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MODERNIZATION OF AN ETHANOL PRODUCTION PLANT WITH THE DEVELOPMENT OF A STEAM GENERATOR

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ANNOTATION:*The process of ethanol production by direct hydration of ethylene, the subject of steam generator modernization, was investigated.*

KEYWORDS:*STEAM GENERATOR, HYDRATION, ETHANOL, ETHYLENE*

МОДЕРНІЗАЦІЯ УСТАНОВКИ ВИРОБНИЦТВА ЕТАНОЛУ З РОЗРОБКОЮ ПАРОГЕНЕРАТОРА

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АНОТАЦІЯ: *Досліджено процес вироблення етанолу прямою гідратацією етилену, предмет модернізації парогенератора.*

КЛЮЧОВІ СЛОВА: *ПАРОГЕНЕРАТОР, ГІДРАТАЦІЯ, ЕТАНОЛ, ЕТИЛЕН*

Ethanol, also known as ethyl alcohol, is widely used in various industrial and manufacturing operations. It is used as a chemical solvent, fuel, cleaner, or antiseptic, and as a chemical intermediate. In addition, ethanol is commonly known as the psychoactive substance in alcoholic beverages. It can be produced naturally by fermenting grains (i.e., "bioethanol ethanol") or synthetically through petrochemical processes. Ethanol is a renewable fuel made from a variety of plant materials, collectively referred to as "biomass". [1]

The urgency of modernizing the ethanol production plant is due to the country's demand for cheap energy sources and chemical elements for heavy industry, reducing dependence on imported petroleum products..

The substance is a transparent, volatile, liquid substance that has a very characteristic pungent odor. Flammable, does not show signs of spontaneous combustion, but easily ignites upon any contact with fire. [2]

Areas of application:

The importance of ethanol is due to its wide range of applications.

- One of the strategically important areas of application of ethanol as an additive is fuel. According to The Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding the Mandatory Use of Liquid Biofuels (Biocomponents) in the Transport Sector" dated 04.06.2024 establishes a mandatory ethanol content of at least 5% in all volumes of automotive gasoline sold at wholesale and retail fuel stores.[3]
- In industry as a renewable fuel, with the aim of achieving less pollution or reducing costs.[3]
- In recent years, the demand for antiseptics in all their possible forms has increased significantly. In this industry, ethyl alcohol plays a key role, confirming the relevance of modernizing the technologies of the target component.[4]

- In pharmaceuticals, for the creation of various medicinal formulations such as infusions, tinctures, solutions, etc. It can be important for the extraction of active substances from plants.[4]

Methods of obtaining:

- Fermentation is a biological process where yeast converts sugars (from grains, fruits, etc.) into ethanol and CO₂. It is used to make alcoholic beverages (beer, wine).

- Distillation is a physicochemical method of purifying and concentrating alcohol through evaporation and condensation. It is used to produce spirits.

- Ethylene hydration is an industrial process where ethylene reacts with water in the presence of a catalyst. It produces high ethanol yields and energy costs.

- Acetaldehyde reduction is the chemical synthesis of ethanol from acetaldehyde using catalysts and hydrogen.

- Biomass processing – using enzymes or bacteria to convert cellulose (wood, straw) into ethanol. A promising method for biofuels.

