AN EOR APPLICATION @ LIAOHE OIL FIELD IN CHINA

Tests of Pumping Boiler Flue Gas into Oil Wells

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- ***SUMMARY***

This paper reports the preliminary test results for enhanced oil recovery (EOR) by pumping boiler flue gas (contenting 12-13 % CO_2) into an oil reservoir located at Liaohe Oil Field (LOF) in N-E China. The attached figure 2 shows a view of LOF.

The LOF is the third largest oil field in China, which is currently in production decline, and adopted pumping steam into oil reservoir for oil recovery increasing.
Driving by EOR technology by pumping CO_2 into reservoir, which is currently conducted in the world, Huafu Electrical Appliance Co., Ltd. (HF) has carried out tests by pumping 12-13 % CO_2 boiler flue gas into oil reservoir (oil well) to increase oil recovery. The application of EOR by pumping boiler flue gas is not only directly benefit to increase the oil recovery, but also promote the environment protection by CO_2 sequestration.

The phase one tests @ HF included to simultaneously (through concentrically pipe) inject steam and flue gas into oil wells for propose of a higher oil recovery without pre-mixing of them. The steam was supplied from an on-site natural gas firing boiler. Its dry flue gas

contents 12-13 % CO_2 and 3.6% excess Oxygen. The rests are Nitrogen and its oxides etc. After steam and flue gas were pumped into oil reservoir, the oil well was closed for few days to allow the pumped gases having sufficient time for diffusion and penetration along the reservoir to achieve the best oil recovery effect.

The preliminary test results demonstrated that the EOR effect by steam-flue gas pumping is great. Comparing to steam pumping only, the oil recovery has increased from 20-30 % to 50-60 %.

The tests also revealed that the refilling metal pipe has a corrosion problem, and it needs to be solved.

HF is currently undertaking tests by pumping pre-mixed boiler flue gas with water into oil well for enhanced oil recovery. HF also has planned an R&D project to inject high concentration CO_2 gas for EOR by use of the membrane technology for the purification of CO_2, which is still obtained from boiler flue gas.

- ***INTRODUCTION***

With a continuous development and utilization of oil and gas resource, the recoverable resources gradually decline. The most of existing oil fields in China have been extracted for considerably long years and now the pressure in the oil containing beds and their saturation of oil content started to decrease, the driving condition for oil recovery becomes worse. The remaining oil resource for utilization steps into a difficult stage. The oil recovery from such oil fields needs to apply enhanced oil recovery (EOR) technology for further deep extraction oil from underground. Therefore the EOR becomes a key for a high recoverability to such oil fields.

The issue of increasing oil recoverability has become a major target for secondary and tertiary oil recovery processing. Since the middle of 70's years, a method has been developed to boost the oil recovery to 90 % and above, which is to utilize the Alkanes type gaseous for enhance oil recovery.

However due to the high cost and a limited supply of such gaseous, EOR technology turns to seek a cheap resource to replace the Alkanes type EOR medium. Since 80's the nitrogen and carbon dioxide gaseous were selected to replace Alkanes gaseous and to be pumped down into oil wells for enhancing oil extraction, up to present they have almost replaced Alkanes gaseous for EOR. The enhancing effect by such common gases attracts oil industry's interesting. More such projects are undertaking.

The utility and industrial boilers burn fossil fuels to generate steam and power. The fossil fuel combustion produces flue gas, which typically contains 10-14 % of CO2; ~ 80 % of N_2 and few percentages of excess oxygen left by combustion process as its majority components. The boiler flue gas is normally exhausted into atmosphere without any utilization. It is the main green house gas being emitted into atmospheric by human

activities. Therefore the utilization of boiler flue gas is a double benefits for oil industry and for carbon sequestration.

This EOR project under taken was set based on the existing status at LOF, where either thick or thin crud oil is produced. The project was initiated by Jingzhou Oil Extraction Plant and, but is led by Huafu to execute R&D tests with jointly Jingzhou. Based on the preliminary tests by pumping CO_2 down to oil well at Block 45 #, the effect of enhancing oil recovery is quite good as expected. The application of EOR by flue gas into the shallow thick oil reserves considerably increases the recoverability. It can be applied either for a single well application, or for multiple -wells application covering a large area.

