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ETHANOLIC DISTILLATION: a case study of ethanol loss upon degassing

DESTILAÇÃO DE ETANOL: um estudo de caso sobre a perda de etanol após desgaseificação

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Area: Engenharias, Tecnologias e Gestão

ABSTRACT

Ethanol plays a crucial role in Brazilian and global contexts, serving as a viable and sustainable alternative to fossil fuels. Brazil stands out as a leader in ethanol production, particularly from sugarcane, thereby establishing itself as a benchmark in industrial sustainability. The country's large-scale production of this biofuel boosts the national economy and promotes diversification of the energy matrix, reducing reliance on nonrenewable fuels. The efficiency of ethanol production is inherently linked to minimizing losses during the process. Therefore, the primary objective of this article was to describe the factors that affect ethanol loss during the degassing process. For this purpose, a case study was conducted involving interviews with operators from the alcohol distillation sector of two sugarcane energy plants and extensive research based on the literature. The findings of this study indicate that parameters such as temperature, pressure, and composition of the wort directly influence ethanol loss during degassing. Furthermore, the alignment between manual and automated activities is an essential factor in overcoming these challenges faced by the sector, ensuring reduced losses in this process, and maintaining the quality of the produced ethanol.

Keywords: sugarcane; reducing losses; quality parameters; industrial improvement; bioethanol.

RESUMO

O etanol desempenha um papel crucial nos contextos brasileiro e global, servindo como uma alternativa viável e sustentável aos combustíveis fósseis. O Brasil se destaca como líder na produção de etanol, particularmente a partir da cana-de-açúcar, estabelecendo-se como um exemplo de sustentabilidade industrial. A produção em larga escala desse biocombustível no país impulsiona a economia nacional e promove a diversificação da matriz energética, reduzindo a dependência de combustíveis não renováveis. A eficiência da produção de etanol está intrinsecamente ligada à minimização de perdas durante o processo. Portanto, o objetivo principal deste artigo foi descrever os fatores que afetam a perda de etanol durante o processo de desgaseificação. Para isso, foi realizado um estudo de caso envolvendo entrevistas com

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operadores do setor de destilação de álcool de duas usinas de energia de cana-de-açúcar e uma extensa pesquisa baseada na literatura. Os resultados deste estudo indicam que parâmetros como temperatura, pressão e composição do mosto influenciam diretamente a perda de etanol durante a desgaseificação. Além disso, a alinhamento entre atividades manuais e automatizadas é um fator essencial para superar os desafios enfrentados pelo setor, garantindo a redução de perdas nesse processo e mantendo a qualidade do etanol produzido.

Palavras-chave: cana-de-açúcar; redução de perdas; parâmetros de qualidade; melhoria industrial; bioetanol.

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1 INTRODUCTION

Ethanol commercialization plays a crucial role in the global energy landscape, serving as an essential alternative to promote environmental sustainability, energy security, and economic development (Goldemberg, Coelho, Guardabassi, 2018). The United States leads the world in producing this biofuel, primarily using corn as the raw material. Brazil ranks second in this area, distinguished by its use of sugarcane as the primary raw material (Renewable Fuels Association, 2023).

Ethanol production occurs through the fermentation of sugars recovered from saccharides (Bordonal et al., 2018), starch (Mosier, Ileleji, 2019), and, more recently, lignocellulosic biomasses (Toor et al., 2019). Sugarcane is the predominant raw material used and has the advantage of lower fossil energy consumption during plant growth, resulting in production costs approximately 50 to 60% lower than those associated with processes using corn and biomass, for example (Manochio et al., 2017).

The processing of sugarcane for ethanol production involves several stages. First, the juice is extracted and subjected to chemical treatment to remove soluble and insoluble impurities. Next, the sucrose in the prepared juice is converted to ethanol by the action of *Saccharomyces cerevisiae*, resulting in a mixture with an alcohol content greater than 10° GL, known as wine. Finally, the ethanol in the wine is recovered through alcohol distillation (Dias et al., 2015).

