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Basic Issues of Brandy Industry Waste Conservation

Abstract: The purpose of the study is to cost-effective and environmentally friendly procedures for the condensation of waste generated from brandy production (distillery dreg) for agricultural use. The experiments were carried out between 2020–2022 under laboratory conditions. It has been shown that in order to reduce the significant cost of distillery dreg transportation, it is advisable to carry out its condensation by means of distillation. Laboratory studies and feasibility calculations revealed that distillery dreg may be condensed by up to five times, allowing for a corresponding reduction in transportation costs, while maintaining its quality indicators. It is suggested that the brandy alcohol distillation process be altered in a way that will allow for the production of condensed distillery dreg substance, with minimal additional energy expenditure and capital investment. The suggested method makes it possible to not only improve the ameliorative conditions of agricultural land, but also to address significant environmental protection issues.

Keywords: brandy industry waste, distillery dreg, optimal condensation, cost reduction, agricultural land improvement

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1. Introduction

Since the adopted method might lessen certain detrimental effects on the environment, the issues of conservation and the utilization of agricultural and industrial waste have been taken into consideration. First and foremost, two interconnected challenges must be solved in order to harmonize the relationship in the production-nature system. By reducing waste or using it, one can prevent environmental degradation and make better use of natural resources [1]. Such studies must be carried out in order to provide scientific answers, particularly to the question of whether it is possible to adopt practical and creative approaches to the use, management, and preservation of natural resources in agriculture. Numerous strategies have been employed in this regard for a long time [2, 3] and many scientific studies have been conducted which have focused on the potential use of waste in production [4, 5]. However, there are few studies that address the usage of numerous valuable nutrients and micronutrients in agricultural waste [6, 7].

One of the challenges to sustainable agricultural development is the ever-increasing demand for fertilizers [8]. According to some studies, agriculture's reliance on chemical fertilizers has resulted in an overuse of these substances [9]. As a result, there is a concern about the preservation of soil, water, and aquatic ecosystem quality, as well as dangers to human health [10–12].

Given the above-stated facts, it seems it would be beneficial to convert agriculture into a recyclical model based on waste reuse and reproduction [13].

According to various estimates, agricultural systems generate approximately 570 million tons of waste globally per year [14]. It takes a high quantity of raw material with a great potential for processing to produce biofertilizers and can play a critical role in reducing mineral fertilizer use [15]. Another factor that makes the recycle approach appealing, socially acceptable, and convenient is the promise of lowering the environmental impact and disposal costs of waste [16]. In this context, biofertilizers lower the risks of pollution and environmental degradation by boosting plant nutrition and ensuring proper nutrient uptake.

A study of global experience shows that brandy production waste currently causes serious environmental problems when it is not disposed of according to established requirements [17]. At the same time, these wastes contain a large number of useful substances, which could be effectively directed to the fertilization of cultivated lands (for the reclamation of saline-alkaline soils, to boost soil fertility) due to its high organic and mineral content [18].

Brandy production waste, such as distillery dregs (DD) is a dark brown liquid with low pH (3.1–3.4). It contains up to 6% of dry substances, and up to 13 L of DD are directly obtained from each liter of alcohol. It contains 5.647 g/L of acids, of which 3.89 g/L is tartaric acid, 1.452 g/L is malic acid, and 0.305 g/L is acetic acid, with a total titratable acidity of 75–104 meq/L, as well as nutrients such as nitrogen (0.224 g/L), phosphorus (0.592 g/L), potassium (1.193 g/L), some microelements, valuable vitamins and enzymes [19, 20].

The global volume of brandy production is increasing annually. France is the world's leading brandy exporter (95%), with brandy production increasing by 16% in 2021 compared to 2020 [21].

