# Minimising Butadiene Level in Liquefied Petroleum Gas (LPG) via Non-Stirred Blending with Numerical Approach

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Abstract  LPG has variable commercial grades due to its varying LPG composition will yield different properties. Because their properties depend on the composition, the LPG quality will differ based on the source of its production extracted either from refinery streams or natural gas. The composition of propane and butane, which are the two major components in LPG composition, play an important role in reflecting the properties of LPG, as the mixtures influence the boiling points and also meet product specification requirements. Butadiene is also present in LPG, albeit in trace amounts. Although butadiene is a minor component, it must be kept minimised of the total weight fraction due to regulatory limits. Butadiene is a hazardous chemical that, when inhaled, can cause cancer and genetic defects. LPG used for commercial purposes that contain of any carcinogenic substance such as butadiene must also be classified as carcinogenic. The LPG plant operator is facing the problem that imported LPG composition from outside sources contain levels of butadiene that exceed the regulatory limit of 0.5% of weight fraction. LPG composition, containing butadiene levels that exceed 0.5% of weight fraction is considered as off-specification, while butadiene levels less than 0.5% of weight fraction are considered as on-specification the LPG products. To reduce the levels of butadiene that exceed 0.5% of the weight fraction in off-specification LPG products, the blending of on-specification LPG products with off-specification was introduced and provided the most economical method inside the plant. The jet mixing approach was selected to predict the homogeneous blending time for each different off-specification LPG composition because it is the best approximation for natural mixing behaviour. Four empirical mixing time correlations of jet mixing were applied for the prediction of homogeneous blending time; the correlations were derived by Lane and Rice (1982), Maruyama, Ban and Mizushina (1982), Grenville and Tilton (1997) and Hiby and Modigell (1978). The homogeneous blending time predicted by these four mixing time correlations decreased as the quantity of on-specification LPG required increased, which is in good agreement with both simulation results of 95% and 99% mixing. Therefore, due to the development of individual jet mixer correlation, these four mixing time correlation results in different homogeneous blending times was going through the different measurement techniques and monitoring methods in jet mixed tanks.

**Keywords**: CFD, LPG, off-specification, on-specification, jet mixing, homogeneous blending time.

## Introduction

Liquefied petroleum gas (LPG) is a non-renewable energy source, like other fossil fuels extracted from natural gas and crude oil. In 1912, Dr Walter Snelling, an American scientist, discovered that under moderate pressure, LPG can be stored and converted into liquids. From 1912 to 1920, the use of LPG

increased. The first LPG cookstove was made in 1912, and the first LPG-fuelled car was designed in the following year of 1913. Before World War I, the LPG industry was rapidly expanding. During that time, a problem arose in the distribution process of natural gas, and the facilities were gradually built for natural gas cooling and compression systems, as well as a gases separation system capable of converting gases into liquid form to produce LPG which mainly consisted of propane and butane. In 1920, LPG was first used and distributed commercially [1]. LPG is a hydrocarbon gas mixture that mainly consisted of propane (30-35%) and butane (70-75%) at room temperature. Although LPG exists in gaseous form at normal temperatures and atmospheric pressure, it can be stored and distributed in liquid form [2]. LPG is an odourless gas and a colourless liquid that vaporises readily into a gas for use. Because LPG is an odourless gas, an odorant was injected into it to help users in an event of a leak. LPG is typically sold and stored as a liquid, and it is often used in the cooking process, space heating, and automotive. In Malaysia, LPG cylinders are available in 14 kg, 12 kg or 10 kg sizes and are used for cooking in domestic settings such as households. Commercial and industrial users use 50 kg LPG cylinders [3]. LPG is a gas that is flammable, colourless, non-toxic and non-corrosive. LPG is stored and shipped as liquids that are easily converted to liquids at ambient temperature and under pressure. LPG contains gases such as butane, isobutene, propane, butylenes (butenes), propylene (propene), pentane, butadiene and other heavier hydrocarbons. The liquid phase contains the lightest hydrocarbons in the paraffin series such as propane, isobutene and n-butane. The lightest hydrocarbons in the mono olefin series between pentene and ethylene are propylene, isobutylene, 1-butene and 2-butene. The members of the paraffin series end in –ane, whereas the members of the mono olefin series end in –ene. In the paraffin series, LPG is chemically stable and odourless. LPG is soluble in alcohol and ether in varying degrees of temperature [3]. LPG has variable commercial grades due to its various compositions, which result in different properties. Because their properties are determined by the composition of LPG, the composition would be varying based on the source of its production, either as a co-product of gas production or extracted from petroleum refining [4]. Although the composition of propane and butane is important in LPG, the presence of traces of other light C2 to C5 hydrocarbons [4] reflects the quality of LPG and ensure that it meets production specification requirements. Suppliers have specific compositions and grades based on the variable composition of LPG mixtures [5]. Other small amounts of hydrocarbon such as butadiene were found in LPG products, which are influenced by LPG sources and their production processes [6]. Although LPG contains a variety of hydrocarbon mixtures, this study only considers two main components, propane and butane, with the main focus on butadiene levels. Although butadiene was a minor component, it shall be limited to less than 0.5% of the weight fraction due to the regulatory limit [7].

Butadiene is a hazardous chemical that, when inhaled, can cause cancer and genetic defects. LPG used for commercial purposes contained more than 0.1% of any carcinogenic substance [8], [9], [10]. Another reason for limiting butadiene content in LPG is that butadiene has a higher explosion limit of 2.0-11.5% volume than propane and butane, which are 2.1-9.5% of volume and 1.8-8.4% of volume, respectively [11]. The higher the concentration of butadiene in LPG, the wider the explosion limit [11].

The LPG plant operator is facing a problem in which the level of butadiene in imported LPG composition from outside sources exceeds the regulatory limit of 0.5% of weight fraction [7]. As stated in the material safety data sheet of the LPG products, LPG compositions containing butadiene levels exceeding 0.5% of weight fraction are considered off-specification products. To reduce the butadiene level in off-specification LPG products, this study blended on-specification LPG products with off-specification LPG products using a numerical approach and simulation via computational flow dynamics (CFD). The blending took place naturally in the tank, with no mechanical mixing devices used. The reason for this is that many existing tanks in LPG plants do not have such mechanical mixing devices and purchasing a new tank with mixing devices requires high capital. Therefore, this study provides valuable knowledge to LPG plants while potentially saving money.

