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The liquid CO_2 disposal in sea pits near Greece

Lucian Mândrea[1*], *Viorel* Bădescu[2] and *Gheorghe* Militaru[3]

[1]University POLITEHNICA of Bucharest, Department of Hydraulics, Hydraulic Machinery and Environmental Engineering, 313 Splaiul Independentei, Bucharest, Romania
2 Candida Oancea Institute, University POLITEHNICA of Bucharest, 313 Splaiul Independentei, Bucharest, Romania
[3]University POLITEHNICA of Bucharest, Department of Entrepreneurship and Management 313 Splaiul Independentei, Bucharest, Romania

Abstract. As long as human activity requires much energy, a large amount of CO_2 is produced. The World Meteorological Organization announced that in 2016 the CO_2 concentrations in atmosphere reached a new record. This is the highest growth in the last 30 years, based on measurements performed in 51 countries. The growth concentration is with 50% higher than the mean level of the last 10 years. The level of the CO_2 in the atmosphere is 100 times higher than at the end of the glacial era. This can cause unexpected changes of the climate and also severe destructions of the economic system. Even if researchers believe that the raised level of CO_2 is not responsible for the rise of the temperature on the globe, we agree that the initiative to diminish the CO_2 level in the atmosphere is a useful one. We propose the possibility to deposit an amount of liquid CO_2 in a deep pit near Greece as an example of what can be done to protect the environment. We solved at the beginning the problem using an integral calculus to estimate the liquid CO_2 flow rate. Then we calculated the time in which a pit can collect what is sent at the bottom of the Mediterranean Sea.

1 Introduction

One of the methods the world can get rid of the exceeding amount of CO_2 in the atmosphere is the liquefaction and the deposition of the gas at deep levels in seas and oceans. There are many deep zones on the planet. Some of them are close to countries which produce large amounts of CO_2 and therefore these locations are more economically interesting.

We shall analyze in this article a geographical area close to Greece. It is a place in the south part of that country, in the Mediterranean Sea, near the Matapan head. It spreads between 21º and 22.5º longitude, 36º and 37º latitude. The sea depth that we assume useful for our application exceeds 4500 m, as shown in Figure 1.

*Corresponding author: lucian.mandrea@upb.ro

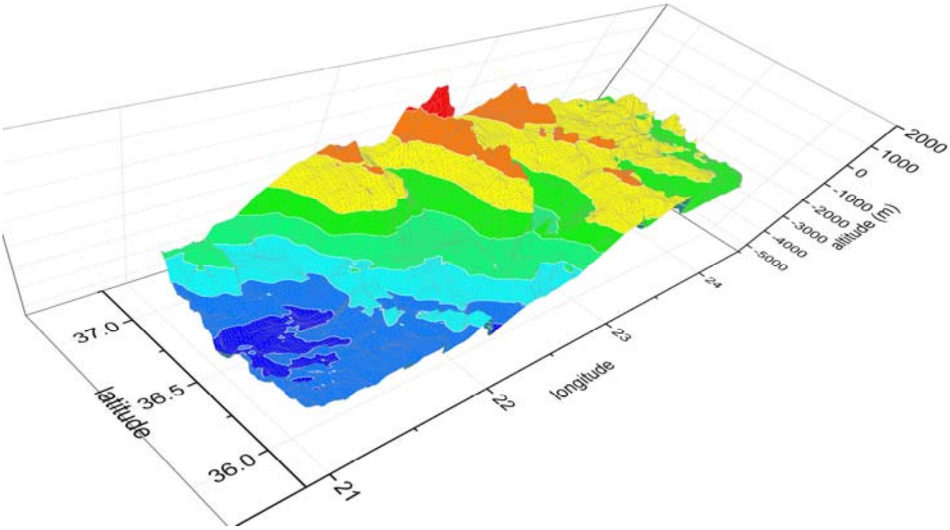

Fig. 1. The pit of the Mediterranean Sea near the Matapan head.

2 Theoretical approaches

We shall analyze two cases. In the first one, the liquid CO_2 is unloaded at the superior part of the pit. In the second case, the exit of the pipe is at the bottom of the pit.

