Heat Transfer Enhancement in Separation Process of Ethanol from Ethanol Water Mixture by Using Surfactants

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Abstract: Here the investigations are done while distillation of ethanol-water mixture for separating ethanol from fermentation process. Focus is to study reduction in time required and hence saving in energy for the distillation process of ethanol-water mixture under the influence of surface-active agents (Surfactants). This novelty is from observation of these surfactants to enhance heat transfer rate because of surface tension reduction in aqueous solutions. SDS (Sodium Dodecyl Sulphate), NH_4Cl (Ammonium Chloride) and SLBS (Sodium lauryl benzene sulphonate) surfactants in different concentration are experimented. The concentration of these surfactant is varied from 1700 ppm to 2800 ppm. This range is decided by observing critical micelle concentration of used surfactants. Results showed that time is reduced and hence energy consumption is also reduced. Results shown by NH_4Cl are found to be more useful as it is ecofriendly surfactant which is not affecting ethanol-water mixture. Use of ammonium chloride as surfactant in distillation is actually useful to reduce energy without hampering the quality of process is the novelty of this work.
***Keywords*:** Distillation, Ethanol-water Separation, Specific Gravity, Surface Tension, Separation Purity

1. Introduction

Bioethanol production has recently attracted attention for two basic reasons. First is, frequent use as oxygenated fuel in place of tetra-butyl methyl ether (MTBE). The second is related to its ability to use as an alternative fuel. Bioethanol is produced by the process of fermentation of sugar cane molasses. Also, it can be produced as a by-product of certain chemical processes. Sugar cane is the main sources of ethanol in India. Research is also underway on the use of solid waste to produce fuel like ethanol. Ethanol (C_2H_5OH) is a clear, biodegradable, colorless, low toxic and low environmental pollution spill. After burning of ethanol, carbon dioxide and water are produced which helps to reduce associated pollution due to petroleum like SOx and NOx.

Ngema [1] studied the extraction and evaporation methods of pure ethanol separation from ethanol-water mixture. Extraction process requires salt for separation and evaporation process does not required the salt for the same. Also, different types of separating agents used in extraction process are also reviewed in this paper.

The production of alternative fuels is becoming important since the limited stocks of crude oil and day by day increase in demand is affecting its cost. Bioethanol is attracting more and more attention as an alternative fuel of choice and its growth potential is virtually unlimited being agriculture product. However, the important aspect of bioethanol production is, how to get pure ethanol from mixture of ethanol and water? The ethanol separation from ethanol and water mixture is difficult because of an azeotrope present in the mixture. Therefore, to separate ethanol from mixture of ethanol-water, it is proposed to study the effects of adding surfactants such as SDS, NH_4Cl and SLBS in the mixture to reduce the time and energy consumption for the separation process.

Nafey et al. [2] studied the effect of surfactant additives on solar water distillation process. Different concentrations of Sodium lauryl sulfate (SLS) including 50, 100, 200 and 300ppm were used in this work. The results showed that the system daily productivity (DP) did not be affected when the concentration of surfactant reached more than 300ppm. On the contrary, it was observed that DP was reduced by 6% at surfactant concentration more than 400ppm. The authors attributed the increase of the DP to the depression of surface tension.

More than half of the total production energy of ethanol is consumed by distillation only. Distillation is a technique widely used in organic chemistry to separate compounds according to their boiling points. If one compound from the

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mixture of two compounds is more volatile than the other, the compounds can be separated with simple distillation. If difference between boiling points of two compounds is less than 40°C, they cannot be effectively separated by simple distillation, and fractional distillation becomes essential. Generally, ethanol percentage varies from 0 to 20% (v/v) in the fermenter before the distillation process.

Yang et al. [3] studied the effect of surface tension of the surfactant solution. It is found that surface tension is having a significance influence on the heat transfer. SLS and SLBS surfactant were studied and found that because of the SLS, heat transfer coefficient increases but due to SLBS critical heat flux increases as compared to the SLS.

Wasekar et al. [4] proposed that the dynamic surface tension of the aqueous surfactant solution is the main parameter of the nucleate boiling process. They tested four surfactants namely SDS, SLES, Triton X-100 and triton X-305 and found that heat transfer increases with decrease in molecular weight of these surfactants.

