

NEW METHOD OF CARBON DIOXIDE UNDERGROUND STORAGE COUPLED WITH SHALE GAS RECOVERY

Tadeusz Niezgoda, Danuta Miedzińska, Piotr Kędzierski

Military University of Technology
Department of Mechanics and Applied Computer Science
Kaliskiego Street 2, 00-908 Warszawa, Poland
tel.: +48 22 6839461, +48 22 6837096, +48 22 6837610, fax: +48 22 6839355
e-mail: tniezgoda@wat.edu.pl, dmiedzinska@wat.edu.pl, p_kedzierski@wat.edu.pl

Abstract

Shale gas is natural gas produced from shale, a type of sedimentary rock. Shale gas has become an increasingly important source of natural gas in the United States over the past decade, and interest has spread to potential gas shales in Canada, Europe, Asia, and Australia. One analyst expects shale gas to supply as much as half the natural gas production in North America by 2020.

As of 2010, Poland imports two-thirds of its natural gas from Russia. ConocoPhillips has announced plans to explore for shale gas in Poland, along with Lane energy. The recently made available US Department of Energy report revealed that the largest reserves of shale gas in Europe are in Poland. The authors of the report calculate that Poland has reserves of about 22.45 trillion cubic meters of shale gas, of which 5.30 trillion cubic meters is immediately available for extracting.

The most common method of shale gas recovery is hydraulic fracturing - the propagation of fractures in a rock layer caused by the presence of a pressurized fluid. Hydraulic fractures form naturally, as in the case of veins or dikes, and is one means by which gas and petroleum from source rocks may migrate to reservoir rocks. This process is used to release petroleum, natural gas (including shale gas, tight gas and coal seam gas), or other substances for extraction, via a technique called induced hydraulic fracturing. The method is critically assessed by ecologists.

The paper deals with new method of gas shale fracturing and gas recovery coupled with carbon dioxide storage. It allows to effectively mine the shale gas and to store carbon dioxide in shale rock. It must be noticed that CO₂ pollution is a very important problem in Poland, because of European Union CO₂ limits. Also the numerical calculation of carbon dioxide thermodynamical process of decompression process, which simulates the injection of the cold liquid gas into the shale formation (high temperature and pressure conditions) and its influence on shale rock fracturing will be presented.

Keywords: shale gas, carbon dioxide, storage system

1. Introduction

Shale gas is natural gas formed from being trapped within shale formations [1]. Shale gas has become an increasingly important source of natural gas in the United States over the past decade, and interest has spread to potential gas shales in the rest of the world. One analyst expects shale gas to supply as much as half the natural gas production in North America by 2020 [2].

As of 2010, Poland imports two-thirds of its natural gas from Russia. ConocoPhillips has announced plans to explore for shale gas in Poland [3], along with Lane energy [4].

The recently made available US Department of Energy report [5] revealed that the largest reserves of shale gas in Europe are in Poland. The authors of the report calculate that Poland has reserves of about 22.45 trillion cubic meters of shale gas, of which 5.30 trillion cubic meters is immediately available for extracting. Most of the shale gas is in Baltic Sea basin about 3.66 trillion cubic meters, about 1.25 trillion cubic meters within the region of Lublin Voivodship, or Lublin Province, and next 0.4 trillion cubic meters in Podlaskie Voivodship [Fig. 1].

The companies such as BNK Petroleum, Talisman Energy, Marathon Oil, Chevron and ExxonMobil are actively drilling to find the potential new gas well sites. The region with the

greatest shale gas potential in Poland is the Baltic Basin where leases have already been awarded to participating oil companies. The most active company in Baltic basin region is 3Legs Resources, subsidiary of Lane Energy Poland in a joint venture with ConocoPhillips. The results of first borings were announced on 21 June 2011. They showed large gas saturation in the well [6].

Lublin Voivodship is the basin bounded to the north by the Trans European Fault near Grójec, to the east by Polesie Lubelskie and to the south by the Ukrainian border.

One active company in this region is Halliburton, which in September 2010 carried out the first drilling for the Polish consortium PGNiG. The results to date remain confidential. Six other firms have acquired concessions in that region including ExxonMobil, Chevron and Marathon Oil.

The last region with shale gas potential is the Podlaski basin, although exploration drilling in that area has not yet begun. The concession for this region has been acquired by Exxon-Mobil [7].

