounts of the electrolyte were supplied taking into account the speed of the reaction, and the solubility of sodium bicarbonate (10.3 g / 100 g).

Potassium hydroxide: It's the electrolyte most mentioned in literature works. It also was used 500 g of KOH in solid state. Due to its solubility (119 g / 100 g) the concentration was varied from 2 g to 6 g. Highest amounts, makes the reaction rate increase considerably and it was difficult to observe and analyses the behavior of the variables.



(a)



(b)

Figure 4. (a) Sodium bicarbonate (NaHCO_3). (b) Potassium hydroxide (KOH).

3. EXPERIMENTAL VALIDATION OF THE FUEL CELL

The experimental tests on the electrolytic alkaline cell was carried out at different concentrations of NaHCO_3 and KOH to analyze the effect of the energy supplied (heat potential) by the electrolyte on the electrochemical reaction. The variation of temperature and flow is also affected by the variation. of concentrations.

In Fig. 5 it can be observed the changes in the temperature of the cell with respect to the time for different concentrations of NaHCO_3 . The speed of the reaction is slow and despite the different amounts of the electrolyte the settle time for all the NaHCO_3 concentration is about 850 s. The temperature has a directly proportional variation with the quantity of electrolyte, increasing its heat potential during the process with a maximum value of it of 34.68°C (20 g).

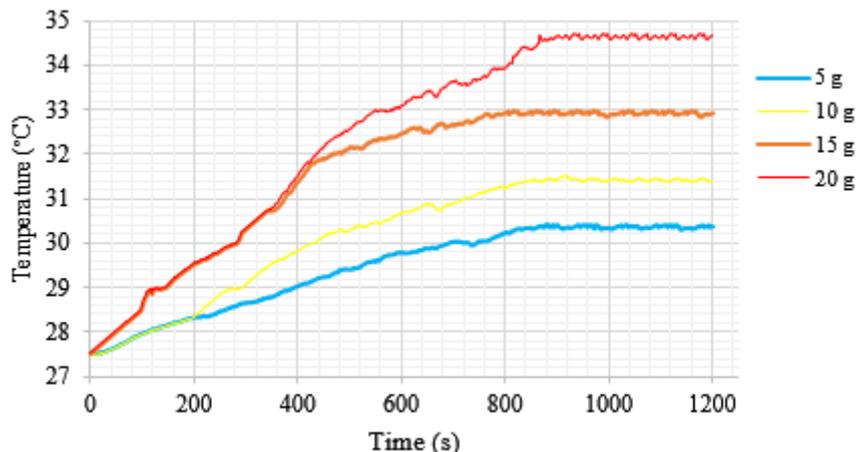


Figure 5. Alkaline fuel cell temperature with different concentration of NaHCO_3 .

Similar to Fig. 5, in Fig. 6 the variation of the reaction temperature with respect to time can be observed for different concentrations of KOH. The settle time of the cell temperature are 950 s, 900 and 740 s for the for the KOH chosen amounts of 2g, 4g and 6g, respectively. in this way with the increase of the electrolyte in the solution the temperature reaches its stability faster with a maximum value of 42.20°C (6 g).

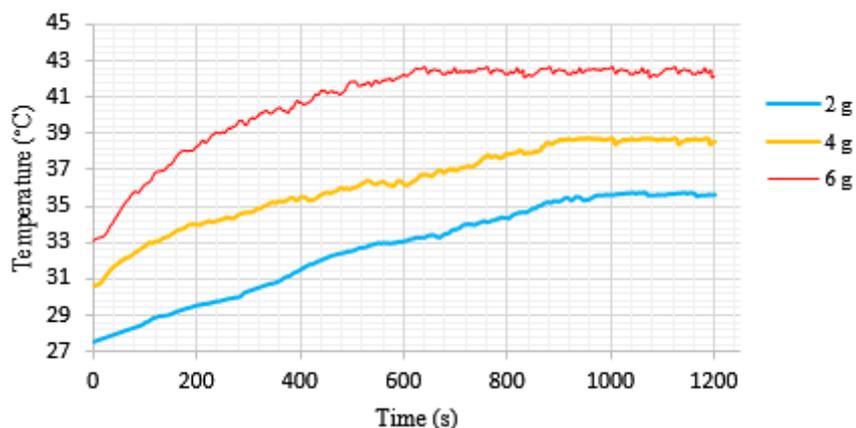


Figure 6. Alkaline fuel cell temperature with different concentration of KOH.

