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Experimental Study on the CO_2 Fracturing Mechanism

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ABSTRACT

The amount of CO_2 being used as fracturing fluid has been more than 30,000 tons at Changqing oilfield in 2022，Which above several times over the sum of the last five years.A serials of experi-ments and experimental analyses devoted to the CO_2 fracturing me-chanism were conducted in order to provide some advices for the CO_2 fracturing treatment design and improve the well performance. An experimental analysis of the CO_2-core leakoff experiments was made which compares the leakoff characteristics under the liquid and gas phase of CO_2.The plot for the square-root time vs.leakoff rate be got.Two sets of CO_2 fracturing physical simulation experiments on the cores of 762 × 762 × 914.4mm were carried out，which compares the fracture's geometry and size with the slick water's experimental results.The mechanism of rock breakdown pressure's decrease with CO_2 fluid is researched based on the Elasticity mechanics and the Fracture Mechanics theory.The results show that CO_2 has a very high leakoff rate within the core which leads to a lower breakdown pressure value and a smaller fracture size and an excellent capacity for complicating the rock's fractures than the conventional fracturing fluid.

Keywords: CCUS, CO_2,CO_2 fracturing,CO_2 leakoff,leakoff experiment,fracturing simulation

NONMENCLATURE

Abbreviations	
CO_2	Carbon Dioxide
Symbols	
Б	Stress

1. INTRODUCTION

More and more CO_2 being used as fracturing fluid in oilfield in recent years.The amount of CO_2 being used as fracturing fluid has been more than 30,000 tons at Changqing oilfield in 2022，Which above several times over the sum of the last five years. An enhancement for the fracturing fluid's flow back after the treatment has been recognized that the CO_2 fracturing saved a lot of times and reduced the cost spent on the uplift when the fracturing fluid could not flow back independently.

In addition to the uplift ,the people have been concerning on the stimulation performance.There are two important issues need to be figured out:What about the fracture's geometry and size fractured with the CO_2 fracturing fluid?What's difference between CO_2 fracturing fluid and the conventional?

In order to address these issues and give some advices to the fracturing design job.

The paper illustrated the studies result from the core leak off experiments and the core fracturing physical simulation experiments and the analyses based on the Elasticity Mechanics and the Fracture Mechanics.

2. THE FRACTURING PHYSICAL SIMULATION EXPERIMENTS

2.1 Specimen

A natural sand stone and an artificial cement specimen were used as the rock specimens in this study.

The natural sand stone,which was quarried from Chang6 formation located in Shaanxi province of China,has no any cracks or fissure obviously,and it mainly consist of quartz,orthoclase and clay.The artificial cement was made of the cement of G-grade used for the well cementing process and within which two artificial bedding planes paralleled to the minimum horizontal stress were prefixed.

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The size of specimen was 762 × 762 × 914.4mm,and the hole with the diameter of 25.4mm was bored .

2.2 Experimental system

Fig. 1 shows the schematic diagram for the experimental system.The experimental system mainly consists of the true triaxial compression machine,the supplying system of the CO_2 fluids,and the measuring system.Fig.2 shows the rock specimen set in the true triaxial compression machine.Three compression stresses were applied to the specimen using three hydraulic rams of the true triaxial compression machine.The super CO_2 was used as the fracturing fluid and was injected into the borehole of the specimen.