The steam is typically needed for the oil extraction for a thick crud oil reservoir, where steam is pumped down into oil containing beds in reservoir by conventional oil extraction processing. Therefore an industrial size boiler on site is set for steam supply. The flue gas from that boiler is compressed after clean treatment, then being pumped into underground oil reservoir. The effect of flue gas plays some kind of solution and mixed with the residue of the raw oil remaining in the oil bed to form an easy flowing mixture for extraction. The effective components of flue gas for EOR are CO_2 and N_2. The flue gas treatment could be a clean processing only or an enriching processing. The useless components in flue gas are the moisture and particulars. The moisture present in gas increases the chance of corrosion due to the formation of acids. The dust might cause the blockage of the flue gas passage. The pre-treatments of flue gas are de-watering and dust removing.

The technology of simultaneous pumping steam and flue gas is called “double injection” EOR technology. The hot steam provided by site boiler is pumped into an oil well along the center pipe where the space is for oil extraction when the steam injection is finished. Boiler flue gas is pumped through the external annular space into oil well. The steam and flue gas is separated until they reach oil well bottom, and they mixed with the oil residue in oil containing bed. The attached figure 4 shows the ordinary oil extraction in an oil well.

There is another technology called “double injection” EOR technology too. This type EOR is to use oil-contaminated wastewater to premix with boiler flue gas. Then the mixture is pumped into oil reserves along oil extraction pipe for EOR.

- ***ADVANTAGES OF FLUE GAS INJECTION***

1. To Enhance Oil Recovery

This is a major feature of the application of boiler flue gas injection. It increases the oil recovery a lot. It will be discussed later.

2. To Protect Oil Extraction Pipe & To Reduce Heat Loss

When the flue gas is introduced into the external annular space, it greatly improves the insulation and increases the dryness of steam at oil well bottom. Comparing to the conventional steam injection, for a 1000 meter deep well if the steam parameters at the well inlet are 15 MPa/343 C/ 70% dryness, the dryness at well bottom increases from 19% to 42 % and, the heat loss drops from 21% to 12%. The pipe wall temperature reduced from 292 C to 188 C (below the 250 C pipe temperature limit C).

3. To Increase Water Recoverability

Pumping flue gas into oil reservoir helps to drive the oil and gas mixture moving forwards to oil well for extraction. It greatly reduces the water content near well zone and improves the EOR effect for multiple steam injection process.

4. To Reduce Crud Oil Viscosity & Improve Its Flowing

The viscosity of crud oil will reduce when it saturated by flue gas. It is especially benefit for thick crud oil recovery.

5. To Improve Penetration of Crud Oil within Oil Reservoir

The CO_2 in flue gas will resolve into water to form acid and further reacts with the carbonates. It might increase the porosity of the rock in oil bed to help the penetration of crud oil in bed for better recovery.

- ***PROCESS OF BOILER FLUE GAS INJECTION***

1. The major technical steps

It includes the flue gas collecting; gas temperature cooling down for dust remove; flue gas purification; reducing gas temperature again for drying; compressing and measuring; treatments by additives mixing; pumping gas into underground.
The details can be found from the attached figure 3, the processing flow chart.

2. The scheme of the technical flow chart

The technical flow chart can be described as follows:

Steam generation →Heat Pipe Heat Exchanger →ID Fan → Sseparator →Purification

→ Pre-cryogenic for Drying →First Stage Compressor →Cryogenic for Drying →

Second Stage Compressor →Distribution & Measuring →Adding anti-corrossion

Additives →Entering into High Pressure Net System →Injecting Into Underground

The flue gas is collected from a steam boiler @ site. In order to reduce the oxygen content remining in flue gas, a on-line O_2 sensor takes the O_2 reading for combustion air control. Then flue gas is droven by ID fan and flows into a heat pipe heat exchanger for gas temperature reducing from 160 C to 40 C. The horizontal setting sidementor (separator) removes most of particulars and moisture. The gas purificator is designed to

remove the fine 1-2 micro particulars. Before gas enters the first stage compressor being boosted to 1.2 MPa, the gas humidity should be reduced down to below 40% in order to protect the compressor from corrossion. Then gas is dried by a cryogenic type cooler for a deep de-wateering processing. The very dry gas then is further compressed to 16 MPa and enters the distribution and measuring system. After being adding some additives, the pure-dry high pressure flue gas is pumped into underground through the pipe system.

3. The main technical requirements for gas injection

(1). The gas volumn for a single well injection should be greater than 3000 m3 (volumn, converted at underground comditions).
(2). The injection flow rate should be greater than 600 M3/hour.
(3). The maximum pressure of gas injection is 15 MPa.
(4) The component of flue gas should be CO_2>10%; Moisture<0.1%; O_2<2%; N_2 is around 88% and SO_2 is 0 %.

