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Modeling and Simulation of Drilling Gas Mixing Process with Various Conditions in Oil and Gas Pipeline Network

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ABSTRACT

This research aims to model and simulate the gas drilling mixing process with various conditions in the inlet gas flow. This mixing process is very crucial because it can affect the phase stability in the storage tank. Based on this, the gas that has been mixed must be ensured that it is in a perfectly mixed condition before entering the storage tank. The simulation method used in this research is Computational Fluid Dynamics (CFD) with ANSYS Fluent software. The data used as input in this simulation includes flow velocity, temperature, pressure and drilling gas composition. The simulation results are expected to show that flow velocity and pressure have a significant effect on the drilling gas mixing process in the pipe flow. In addition, the differences in the composition of the drilling gas also have an impact on the mixing process, where the more diverse the composition of the drilling gas, the more difficult it is to mix the gas homogeneously. However, by using baffle plates as a barrier and agitator in the pipe, the simulation results show that the mixing of drilling gas can be significantly increased.

1. Introduction

The gas pipeline network in Indonesia is used to transport natural gas from its source in natural gas fields to various places throughout Indonesia, both for domestic and industrial needs. These pipes are also supported by various other supporting facilities such as compressor stations and measuring stations, which ensure the smooth distribution of natural gas and meet consumer needs. The pipeline network covers most of Indonesia and includes the islands of Java, Sumatra and Kalimantan. One of the most important things to be eliminated in the process of transporting natural gas from sources to various places in Indonesia is the safety factor. Safety is one of the main issues in the transportation of natural gas since the natural gas is flammable and can pose a risk of fire or explosion. Therefore, strict safety measures are required in the entire process of transporting natural gas from source to its destination [1–4].

In the existing gas pipeline network, it is necessary to pay attention to the meeting point between the network from one source to another. This will greatly influence the standards of gas products

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both in terms of composition and quantity. In addition, the process of installing subsequent process equipment and measuring devices also needs to be considered when there is a mixing process, because it can reduce the effectiveness of the equipment in processing and measuring gas flow after the mixing process. Therefore, it is necessary to conduct a study to model and analyze the meeting point of these two pipe networks.

Melaina *et al.,* [1] reviewed the main issues related to the option of injecting hydrogen into natural gas pipeline systems, including impacts on end-use systems, safety, durability and material integrity management, leakage, and downstream extraction.

Wu *et al.,* [5] regarding the mixing of hydrogen gas and natural gas in an internal combustion engine. This study uses numerical simulation and experimental methods to evaluate the effect of the ratio of a mixture of hydrogen gas and natural gas on engine performance. Shiehnejadhesar *et al.,* [6] studied the "porous" nature of packed beds which causes streak formation and can affect gas mixing and combustion. Therefore, in his research on the streak formed in the combustion of the gas phase, a gas streak model based on the correlation between local gas residence time and mixing time has been developed based on numerical simulations. Feldmann *et al.,* [7] mathematically, explained the behavior of a compositional two-phase flow model with water and gas as phases and all relevant chemical species as components (H_2, H_2O, CH_4, CO_2, N_2, H_2S, etc.). Spatial variation of the gas phase composition between the injected gas and the starting gas causes density and viscosity contrasts which affect the transfer process. The mixing of gases with different compositions is controlled by molecular diffusion or mechanical dispersion depending on the flow rate.

Research by Wang *et al.,* [8] regarding the mixing of hydrogen gas and natural gas in natural gas pipelines. This research uses numerical simulation methods to model the flow of a mixture of hydrogen gas and natural gas in a pipe and evaluates the influence of flow parameters on the mixing process. Lee *et al.,* [9] about mixing methane gas and hydrogen gas in natural gas engines. This research uses numerical simulation and experimental methods to evaluate the effect of the mixture ratio of methane gas and hydrogen gas on engine performance. Liu *et al.,* [10] regarding mixing methane gas and hydrogen gas in a gas storage system. This research uses numerical simulation methods to model the mixing and storage process of methane gas and hydrogen gas in storage tanks. Li *et al.,* [11] about mixing methane gas and hydrogen gas in a gas turbine engine. This research uses numerical simulation and experimental methods to evaluate the effect of the mixture ratio of methane gas and hydrogen gas on engine performance.

Natural gas has very diverse contents, in this gas network there are more than 10 components that need to be analyzed comprehensively to see the behavior of the gas during the transportation process from the source to the storage area. The method commonly used in multi-species simulations is species transport in computational fluid dynamics. Evaluation of a process through simulation process could gave anther perspective on the future decision and also able to avoid any disasters caused by the processes [12–14]. Ibrahim *et al.,* [15] investigated the flow and combustion simulation of methane-air mixtures with Ansys Fluent. This research uses Ansys Fluent to model the combustion of a methane-air mixture in a burner. The simulation results show that the temperature distribution and mass fraction of the species involved in combustion can be predicted well. Modeling of species transport and reactions in internal combustion engines has also been carried out by Said *et al.,* [16]. This research uses Ansys Fluent to model the transport and reactions of species in an internal combustion engine. The simulation results show that the species transport model used is quite accurate in predicting the species concentration profile in the gas flow. Wibowo *et al.,* [17] simulated the separation of gas species in a permeable membrane with Ansys Fluent. Ansys Fluent is used to model gas flow and the separation of gas species in a permeable membrane. The simulation results show that the species transport model used is quite accurate in predicting the efficiency of gas species separation. Simulation of species transport in the wood pyrolysis process with Ansys Fluent was also carried out by Wijayanti *et al.,* [18] where this research uses Ansys Fluent to model species transport in the wood pyrolysis process. The simulation results show that the species transport model used is quite accurate in predicting the species concentration profile in the gas flow.