About 200,000 t of technical sorts of grapes are harvested in Armenia annually, providing raw material for winemaking and brandy production and around 100,000 t of DD are generated as waste. Researches has shown that the application of 15,000–20,000 t/ha of DD contributes to the reclamation of saline-alkaline soil, improves its physical and chemical properties, regulates the nutritional regime in semi-desert brown soils, and increases fertility indicators [22]. However, significant transportation costs are a major barrier to the use of DD. For example, to reclaim 1 ha of saline-alkaline soil, 800 loads from a 25-tonne tanker travelling an average distance of 30 km are necessary, costing approximately USD 32,000 in Armenia [23]. In the case of using DD as fertilizer, 28 tanker loads with the same capacity will be required at a cost of USD 1,120. As a result, only the Yerevan Cognac Factory, among the firms producing DD, supplies it free of charge to farmers to improve agricultural lands in order to tackle environmental concerns, provided that the route length for waste trucks does not exceed 10–15 km. Other factories generally dispose of their production wastes into surface water. The high-temperature (90–95°C) of waste discharged into the water basin has a very unfavorable influence on the ecosystem [24]. The dark-colored DD can block out sunlight, inhibiting photosynthesis and reducing the solubility of oxygen in water, which make it harmful to aquatic life [25]. Thus, untreated DD causes depletion of dissolved oxygen in water bodies and harms aquatic flora and fauna [26]. In order to prevent the negative impact of DD on the environment, Western countries have established strict regulations prohibiting any sort of discharge [27, 28].

Numerous methods of DD conservation have been developed, allowing for economic benefits from alcohol dregs while also addressing some environmental issues [29]. Condensation procedures are primarily as follows:

- Anaerobic fermentation method in which methane gas is stored and, after purification, used for its own needs. This method has not been widely employed since, after the processing a considerable amount of DD, the issue of preserving the sludge, formed during fermentation and which contains many useful compounds, must also be addressed [30].
- Electrodialysis technology, which allows the most valuable components from wine grapes, particularly tartaric acid, to be extracted [31].
- The distillation method, which allows for the reduction of waste volume while conserving valuable compounds, but it is energy intensive, and there is a need to lower the expenses associated with this process [32, 33].
- Thermal treatment technology for a variety of alcohol crops – cereals, potatoes, corn – has been used, results a dry mass that is useful for fodder. However, as DD does not contain sufficient amount of dry matter, the aforementioned method is not used for that purpose [34, 35].

After analyzing the presented methods, we came to the conclusion that the most effective method for DD condensation is distillation, which uses the difference in boiling temperatures between components of the mixture, resulting water and DD condensed substance. Evaporation and condensation of the mixture make it possible to almost completely preserve the substances contained in it. It should be noted that most of the distillation alternatives perform only partial separation and it is not possible to obtain a product without losing valuable materials.

Therewithal, to carry out utilization by various methods, it will be necessary to transport DD from brandy factories to the place of their processing, which will require high transportation costs. Due to the high content of nitrogen, phosphorus, and organic substances in these wastes, they are used for soil direct fertilization (spreading over fields and plowing) in some countries. However, due to the above-mentioned constraints, such a measure is not cost-effective. The biggest downside of distillation is its significant energy consumption [36]. To reduce energy consumption during distillation, the method of vacuum distillation was used. This method aims to ensure that, with a decrease in pressure, the boiling point of liquids also decreases. It has been determined that the boiling point of alcohol drops by 15°C with a 0.5-atmosphere decrease in pressure, meaning that boiling takes place at 63°C. However, the most apparent drawback of vacuum distillation is the expensive cost of the apparatus [37].

Nonetheless, it is possible to use the energy resources available in the brandy distillation process to carry out DD condensation procedure without incurring additional financial charges. Thus, we propose removing water by distillation, directly in the process of distilling brandy alcohol, using the energy resources which are lost in this process and significantly reduce the costs of distilling DD.

In the above mentioned context, the scientific hypothesis of the presented research is to investigate the potential of waste for the production of biologically based substances, such as biofertilizers for regulation of the soil nutrient regime, as well as some organic acids for improving the physical and chemical properties of the alkaline soils. The benefit of the proposed strategy is that it defines sustainable strategies to reduce the negative environmental impact caused by the disposal of specific wastes, and on the other hand, the application of the produced products fosters increased agricultural land fertility and crop output.