4. The Components of Boiler Flue Gas

The components of boiler flue gas is mainly depending upon the fuel as fired and combustion conditions. The EOR effect by boiler flue gas injection is determined by its CO_2 and N_2 gas contents. The more CO_2, the better EOR effect. The EOR effect by N_2 gas is less than CO_2.
But the CO_2 for EOR also has its side effects. The pressure of a mixed phase by flue gas and raw oil is higher than the pressure mixed by pure CO_2 and raw oil. The impurities in flue gas, such as O_2 , NO, CO etc. will cause the erossion of equipment if moisture presents in flue gas. At the condition of underground, the CO_2 is favor to react with the high-bitumen content raw oil and causes setting of bitumen. It therefore has a negative effect on the porosity of oil bed. In order to eliminate the corossion and bitumen setting by flue gas application, some kind of anti-corossion additives must be used.
Due to the high cost of de-SOx device of the application for boiler flue gas injection, in the first stage of the tests of the boiler flue gas application, the test flue gas is collected from a boiler firing natural gas without sulphere content. The second phase flue gas EOR project will extend tests to collect flue gas from a oil fired boiler with a De-SOx system.

5. Technical Points of Projects of EOR by Boiler Flue Gas Injection

(1). Flue gas collection
A flue gas collector is set in the flue gas duct to control the the collecting volumn for EOR application without interfer the normal work of the steam boiler. The collector is operated under a slightly positive pressure. Then flue gas is extracted by a ID fan to next steps for further treatment.
(2). Three stages de-watering and drying by cryogenic method
In order to prevent a formation of acid and avoid corossion, the three stages of de-watering and dry process are adopted to achieve a deep de-watering processing. It can effectively to reduce the risk of metal corossion by acid.
The first stage process adopts the cooling and setting, which can remove most of moisture droplets within flue gas. As estimated, if the temperature of flue gas dropped

from 250 C down to 40 C, the moisture could be reduced from 18 % to 5.5% . The gas velocity must also be proper designed for droplets setting.
The second stage applies a fiber type filter to remove droplets bigger than 1-5 micro.
The third stage utilizes the cryogenic to remove the rest of moisture. After the third stage treatment the flue gas humidity is lowered down to 7 %, i.e. equvelant to 1 g/kg.
(3). Three stage dust removing to achieve a high purification processing
The first stage dust remove is completed in separator. During the moisture condensation droplets capture dust to from gas to remove the most of particulars.
The second stage adopts a cyclone for gas purificator. It can remove particular bigger than 5 micro.
The third stage utilizes the fiber type filter to remove dust of 1-5 micro size.
(4). Two stage compressing and saving power
The first stage compresor boosts the pressure to 1.2 MPa by a screw type compressor for a better de-watering conditions, then further to compress gas to 16 MPa by a reciprocating compressor.
(5). New type anti-corossion additive application
The new type anti-corossion additive is developed. It can effectively slow down the corossion processing. This type additive can set on the metal surface, and becomes a thin film to protect surfaces.
(6). Air cooling system of compressor simplfies the system.

- ***ENRICHING BOILER FLUE GAS FOR EOR APPLICATION***

Huafu has set its second phase EOR application project by enriching boiler flue gas. The flue gas will collected from an existing oil firing boiler. The flue gas may content more or less SO_2. Therefore phase two R&D project includes CO_2 enriching and De-SOx technologies etc.

1. Flue Gas Conponents Collected from a Oil Firing Boiler

The average gas contents of a boiler firing blended oil are:
CO_2 <12%; CO<50 ppm; SO_2<0.03 %; NOx<0.06%; O_2<3.5%; N_2 from 74-83%; H_2O <0.1 %.
The flue gas, collected from an oil firing boiler after treatments for EOR application, should achieve:
CO_2>12%; SO_2<6 mg/m3; Oil<3 ppm; O_2< ppm; N_2~85%; H_2O< 0.10%; Solid particular less than 5 micro<0.05mg/m3.

2. Enriching CO2 Content by Flue Gas Recirculation

To enrich the CO_2 content in boiler flue gas, the pure Oxygen or enriched O_2 air (37.9% O_2) wiil be supplied for combustion process instead to supply air. The 82-89 % of exhast gas is recirculated back and mixed with pure O_2 for combustion. To do so the CO_2 content in flue gas can be enriched to above 60-95%.
The pure O_2 can be obtained from an existing air separation station, which is used to supply N_2 for another propose.

3. Variable Pressure Absorption (PSA) to Purify CO_2

By PSA, the CO_2 in boiler flue gas can be purified to reach 99.99%. But the operation cost is high at present, which asks a power rate of 1000 kwh per ton of CO_2.