Zhang [5] confirmed the hypothesis by measuring many interfacial properties like dynamic and equilibrium surface tensions, and wettability for different surfactant solutions. It was shown that a dynamic surface tension, which decreases to an equilibrium value after a long-time duration, is the most critical factor of the phase- change phenomenon because it has a big impact on the surfactant adsorption- desorption process, which is time-dependent.

Elghanam et al. [6] carried out an experimental study to enhance saturated nucleate pool boiling by means of surfactant additives. Sodium dodecyl sulfate (SDS) and sodium laurel ether sulfate (SLES) as anionic and Triton X-100 as nonionic were used as surfactants, and the working fluid was distilled water. The percentages of heat transfer enhancement reached to 133% for Triton X-100, 185% for SLES and 241% for SDS. They concluded the depression of surface tension is the main reason.

Hetsroni et al. [7] investigated the nucleate pool boiling of pure water and water with cationic surfactant. They found that the surface tension and the kinematic viscosity have a big impact on heat transfer coefficient. At low concentration less than 530ppm, the heat transfer coefficient increases due to the decreasing of surface tension. However, for high concentration (1060ppm), the heat transfer coefficient decreased because of the increase in kinematic viscosity.

Shoghl et al. [8] concluded that surface tension and viscosity are two important parameters which can influence the boiling performance of surfactant solution. CuO and ZnO water-based nanofluids were used and Sodium Dodecyl Sulfate (SDS) was used as surfactant. Result from experiments demonstrated that the addition of SDS to nanofluids solution resulted in improving boiling performance. An optimum value for heat transfer coefficient was found by increasing of surfactant concentration within CuO nanofluid (0.01wt%CuO).

Peng et al. [9] experimentally studied effect of surfactant additives on nucleate pool boiling heat transfer of refrigerant-based nanofluids. Three types of surfactants including Sodium Dodecyl Sulfate (SDS), Cetyl Trimethyl Ammonium Bromide (CTAB) and Sorbitan monooleate (Span-80) were used in the experiments. The refrigerant-based nanofluids was formed from Cu nanoparticles and refrigerant R113.They observed an improvement in boiling performance on most conditions except at high surfactant concentrations.

Acharya A.R. et al. [10] presented the literature review on Ammonium Chloride as Surfactant for Heat Transfer Enhancement in Pool Boiling. They presented Ammonium Chloride (NH_4Cl) as test surfactant and added separately in water with varying concentration. The results of surfactant NH_4Cl up to 2800 ppm in pure water showed the heat transfer enhancement and above this range no enhancement was observed.

Gajghate S.S. et al. [11] work showed that a small amount of 2 ethyl 1 hexanol additive makes the nucleate boiling heat transfer coefficient considerably much higher and that there was an optimum additive (500–1000 ppm) concentration for higher heat fluxes. A most appropriate level of enhancement was observed up to a certain amount of additive 500–1000 ppm in the tested range.

Nakao S. et al. [12] have presented the literature review on continuous ethanol extraction by evaporation from a membrane bioreactor and their estimation showed than more than half of the total production energy is consumed by distillation. In the case of the production of alcoholic fuel, however, high productivity and low production costs are much more important.

Acharya A.R. et al. [13] in literature review revealed that, surface tension of the surfactant solution and amount of surfactant added on a solution plays an important role in heat transfer enhancement. By addition of surfactants like SDS and SLS increases heat transfer in nucleate pool boiling significantly except at high surfactant concentrations. For extraction distillation process by addition of salt based separating agent's pure ethanol can be obtain from ethanol-water mixture. From this discussion, most of work is carried out for enhancing heat transfer in pool boiling by using surfactants, keeping this aspect in mind; enhancement of heat transfer in separation process of ethanol from ethanol water mixture by using surfactants is selected for this dissertation work.

2. Experimental Procedure

The apparatus for the separation process is fractional distillation because of azeotropic nature of the ethanol-water mixture. It consists of heating mantle having 1-liter capacity, round bottom flask, fractionating column, water condenser and receiving flask.

