Scientia Iranica, Vol. 15, No. 4, pp 502–506

SCIENTIA
IRANICA

Research Note

Effect of Permeable Contacts on the Performance of a Gas-Oil Gravity Drainage Mechanism in a Stack of Matrix Blocks

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In the gas invaded zone of a well fractured carbonate reservoir, gravity drainage mechanism plays the main role in expelling oil from dense, low permeability matrix blocks. Whenever the active mechanism is gravity drainage, reinfiltration and capillary continuity phenomena notably influence the rate and amount of oil recovery from matrix blocks. In the current research, six experiments were performed to study the effects of a permeable contact area (between two blocks located on top of each other) on reinfiltration and capillary continuity. Two of the experiments were performed using single blocks of 30 and 60 cm height, whilst others were stacks of two 30 cm high blocks. Results of the experiments reveal that, by increasing the permeable contact area between blocks, due to capillary continuity and reinfiltration, there will be more communication between them, consequently, both ultimate oil recovery and production rate will improve. It is also noticeable that, if the permeable contact area is approximately greater than 20% of the total block surface area, the stack of blocks behaves analogous to a unique block with a height equal to that of the stack. The outcome of the present work, along with data from other studies, such as the effects of horizontal fracture apertures and fracture dips, can be utilized in order to have a better understanding of block to block effects. By this, the modeling of the gravity drainage mechanism, while injecting gas into fractured carbonate formations, would be improved.

INTRODUCTION

In the gas invaded zone of fractured carbonate reservoirs, oil is produced by gas-oil gravity drainage mechanism. Capillary and gravity forces interact with each other and affect oil recovery and the performance of this mechanism [1]. The magnitude of either force is determined by the physical properties of the rock and fluids. The production rate and total recoverable oil from a single matrix block surrounded by gas is a function of gas-oil relative permeability, capillary pressure and matrix height [2]. In a stack of blocks, as well as the mentioned factors, fracture parameters and phenomena such as reinfiltration and capillary continuity, significantly affect the system performance.

Reinfiltration and capillary continuity have been formerly studied by various researchers. It is well established that the flow of oil in the gas invaded zone will be, to a large extent, through the matrix rather than through high permeable fractures [3-7]. Saidi [8] studied the process of block to block flow within a column of matrix blocks that were not in contact with each other. He concludes that, if the fracture aperture is about 50 μm or more, the capillary continuity between a stack of blocks cannot be realized [8]. Jerome Vidal and Elf Aquitaine also performed some experiments to outline factors affecting the reinfiltration phenomenon and the effect of capillary continuity on flow distribution between the fracture and the matrix [9]. In 1994, Firoozabadi and his coworker suggested that if more liquid bridging occurred across a horizontal fracture, more total flow would occur through it and final recovery would be improved [10].

It is known that, by enhancement in block contacts, more liquid bridges will form and final oil recovery will improve. Furthermore, by decreasing the fracture aperture and increasing the contact area, the recovery rate from the stack of blocks will improve. The purpose of this study is to quantitatively demonstrate the effect of a permeable contact area on reinfiltration

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and capillary continuity and its effect on the fluid transmission between blocks.

EXPERIMENTS

In the current research, six experiments were performed. Two of them were carried out employing single 30 and 60 cm high blocks and four were stack block experiments, in which two 30 cm high blocks were used.

Single block experiments were performed in order to have two standard minimum and maximum extreme bases for the obtained results. As two 30 cm high blocks were employed in the stack block experiments and the minimum ultimate oil recovery of such a system would be the same as the ultimate recovery of a 30 cm block and production rate of a single 30 cm block times two, a single block test using a 30 cm high block was performed. On the other hand, since the maximum ultimate oil recovery and production rate of such a system would be that of a 60 cm high block, a single block test, implementing a block with that height, was undertaken.