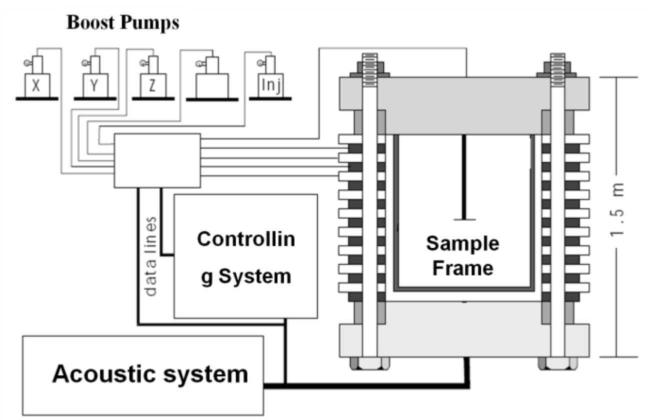


Fig. 1. The Diagram for the Physical Simulation Hydraulic Fracturing System

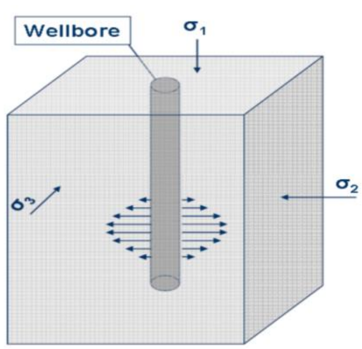


Fig.2.The Diagram for the Specimen and Wellbore and Stresses Loading

Tab.1.Experimental conditions for the CO_2 fracturing experiments

Fracturing fluid	Specimen	Permeability (mD)	Flow rate (L/min)	CO_2 pumping volume(mL)	Stress condition(MPa)	Temperatue (℃)
CO_2	A natural sand stone(Chang 6)	3.0	1.2	2886	Б3=10 Б2=15 Б1=20	41
CO_2	An artificial cement	0.02	0.24-0.48	2884	Б3=12 Б2=15 Б1=20	34
Slick water	A natural sand stone(Chang 6)	3.0	0.015-0.15	1897	Б3=7 Б2=14 Б1=21	20

The CO_2 gas was supplied from the gas storage tank and was pumped into the wellbore by a cylinder pump.The temperature of the CO_2 was controlled and conditioned through an unit of heating/cooling system outside of the flow lines.

2.3 Experimental conditions

Table 1 shows the experimental conditions for the CO_2 fracturing experiments.We first used supercritical CO_2 as the fracturing fluid.The flow rate were 1.2L/min and 0.24-0.48L/min.Then,we used red slick water with the viscosity of 5 mpa.s as the pumping fluid to colored the fracture walls.The colored specimens were cut with a rope saw,and the cut surfaces were scanned by the image scanner.We traced the fractures from the scanned images,and calculated the sizes of the fractures by a software.The traced images were arranged to the cubic form to clarify the fracture shapes obtained for the each condition.

2.4 Results and discussion

<u>2.4.1Pressure during the fracturing experiments</u>

Figure 3 and figure 4 show the pressures during the fracturing experiments using the CO_2 with flow rate of 1.2 L/min and 0.24-0.48 L/min.After the CO_2 was supplied,the pressure increased rapidly firstly.Then,the pressure keep constant approximately till the pump was shutdown.Compared the both of pressure curves,it could be seen that the breakdown pressure with the cement specimen was lower and more obvious than the sand stone specimen's.The reason due to that the treatment pressure of the sand stone specimen was higher than the cement's is that the pump rate of sand stone was bigger.After the pump rate was shut down,the pressure dropped to approach the minimum stress of the specimens.