- ***BENEFIT FOR CO2 SEQUESTRATION FOR ENVERONMENT FROTECTION***

The benefit of the boiler flue gas EOR application on environment is one of the tasks of boiler flue gas EOR application project.

The LOF, the third largest oil field in China, has 180 industrial steam boilers to generate 3200 t/h steam for daily oil production. The total boiler flue gas emitted into air is 3 million t/h.

The surronding areas have several chemical planta and power plants. The emitted CO_2 amount into air are considerably large.

Therefore the application of the boiler flue gas for EOR has doule benefits. It is not only good for oil recovery but also it reduces the green house gas emission and in turm brings benefit to environment.

- ***TEST RESULTS & ITS ECONOMIC ADVANTAGES***

1**. Test Oil Field**

The Jing Block NO. 45 is a 890-1180 m shellow thick oil resovior. The density of raw oil is 0.978 g/cm3. The visicosity of the raw oil at ground after de-air is 497-7697 mPa.s. The content of bitumen varies from 26.8-38.1%.

Since 1984, the oil recovery by steam injection has been already applied at Liaohe. Each single well, in average, had conducted 7.6 times of steam injection-oil recovery processing for EOR propose. The total recovered oil amounts were 12.06 million tons. The acumulated steam amounts being injected was 18.62 million tons. The ratio of recovable oil vs. the steam injected was 0.7 t/t.

Now some of the oil wells have no oil being extraction with steam injection.

2. Test Conditions of Double Injection

The double injection tests by steam and boiler flue gas were started @ well No. 13-12 in Aug. 1998. This well has already no oil being extracted with steam injection. In order to demostrate the effect of EOR by boiler flue gas injection, HF decided to select it for double injection tests.

The composition of boiler flue gas varied depending the natural gas as fired which was supplied from Jing Block 45. The composition of the natural gas is:

CH_4-97.9%; C_2H_6-0.28%; C_3H_8-0.04%; CO_2-1.15%; N_2-0.57% and no Sulpur.

The composion of flue gas firing the above natural gas, per analysis, are

CO_2-12.4%; N_2-83.98%; O_2-3.6%; CO-0.02%; NO-undetectable; H_2S-non;

The parameters of steam being injected:

Pressure-8.17 MPa; Rate-17 t/h; Dryness-63.1 %; Temerature-296 C; Acumulated injected amount-2500 ton.

The parameters of boiler flue gas injected:
Pressure-8.17 MPa; Rate-600 M3/ h; Moisture-non; Temperature-58 C; Acumulated injected amount-86400 m3.

3. Double Injection Tests

The steam and boiler flue gas were simutantly injected into oil bed. The double injection process was finished in Aug. 25, 1998. The acumulated amount of steam and flue gas injected was 2500 tons and 86400 NM3 respectively. The injected gas volumn is equvelent to 2690 M3 at the underground condition of oil bed. The well then was closed for 4 days and re-opened in Aug. 8. Due to the leakage of oil extraction pump, the well was re-closed until Sept. 3. The liquid extracted was 65 ton and contented 95,4% water at that day. The well was closed again allowing sufficient time for penetration of gases with in oil bed. In Sept. 5, the well was re-openned and, the raw oil extracted increased to 43 t/day. Upto Sept. 16, the daily liquid extraction remains at 50 t/day with 50 % water content.

Meanwhile tests @ second oil well-049-35 started inAug. 29,1998. The injection rate of boiler gas was 600 m3/h, but the gas pressure/temperature was increased to 11.7 MPa/60 C. The test results confirned a great EOR effect by boiler flue gas injection, which will be reported later.

4. The Eonomic Effect by Double Injection

The double injection by steam and boiler flue gas has demostrated advantages. Comparing to a single steam injection and, taking the results received from Well# 13-12 as an example, the advantages may be concluded as follows:
(1). The enhanced oil recovery effect by boiler flue gas is great. The dead well can be re-extracted oil by double injection,
(2). The flue gas injection great reduces the heat loss from steam injected and, the loss of steam dryness at well bottom, 907 meter depth, was only 4.3%. The flue gas injection can replace the insulation pipe or N_2 injection for heat insulation propose.
(2). The plunger pump can be applied for this case to save a lot of underground work.
(3). Comparing to a single steam injection, 1000 tons steam, i.e.more than one third, can be saved due to the double injection.

Based on the above points, 160000 RMB cost can be saved for one injection per oil well comparing to the one injection by steam only.

The remaining problem is to find a solution for the metal pipe corrosion.