Figure 1. Fractional distillation set-up

Ethanol concentration considered here is 10% and 20% (v/v). First ethanol-water mixture separated using fractional distillation apparatus without surfactant and then the effect of addition of surfactant at different concentrations from 1700 ppm to 2800 ppm is studied. This range is decided by observing critical micelle concentration of used surfactants. The energy input given to heater is 1000 W. Mass flow of 0.0294 kg/s of water in condenser is kept constant for all the readings. Heat input given is also kept constant. This experiment is done in a room and care is taken that no outside airflow or temperature will affect the results of experiment.

3. Results and Discussions

Fractional distillation of ethanol-water mixture of 500ml solution was carried out to determine time required to distillate and energy consumption for the process. The following table shows the data calculate without addition of the surfactant.

Table 1. Different properties without surfactants

Ethanol % in Mixture	Time Required to Distillate (minutes)	Specific Gravity After Distillation	% Ethanol by Volume in Distillate Mixture	Surface Tension of Mixture Before Distillation (Dyne/cm)	Energy Consumption (kWh)
10	33.37	0.8808	60.84	53.65	0.6395
20	32.53	0.8667	66.82	47.21	0.6235

Effect of SDS, NH_4Cl and SLBS at different concentration on distillation of 10% Ethanol and Water Mixture

Surfactant is well known to increase the heat transfer rate in boiling up to CMC (Critical Micelle Concentration) values. SDS (Sodium Dodecyl Sulphate), NH_4Cl (Ammonium Chloride) and SLBS (sodium lauryl benzene sulphonate) were used with 1700, 2000, 2300, 2500 and 2800 ppm in ethanol-water mixture.

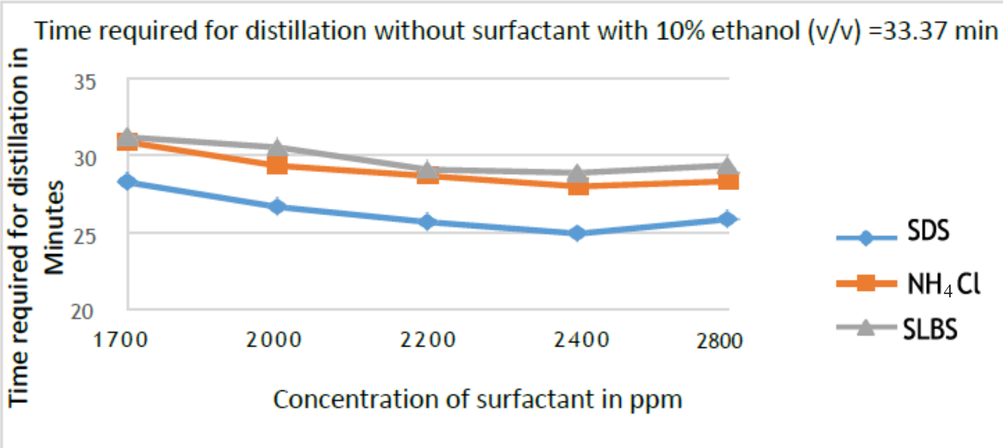

Figure 2. Variation of Time required for distillation with concentration of surfactant for 10% ethanol (v/v) mixture

Fig. 2 shows the comparison between SDS, NH_4Cl and SLBS for 10% ethanol-water mixture. The graph shows that SDS decreases the time required for distillation up to 2500 ppm. For NH_4Cl and SLBS the case is same but SDS provides better result, that is, it increases the heat transfer rate more than the NH_4Cl and SLBS. The percentage decrease in distillate time for NH_4Cl, SLBS and SDS is 16.04%, 13.40% and 25.23% respectively.

