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OPTIMAL DIMENSIONING OF PIPES ABOVE GROUND

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1. INTRODUCTION

Structural optimization is one of the most developing design method in structural design. The aim of this kind of design is to find the lowest cost or weight for a loaded structure.
In this paper CO_2 transportation pipelines are investigated which is the part of e.g. CCS technology [Figure 1.]. The countries that have accepted Kyoto Protocol's directives have been studying the reduction of CO_2 emission [1], and CCS is a possibility for that.

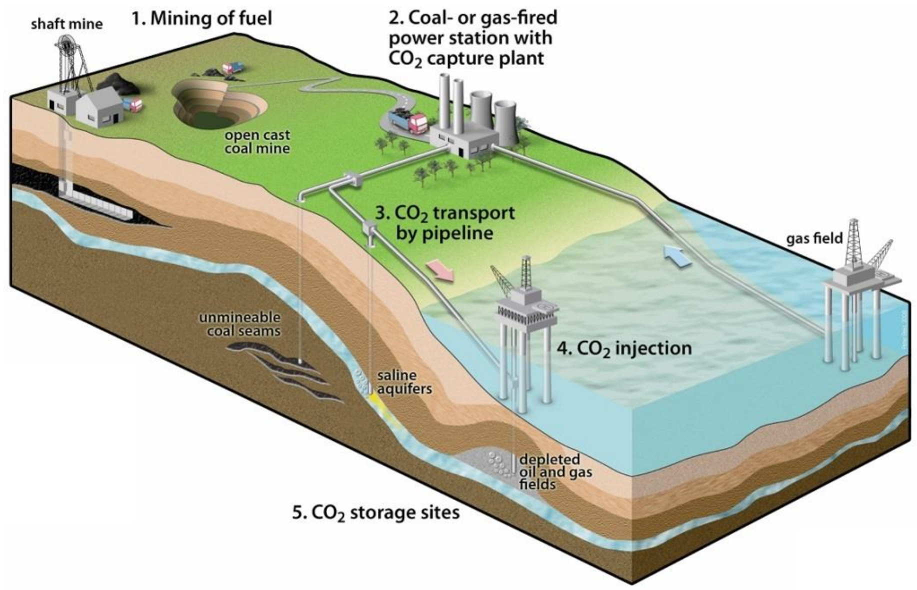

Figure 1.
The CCS technology [2]

Pipelines can be considered the most suitable method for transporting CO2, since the cost for this technology depends mainly on the distance, the quantity transported and whether the pipelines are onshore or offshore [3]. The reliable design of pipes is so important because the post-reinforcement is expensive and complicated [4]

2. DESIGN CONSTRAINTS

In this kind of design for above-ground high pressure pipeline transportation three kinds of constraints are to be used. These are the stress, deflection and stability constraints.

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2.4 The limit of flow velocity

The specific conveyed medium always determines the economic flow rate (Table 1.). In case of too high flow velocity undesired phenomena may occur e.g. noise, vibration or erosion. Therefore there is a limitation of flow velocity.

Table 1.
Economic flow rates of gases and fluids [5]

Medium	Type of pipeline	Velocity (m/s)
Water	Waterworks and distribution system conduits - main - long-distance - local network Feedwater Cooling water	 1...2 <3 0,6...0,7 1,5...3 0,6...2
Steam	low pressure (up to 10 bar) medium pressure (10...40 bar) high pressure (60...125 bar)	15...20 20...40 40...70
Air	compressed air	20...25
Oil	Long-distance pipelines Lube oil	1,5...2 0,5...1

