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Research note

Experimental Investigation on the Effect of Parameters Influencing the Performance of a Horizontal Styrene-Water Separator

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Abstract
The separation of immiscible liquids plays an important role in the oil and petrochemical industries. In the outlet stream of a catalytic reactor of dehydrogenation of ethyl benzene to styrene monomer, water is present because it is used as high pressure steam to provide reaction heat. Therefore, aqueous and immiscible organic phases should be separated in a horizontal separator before fractionation. The objective of this work is to study the separation of ethyl benzene, styrene, and water in a horizontal pilot scale separator. Experiments showed that the performance of the separator is affected by feed flow rate and composition. Furthermore, the thickness of mesh installed in the inlet zone of the separator has an effect on the hydrodynamic behavior of the separator and its performance.

Keywords: *Horizontal Separator, Phase Separation, Immiscible Liquids, Styrene Production*

1. Introduction

The separation of immiscible liquid phases is one of the most important processes in the oil and petrochemical industries. The first step of the separation of the crude oil produced from wells accompanied by water and gas is traditionally performed in a horizontal cylindrical gravity settling vessel in which water and gas are separated from oil [1]. Furthermore, in those petrochemical processes where steam is used to provide the required heat of reactions, like catalytic dehydrogenation of ethyl benzene (EB) to styrene monomer (SM), water vapor (W) is present in the outlet stream of the reactor. After condensation, this mixture is indeed a hydrocarbons-in-water dispersion because these compounds (SM, EB and other byproducts of the reaction) are almost immiscible with water. Thus, before fractionation or distillation of the stream obtained from dehydrogenation reactor, it is necessary to separate hydrocarbons from water in a horizontal gravity separator [2-3].

These separators are usually large in size because the volume flow rates of streams in oil and petrochemical industries are usually high, and therefore costly to purchase and

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install. Reducing their size without losing separation efficiency would reduce capital cost [1]. In addition, depending on the process, the separated water may then be recycled and reused or discharged. In both cases, it is essential that the amount of hydrocarbons in water should not exceed certain limits. Therefore, operational problems of these vessels should be investigated.

In recent years attention has been directed towards understanding the vessel hydrodynamics using residence time distribution (RTD). Further, computational fluid dynamics (CFD) has been applied to these separators in order to understand where dead zones are likely to occur. In addition, many efforts have been focused upon the modification of the vessel internals by introducing structured packing [4-7]. However, these investigations are almost restricted to oil-in-water dispersions and there is no data for the separation of SM/EB in water dispersion in the literature.

In styrene monomer plants, horizontal separators are subject to self-polymerization of styrene, causing blockages and consequently increasing the water height in separator, thereby high cross-entrainments are observed.

The objective of this work is to study the separation of ethyl benzene, styrene, and water in a horizontal separator. Experiments have been carried out in a pilot scale separator to figure out the effect of feed composition and flow rate and thickness of mesh installed in the input zone of separator.

2. Experimental

2-1. Equipment

All experiments were carried out in a pilot scale model of a horizontal separator used in the Styrene Monomer Plant at Tabriz Petrochemical Complex. The pilot consists of a horizontal separator 160 cm in length and 35 cm in diameter manufactured from carbon steel. Different thicknesses of metal mesh of 98% free space can be installed inside the separator close to the inlet pipe which is supported by a metal ring. To prepare the feed, a mixing tank manufactured from carbon steel having a diameter of 66 cm and height of 90 cm was considered. A shaft with a marine impeller was used to mix pure SM, EB and water. An electromotor (Deg, 0.55 kW, Germany) controlled by a vector inverter (LS, 2001S, 0.57 kW, Taiwan) was used in order to have variable mixer speed. The prepared mixture is delivered to a pump (QB-60, Diana, 0.37 kW, China) and its outlet was split into two paths; the main path (to feed the separator) and a bypass (to control the flow rate of main stream). A rotameter (ALW, George-Fischer, Germany) was installed in the main path to measure the flow rate of feed into the separator. To measure the depth of hydrocarbon phase, two flat windows were created in the inlet and middle of the separator. A picture of the pilot is shown in Fig. 1 and a schematic diagram of the separator is shown in Fig. 2.

2-2. Measurement

Although RTD measurement is the most common way to understand the performance of horizontal phase separators, in this work a simple way was used to understand the effect of different conditions on the separator performance. The depth of hydrocarbon above rag layer at the inlet and middle of the separator can be considered as a criterion for its performance. It is clear that the depth of hydrocarbon at the inlet is less than at the middle of separator. In addition, increasing depth or height of hydrocarbon at the middle of separator will increase the performance of separator. As mentioned previously, two flat windows were installed at the inlet and middle of separator by which depth of hydrocarbon can be measured. The depths of hydrocarbon at different conditions (different feed compositions, feed flow rates and thicknesses of mesh) were diagrammed to show performance of the separator.

