NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

February 1, 2022

MATERIALS LABORATORY STUDY REPORT Report No. 21-098S

A. ACCIDENT INFORMATION

Place	:	Farmersville, TX
Date	:	June 28, 2021
Vehicle	:	Natural gas pipeline
NTSB No.	:	PLD21FR002
Investigator	:	Sara Lyons

B. ACCIDENT SUMMARY

For a summary of the accident, refer to the *Accident Summary* report within this docket.

C. DETAILS OF THE STUDY

This study examines the steps of the pig loading procedure and the flammability conditions within the launcher during that procedure.[1] The flammability conditions were assessed by modeling the buoyancy driven migration of the natural gas through the launcher body and valves at each step of the pig loading procedure. The modeling was done using a computational fluid dynamics software package developed by the National Institute for Standards and Technology called Fire Dynamics Simulator (FDS). Although no combustion was modeled, the model was used to evaluate the movement of natural gas and air through the launcher barrel, valves, and piping. The modeling was not intended to provide a temporally exact solution to the gas concentration within the components of the pig launcher barrel but instead was used to provide a qualitative understanding of the flow paths and overall conditions within the launcher. Due to the rectilinear grid employed by the FDS solver, the geometry of the launcher assembly was approximated by rectangular sections representing the launcher body, valves, flare system pipes and equalizer pipe. More detail about the model will be given later in the report.

Overview of Pig Launching Procedure

The pig launching procedure[2] reference in this study was taken from Appendix R of the Atmos Energy pipeline integrity management plan dated July 29, 2019, and in effect at the time of the accident. This procedure provided the field crew with safety and

[1] A *launcher* is the portion of the pipeline facility used to insert in-line inspection tools, commonly referred to as pigs, into a pipeline.
[2] See docket item Atmos Pigging Procedures.

procedural instruction for loading and launching a pig as well as receiving a pig. In this report only the safety and loading portion of the instructions was examined up to the point where the accident occurred.

Appendix R begins with a general safety notice with a bulletized list of safety issues for the crew to keep in mind. This list of safety issues is general and allows judgement by the crew by including terms such as “as necessary” to some of the safety suggestions. The safety issues that pertain to flammability hazards of the procedure are the following:

- Other PPE (hard hat, FRC’s, etc.) should be worn at all times
- Flame retardant clothing should be worn as necessary during loading by loading personnel
- Eliminate all sources of ignition (i.e. cell phones) during loading
- Monitoring devices or equipment for oxygen, hydrocarbons, H_2S, and NORM should be used
- Stay clear of gas release (in case of ignition)
- Never stand directly in front of the pig launcher/receiver door
- Class ABC Fire extinguishers for flammable solids (i.e. paper wood plastic), liquids and gasses as well as those involving electrical equipment shall be manned during loading and launching
- Class D fire extinguishers to manage pyrophoric material (reactive metals i.e. iron sulfide) shall be manned during loading and launching. Class D is ineffective for class ABC

In part II of the loading and launching procedure potential hazards are called out where flammability and flying projectiles are mentioned.

The loading procedure (part III on page R-2) begins with a disclaimer that the procedure is meant to be a guide for loading a pig under ideal conditions and configurations. It is stated that “Many pig receivers are configured differently, and valves may be in different locations or not there at all. Be sure you know which valves are similar to the ones in standard drawing PD13200. Operations is responsible for adjusting procedure due to configurations or project conditions to ensure that loading and launching are performed in a safe and controlled manner.”

The loading procedure begins with a section (part A) instructing the crew to inspect the facilities. Part of the facilities inspection includes inspecting the grounding of push/pull rods as well as inspecting lithium battery[3] temperatures and levels prior to loading. No specific guidance is given as to how to accomplish these inspections or any metrics with which to qualify them.

[3] Lithium batteries can be used in transponders.

The loading procedure continues to part B “De-pressurizing launcher”. The procedure here references the valves depicted in the standard drawing PD13200 (Figure 1). This de-pressurization procedure had 3 steps:

1. Verify valve #1 (Main Line Valve) is open and valves #2 (Launcher Main Line Valve) and Valve #3 (Kicker Line Valve) are closed.

2. Slowly open Valve #4 (Equalizer Valve) then valves #5 (Blow Down Valve) and valve #6 (Vent valve) to vent any pressure from the launcher.

3. Open valves #7 (Vent valve), valve #8 (Vent valve) and valve #9 (Vent valve) to assure all pressure is off the launcher.

The loading procedure then continued to part C “Loading Pig and Pressurizing launcher”. This part of the procedure was completed up to step 5 (mislabeled as step 3 in the Appendix) shortly after which the accident occurred. The steps leading up to step 5 were the following:

1. Verify the barrel is relieved and not pressurized by checking the gauge and purge point installed.

2. Open pressure alert valve on closure door and relieve any pressure build up within the barrel.

3. Stand clear of the launcher door while opening. Note: All valves should still be in the same position as in section B.

4. Load pig (This step was mislabeled as 2)

    i. When using push bar to load pig, connect a grounding cable between the push bar and the launcher.

5. Seat the pig in the launcher reducer. (This step was mislabeled as 3)

This ends the overview of the pig loading procedure as outlined in Appendix R of the Pipeline Integrity Management Plan up to the step that preceded the accident.

Pig Loading Procedure as Performed by the Work Crew.

The procedure followed by the work crew on the day of the accident was not exactly as outlined in the previous section. For environmental reasons Atmos Energy had begun employing a flaring system to burn off the natural gas being released during the de-pressurization of the launcher barrel. This consisted of piping attached to the vent valve (#9 in the PD13200 drawing) leading to a flare stack where combustion of the escaping natural gas was performed (figure 2). In addition, no other valves on the launcher barrel were employed during the de-pressurization process. The work crew used the time of the extinguishment of the flare as the indicator that the pressure inside the launcher barrel had been relieved. The work crew members stated that after the flare had extinguished additional time had been allowed to pass before moving on to opening the launcher door and inserting the pig. The crew members opened the launcher door. Once prepared, the pig was placed within the opening of the launcher with the assistance of lifting straps and an excavator to lift and place the pig at the launcher opening. Once the pig was within the launcher the work crew used a push pole to push the pig forward until it was seated in the reduced section of the launcher barrel. The push pole was a 16-foot-long metal pipe used to push the pig far enough into the launcher barrel to reach the reduced section.[4] Once the pig had reached the reduced section of the barrel and could not be pushed in further manually, the excavator was brought up to the end of the push pole to push and further seat the pig into the reduced section of the barrel. The push pole had a cylindrical cup welded onto the end that was in contact with the rear of the pig. The work crew used a cable with magnetic contacts on both ends to ground the push pole. One contact was affixed to the push pole and subsequently moved along the push pole as it was being inserted into the launcher barrel while the other magnetic contact on the other end of the cable remained stationary and affixed on the exterior of the launcher barrel. After the excavator had finished seating the pig in the reduced section of the barrel, the excavator backed up so the crew could extract the push pole from the launcher. While the crew was extracting the push pole, workers observed that it was being dragged along the bottom of the launcher barrel. At this point a crew member standing near the opening of the launcher stated that he thought he saw a flash followed by a booming sound. The push pole and pig were ejected from the launcher, striking some of the work crew members that were at the open end of the launcher.

