$$U_{2N}^{1}\left(x_{0i},x_{jr}\right)=-\frac{4}{l_1 l_2}\frac{1+n}{1-n}\sum_{k=1}^{\infty}\sum_{m=0}^{\infty}\frac{c_{km}\left(e_N\right)l_{1k}\,l_{2m}}{D_{km}^{4}}F_{km}^{cs}\left(x_{0i}\right)F_{km}^{sc}\left(x_{jr}\right);$$

$$U_{2N}^{2}\left(x_{0i},x_{jr}\right)=\frac{4}{l_1 l_2}\sum_{k=1}^{N}\sum_{m=0}^{N}\frac{1}{D_{km}^{4}}\left(l_{2m}^{2}+\frac{2}{1-n}l_{1k}^{2}\right)F_{km}^{sc}\left(x_{0i}\right)F_{km}^{sc}\left(x_{jr}\right);$$

$$U_{2N}^{s}\left(x_{0},x_{jr}\right)=-\frac{4\left(1-n\right)}{l_1 l_2}\sum_{k=1}^{N}\sum_{m=0}^{N}\frac{c_{km}\left(e_N\right)l_{2m}}{D_{km}^{2}\left(a^2 l_{km}^{2}+a\right)}\,e^{-\left(a^2 D_{km}^{2}+a\right)t}\Big|_{sDt}^{(s-1)Dt}F_{km}^{ss}\left(x_{0i}\right)F_{km}^{sc}\left(x_{jr}\right);$$

$x_{0i}\left(x_{0i},y_{0i}\right)$, $x_{jr}\left(x_{jr},y_{jr}\right)$ – points where the coordinates might be calculated according to formulas (1) and (3).

For the functions determining thermoelastic state of plate at free points, we will get from (9) the analogical (11) discreet quantifiers.

Effective numerical equation system solutions (11) for the case $l_1=p$, $l_2=2p$, $b_1=3p/8$ are designed with the following parameters values: $r<0,005$; $e<0,001$; $n=80$; $N=800$. Considering low values $\max\left\{b_i/l_j\right\}<0,1$ the given model is exact model of thermoelastic state of unlimited plate with inclusions.

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PROJECT MANAGEMENT OF CARBON DIOXIDE PRODUCED DURING OPERATION OF LOW POWER BOILER IN SMALL TOWN IN CENTRAL EUROPE

The main point of the article is reducing carbon dioxide. The ways of carbon sequestration for energy and mining corporations are presented. It is shown that joint action to protect the environment can bring tangible benefits.

Key words: Sequestration, carbon dioxide emission.

Розглянуто зменшення обсягів викиду двоокису вуглецю. Представлено способи секвестрації вуглецю для енергетичних і гірничодобувних корпорацій. Показано, що спільні дії щодо захисту навколишнього середовища можуть принести відчутну користь.

Ключові слова: секвестрація, викид двоокису вуглецю.

Introduction

In recent times global warming topics are getting very trendy on the media. They usually say that the main reason for global warming is the excessive carbon dioxide emissions caused by the rapid development of civilization. For the existing state of things they blame large industrial plants, energy facilities or processing plants that are using coal or other fossil fuels for combustion and then pollute the environment with carbon dioxide. On the other hand, global warming skeptics argue that putting restrictions on carbon dioxide emissions is only a pretext for western industry lobby to limit the development of poor countries and leave the monopoly of enrichment only to the western countries. The truth, however, is always in the middle. Carbon dioxide definitely has an impact on climate change occurring on Earth (mainly on growth of average temperature), but it is not the only factor that affects the atmosphere. Deforestation and also nature itself contribute on climate changes. Oceans and seas contain about 50 times more carbon dioxide than the atmosphere. When water evaporates it releases the captured carbon dioxide to the atmosphere. Therefore, global warming was not caused solely by mankind. In the history of the Earth can be observed that in the past million years we had ten great ice ages that lasted for about 100 000 years. Among which were a breaks – the warm years that we call interglacial for about 10 000 years. Our global warming in which we live today has lasted 11,000 years. It is entirely possible that when the warming process ends, it will be time for another ice age.

Characteristics of carbon dioxide

Carbon dioxide (CO_2) is an inorganic chemical compound. CO_2 at room temperature is a colorless, odorless and non-flammable gas, very soluble in water, and about 1.5 times heavier than air. The concentration of this gas in air is about 0.0385 %. It is one of the greenhouse gases. In nature, carbon dioxide is common, it is a product of combustion and respiration. Formed by oxidation and fermentation of organic substances that occur among other in the mines, sugar mills, wineries, grain silos, distilleries, breweries, sewage pit. It is used by the plants in the process of photosynthesis to form oxygen and hydrocarbons from water, carbon dioxide, with the participation of the solar energy during the day.