Ethanol production in Brazil is expected to increase significantly in the coming years. This expansion is due to the country's commitment to increasing the share of sustainable bioenergy in its energy matrix to 18% by 2030, primarily through expanding this biofuel supply (Brasil, 2015; Budzinowski, 2018).

Although the outlook is promising for the Brazilian economy, maintaining Brazil's position as the leading producer of sugarcane-based ethanol and its ability to meet established global agreements face challenges related to the sector's sustainability. Increasing ethanol production often implies additional land use for raw material cultivation, which can result in biodiversity loss, soil degradation due to chemical use and agricultural practices, and competition between food and fuel production, raising important questions about food security (Goldemberg, Coelho, and Guardabassi, 2018; Budzinowski, 2018).

The sector must improve ethanol production efficiency by using the raw material already available in the plant (Dias et al., 2015) to overcome this challenge. This improvement can be achieved by adopting new technologies focused on reducing losses and

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improving process sustainability at different production stages (Tgarguifa, Abderafi, Bounahmidi, 2017; Barbosa et al., 2017; Gonçalves Filho et al., 2018; Lopez-Castrillon et al., 2018).

The distillery sector plays a fundamental role in the overall efficiency of sugarcane energy industries. Distillation is a crucial step in the process of fermentation, during which the ethanol produced during fermentation is separated from other components in the wine, resulting in high-purity fuel (Dias et al., 2015). The sector's efficiency was assessed by the ratio of the amount of ethanol recovered to the amount present in the wine fed into the distillation columns. The unrecovered ethanol is lost in the bottom streams of the columns (vinasse and phlegm), the degassing modules of noncondensable gases, and the second alcohol stream (Generoso, 2021).

The loss of ethanol in vinasse and phlegm, considered determinable losses, are essential parameters during distillery operation, as they are employed in calculations of distillation efficiency (Generoso, 2021). However, although ethanol can be significantly lost during degassing, this process is still underdiscussed in the literature.

Thus, there is a gap in the literature regarding ethanol loss during degassing. Considering the importance of this issue for the sector, this study focuses on the following questions: what factors contribute to ethanol loss during the degassing process, and how can ethanol recovery during degassing be improved?

Hopefully, this study will contribute to a deeper understanding of the distillation parameters affecting ethanol loss through degassing. The aim is to advance the current state of knowledge of this process to enable the development of new strategies to minimize these losses, increase the profitability of the biofuel industry, and expand the availability of this product both in Brazil and worldwide.

2 THE ETHANOL MARKET

The ethanol supply is increasingly important for providing renewable fuels for the transportation sector in Brazil. This trend is driven by worldwide greenhouse gas emission reduction and the imperative need to expand the use of renewable energy sources in this sector (International Energy Agency, 2022). Furthermore, implementing public policies, such as mandatory blending requirements, differentiated taxation systems, and subsidies, bolsters biofuel demand. In this context, Brazil stands out as the only country in the world where the use of biofuels accounts for more than 10% of the energy demand for the transportation sector (Organization for Economic Cooperation and Development; Food and Agriculture Organization of the United Nations, 2021).

The United States leads in global ethanol production, contributing 55% of the total volume produced and being the leading exporter. The major markets for American ethanol include Canada, South Korea, and the European Union. Like the U.S., Brazil is the second-largest ethanol producer, accounting for 26% of the global production volume (Renewable Fuels Association, 2023). North America and the Asia-Pacific region are the primary destinations for Brazilian ethanol, with South Korea being the largest importer from Brazil, receiving 40% of the total exported volume (Agência Nacional do Petróleo, 2022).

Although the expansion of the electric and hybrid vehicle markets may impact ethanol demand, biofuels still have advantages in terms of distribution infrastructure and cost compared to other alternative fuels. Additionally, technological advancements are driving second-generation ethanol production, which uses agricultural and forestry residues as raw materials, broadening the prospects for sustainable production (International Energy Agency, 2022).