Marathon Oil has extensive leasehold in Poland, which it intends to explore for Silurian-age shale gas.

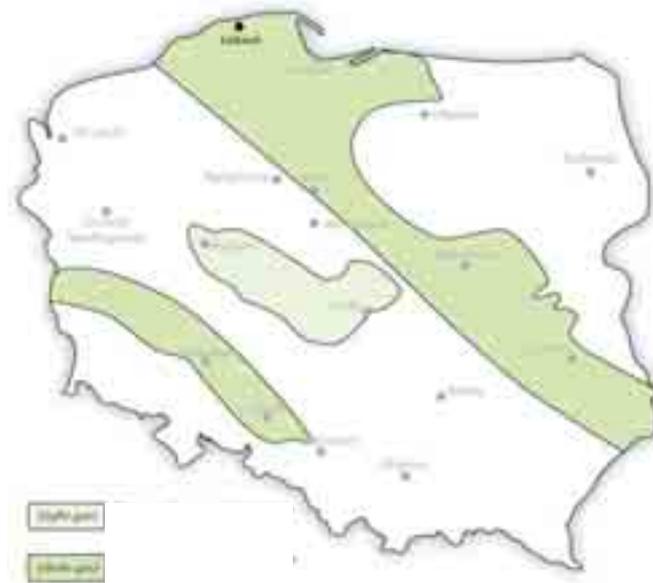


Fig. 1. Shale gas reservoirs in Poland [9]

Previous reports indicated that Poland might have the large shale gas resources in Europe. If recent reserve estimates of a minimum of 3 trillion cubic meters are accurate, Poland would have gas reserves of more than 200 times annual consumption, and more than 750 times Poland's current annual production (2009) [8].

Such shale gas resources would greatly boost the Poland proven reserves, and lessen the importance of gas imports from Russia.

The paper deals with new method of gas shale fracturing and gas recovery coupled with carbon dioxide storage. It allows to effectively mine the shale gas and to store carbon dioxide in shale rock. It must be noticed that CO₂ pollution is a very important problem in Poland, because of European Union CO₂ limits. Also, the numerical calculation of carbon dioxide thermodynamical process of decompression process, which simulates the injection of the cold liquid gas into the shale formation (high temperature and pressure conditions) and its influence on shale rock fracturing will be presented.

2. Method of carbon dioxide underground storage coupled with shale gas recovery

Shale is characterized by its dual porosity: it contains both primary (micro pores and meso pores) and secondary (macro pores and natural fractures) porosity systems. The primary porosity systems contains the vast majority of the gas-in-place, while the secondary porosity system

provides the conduit for mass transfer to the wellbore. Primary porosity gas storage is dominated by adsorption. Primary porosity is relatively impermeable due to its small pore size. Mass transfer for each gas molecular species is dominated by diffusion that is driven by the concentration gradient. Flow through the secondary porosity system is dominated by Darcy flow that relates flow rate to permeability and pressure gradient – see Fig. 2 [10].