The novelty of the presented work is the developed technology of DD condensation with minimal additional energy expenditure and capital investment, which will simultaneously allow the prediction of DD condensed substance as a fertilizer.

2. Materials and Methods

Within the framework of the present study, the benefits obtained from the possible processing of brandy production waste, the indicators of brandy production in RA were studied, and laboratory experiments of DD condensation were carried out. A new DD processing technology was proposed.

The experiments were conducted using DD samples from the RA MAP wine brandy factory. This facility is one of the pioneers in Armenian brandy production, with approximately 53,000 t of grapes procured annually. As a result of its processing, approximately 2,000 t of brandy alcohol is produced and 26,000 t of DD is formed as waste.

The laboratory experiments were conducted to determine the optimal degree of DD condensation in order to preserve its quality indicators: total acidity and nitrogen, phosphorus and potassium contents.

The distillation method is used for DD condensation. For this purpose a laboratory distillation apparatus was assembled. This equipment is responsible for facilitating the separation of substances from a liquid mixture that intends the DD heating to its boiling point, transferring the vapor to a different part of the apparatus, then condensing the vapor and collecting it in another container.

A laboratory test is also required to identify the changes in the qualitative and quantitative indicators of DD condensate during the distillation process. For this purpose 500 mL of DD was taken to carry out distillation. After each 25 mL distillation, the solutions were separated and analyzed for their chemical composition. During distillation, 18 distillates were collected. Distillation was stopped after having distilled 450 mL of liquid, and the remaining 50 mL of DD concentrate was left in the vessel. Distillation was carried out at 96°C and only the final 18^{th} batch was distilled at 100–103°C.

Distillation was repeated three times and averaged data were presented.

The total acidity was determined by the titration method; pH and electrical conductivity (EC) by the electrometric method; nitrogen content by the Tyurin–Kononova method; phosphorus and potassium by the Machigin method. These indicators are determined in both distilled and initial solutions.

The degree of DD condensation (A) was determined by Formula (1):

$$A = \frac{B}{B - E} \tag{1}$$

where:

B – the amount of DD taken for distillation [mL],
E – the amount of distilled solution [mL].

Thus, for instance, if 500 mL DD is taken for distillation and 450 mL is distilled, then the degree of DD condensation is equal to 10.

The DD transportation cost R (in USD) was calculated by the following formula:

$$R = \frac{VY}{P} \tag{2}$$

where:

V – the mass of the DD being transported [t],
P – the capacity of the waste transporting tanker [t], $P = 25$ t,
Y – the cost of one run of the tanker [USD], $Y = 40$ USD.

For assessing the total acidity loss (indicator using for calculation the norm of ameliorant for reclamation of alkaline soils), it is proposed to use the cost of equivalent norms of gypsum (C), which is calculated by the following formula [38]:

$$C = \frac{\eta NT}{100} \quad (3)$$

where:

- C – cost of equivalent norms of gypsum [USD],
- η – the amount of total acidity loss during the DD distillation [%],
- N – the average norm of gypsum for the reclamation of saline-alkaline soils [t/ha], $N = 200$ t/ha,
- W – the average norm of the DD for reclamation 1 ha of saline alkaline soils [t/ha], $W = 20{,}000$ t/ha,
- T – the cost of gypsum [USD/t], $T = 130$ USD/t.

3. Results and Discussion

It was found that the total titratable acidity is 77 meq/L, the total concentration is 5.78 g/L, EC index is 11.01 mS/cm, pH = 3.4, nitrogen –0.224, phosphorus – 0.592 and potassium – 1.193 g/L.

Summarizing the indicators given in Table 1, it can be stated that all the solutions have an acid reaction, which supplies grounds for asserting that the acid removal process is underway during distillation [39]. In the solutions I–IX, the pH ranges from 3.2–3.4, and the last ones X–XVIII, from 3.0–3.2, and this indicates that the removal of acids during distillation gradually increases.