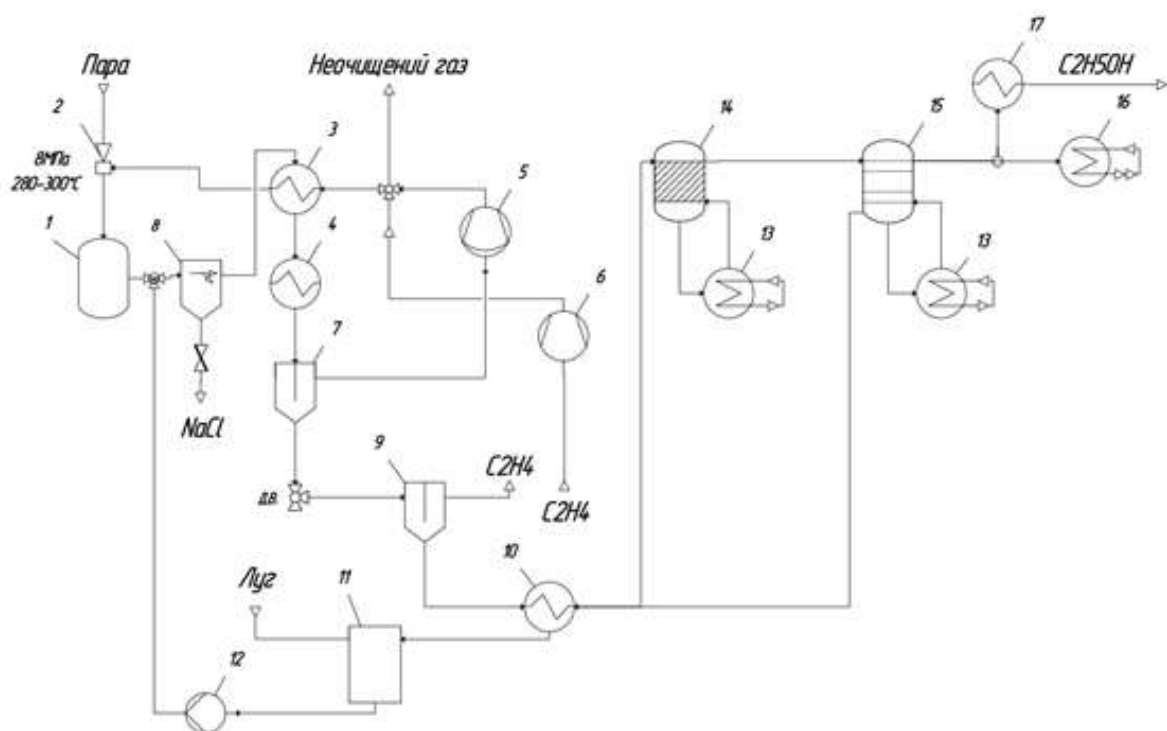
In accordance with the set goal, the process of producing ethanol by hydration of ethylene was chosen due to the potentially high energy costs, which determines the importance of developing innovative methods of thermodynamics, hydrodynamics, and mass transfer in devices.

Technological process of synthetic ethanol production

The process of producing ethyl alcohol by direct hydration of ethylene is based on an exothermic reaction catalyzed by phosphoric acid. Superheated water vapor from the injector (2) is fed to the reactor (1), where it interacts with ethylene in a ratio of 0.7:1. After the reaction, the resulting gas-vapor mixture is sent to the

separator (8), where salts are removed. The main part of the ethylene is supplied by the pump (6), and the circulation compressor (5) ensures the recirculation of the unreacted gas. Both streams are connected in a tee, after which they are sent to the heat exchanger (3), where preheating occurs due to the heat of the reaction products.

The resulting mixture contains phosphoric acid, a reaction catalyst, the pH of which negatively affects the durability of the equipment and pipelines. In order to reduce the aggressiveness of the medium, the acid is neutralized with alkali, which comes from the tank (11) and is pumped by the pump (12) into the reactor (1). After separation in the apparatus (8), the products are cooled in the recovery heat exchanger (3) and the condenser-refrigerator (4), where they pass into the liquid phase. Unreacted ethylene gas is separated in the high-pressure separator (7) and again enters the circulation line, from where it returns to the tee for mixing with fresh ethylene.



