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Effect of Geometry on Homogenization of Two Layers Stratified Liquid

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Generally, cylinder shaped tanks are used to store liquid. However, some specially designed containers are also presented. In this research 2, 3, 4, 5 cylinders are continuously integrated into one vessel to make special storage tanks. The laboratory equipment was a copy of a tank which is used for industrial application. In this work, the effect of the shape of the container was investigated on mixing. Stirring was achieved by an external pump. The residence time was 3 h as in the industrial case. The aim was to examine the influence of special shape on mixing efficiency by using constant residence time. By utilizing lower residence time, the mixing efficiency might be risen however with the lower residence time the flow rate should be increasing consequently the energy consumption of recirculation become greater. Consequently in all experiments the residence time, calculated by the volume and flow rate, was constant. Borax solutions were used as a stratified liquid layer. The density of the upper layer was 1.0022 g/cm^3 and the lower layer was 1.0136 g/cm^3 density. The inlet was positioned above the liquid level. Concentration changes have been followed by electrical conductivity measurements. Residence time distribution and recirculation measurements were achieved. The data was evaluated by the time request to reach 95 % homogeneity. The concentration differences among the sampling points in time also were examined. The results were compared with the examination with a conventional cylinder tank. The experiments indicate that free convection is more dominant than forced convection. The results show reproducibility. The effect of the shape of the tank on mixing by recirculation is remarkable.

1. Introduction

In chemical industrial applications the homogeneity is an emphasized requirement. Heterogeneity can cause problem in operation and it can induce decadency of product quality. In liquid mixing process several methods are developed to achieve the required quality. Stirring by mechanical mixers and by static mixers is a widely investigated research field. In the industry there are some applications (petrochemical, nuclear industries, wastewater plants) where mixing is achieved by external pump circulation. In spite of this, mixing effects in recirculation method is poorly studied (Zellouf and Portrainer, 2011). Mixing of two or more miscible fluids can be achieved several ways (Orsi et al, 2013), however problem is posed when two liquids have very different viscosity or the stirring is carried out by external pump with low volumetric flow rate (Coulson, Richardson, 1999). Density stratification can be occurred in several cases, like one batch of liquid is loaded on the top of another batch in the same storage tank (Degawa et al., 2017) or when the multi-component liquid needs to be stored for a long time (Farooq et al., 2019). Generally cylindrical tanks are used to store and mix materials. Nowadays more and more researchers attend to micro-channels (Oualha et al., 2017) and micro-reactors (Qaderi et al., 2019) on the contrary investigation of special geometry which is an integration of several cylinders is not favour. This special geometry is presented in the industry when space need to be saved in the plant area.
Determination of the efficiency of mixing, what is depend on fluid flow in the investigated equipment, is not an easy task. Firstly to get information about the fluid flow, residence time distribution measurements need to be achieved (Dankwerts, 1953). One method to ascertain the degree of mixing is utilizing the variance of mean age (Liu, 2012) however this calculus has several limitations. Nowadays to describe fluid flow in different geometry computational fluid dynamics (CFD) technics are widely spread (Galletti et al., 2017). In investigation of mixing effects, the detection system of the changes is a main key. There are several techniques like optical, conductivity, radioactive particle tracking or electrical signal measurement. The suitable choice of measurement

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techniques firstly depends on turbulent or laminar flow property of the system. The detection system must not effect on flow or act as a baffle (Meng et al., 2016).

2. Experiment

Aim of the research was to investigate the effect of the geometry of a tank on mixing time. Our experimental device was a specially designed container which was built-up from 5 cylinders tank (Figure 1a). Only one laboratory equipment was structured which can be modified with a removable wall to get the desired geometry. The total length of the tank was 450 mm, the height was 130 mm. In any case, the liquid level was 85 mm, so the maximal recirculated volume of liquid was 5.2 L. The inlet of the tank was at 100 mm with 4 mm inner diameter, respectively. The removable wall also contains an inlet at the same height. The outlet was 5 mm above the tank bottom with 4 mm inner diameter (Figure 1a).
The solution that needs to be mixed was a density stratified liquid. At the beginning of the experiment, a two-layer liquid phase was achieved. The heavier (29.6 g/L, 1.0136 g/cm^3) borax solution was layered under the thinner (6.3 g/L, 1.0022 g/cm^3) one (Figure 1c). The content of the tank was circulated with a peristaltic pump (2.). To eliminate the uncontinuous feed into the experimental tank (1.), a buffer tank (3.) was built into the feed stream and the inlet was ensured by gravity flow from it. The overflow outlet of the buffer tank (3.) was also constructed into the equipment however the fluid level was constant so overflow was not noticed in 4. storage tank. To check the inlet flow rate, a rotameter (5.) was installed between the puffer and experimental tank. The actual concentration was detected by conductivity measurements. Two probes (graphite-two cells/probe) were placed into the system. The conductivity measurements were automatically compensated with temperature. The outlet was sampled continuously by one of the probes (CH2) and the position of the other one (CH1) was modified by the change of the geometry (Figure 1, Table 1). The values of conductivity were being sampled in every 30 seconds and stored on PC.