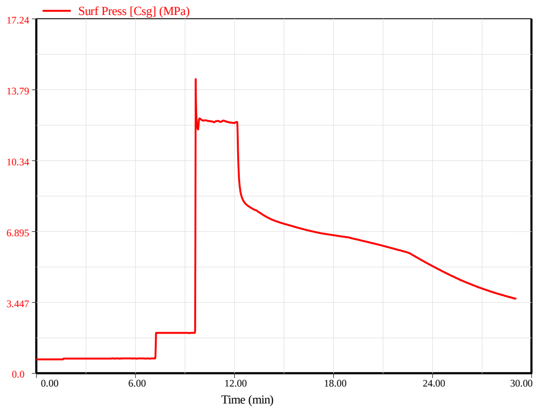


Fig.4. Fracturing pressure plot for the specimen of artificial cement

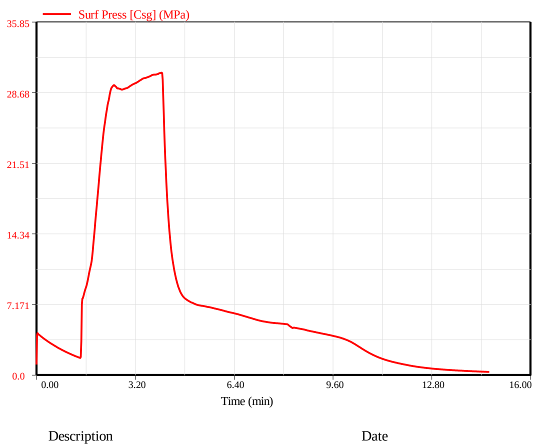


Fig.3.Fracturing pressure plot for the specimen of Chang 6 sand stone

2.4.2Fractures created by the CO_2 fracturing experiments

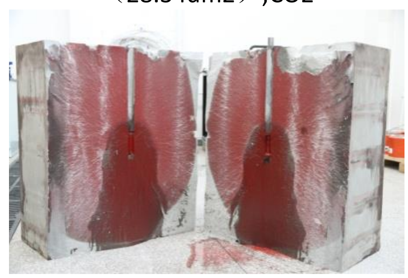
Fig.5 shows the perspective views of the fractured specimens.Fig.5(a),(b) are the perspective views of the fractured specimens pumped with the CO_2,while (c) is that obtained with the slick water.It could be seen that the fractures are all the ones of single fracture.The size of the fractures were calculated with an AUTO CADE software that they are 8.14dm2, 28.34dm2 and 58.72dm2 ,respectively.We found that the fracture's area created by the CO_2 is only 13.86% of the slick water's with the same kind of specimen of sand stone.And the fracture's area within the sand stone specimen is 28.7% of the artificial cement specimen's.

2.4.3Penetration depth of the CO_2

It's known that the volume of CO_2 pumped and the fracture's area.The penetration depth of CO_2 could be calculated that the volume of CO_2 lost was penetrated into the specimen.We calculated that the average penetration depth of CO_2 within the sand stone specimen is 35.5mm, the average penetration depth of CO_2 within the artificial specimen is 10.2mm.However, the average penetration depth of slick water within the sand stone specimen is only 3.2mm.

Main results obtained in this study can be summarized as follows:The fracture's area created by the CO_2 is very sensible to the permeability of the specimen.The capability for fracturing of the CO_2 is weaker than the slick water very much.

(a)Sand stone（8.14dm2）, CO2 (b)Cement （28.34dm2）,CO2



(3) Sand stone（58.72dm2）,slick water

Fig.5.Perspective views of the fractured specimens

3. *ANALYSES ON THE LABORATORY MEASUREMENTS OF LEAKOFF FOR CO_2[14]*

A paper titled " Field and Laboratory Measurements of Leakoff Parameters for Liquid CO_2 and Liquid CO_2/N2 Fracturing " was published in 1997.The paper introduced CO_2 leakoff experiments on the sandstone cores.The main points what we concerned are summarized as follows:

3.1 Cores used

A paper titled " Field and Laboratory Measurements of Leakoff Parameters for Liquid CO_2 and Liquid CO_2/N2 Fracturing " was published in 1997.The paper introduced CO_2 leakoff experiments on the sandstone cores.The main points what we concerned are summarized as follows:

3.2 Experimental equipment

Liquid CO_2 was maintained at 10MPa in the top of an accumulator in the injection line by means of N2 gas underneath the accumulator piston(Fig.6).At the beginning,2L of liquid CO_2 was exposed to the core by opening a valve in the injection line.The injection line included a 30cm long concentric tubing section(with -

20℃ to -25℃ glycol-water in the annulus) to keep the CO_2 temperature at about -20℃ as it flowed through the pressure vessel wall to the core-holder inlet.

Thermocouples were placed every 5 cm along the core starting at the core inlet and ending at the core outlet.The thermocouples were along the central axis of the core,and were inserted from the side of the core.

A dry gas meter was to used to measure the rate at which gas exited the core.