CFD Modeling of the Natural Gas in the Launcher Barrel During Venting

The natural gas concentrations in the launcher barrel resulting from the various steps of the de-pressurization and pig loading procedure were examined. The density of natural gas was approximated by the specification of methane (ρ=16.04g/mol) as the flammable gas in the model. Rectangular representations of the launcher barrel, flare piping and equalizer piping were constructed as shown in figure 3. An attempt was made to size the rectangular cross sections of the launcher barrel and piping as close as possible to the actual equipment on-scene[5]. The rectilinear grid pattern and requirement of grid cell alignment of the modeling software's solver required some deviation from the actual physical dimensions. Additionally, a change to the gravity vector in the model was employed to give the launcher barrel a 5-degree upward slope towards the launcher door. As previously stated, the purpose of this modeling was not to establish an exact temporal representation of the gas concentrations and resulting time of flammable conditions but to explore the flow direction of the natural gas after de-pressurization and to qualitatively assess the flammability of the launcher barrel to determine how a flammable mixture could accumulate and ignite, ejecting the pig from the launcher. Various scenarios of natural gas venting post de-pressurization were examined. These scenarios varied by the number of open vent valves available to vent the launcher body and by the use or not of the flare system. The initial condition of the models assumes that the launcher body and flare piping (when employed) are full of natural gas at

[4] The push pole was found deformed and rusted after the accident.
[5] See docket item Atmos Drawing of Launcher.

atmospheric pressure post de-pressurization. The scenarios examined are shown in Table 1.

Table 1: Venting scenarios post de-pressurization.

	Venting pathways	Result summary
Scenario 1	Venting from flare pipe only (launcher door is closed)	Methane gas from vertical section of flare stack is expelled into the atmosphere and replaced by air. Venting ceases thereafter.
Scenario 2	Venting from flare and one vent valve (launcher door is closed)	Methane gas slowly vents from flare stack while air enters launcher barrel from the open vent valve
Scenario 3	Venting from one valve only (launcher door is closed)	Methane gas and air alternately exit and enter the launcher barrel in an oscillating fashion through the one open valve.
Scenario 4	Venting from two valves (launcher door is closed)	Methane gas slowly exits one valve while air enters through the other valve

Scenario 1 was representative of the actual venting configuration on the day of the accident. The work crew were using the flaring system to de-pressurize and burn off the escaping natural gas while all other valves were closed. The model showed that regardless of the time allowed, the concentration of natural gas within the launcher barrel would have remained at or near 100% natural gas. At 10 minutes into the simulation, the concentration of natural gas in the flare piping and launcher barrel are as shown in figure 4.

Scenario 2 was representative of the venting had an additional venting valve been opened on the launcher barrel. In this situation, air would have entered through the open venting valve and allowed natural gas to rise and flow through the flare piping and vent to the atmosphere. This is a relatively slow process but given enough time, eventually the launcher barrel would have been clear of natural gas. Figure 5 shows the gas concentration within the launcher barrel after 3 minutes. At 14.5 minutes the average natural gas concentration withing the launcher barrel was still above 60% natural gas.

Scenario 3 was representative of the venting configuration if the flaring system was not used, and a single valve had been simply opened to the atmosphere. With no additional venting valves opened, this configuration caused a back-and-forth oscillating flow of natural gas escaping the launcher barrel followed by periods of air entering the launcher barrel through the single valve. This would be a very time-consuming venting method which would eventually allow all the natural gas to exit the launcher barrel. The simulation found that at 20 minutes into the simulation, the average concentration of natural gas within the launcher barrel was still above 90% (Figure 6).

Scenario 4 was representative the situation where two venting valves were opened allowing the natural gas to vent from one valve while air was entering the launcher barrel from the other. This scenario was similar in venting rate as scenario 2 and while it eventually would allow all the natural gas to vent from the launcher barrel it would be a slow process.

CFD Modeling of Natural Gas Venting through the Launcher Door

Although the model demonstrated that all but scenario 1 would have eventually allowed the natural gas to vent from the launcher barrel, they were shown to be protracted processes for which there was no guidance given in the procedures for how long to allow them to take place. The next model scenario examined the rate of venting when the launcher door is opened prior to inserting the pig. As a worst-case scenario, an initial condition of the launcher barrel and flare piping being full of natural gas is considered. This venting of the launcher barrel through the open launcher door and open valve to the flare piping is considered in scenario 5. During the first few seconds of scenario 5, it is seen how rapidly the air begins to enter the launcher barrel along the bottom of the launcher door's cross section while natural gas escapes along the top of the open door's cross section (Figure 7). It can also be seen that air is flowing down the flare stack piping and into the launcher barrel.

At 60 seconds into the simulation of scenario 5 (Figure 8), the majority of the launcher barrel has a natural gas concentration within the flammable limits of natural gas (15 – 5 %). At 120 seconds into the simulation of scenario 5, the areas of flammable concentrations of natural gas are limited to areas along the top of the launcher barrel (Figure 9). At 180 seconds into the simulation of scenario 5, there are no longer any areas of flammable gas concentration (Figure 10).

CFD Modeling of the Venting Followed by the Insertion of the PIG

During the investigation it was found that a natural gas leak existed within the launcher barrel[6]. That leak was measured on site and found to be approximately 1590 standard cubic feet per day. When the launcher main line valve was tested[7] it was found to be the source of that leak. Now that the venting through the flare piping and the open launcher door has been examined, the next scenario (scenario 6) will go one step further into the pig loading procedure by the addition of the pig being inserted into the launcher barrel. The insertion of the pig is simulated in the model by introducing a blockage[8] between the reduced and enlarged sections of the launcher barrel. This effectively splits the launcher barrel into two sections that only communicate via the equalizer piping. Additionally, the leak that was measured on-site is also included in scenario 6 to evaluate the rate of formation of a flammable atmosphere inside the launcher barrel and to see if it would extend to the section of the launcher barrel with the loading door. Scenario 6 begins with an initial condition matching the conclusion of scenario 1. The launcher door is opened 60 seconds into scenario 6 (Figure 11) and the launcher barrel is allowed to vent to the atmosphere for 300 seconds after which the pig blockage is introduced. Prior to the introduction of the blockage, the

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[6] See *Pipeline Operations Group Chairman's Factual Report* in this docket
[7] See Materials Laboratory Report 21-094 in this docket
[8] In the model the pig is treated as a complete blockage within the launcher barrel preventing gas flow past it. In reality, the pig may allow a limited amount of gas to bypass it.

launcher barrel was not completely free of natural gas (Figure 12). This was due to the leak of natural gas simulated at the launcher's main line valve. The simulation of scenario 6 found that the reduced section of the launcher barrel had a layer of a flammable gas mixture along the top prior to the insertion of the blockage. Once the blockage was introduced the concentration of natural gas began to increase substantially within the reduced section of the launcher barrel and dissipate into the open section of the launcher barrel (Figure 13). At one minute after the insertion of the blockage (Figure 14) a large portion of the reduced section was within the flammable range while the open section of the launcher barrel did not contain flammable regions. At 600 seconds regions along the top of the reduced section and the flare line began to exceed the upper flammable limits (Figure 15). Examination of the direction of flow of gasses through the equalizer piping indicate that air was traveling from the open end of the launcher barrel towards the reduced section of the launcher barrel. Examination of the flow of gas through the flare piping indicated that the gas mixture in the reduced section of the launcher barrel was flowing through the flare piping and out to the atmosphere.