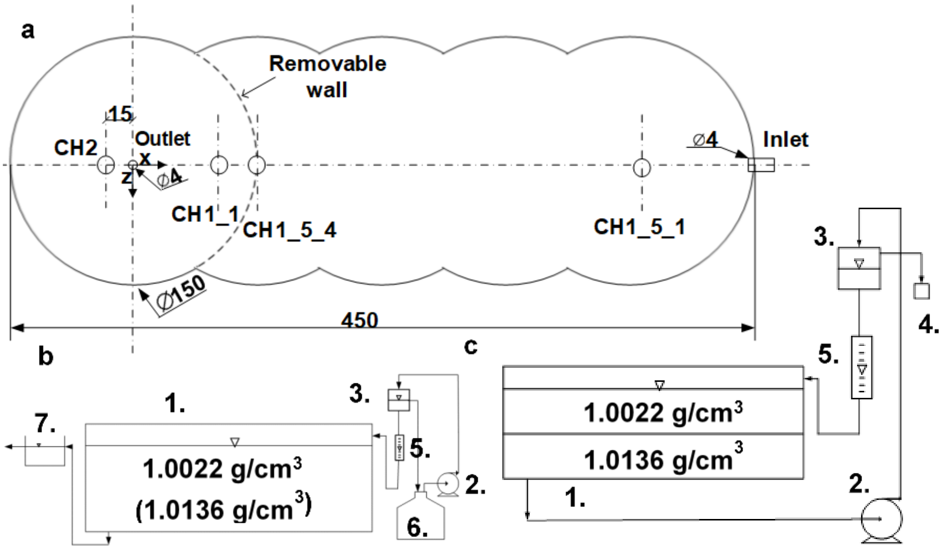

Figure 1: a: Schematic of positions of the inlet, the outlet and the conductivity probes (in mm, top view), b: Schematic of experimental apparatus during pre-experiment c: Schematic of experimental apparatus during recirculation measurements

To study the influence of geometry on homogeneity, the residence time, calculated from the flow rate and from the volume occupied by the liquid, was set at constant 3 h. This research was based on an industrial problem. In the industrial, 1-cylinder tank case the residence time was ~ 3 h, therefore that value of residence time was decided. To keep the residence time at a fixed value, the inlet flow rate needed to be varied with the change of geometry (liquid volume). In experiments when 5-cylinders shape was examined the volume was 5.2 L and the flow rate was 1.7 L/h. As long as the laboratory device built-up from 1-cylinder, the volume was 1.5 L and the flow rate was 0.5 L/h. In the case of 1-cylinder experiment, the removable-wall was fit into the container and the inlet was achieved on it.

Table 1: Position of inlets, outlet and sampling points in mm

	Inlet		Outlet	CH2	CH1	
1		x_1=75	x=0	x=-15		x_1=70
5_1	y=100	x_{5_1}=450	y=5	y=3	y=50	x_{5_1}=300
5_4	z=0	x_{5_4}=450	z=0	z=0	z=0	x_{5_4}=75

The conductivity data were transformed into concentration results and the results were evaluated with homogeneity. Homogeneity (Ht,%) (Eq(1)) was calculated in time with actual concentration (ct), final concentration (c_{max}) and concentration difference between initial and final concentration (Δc).

$$H_t(\%) = 100 - \left(\frac{|c_t - c_{max}|}{\Delta c}\right) * 100 \quad (1)$$