We shall calculate the flow rate and the necessary time to fill the pit with liquid CO_2.

For the first case, as pointed out in Figure 2, we suppose that the sea has three layers of different densities.

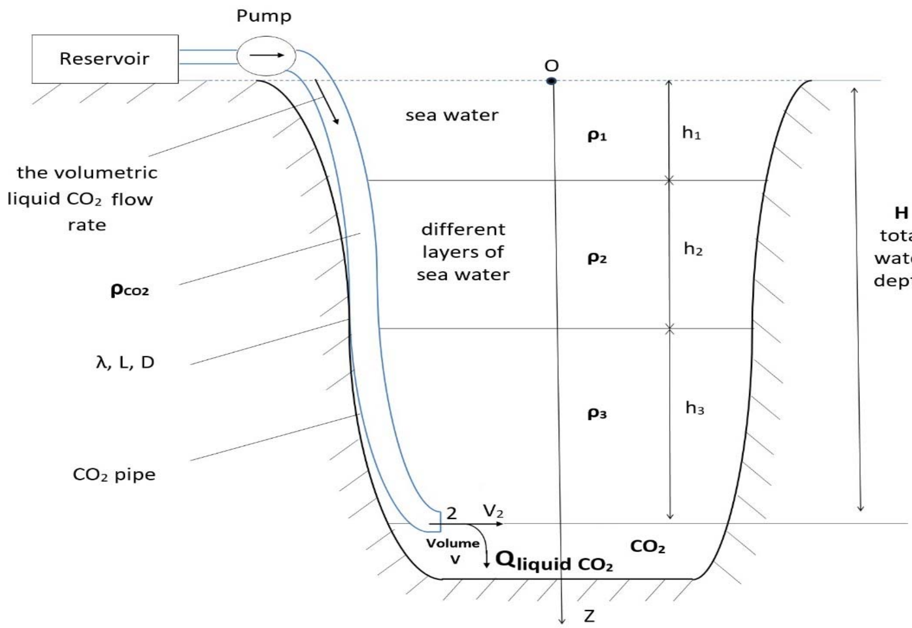

Fig. 2. The pit full with liquid CO_2 at the sea bottom.

The pressure of the liquid CO_2 at the exit of the pipe is:

$$p_{\mathrm{int},2} = \int_0^H \rho_{CO_2}(t^\circ(z))g(z)dz \tag{1}$$

The pressure of the sea water at the exit of the pipe is:

$$p_{ext,2} = \int_0^{h_1} \rho_1(t^\circ(z))g(z)dz + \int_{h_1}^{h_1+h_2} \rho_2(t^\circ(z))g(z)dz + \int_{h_1+h_2}^{H} \rho_3(t^\circ(z))g(z)dz \tag{2}$$

Here, we assumed that the sea depth consists of three layers. The difference of pressure between the sea water and the liquid CO_2 at the exit of the pipe, can be obtained by using the Bernoulli relation, considering only the linear hydraulic losses along the pipe:

$$\Delta p = p_{\mathrm{int},2} - p_{ext,2} = \frac{\rho_{CO_2,2} v_2^2}{2} + \lambda \frac{L}{D} \frac{\rho_{CO_2,2} v_2^2}{2} \tag{3}$$

We can obtain, in this way, the mean speed of the liquid CO_2 at the exit of the pipe:

$$v_2 = \sqrt{\frac{2\Delta p}{\rho_{CO_2}\left(1 + \lambda \frac{L}{D}\right)}} \tag{4}$$

Because the exit of the pipe is at the top of the pit, the growing level of the liquid CO_2 does not influence the pressure difference and the volumetric flow rate is:

$$Q = \frac{\pi D^2}{4} v_2 \tag{5}$$

Bearing in mind the assumption of a constant volumetric flow rate, the necessary time to fill the pit of volume V is:

$$T = \frac{V}{Q} \tag{6}$$

This case is quite economical since the pipe has a minimum length L to send the liquid CO_2 at the bottom of the sea. Indeed, because the pipe has a minimum length L, it also has minimum hydraulic linear losses, so the mean speed will be higher and the pit will be filled quite fast.