From the previous studies, modelling and simulation of a syn gas mixing phenomena in the pipeline network has not been done. Hence, the objectives of the present study are to develop a CFD models to capture the representative flow behaviour of gas mixing process at the meeting point in the pipe line network. The second aim is to characterize the pressure loss in pipelines with varying inlet gas parameter condition.

2. Methodology

The design data for this study was obtained from the field data collection where the case occur. The gas source process conditions and the detailed gas compositions are shown in Tables 1 and 2 respectively.

Table 1
Parameter condition from two sources of gas

Parameter	CASE 1		CASE 2		CASE 3	
	Gas A	Gas B	Gas A	Gas B	Gas A	Gas B
T (K)	317.18	304.90	317.18	304.90	317.14	304.90
P (Psig)	559.50	555.00	559.60	555.00	592.99	589.83
Mass flow (kg/hr)	10870.2	91242.6	13587.8	102191.5	20382.4	168798.4
Mass flow (kg/s)	3.020	25.345	3.774	28.387	5.662	46.888

Table 2
Gas Composition from two sources of Gas

Composition	Case 1		Case 2		Case 3	
	Gas A	Gas B	Gas A	Gas B	Gas A	Gas B
Methane	0.6009	0.9065	0.6009	0.9065	0.6009	0.9065
Ethane	0.0381	0.0325	0.0381	0.0325	0.0381	0.0325
Propane	0.0194	0.0108	0.0194	0.0108	0.0194	0.0108
CO_2	0.3393	0.0451	0.3393	0.0451	0.3393	0.0451
N_2	0.0022	0.0052	0.0022	0.0052	0.0022	0.0052
H_2S	0.000102	0	0.000102	0	0.000102	0

Table 3 shows the detailed pipe size where the blending process was occurred.

Table 3
Pipe size

No	Parameter	Value
1	Length of pipe A	80 inch
2	Length of pipe B	80 inch
3	Length of the outlet pipe	600 inch
4	Header height	500 mm
5	Header diameter	20 inch

Schematic diagram for pipeline is shown in Figure 1.

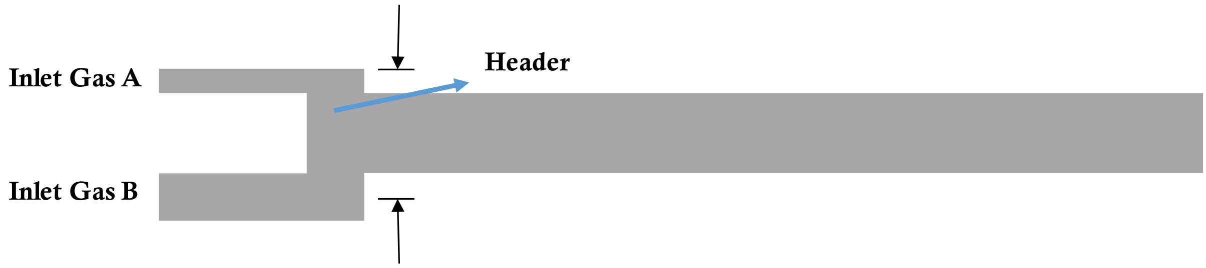


Fig. 1. Schematic diagram of gas pipeline network

In this case, the blending process of stream A and B will be simulated by using ANSYS. There are several terms that needed to be calculated in ANSYS such as the energy balance, momentum balance, turbulence model and species transport.

Since there are two streams with different temperature, the conservation of energy equation is needed to calculate the mixture temperature. The equation is shown in Eq. (1).

$$\frac{\partial(\rho E)}{\partial t}+\nabla(U_i(\rho E+p))=\left(k_{eff}\nabla T-\sum_{j'}h_{j'}J_{j'i}+(\tau_{ij})_{eff}\right)+S_h \tag{1}$$

where, ρ is the density, E is the total energy, ∇ is tensor, $U_{i,j}$ is the velocity, p is pressure, k_{eff} is effective conductivity, T is for temperature, h_j is enthalpy of ideal gas, J_j is fluxes of species diffusion, $\tau_{i,j}$ is the shear stress and Sh is user source term.

Newton's second law stated that the rate of change in momentum on a particle is equal to the amount of forces acting on the particle. These forces can be divided into two types, namely surface force and body force. Surface force includes pressure force and viscous force, while body force includes gravity force, centrifugal force, and electromagnetic force. Body force is usually expressed as the source term in a momentum equation[19]. In Cartesian coordinates, the equation for momentum that occurs in the x, y and z axes is as shown in Eq. (2):

$$\frac{\partial(\rho U_i)}{\partial t}+\frac{\partial}{x_j}(\rho U_i U_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_j}-\frac{2}{3}\frac{\partial U_k}{\partial x_k}\delta_{ij}\right)\right]+\rho g_i+F_i \tag{2}$$

The k-ε model is one of the most common turbulence models, although it just doesn't perform well in cases of large adverse pressure gradients. It is a two equation model, that means, it includes two extra transport equations to represent the turbulent properties of the flow. This allows a two equation model to account for history effects like convection and diffusion of turbulent energy [20].