Tab.2.Summary of results of Runs Frac1 -Frac4[14]

	Frac1	Frac2	Frac3	Frac4
Estimated initial water saturation (%)	0	0	49	49
Pre-Run Kg(mD)	120	120	6	8
Lowest core inlet temperature during injection（℃）	-	-18	4	-9
Lowest core temperature(5cm from core inlet) during injection（℃）	-	-16	16	15
Injection pressure at end of injection period (MPa)	1.3	2.4	10.4	9.8
Core mid-point pressure at end of injection period(MPa)	1.3	2.4	1.2	6.5
Pressure drop in front half of core at end of injection period(MPa）	<0.1	<0.1	9.2	3.3

3.3 Experimental procedure

There were two sets of leakoff experiments :the first set using two dry cores and the second using two cores flooded with saline solution.

In the first set of experiments (Frac1 and Frac2)the core's permeability was 120mD.

In the second set of experiments9(Frac3 and Frac4) the core was flooded with 4300PPM saline solution first.CH4 was then injected to displace excess saline solution from the core until a constant pressure drop was obtained.The total length of the CH4 injection period was 2.87h.Following this procedure ,the gas phase effective permeability was 6-8mD,and the water saturation was 49%.The core was exposed to the liquid CO_2 for 5 minutes and then the injection valve was closed.

Core temperatures and pressures were recorded every 1.5 seconds.Cumulative gas production was recorded every 15 seconds for the first 10 minutes and subsequently,every 30 seconds.

3.4 Discussion of results

The first two leakoff experiments(Frac1 and Frac2) involved exposing a 100% CH4 saturated core to liquid CO_2 at 10MPa.The core was at pressure of 1MPa initially.In these two experiments,a high flow rate was obtained due to the high permeability (120mD).Essentially all of the 500 std L of the CO_2 in the injection accumulator passed through the core in the first 1.5 minutes that's equivalent to a leakoff rate of 260,000 std L/m2/min.

In runs experiments of Frac3 and Frac4,the Berea sandstone core had a low gas phase permeability due to the presence of saline solution(4300PPM).For these runs,the produced gas rate after the initial 1.5 minutes was in the range of 900 -1,800 std L/m2/min.

In runs experiments of Frac3 and Frac4,the temperature at the inlet of the cores in experiments of Frac3 and Frac4 was 4 ℃ and -9℃ and the pressure drop was 9.2 MPa and 3.3 MPa respectively.The CO_2 was during the transition range between the gas phase and liquid phase in Frac3.However the CO_2 was under the liquid phase in Frac4.

Main results obtained in this study can be summarized as follows:The leakoff rate of CO_2 was very high especially within the cores with high permeability.Most of the pressure drop is in the part of the core where CO_2 vaporization occurs.It means that the vaporization for CO_2 could reduce the rate of leakoff of CO_2.

4. MECHANICS ANALYSES BASED ON THE ELASTICITY MECHANICS AND FRACTURE MECHANICS

The concentration of stress near the wellbore is known widely which shows the stress is higher where the distance is closer to the wellbore.Tab.3 shows the stress values located in the different distance to the wellbore in an specific simple plane stress model based on the Elasticity Mechanics theory.This explain why the breakdown pressure of CO_2 fluid is lower than the conventional fracturing fluids which come from the high penetration depth for CO_2.

In the Fracture Mechanics theory,the crack tip's stress intensity factor is the function of the length of the crack(KI=б(πa)0.5).This explain the CO_2 fluid achieved

Table3. The stress distribution in an specific simple plane stress model.

Distance to the wellbore (R=wellbore diameter)	Stress(б=boundary stress)
R	3б
2R	1.22б
3R	1.07б
4R	1.04б

more depth in the crack could create more complicated fracture nets compared to the conventional fluids.

5. CONCLUSIONS

In this study,the CO_2 fracturing experiments were conducted on 762 × 762 × 914.4mm sandstone and artificial cement specimens,the CO_2 core leakoff experi-ments were carried out on ¢3.8cm*30.48cm sandstone cores.Main results obtained in this study could be summarized as follows:CO_2 fracturing fluid has a very high leakoff rate with which the fractures' area was smaller prominently than the slick water's.Most of the pressure drop is in the part of the core where CO_2 vaporization occurs.The leakoff rate is controlled by the rate at which liquid and gaseous CO_2 can flow through the formation.CO_2 with high leakoff rate is better in lowering the rock breakup pressures and complicating the fracture net.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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