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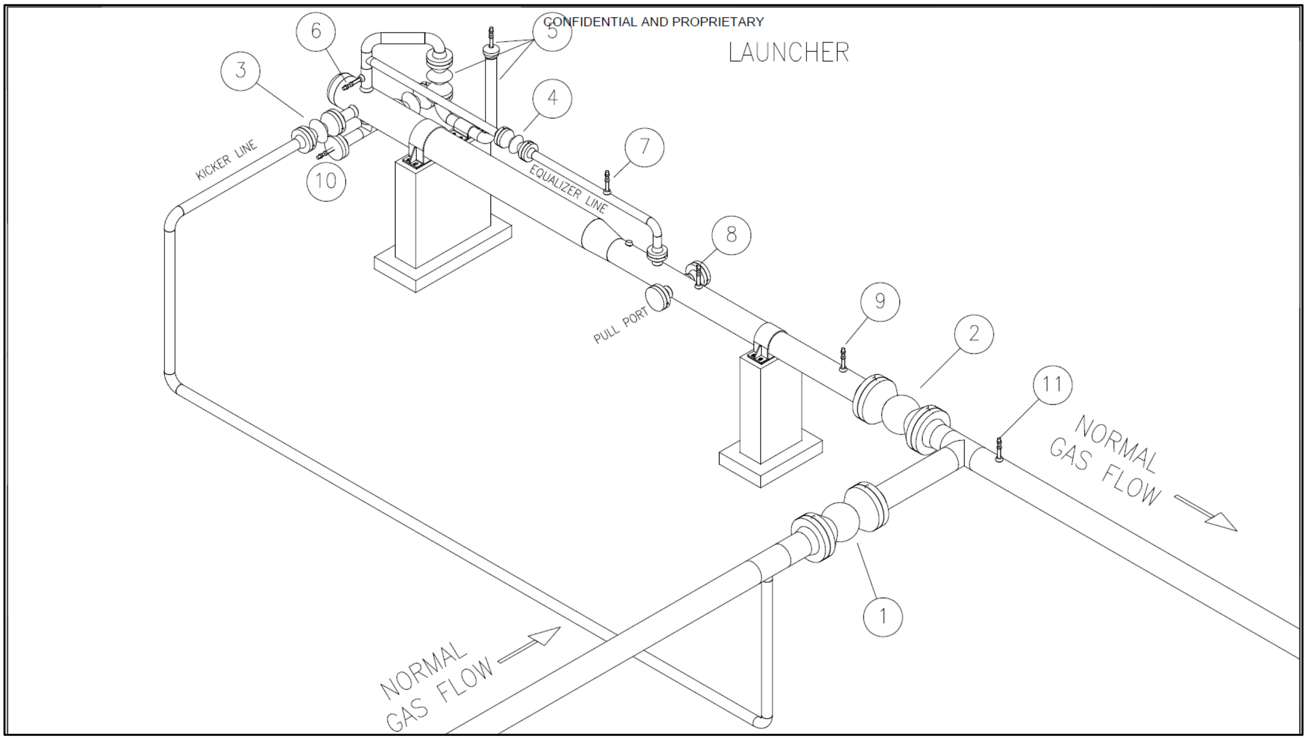

Figure 1: Appendix R PD13200 drawing.

Figure 2: Launcher #2 connected to flare rig.

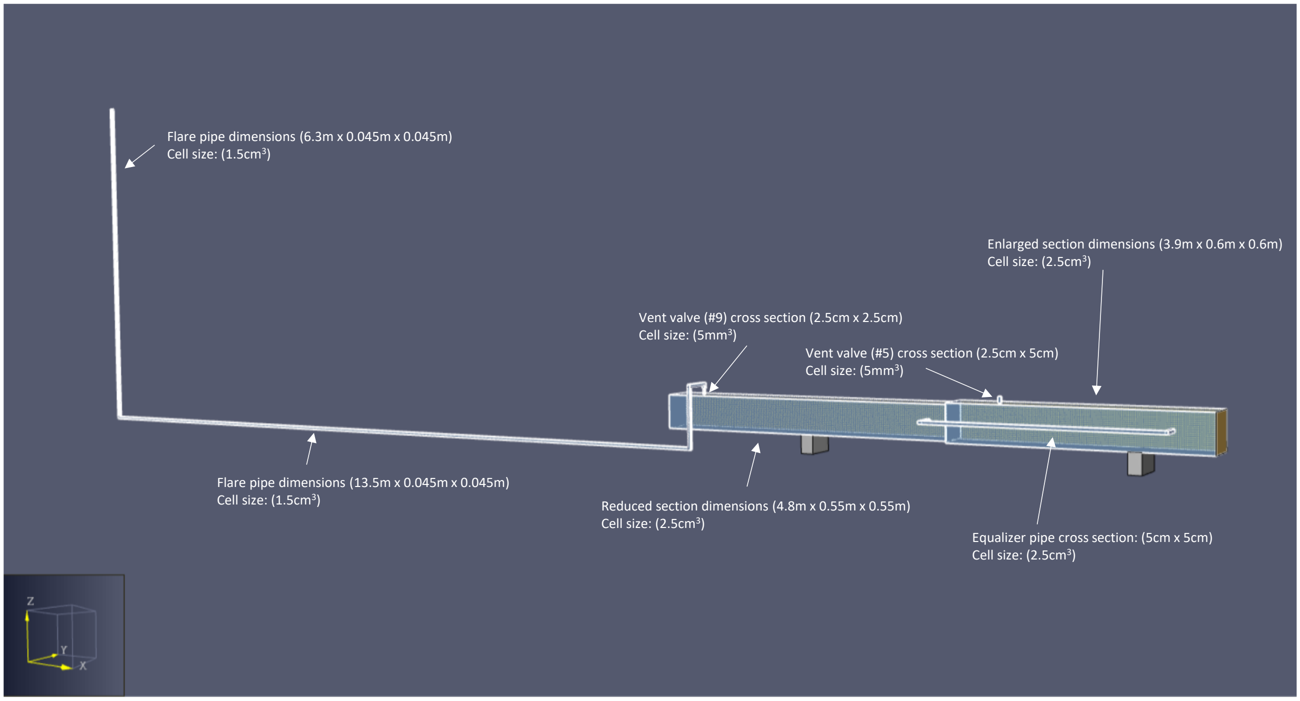

Figure 3: Perspective view of model geometry and dimensions.