The contribution of the KOH calorific potential is greater when compared to NaHCO_3 in the reaction. Thus, comparing the experimental results from Fig 5 and Fig 6, it can be observed that the temperature achieves values of $34,68^\circ\text{C}$ and 42.20°C for the maximum concentrations of NaHCO_3 (20 g) and potassium hydroxide (6g), respectively. On the other hand, the time of establishment with KOH is smaller, allowing the production of HHO gas to be faster and more uniformly.

Figure 7 shows flow rate of the production of HHO in the electrolyzer with different concentrations of NaHCO_3 . The increase in the sodium bicarbonate amount leads to an increase in the flow rate that reaches a maximum value of 0.291 ml/s. Similar, In Fig. 8 it is possible to observe the variation of the HHO flow rate of the cell with different KOH, where the maximum HHO production reach a flow rate of 0.393 ml/s for the maximum concentration of KOH.

The effect of the calorific potential of the electrolyte is also reflected in the HHO flow of the cell, with 6 g of KOH produced more flow (0.393 ml / s) than 20 g of NaHCO_3 (0.291 ml/s).

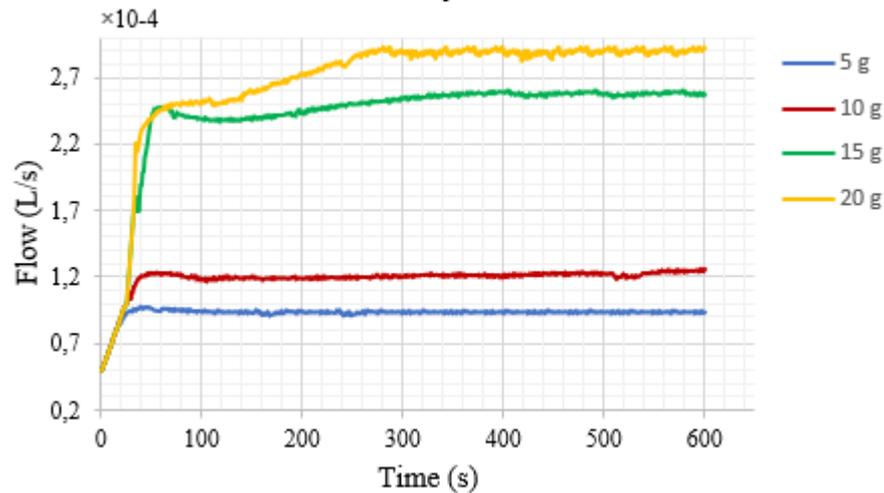


Figure 7. HHO flow rate production with different concentration of NaHCO_3 .

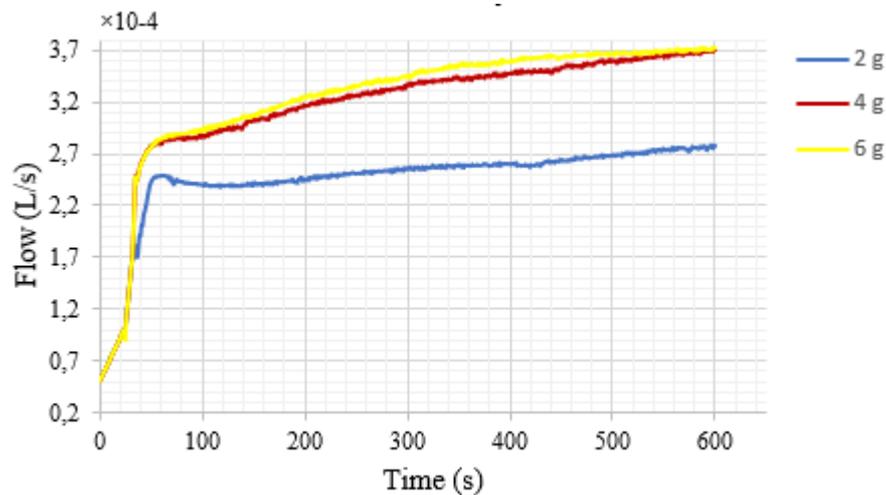


Figure 8. HHO flow rate production with different concentration of KOH .

