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Simulation of the Dispersion of Carbon Dioxide During Accidental Releases from Gas Processing Facilities

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ABSTRACT

Carbon capture and storage (CCS) from oil facilities is an important and effective way to reduce the concentration of carbon dioxide in the atmosphere. Consequently, gas-processing facilities will be dealing with a tremendous quantity of CO_2 with high pressure. Therefore, the aim of this study is to simulate the dispersal of CO_2 gas leakage from high-pressure pipelines of the gas-processing facilities. The modeling of CO_2 leakage from pipelines at CCS process has been problematic because of the lack of appropriate source term models that handle the complex behavior of CO_2 correctly during release. In this study, OLGA 7 simulator was utilized for predicting outflow rates and duration of ruptured CO_2 pipelines at different leakage scenarios (leakage sizes). OLGA 7 simulator was selected due to its capabilities in simulating gas pipeline leak scenarios in various designs and operating conditions such as Operation Pressure, Isolation valve spacing (IVS), and Emergency response time (ERT). The results of the OLGA 7 simulator provide appropriate source conditions for the selected dispersion models. Gaussian atmospheric dispersion model was chosen to simulate the CO_2 gas dispersion behavior within the platform; it is very effective and simple. The effect of operating and design parameters (Operation Pressure, Isolation valve spacing (IVS), and Emergency response time (ERT) on the dispersion behaviors of the released gas in different leak scenarios was studied. The results showed that the emergency response time has the greatest effect on the mass of the accumulated leak (kg) and thus on the level of gas concentrations, and this effect is more pronounced for large leakage sizes. Also, the results showed that the emergency response time had no effect on levels of distance gas concentrations, but it had a significant effect on the duration of the leaking.

Keywords:
CCS technology.
OLGA simulator.
Gas Dispersion.

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1 INTRODUCTION

In recent times, great interest has become in studying the risks of environmental pollution of gases because of the growth of human activity, especially in the chemical industries. Therefore, various technologies to reduce the risks of gases applied widely in industries and used as a new energy source. Carbon dioxide gas is one of those gases threatening the environment. it also brings the major concern being one of the major causes of global warming; where the large quantities of CO_2 are already available either from natural processes (natural wells, biological processes, natural gas fields…) or as a by-product of industrial activities mostly related to combustion or chemical reactions are dangerous.

Carbon capture and storage (CCS) is one of a technology that would prevent carbon transported by being captured at emission points at high pressure to injected underground reservoirs, where, CO_2 transportation by high -presser pipelines is the most convenient way of carrying. Thus, it is important to look into for safe process transportation of CO_2 in this developing field of CCS [1-4]

If CCS technology introduces it will be possible to have different accidental leak on pipelines. It might be due to corrosion, fractures, or leaks. Human exposure to elevated levels concentration of CO_2 is hazardous is direct toxicity will cause adverse effects, including death, at concentrations above 30,000 ppm, CO_2 gas can cause asphyxiation as it replaces oxygen in the blood. Other health effects include headache, loss of judgment, dizziness, drowsiness and rapid breathing. Thus, the plume of gaseous CO_2 sublimed from the bank could pose a risk for people and the environment [6]. The main objective of this work is to study the risk assessment for dispersion of the CO_2 gas plumes caused by high-pressure pipeline leaks and identifies the safe areas of concentration limits of inhalation, inside gas-processing facilities.

2 METHODOLOGY

2.1 Accident probability

Accident probability is a complex process and it is an essential for risk management for both an existing and new plants. However, for new chemical plant and during plant and equipment design the probability of failure should always be a nonzero probability, which means guaranteed occurrence. Therefore, if failure occurred under any circumstances, a safe working exposure limits for the worker is guaranteed. In this work, the methodology is based on the assumption that the probability of failure is a nonzero probability.

2.2 Simulation of source terms by OLGA7

The simulated pipeline was constructed with two pressure nodes at the two ends. Two valves isolate these two pressure nodes. The leak node is installed between the two valves. Leakage was considered as a horizontal pipe on ground level see Figure (1).