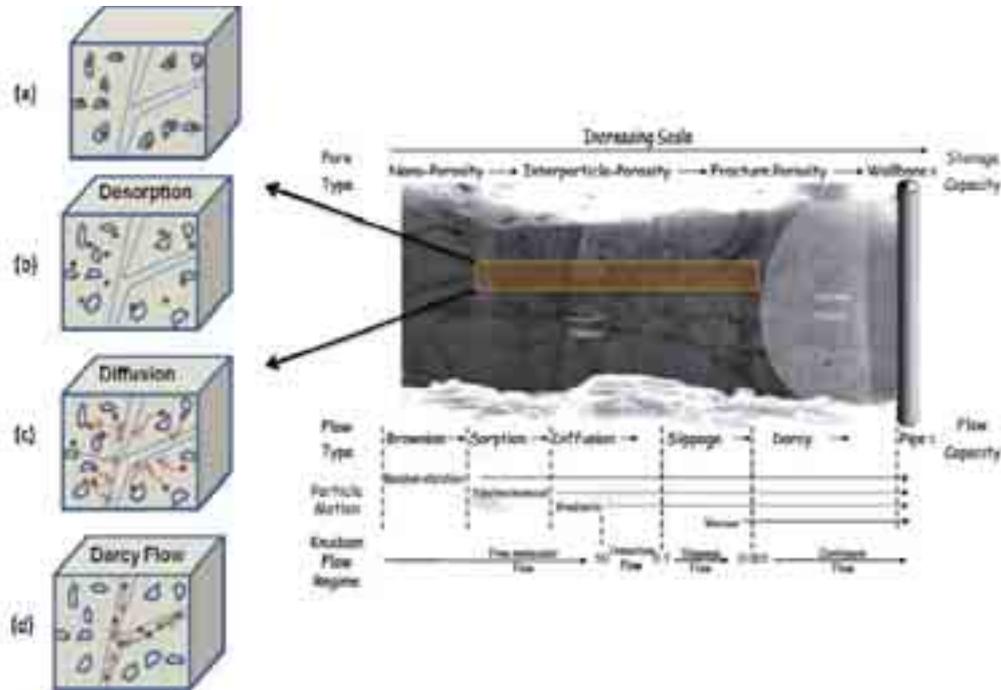


Fig. 2. Flow types and behaviour in shale reservoirs [10]

When the pressure of natural fracture system in shale drops below the critical desorption pressure, methane starts to desorb from the primary porosity and is released into the secondary porosity system near the natural fractures is reduced. This reduction creates a concentration gradient that results in mass transfer by diffusion through the micro and meso porosity. Adsorbed gas continues to be released, as the pressure is reduced [11]

On the base of those mechanisms analyses a new innovative method of gas shale fracturing and gas recovery coupled with carbon dioxide storage was developed in Department of Mechanics and Applied Computer Science of Military University of Technology.

Fracturing has been widely used since the 1970s to increase production from formations with low permeability or wellbore damage. Unlike conventional hydraulic and acid fracturing techniques, CO₂-sand fracturing stimulates the flow of hydrocarbons without the risk of formation damage and without producing wastes for disposal. A mixture of sand proppants and liquid CO₂ is forced downhole, where it creates and enlarges fractures. Then the CO₂ vaporizes, leaving only the sand to hold the fracture open—no liquids, gels, or chemicals are used that could create waste or damage the reservoir. Any reservoir that is water sensitive or susceptible to damage from invading fluids.

The presented method of gas shale fracturing and gas recovery coupled with carbon dioxide storage was submitted by Military University as patent no P.398228.

The method of the shale gas recovery coupled with CO₂ sequestration from the horizontal small-diameter wellbores made in single vertical wellbore was the subject of the proposed innovation.

The steps of the proposed method are presented below:

1. Firstly the horizontal wellbores have to be specially prepared in the shale gas deposit situated between solid rock beds (Fig. 3a). The existing horizontal wellbores can be also used.
2. Then the horizontal small-diameter wellbores are made circumferentially in a single vertical wellbore at a few depths (Fig. 3b).

3. The shale rock in the deepest wellbore can be initially perforated with the use of e.g. quasi-cumulative explosives. The upper not perforated horizontal wellbores are closed with the use of pins or valves. The elastic or half-elastic isolated or pre-cooled pipelines are installed in the open horizontal wellbores (Fig. 3c).
4. Then liquid cooled CO_2 is injected to the shale gas reservoir with the use of cryogenic pump. During the injection the pipelines are progressively pull out from the horizontal wellbores for the precise filling of fractures. The CO_2 injection process is finished after total pipeline pulling out (Fig. 3d). The CO_2 injection process needs a continuous control of the temperature and pressure in the wellbore.
5. The open wellbores are closed with pins or valves controlled from surface. The thermodynamical process of heating cooled liquid CO_2 in the reservoir is started. The process adsorption of CO_2 and desorption of CH_4 can last about 2 weeks (Fig. 3e). The temperature and pressure in the reservoir are controlled with the special set of sensors.
6. The upper not perforated horizontal wellbores are opened. The recovery of the shale gas can be carried out intrinsically (Fig. 3f). The whole process can be repeated for upper wellbores.