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2.1 Sugarcane ethanol production

Sugarcane ethanol is more favorable than other biomass sources, such as corn and beet. The processing of sugarcane requires less energy and is more cost-effective. Furthermore, sugarcane has a high ethanol yield and a lower carbon footprint, making it a more sustainable and advantageous option than other raw materials (Manochio et al., 2017).

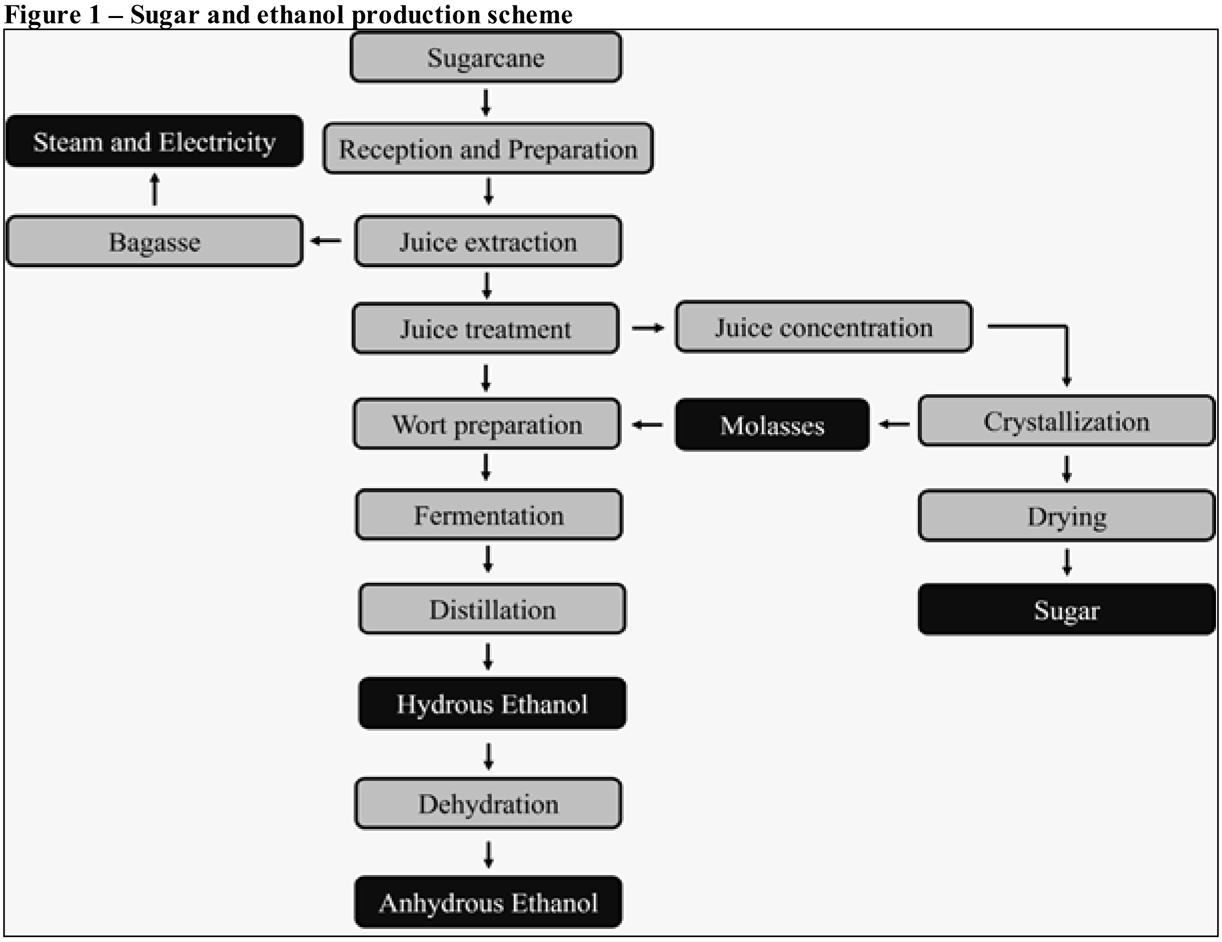
Sugarcane processing into ethanol consists of various steps, as summarized in Figure 1 and detailed in subsequent sections. In Brazil, it is common for a single factory to utilize sugarcane for sugar and ethanol production. Here, molasses, a byproduct of sugar crystallization, may be added to wort for alcoholic fermentation. The industry self-generated the entire energy requirement for this processing, using sugarcane bagasse as fuel for boilers that produce high-temperature and high-pressure steam (Dias et al., 2015).

