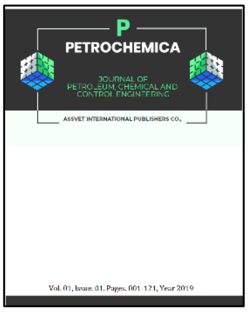

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Exploration and Estimating Recovery Rate of Oil Shale by In-Situ Combustion

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Abstract:

Shales generally have insufficient permeability to allow significant fluid flow to a well bore, most of the shales are not commercial sources of Hydrocarbon. Shale is one in a number of unconventional sources of Hydrocarbon; which include coal CBM, tight sandstones, and methane hydrates. The geological risk of not finding Shale is low in resource plays, but the potential profits per successful well are usually also lower. Due to low matrix permeability in shales, oil gas production in commercial quantities requires fracturing to provide sufficient permeability. Mainly from the natural fractures Shale gas has being produced for years. Oil shale exploration in situ processing research expands in the past recent years because it innovates the method of oil shale exploitation and enable to develop deep oil shale. But commercialization of oil shale in situ processing decreased due to the uncertainty of recovery rate which closely related to profit. The amount of oil generated during in-situ and amount of oil flowed to the surface during the oil shale in situ processing operation, this study analyses the recovery rate and effecting factors such as, the permeability and pressure variation under high temperature during the experiments. The result proves that recovery rate can be influenced mainly by formation pressure, moisture content and heating rate. According to Fischer Assay for the experiment the total recovery rate is around 60.5%. Gas injection, temperature optimization and stimulation were also performed to improve the recovery type.

Keywords: Oil shale, recovery rate, Hydrocarbon, permeability

1. Introduction

Oil shale is a great potential alternative resource which is rich in organic content and abundant reserve. It have been estimated that life-cycle of greenhouse gas (GHG) emissions from shale gas are similar to those of conventional natural gas, and are much less than those from coal, usually about half the greenhouse gas emissions of coal. The total organic carbon of oil shale with high quality can reach 50% [1]. There are 411 billion tons of equivalent oil in oil shale in the world according to recent statistics [3]. The surface rejoining was widely applied in the past few decades to get oil from the oil shale by mining and heating oil shale in the muffle furnace. However, it brings environment pollution and it will be unable to utilize deep oil shale. Oil Shale exploration is being conducted generally using Micro seismic imaging. Seismic imaging technique illustrate the 3D image of the ground along with their particular formations beneath. Various approach of oil shale in situ processing were proposed and tested in the field such as in situ Conversion Process (ICP), Electrofrac, Conduction, Convection and Reflux (CCR) and. An operation by Shell in green river oil shle deposit using ICP pilot test shows great success and they were technically feasible, meanwhile, the other technique of in situ processing pilot test were carried out in USA, Israel, Jordan and China [8]. Actually, the profit always plays important role to technology development, the final recovery rate and energy input for specific oil shale deposit are the main factor affecting profit. There are many findings which addresses about heating method to save energy input to minimize the cost. But few were addressed about recovery rate estimation. Estimation of recovery rate mainly involved how much oil and gas can be generated in place from organic material thermal degradation and how much oil and gas can be lifted up to the surface. Although a lot of work have done to examine oil yield from kerogen pyrolysis, For estimating oil content of oil shale pyrolysis Fischer Assay method was extensively used, but it is not accurate to assess oil yield for oil shale in situ processing because the reaction condition which change dratically during the operation process was different [9]. In situ process includes heating, pyrolysis and flow. Not only the pyrolysis but also temperature distribution, pressure distribution, products composition and properties, porosity and permeability change must be considered [12]. In terms of pyrolysis, some mechanism of in situ processing is still unclear partly because of the molecular structure of kerogen is in largely unknown and condition varies complicatedly and quickly. This paper discusses the challenges of oil recovery estimation and dominant factors including pyrolysis feature, porosity, permeability and pressure based on laboratory research. The methods of improving recovery rate for in situ processing are also included. Pyrolysis is performed under muffle furnace with the help of inert gas argon in the laboratory.