The first transported variable is turbulent kinetic energy, k. The second transported variable in this case is the turbulent dissipation, ε. It is the variable that determines the scale of the turbulence, whereas the first variable, k, determines the energy in the turbulence.

Equation for turbulent kinetic energy (k) and the dissipation (ε) are shown in Eqs. (3) and (4) respectively.

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right]+2\mu_t E_{ij}E_{ij}-\rho\varepsilon \tag{3}$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\epsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}E_{ij}-C_{2\epsilon}\rho\frac{\varepsilon^2}{k} \quad (4)$$

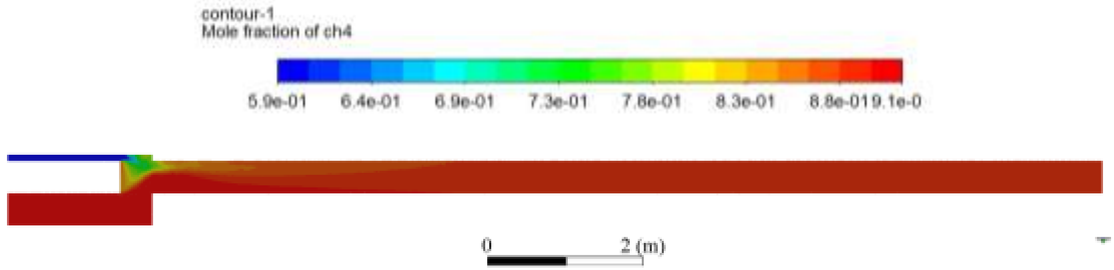
The convection, diffusion, and reaction sources conservation equations for many component species will be solved by using species transport (without reaction). Multicomponent transport inevitably introduces several important physical effects into the system, such as temperature gradients, enthalpy transmission, and diffusion.

3. Results

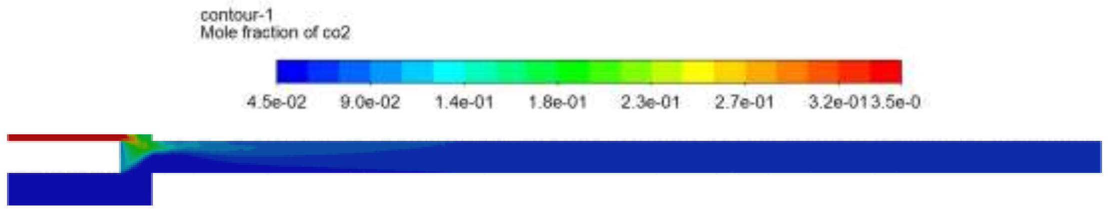
3.1 Effect of Feed Composition on the Component Profile

Mole fraction of CH_4, H_2S and CO_2 from the simulation of case 1 are shown in Figure 2(a) - (c). It can be seen that the gas is slightly unevenly mixed after going through half length of the pipe from the header.

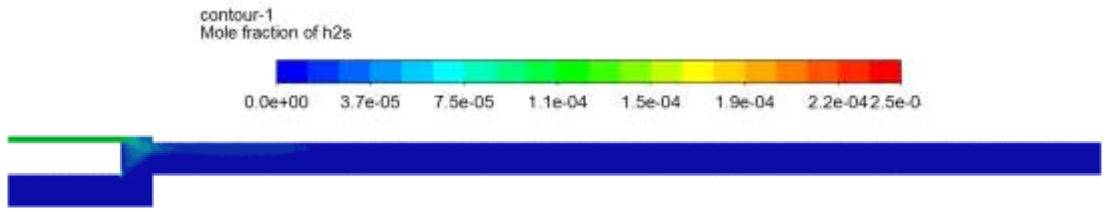
From Figure 2 it can be seen that at the mixing point from Gas A and B there are a turbulence between gasses in the header. Higher flowrate at gas B compared to gas A cause that the turbulence dominated at the top of the pipe and it tries to reach the fully developed profile along the outlet gas pipe. Gas CH_4 and CO_2 need longer pipe to reach its steady state conditions compared to H_2S gas. It is due to the high amount of its gases, mole fraction of H_2S is quite small which is almost 0.1% [3].



(a)



(b)



(c)

Fig. 2. Mole fraction of (a) CH_4 (b) CO_2 and (c) H_2S profile along the pipe from case 1 simulation

Figure 3(a) - (c) shows the mole fraction profile along the pipe for case 2. From the figure it can be seen that gas concentrations are spread around the 1st meter from the header. At the rest of the pipe, it shows the uniform mole gas fraction along the pipe.

Similar profile also presented in Figure 3 where there is a slight distinguish color map at the several lengths after the header. High turbulence at that point caused non uniformity index for all of the gasses and caused the gasses requires more length to achieve its steady condition. Based on the calculation result, the pipe length needed to achieve its uniformity index for all of the components in case 2 is shorter than length needed for the case 1. Its due to the low ratio of gas A and B which is only 1:7 while for case 2, the ratio of gas A and B is 1:8. Higher flowrate of the stream will need longer length of pipe to reach the fully developed flow regime [21].