2.1.1 Reception and sugarcane preparation

Sugarcane undergoes several procedures at the factory to ensure quality and efficiency in juice extraction. Once weighed, all the received sugarcane is directed to the extraction sector. Most mills use a dry-clean system for raw material to prevent sucrose loss, which can be prechopped via mechanized harvesting (Castro et al., 2018).

During preparation, rotating knives and shredders pulverize the cane mass, opening its cells and facilitating sugar extraction during milling. The contractor transports the shredded cane to the mill's feed, where the cane level controls the flow for extraction (Dias et al., 2015).

Figure 1 – Sugar and ethanol production scheme



Fonte: autoria própria (2024)

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2.1.2 Juice Extraction

Sugarcane juice extraction can be carried out through two main processes, milling and diffusion, both of which involve the physical separation of fibers (bagasse) from juice (Santos et al., 2020). Although more energy intensive, milling is preferred in Brazil due to its efficiency and lower operational costs (Dias et al., 2015).

In the milling process, separation is achieved by applying mechanical pressure from the mill's rollers onto the layer of preshredded cane. During diffusion, separation occurs by washing the sucrose absorbed by the cane layer (Castro et al., 2018).

Both procedures aim to extract juice containing sucrose, which is subsequently used to produce ethanol and sugar.

2.1.3 Juice Treatment

Treating sugarcane juice for ethanol production involves physical and chemical procedures. Initially, screens remove suspended solids, followed by flocculation and coagulation techniques to eliminate colloidal residues and impurities. Chemical treatment includes the use of lime to adjust the pH of the juice and heat, changing its characteristics (Castro et al., 2018) through the formation of insoluble solids. The air present in the treated juice is removed, and in the clarifier, an anionic polymer is added, facilitating the phase separation of clarified juice and mud. The first is sent for subsequent stages, during which the sludge is sent to a filtration station to recover the present sucrose (Santos et al., 2020). After mud filtration, the recovery sucrose starts again during juice treatment, after which a solid residue is formed: a filtered cake, which is used for soil fertilization (Albuquerque, 2011). For ethanol, a soft treatment was used with different pH values adjusted from 7 (sugar process) to 6. Softening treatment is performed to preserve nutrients in clarified juice.

2.1.4 Wort preparation

Wort preparation involves adjusting the sugar concentration, pH, nutrient concentration, and contaminant concentration, ensuring highly efficient fermentation. At this stage, molasses, a sugar crystallization byproduct, can be incorporated into the juice (Zohri et al., 2022), requiring dilution. The final sugar concentration in this mixture is commonly measured in Brix degrees (°Brix), ranging between 18 and 26 (Rebelato et al., 2019).

The pH was adjusted to 4.5 to benefit the yeasts in the fermentation step, while nutrients previously removed during juice treatment for sugar production needed to be reintroduced when using molasses waste. These essential nutrients are replenished by applying nitrogen and phosphorus-containing products (De Souza et al., 2015). Once prepared, the Wort advances to the fermentation stage.