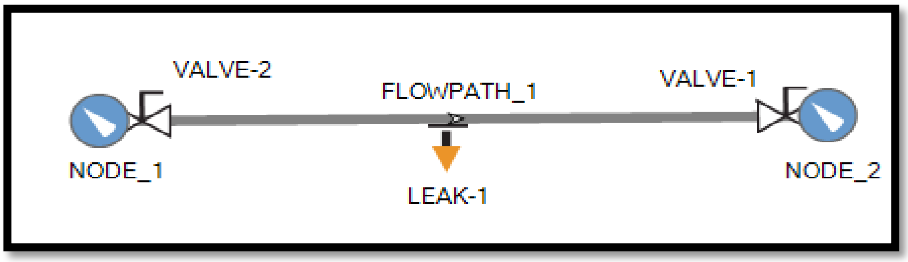

Figure 1. OLGA simulator Pipe Model.

The pressure drop between the two pressure nodes was set to obtain the desired mass flow rate

(24 kg/s). Ambient temperature is set to 20^{o}C, and the fluid is assumed to be in thermal contact with the walls. A different leakage scenario was performing by using different leak size (0.005 to 0.25) m and 0.25 m was regarded as the worst case of leak. More details on OLGA simulation can be found in our previous study [5].

2.3 Dispersion modeling

The selected model equation is the Gaussian Atmospheric Dispersion Model [6-8]. Characterization of the source term includes considerations such as whether the gas release regarded as instantaneous or continuous release. Instantaneous release is one that occurs over a short period and looks like a puff, whereas a continuous release has a long duration and the emission rate is continuous in time. For continuous leakage wand and constant speed u in x Direction the equation is [9-11]:

$$C(x,y,z) = \frac{Q_m}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\left(\frac{y}{\sigma_y}\right)^2 + \left(\frac{z}{\sigma_z}\right)^2\right)\right] \tag{1}$$

The dispersion coefficients $\boldsymbol{\sigma_x}$, $\boldsymbol{\sigma_y}$, and $\boldsymbol{\sigma_z}$, for continuous source are given in Table 1[4].

Table 1. The Equations for dispersion coefficients for continuous source. (The downwind distance x has units of meters) [4]

Pasquill-Gifford Stability class	σ_y (m)	σ_z(m)
Rural conditions		
A	$0.22x(1 + 0.0001x)^{-1/2}$	$0.22x$
B	$0.16x(1 + 0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1 + 0.0001x)^{-1/2}$	$0.08x(1 + 0.0002x)^{-1/2}$
D	$0.08x(1 + 0.0001x)^{-1/2}$	$0.06x(1 + 0.0015x)^{-1/2}$
E	$0.06x(1 + 0.0001x)^{-1/2}$	$0.03x(1 + 0.0003x)^{1}$
F	$0.04x(1 + 0.0001x)^{-1/2}$	$0.016x(1 + 0.0003x)^{-1}$
Urban conditions		
A-B	$0.32x(1 + 0.0004x)^{-1/2}$	$0.24x(1 + 0.0001x)^{-1/2}$
C	$0.22x(1 + 0.0004x)^{-1/2}$	$0.20x$
D	$0.16x(1 + 0.0004x)^{-1/2}$	$0.14x(1 + 0.0003x)^{-1/2}$
E-F	$0.11x(1 + 0.0004x)^{-1/2}$	$0.08x(1 + 0.0015x)^{-1/2}$

3 RESULTS AND DISCUSSION

3.1 Effects of operating pressure on dispersion characteristics of CO_2 gas.

The high-pressure pipeline is considered as a potential hazard and therefore requires a preliminary risk analysis. The most commonly used operating pressure in CCS system is between 60 bar, 150 bar [12, 13], and this is a very high-pressure pipeline.

This section presents an evaluation of the impact of operational pressure on the results of risk assessment. The results for the effects of operating pressure on dispersion of concentration of CO_2 gas associated with two failure sizes of 0.12 cm and 0.01 cm are presented in Table 2. Atmospheric stability F and wind speed of 1.5 m/s has been used for the simulation. Personal risk analyses were analysed for three different levels of CO_2 concentration exposure limits and related duration of exposure: 100000 ppm for 5min, 15000 ppm for 480 min, 2000 ppm for Long-Time exposure limit. The downwind distances for all CO_2 concentration exposure limits were determined for each scenario.