Table 1. pH and EC indicators of solutions separated during DD distillation

Indicators	Number of distillates								
	I	II	III	IV	V	VI	VII	VIII	IX
pH	3.4	3.3	3.2	3.2	3.3	3.4	3.4	3.2	3.2
EC [μs/cm]	411	445	464	474	483	494	515	534	541
Indicators	Number of distillates								
	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII
pH	3.1	3.2	3.1	3.2	3.2	3.0	3.0	3.1	3.0
EC [μs/cm]	564	581	610	634	674	734	803	916	1,274

During the DD distillation process, a constant increase of EC indicators is observed. Solutions I–IX show an increase in EC indicators from 411 µs/cm to 541 µs/cm, while solutions X–XVIII show an increase from 564 µs/cm to 1274 µs/cm. The maximum increase in EC is observed, especially in solutions XV–XVIII. Figure 1 shows the relationship between the relative indicators of the total acidity removed during the DD distillation process (percent of the acids contained in the DD before distillation) and the degree of condensation.

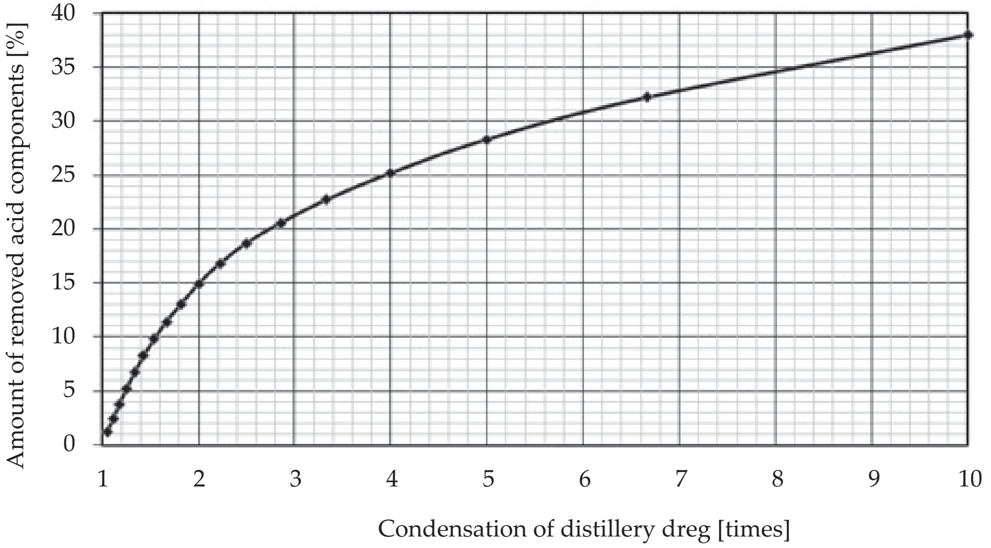

Fig. 1. The relationship between the relative mass of the total acidity removed during the distillation and the degree of DD condensation

By examining the indicators presented in Figure 1, it can be concluded that the condensation of DD is accompanied by the removal of a certain amount of the total acidity contained in it. For instance, if the DD is condensed twice, 15% of the total acidity is removed, and if it is condensed 10 times, 38% of the acidity is removed, significantly reducing the DD norm as a chemical ameliorant. This suggests that determining the optimal degree of condensation in DD can be challenging, as too much condensation can lead to a significant reduction in its ameliorant properties [39, 40]. These findings are vital for understanding the distillation process's impact on the quality indicators of DD and for optimizing its use as an ameliorant.

It is well known that DD condensation leads to a reduction in the volumes of transported DD. Figure 2 demonstrates that the dynamics of the reduction of the volume of 10,000 t DD produced in a brandy factory depend on the degree of DD condensation. It is shown that, for instance, in the case of 2-fold condensation of DD, the transported volume is 5,000 t, whereas, in the case of 10-fold condensation, it is 1,000 t, and this lead to a reduction of transportation costs.