2. Estimation of Oil Yield In situ

Oil shale rock is composed of a solid, insoluble organic kerogen and other inorganic matter. It was acceptable that Kerogen began to convert into bitumen, oil, gas and coke when temperature reaches certain magnitude by heating [1]. There are mainly three kind of reactions during oil shale in situ processing include decomposition, cracking and coking reactions which ensures the amount of oil and gas generated [9]. Pressure plays an important factor of estimation of oil yield in situ. The oil shale layer is buried several hundred meters below the surface. Oil generation, degradation and other reaction occurs during pyrolysis of oil shale over a specific temperature and hydrostatic pressure. Using core samples with original oil content of 6.5% of Fischer Assay, taken from oil shale deposit in Cambay Basin in Gujarat, the pyrolysis experiment were conducted to study effect of pressure on oil yield at heating rate of 15°C/h, the final temperature is 300°C and duration time is 2550 min. The result indicates that th composition of products generated during a pyrolysis temperature range depend on operation pressure. The oil yield increase when temperature increases from 3 MPa to 5 Mpa and drop when temperature continues to increase up to 8 MPa. While the total HC gas deceased continuously with the pressure increase from 3 MPa to 8 MPa. It can be explained that high pressure can inhibit the reaction process which causes gas result in system volume increase. Furthermore, rejoin of gas generation is helpful to increase oil amount under relatively low pressure because the process of oil conversion to gas slows down. However, the whole reaction is being inhibited when pressure increases to certain magnitude (Figures 1 and 2). Using core sample from same layer, the thermal cracking experiment were conducted to study effect of water content on oil yield at same heating method. The results shows that hydrous pyrolysis can get more oil and gas than pyrolysis without water, oil yield increase with the moisture content increase based on experiment of hydrous pyrolysis with temperature (Figure 3), Generally, more water content will consume more energy. According to calculation combined by laboratorial data, oil shale formation with about 10 wt% moisture content would be an ideal target for in situ rejoining. The heating rate related to residence time, final temperature and products distribution, are the major importance factors to oil yield in situ oil shale processing. For in situ processing, samples are huge sedimentary rock particles which needs heating for about several month or several years because if we slow down the heating rate to about 1°C per day less oil yield would be obtained at low heating rate. For example, at a heating rate of 2°C/h, 83% of Fischer Assay oil is collected whereas at a rate of 180°C/h the yield is 99% based on Lawrence Livermore Laboratory work. It indicates that oil yield might be very less than 83% of Fischer assay oil having a heating rate of 1°C/day. The liberated shale oil can be degraded by cracking and coking reaction. So, the oil in-place is subjected to two competing process of oil degradation and oil removal. The degradation reaction will be more prevalent than oil removal at low heating rate which lead to less oil yield. The yield was determined by the time and temperature of liberated oil and not by the thermal history of the kerogen. At lower heating rate API gravity of generated hydrocarbons increase which means the oil quality is better for in situ processing [4].

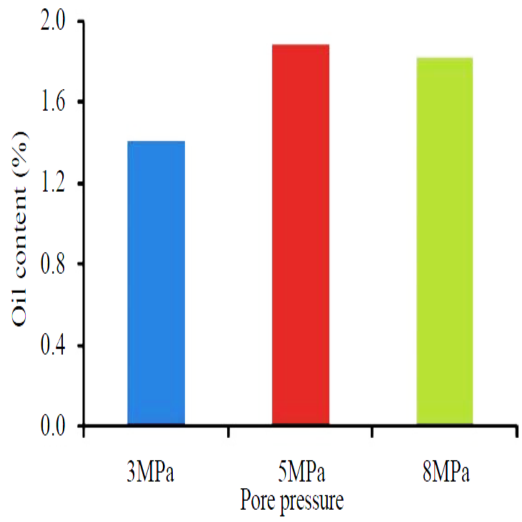

Figure 1: Oil content at different pore pressures.