Mixing can be accomplished using a variety of mechanisms and equipment, the most common of which are mechanical agitators and jets in chemical processing. Mechanical mixing requires an agitator or impeller driven by a prime mover, which determines the geometry of the mixer. This geometry plays an important role in mixing because it contributes to determining the effectiveness of design geometry. The

type of mixing mixer used is determined by the mixing target. According to the plant's existing LPG tank design, the existing tank was designed without a mechanical mixer or impeller. Before this limitation, natural blending was more practical through the use of a jet mixer. In comparison to conventional impellers, jet mixing is an alternative mixing device that offers several advantages, including a simple design with non-moving parts, low operating costs, ease of installation and lower maintenance costs [12], [13]. Furthermore, jet mixers do not require support at the top of the mixer tank, making installation easy [12]. The agitator or impeller would require thicker walls made of a stronger material for the mixer tank [12]. LPG blending would undergo without the use of an agitator or impeller, but natural blending is possible. By applying a numerical approach, the required quantity of on-specification products to reduce the butadiene level in off-specification products is important for plant operators to fine-tune the off-specification products. The homogeneous blending time is revealed because it is a crucial data for plant operators to fine-tune off-specification products with effective production time. Hence, the jet mixing time correlation was selected to predict the homogeneous blending time for variable off-specification LPG, which contain butadiene compositions that exceed the regulatory limit. The jet mixing theory is the best approach for natural mixing of fluid behaviour.

The jet mixing approach for mixing is widely used in applications such as blending the inhibitor to stop runaway reactions, emergency cooling systems, homogenisation in hydrocarbon and LNG storage tanks, jet reactors in various processes and acid mixing [14]. Over the last 60 years, many extensive experimental studies of jet mixing tanks have been published [14]. Previous researchers made several experimental correlations available. Lane and Rice (1982) proposed a mixing time correlation in which the tank with the longest jet path length contributed to the shortest mixing time, as expressed in Equation 1 [8], which is similar to a previous study by Coldrey [15].

$$T_m = \text{f}\frac{H^{0.5}\text{D}}{(U_jD_j)^{0.667}g^{0.166}}, \text{f} = 113.133\text{Re}_j^{-0.146} \tag{1}$$

where $T_m$ is the homogeneous blending time, $R_e$ is the Reynolds number, D is the diameter of cylinder tank and $d_j$ is the diameter of nozzle inlet respectively with the assumption that the diameter of inlet nozzle $d_j$, is the diameter of tank inlet, $U_j$ is the initial velocity of on-spec LPG at the tank inlet, and g is the gravitational acceleration of 9.81 m/s. According to Maruyama, Ban and Mizushina (1982), the mixing time is dependent on liquid depth, nozzle height and nozzle elevation angle, as expressed in Equation 2 [12].

$$\left(\frac{T_m}{t_r}\right)\left(\frac{H}{d_j}\right) = 9, \text{ Re} > 4000 \tag{2}$$

where $T_m$ is the homogeneous blending time, Re is the Reynolds number, $d_j$ is the diameter of the nozzle inlet that is assigned as tank inlet, and H is the liquid height inside the cylinder. Grenville and Tilton (1997) established a mixing time correlation, as presented in Equation 3, and discovered that the attachment to the vessel base by jets with shallow angles reduces the entrainment efficiency and requires more liquid to circulate through the nozzle to achieve the desired degree of mixing [16].

$$T_m = k\frac{D^2H}{U_jD_jL}, \ k = 9.38 \ ,\theta > 15°, \ k = 13.8 \ ,\theta < 15° \tag{3}$$

where $T_m$ is the homogeneous blending time, D is the diameter of the cylinder tank, L is the length of the cylinder tank, k is a constant, $d_j$ is the diameter of nozzle inlet that is assigned as the tank inlet, and H is the liquid depth inside the cylinder. Hiby and Modigell (1978) [17] studied the axial jet in the cylindrical tank with a flat base and proved that the mixing time was dependent on the jet Reynolds number when the jet Reynolds number had been less than 1,000,000, resulting in the mixing time correlation, as shown in Equation 4.

$$T_m = T^*\frac{D^2}{U_jD_j}, T^* = 2.3 \ when \ Re_t > 1,000,000, T^* \infty Re \ when \ Re_t < 1,000,000 \tag{4}$$

The selection of the experimental correlation in jet mixing application is dependent on the current design mixer tank, which is a cylindrical tank type, and also how the liquid is injected into the tank, either vertically or gravitationally. Typically, model validations have been conducted for mixing time simulations by comparing the predicted overall mixing times with experimental data or mixing time correlation [14]. In general, computational fluid dynamics (CFD) is capable of providing clear insight into a variety of fluid flow phenomena based on the numerical solutions of partial differential equations to produce large volumes of results at a lower cost than experimental works [14]. The most widely used finite volume commercial CFD code for jet mixing tank modelling is FLUENT software that is adapted to simulate various jet mixing tank geometries [14]. The commercial CFD code, FLUENT, was also used to investigate the flow pattern and mixing performance inside a cubic jet mixing tank [18], jet mixing tank with cooling coils [19], as well as a tank with multiple jets [20], [21]. The validation between predicted overall mixing time and mixing time correlations was originally reported by Ranade [22], in which he compared the overall mixing time with the mixing time correlation of Revill [23] and Simon and Fonade [24]. The simulated results showed that the main features of fluid dynamics and mixing were adequately captured by Ranade's model [22]. Lee [19] simulated jet mixing tanks with cooling coils and compared the predicted results with the mixing time correlation of Greenville and Tilton [25]. Zughbi and Rakib [26] compared the prediction of mixing time with the correlation of Lane and Rice [8] to validate their model. Zughbi and Rakib [27] extended their research with the inclined side entry jet mixing tank models by comparing to mixing correlations developed by Fosset and Prosser [18], Lane and Rise [8], and Grenville and Tilton [25], and they found out that the predicted mixing time agreed well with the correlation of Lane and Rise [8] and Grenville and Tilton [25], except for the Fosset and Prosser [18] correlation that refused to provide good agreement.

## Materials and Methods

### Numerical Approach
In this study, on-specification LPG that needed to be blended with off-specification LPG was, numerically calculated via mass balance calculation. LPG containing butadiene of more than 0.5% of weight fraction was considered as an off-specification LPG product. Table 1 summarises all of the five samples of different compositions of butadiene level in off-specification LPG that was blended with on-specification LPG.