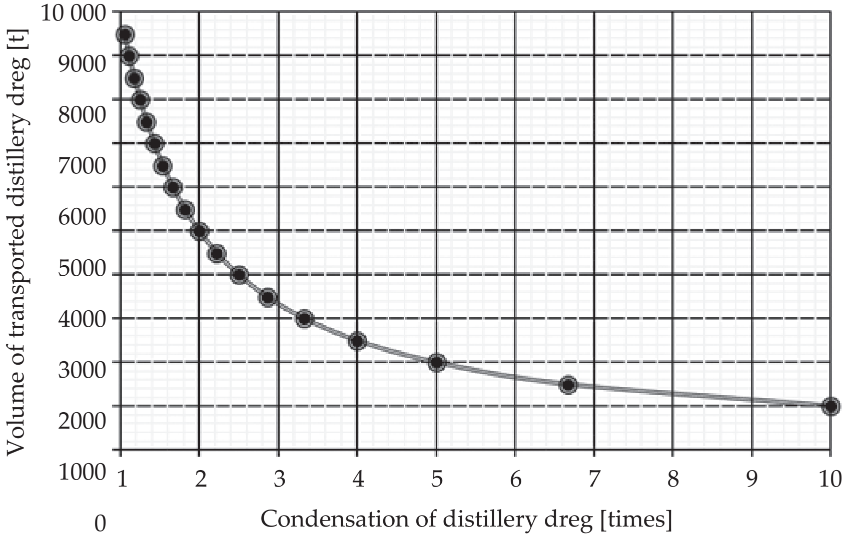

Fig. 2. The dynamics of reduction volume of transported distillery dreg depending on the condensation degree

The following observation was performed to calculate the cost of equivalent norms of gypsum: chemical improvement of 1 ha of saline-alkali soil requires 200 t of gypsum, which is equivalent to 20,000 t of DD, where the price of gypsum per ton is USD 130 (plus shipping costs), and the cost of equivalent norms of gypsum (C), calculated by Formula (3), expressed the loss of total acidity during DD condensation.

Figure 3 shows the dependence of DD transportation costs (curve 1) and the cost of equivalent norms of gypsum (curve 2) on the degree of DD condensation.

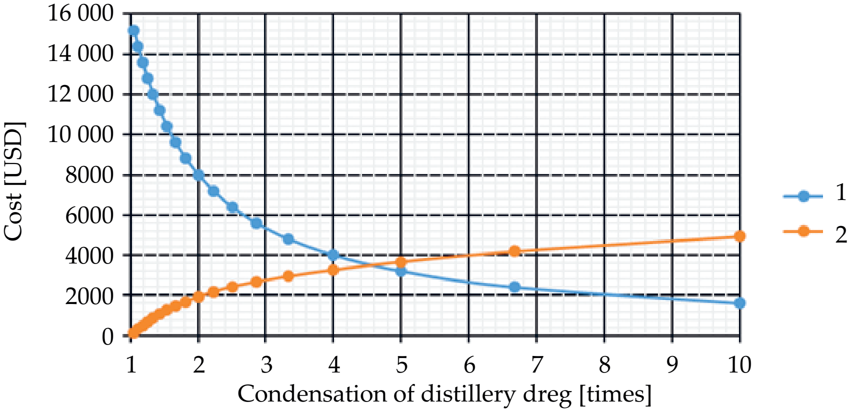

Fig. 3. Dependence of DD transportation costs and the cost of equivalent norms of gypsum on the degree of DD condensation:
1 – cost of DD transportation, 2 – cost of equivalent norms of gypsum

In Armenia, the transportation of 10,000 t of DD without condensation approximately costs USD 18,000. However, depending on different degrees of condensation, these costs can be significantly reduced. When DD is condensed 10 times, the transportation costs can be reduced, amounting to USD 1,800. On the other hand, the DD condensation leads to a reduction in total acidity, which is expressed in terms of the cost of equivalent norms of gypsum. This cost grows from zero to about USD 5,000 when DD is condensed from 0 to 10 times. The point of intersection of these two curves defines the degree of optimal condensation of the DD, which is 4.5–5.0 times. It allows both the transportation costs and the loss of the total acidity during the distillation of the DD at the same time to be minimized. Thus, in the case of a 5-fold condensation of DD, the transportation costs are reduced 5 times to reach 3,600 USD, which is a good indicator for the land development.