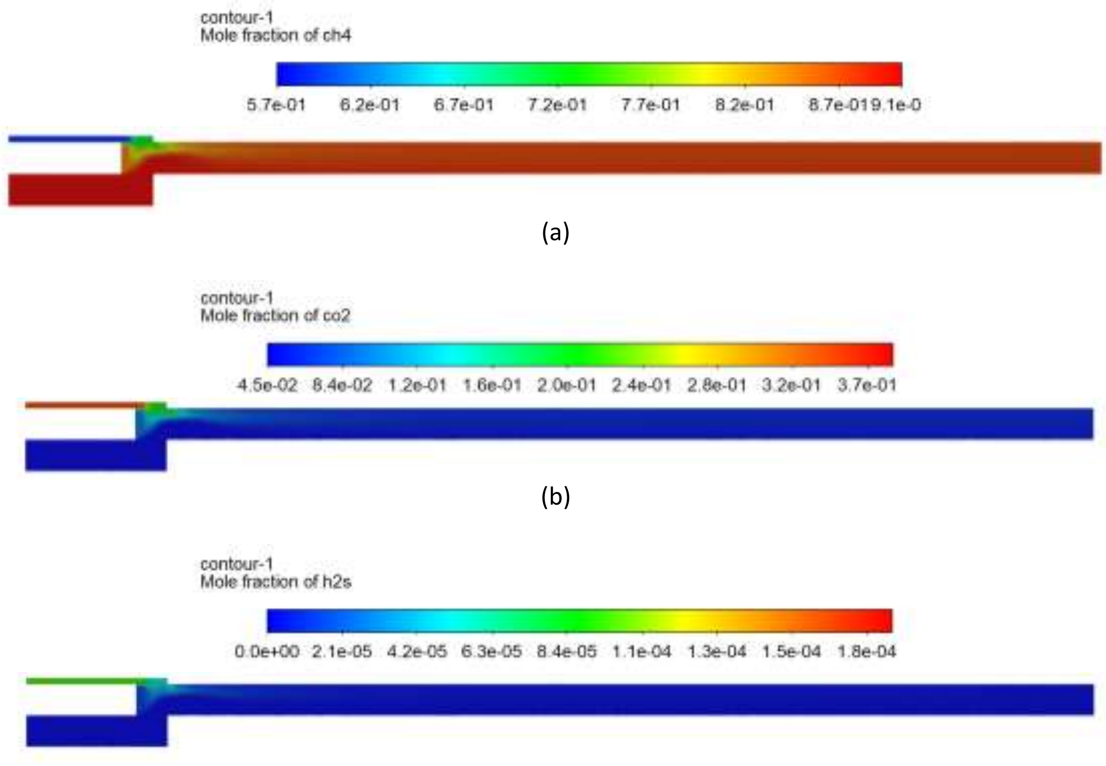
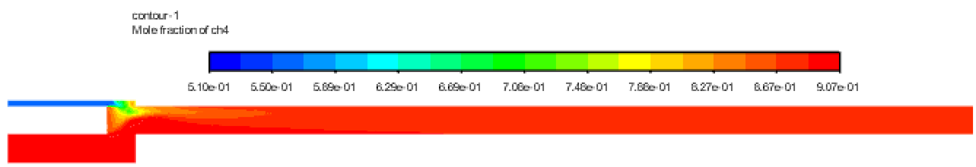
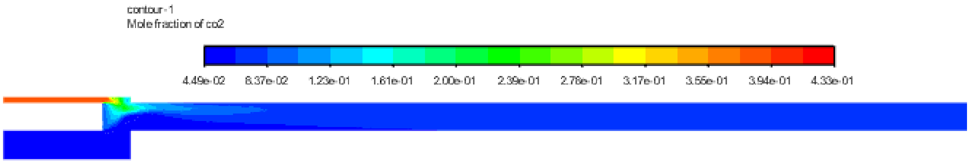


Fig. 3. Mole fraction of (a) CH_4 (b) CO_2 and (c) H_2S profile along the pipe from case 2 simulation

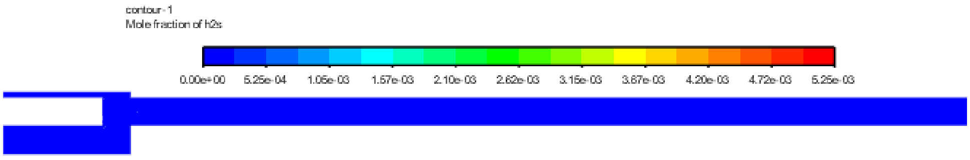
From Figure 4(a) - (c), CH_4 and CO_2 gases concentrations are spread around the 7th meter of the pipe. At the rest of the pipe, it shows the uniform mole gas fraction along the pipe. Pipe length in case 3 needed for the gases to be perfectly blended is the longest compare to all cases. Its due to the high amount of gas B which is around 170,000 kg/hr. it can be observed that the gases tend to concentrate on the upper part of the pipe. In this case, gravity acts against the inertia that tends to concentrate gas on the lower pressure side and create gas pockets. The relation between inertia forces and gravity has an important role in flow distribution and the gas concentration[22].