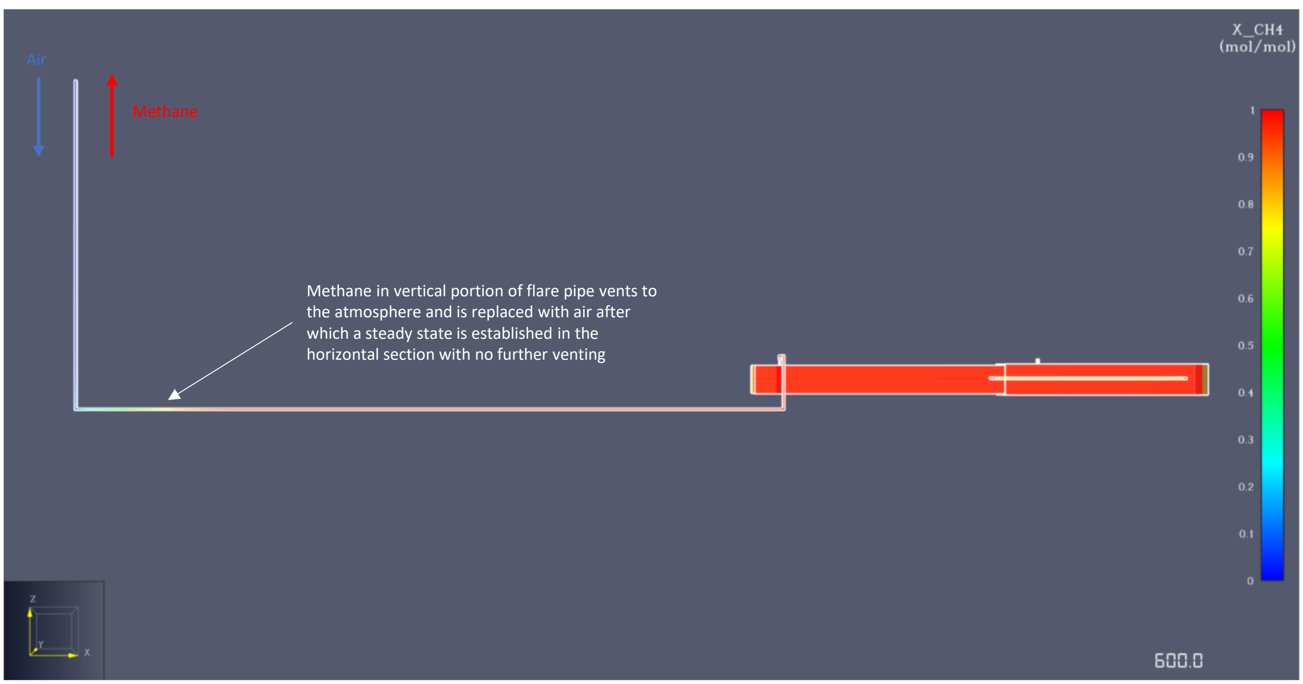

Figure 4: Scenario 1 at 600 seconds. (Side view.)

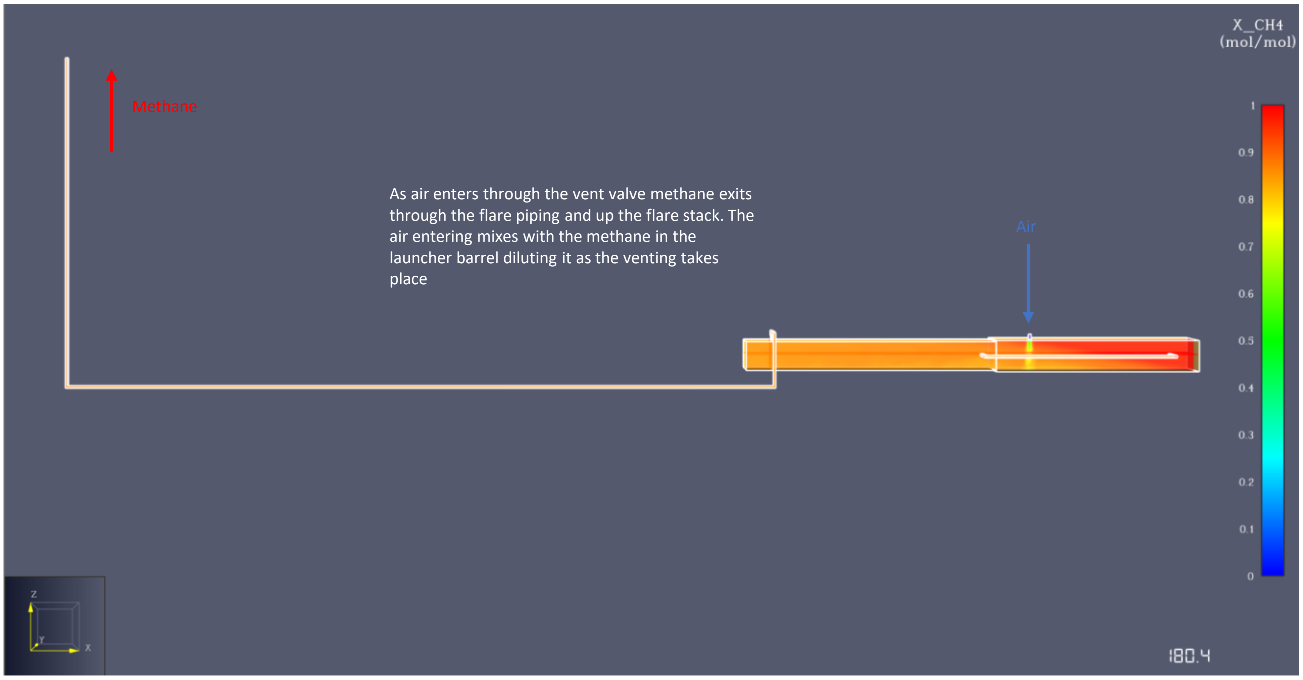

Figure 5: Scenario 2 at 180 seconds. (Side view.)

