Ethanol as an alternative to water vapor for saving energy and fossil fuels in thermoelectric plants

El etanol como alternativa al vapor de agua para el ahorro de energía y de combustibles fósiles en plantas termoeléctricas

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Abstract

This article proposes the use of ethanol in a 96% azeotropic mixture as an alternative to water vapor in thermoelectric generators with notable advantages in saving fuel. As is known, water is a cheap resource, available everywhere in a liquid state. However, water has an unusually high heat of vaporization and an equally high boiling point, so converting water to steam requires consuming large amounts of fossil fuels to break the hydrogen bonds in this substance. In contrast, evaporating ethanol requires only 37 percent of the fuel needed to evaporate water. In addition, water, before turning into steam, needs to be softened and treated with chemicals to prevent oxidation and scale deposits in pipes. If quality ethanol is used, this process of adjusting the water would not be necessary, which represents another saving. On the other hand, it is possible to resort to the use of solar heaters to raise the temperature of the ethanol to around 70ºC to later heat it to 80ºC or more, if necessary, with fossil fuels, making more significant savings. Objectives: To propose the replacement of water vapor by ethanol vapor as a working fluid to move the turbines of thermoelectric plants to reduce the consumption of fossil fuels. Methodology: Analyze the physical properties of water and compare them with those of ethanol to know the advantages and disadvantages of one and the other as working fluids Contribution: Through small modifications in thermoelectric plants it is possible to reconvert them to operate with ethanol vapor and save on fossil fuels.

Ethanol, Hydrogen bonds, Water

Resumen

En este artículo se propone el uso de etanol en una mezcla azeotrópica al 96% como alternativa al vapor de agua en los generadores termoeléctricos con notables ventajas en el ahorro de combustibles. Como se sabe, el agua es un recurso barato, disponible en todas partes en estado líquido. Sin embargo, el agua tiene un calor de vaporización inusualmente elevado y un punto de ebullición igualmente elevado, por lo que para convertir el agua en vapor se requieren consumir grandes cantidades de combustibles fósiles para romper los enlaces de hidrógeno de esta sustancia. En contraste, para evaporar el etanol se requiere solamente el 37 por ciento del combustible necesario para evaporar el agua. Además, el agua, antes de convertirse en vapor se necesita ablandar y tratar con productos químicos para evitar oxidación y depósitos de sarro en tuberías. Si se usa etanol de calidad no sería necesario este proceso de adecuación del agua, lo que representa otro ahorro. Por otra parte, se puede recurrir al uso de calentadores solares para elevar la temperatura del etanol hasta alrededor de los 70ºC para, posteriormente, calentarlo hasta los 80ºC o más, de ser necesario, con combustibles fósiles, haciendo más ahorros significativos. Objetivos: Proponer la sustitución del vapor de agua por vapor de etanol como fluido de trabajo para mover las turbinas de las plantas termoeléctricas para abatir el consumo de combustibles fósiles. Metodología: Analizar las propiedades físicas del agua y compararlas con las del etanol para conocer las ventajas y desventajas de uno y otro como fluidos de trabajo Contribución: Mediante pequeñas modificaciones en las plantas termoeléctricas es posible reconvertirlas para operar con el vapor del etanol y ahorrar en combustibles fósiles.

Etanol, Enlaces de hidrógeno, Agua

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Introduction

Steam has been used to drive the turbines of electricity generating plants everywhere. (Aminov & Egorov, 2019; Eftekhari & Ehyaei, 2020; Feng et al., 2014). The reasons are diverse: water is liquid over most of the earth's surface, it is an abundant and inexpensive resource (Lara-De La Cruz et al., 2020)..

However, water has a high boiling point (at sea level of 100°C) and a high heat of vaporization value (the amount of energy required to transform a fixed amount of a liquid substance into vapor at a constant temperature). (Bai et al., 2021; Yang *et al*., 2021; Yin *et al*., 2021). The heat of vaporization of water is about 540 cal/g at 100°C. (Galovic *et al*., 2010).

There are fluids that have lower boiling and vaporization temperatures. If another fluid could be used, we could achieve savings in fuel and carbon footprint.

On the other hand, savings can be made in terms of the treatments that are normally done to the water, such as softening, filtering and others, before introducing it to the boiler, to ensure that deposits of scale in the tubes and rust and boiler foam are not made (Shulga et al., 2020).

However, the efficiency of the steam generator alone is not representative of what happens to the entire thermal power plant. The thermal efficiency of the cycle is typically in the range of 30% to 35.3%.

1.1 Properties of water and ethanol.

Water is a cheap resource, available practically everywhere on the globe, except at the poles and in the high mountains in liquid form. It also has an unusually high heat of vaporization, which means that converting water to steam requires the consumption of large quantities of fuels.

The high boiling point of water (100°C) is due to its intermolecular hydrogen bonds. Such bonding is partially responsible for the structure of molecules such as water or organic molecules such as proteins. This bond, sometimes called hydrogen bridging, is an electrostatic force and results from a charge-dipole attraction of a hydrogen atom to a nitrogen or oxygen atom.

Ethanol or ethyl alcohol is obtained by fermentation of vegetable foodstuffs rich in starch and sugars, such as corn, sugar cane or wheat, and is relatively cheap and affordable. For this work, the psychoactive effects of ethanol are of no relevance.

Ethanol at the concentration of 96 % with water forms an azeotropic mixture. An azeotropic mixture behaves as if it were made up of a single compound, so it is proposed that 96% concentrated ethyl alcohol be used instead of water as the working fluid in steam turbines. Ethanol also has hydrogen bonds, although not as many as water, which may explain why it has a higher boiling point than water. Ethanol (CH3-CH2-OH), under normal pressure and temperature conditions, is a colorless, flammable liquid with a boiling temperature of almost 80°C (78.4°C).