4. CONCLUSIONS

In this work, an experimental investigation intended to determining which is the most favorable electrolyte in the operation of an alkaline fuel cell was carried out using two electrolytes, potassium hydroxide KOH and sodium bicarbonate NaHCO_3 . Hence, from the experimental results obtained, the next can be conclude:

- The experimental data of cell temperature and HHO flow rate allowed to observe the effect of the calorific potential of the electrolytes (NaHCO_3 and KOH). In this sense, it was evidenced that the highest energy contribution in the electrochemical reaction is provided by the KOH with a temperature value of 42.20°C and flow 0.393 ml/s .
- The analyzed variables (cell temperature and HHO flow rate) showed to be directly proportional to concentration of the electrolyte, that is, as the amount of electrolyte was increased both, cell temperature and HHO flow rate increased.
- Was verified that the obtained results are according to the literature, e.g. Mekhilef et al (2012) affirm that with potassium hydroxide the temperature reaches high values and the HHO flow increases, making it the most suitable electrolyte for AFCs.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

- Das, S. K., & Gadde, K. K. (2015). Experimental performance evaluation of a combustion heat-assisted catalytic flat plate fuel reformer for fuel cell grade hydrogen. *International Journal of Hydrogen Energy*, 40(46), 15913–15922. <https://doi.org/10.1016/j.ijhydene.2015.09.049>
- Demeneix, B. A. (2020). How fossil fuel-derived pesticides and plastics harm health, biodiversity, and the climate. In *The Lancet Diabetes and Endocrinology* (Vol. 8, Issue 6, pp. 462–464). Lancet Publishing Group. [https://doi.org/10.1016/S2213-8587\(20\)30116-9](https://doi.org/10.1016/S2213-8587(20)30116-9)
- Elmer, T., Worall, M., Wu, S., & Riffat, S. B. (2015). Fuel cell technology for domestic built environment applications: State of-the-art review. *Renewable and Sustainable Energy Reviews*, 42, 913–931. <https://doi.org/10.1016/j.rser.2014.10.080>
- Inal, O. B., & Deniz, C. (2020). Assessment of fuel cell types for ships: Based on multi-criteria decision analysis. *Journal of Cleaner Production*, 121734. <https://doi.org/10.1016/j.jclepro.2020.121734>
- Mekhilef, S., Saidur, R., & Safari, A. (2012). Comparative study of different fuel cell technologies. *Renewable and Sustainable Energy Reviews*, 16(1), 981–989. <https://doi.org/10.1016/j.rser.2011.09.020>
- Mukhopadhyay, K., & Forssell, O. (2005). An empirical investigation of air pollution from fossil fuel combustion and its impact on health in India during 1973-1974 to 1996-1997. *Ecological Economics*, 55(2), 235–250. <https://doi.org/10.1016/j.ecolecon.2004.09.022>
- Norman, C. S., DeCanio, S. J., & Fan, L. (2008). The Montreal Protocol at 20: Ongoing opportunities for integration with climate protection. *Global Environmental Change*, 18(2), 330–340. <https://doi.org/10.1016/j.gloenvcha.2008.03.003>
- Perera, F., Ashrafi, A., Kinney, P., & Mills, D. (2019). Towards a fuller assessment of benefits to children's health of reducing air pollution and mitigating climate change due to fossil fuel combustion. In *Environmental Research* (Vol. 172, pp. 55–72). Academic Press Inc. <https://doi.org/10.1016/j.envres.2018.12.016>
- Petrov, O., Bi, X., & Lau, A. (2017). Impact assessment of biomass-based district heating systems in densely populated communities. Part II: Would the replacement of fossil fuels improve ambient air quality and human health? *Atmospheric Environment*, 161, 191–199. <https://doi.org/10.1016/j.atmosenv.2017.05.001>
- Sharaf, O. Z., & Orhan, M. F. (2014). An overview of fuel cell technology: Fundamentals and applications. *Renewable and Sustainable Energy Reviews*, 32, 810–853. <https://doi.org/10.1016/j.rser.2014.01.012>
- Talpone, J. I., Puleston, P. F., More, J. J., Griñó, R., & Cendoya, M. G. (2012). Experimental platform for development and Evaluation of hybrid generation systems based on fuel cells. *International Journal of Hydrogen Energy*, 37(13), 10346–10353. <https://doi.org/10.1016/j.ijhydene.2012.01.161>
- Ursúa, A., Gandía, L. M., & Sanchis, P. (2012). Hydrogen production from water electrolysis: Current status and future trends. *Proceedings of the IEEE*, 100(2), 410–426. <https://doi.org/10.1109/JPROC.2011.2156750>
- Verma, A., & Basu, S. (2007). Experimental evaluation and mathematical modeling of a direct alkaline fuel cell. *Journal of Power Sources*, 168(1 SPEC. ISS.), 200–210. <https://doi.org/10.1016/j.jpowsour.2007.02.069>