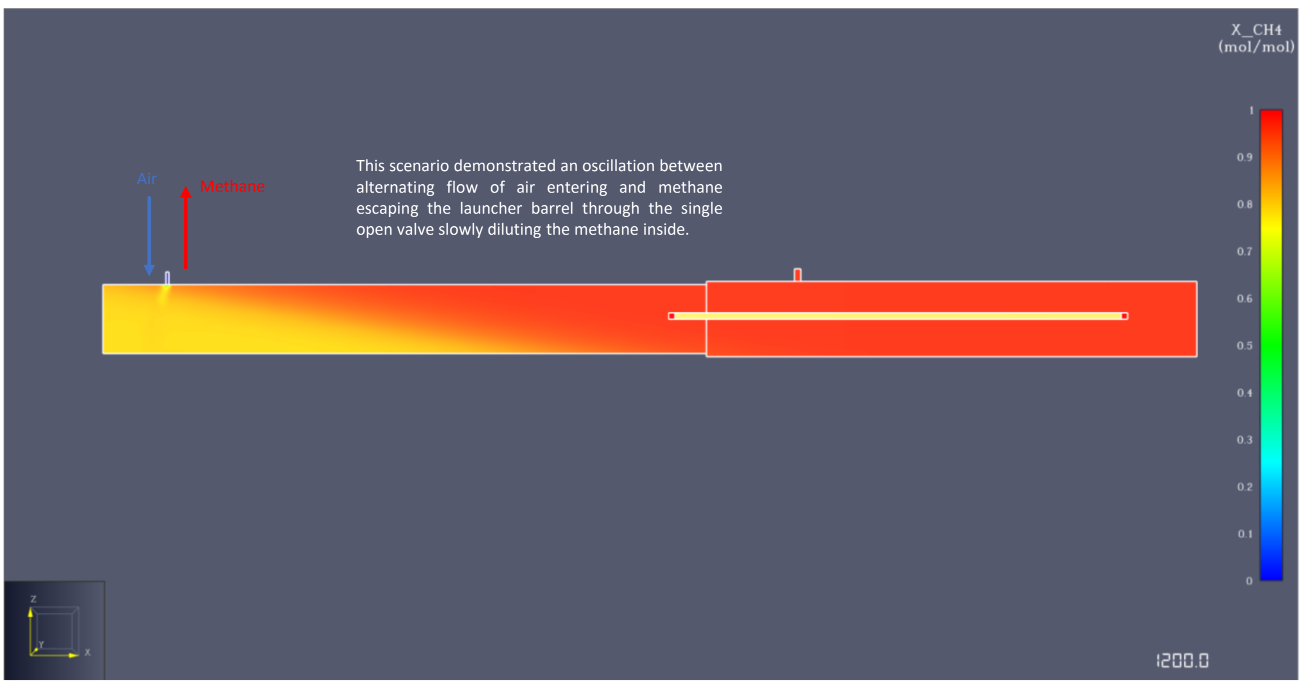

Figure 6: Scenario 3 at 20 minutes. (Side view.)

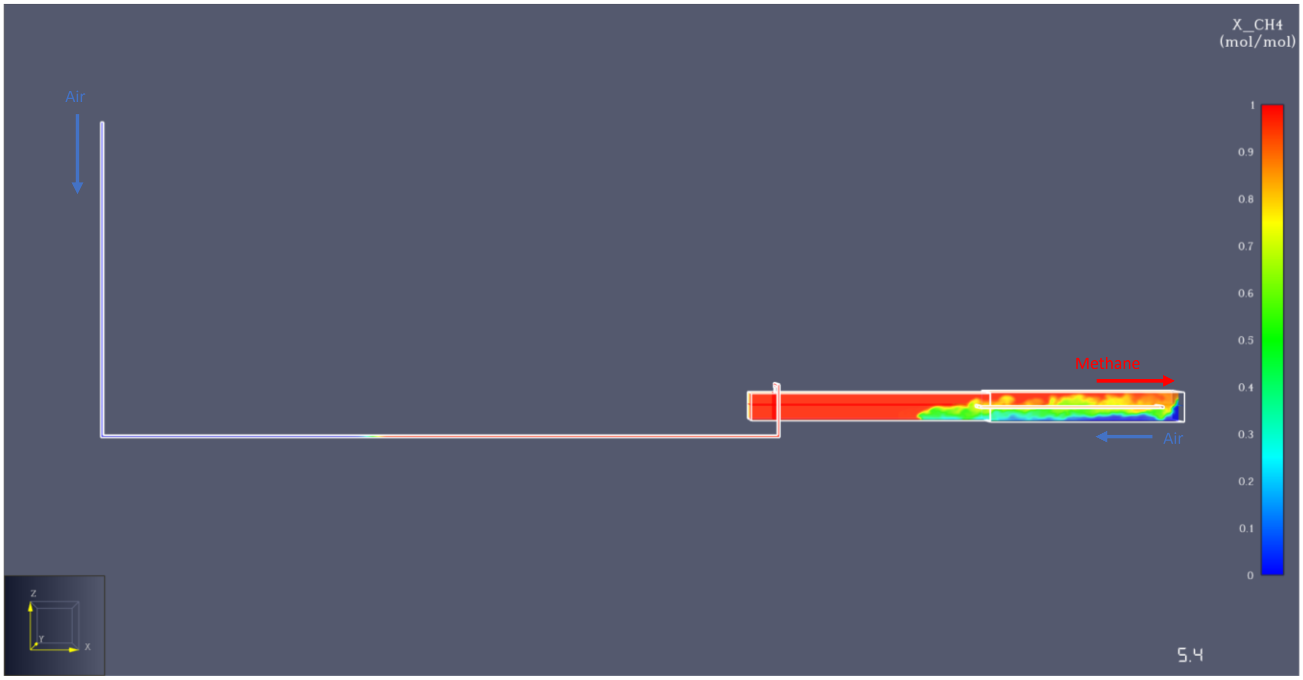

Figure 7: Scenario 5 at 5.4 seconds after the launcher door was opened. (Side view.)

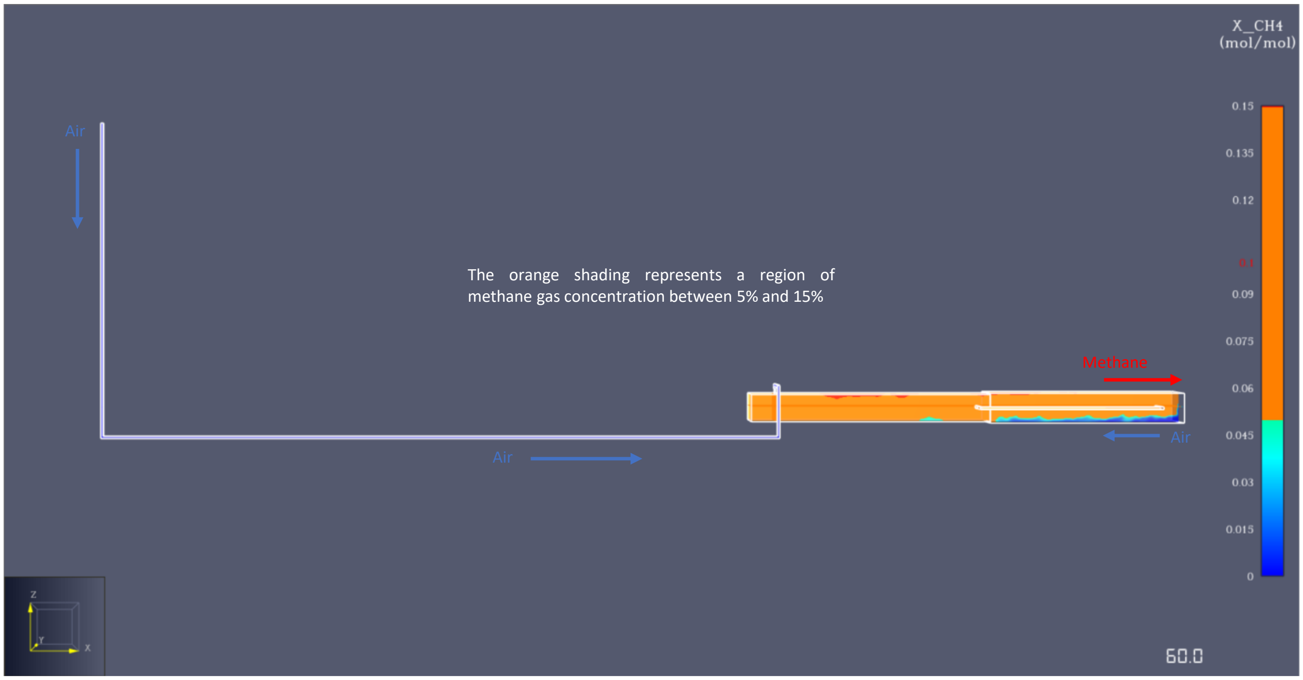

Figure 8: Scenario 5 at 60 seconds. Almost the entirety of the launcher barrel is within the flammable limits. (Side view.)