1 – reactor; 2 – injector; 3 – heat exchanger-recuperator; 4,17 – refrigerators-refluxers; 5 – circulation compressor; 6 – compressor; 7 – high-pressure separator; 8 – separator; 9 – low-pressure separator; 10 – heat exchanger; 11 – reactor; 12 – high-pressure pump; 13 – steam generator; 14 – stripping column; 15 – rectification column; 16 – reflux condenser; 17 – heat exchanger; D.V. – throttle valve

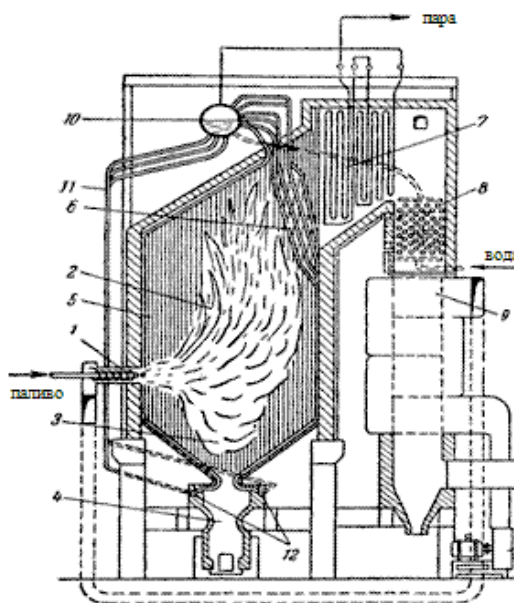
Figure 1 – Scheme of ethanol production by direct hydration of ethylene[5]

In the high-pressure separator, the 15% ethanol solution obtained is directed through a throttle valve to the low-pressure separator, where the ethylene residues are also returned for recycling. The resulting aqueous solution is heated in a heat exchanger (10) using the bottom liquid from the distillation column (15) and enters the stripping column (14). Here, volatile components are pre-separated before the final distillation in the column (15), where concentrated ethyl alcohol is obtained. The steam generator (13) in the scheme performs the function of a recuperative boiler, providing heating of the bottom liquid and stabilization of the temperature regime in the distillation system.[5]

Selecting the device type

1. Drum steam generators:

Water is fed into the drum, where it is distributed over a water tube bundle, which is heated externally by combustion gases. The water in the tubes boils, and the steam formed returns to the drum, where it is separated.



- 1 – burner; 2 – furnace; 3 – cold funnel; 4 – slag shaft; 5 – screen tubes;
6 – festoon; 7 – superheater; 8 – economizer; 9 – air preheater; 10 – drum;
11 – downcomer tubes

Figure 2 – Scheme of drum steam generator

Advantages:

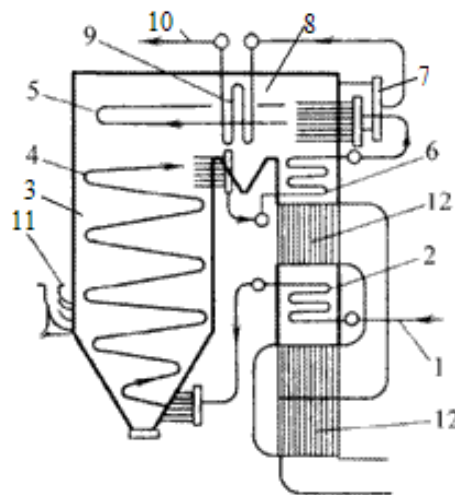
- High efficiency under heavy loads.
- Works at high pressures and temperatures.

Disadvantages:

- Complex design.
- Inexpediency in the steam-gas mixture rectification system for ethanol production
- The need for an additional energy source[6]

2. Direct-flow steam generators:

The water flows through a long pipe where it is gradually heated and converted into steam without forming a drum. The entire process occurs in a single pass cycle



1 – feedwater inlet; 2 – water economizer; 3 – furnace; 4 – lower radiation section; 5 – upper radiation section; 6 – transition zone; 7 – collector; 8 – horizontal shaft; 9 – convective superheater; 10 – superheated steam outlet; 11 – pulverized coal burner; 12 – air preheater.