Chemical analyses of nitrogen, phosphorus, and potassium were also performed on the solutions extracted during the DD distillation process as part of the study. The results reveal that there is no removal of these nutrients during the distillation process, and therefore, the qualitative indicators of DD do not change when using it as a fertilizer.

It should be noted that there is a need to develop technologies that allow energy costs to be minimized during the DD distillation [41]. The proposal for energy saving DD condensation technology and the operating one are presented in the following paragraphs.

3.1. Operating Technological Scheme of Brandy Alcohol Distillation

The process of distilling brandy alcohol from wine feedstock is illustrated in Figure 4.

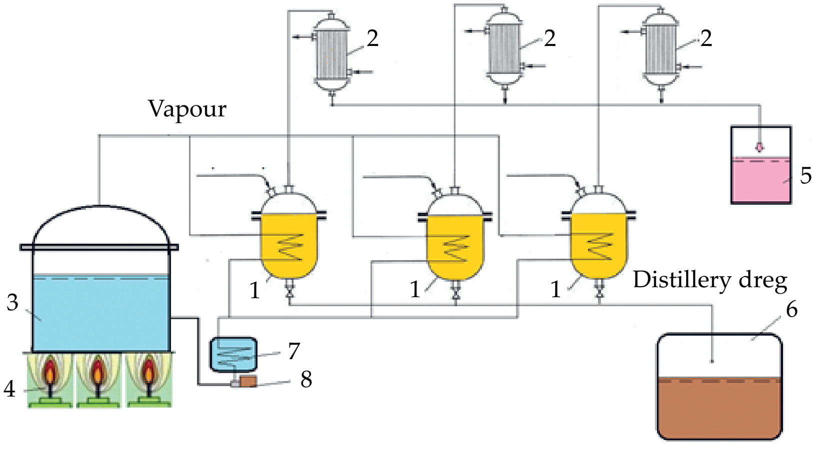

Fig. 4. Operating scheme for distillation of brandy alcohol from wine feedstock: 1 – distillation apparatus, 2 – refrigerator, 3 – vapour production boiler, 4 – heater, 5 – alcohol collection container, 6 – distillery dreg collection container, 7 – refrigerator, 8 – pump

Steam from boiler (3), which is heated by a heater (4), supplies the distillation apparatus (1), and reverse vapors are cooled in refrigerator (7), after which water is pumped back to boiler (3) with the help of a pump (8). Alcohol vapors from apparatus (1) pass into refrigerator (2), where the alcohol is liquefied by a stream of cold water and transferred to the container (5). Once the distillation process is completed, the DD from apparatus (1) is transferred into container (6) and the cycle repeats.

To produce a condensed substance of DD, we propose to modify this technological scheme in a way that will allow carrying out the distillation process without additional energy consumption.

3.2. The Proposed Technological Scheme for the Distillation of Brandy Alcohol

The proposed technological scheme is shown in Figure 5, where the steam from the boiler (3), heated by the heater (4), supplied the distillation apparatus (1), from which alcohol vapors pass through refrigerator (2), where the alcohol is liquefied by a stream of cold water and transferred to a container (5). The reverse vapours are cooled in refrigerator (8). Afterward, the water is pumped back to boiler (3) with the help of the pump (9), while valve (6) is opened and valves (7) and (10) are closed. Once the distillation cycle is complete in apparatus (1), valve (10) opens, and DD with a temperature of about 95°C is transferred to the DD distillation apparatus (11).