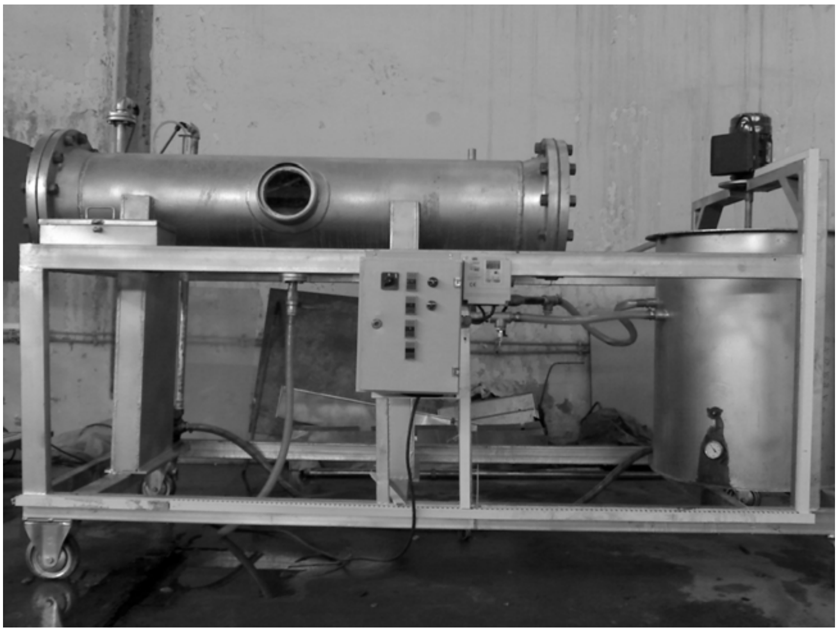


Figure 1. Picture of the pilot

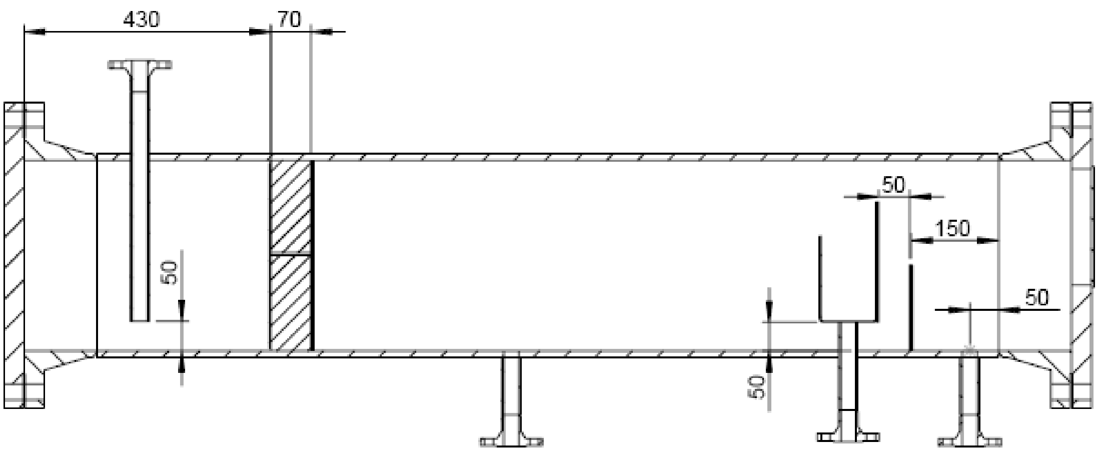


Figure 2. Schematic diagram of the pilot-scale separator

3. Results and discussion

As mentioned above, to prepare the feed to the separator, a mixing tank was provided to do the task and different amounts of SM, EB, and water (W) were completely mixed. To figure out the stability of the feed and the mixing speed by which feed is prepared, batch tests were conducted and it was observed that the stability of mixtures composed of EB and W is more dependent on mixing speed than that of those composed of SM and W. A full description of batch separation of styrene/ethyl benzene/water dispersions has been given by Jafarzadeh et al. [8].