Experiments three to six were stack block tests with different fracture conditions. A fracture with a 1 mm aperture was present between the blocks in these experiments, which was filled with different amounts of glass beads to create permeable contacts with various areas between the blocks. In Experiment 3, the fracture was not filled and just one 1 mm diameter glass bead was placed between the blocks to maintain a 1 mm fracture aperture (Figures 1 and 2). In Experiment 4, four 1 mm diameter glass beads were placed in the fracture (Figure 3) and liquid bridges could be formed around theses particles throughout the experiment. By

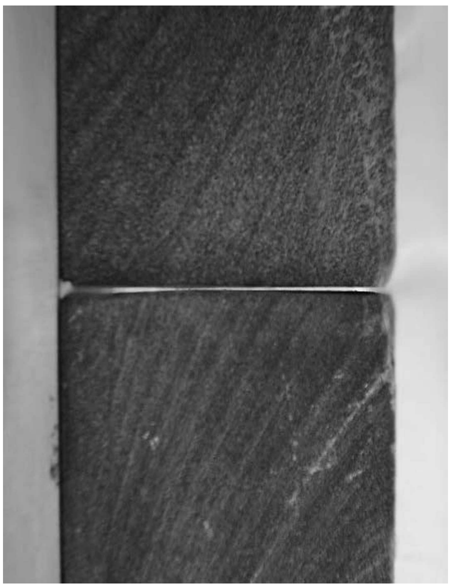

Figure 1. 1 mm aperture between blocks in Experiment 3.

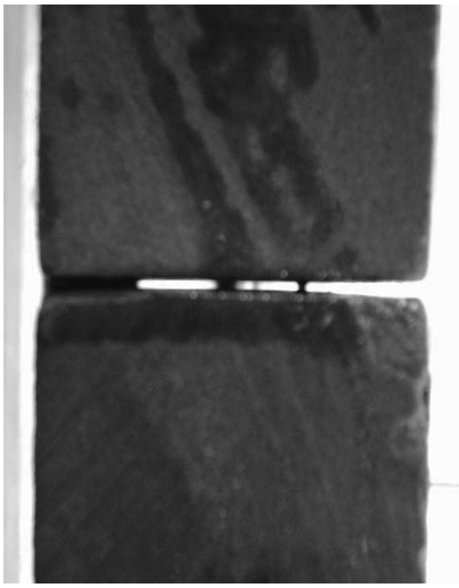

Figure 2. Liquid bridges formed between blocks in Experiment 3.

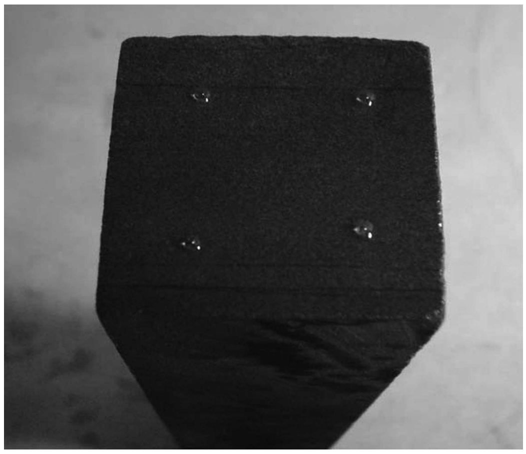

Figure 3. Glass beads placed between the blocks in Experiment 4.

subtracting the size of the glass beads from the size of the liquid bridges and taking into account the fracture plane area, it was considered that about 0.5% of the total block surfaces were in contact with each other via the liquid bridges. In Experiments 5 and 6, 0.5 mm diameter glass beads were placed in the fracture (Figures 4 and 5) and 1 mm glass beads were used to maintain the fracture aperture. Using different amounts of 0.5 mm particles, 5.0% and 20% of the total block surface area were covered in these two tests.

In addition, it should be noted that, by use of some tiny spacers, the lower block was placed about 2 mm above the inferior plane covering the bottom of the system (in all experiments), otherwise oils expelled from the matrixes would have filled the space between the matrix and the apparatus walls (vertical fractures around the blocks) and would have had to flow all the

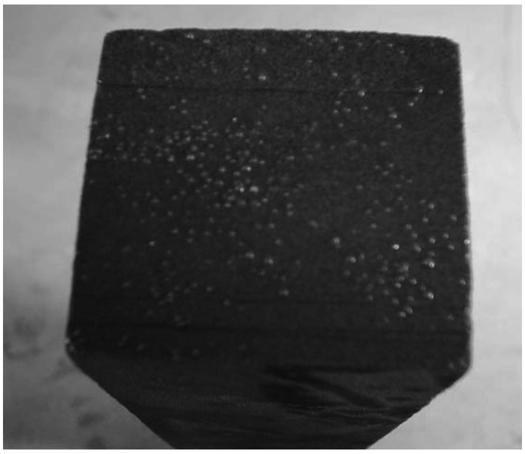

Figure 4. Glass beads placed between the blocks in Experiment 5.