Despite the fact that at low concentrations carbon dioxide is not toxic for humans it can be a dangerous gas. When you breathe air containing carbon dioxide at low concentrations (less than 5 % of the inspiratory air) may lead to hypercapnia. At concentrations above 10 % of the shortness of breath and weakness grow up, also hallucination, confusion and convulsions may appear. Concentrations above 20 % results in death within a few minutes, and more than 30 % results in immediate death. Hypoxia and brain swelling can cause irreversible changes even though the person was saved. CO_2 poisoning occurs mainly in the industrial plants primarily in the mines (suddenly as a result of mining works or movement of the rock mass can be released significant amounts of gases), confined spaces, where as a result of the fermentation carbon dioxide increase its concentration in the air (such as sugar mills, wineries, grain silos, breweries, sewer pits and other similar).

Carbon sequestration

Sequestration in the legal sense – is putting the dispute to a third party for safekeeping until judgment.

Sequestration in terms of technology – is defined as activities designed to capture, transport and disposal or permanent deposit and isolation from the biosphere of carbon dioxide.

CCS (carbon capture and storage) – that is, the capture of CO_2 from industrial installations, transport to storage and injecting into suitable geological formation for permanent storage.

Sequestration process steps are:

- Separation of carbon dioxide from the flue gas stream.
- The transportation to the storage or disposal (you can skip this step if the disposal or storage of carbon dioxide will be in the place its formation).
- Disposal or permanent deposit.

Methods for separation of CO_2 from exhaust gases are based on chemical or physical absorption (for example, activated carbon), the physical adsorption of methanol, ethylene glycol, and the cryogenic process, which due to the cost (the cooling of the gas stream) appear to be unlikely to apply in practice. This is the most expensive step in the sequestration process. It is estimated that about three-quarters the cost of carbon sequestration absorb the entire separation of carbon dioxide from flue gas.

You can distinguish the following methods of separation:

1. Pre-combustion (fuel is reacted in an atmosphere of depletion of air or with water vapor. By chemical reaction CO and H_2 is formed. Then in the presence of water vapor in the catalytic reactor, the

CO is converted to CO_2. Products of this reaction are carbon dioxide and hydrogen. Carbon dioxide is separated from the gases in the capture unit for example by physical absorption. Formed hydrogen is sent to the gas turbine which produces electricity. Such technology is used in IGCC installations (Integrated Gasification Combined Cycle).

2. During the combustion (in another way – oxygen combustion of coal – it is a combustion process which uses oxygen-enriched air. Due to the removal of nitrogen in the exhaust gases carbon dioxide and water vapor is obtained. Water is separated by cooling and condensation, and carbon dioxide is recycled in order to increase its concentration.)

3. After combustion (carbon capture method after combustion of the fuel is the removal of CO_2 from flue gases that are directed to the chimney. Usual method of separating carbon dioxide from the exhaust gas is CO_2 leaching during chemical absorption process with the use of MEA ((monoethanolamine)).

The most commonly used methods of separation of carbon dioxide from the flue gases are:

1. Chemical absorption – a process of penetration of one substance (particles, atoms or ions) to any other substance to form a continuous phase (gas, liquid, solid). It consists of passing a pre-cleaned and cooled to a suitable temperature of the flue gas through an absorption column in which it comes into contact with the solvent of carbon dioxide which absorbs CO_2. Then the solvent saturated with carbon dioxide bubbled through desorber where the gas is released then compressed and later purified. By applying this method a high degree of purity of the product can be obtain and the process is very efficient. It is the most common method of separating carbon dioxide from flue gas.

2. Adsorption – is the process of binding molecules, atoms or ions on the surface or phase boundary, causing local changes in concentration. This method is based on physical attraction between solid and gas. It is based on bringing the gas into a solid layer, which adsorbs only carbon dioxide, and other gases can pass through it. After adsorption of carbon dioxide it can be recovered from the layer. To be effective the adsorption process requires low temperature and high pressure. The materials used as a permanent layer must have a high specific surface area (activated carbon, corundum, silica or aluminum gel).

3. Membrane separation – this method involves the separation of the gases on the membranes using different physical and chemical interactions between the various components of the gas mixture and the material from which the membrane was made. In general terms one of the components may be dissolved in the material of the membrane, then it can diffuse through it to the other side where it is intercepted. Distinction is made between gas separation membranes and membrane gas absorption.

4. Cryogenic fractionation – involves compressing and cooling the gas, and subsequently removing the liquefied or crystallized carbon dioxide. This method allows you to obtain carbon dioxide with high purity at the expense of significant energy consumption. The product of a cryogenic separation of CO_2 comes in the form of liquid or solid.