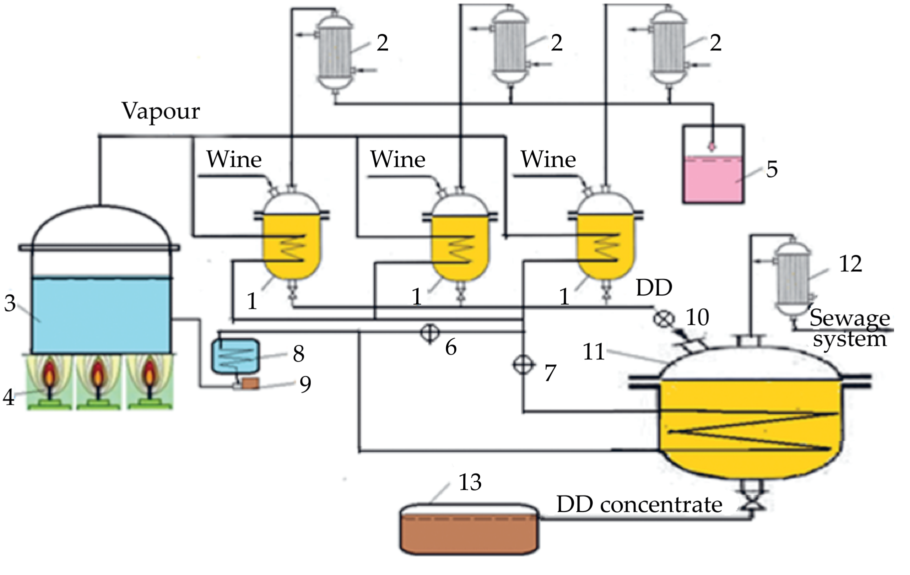

Fig. 5. Proposed technological scheme for the distillation of brandy alcohol from wine feedstock: 1 – wine feedstock distillation apparatus, 2, 8, 12 – refrigerators, 3 – steam boiler, 4 – heater, 5 – alcohol collection container, 6, 7, 10 – valves, 9 – pump, 11 – DD distillation apparatus, 13 – DD concentrate container

The volume of DD distillation apparatus (11) is equal to the volume of all wine feedstock distillation apparatuses (1). Then the valve (6) closes, the valve (7) opens and the reverse vapors from distillation apparatus (1) pass through a closed pipeline of DD distillation apparatus (11). After that, it passes through the refrigerator (8), where the liquefied water is pumped to boiler (3) with the help of a pump (9). The vapors obtained from the DD distillation apparatus (11) pass through refrigerator (12), where, after cooling, they are sent to the sewage system. Five times condensed DD is then transferred to the container (13), designed for that purpose, and can be used to improve agricultural land.

It is possible to have two comparable apparatuses for the distillation of DD to maintain the cycle's continuance.

Thus, the proposed technological scheme for DD condensation in the brandy alcohol distillation process allows the production of DD concentrate without additional energy costs. The advantage of this method is that the DD is already heated up to 95°C, which eliminates the need for further energy consumption on heating.

4. Conclusion

Due to the gradual increase in global brandy production, the problem of their waste (DD) utilization has arisen, and when it is eliminated by surface water, it leads to serious environmental problems. DD contains a significant amount of organic acids and nutrients, that makes it an ideal chemical ameliorant for improving the chemical and physical properties of alkaline and semi-desert gray soils, moreover it can be used as a fertilizer to improve the nutritional regime of soils, however, due to high transportation costs, its application is limited.

To reduce the significant cost of DD transportation, its condensation is suggested. Economic calculations revealed that the optimal level of DD condensation (five times) not only reduces the transportation costs by five times but also preserves its quality indicators.

It was proposed to make changes in the brandy alcohol distillation process in a way that would enable the production of acondensed DD substance, with minimal additional energy expenditure and capital investment. The method not only provides the opportunity to use it as a chemical ameliorant, but also as a means to solve important environmental issues.

Author Contributions

Samvel Sahakyan: conceptualization, methodology, formal analysis, investigation, validation, resources, writing – original draft preparation, visualization, supervision, project administration, funding acquisition.

Tatevik Yedoyan: conceptualization, methodology, formal analysis, validation, writing – original draft, review and editing.

Robert Sukiasyan: validation, formal analysis, investigation.
Armine Baghdagyulyan: validation, investigation, resources.
Satenik Bakunts: writing – review and editing, validation.

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