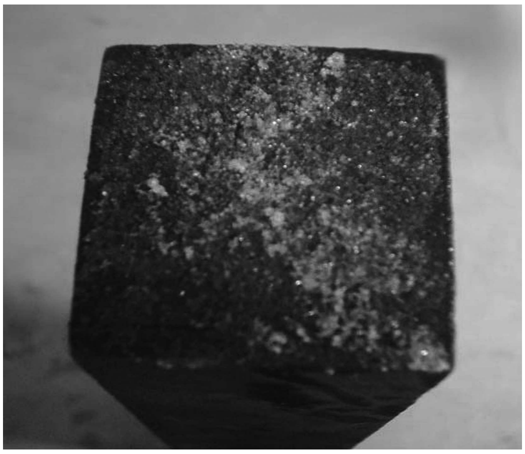

Figure 5. Glass beads placed between the blocks in Experiment 6.

way through the inferior matrix block to be produced via the vent. Such a case could have led to great errors. On the other hand, it was not desired that the bottom plane of the lower block be in contact with the expelled oils in order to compare the results of these experiments with other useful data and the work of others.

MODEL PREPARATION AND EXPERIMENT PROCEDURE

In order to prepare the models for the experiments, the following efforts were applied:

1. The models were washed with toluene with a conventional apparatus for about 48 hours. After the models were completely clean, they were placed in the oven for 48 hours to be dried out;
2. Subsequently, clean, dry models were put in the apparatus. Figure 6 depicts a schematic of the apparatus that was used to perform the experiments;
3. Afterwards, the system was vacuumed for about 4 hours and then saturated with dead oil (Table 1 presents useful liquid properties);
4. By opening the upper (vent to the air) and lower valve, oil could be expelled out of the blocks by gravity force and the total oil recovery was recorded versus time. Experiments were performed at room conditions (pressure and temperature).

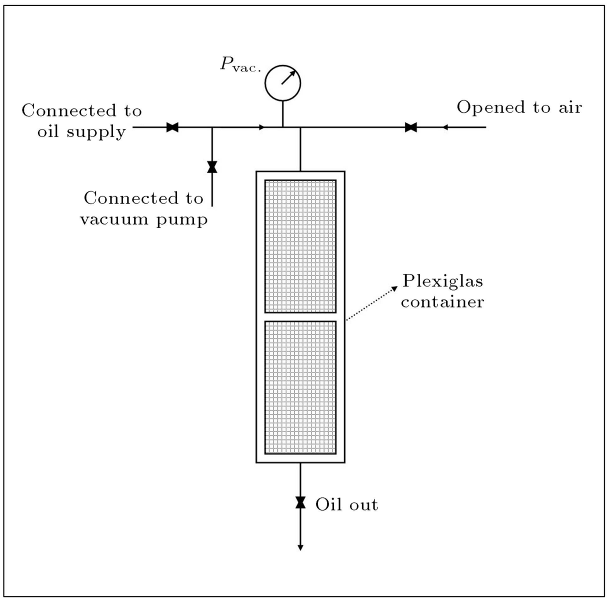

Figure 6. Apparatus used to perform experiments.

RESULTS AND DISCUSSION

Results of the experiments are briefly described in Table 2. Graphs of the oil recovery and oil production rate versus time are also depicted in Figures 7 and 8 for all performed experiments.

- At the beginning of Experiment 3, the oil present in the horizontal fracture was not completely produced and the blocks were in capillary continuity. This improved the gravity force and, consequently, as it has been observed, the primary oil production rate in this experiment was more than two independent 30 cm matrix blocks. But, as time transpired, the oil present in this fracture, along with oil that was draining from the upper block, was imbibed

Table 1. Important rock and fluid, physical properties.

Rock Properties		Fluid Properties	
Permeability (md)	320	Oil used to perform the experiments was synthetic oil	
Porosity (%)	28	Density (gr/cc)	0.88
Size of the blocks	$6 \times 6 \times 30$ cm^3 $6 \times 6 \times 60$ cm^3	Viscosity (cp)	5

Table 2. Summary of the experiment parameters and results.