2.2 Stress constraint

The stress constraint can be calculated as follows.
The distributed load is

$$p = \left(1,2A\rho_a + 1,1A_t\rho_g\right)g \tag{1}$$

where ρ_a is the density of the steel, A_t is the area of transportation, ρ_g is the density of high pressure gas and the area of the pipe wall is

$$A = \frac{\left(D^2 - d^2\right)\pi}{4} \tag{2}$$

In structural analysis, Clapeyron`s theorem of three moments is a relationship between the bending moments at three consecutive supports of a horizontal beam. Let *A*, *B*, and *C* be the three consecutive points of support, and denote by *l* the length of *AB* and by *l*` the length of *BC*. Then the bending moments M_A, M_B, M_C at the three points are related by

$$M_A l + 2M_B(l + l') + M_C l = \frac{6a_1 x_1}{l} + \frac{6a_2 x_2}{l'} \tag{3}$$

where a_1 is the area on the bending moment diagram due to vertical loads on AB, a_2 is the area due to loads on BC, x_1 is the distance from A to the center of gravity for the bending moment diagram for AB, x_2 is the distance from C to the center of gravity for the bending moment diagram for BC.
So the bending moment at the middle support according to the Clapeyron formula is

$$M_2 = \frac{2,5pL^2}{4} \tag{4}$$

where L is the distance between the supporters.
The stress is

$$\sigma_1 = \frac{M_2}{K_x} \tag{5}$$

where

$$K_x = \frac{\left(D^4 - d^4\right)\pi}{32D} \tag{6}$$

where D is the outside diameter and d is the inside diameter.
Barlow’s formula can be calculated as

$$\sigma_2 = \frac{p_b d}{2t} \tag{7}$$

where D is the outside diameter and d is the inside diameter.
Reduced stress is

$$\sigma_R = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2} \tag{8}$$

The permissible stress is

$$R_{adm} = \frac{f_y}{n_e} \tag{9}$$

where safety factor n_e is 1,2 and f_y is the yield stress.
The stress constraint is

$$\sigma_R \le R_{adm} \tag{10}$$

2.3 Deflection constraint

The deflection of the pipe between the supports can be calculated as follows

$$w = \frac{pL^4}{284 E I_x} \tag{11}$$

where E is the elastic modulus and the moment of inertia is

$$I_x = \frac{\left(D^4 - d^4\right)\pi}{64} \tag{12}$$

The limitation of the deflection is

$$w \leq \frac{L}{300} \tag{13}$$

2.4 Stability constraint

This constraint depends on the ratio between the outer diameter and the wall thickness. The limit is given by Eurocode to avoid local buckling in the tube walls:

$$\frac{D}{t} \leq 90\varepsilon^2 \tag{14}$$

where

$$\varepsilon = \sqrt{\frac{235\text{MPa}}{f_y}} \tag{15}$$

3. NUMERICAL EXAMPLE

The aim of this survey is to find the lowest mass per unit length pipe for a given transporting volume flow rate. To obtain this optimum, the best number of pipes, outside diameter and wall thickness combination has to be found under the European Standard [6] which meets the three design constraints and although hydrodynamic investigation is not taken into account the velocity of flow is limited by 20 m/s.

In this numerical example the mass flow rate is 5000 tons per day, what is about 29,2 m^3/s. The distance between the supports is L = 20 m and the yield stresses of the material of the tube are fy = 355 and 448 MPa.

The optimum results for different diameters calculated by a MathCad code where the unknowns were the number of pipes, outside diameter and wall thickness. The results for different number of pipes and different materials are shown in Table 2. and 3.

Table 2.
20m 448 MPa

Number of pipes	Outside diameter [mm]	Wall thickness [mm]	Mass per unit lenght [kg/m]	Total mass per unit lenght [kg/m]
1	1524	36	1321	1321
2	***1016***	***22,2***	***544***	***1088***
3	864	20	416	1249
4	762	17,5	321	1285
5	660	14,2	226	1131
6	610	14,2	209	1252
7	559	12,5	168	1179
8	***508***	***11***	***135***	***1080***
9	508	11	135	1213

Table 3.
20m 355 MPa

Number of pipes	Outside diameter [mm]	Wall thickness [mm]	Mass per unit lenght [kg/m]	Total mass per unit lenght [kg/m]
1	***1422***	***25***	***861***	***861***
2	***1016***	***17,5***	***431***	***862***
3	864	16	335	1004
4	***711***	***12,5***	***215***	***861***
5	660	12,5	200	998
6	610	11	162	975
7	559	10	135	948
8	508	8,8	108	867
9	508	8,8	108	975

In the tables there are close results for different pipe numbers. In this cases low number of pipes can be more economical because of the building and maintenance cost.

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