(a)



(b)



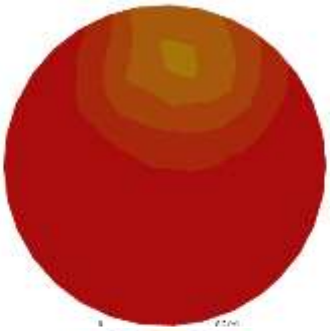
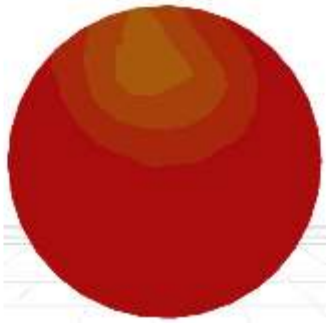
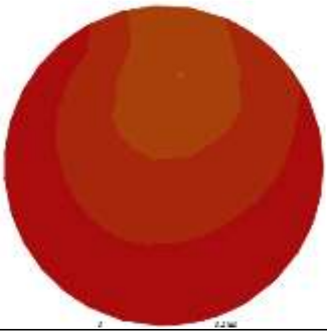
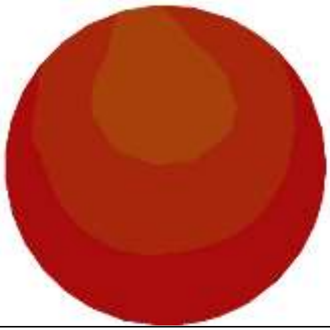
(c)

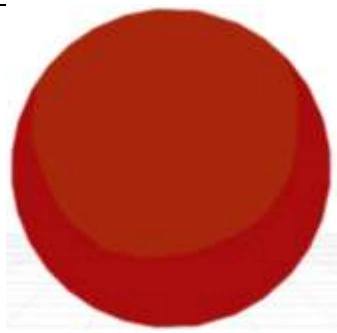
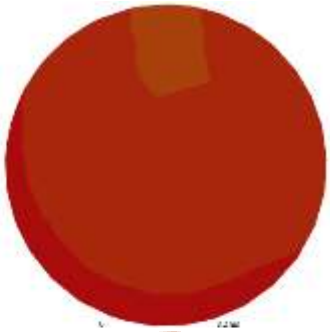
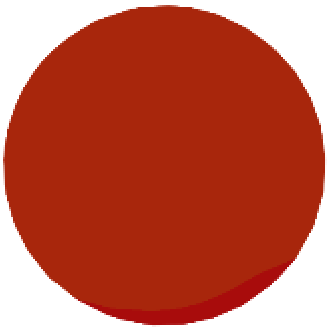
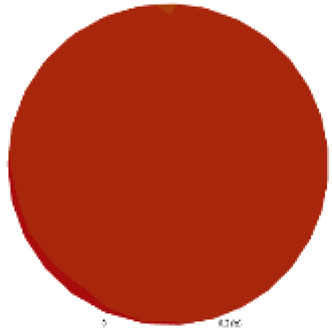
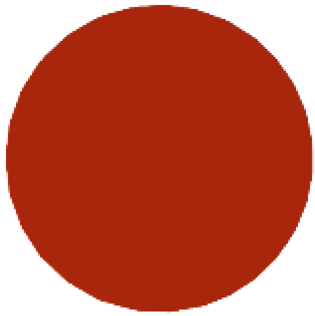
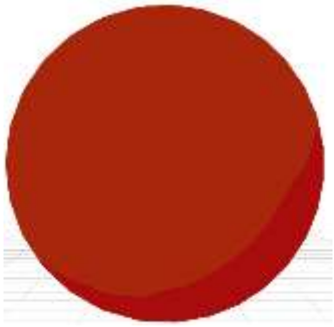
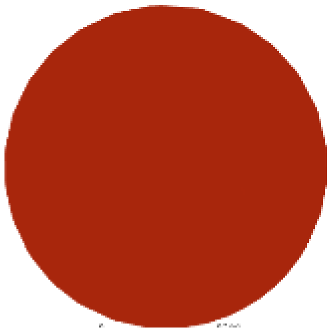
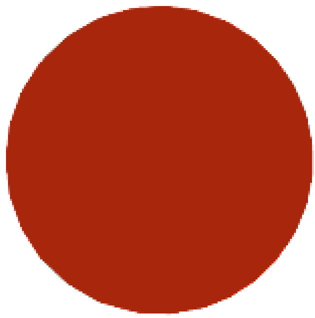
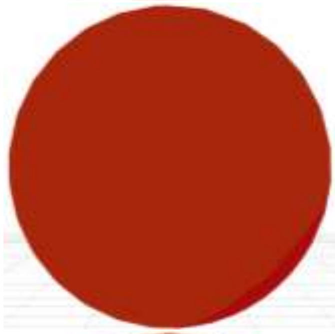
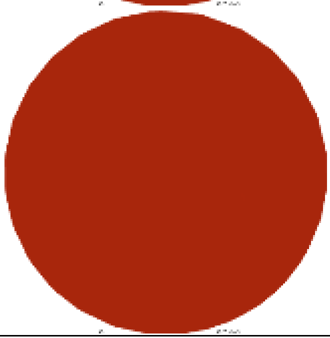
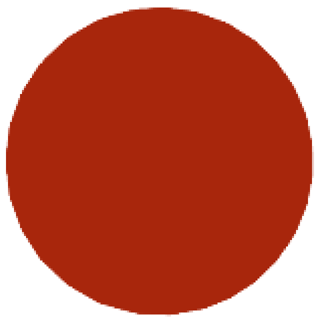
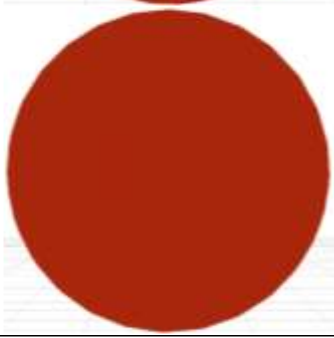
Fig. 4. Mole fraction of (a) CH_4 (b) CO_2 and (c) H_2S profile along the pipe from case 3 simulation

3.1.1 Component profile of CH_4

The profile of gas CH_4 from the gas header to the outlet pipe are shown in Table 4. This profile was obtained by creating a circular plane on the outlet pipe with an increment of 1 meter. Mole fraction of CH_4 was then presented on that circular plane.