Before recirculation measurements, pre-experiments were carried out to convince that concentration at sampling point CH1 does not depend on the horizontal position of it. Two tests, 5_1 and 5_4, were done with two CH1 positions in 5-cylinders geometry (Table 1). In both cases, the vertical position was the same (y = 50 mm). At measurement 5_1 the position of the CH1 probe was 300 mm far away from the outlet (x = 0 mm), while at 5_4 sampling point was 75 mm far. These experiments were implemented (see Figure 1b) in 5-cylinders shape tank filled with 1.0022 g/cm^3 solution meanwhile the inlet liquid density was 1.0136 g/cm^3 solution. Experiments were carried out the other way around, as well (1.0136 g/cm^3 tank solution, 1.0022 g/cm^3 inlet). The uniformity of the inlet flow into the experimental tank (1.) was ensured by gravity flow from a buffer tank (3.). The liquid volume in the buffer tank (100 mL) was constant, achieved by an overflow outlet and continuous feed through a peristaltic pump (2.) from the solvent storage tank (6.). To generate constant outlet flow rate another tank (7.) was built into the system. The inlet of the 7. tank was at the same height as the liquid level in the experimental tank (1.). The outlet and the inlet flow rate were set and checked before all experiments.

3. Results and discussion

3.1 Pre-experiments

The assumption was that the horizontal concentration difference at extreme far points is negligible in comparison with vertical changes. In Figure 2a the homogeneity in time at sampling point CH1 can be seen. The curves run together pretty well at experiments with the dilute inlet. The concentration at 50 mm (CH1) was being changed continuously from the beginning. This phenomenon indicates that by the specific gravity the thinner solution layered above the main liquid body (1.0136 g/cm^3). The tank was occupied by 6.3 g/L by layer to layer from the top of liquid level, while the heavier one was removed at the bottom of the tank. Finally, the heavier fluid body was displaced totally with the thinner one.

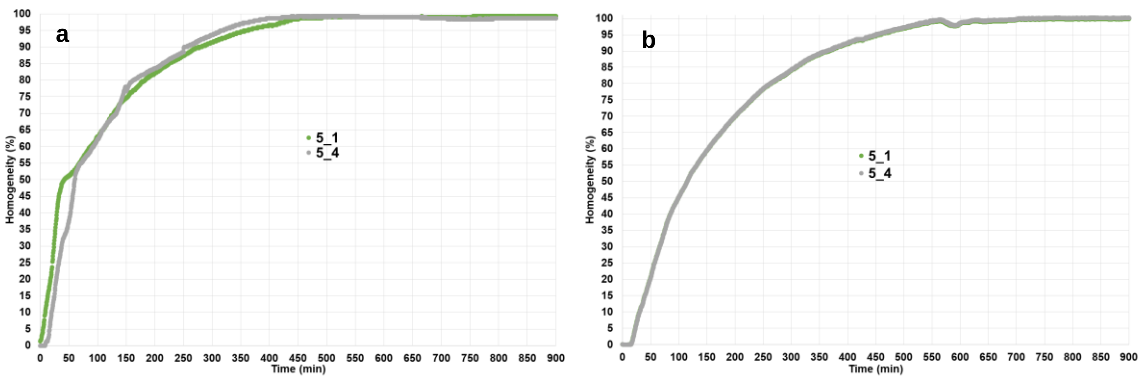

Figure 2: Homogeneity at sampling point CH1 at two different horizontal position (x_{5_1} = 300, x_{5_4} = 75 mm) a: 1.0022 g/cm^3 inlet, b: 1.0136 g/cm^3 inlet)

Measurements with the heavier inlet (Figure 2a) the curves fit almost completely. In the first 25 min, the concentration was not changed at the bottom of the tank (CH1). This experience suggests that the concentrated layer was fallen onto the tank bottom according to the specific gravity. Later the concentration was increased successively.

Results at sampling point CH2 (Figure 3), which was directly nearby the outlet, confirm the previous establishments. Curves occurred during experiments with the thinner inlet (Figure 3a), begin with a constant part. The stand segment (~50 min) at the beginning indicates that the thinner fluid elements were climbed above the heavier liquid layer. On the other hand, results with heavier inlet (Figure 3b) showed concentration changes at the outlet from the beginning of the measurement. It follows that the concentrated liquid was sunk below the thinner layer, driven by specific gravity. Curves fitting at thinner inlet implies that discharge of heavier fluid is more hectically than at heavier inlet.