**Table 1.** Composition of On-Specification and Off-Specification LPG products

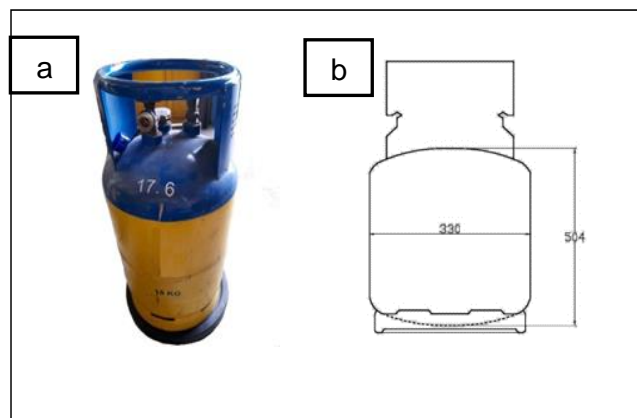| Components | LPG composition (Percentage of Weight Fraction) | | | | | |
|---|---|---|---|---|---|---|
| | On-Specification LPG | Off-Specification LPG | | | | |
| | | Sample No. 1 | Sample No. 2 | Sample No. 3 | Sample No. 4 | Sample No. 5 |
| Propane (%) | 36.74 | 39.70 | 39.65 | 39.60 | 39.55 | 39.50 |
| Butane (%) | 63.25 | 59.70 | 59.65 | 59.60 | 59.55 | 59.50 |
| Butadiene (%) | 0.01 | 0.60 | 0.70 | 0.80 | 0.90 | 1.00 |



**Figure 1.** (a) cylindrical mixer tank. (b) dimension of mixer tank

The blending off-specification and on-specification LPG were done in a mixer tank with a capacity of 15kg LPG, a diameter of 0.33m, and a height of 0.504m, as shown in Figure 1. The blending of off-specification LPG with on-specification LPG would take place under the assumption of constant temperature at 20.3°C and no vaporisation within the mixer tank. The operating pressure inside the tank was assumed to be the vapour pressure of off-specification LPG, which was located as a stagnant fluid inside the mixer tank, and no pressure increase was assumed to occur during the blending process. The off-specification LPG product was gravity-filled into the mixer tank according to the ratio blending calculated in Table 1, and the quantity of required on-specification LPG had to be varied until the butadiene weight fraction percentage was reduced to 0.5% in the blended products inside the mixer tank. The blending ratio between on-specification and off-specification was determined by the level of butadiene in off-specification LPG products.
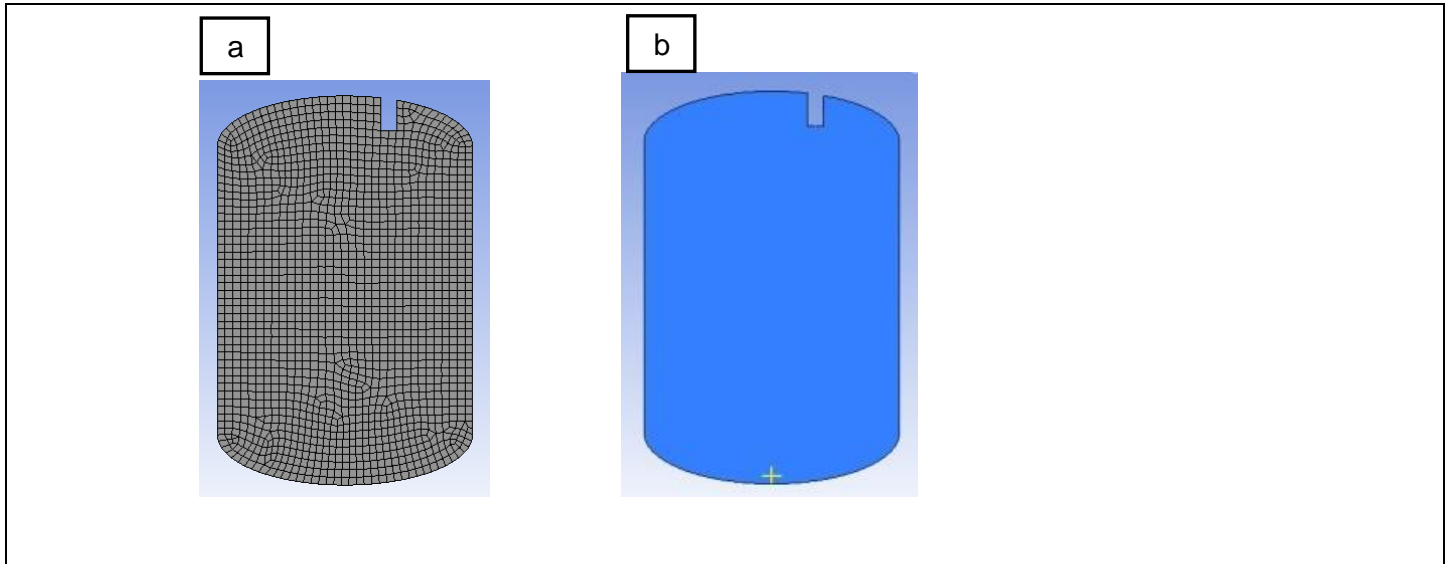


**Figure 2.** (a) 2D representation of meshed mixer cylinder tank model and (b) tracer point

**Simulation Approach**

The simulations were carried out using FLUENT to observe and analyse the homogeneous blending time by varying the blending mass ratio between on-specification LPG and off-specification LPG based on composition, as stated in Table 1. The modelling of the mixer tank and meshed model, as shown in Figure 2(a), followed the specification of the mixer dimension, as sketched in Figure 1(b). The insertion point into the mixer tank had a dimension of 0.02m and the velocity of on-specification LPG inserted into the mixer tank was fixed at 3.133 m/s, which were calculated from gravitational effect at an elevation of 1.3m above ground level. The off-specification LPG was patched into the mixer tank that represented the stagnant bulk fluid inside the mixer tank. The measurement of homogeneous blending time was monitored with a tracer concentration technique that was placed on the bottom of the mixer tank and a point was patched inside the mixer tank domain, as shown in Figure 2(b), to record the concentration profile respective to the flow time of on-specification LPG blended with off-specification LPG inside the mixer tank. The tracer point monitor was placed at the bottom centre according to Okita and Oyama (1963), and the mixing time was defined as the time between tracer addition and the moment at which there were no differences in concentration measured by probe [28]. The blending time profile of tracer concentration was then measured and defined as the time at which concentration (c) has reached (or nearly reached) the final mean tracer concentration (c̄), as shown in Equation 5,

$$\mathrm{m} = \frac{|c - \bar{c}|}{\bar{c}} \qquad (5)$$

where m is defined as the maximum acceptable absolute value of the relative deviation of the fluid mixture [14]. The completed homogeneity of liquid blending was achieved when the value of m had been

equal to 0. In the experimental approach, two general criteria were commonly used to quantify the homogeneous blending time: (i) m equal to 0.05 for 95% blending and (ii) m equal to 0.01 for 99% of blending [14].