Table 4
Component Profile of CH_4 on the surface area of outlet pipe

Length (m)	Case 1	Case 2	Case 3
1			
2			

Length (m)	Case 1	Case 2	Case 3
3			
4			
5			
6			
7			

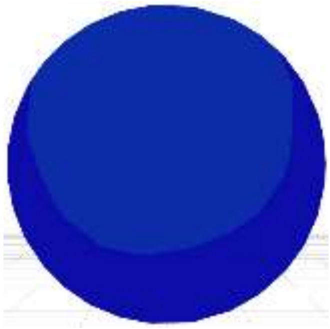
Case 2 shows that the CH_4 gas profile already reach the uniformity index at the 5th meter from the header, while the uniformity of case 2 reached at the 6th meter and case 3 requires the longest pipe length to get the CH_4 fully mixed in the outlet pipe. The degree of mixing could be demonstrated by the histogram of gas volume fraction at outlet, however it is not easy to distinguish among different cases in the condition of changing the gas operating condition and its parameter. In the binary liquid systems, usually the gravitation to viscous force ratio governs the mixing behavior and flow pattern [23].

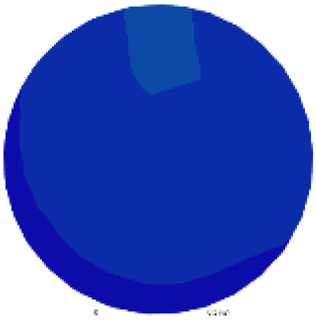
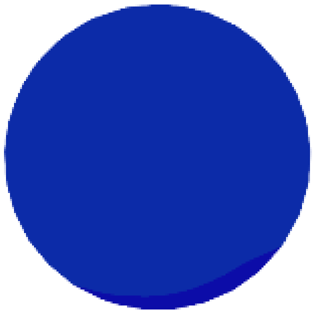
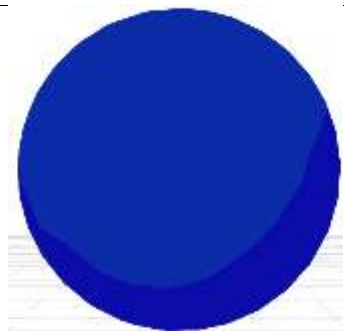
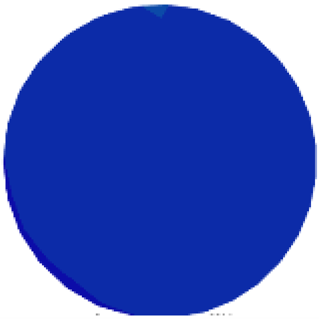
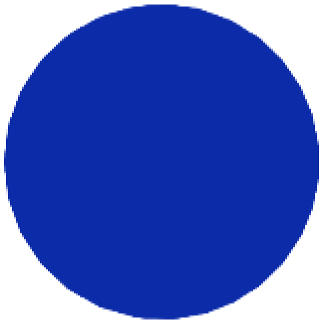
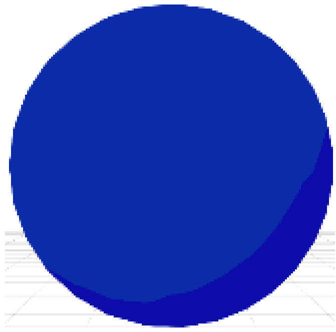
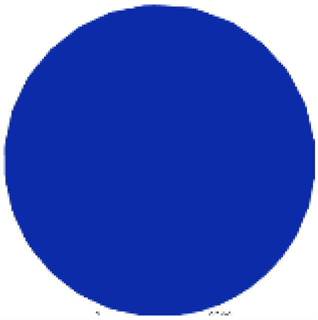
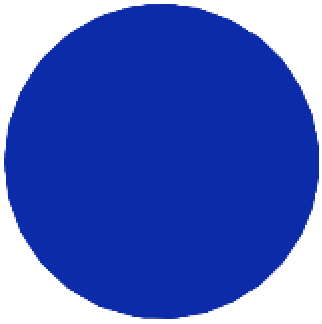
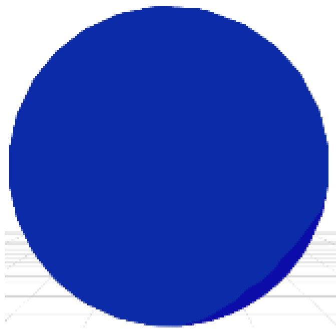
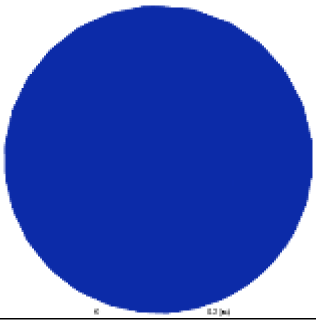
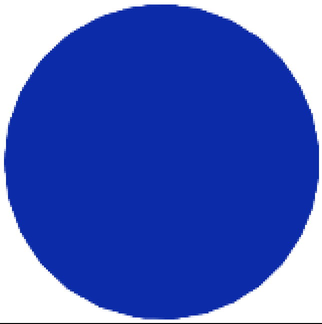
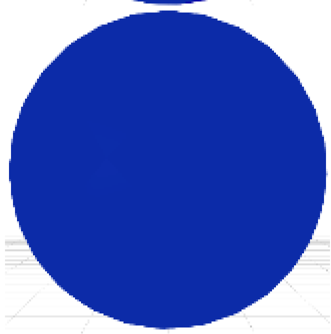
CH_4 composition for case 3 at the 6th meter from the header shows only slight distinguish color. It can be seen at the right bottom of the pipe. It can be caused by the turbulence of the other gasses which create a momentum in the movement of CH_4 gas. However, in the designing of pipeline network this length is not recommended since it will be dangerous when the gasses enter the upcoming equipment such as flash separating column. The non-uniformity of the gasses can disturb the separation process due to its turbulence which is still occurred at this point [24].