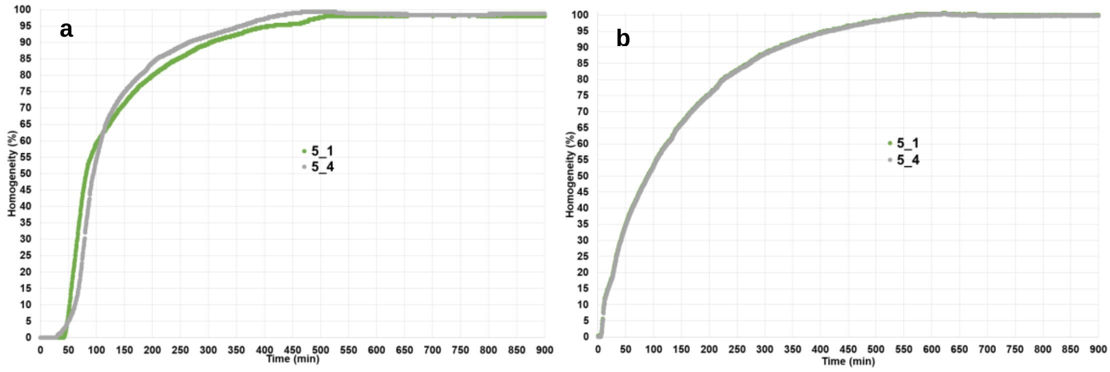

Figure 3: Homogeneity at sampling point CH2 at two different horizontal position (x_{5_1}=300, x_{5_4}=75 mm) a: 1.0022 g/cm^3 inlet, b: 1.0136 g/cm^3 inlet

Results suggest reproducibility which is very important to carry out representative measurements. Further experiments 5_4 CH1 sampling point was used.

3.2 Circulated measurements

Homogeneity results are shown in Figure 4. Homogeneity was calculated by Eq(1). The base of comparability was the time demand to reach 95 % homogeneity. 5-cylinders shape is signed with number 5, and 1 cylinder geometry is indicated by number 1 in figures. Figure 4a demonstrates the homogeneity in time at the outlet (CH2) at both tank geometries. At the beginning of the experiments, a sharp rose was occurred in both cases and 95 % homogeneity was attained in 33 min. After the peak was maximized at 100 %, the results were initially declined below 95 %. This phenomenon was caused by dilution in concentration at the outlet. Because the outlet was at the bottom (5 mm) of the tank, immersed in the heavier layer, the first fluid elements which were recirculated were ensued from the heavier layer. By the specific gravity, the more concentrated liquid elements sink under the diluted layer after intake, moreover thinner fluid elements were grabbed by heavier ones, cause dilution in the deeper layer. Finally, homogeneity results were climbed again over 95 %, at measurement with 5-cylinders geometry in 208 min, while at 1-cylinder shape geometry it was reached in 316 min.

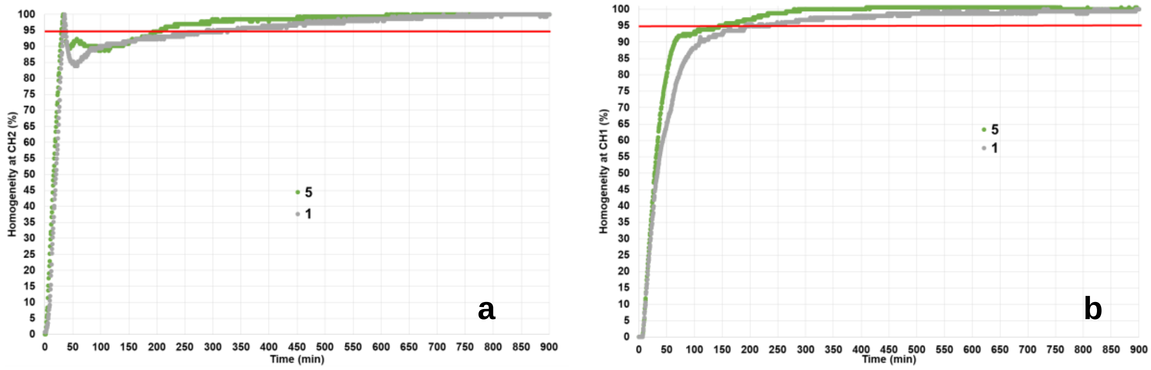

Figure 4: Homogeneity at sampling point CH2 (a) and CH1 (b) in case of differential geometry

By the investigation of the homogeneity at sampling point CH1 the same trend can be recognized as at CH2 such as in the first 50 minutes of the experiment the curves run together irrespectively of the shape of the tank.