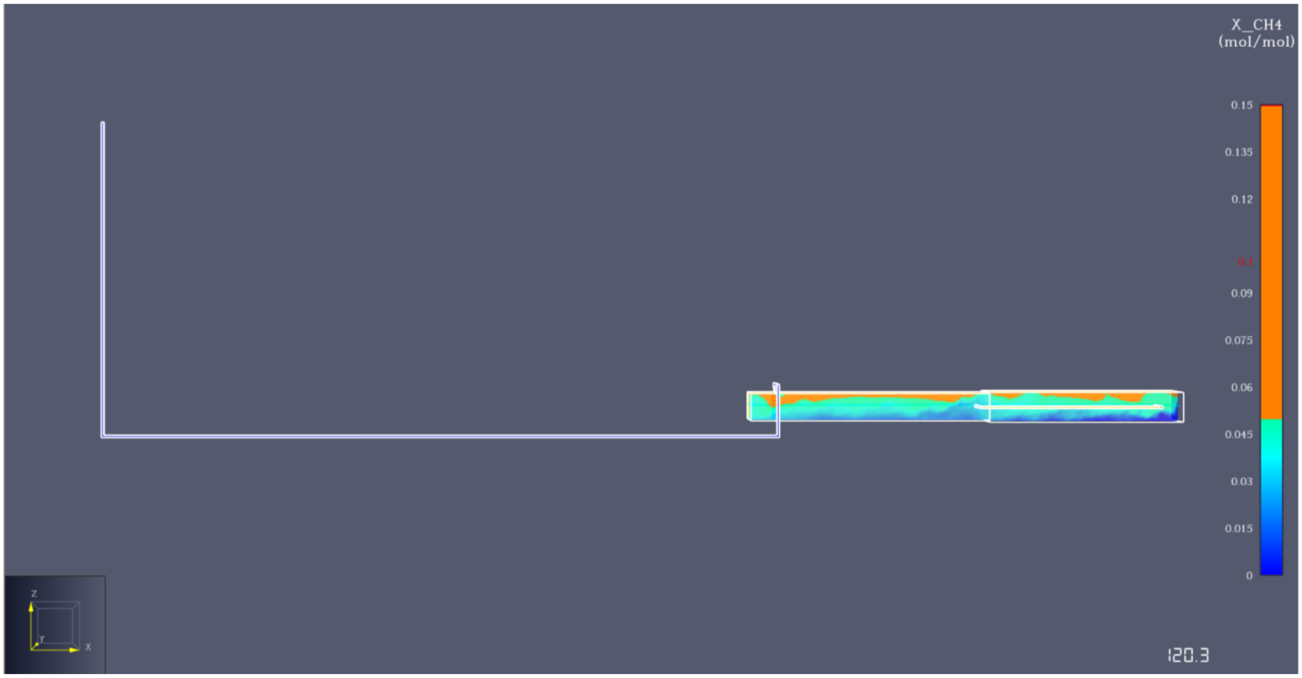

Figure 9: Scenario 5 at 120 seconds. Flammable regions persist along the top of the launcher barrel. (Side view.)

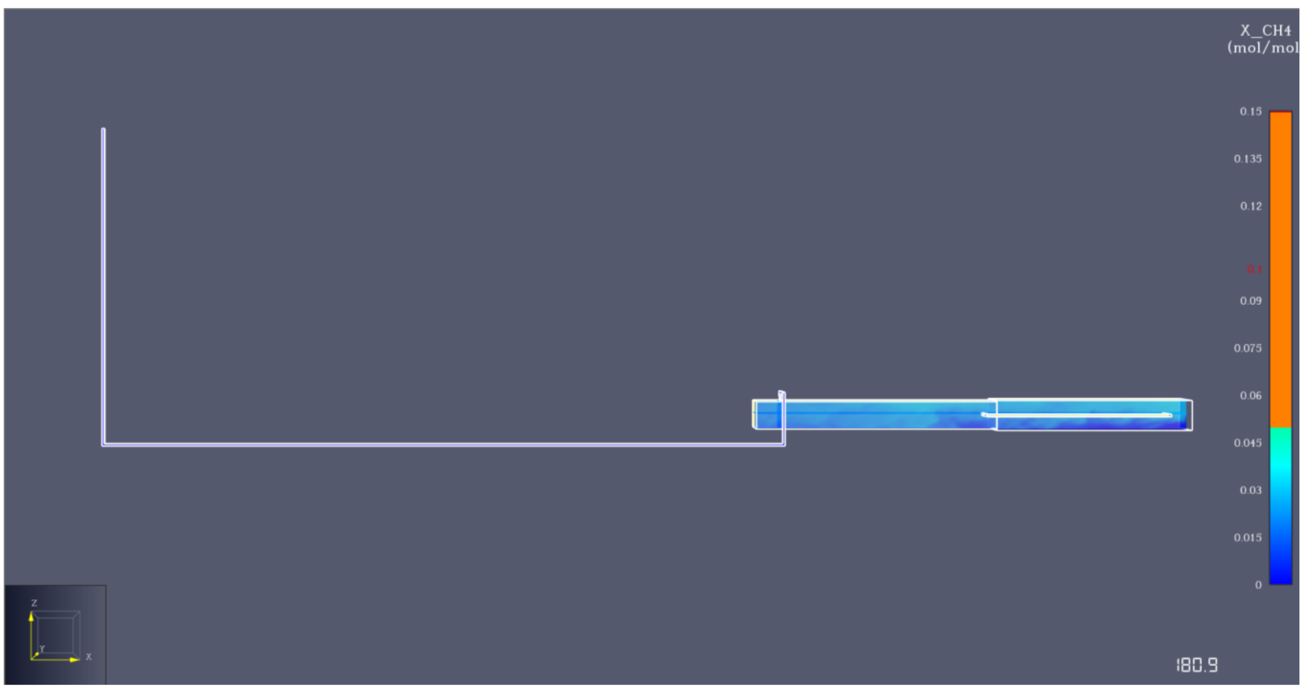

Figure 10: Scenario 5 at 180 seconds. No more flammable regions exist withing the launcher barrel. (Side view.)