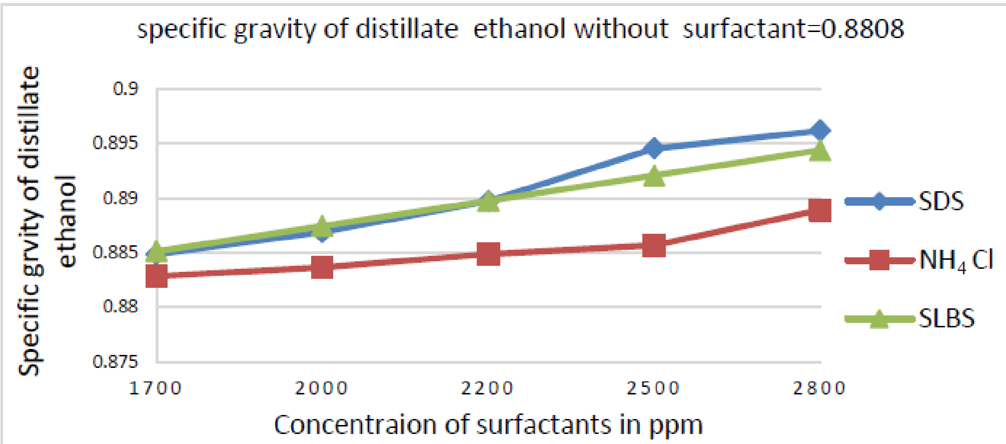

Figure 3. Variation of Specific gravity after distillation with concentration of surfactant for 10% ethanol (v/v) mixture

Fig. 3 shows the variation of specific gravity with different concentration of surfactants. In this case NH_4Cl shows better specific gravity variations than the SDS and SLBS. The percentage variation in specific gravity for NH_4Cl is (0.227% to 0.9%), for SDS it varies from (0.45% to 1.73%) and for SLBS it varies from (0.408% to 1.46%).

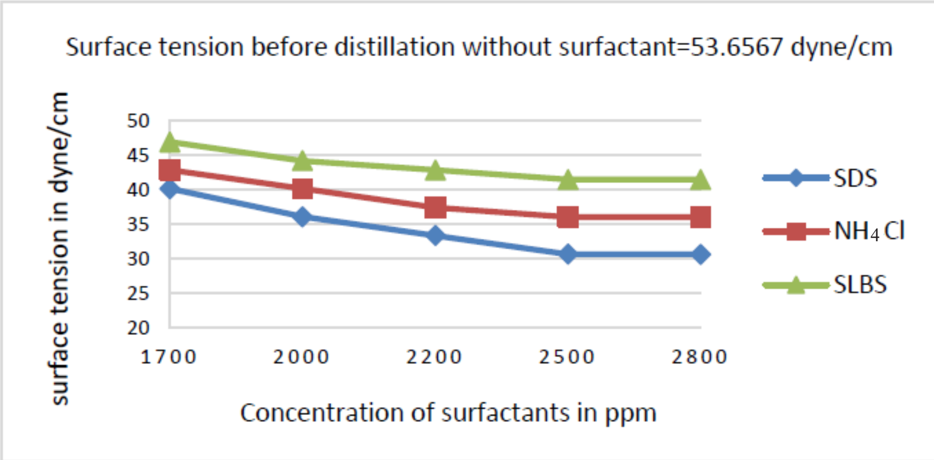

Figure 4. Depression in surface tension before distillation with concentration of surfactant for 10% ethanol (v/v) mixture

Fig. 4 gives the depression in surface tension before distillation with different concentration of surfactants. In this case SDS gives high depression in surface tension than the NH_4Cl and SLBS. The surface tension of the ethanol-water mixture is found to decrease as concentration of surfactants increases and reaches minimum at 2500 ppm. After 2500 ppm surface tension of the mixture does not vary very much. Depression in surface tension is more in case of SDS than the NH_4Cl and SLBS.

Ethanol is added in 20% with 80% distilled water and effect of surfactant addition at different concentration is studied.