# Results and Discussion

## Blending of On-Specification and Off-Specification LPGs at Different Ratio using Numerical Approach

Table 2 shows the blending of off-specification and on-specification LPGs at various ratios and the calculated final content of butadiene in the final blended LPG.

**Table 2.** Blending ratio between on-spec and off-spec LPG

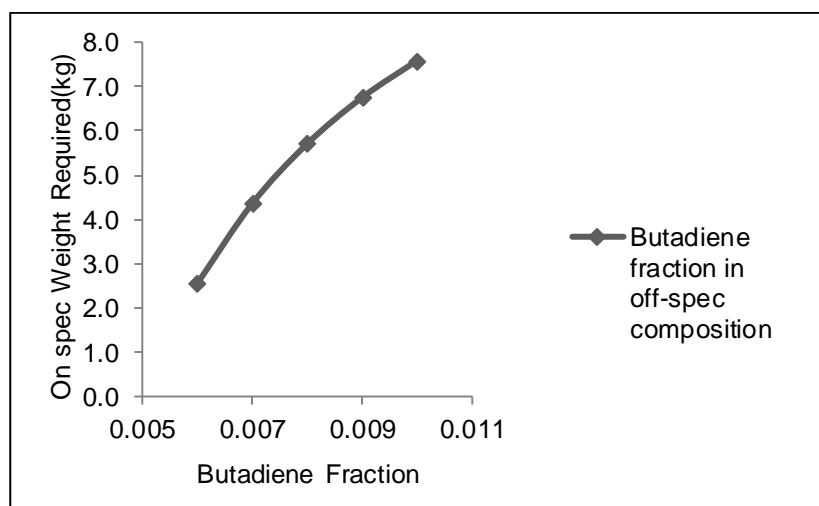| LPG Off-Specification Products | Blending Ratio for Minimised the Butadiene Level Below 0.5% of Weight Fraction | | | | |
|---|---|---|---|---|---|
| Sample number | 1 | 2 | 3 | 4 | 5 |
| On-Specification LPG (%) | 17% | 29% | 38% | 45% | 51% |
| Off-Specification LPG (%) | 83% | 71% | 62% | 55% | 49% |
| Calculated on-specification LPG weight required (kg) | 2.5500 | 4.3563 | 5.7060 | 6.7518 | 7.5861 |
| Butadiene Content After Blending (95% homogeneous) | 0.21% | 0.16% | 0.12% | 0.22% | 0.27% |
| Butadiene Content After Blending (99% homogeneous) | 0.22% | 0.08% | 0.11% | 0.21% | 0.24% |



**Figure 3.** On-Specification LPG required to reduce butadiene level below 0.5% of weight fraction in Off-Specification LPG
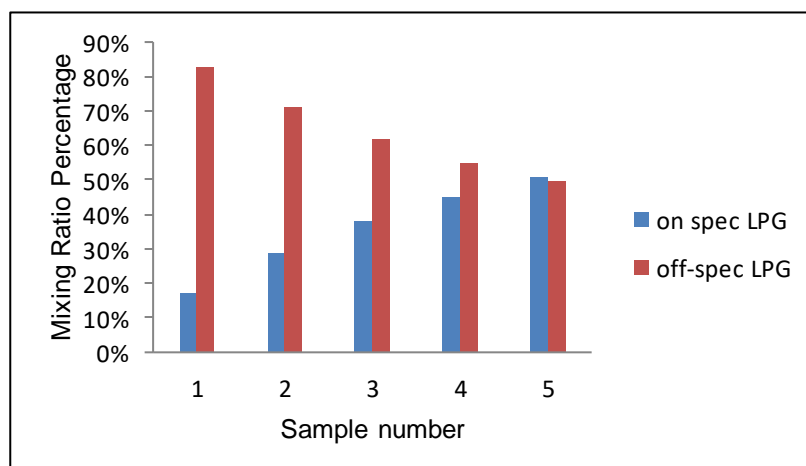


**Figure 4.** Blending ratio between On-Specification LPG and Off-Specification LPG to Minimise butadiene level below 0.5% of weight fraction

Figure 4 represents the blending ratio between on-specification and off-specification LPG, demonstrating that the percentage of on-specification LPG needed to be blended is increasing while the percentage of off-specification LPG is decreasing as the level of butadiene increases in off-specification LPG products. The quantity of on-specification LPG required increases when the butadiene level increases in off-specification LPG, as shown in Figure 3. This scenario happened because of the higher weight fraction percentage of butadiene in off-specification LPG; the higher on-specification LPG is required to reduce the total percentage of weight fraction of butadiene in mixture products after blending. Whenever the total weight of propane and butane increases due to the addition of more on-specification products into blended products, the total weight of butadiene in mixture products will become lower in total. Although the total weight of butadiene increased in blended products, the weight fraction of butadiene lowered because of the increasing total weight of propane and butane results from increasing the blending ratio of on-specification products that contained less butadiene.