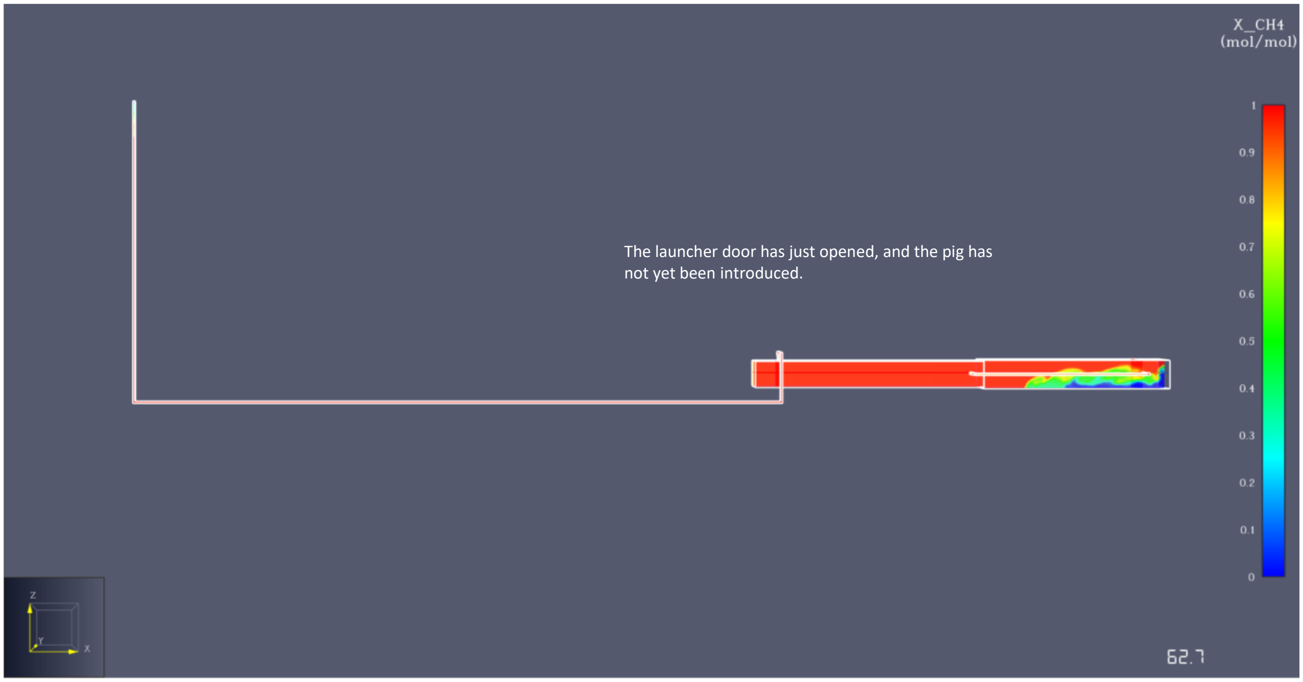

Figure 11: Scenario 6 at approximately 63 seconds. This is approximately 3 seconds after the launcher door is opened. (Side view.)

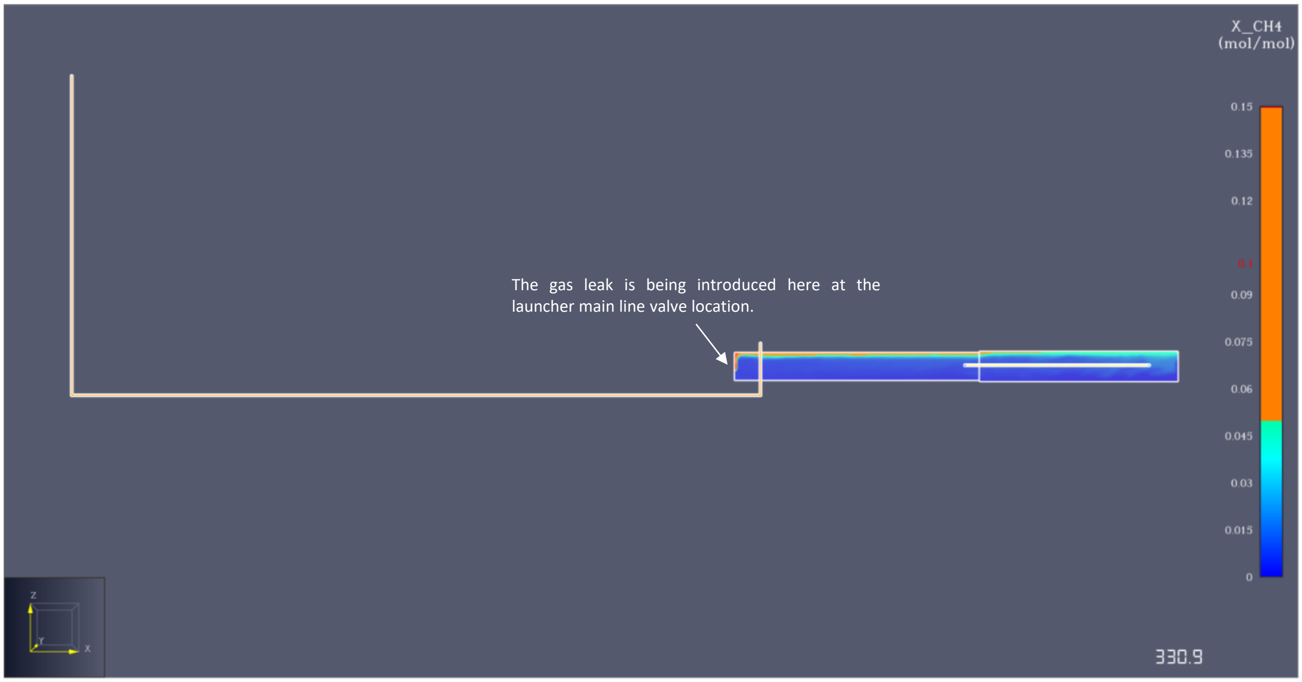

Figure 12: Scenario 6 at 331 seconds. This is 30 seconds prior to the insertion of the pig. a flammable gas concentration can be seen along part of the top of the launcher barrel. (Side view.)