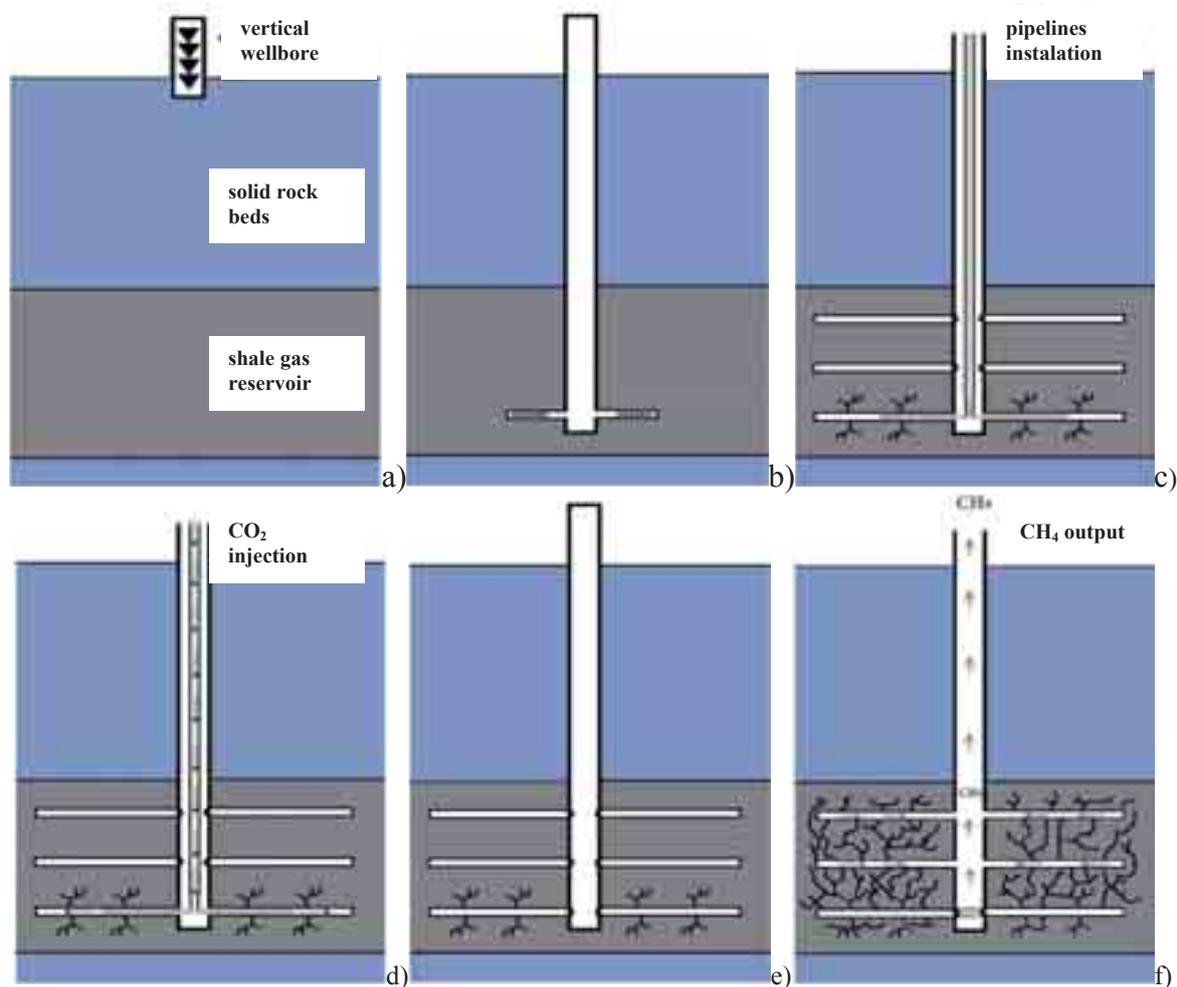


Fig. 3. Scheme of method of gas shale fracturing and gas recovery coupled with carbon dioxide storage

3. Experimental and analytical verification of the method

The method was verified on the base of analytical and experimental research.

The value of shale gas tensile strength can be found in the literature [12]. It varies between 3 and 18 MPa (depending of the shale deposit location) under the standard pressure. So if the pressure of CO_2 after heating in the deposit reaches that value, the method will be assumed to be correct.

The analytical calculations for thermodynamic behaviour of isochoric heating of CO₂ from the temperature value of -40°C (2MPa) to 120°C (temperature in the shale reservoir) and from 20°C (7MPa) to 120°C.

The calculations were carried out with the use of REFPROP (Reference Properties) computer code developed by National Institute of Science and Technology (NIST). The code calculates the thermodynamic and transport properties of industry fluids and their mixtures with special consideration of cooling agents and hydrocarbons.