## Blending of On-Specification and Off-Specification LPGs using Simulation Approach via CFD
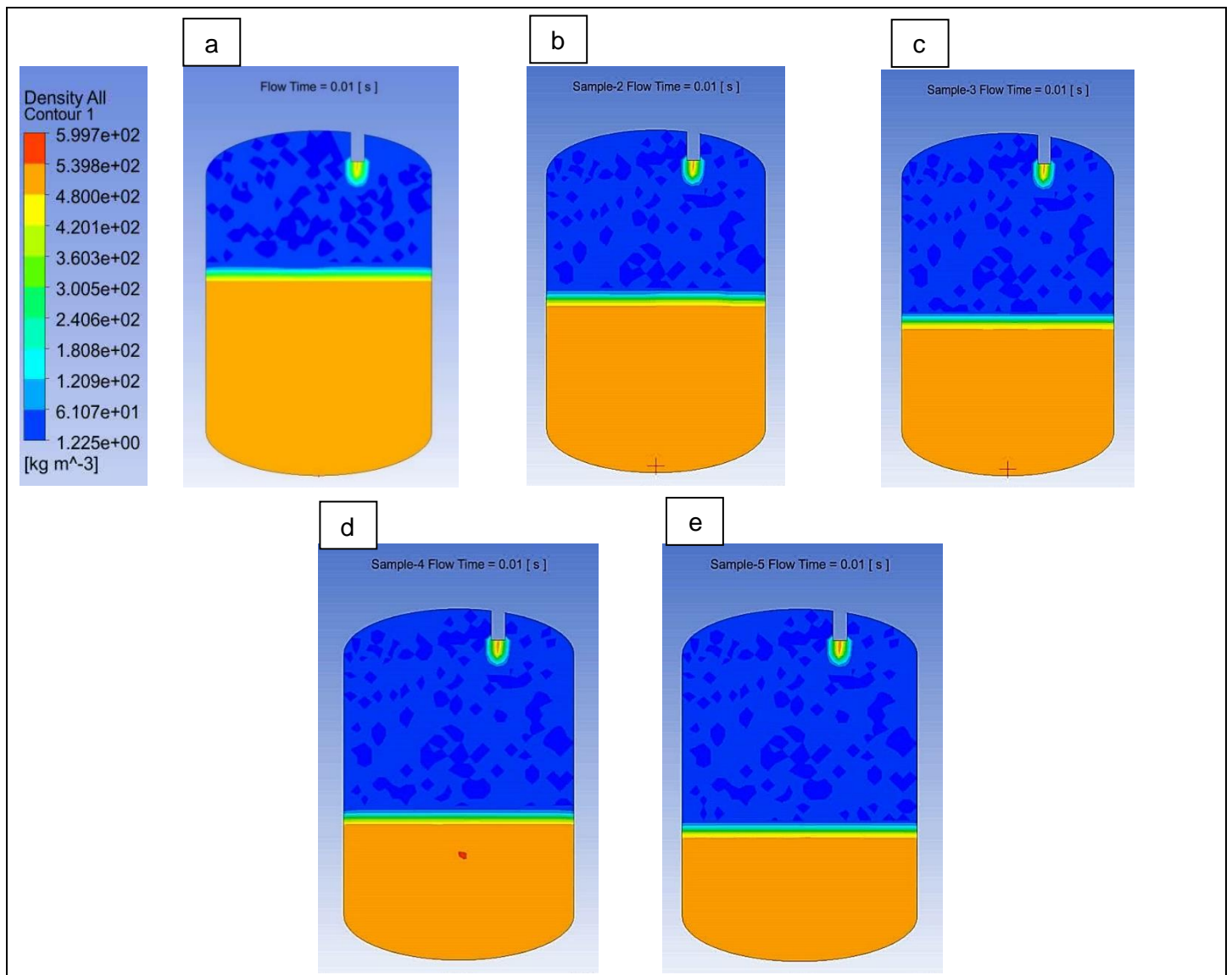


**Figure 5.** Off-Specification LPG starts flowing into the mixer tank at 0.01 s. (a) Sample 1. (b) Sample 2. (c) Sample 3. (d) Sample 4. (e) Sample 5

At the initial stage which flow time, t equal to 0, the off-spec LPG which contains high butadiene was filled inside the mixer tank. Figure 5 indicated that the quantity of off-spec LPG inside the mixer tank from Sample 1 to Sample 5 was decreasing as calculated in Table 1 which because the level of butadiene increase and the total mixture after the blending would be maintained to 15 kg. Once blending started, on-spec LPG flowing into mixer tank through 0.02 m$^2$ of insertion hole with velocity of 3.133 m/s by gravitationally and the contact time between on-spec LPG with off-spec LPG inside the mixer tank was observed. Sample 1 need 0.06 s for on-spec LPG contact with off-spec LPG followed by Sample 2, Sample 3, Sample 4 and Sample 5 with results 0.08 s for Sample 2 and 0.09 s for Sample 3, Sample 4 and Sample 5 as showed in Figure 6. This phenomenon occurred due to different liquid level from Sample 1 to Sample 5 which off-spec LPG in Sample 1 was observed to have highest liquid level compared to other sample which results the flow time decreasing.
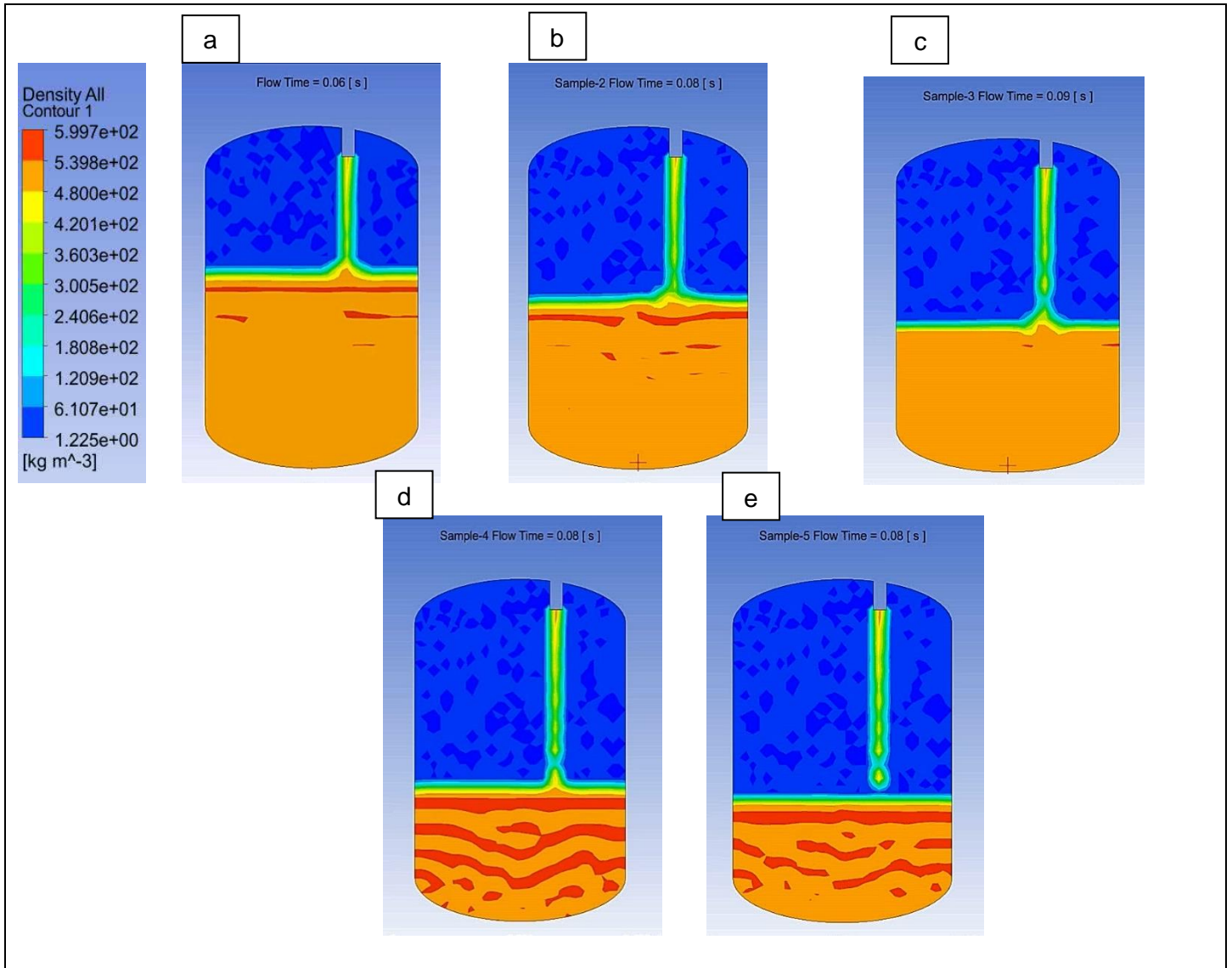