2.1.5 Ethanol Fermentation

Alcoholic fermentation is the process by which sugars in wort are converted into ethanol and carbon dioxide by the action of *Saccharomyces cerevisiae* (Castro et al., 2018). Fermentation occurs in vats under controlled temperature, pH, and agitation conditions to promote yeast growth and maximum fermentative capacity (Santos et al., 2020; Dias et al., 2015). The process can last 6 to 10 hours, resulting in the separation of wine, a mixture of low alcohol fermented products, from the yeasts through centrifugation. Wine contains a high

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percentage of contaminants such as acetaldehyde, higher alcohols, and more volatile substances (Zarpelon, 2020).

The separated yeast was treated and reintroduced into a new batch of Wort for a new fermentation cycle (Madaleno et al., 2016; Santos et al., 2020). The wine is then directed to the distillery sector.

2.1.6 Distillation

Distillation begins with the admission of heated wine at the top of column A1. The more volatile compounds are vaporized and concentrated at the top of column D, where they are condensed to form raw or second-grade alcohol. Part of this condensate returns to column D to maintain its feed. Nonalcondensable gases (CO_2, SO_2, and NH_3, among others) are eliminated through vents (Zarpelon, 2020), while at the base of column A, less volatile products are concentrated, resulting in vinasse.

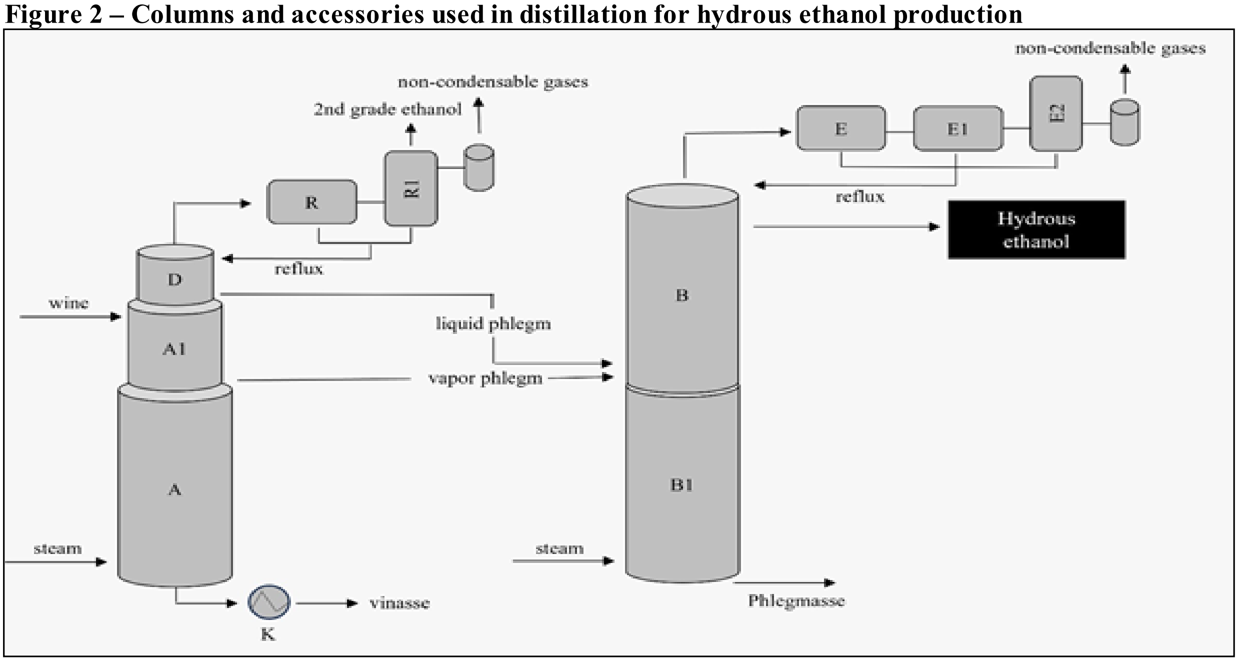
Ethanol-rich streams, called vapor phlegm and liquid phlegm, are obtained at the top of column A1 and the base of column D, respectively. These two phlegm plants are fed into column B at different stages (Dias et al., 2015).