Figure 3 – Scheme of a direct-flow steam generator

Advantages:

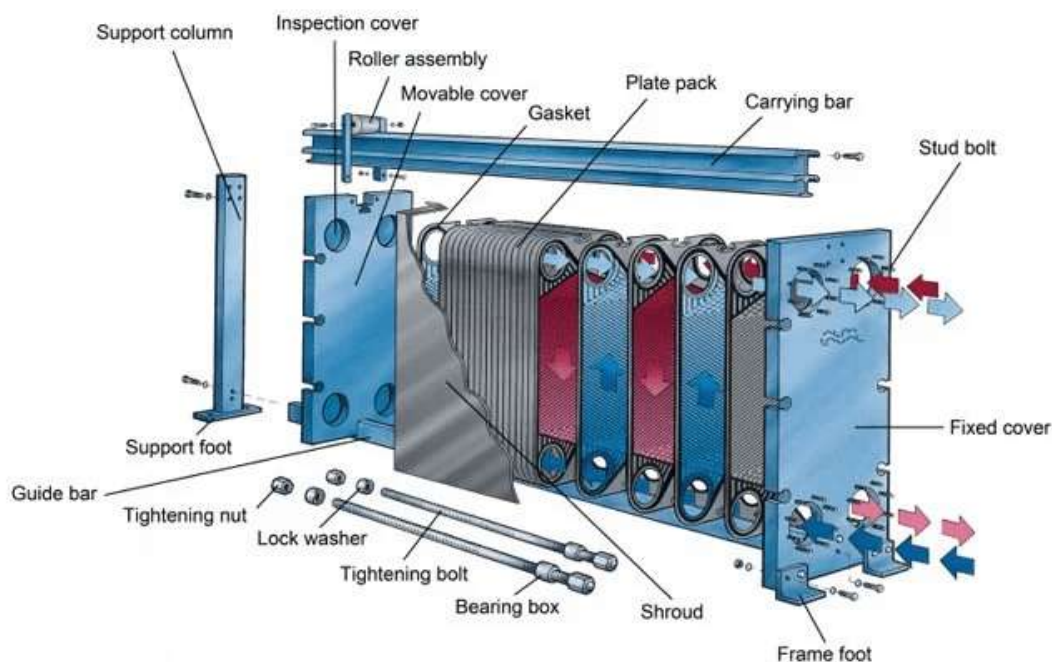
- High steam output

Disadvantages:

- High system pressures
- Sensitivity to sediments due to the lack of a sedimentary zone.
- Difficulty in temperature regulation[6]

3. Plate steam generators

A plate heat exchanger consists of a series of thin, corrugated metal plates with channels between them for the flow of coolant. Hot steam passes through some channels, transferring heat through the plates to the cold liquid in the adjacent channels, which causes it to heat up or evaporate. The corrugated structure of the plates provides turbulent flow, increasing the efficiency of heat transfer.



Support column, 2. Inspection cover, 3. Roller assembly, 4. Movable cover, 5. Plate pack, 6. Gasket, 7. Carrying bar, 8. Fixed cover, 9. Support foot, 11. Guide bar, 12. ShroudFrame foot

Figure 4 – Diagram of a plate steam generator

Advantages:

- High heat transfer coefficients
- Large heat exchange surface

Disadvantages:

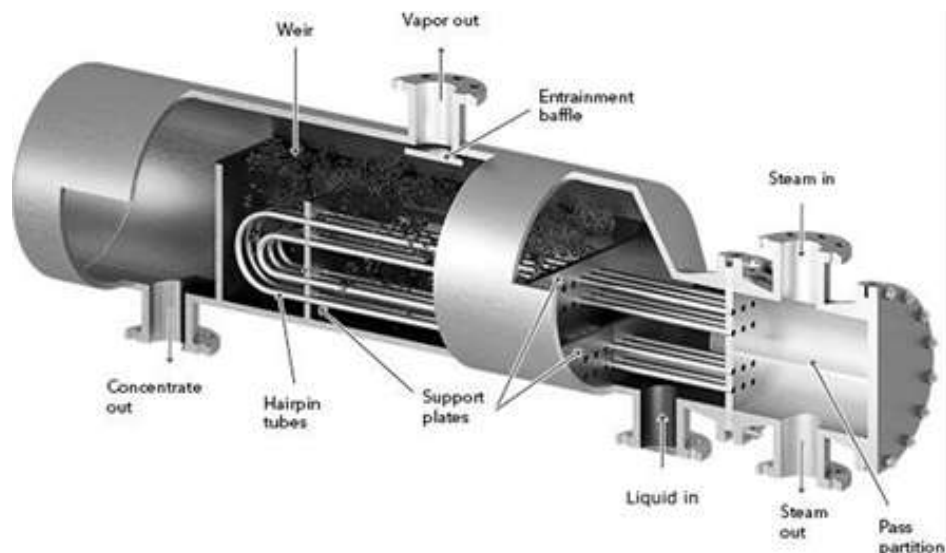
- Rubber seals create significant limitations from temperature and barometric loads
- Susceptibility to corrosion.[7]