**Figure 6.** On-spec LPG filling into mixer tank and contact with Off-Spec LPG at (a) Sample 1 at 0.06 s (b) Sample 2 at 0.08 s (c) Sample 3 at 0.09 s (d) Sample 4 at 0.08 s (e) Sample 5 at 0.08 s

Figure 7 shows the simulation result of on-specification LPG blended with off-specification LPG, which achieved 95% blending and monitored the concentration profile at the tracer positioned at the centre bottom of the mixer tank. At a flow time of 7.9s, sample 1 achieved 95% homogeneous mixing followed by sample 2 at 5.5 s, sample 3 at 4.2 s, sample 4 at 1.3 s and sample 5 at 0.7 s. The blending time for 95% mixing decreased when the quantity of on-specification LPG with less butadiene content was increased.
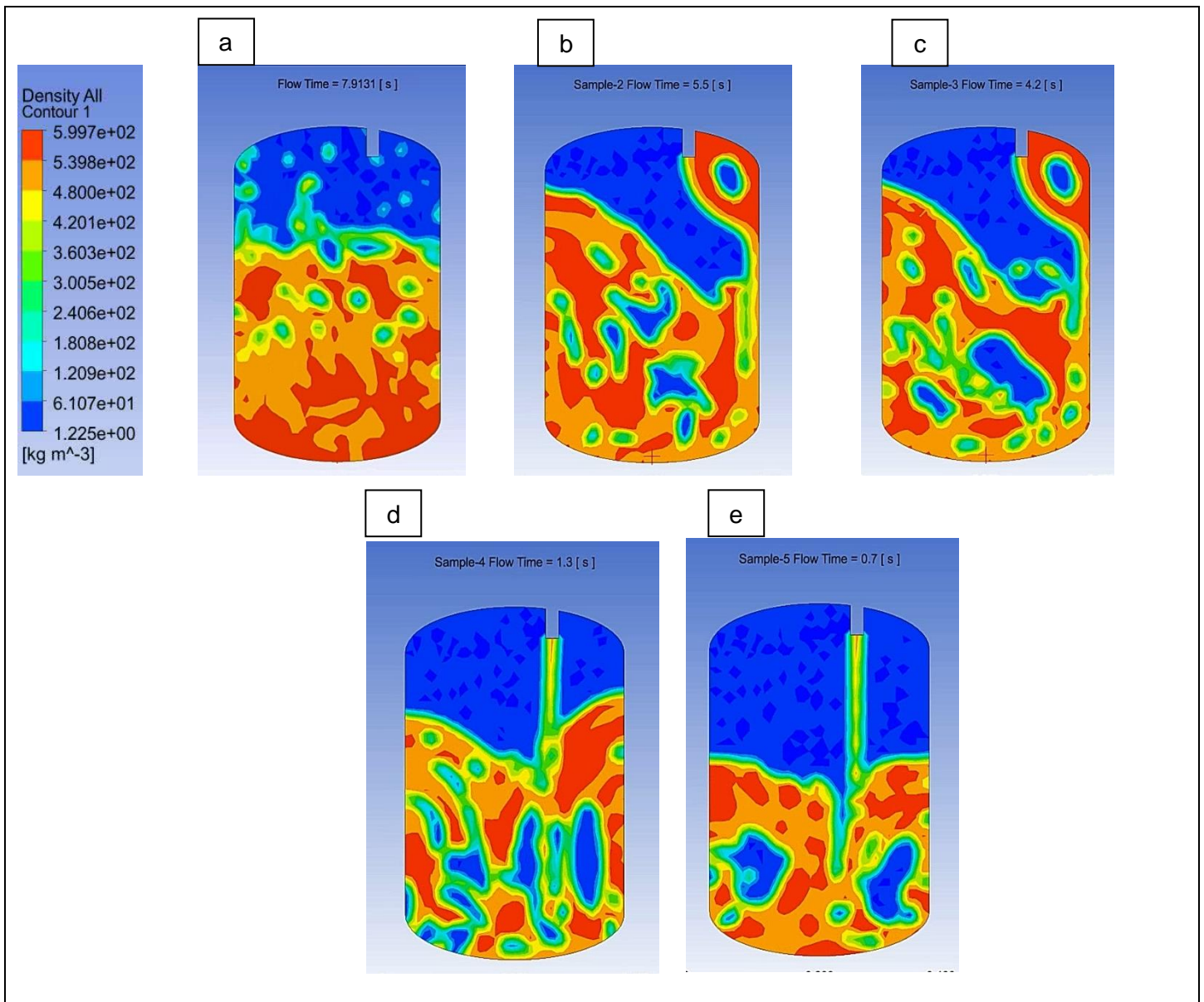
**Figure 7.** 95% homogeneous blending recorded by tracer at the centre bottom of the mixer tank (a) Sample 1 at 7.9 s (b) Sample 2 at 5.5 s (c) Sample 3 at 4.2 s (d) Sample 4 at 1.3 s (e) Sample 5 at 0.7 s