3.1.2 Component profile of CO_2

The profile of gas CO_2 from the gas header to the outlet pipe are shown in Table 5. This profile was obtained by creating a circular plane on the outlet pipe with an increment of 1 meter. Mole fraction of CO_2 was then presented on the circular plane.

Table 5
Component Profile of CO_2 on the surface area of outlet pipe

Length (m)	Case 1	Case 2	Case 3
1			
2			
3			

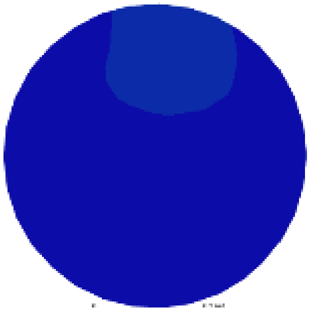
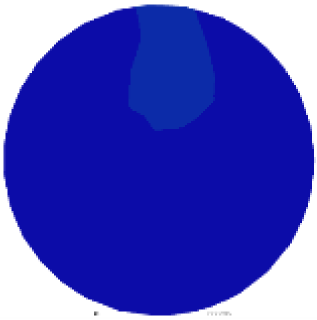
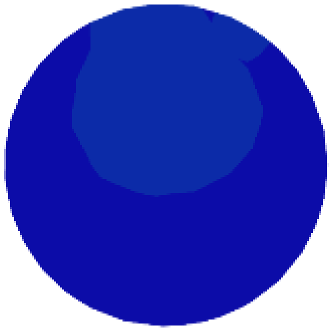
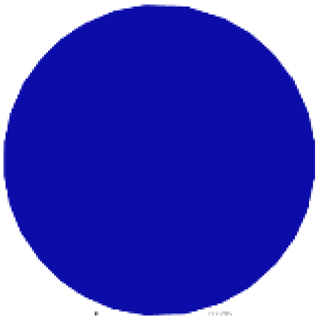
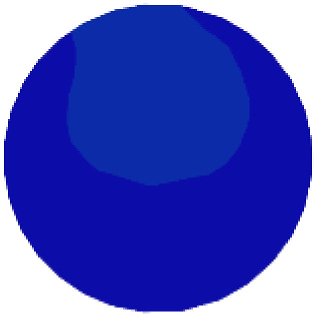
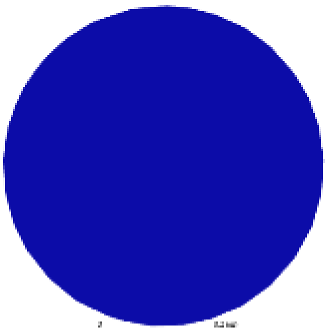
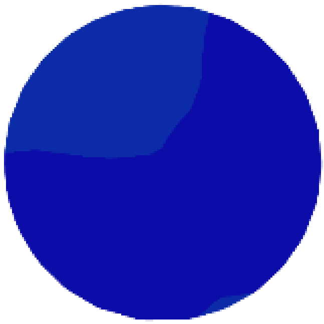
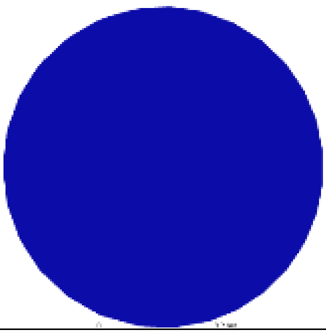
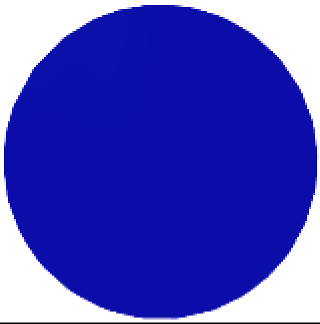
Length (m)	Case 1	Case 2	Case 3
4			
5			
6			
7			

The CO_2 gas profile are quite for case 1 – 3 are quite similar to the profile of CH_4 gas. The non-uniformity component profile is mostly influenced by the flowrate of the gasses and also the connection between gravity and the viscosity if the gasses. Case 3 shows the longest pipe needed to reach its uniformity index.