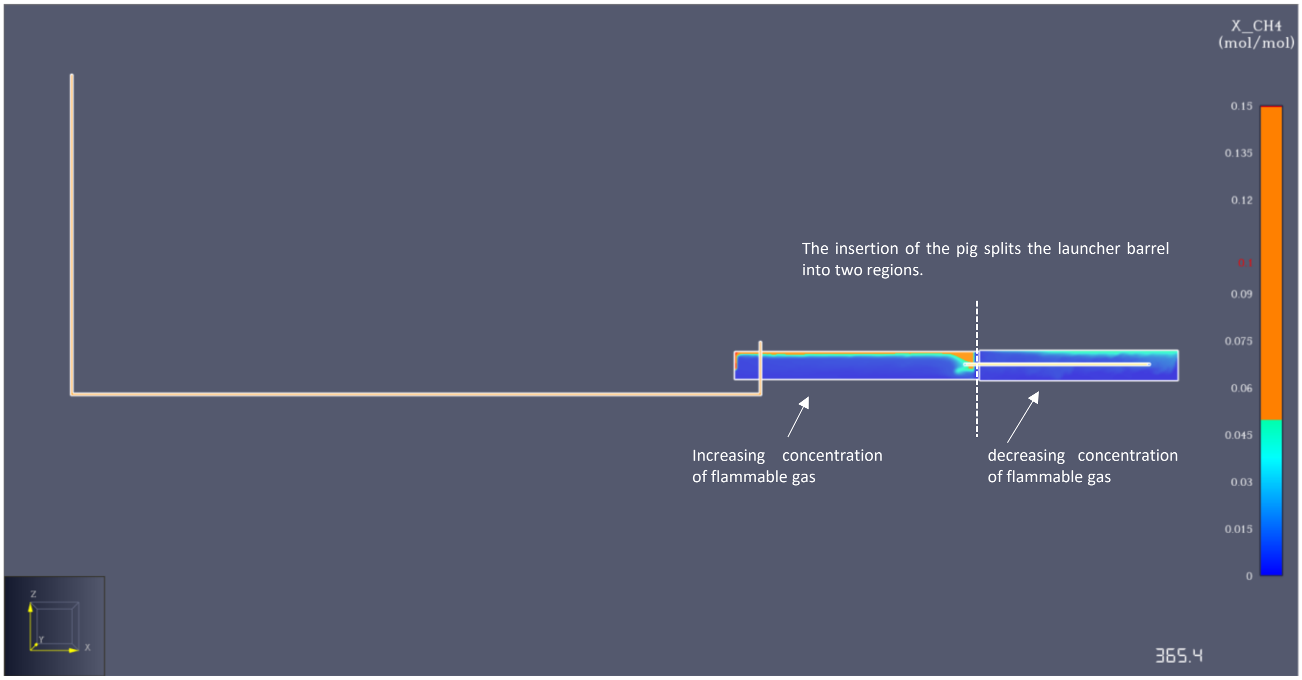

Figure 13: Scenario 6 at 365 seconds. The pig has just been introduced effectively splitting the launcher barrel into two regions joined only by the equalizer piping. (Side view.)

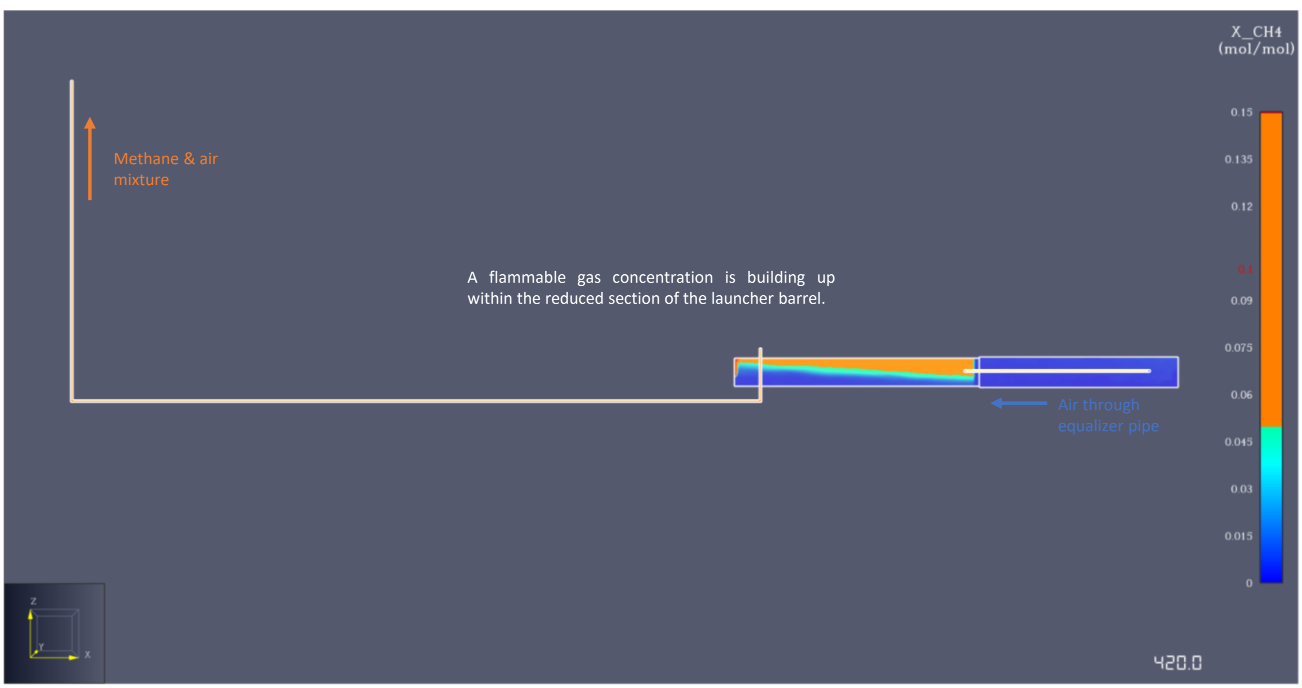

Figure 14: Scenario 6 at 420 seconds. This is 60 seconds after the pig was introduced. (Side view.)

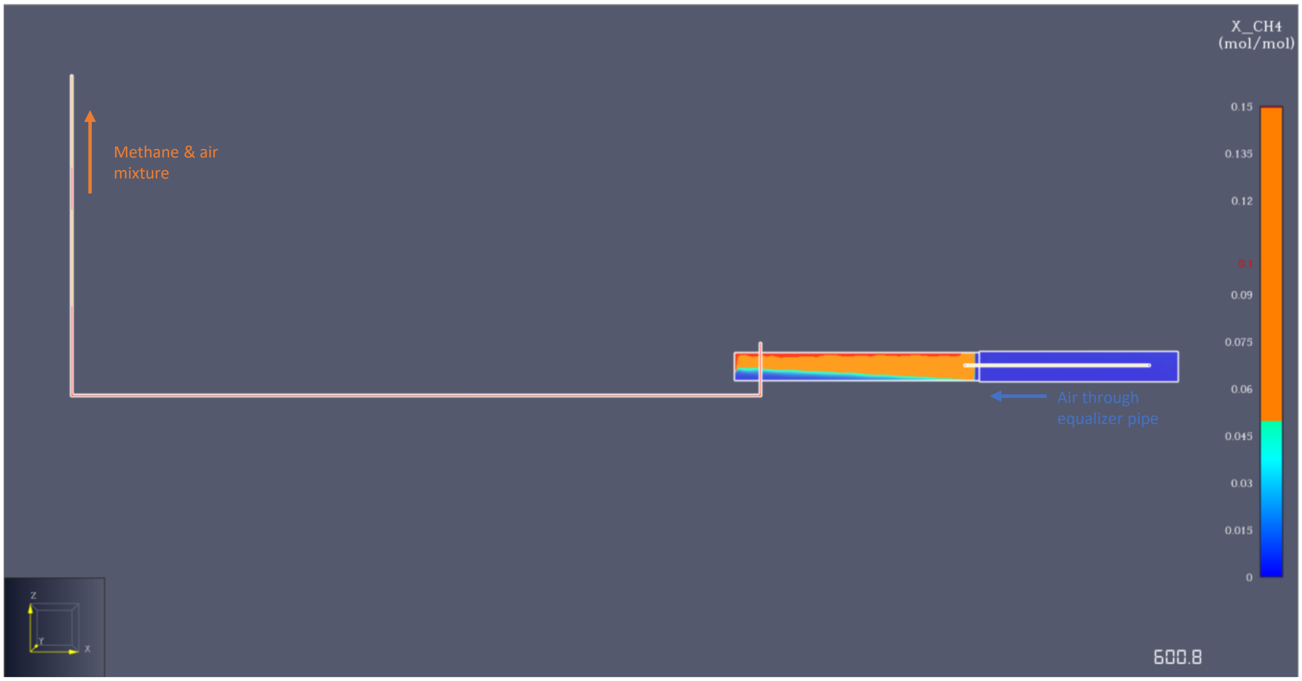

Figure 15: Scenario 6 at 600 seconds. (Side view.)