Later the difference between the results detected in different geometries was become greater. In 1-cylinder shape geometry, the 95 % homogeneity value was reached over 194 min, as long as in 5-cylinders tank it was in 144 min.
According to the residence time was 3 h, the difference between measured values from varied geometry, might be caused by dead-volume parts. Dead-volume is a part of the fluid body which is out of convection. Material transportation from these liquid parts driven by conductive transport (diffusion), what is more time demand transport phenomena than free or forced convection. The results imply that more dead volume parts were existed in 5-cylinders shape geometry which was driven to shorter time consumption to reach the desired value at the sampling point. It should be noticed that 2 sampling points do not represent the concentration in total liquid volume. To confirm this hypothesis more experiments should be carried out to develop the dead volume parts of the tanks.
In Figure 5 the concentration difference between the two sampling points was compared in varied tank geometry. At the beginning (75 min) the concentration was changed sharply, later the concentration was maintained nearly constant. The steep range of the curves might be caused by the great concentration difference between the two layers. The concentration diversity is the driven force of the free convection. The dissimilarity in concentration was declined by time equally the driven force was dropped too, that is why the mixing effect was more dominant at the beginning of the experiment. The results show similarity independently of the investigated geometry, however in previous figures grater divergence was occurred between the different shapes. Moreover, the concentration difference between the two sampling points shows shorter time demand to reach 95 % homogeneity. Consequently, when the difference between 2 sampling point is under a limit does not necessarily mean a total homogeneity in the system.

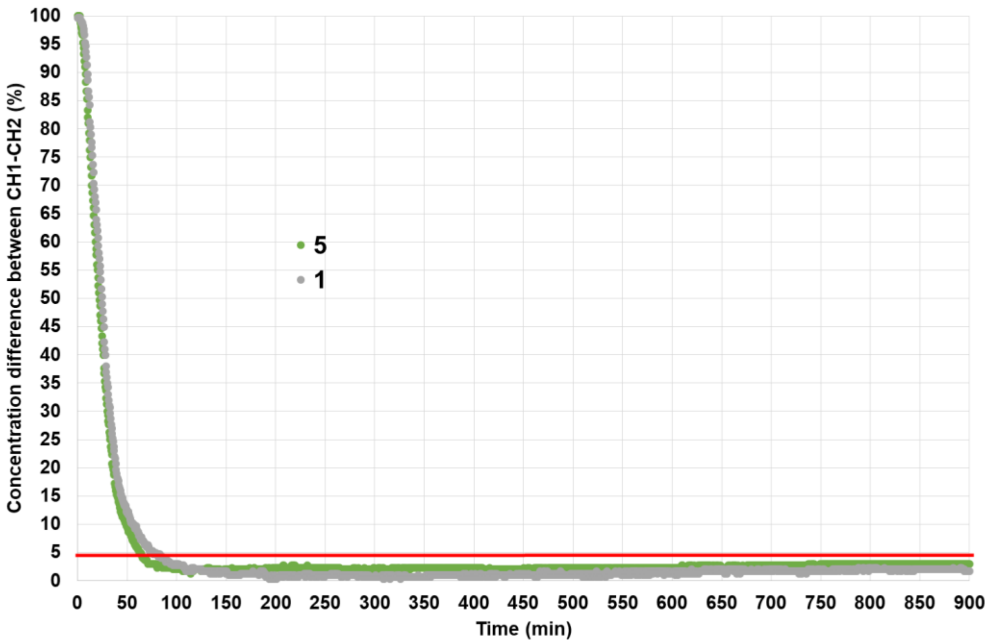

Figure 5: Concentration difference between the two sampling points in time occurred in varied geometry

4. Conclusion

In this work, the influence of the tank geometry on mixing time was investigated. A special tank was designed which was contained 5 cylinders continuously. A removable wall was also installed what was used for creating the desired tank geometry. The residence time was 3 hours, respectively. Moreover, our aim was to mix a stratified solution. The solvent should be mixed was borax in two different concentrations. The heavier borax (1.0136 g/cm^3) was layered under the thinner (1.0022 g/cm^3) one. To trace the concentration changes during the mixing process conductivity measurements was used with two probes. The flow inside of the tank was remarkably slow consequently the probes did not act as baffles. One of the probes was sampling the outlet and the position of the other was varied by the change of the geometry. Results were evaluated in value of homogeneity.