3.1.3 Component profile of H_2S

Table 6 shows the profile of H_2S mole fraction along the outlet pipe. The data was obtained by extracting the simulation and presented by using a circular plane at the outlet pipe started from the pipe header.

Table 6
Component Profile of H_2S on the surface area of outlet pipe

Length (m)	Case 1	Case 2	Case 3
1			
2			
3			
4			
5			

Mole fraction profile of H_2S in Table 6 shows that the uniformity index was obtained at the 3rd, 5th and 1st meter from the header for case 1 – 3 consecutively. This condition was caused by the small amount of H2S in the gas. However, the small amount of H_2S still need an attention to be simulated since it is extremely poisonous to humans, corrosive, and very flammable[25].

3.1 Effect of Feed Composition on the Pressure Profile

Figure 5 shows the pressure profile of the mixture fluid along the pipe with the distance from its header for case 1 - 3.

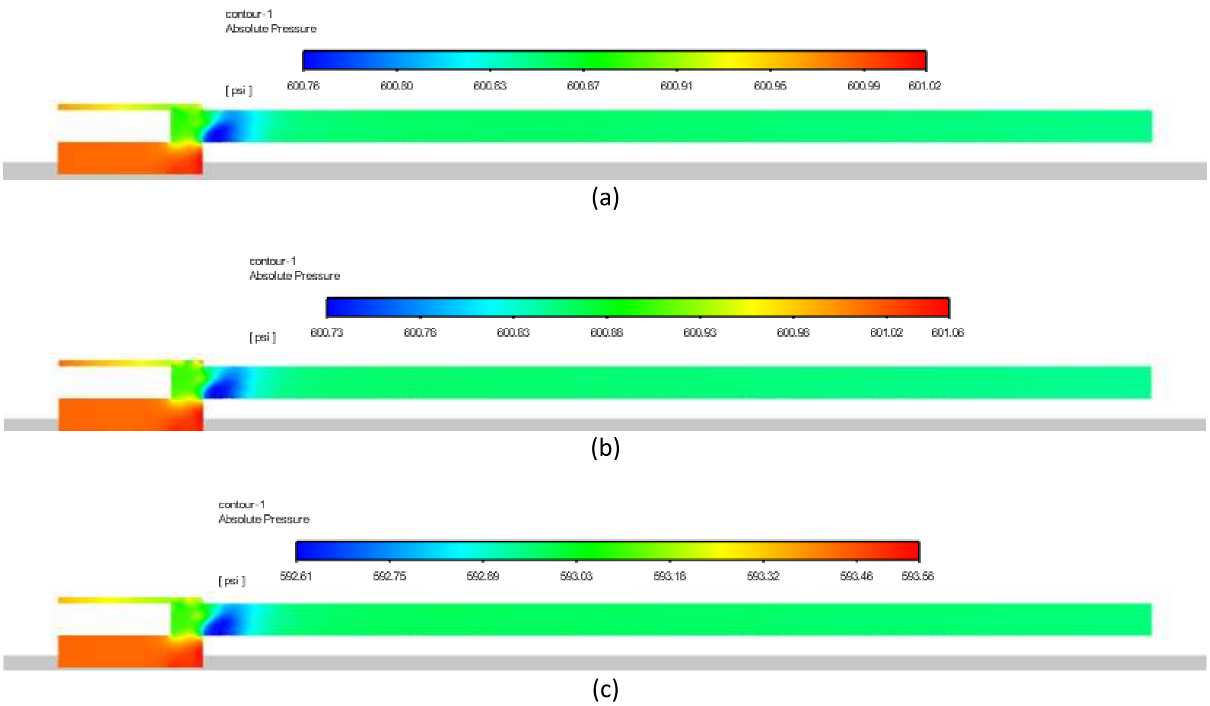


Fig. 5. Pressure profile of gas mixture along the pipe for (a) case 1 (b) case 2 and (c) case 3

Table 7 shows the pressure profile of the mixture fluid along the pipe with the distance from its header.

Table 7
Pressure profile along the outlet pipe

Length from the header (m)	Case 1	Case 2	Case 3
1	559.37793	559.47724	592.87705
2	559.41181	559.51513	593.00015
3	559.41483	559.51828	593.01256
4	559.41562	559.5186	593.01608
5	559.41542	559.51781	593.01296
6	559.41557	559.5169	593.01141
7	559.41467	559.51592	593.00929
8	559.41384	559.51519	593.00493
9	559.41345	559.51411	593.00494
10	559.41231	559.51345	593.0014
11	559.41191	559.51236	592.99961
12	559.41098	559.51148	592.99694
13	559.41022	559.51043	592.99508
14	559.40949	559.50946	592.99288

It can be seen that case 3 has the highest pressure drop, it is due to the high mass flow rate which flows inside the pipe. It is naturally can be found when a higher fluid flows in a pipe will have a higher pressure drop to transport the fluid from the source point to the destination [26].

4. Conclusions

Based on the simulation results, higher volumetric flowrate of gas B will cause the H_2S fully mixed faster. While the CH_4 and CO_2 approximately require 6 meter from header to reach the fully developed flow profile. From the simulation result, it can be concluded the higher flowrate of the gas mixture it will give higher pressure drop along the pipe. Based on the engineering data, it can be guaranteed that 8 - 10 m will be enough for gas A and B to become fully mixed.

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