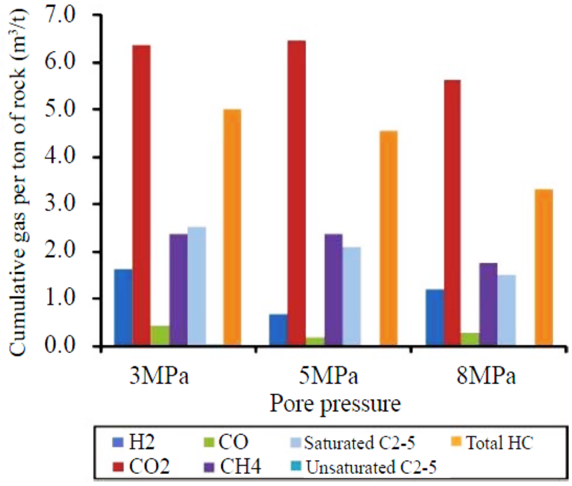

Figure 2: Cumulative gas per ton of rock at different core pressures.

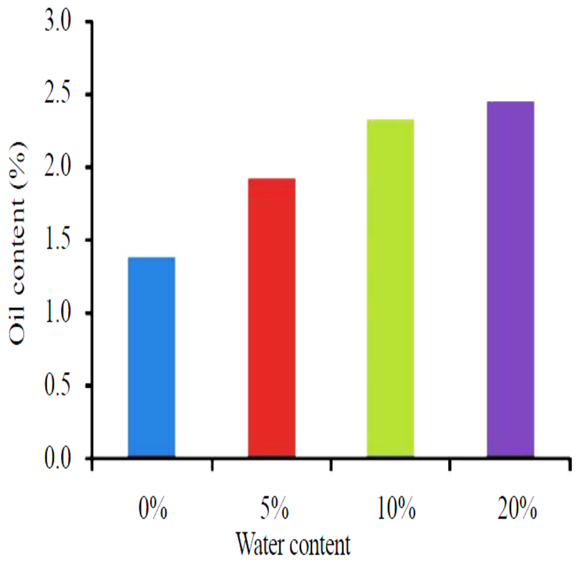

Figure 3: Oil content at different water content conditions.

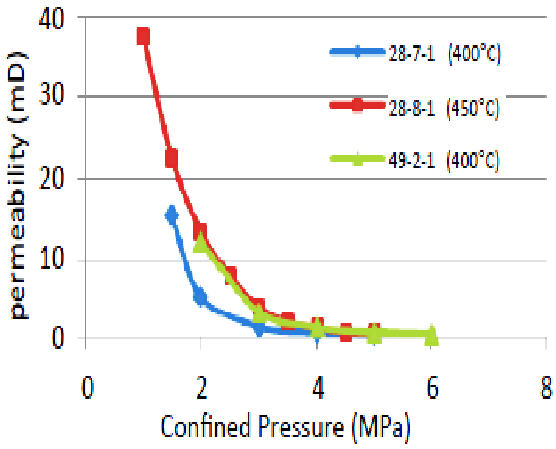

Figure 4: Permeability of oil shale after heating under confined pressure.