The next step is the transport of carbon dioxide. This is the simplest and cheapest step of carbon sequestration. Carbon dioxide may be transported in gaseous, solid, liquid or in transition state which is known as a dense gas phase. Most often it takes place in the liquid phase by CO_2 pipelines. Oil tankers which are specially adapted for the transport of carbon dioxide are also used in the case of underwater storage of CO_2. While in the case of small installations of underground injection of carbon dioxide cistern trucks can be used. The cost of transport depends mainly on the distance of the emission source to the storage area.

Last but not least, in the process of carbon sequestration is the storage. Storage of carbon dioxide is an attempt to postpone the time of development of carbon dioxide, imprisonment of excess produced by man under the ground that in the future the development of low-cost methods of disposal of carbon dioxide can be used to neutralize CO_2.

There are several basic ways to store CO_2 on dividing into individual methods of disposing of carbon dioxide:

- Storage of CO_2 in geological formations (geological sequestration)
  - Enhanced oil recovery.
  - ECBM (Enhanced Coal Bed Methane).

    - Storage of carbon dioxide in deep aquifers.
    - Storage of carbon dioxide in salt caverns.
    - Storage in closed underground mines.
- Storage of CO_2 in the oceans (seas).
    - Dissolution at a depth of about 1000 meters.
    - Embossing to a depth greater than 3000 meters – formation of carbon dioxide lakes.
    - Dropping dry ice into the oceans from ships.
    - CO_2 injection through tube towed by a sailing ship.
- Carbonation of CO_2 (permanent bond).
- Binding in the Earth ecosystems.

The calculation of emissions for low-power boiler

The calculation will be carried out for the low-power boiler (5 MW).

The demand for coal can be calculated using the following formula:

$$P = \frac{Q_i^r \cdot m_w \cdot \eta}{t}, \tag{1}$$

where P – power [kW]; $Q^r{}_i$ – calorific value of the fuel [kJ/kg]; η – boiler efficiency [%]; m_w – fuel requirement (kg/h); t – combustion time [h]

Recived:

$$m_w = \frac{P \cdot t}{Q_i^r \cdot \eta}. \tag{2}$$

Since the exact chemical composition of coal has not been determined, and it is assumed that the air demand can be calculated you can use the approximate empirical formula:

$$V_{t,pow} = 1.012 \cdot \frac{Q_i^r \left[\frac{kJ}{kg}\right]}{4186.8} + 0.5. \tag{3}$$

Actual air consumption can be calculated according to the formula

$$V_{rz,pow} = \lambda \cdot V_{t,pow}, \tag{4}$$

where λ – air – fuel ratio, determines how much of air must be supplied in order to obtain complete combustion.

The theoretical volume of wet gas can calculate using the formula:

$$V_{t,pow}^m = 0.89 \cdot \frac{Q_i^r \left[\frac{kJ}{kg}\right]}{4186.8} + 1.65 \left[\frac{nm^3}{kg}\right]. \tag{5}$$

The exhaust gas stream in the contractual conditions can be calculated from the formula:

$$\dot{V}_{sp} = m_w \cdot V_{rz,sp}. \tag{6}$$

Exhaust gas flow in real conditions can be calculated from the formula:

$$V_{rz,śp} = V_{sp} \cdot \frac{273 + t_{sp}}{273}. \tag{7}$$

The internal diameters of the chimney outlet can be calculated from the formula:

$$d = \sqrt{\frac{4 \cdot V_{rz,śr}}{3600 \cdot \pi \cdot W_{sp,k}}}, \tag{8}$$

where: $W_{sp,k}$ average velocity of gas flowing out from the chimney [m/s]

Thermal power emitted into the atmosphere from the exhaust can be calculated by the following formula:

$$Q_{sp} = \frac{V_{sp} \cdot C_{p,sp}}{3600} \cdot \left(t_{sp} - t_o\right) [kW], \tag{9}$$

where Cp,sp – the average specific heat of the flue gas [kJ/nm3K]

For the next step the above values will be needed in the [kcal/s] unit, therefore, converting formula was used:

$$Q'_{sp} = \frac{Q_{sp}}{1.163 \cdot 3600} . \tag{10}$$

Elevation of flue gas calculated according to the Holland formula:

$$\Delta h_H = \left(1.5 \cdot w_{sp,k} \cdot d_k + Q_{sp} \cdot 4.1 \cdot 10^{-2}\right) \cdot \frac{1}{w} , \tag{11}$$

where $w_{sp,k}$ – velocity of flue gas outflow from the chimney [m/s]; d_k – inner diameter of the chimney [m]; Q_{sp} – heat output carried away to the atmosphere with the flue gas [kcal/s]; w – wind speed at the height of the emission source [m/s]

Height of emission – it is, the total height of the emission (the sum of the total height of the chimney and the elevation of outlet gases above the chimney). According to the nomenclature used in the protection of the environment it is simply a chimney. The height of the emission can be calculated using the formula:

$$H = h + \Delta h_H , \tag{12}$$

where h – height of chimney [m].