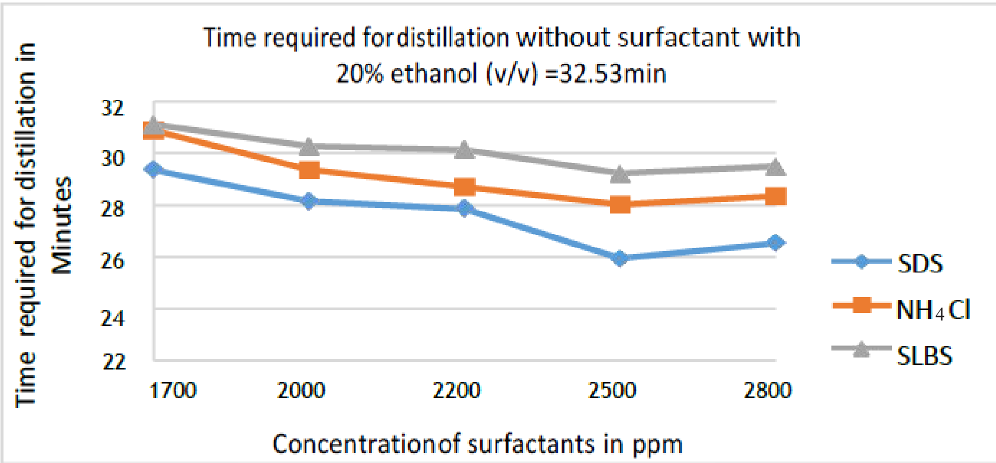

Figure 5. Variation of time required for distillation with concentration of surfactant for 20% ethanol (v/v) and water mixture

Fig. 5 shows time required to distillate the 20% ethanol water mixture is minimum with SDS at 2500 ppm. NH_4Cl reduces the distillate time from 7.83% at 1700ppm to 14.23% at 2500ppm, SLBS reduces the distillate time from 4.34% at 1700ppm to 9.31% at 2500ppm while SDS reduces it from 9.77% at 1700ppm to 20.22% at 2500ppm.

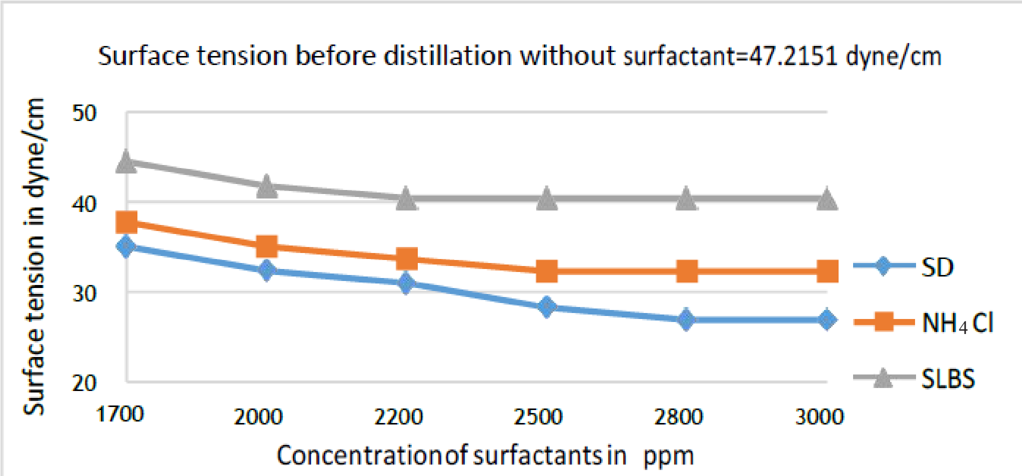

Figure 6. Depression in surface tension before distillation with concentration of surfactant for 20% ethanol (v/v) mixture

Fig. 6 shows the depression in surface tension before distillation with different concentration of surfactants. In this case SDS gives high depression in surface tension than the NH_4Cl and SLBS. The surface tension of the ethanol-water mixture is found to decrease as concentration of surfactants increases and reaches minimum at 3000 ppm. After 2800 ppm surface tension of the mixture does not vary very much. Depression in surface tension is more in case of SDS than the NH_4Cl and SLBS.

4. Conclusions

The Following conclusions can be drawn from these results:

1. Time required to distillate 10% and 20% ethanol (v/v) is minimum for SDS compared to NH_4Cl and SLBS and maximum decrease in time occurs at 2500 ppm for SDS and 2500 ppm for NH_4Cl and SLBS.

2. Specific gravity goes on increasing for all the surfactants as concentration of surfactant increase. NH4Cl gives better specific gravity variation within 1.15 % than the SDS and SLBS.

3. Energy consumed to distillate ethanol-water mixture is found to be less for SDS as compared to NH_4Cl and SLBS.

Conflict of interest

The authors declare that they have no conflict of interest.

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