Figure 8 presents the inside of the mixer tank, where tracer concentration detected 99% mixing homogeneity between on-specification LPG and off-specification LPG after blending. According to this flow time recorded, only Sample 1 in Figure 6 (a) achieved 99% of homogeneous mixing after the filing time was completed. Sample 2 to Sample 5 indicated that 99% of homogeneous mixing was achieved before the on-specification LPG filling was completed. This mixing behaviour contributed to a decrease in homogenous blending time when the quantity of on-specification LPG increased to reduce the butadiene content to 0.5% of the weight fraction.
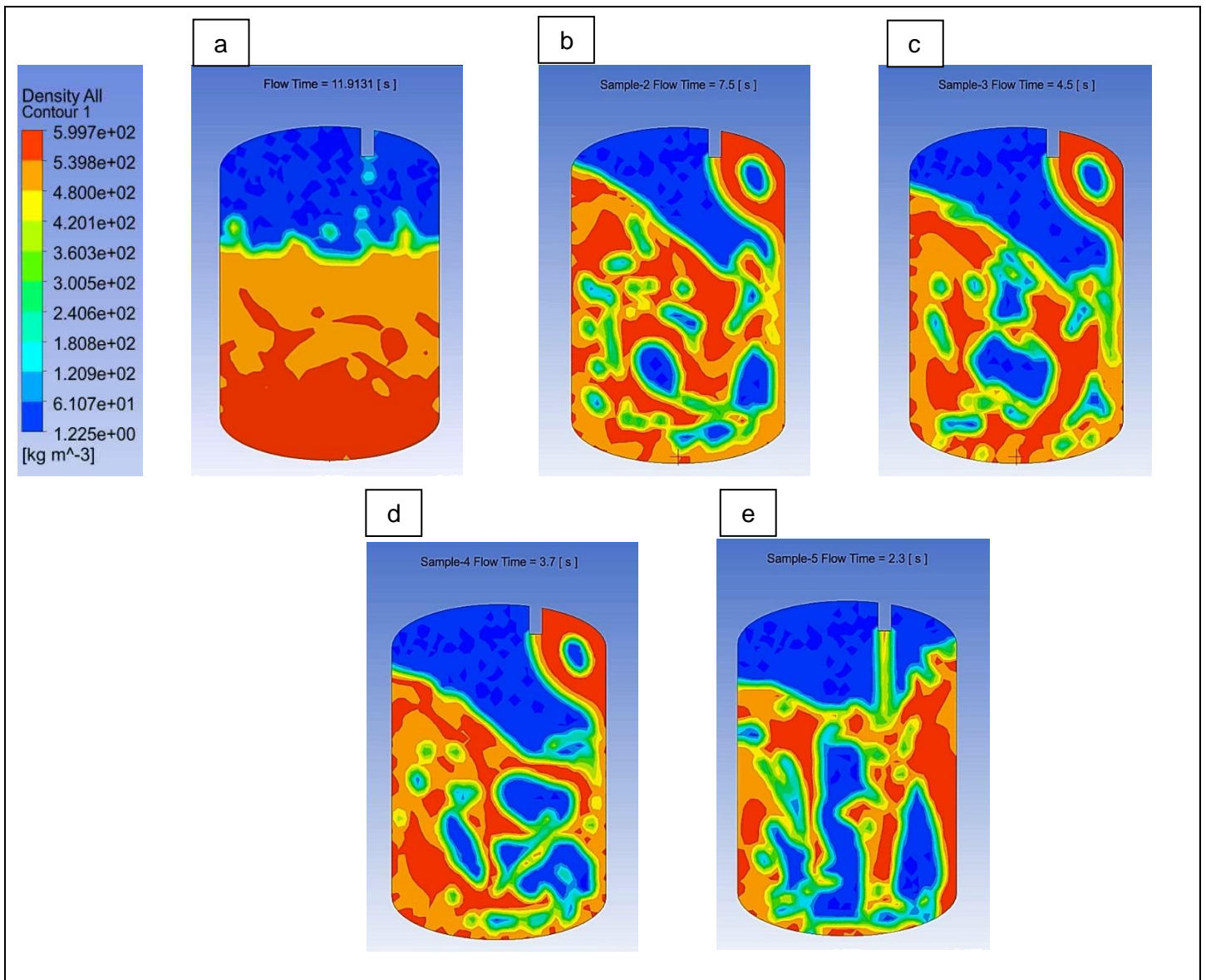
**Figure 8.** 99% of blending recorded by tracer at the centre bottom of the mixer tank (a) Sample 1 at 11.9 s (b) Sample 2 at 7.5 s (c) Sample 3 at 4.5 s (d) Sample 4 at 3.7 s (e) Sample 5 at 2.3 s
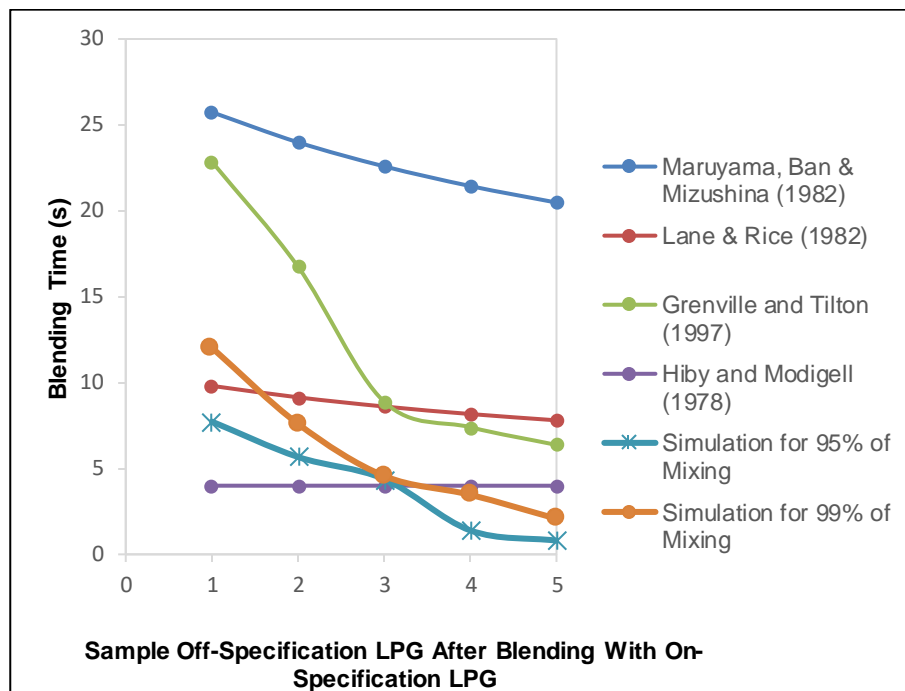
**Homogeneous Blending Time**