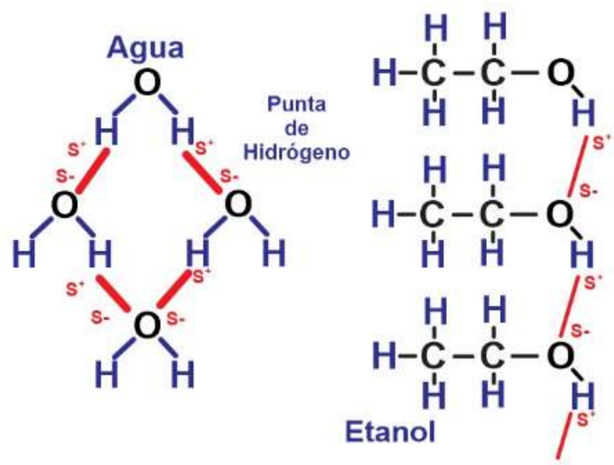

Figure 1 Hydrogen bonds in water and etanol
Own Material

1.2 The heat of vaporization at constant temperature

The heat of vaporization is the heat energy required to convert one gram of a substance into vapor. The heat of vaporization for one gram of water is 2260 joules/gram (541 cal/gram), while for ethanol it is 841 joules/gram (201 cal/gram), 37 percent. These data, when compared, can give us an idea of the significant fuel savings that can be obtained by opting for ethanol.

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1.3 Thermoelectricity in Mexico

In Mexico, efforts have been made to convert to gas in thermoelectric plants. However, fuel oil is the most widely used fluid fuel for electricity generation, despite the fact that it contains large amounts of impurities that cause significant ecological damage, such as sulfur, ash and nitrogen. These impurities can subsequently cause acid rain and other ecological problems, in addition to the well-known greenhouse effect caused by combustion alone. It is estimated that the Federal Electricity Commission (CFE) consumes almost 600 million cubic feet of this fuel (Sener, 2016). The consumption of a fuel such as fuel oil represents a serious problem.

The dielectric value of alcohol would have no relevance by virtue of the fact that it would only function as a working fluid. Current thermoelectric power plants operate up to 140 bar pressure and 540 °C maximum temperature.

2. Methodology to be developed

The heat of vaporization is the energy required to change one gram of a pure substance in liquid state to the gaseous state just at the boiling point. This heat of vaporization is the energy needed to break the hydrogen bonding forces, but it must also provide the energy needed to expand the gas. What is sought is that all of the gas used as a working fluid has as much molecular kinetic energy as possible. However, a small part of the energy is vibration and another part is invested in the rotation of the particle.

Of course, vaporization of a liquid involves a significant change in the volume of the substance. If water is considered as a working fluid and treated as an ideal gas, one mole of water consists of 18 grams of this substance, and at standard temperature and pressure, one mole occupies a volume of 22.4 liters. Keep in mind that the standard temperature condition is 273.15 K (0 °C) and the standard pressure is 105 pascals (1 bar or 0.986 923 27 atm). Obviously, let us consider water as if it were an ideal gas.

Regarding seals, stoppers, gaskets and tubing materials that are compatible with ethanol, there are no major complications.

Natural rubber sheeting has high tensile strength, compressibility, elongation and excellent tear resistance. It can be used to seal water, organic acids, alcohols, acetones and aldehydes. It is attacked by ozone, strong acids, fats and oils and hydrocarbons (Figueroa, 2001).

It is estimated that only 37 percent of the fuel needed to evaporate water is required to evaporate ethanol. This already represents a significant fuel saving. In addition, the water needs to be softened and treated with chemicals before it becomes steam. With quality ethanol, this process would not be necessary, and solar heaters can be used to raise the temperature of the ethanol to around 70ºC and heat up to 80ºC or more with fossil fuels or any other type of fuel. It would be a good alternative if solid waste fuels were used (Badrán, 2019) Current thermoelectric power plants operate at up to 140 bar pressure and up to 540°C maximum temperature.

Results

If we consider ethanol (46.07 g/mol.) and assume it as an ideal gas when vaporized, the volume of one mole of this gas is 22.4 liters.

If the change is from liquid water to vapor at 100°C, instead of 0°C, then the volume increases proportionally according to the ratio of the absolute temperatures, 373K/273K, or 30.6 liters. Comparing this with the volume of liquid water, there has been an expansion factor of 30600/18 = 1700, when evaporated at 100°C.

If we were talking about ethanol, we would have a ratio of 30600/46.07 g/mol of 664.20 times increase in volume.

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Conclusions

The reconversion of an industry is an expensive but necessary step to improve quality, reduce costs and downtime, modernize, improve processes, have the least possible impact on the environment and even extend the useful life.

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This article attempts to demonstrate that replacing water in combined cycle electric generators or even designing turbines that use ethyl alcohol steam can work and save fuels and reduce pollution.

Future research will focus on the following:

1. Design of a closed-cycle cooling system to prevent ethanol vapor from escaping into the atmosphere.

2. Design of turbines and all their special components for ethanol vapor.

3. It is necessary to carry out the study of the combustion process for ethanol in the steam generator hearth, considering independent variables such as fuel flow, air-fuel ratio and the fraction of recirculation gases, depending on these variables, taking into account the properties of the combustion gases such as their temperature and mass flow (Jimenez. 2019).

4. Perform an evaluation with the true excess air in order to obtain greater energy and energy efficiency (Diaz, 2020).

5. Perform an economic study for the implementation of a cycle with regeneration. (Diaz, 2020).

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