Before recirculation measurements, pre-experiments were conducted in 5-cylinders shape geometry to investigate the horizontal concentration distribution in the system. Two experiments were carried out with thinner inlet, once the sampling point CH1 was at position 5_1 after at position 5_4. The investigation was carried out the other way around, as well (1.0136 g/cm^3 inlet). The curves of homogeneity run together pretty well independently of the position of CH1. At the outlet the results had the same trend. These experiences implied reproducibility and suggested that horizontal position of CH1 is negligible. According to the pre-experiments, the dominance of specific gravity was occurred. The thinner feed was declined above the heavier one by buoyancy force, while in case of concentrated intake it was sunk under the thinner one.
Results of recirculation measurements indicate a relation between time consumption to reach 95 % homogeneity and tank geometry. In the case of 1-cylinder shape container, to increase over 95 % homogeneity took more time than in the case of 5-cylinders tank however the residence time was the same. This phenomenon might imply that dead volume fluid parts were existed in the system. Further investigation is necessary to identify these liquid parts. Concentration difference between the two sampling points was also researched. The curves run together and indicate shorter mixing time.

Acknowledgments

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References

Coulson J.M., Richardson J.F., 1999, Coulson & Richardosn's Chemical Engineering, Volume 1 Fluid flow, heat transfer and mass transfer, Butterwort Heinemann, Oxford, United Kingdom, 274-277. ISBN 0 7506 4444

Dankwerts P.V. 1953, Continuous flow systems, Distribution of residence time, Chemical Engineering Science, 2, 1-13. doi: 10.1016/0009-2509(53)80001-1

Degawa T., Fukue S., Uchiyama T.,Ishikawa A., Motoyama K., 2017,Behaviour of a Jet Issuing Diagonally Upward into Two-Layer Density-Stratified Fluid in a Cylindrical Tank, Journal of Flow Control, Measurement & Visualization, 5, 51-64. doi: 10.4236/jfcmv.2017.53004

Farooq A., Shafaghat H., Jae J., Jung S.C., Park, Y.K. 2019, Enhanced stability of bio-oil and diesel fuel emulsion using Span 80 and Tween 60 emulsifiers, Journal of Environmental Management, 231, 694-700. doi: 10.1016/j.jenvman.2018.10.098

Galletti C., Brunazzi E., Siconolfi L., Spaltro D., Mauri R., 2017, Mixing Performance of Arrow-Shaped Micro-Devices, Chemical Engineering Transactions, 57, 1309-1314. doi: 10.3303/CET1757219

Liu M., 2012, Age distribution and the degree of mixing in continuous flow stirred tank reactors, Chemical Engineering Science, 69, 382-393. doi: 10.1016/j.ces.2011.10.062

Meng J., Tabosa E., Xie W., Runge K., Bradshaw D., Manlapig E., 2019, A review of turbulence measurement techniques for flotation, Minerals Engineering, 95, 79-95. doi: 10.1016/j.mineng.2016.06.007

Orsi G., Galletti C., Brunazzi E., Mauri R., 2013, Mixing of Two Miscible Liquids in T-Shaped Microdevices, Chemical Engineering Transactions, 32, 1471-1476. doi: 10.3303/CET1332246

Oualha M., Amar B.M., Michau A., Kanaev A., 2017, Cavitations Phenomenon in T-mixer with Exocentric Inputs, Chemical Engineering Transactions, 57, 1231-1236. doi: 10.3303/CET1757206

Qaderi A., Jamaati J., Bahiraei M., 2019, CFD simulation of combined electroosmotic-pressure driven micro-mixing in a microchannel equipped with triangular hurdle and zeta-potential heterogeneity, Chemical Engineering Science, 199, 463-477. doi: 10.1016/j.ces.2019.01.034

Zellouf Y., Portannier B., 2011, First step in optimizing LNG storages for offshore terminals, Journal of Natural Gas Science and Engineering, 3, 582-590. doi: 10.1016/j.jngse.2011.07.011