This first case could have the disadvantage of a higher turbulence of the flow after the pipe exit because the liquid CO_2 falls from a long distance from the sea bottom and so a part of it can be dispersed into the sea.

For the second case, as shown in Figure 3, we suppose that the sea has four layers of different densities. In the fourth layer, the sea water will be replaced in time with the liquid CO_2 which is evacuated, in this case, at the level of the sea bottom.

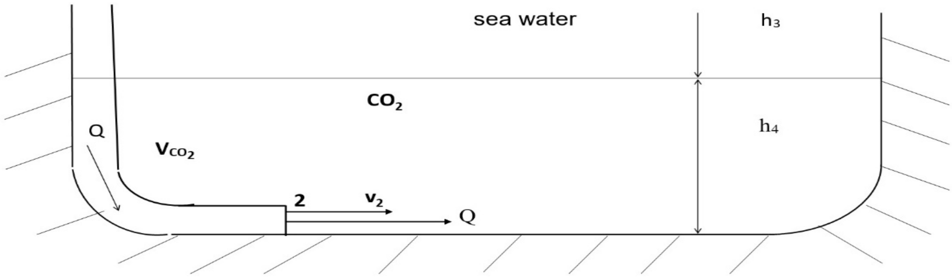

Fig. 3. The case with the pipe reaching the sea bottom, details.

The pressure of the sea water at the exit of the pipe is:

$$p_{ext,2} = \int_0^{h_1} \rho_1(t°(z))g(z)dz + \int_{h_1}^{h_1+h_2} \rho_2(t°(z))g(z)dz + \int_{h_1*h_2}^{h_1+h_2+h_3} \rho_3(t°(z))g(z)dz + + \int_{h_1+h_2+h_3}^{H} \rho_4(t°(z))g(z)dz \quad (7)$$

In the previous relation, the total depth of the sea with four different layers is:

$$H = h_1 + h_2 + h_3 + h_4 \quad (8)$$

In this case, the fourth term from Eq. (7) will change continuously because the water will be replaced by the rising liquid CO_2. This term should be calculated as a sum of two terms, one with the density of the sea water at the bottom level and the other with the density of the liquid CO_2.

Because the movement is not in a steady-state, the volumetric flow rate is no longer constant and it is a function of the vertical variable *z*. An integral calculus must be performed.

In order to calculate the total time flow, we shall write the infinitesimal volume of the liquid CO_2 in two different ways, as indicated in Figure 4.

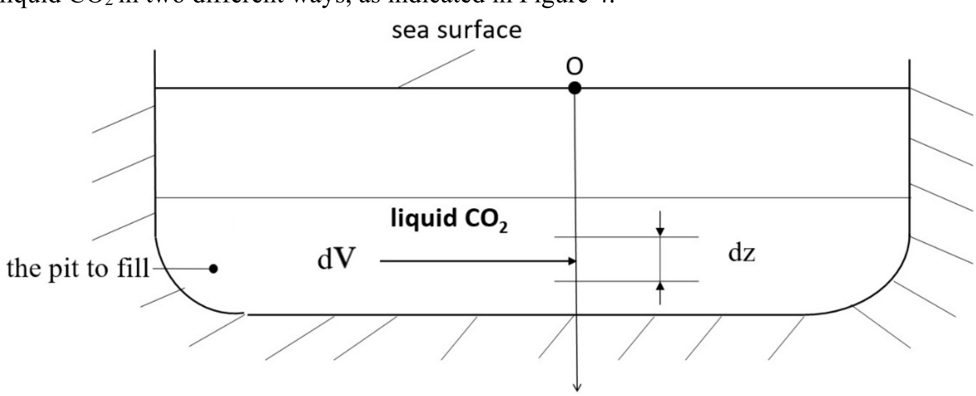

Fig. 4. The infinitesimal volume of liquid CO_2 *dV* filled in the time *dt* when the level rises with *dz*.

The volume of the liquid CO_2 which exits the pipe during an infinitesimal time *dt* is equal with the volume of the liquid CO_2 which fills the pit by rising together with the infinitesimal level *dz*.