Sulfur dioxide emissions can be calculated using the equation:

$$E_{SO_2} = \frac{m_w \cdot S^r}{180} , \tag{13}$$

where S^r – the total sulfur content in the fuel [%]; m_w – fuel requirement [kg/h]

The maximum concentration of sulfur dioxide at ground level can be calculated using the equation:

$$S_{\max, SO2} = 0.183 \cdot \frac{E \cdot 10^3}{w \cdot H^2} . \tag{14}$$

For the calculation of carbon emissions composition of fuel is necessary (chemical composition). It can be determined using theoretical – empirical models. One such pattern is the Boie pattern:

$$Q_w^r = 348.3 \cdot C^r + 938.7 \cdot H_2^r + 104.7 \cdot S_c^r + 62.8 \cdot N_2^r - 108 \cdot O_2^r - 24.5 \cdot W_c^r \tag{15}$$

where C^r – total carbon content [%]; H^r_2 – total hydrogen content [%]; S^r_c – total sulfur content [%]; N^r_2 – Total nitrogen content[%]; O^r_2 – total oxygen content [%]; W^r_c – total moisture content [%]

The maximum content of carbon dioxide in the exhaust gas can be determined by using the following formula:

$$CO_{2\max} = \frac{21 \cdot C^r}{C^r + 2.37 \cdot \left(H_2^r - \frac{O_2^r - H_c^r}{8} \right)} . \tag{16}$$

Using the previously calculated theoretical value of the exhaust stream and the maximum content of carbon dioxide, maximum flow volume of carbon dioxide produced can be calculated which is given by:

$$\dot{V}_{sp,CO_2} = CO_{2\max} \cdot \dot{V}_{sp} . \tag{17}$$

Emissions can be calculated by using the dependence

$$E = \dot{V}_{sp,CO_2} \cdot \rho_{CO_2} , \tag{18}$$

where $\dot{V}_{sp,CO_2}$ – maximum flow of carbon dioxide [um^3/h]; ρ_{CO_2} – density of carbon dioxide [kg/um^3]

Cost of sequestration

The costs of carbon sequestration depends on many factors such as: the amount of stored gas, the cost of separation, transportation, injection and compression, distance from emission source to the storage, the storage, the cost of drilling holes, the size of the tank and absorption of the tank, land development, infrastructure.

The most expensive stage of geological sequestration is the first step, which is the separation of carbon dioxide from flue gas. These costs are the main obstacle standing in the way of rapid development of underground storage of CO_2, and concern for the environment and the welfare of people they should be reduced. The cost of the capture of carbon dioxide depends on the coal combustion technology, and is about 10 to 80 USD per ton of captured CO_2. The introduction of mandatory separation of carbon dioxide would increase the cost of electricity by about 30–50 %. CO_2 capture costs for industrial facilities are lower.

The cheapest step in the process of carbon sequestration is its transport to disposal or permanent deposit. Costs mainly depend on the method of transporting carbon dioxide, and the distance at which the gas has to be transported. They can be zero if after the separation of carbon dioxide there is no need to transport CO_2 but it is immediately disposed of.

The last but not the least important stage in the process of CO_2 sequestration is under-ground storage. The cost of such operation depends mainly on the location and depth of gas storage. In some cases (especially in the case of carbon dioxide injection for enhanced oil recovery (EOR) or injection into off balance coal deposits in order to recover methane (ECBM)), it turns out that such operation does not necessarily generate additional costs and it can even generate tangible benefits. Relatively high carbon injection costs are mainly due to high costs of drilling holes and operating costs (depth, permeability of the storage tank, the type of tank).

Summary

Undeniably the issue about ways of reducing carbon dioxide is hot topic in the media nowadays. Therefore, it is important to zoom in and dissemination of knowledge on how to reduce emissions, as well as a rise awareness of energy and mining corporations that joint action to protect the environment can bring tangible benefits to both the entrepreneur. At present, carbon sequestration is not very profitable mainly because of the huge costs of capture of the carbon dioxide from the exhaust stream formed by the combustion of fossil fuels. In order to make energy production in plants with CO_2 capture systems profitable, energy companies would certainly increase electricity prices, which are not small. In many cases, this fact could significantly affect the budget of a typical household. It is also possible that then more people would be willing to save more electricity, resulting in an even greater amount of pollution does not permeate to the environment.

Sequestration costs are high and the compulsory use of separation of CO_2 in the boiler plants and power plants would significantly increase the price of energy and heat. Sequestration costs reduce profits from the sale of electricity or heat by nearly three quarters. As of today, you cannot use sequestration on a large scale. Reduction of carbon emissions, would be possible if coal of better quality would be used (less impurities, in particular ash and higher calorific value).

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