3. Estimation of Oil Yield on Surface

Oil yield on surface strongly holds on permeability, residual oil saturation and the pressure difference. The permeability varies with the temperature rising due to thermal expansion and pyrolysis which causes pore structure change. There is no effective approach and apparatus to measure permeability data directly during pyrolysis under high temperature such as 300°C and under overburden pressure as several million Pascal. The procedure of experiment can be prescribed as: First the initial permeability is evaluated at room temperature, and then the sample is heated to pyrolysis temperatures and then cooled to room temperature to measure the permeability again after rejoining. The results show that there is much difference between oil shale from different region by using makeshift experiment. With the temperature rising, the permeability increases at first and then drops to a minimum value followed by continues increase in pore change and fluid phase change. The stress affects the permeability usually. Permeability experiments provides the data of the strong stress sensitivity due to weak shear stress in oil shale rock. The preexisting fractures and fractures generated in the heating begin to close when confined pressure subjected on the sample. The magnitude of permeability can reach about 10 mD after heating in 400°C and 450°C under 3 MPa confined pressure (Figure 4). Actually, well testing is a reliable way to estimate the permeability if pilot test was carried out in the field. The conclusion is not be suitable for other type of oil shale resulting from different mineral composition, mechanical properties, pores structure and stress. How much oil generated would detain in formation depend on residual oil saturation which involve wettability, capillary force and properties of fluid. The experiments shows that oil shale wettability can change gradually from water-wet under original condition to oil-wet when oil release due to organic cracking. By Mercury injection Residual oil saturation can be determined for the relative permeability curve. Unfortunately, it is not easy to get the permeability curve data because the wettability and capillary pressure change result from fluid composition and pore structure change when the pyrolysis are in progress during the heating process. The oil and gas produced from oil shale rejoining area to wellbore of production well at above 300°C temperature. There is no method to achieve high temperature relative permeability curve data till now, but the residual saturation value is relatively high which is not helpful to improve the recovery rate for shale formation. The pressure difference between external fluid and internal fluid experiment is conducted to estimate the pressure increase at the heating process using core sample. With the temperature rise, the pore pressure increase. The pressure will jump high when the temperature reaches above 330°C because to organic materials starts to pyrolysis and releases fluid and gases. The pressure will increase particularly from 2 MPa to 8 MPa.

4. Recovery Rate and Improvement for in situ Processing

Recovery rate depends on both oil amount generated in situ and oil amount of oil that can flow into surface. Estimation of recovery rate for specific oil shale deposit need particular study on oil content, mineral composition, pore structure, well-pattern and heating design. The residual oil saturation of shale is generally much larger which shows low recovery rate for oil shale processing, but now it did not reflect the characteristics of oil shale under high temperature and dynamic properties of formation. In addition to that fractures and cracks generated by heating would change the pore structure which leads to different relative permeability behavior on the shale formations. In order to evaluate the final recovery rate of in situ processing, simulation experiments were performed using core samples in close system conducted at heating rate of 15°C/h and final temperature is 500°C. At the end of experiments 4.72% oil of sample weight was collected, which mentioned the final recovery rate for oil shale processing is about 60.5% of Fischer Assay oil yield. The recovery rate for oil shale in field is less than experimental data for same oil shale layer. Some alternative measures may be taken to improve the recovery rate for oil shale in situ processing. By optimizing the temperature of pyrolysis zone of oil shale, Pressure within the formation can be controlled to vary the composition of the produced fluids to allow hydrocarbons materials to be more easily removed from sedimentary formation. Well design pattern is needed to be improved for volumetric heating efficiency and sweep efficiency. Gas can be injected to formation in the last stage to provide drive energy as well as can remove liberated oil as soon as possible to reduce the degradation reaction. A reducing agent is provided to the formation which may react with hydrocarbon fragments for selected products or inhibit the production of non-selected products. Stimulation operation can be best applied in production well to provide high conductivity to allow the relatively vicious oil to flow into wellbore.

5. Conclusion

1. The amount of oil produced in situ combustion is sensitive to pressure, moisture content, heating rate for oil shale processing. A particular pressure, moisture and high heating rate tends to increase the oil yield in place.

2. Porosity and permeability will increase gradually with the temperature rise which is helpful to improve the recovery rate. From deposit to deposit the magnitude of improvement is different because of different kerogen type, mineral composition and original pore structure.

3. The fractures occurred under high temperature may cause change in relative permeability and major portion of the oil to flow out from sedimentary formation by the gas phase which require less permeability. The recovery rate for in situ processing may be reassuring comparing to data based on traditional oil residual saturation experiment.

4. The total recovery rate can reach to 60.5% of Fischer Assay oil content based on experiment using the specific core sample from the wellbore of well.

5. The recovery rate can be improved by the optimization of temperature pyrolysis zone, reducing agent injection which can increase the oil yield in situ. The gas injection in heating well in the last stage and stimulation operation in producing well establish high conductivity channel to allow liberated oil to move out quickly which is bound to oil yield on surface.

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