Exp. NO	Type	Length of the Block (s)	Pore Volume	Fracture Aperture	Area of the Permeable Contact	Recovery Factor	Initial Production Rate (cc/hr)
1	Single	30 cm	303 cc	—	—	42 %	77
2	Single	60 cm	607 cc	—	—	54 %	135
3	Stack	60 cm	604 cc	1 mm	0 %	43 %	81
4	Stack	60 cm	604 cc	1 mm	0.5 %	44 %	85
5	Stack	60 cm	604 cc	1 mm	5.0 %	49 %	96
6	Stack	60 cm	604 cc	1 mm	20 %	53 %	115

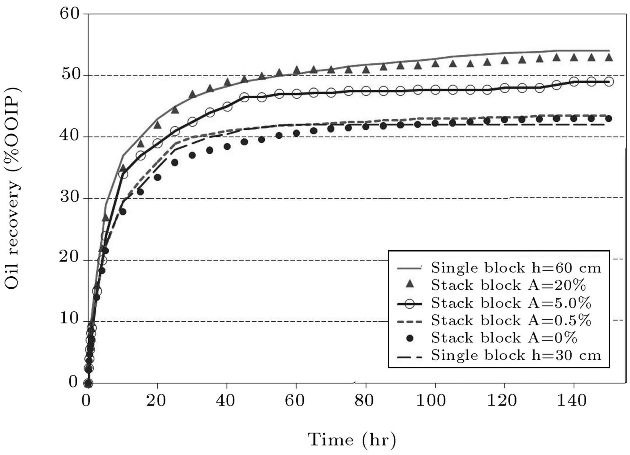

Figure 7. Graph of oil recovery factor vs. time for the experiments.

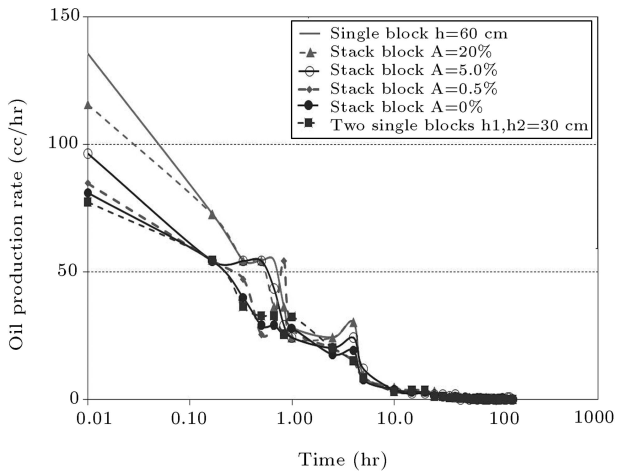

Figure 8. Semi-log graph of oil production rate vs. time for the experiments.

into the lower block and, despite some temporary liquid bridges, there was no connection between the blocks. Consequently, the oil production rate from stack of blocks in Experiment 3 was somehow analogous to two independent blocks. Furthermore, it should be noted that the final oil recovery factor in Experiment 3 was almost the same as Experiment 1 and does not weaken Saidi's statement [5];

- Four 1 mm glass beads that were used in Experiment 4 created four permanent sites, in which liquid bridges were formed between the blocks throughout the experiment. However, the area covered by these liquid bridges was not comparable with the fracture plane surface area. Consequently, the physical conditions of this experiment were comparable with that of Experiment 3 and the obtained results from Experiments 1, 3 and 4 were almost the same;
- In the last two experiments, where 5% and 20% of the fracture between the blocks was occupied by a permeable medium, 49% and 53% of the OOIP was recovered. The results of these experiments reveal that increasing the permeable contact area between blocks, on the one hand, would recover more oil and, on the other hand, would drastically improve the drainage rate. This observation confirms earlier works by Firoozabadi et al [1,3];
- Furthermore, it is noteworthy that, in Experiment 6, where 20% of the fracture was filled with glass beads, the oil recovery graph is comparable to experiment 2, where a single 60 cm high block was used. It can be deduced that, if the area of permeable contact between blocks exceeds a certain value (dependent on the system's physical properties) the stack of blocks will behave analogous to a single block with a height equal to that of the stack.

NOMENCLATURE

GIZ	gas invaded zone
md	milli Darcy
OOIP	original oil in place

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