4. Shell-and-tube steam generators

The liquid passes through the space between the tubes or in the tubes, which are heated by steam or another coolant. Evaporation occurs as a result of heat transfer through the tube walls, and the vapor-gas mixture is separated in the upper part of the apparatus.

Advantages:

Operation diagram of a horizontal shell-and-tube steam generator[8]



1. Liquid In, 2. Weir, 3. Hairpin Tubes, 4. Steam In, 5. Steam Out, 6. Support Plates, 7. Entrapment Baffle, 8. Concentrate Out, 9. Vapor Out.[6]

Figure 2 - Scheme of operation of a two-pass steam generator

- Large heat exchange area.
- Easy to clean and suitable for systems with high corrosive activity.
- Standardized design, providing cost-effectiveness
- Flexibility in using different types of energy carriers

Disadvantages:

- Large dimensions with high performance.
- May form scale with prolonged use with aggressive environments.
- Dependence of the heat transfer coefficient of the pipe surface on the

scale formation criterion for chemically active evaporation agents[8]

According to the analysis of possible evaporators, a horizontal shell-and-tube steam generator was selected due to its corrosion resistance and the ability to work with bottom liquid of distillation systems, which gives it an advantage among the proposed types of steam generating equipment

The process begins with the liquid entering the lower part of the housing through the inlet pipe (Liquid In), where it accumulates to a level limited by the overflow weir. Heating is carried out by supplying steam through the opening (Steam In) into a tube bundle consisting of U-shaped tubes (Hairpin Tubes). Heat is transferred through the walls of the tubes to the liquid, causing active evaporation in the heat exchange zone. The resulting steam, mixed with liquid microdroplets, rises to the upper part of the device, where droplet separation plates (Entrainment Baffle) are installed, which effectively retain the drops and prevent them from being carried away with the steam.

The purified vapor is discharged through a pipe (Vapor Out) located at the top. The concentrated residual liquid is removed through an outlet (Concentrate Out) at the bottom. The operation of the plant is maintained by regulating the liquid level in the evaporation zone - using an overflow baffle or other engineering solutions - as well as controlling the steam supply. [8]

This type of steam generator is widely used as a bottoms liquid reboiler in distillation columns. The installation scheme provides for the supply of chemically active substances to the apparatus with medium-quality water, which causes an increased criterion for the formation of scale on the surface of the tubes, and the need to choose an effective steam generator design.

Conclusion

The results of the work determined the relevance of the subject of developing a steam-generating unit for the production of ethyl alcohol, and its place in the technological scheme. The key advantages and disadvantages of the devices according to the task of the work were analytically determined. The shell-and-tube type device was preferred among the considered possible types.

List of links:

1. [https://afdc.energy.gov/fuels/ethanol-fuel-basics#:~:text=Ethanol%20is%20a%20renewable%20fuel,\)%2C%20which%20reduces%20air%20pollution.](https://afdc.energy.gov/fuels/ethanol-fuel-basics#:~:text=Ethanol%20is%20a%20renewable%20fuel,)%2C%20which%20reduces%20air%20pollution.)
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9. https://hedhme.com/content_map/?link_id=17433&article_id=270