Table 2. Effect the operating Pressure on Concentration of CO gas.

Leak Size (cm)	Pressure (bar)	Duration Time (s)	Type of Dispersion	Flow rate (kg/s)	Downwind distance (m) to concentration (ppm)		
					100000ppm	15000 ppm	2000 ppm
0.12	100	36	plum	1130	462	1520	6364
0.12	80	42	plum	990	428	1396	6340
0.01	100	3060	plum	8	31	87	257
0.01	80	4260	plum	7	31	82	524

From Table 2 it is clear that for all leakage sizes, changing the operating pressure from 80 bar to 100 bar will have little effect on the downwind distance (m) to concentration for all CO_2 concentration exposure limits.

3.2 Effect of Isolation Valve Spacing (IVS) on of Concentration of CO_2 gas

Pipelines are equipped with emergency shutdown valves to isolate the affected pipeline section in case of leak during operation. The reasons for installation these valves is to limit CO_2 release in case of leakage Accident. The distance between these emergency shutdown valves varies over the pipeline and depends on factors like population density and regulations [13]. Existing regulations for gas transmission pipelines contain provisions regarding maximum valve spacing based on class location.

Table 3 summarizes the dispersion results. Table 3 shows how the distance between emergency shutdown valves does not affect the downwind distances for the three different levels of CO_2 concentration exposure limits.

Table 3. Effect Isolation valve spacing (IVS) on Concentration of CO_2 gas

Leak Size	IVS (m)	Duration Time (s)	Type of Dispersion	Flow rate	Downwind distance (m) to concentration (ppm)

(cm)				(kg/s)	100000 ppm	15000 ppm	2000 ppm
0.12	50	62	Plum	1130	462	1520	6364
0.12	100	172	Plum	990	428	1390	7059
0.12	12000	3400	Plum	970	422	1369	6243
0.01	50	90	Plum	8	31	87	257
0.01	100	4260	Plum	7	31	82	239
0.01	12000	100000	Plum	7	31	82	239

The results show that, for the all leak size scenarios, when the IVS changes from 50 m to 100 m the downwind distances for the three different levels of CO_2 concentration exposure limits was not affected. However, the leaking duration time tremendously affected by the distance between emergency shutdown valves. This is most evident when large distance between emergency shutdown valves is as large as 12 kilometers. The results show that average exposure limit is 1 minute for IVS of 50 m and can be increased to 1 hour for IVS of 12000 m when a similar operating conditions and leakage sizes are applied.

3.3 Effect of Emergency response time (ERT)

The dispersion results of the effect of the ERT are summarized in Table 4. Table 4 shows the emergency response time have on effect on the downwind distance for the three different levels of CO_2 concentration exposure limits.

Table 4. Effect the Emergency response time on concentration of CO_2 gas

Leak Size (cm)	ERT (s)	Duration Time (s)	Leakage accumulated released mass (kg)*	Flow rate (kg/s)	Type of Dispersion	Downwind distance (m) to concentration (ppm)		
						100000 ppm	15000 ppm	2000 ppm
0.15	30	36	-58000	1700	plum	578	2025	9985
0.15	60	72	-110000	1707	plum	590	2044	9786
0.05	30	60	-8000	200	plum	176	506	1836
0.05	60	90	-12000	200	plum	176	506	1836
0.01	30	4260	-4000	8	plum	31	87	257
0.01	60	4680	-4240	8	plum	31	87	257

* The negative sign indicates mass lost

However, results show the emergency response time has a huge effect on the leakage accumulated released mass (kg) particularly this effect is more evident for large leak sizes. Besides increasing the length of time with the emergency response time, it is expected that removing a greater amount of gas will take additional time, making the situation more dangerous.

4 CONCLUSIONS

It is very important to simulate the dispersal of CO_2 leakage in the high-pressure pipelines of the proposed CCS unit within the gas-processing field. This will facilitate the preparation of an emergency action plan for worker safety within the platform. The modelling of CO_2 leakage from pipelines at the CCS process is a very complicated process due to unexpected different leakage scenarios and complex behaviour of CO_2 gas during release. Therefore, an accurate evaluation of the source terms is important for the accuracy of the resulting dispersion.