Since, as the time passes, *dt* is positive and the rising level of the liquid CO_2 is done against the direction of the axis *z*, *dz* is negative, and so a minus will appear in the equation:

$$Q(z)dt = -S(z)dz \quad (9)$$

Separating the variables to calculate the integrals, we will obtain:

$$dt = -\frac{S(z)}{Q(z)}dz \tag{10}$$

Knowing that, at the beginning of the flow, the sea water reached the *H* level and at the end the liquid CO_2 rises at $h_1 + h_2 + h_3$, then the necessary time to fill the pit of volume *V* will be obtained from:

$$\int_0^T dt = -\int_H^{h_1+h_2+h_3} \frac{S(z)}{Q(z)}dz \tag{11}$$

In this relation, the horizontal area of the sea at the depth *z*, *S*(*z*), must be obtained using the bathymetry of the sea bed.

Since in this case we have a longer length of the pipe than in the first case, this is less effective.

Instead, because the liquid CO_2 is introduced at the sea bottom, the flow is less turbulent and the liquid CO_2 will not spread. Therefore, this case is associated with lower effects on the environment.

A simplified formula to determine the necessary time to fill the pit can be this one:

$$T = \frac{V}{\frac{Q_1 + Q_2}{2}} = \frac{2V}{Q_1 + Q_2} \tag{12}$$

Q_1 represents the volumetric flow rate in the first moment of the flow when the zone of depth h_4 is filled with sea water, and Q_2 represents the volumetric flow rate in the last moment of the flow when the zone of depth h_4 is filled with liquid CO_2.

3 Calculus examples

We shall present a practical situation, corresponding to the first case analyzed in the theoretical approach part. We consider the pit near the Matapan head with depths bigger than 4500 m, where the sea water temperature is low enough that even in the future the liquid CO_2 cannot transform in gas again [1].

The maximum depth of the pit is slightly larger than 5000 m.

The Mediterranean Sea has three layers: a surface layer with a depth of 300 m, an intermediate layer with a depth of 300 m and a deep layer with a mean depth of 4751.67 m [2], [3], [4].

For a salinity of 3.5%, we chose for the first layer with the mean temperature of 20º C the density of the sea water $\rho_1 = 1024.9$ kg/m^3; for the second layer with the mean temperature 16º C the density of the sea water is $\rho_2 = 1025.9$ kg/m^3 and for the third layer with the mean temperature 13º C the density of the sea water is $\rho_3 = 1026.4$ kg/m^3.

The liquid CO_2 at the pipe inlet is in the form of a hydrate, a binary clathrate compound with the mean density $\rho_{CO_2} = 1120$ kg/m^3 at around 2º C [3].

The pump from Figure 1 sends the liquid CO_2 in the pipe at a pressure of 1 bar. We chose a diameter of the pipe of 1 m, large enough to diminish the linear hydraulic losses and small enough to diminish the costs.

We obtain from Eq. (4) $v_2 = 8.7$ m/s and from Eq. (5) $Q = 6.84$ m^3/s.

The volume of the pit was calculated with the medium depth corresponding to the surface of the sea bed of 274 km^2 [1] as:

$$V = (H_m - 4500)S \tag{13}$$

We obtain the value for the mean total depth from [2] as $H_m = 4751.67$ m.

In this way, there results the volume of the pit useful to get the industrial deposition of the liquidized aerial carbon dioxide into the natural sea bed $V = 68.958 \cdot 10^9$ m^3.

From Eq. (6), there results the necessary time to deposit the liquid CO_2 at the bottom of the Mediterranean Sea and fill the pit, $T = 10.08 \cdot 10^{12}$ s. That means around $2.8 \cdot 10^9$ hours.

It is a small enough value to avoid generation of earthquakes and high enough to diminish costs per unit time.

4 Conclusions

The present work shows a useful possibility for the deposition of the liquid CO_2 generated in the industrial processes in Europe. The deposit analyzed here as an example may be created on the bottom of the Mediterranean Sea, near the shores of Greece. This solution may help reducing global warming.

Based on the values obtained by the authors, an economical calculus can be done in the future, whose results can be compared with other alternatives to reduce the amounts of CO_2.

For other positions in seas or oceans, the authors' calculus method can be used, by changing the density values and the depths or, possibly, the value of the gravitational acceleration.

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