• *CONCLUSIONS*

These preliminary tests of double injection may be concluded as follows:

1. The EOR effect by boiler flue gas injction is great.
2. The economic benefits are attractive.
3. It demostrates a way for Carbon Sequestration.
4. More tests are planned.

- ***ATTACHMENTS***

1. Table 1—COMPARISION CHART

	(Steam + Flue G) Double Injection	***Steam Injection Only***
Steam Heat Loss		
1. Steam T C	***292 C***	***343***
2. Steam Dryness %	***63.1***	***70***
3. Dryness @ Bottom %	***42***	***19***
4. Heat Loss in pipe %	***12***	***21***
5.Pipe Temperature C	***188 less 250C limit***	***292 pass 250 C limit***
Increasing water recoverable		
1. Daily liquid rate ton	***52***	***non***
2. water content %	***50***	***non***
3.dialy oil production ton	***26***	***non***
Saving work load		
1. under well work	***pluger pump use no more work***	***two more work***
2. work cost	***saving 50000 RMB***	***needs 50000 RMB***
3. insulation pipe cost	***no pipe save 50000 RMB***	***pipe cost 50000 RMB***
Reducing steam amount		
1. steam amount and cost	***save 1000 t, 1/3 of total***	***no saving***
Total cost saving		
Per well per injection	***160000 RMB***	***no saving***

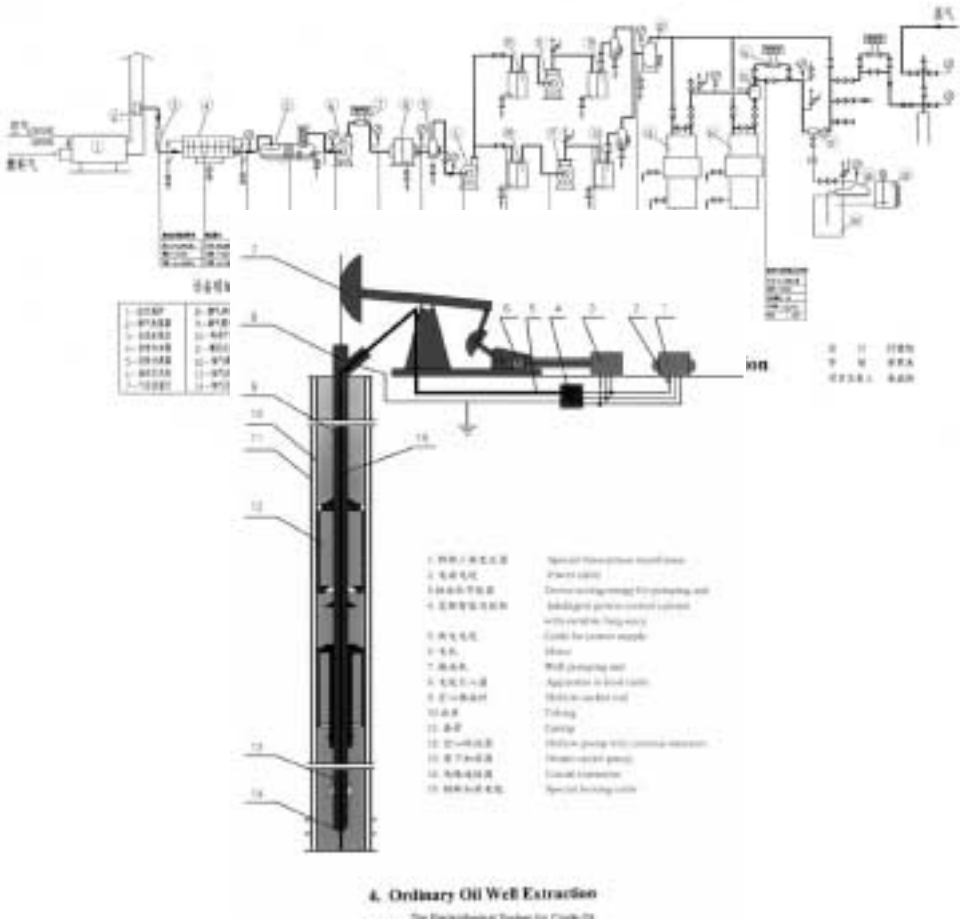
2. A View of Liaohe Oil Field

3. Flow Chart of Double Injection

4. Ordinary Oil Well Extraction

Liaohe Oilfield Development Corporation of Liaohe Oilfield has been exploiting resources of extra and super heavy oil depending on the progress of oil & tech. and has realized a productive capacity with annual output of million tons of crude oil throughout three years.

2. A View of Liaohe Oil Field



4. Ordinary Oil Well Extraction