In column B, the phlegm vapor and liquid are concentrated to obtain hydrated ethanol (92.5 to 94.6% w/w), which is extracted from 4 to 5 trays below the top of this column (Castro et al., 2018). Phlegmasse at the base of column B1, which is mainly composed of water, is removed (Zarpelon, 2020).

In column B, certain oily compounds concentrate and must be removed, resulting in fusel oil, another byproduct of the process. At the top of column B, ethanol-rich vapors pass through three condensers, which aim to convert the vapor into liquid, returning it to the column as reflux. Like in column A, noncondensable gases must be removed because they promote acidity, conductivity, and unpleasant odors in the final product (Zarpelon, 2020).

To produce anhydrous ethanol (99.3% w/w), techniques such as azeotropic distillation with cyclohexane or monoethylene glycol can be used, as can the use of molecular sieves (Castro et al., 2018).

Figure 2 – Columns and accessories used in distillation for hydrous ethanol production



Fonte: adapted from Dias et al. (2015) and Bonomi et al. (2012)

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3 METHODOLOGICAL PROCEDURES

The methodological procedures were based on a literature review, encompassing the analysis of authors and technical documents related to the subject, along with the conduct of a case study involving two companies active in the sugarcane energy sector. The information from these companies was evaluated using a questionnaire detailed in Appendix A. Thus, the present research assumes an exploratory nature with a qualitative approach.

4 RESULTS AND DISCUSSION

This section has been divided into two distinct parts for a more comprehensive understanding. In the first part, a detailed description of the degassing process, which occurs in the condensers attached to the distillation columns, was conducted. In the second section, the distillation parameters that influence the efficiency of ethanol recovery are introduced and discussed, consequently impacting the losses of this fuel.

4.1 Degassing in distillation columns

Degassing is a procedure adopted by industry to reduce noncondensable gases that increase the acidity of hydrated ethanol, directly interfering with the quality of the produced fuel (Bueno et al., 2010; Zarpelon, 2020). The degassing-bleed system occurs after the last stage of condensation. Thus, each grouping of condensers, located at the top of columns A and B, directs the incondensable gases that will be eliminated (Bessa et al., 2010).

Vapors from the top of the columns pass through the condensers, exchanging heat with the cold wine in the case of condenser E, while the others use water in a closed circuit. At this point, a fraction of the hydroalcoholic vapor is condensed and directed to the reflux balloon, where it will return to the column, and the part of the vapor that does not condense feeds the subsequent condenser. The condensers are partial or total condensation equipment, with partial condensation condenser R located in column A and condensers E and E1 in column B. The total condensation events R1 and E2 are in columns A and B, respectively. The vapors from the total condensers, with their remaining fraction, i.e., uncondensed, pass through the bleed-degassing system called vents, promoting the elimination of volatile compounds in the environment (Araújo Júnior, 2022).

Although essential for ensuring compliance with ethanol fuel quality standards, degassing can result in significant losses of ethanol (Bueno et al., 2010). Therefore, identifying the factors influencing ethanol recovery during this procedure is necessary.

4.2 Ethanol loss during degassing

The vents are divided into two streams, namely, the degasification and the liquid fraction, which are directed to a tank, where they will later be recycled in the production process of hydrated ethanol for use as fuel. The liquid–vapor mixture in the bleed balloon reaches a specific temperature at a given pressure, varying according to the temperature and pressure of the distillation column to which the set of condensers is associated (Araújo Júnior, 2021). Elevated temperatures can increase the rate of ethanol evaporation, resulting in significant losses during degassing (Bueno et al., 2010).