**Figure 9.** Comparison of an estimated homogeneous blending time using various model

Figure 9 shows that the homogeneous blending time taken by four jet mixer experimental correlation by Maruyama, Ban & Mizushina (1982), Lane & Rice (1981), Grenville and Tilton (1997), and Hiby and Modigell (1978), and these results were compared with this study for 95% and 99% of mixing corresponding to 5 samples of on-specification LPG and off-specification LPG after blending. The result demonstrated that increasing on-specification LPG reduces the homogeneous mixing time. which increased the blending ratios from Sample 1 to Sample 5. Five samples of different LPG compositions were calculated by jet mixer experimental correlation results for blending between on-specification LPG and off-specification LPG; the results agreed with the simulation from this study, which proved that the homogeneous blending time decreases when the quantity of on-specification LPG required, which contains less butadiene, increases from Sample1 to Sample 5, as presented in Figures 2 and 3.

However, those four jet mixer correlation models produced different results in the prediction of homogeneous mixing time when compared with this study on 95% and 99% of mixing. This scenario occurred because each jet mixer correlation was developed using different measurement techniques and monitoring methods of mixing times in jet mixed tanks [12]. Maruyama, Ban and Mizushina (1982) correlation predicted the homogeneous blending time 5 times longer than the simulation on 99% mixing and 10 times compared to the simulation of 95% mixing. Correlation by Maruyama, Ban and Mizushina (1982) predicted the mixing time on the time required to reduce the concentration variation within 1% of the mixed mean value of the mixture [29]. The application of this correlation was limited for nozzles under the liquid depth to produced circulation flow regimes inside the solution depth [29], while the LPG mixing process was carried out only at the top of the mixer tank and the blending occurred once the liquid of off-specification LPG fell free from the inlet point into the stagnant of off-specification LPG inside the mixer tank.

Meanwhile, Lane and Rice's (1982) correlation predicted the homogeneous blending time to be 2 times longer than the simulation results of 99% mixing and 4 times longer than the simulation results of 95% mixing, because the correlation was developed by using the conductivity technique to measure the mixing time at the point where the fluid pathway was longest throughout the mixer tank [8]. They defined mixing time as the time elapsed between the start of pulsed salt injection and the first time when concentration was consistent within 5% of the final and steady-state concentrations. The pulsed salt injection defined by Lane & Rice (1981) correlation lasted longer compared to blending of on-specification LPG into stagnant of off-specification LPG inside the mixer cylinder tank.

Grenville and Tilton's (1997) correlation results are similar to Lane and Rice (1982), which were 2 times longer than the simulation results of 99% mixing and 4 times longer than the simulation results of 95% mixing because the correlation predicted with jet attachment to the vessel base compared with this work, which inserted on-specification LPG from the top of the mixer tank. According to homogeneous blending time prediction by Grenville and Tilton (1997) and Lane and Rice (1982) correlation, as shown in Figure 9, although the results given almost double compared to the simulation results of 99% mixing, the reducing rate of blending time calculated was comparable to the simulation results where the liquid properties such as water and LPG, which have density ratios almost double.

Hiby and Modigell's (1978) correlation shown in Figure 9 yields good results with an average 4% deviation compared to the simulation results of 99% mixing and 2 times longer compared to the simulation results of 95% mixing. This correlation was developed by approaching the axial jet in a cylindrical tank, which is compatible with this study, but the parameter of liquid height was ignored. The different interpretations of each jet mixer correlation and model resulted in different estimated homogeneous mixing times, but this approximation correlation benefits the plant operator as the basis for projecting the actual homogeneous mixing time during the LPG blending activity in the plant concerning the butadiene composition in off-specification LPG products.

## Conclusions

LPG compositions that contain more than 0.5% butadiene by weight fraction are considered as off-specification LPG products, according to the safety data sheets of the LPG products. To reduce the content of butadiene levels that exceed 0.5% of the weight fraction in off-specification LPG products, the blending of on-specification LPG products with off-specification was introduced and provides the most economical method inside the plant. The jet mixer approach was selected to reduce the butadiene weight fraction below 0.5% of the weight fraction, the amount of on-specification LPG required increased as the level of butadiene in off-specification LPG increased. The Blending ratio between on-specification and off-specification LPG shows that the percentage of on-specification LPG needed to be blended increased while the percentage of off-specification LPG decreased as the level of butadiene in off-specification LPG products increased. The homogeneous blending time predicted by selected four jet mixer correlation models corresponding to butadiene weight fraction in the off-specification LPG mixture contributed to different homogeneous blending times due to the development of individual jet mixer correlation was going through the different measurement techniques and monitoring methods in jet mixed tanks. Five samples of different LPG compositions for blending between on-specification LPG and off-specification LPG was calculated by jet mixer experimental correlation and the results agreed with this study, which proved that the homogeneous blending time decreased when the quantity of on-specification LPG required which content less butadiene increased. Hiby and Modigell's (1978) correlation yields good results with an average deviation of 4% when compared to the current simulation results of 99% mixing, indicating that it is the most applicable to LPG blending behaviour. For future work, the effects of thermal in LPG blending should be employed and studied to obtain a comprehensive CFD model for this system.

## Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

## Acknowledgements

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