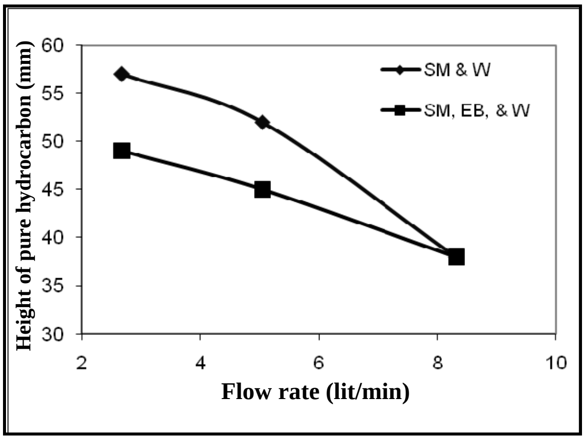
In all experiments feed flow rate was considered as independent variable and depth or height of hydrocarbon was considered as dependent variable. Feed flow rate was varied between 2.67 lit/min and 8.32 lit/min. The feed consists of W, SM, and EB and is dependent on experiments; the volume ratios of percentages of species were varied. In addition, all experiments were performed at 25 ºC.

3-1. Effect of feed composition

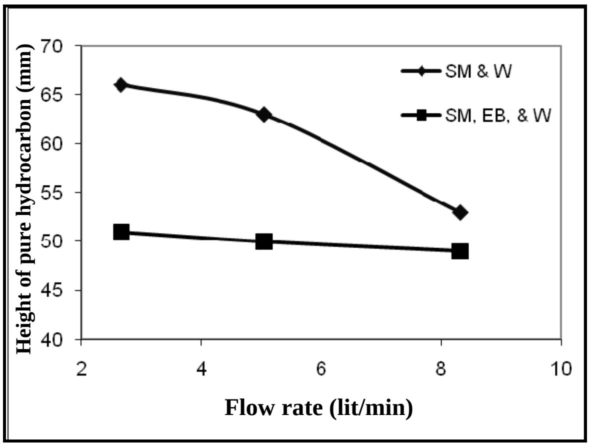
The variation of depth of hydrocarbon phase at the inlet and middle of the separator with changing feed flow rate is illustrated in Fig. 3. These experiments consist of two types of feed; one is composed of 67% W and 33% SM, the other contains 67% W, 22% SM, and 11% EB. As might be expected, the depth of the hydrocarbon phase decreases with increasing feed flow rate. Furthermore, adding 11% EB to the feed decreases the depth of hydrocarbon at both the inlet and the middle of the separator. EB and SM are hydrocarbons that are almost insoluble in water and can be called hydrophobic. But the solubility of SM is much less than that of EB, that is, the amount of Gibbs energy for the transfer of SM from its pure liquid to water is more than that of EB. This may be related to molecular structures of EB and SM. EB has two more hydrogen atoms than SM and this probably increases the hydrogen bond between EB and water and therefore, its solubility in water is more than that of SM [9]. Therefore, increasing the amount of EB in the feed will increase the time required for separation of hydrocarbon and aqueous phases within the separator. These results suggest that the performance of the separator is affected by increasing EB content in the feed. This illustrates that whenever the conversion of EB to SM in the dehydrogenation reactors decreases, the EB content of feed into the horizontal separator, installed after reactors increase and the height of hydrocarbon within the separator decreases so that cross-entrainments would occur. As a result it can be concluded that increasing the conversion of dehydrogenation of EB increases performance of the horizontal separator in the styrene monomer units.

3-2. Effect of mesh thickness

The inclusion of mesh in the separator is expected to break the momentum of feed entering the vessel and smooth flow within the separator. Three different thicknesses of metal mesh were used to examine its effect on the performance of separator. Fig. 4 shows the variation of depths of hydrocarbon at the inlet and middle of the separator with changing feed flow rate. It was expected that increasing the mesh thickness would increase the depth of hydrocarbon, but the results are different.