According to the information collected during this case study, in practice, temperature changes cause modifications in the condenser reflux system, altering the column balance by

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affecting the internal pressure and leading to losses due to increased ethanol vaporization. This loss can be observed as droplets exit the condenser vents.

The control of the operating temperature of the condensers is automated and monitored by the plants' Integrated Operations Center (IOC). The water inlet valves in the condensers were controlled, and ethanol was removed based on the operators' prior experience. The aspect of evaporation during degasification serves as a parameter for adjusting the water flow, while the quality of the ethanol is monitored via laboratory chromatographic analyses. Suppose the upper stream (degasification) contains excess hydroalcoholic vapor released into the atmosphere. In that case, the water valve is opened to increase the condensation rate, more efficiently recovering the volatilized ethanol. A manual valve controls the removal of alcohol mixtures rich in impurities through bleeding. When chromatographic analyses indicate high levels of impurities in the final product, the bleed of the condenser is increased to meet the necessary specifications. However, because of this process, industrial ethanol production is reduced, increasing losses due to volatilization (Araújo Júnior, 2022).

Therefore, it is evident that distillery operators play a fundamental role in this control, mainly because some operations are performed manually and based on their prior experience.

One of the common failures observed in the distillation process consists of reducing the flow of wine (for some process needs) and maintaining excessive vapor pressure, thus increasing the operation temperature, and reducing the efficiency of the cooling system. A condenser with low efficiency or inadequate design can result in substantial ethanol loss (Zarpelon, 2020).

As reported by Bueno et al. (2010), condensers are operated in a way that keeps ethanol loss during degassing at controlled levels. A strict guideline is established that these losses should not exceed the amounts lost in the vinasse and phlegm, i.e., a maximum limit of 0.25% of the ethanol-fed to the process. This finding implies that the total losses during distillation should not exceed the maximum value of 0.50% of the ethanol introduced into the process.

Zarpelon (2020) reported that in addition to gases, other volatile compounds in liquid form should also be eliminated from condensers, as their presence favors the generation of resinous secondary products that obstruct the gas outlet, altering the pressure on the equipment. Thus, it is necessary to avoid designing these pieces of equipment in a way that favors the presence of dead zones that facilitate the accumulation of these elements, projecting them toward the gas outlet at a 180-degree angle relative to the inlet.

The composition of the mixture present in the wine also appears to play an important role in the loss of ethanol during the degassing process. In a study that used simulation techniques and aimed to analyze thermally integrated distillation columns for bioethanol production, it was determined that the presence of CO_2 significantly affects the efficiency of the degassing process by reducing the temperature at the top of the column. According to the authors, this effect can be minimized by increasing the degassing rate, which may result in ethanol losses or require the implementation of an additional system for fuel recovery (Bessa et al., 2012).

The requirement for the quality of the ethanol produced is directly related to the degassing loss rate. Brazilian legislation provides hydrated ethanol fuel conductivity, acidity, and INPM degree specifications only. However, as the industry exports ethanol to different countries, removing other substances present in the ethanol may be necessary depending on the required specifications, causing more significant production losses, which vary according to the required parameters.

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5 FINAL CONSIDERATIONS

This study revealed that variations in temperature, pressure, and composition of wine directly influence ethanol loss during degassing. The manual and automated control exercised by distillery operators is highly important for adjusting operational conditions, optimizing the recovery of volatilized ethanol, and maintaining the quality of the final product. Thus, an integrated approach combining automation and human knowledge is necessary to improve the efficiency and quality of ethanol production continuously.

It is important to emphasize that the information presented in this research is based on a literature review and a case study of the routine in two distinct industrial units. These findings are not supported by specific empirical results that quantify the magnitude of these effects. Considering this gap, future studies should be conducted to empirically investigate ethanol loss during degassing. These experimental studies will allow more precise data on the recovery or loss of ethanol to be obtained, contributing to the optimization of the ethanol production process.

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