The Span-Wagner equation of state was applied for CO₂ thermodynamic behaviour description. The equation is an empirical representation of the fundamental equation of Helmholtz energy. Usually the dimensionless function of Helmholtz energy $\varphi = a/(RT)$ dividend into an ideal gas part φ^0 and residual part φ^r [13] is used:

$$\varphi(\tau, \delta) = \varphi^0(\tau, \delta) + \varphi^r(\tau, \delta), \tag{1}$$

where:

τ – inverse of reduced temperature $\tau = T_c/T$,

δ – reduced density $\delta = \rho/\rho_c$,

T_c and ρ_c – temperature and density at critical point.

The analytical calculations results were presented in Fig. 4. On the base of those results it can be concluded that the final value of heated CO₂ exceeded the value of shale rock tensile strength (212MPa for starting point -40°C, 2MPa and 58MPa for starting point 20°C, 7MPa) and can cause its damage.

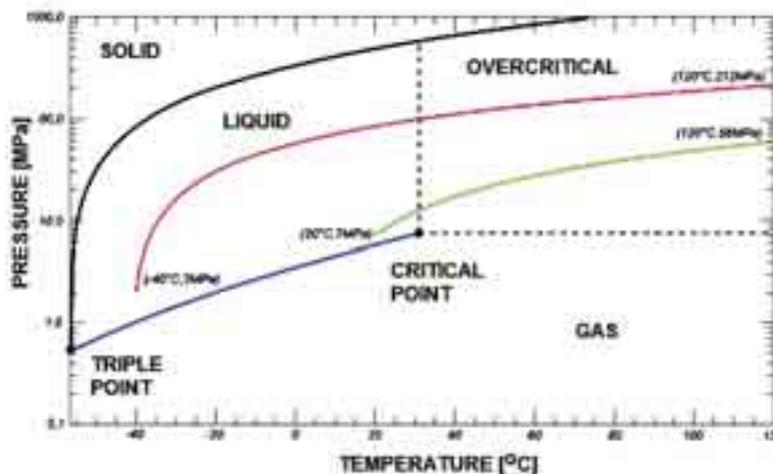


Fig. 4. Isochoric process of heated CO₂ (density of 1120 and 809kg/m³)

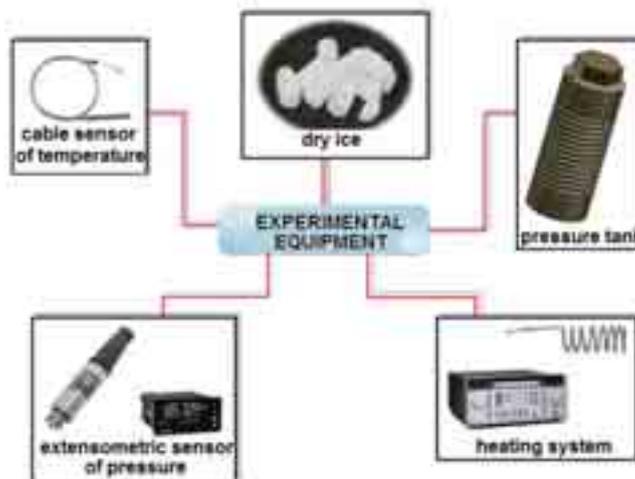


Fig. 5. Research equipment for CO₂ thermodynamic behaviour testing

For the purpose of analytical tests verification the experimental test of isochoric CO₂ heating process was carried out. The CO₂ was used in the form of solid dry ice. It was heated in the closed pressure tank from the temperature of 23°C to 97°C. The temperature was measured with the use of cable sensor and pressure was measured with the use of extensometric tensor. The research equipment was presented in Fig. 5.

The comparison of both analytical and experimental tests was shown in Fig. 6. The results showed good compatibility what proved the correctness of analytical method.