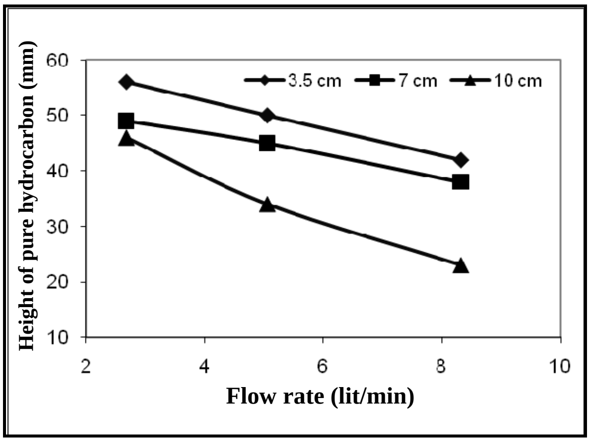
(a) Inlet of separator



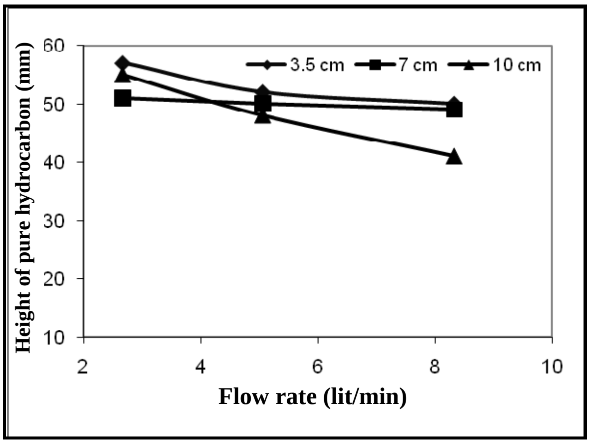
(b) Middle of separator

Figure 3. Variation of height of hydrocarbon with flow rate of feed and its composition when 7 cm of metal mesh is used.

As mentioned above, a metal ring was installed after inlet pipe to support the mesh. Following Simmons et al. [1, 4], the zone behind the mesh is called inlet mixing zone where the fluid flow is turbulent. Increasing the thickness of mesh decreases the volume of mixing zone and consequently increases turbulence of flow at the back and front of the mesh. Thus, the depth of hydrocarbon decreases. This result raises an important issue in sizing and designing horizontal separators: the place of mesh and its thickness should be determined exactly and carefully.



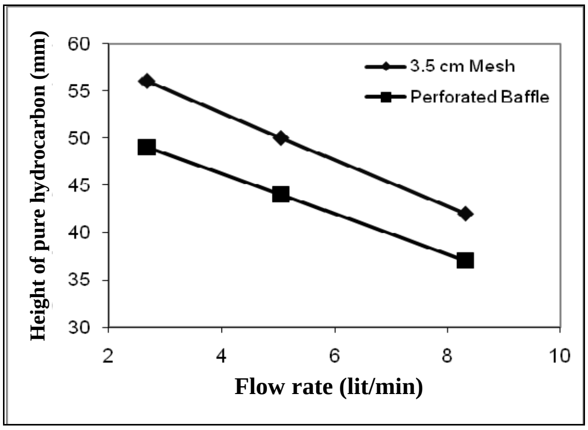
(a) Inlet of separator



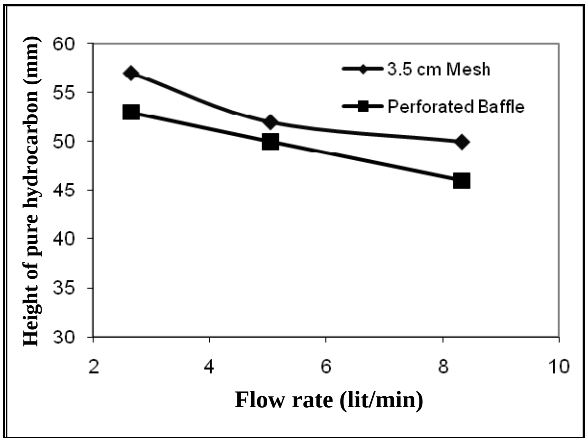
(b) Middle of separator

Figure 4. Effect of thickness of mesh on depth of hydrocarbon when feed volumetric composition is 67% W, 22% SM, 11% EB.

In some separators perforated plates are used instead of mesh in order to smooth the flow through the vessel. To compare the effect of perforated plate and mesh on performance of the separator, feed composed of 67% W, 20% SM, and 13% EB was fed into the separator in which 3.5 cm mesh was installed. Next, the mesh was replaced with a perforated plate which had 14% perforation ratio (67 holes of 15 mm in diameter). Fig. 5 shows that using 3.5 cm mesh, the depth of hydrocarbon at both the inlet and the middle of the separator is higher than when perforated plate was used, as expected. Thus, using perforated baffle is not recommended for this type of separator.



(a) Inlet of separator



(b) Middle of separator

Figure 5. Variation of height of hydrocarbon with flow rate of feed when 3.5 cm mesh is replaced with a perforated plate and feed volumetric composition is 67% W, 20% SM, 13% EB.

4. Conclusions

The separation of styrene, ethyl benzene, and water in a pilot scale horizontal phase separator was studied. The variation of depth of hydrocarbon phase at the inlet and middle of separator was considered as a dependent variable and the feed flow rate and composition and thickness of mesh were considered as parameters. Results show that performance of the separator decreases as the content of ethyl benzene in the feed increases. In addition, increasing the thickness of mesh installed in the inlet of separator decreases the depth of hydrocarbon at both the inlet and middle of the separator, perhaps due to the reduction of volume of inlet mixing zone. However, a 3.5 cm mesh has a better effect than a perforated plate with 14% perforation ratio.

Acknowledgement

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