In this work, OLGA software was successfully applied to simulate the leakage release of CO_2 from high-pressurized pipelines in CCS unit, for different leakage scenarios. Results also show that OLGA simulator offers a quick and appropriate decision for the type atmospheric dispersion model. Results also show that the isolation valve spacing (IVS) has no effect on rate of release of CO_2 leakage, while it has a clear effect on increasing the duration time of the leak. Where the operating pressure has a little effect on the rate of release; also, it increase the duration time especially at small sizes of leakage. The results also showed that any change of operating pressure has a little effect on the distance of CO_2 dispersion at most of the limits of exposure. However, at any change of spacing of valves of Emergency Shutdown (ESD) was no effect on these distances. While the leaking duration time was directly proportional to the distance between valves. The emergency response time has the greatest effect on the mass of the accumulated leak (kg) and on the duration of the leakage. On another hand, it has no effect on the distance of CO_2 concentration.

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محاكاة تشتت غاز ثاني أكسيد الكربون أثناء التسرب الناتج عن الحوادث العرضية في منشآت معالجة الغاز

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الملخص

يعتبر التقاط وتخزين غاز ثاني اكسيد الكربون من الطرق المهمة والفعالة لتقليل تركيز ثاني أكسيد الكربون في الغلاف الجوي. وبالتالي، فإن مرافق معالجة الغاز عند استخدام هذه التقنية سوف تتعامل مع كمية هائلة من ثاني أكسيد الكربون ومع ارتفاع الضغط. بمرور الوقت، يتسبب هذا في حدوث تسرب غير متوقع وانبعاث ثاني أكسيد الكربون من وحدات التشغيل أو خطوط أنابيب النقل. لذلك، فإن الهدف من هذه الدراسة هو محاكاة تشتت تسرب غاز ثاني أكسيد الكربون من خطوط أنابيب الضغط العالي لمنشآت معالجة الغاز. تعد محاكاة تسرب ثاني أكسيد الكربون من خطوط الأنابيب في عملية احتجاز وتخزين ثاني أكسيد الكربون إشكالية بسبب الافتقار إلى نماذج تحاكي كميات ومعدلات مصدر التسرب المناسبة التي تتعامل مع السلوك المعقد لثاني أكسيد الكربون بشكل صحيح أثناء الإطلاق. في هذه الدراسة، تم استخدام جهاز محاكاة OLGA 7 للتنبؤ بمعدلات ومدة التدفق الخارج من خط أنابيب CO_2 الممزق في سيناريوهات مختلفة للتسرب (أحجام التسرب). تم اختيار محاكي OLGA 7 نظرًا لقدراته في محاكاة سيناريوهات تسرب خطوط أنابيب الغاز في العديد من التصاميم وظروف التشغيل مثل ضغط التشغيل وتباعد صمامات العزل (IVS) ووقت الاستجابة للطوارئ (ERT). توفر نتائج محاكي OLGA 7 ظروف مصدر مناسبة لنماذج التشتت المختارة. تم اختيار نموذج التشتت الجوي Gaussian لمحاكاة سلوك تشتت غاز ثاني أكسيد الكربون داخل المنصة انها فعالة جدا وبسيطة. تمت دراسة تأثير معاملات التشغيل والتصميم (ضغط التشغيل، تباعد IVS ووقت الاستجابة للطوارئ) على سلوكيات تشتت الغاز المنطلق في سيناريوهات التسرب المختلفة. أظهرت النتائج أن زمن الاستجابة للطوارئ له أكبر تأثير على كتلة التسرب المتراكم (كجم) وبالتالي على مستوى تركيزات الغاز، وهذا التأثير يكون أكثر وضوحا لأحجام التسرب الكبيرة. كما أوضحت النتائج أن زمن الاستجابة للطوارئ لم يكن له أي تأثير على مستويات تراكيز الغاز عن بعد ولكن كان له تأثير معنوي على مدة التسريب.

الكلمات الدالة:
تقنية احتجاز وتخزين CO_2.
برنامج محاكاة سريان الموائع.
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انتشار الغازات.

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