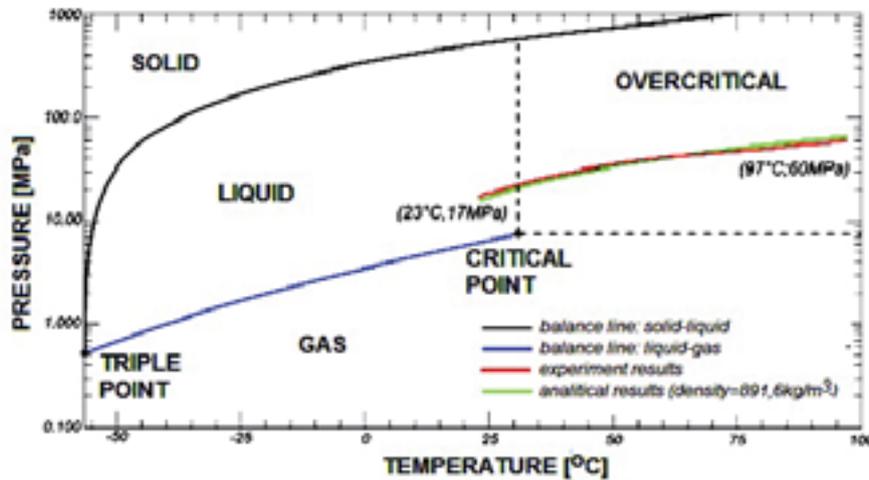


Fig. 6. Comparison of analytical and experimental tests of CO₂ heating

4. Conclusions

The conclusions of the presented research are as follows:

1. The presented research results showed the possibility of liquid CO₂ use for shale fracturing and for damage of rocks at large depth.
2. The analyses showed that the usage of liquid CO₂ of starting parameters of (20°C, 7MPa), that are close to the thermodynamic state in commonly used carbon dioxide tanks, allows to reach the fracturing pressure of shale rocks.
3. The usage of liquid CO₂ can be an alternative for hydraulic fracturing replacing currently used water and chemicals. It must be pointed that the research was carried out only for thermodynamic aspect with the assumption that CO₂ of described state (p,V) is placed in the wellbore on the described depth.
4. The presented method of the shale gas recovery is highly effective: the adsorption and desorption process is carried out at the gas molecular level.
5. Coal and shale gas deposits can adsorb two times more of CO₂ volume than CH₄ one. This property can be used for so called “clean energy” production (reached in closed cycle) – recovered CH₄ combustion for electric energy production near the wellbore and sequestration of CO₂ from that process.
6. The effective shale gas recovery needs an increase of pressure in the deposit. The proposed method allows to reach high pressure values and to increase an effectiveness of gas production.
7. The proposed method can be utilized for greenhouse gas storage after the shale gas deposit exploitation by closing the wellbore. It is an ecologically desirable effect.
8. The method do not need using a large amount of water, chemical admixtures and sand.
9. The significant economical addend value is the possibility of using only one vertical wellbore for whole process. The deep fractured area is reached, what increases the wellbore effectiveness.
10. There is a possibility of usage other greenhouse gases that are heavier than CH₄.

11. The method can be applied in various gas and porous rocks.
12. Finally it can be concluded that the proposed method of gas shale fracturing and gas recovery coupled with carbon dioxide storage is economically and ecologically effective.

References

- [1] U.S. Energy Information Administration.
- [2] Polczer, S., *Shale expected to supply half of North America's gas*, Calgary Herald 27, pp. 2-3, Calgary 2009.
- [3] Reuters, *Conoco sees promise in Polish shale gas-exec*, 9 September 2009.
- [4] Jolly, D., *Europe starting search for shale gas*, New York Times, 22 August 2008.
- [5] US Energy Information Administration, *World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States*, US Department of Energy, April 2011.
- [6] forsal.pl, *3Legs Resources found shale gas in Poland*, 22 June 2011.
- [7] Ceeconsultinggroup.com, *Shale-gas and Poland: A potential game-changer with complications*, January 2012.
- [8] *BP statistical review of world energy June 2010*, BP, June 2010.
- [9] Data of Państwowy Instytut Geologiczny.
- [10] .Kalantari-Dahaghi, A., *Numerical Simulation and Modelling of Enhanced Gas Recovery and CO₂ Sequestration in Shake Gas Reservoirs: A Feasibility Study*, Society of Petroleum Engineers, 2010.
- [11] Reznik, A., Singh, P. K., Foley, W. L., *An analysis of the effect of carbon dioxide injection on the recovery of in-situ methane from bituminous coal: An experimental simulation*, Society of Petroleum Engineers/U.S. Department of Energy 10822, 1982.
- [12] Esemé, E., Urai, J. L. et al., *Review of Mechanical Properties of Oil Shales*, Oil Shale. Vol. 24, No. 2, pp. 159-174, 2007.
- [13] Lemmon, E., Huber, M., McLinden, M., *REFPROP User's Guide Version 8.0*, National Institute of Standards and Technology, Colorado 2007.

