SYNTHETIC (MAN-MADE) SANDSTONE SUITABLE FOR PETROLEUM ENGINEERING STUDIES

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ABSTRACT

Core plugs cored from oil and gas reservoirs are essential for reservoir evaluation studies. Since these types of cores are rarely available in enough quantities and are normally used only for reservoir characterization purposes, there is a lack of reservoir core plugs suitable for research and teaching purposes. As a solution for such a problem synthetic cores with properties more or less identical to that of the available model rock core plugs such as Berea, ARAMCO, and Al-Khafji have been considered. Man-made sandstone was tested for its potential use in petroleum studies and research activities. Mineralogy, grain size distribution, liquid permeability, porosity, and compressive and tensile strengths were measured for the synthetic sandstone. The properties of the synthetic (man-made) cores were then compared with that of Berea, ARAMCO, and Al-Khafji rocks. The results of this study show that the synthetic cores can be adequately used as a replica to Berea and Saudi sandstones.

KEY WORDS: Man-made sandstone, permeability, Compressive strength, Grain size, Saudi Aramco sandstone, Al-Khafji sandstone, Berea sandstone, Synthetic cores.

1. INTRODUCTION

Core analysis is important because it measures rock properties and provides reliable data which reflects the in-situ hydrocarbon recovery conditions [1]. Testing of cores can provide the petroleum engineer valuable information about porosity, permeability, formation damage, etc.

Furthermore, such cores can be used in the enhanced oil recovery studies, stimulation modelling and hydraulic fracturing experimentation. Usually when new techniques need to be verified, synthetic cores must be used to avoid the unnecessary damage of the actual core samples that are needed for several other tests. Several investigators have tested synthetic cores for different purposes [2-3]. Synthetic cores cored from local man-made sandstones that are being used as a building material were used to investigate its suitability for use as core samples in petroleum teaching and research activities. In petroleum engineering studies Berea sandstone cores imported from abroad in addition to sandstone cores supplied by the Saudi ARAMCO and The Arabian Oil Company (AOC) in Al-Khafji are used [4-6]. The cost of purchasing Berea sandstone cores is very high, while ARAMCO samples are rare to find and so are the Al-Khafji cores. The most important properties to be measured in this study are as follows:

i - Mineralogy and granulometric analysis.
ii - Liquid permeability and Porosity.
iii- Compressive and tensile strengths.

2. EXPERIMENTAL SET-UP AND TESTING MATERIALS

2.1 X-Ray Diffraction (XRD) and Granulometric Analysis

Man-made sandstone used as a building material is available in huge quantities. This rock is made by mixing water and cementing material (silica) with local sand. The XRD analysis of the man-made sandstone was done using a Philips fully automated x-ray diffractometer. Fig. 1. shows the x-ray diffractogram of the man-made sandstone. The granulometric analysis of the tested sandstones was investigated using a set of standard sieves and shaker. Table 1. and Fig. 2. show the grain size distribution of this synthetic sandstone as well as that of the model sandstones.

2.2 Permeability and Porosity Measurement

The permeability of the synthetic cores was measured using a steady state liquid permeameter. This was done by forcing an aqueous solution (1% sodium chloride) of known viscosity through a core

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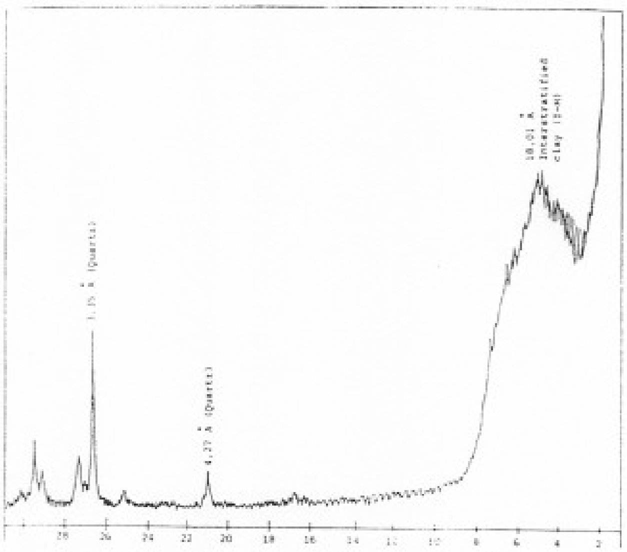

Fig. 1. X-ray Diffractogram of the man-made sandstone.

Table. 1 Granulometric analysis of the tested sandstones.

Mesh	Diameter	Man-made sandstone	Berea sandstone	Al-Khafji sandstone	Saudi ARAMCO sandstone
size	μm	Weight %	Weight %	Weight %	Weight %
20	1000	2.563	2.15	0.740	0.080
40	500	16.50	12.58	20.900	2.72
60	250	45.25	28.30	57.830	67.51
80	180	14.813	29.56	11.050	14.08
100	90	13.75	16.04	2.430	5.04
200	63	3.125	10.38	4.910	9.52
Pan	Pan	3.44	0.95	2.14	1.05

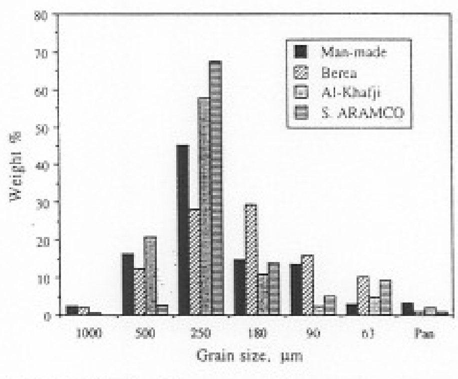

Fig. 2. Grain sizes histograms of the tested sandstones.

plug of known cross sectional area and length. Pressure, temperature and flow rate of liquid through the sample were measured and permeability was calculated as follows:

$$k = [q \mu L] / [A \Delta P] \quad (1)$$

Fig.3 shows a schematic diagram of the liquid permeameter while the liquid permeability data of the man-made sandstone is shown in Table 2. Porosity of the synthetic cores was measured using Ruska porosimeter.

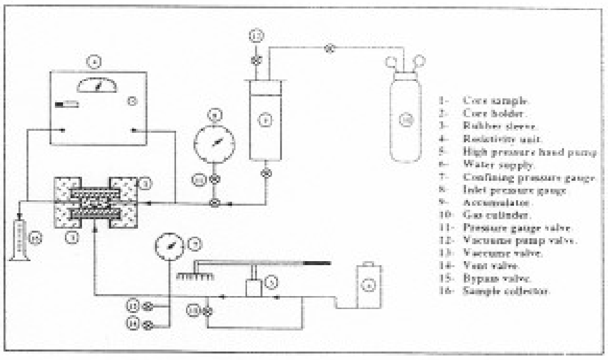

Fig. 3. Permeability measurement apparatus.

2.3 Mechanical Properties Measurement

Mechanical properties of the synthetic cores are of equal importance as the other petro-physical properties. When testing the synthetic sample for its permeability, a specific amount of confining pressure must be applied radially on the sample. Therefore, the sample must remain intact during the test (i.e. sustain the induced tensile and compressive stresses), otherwise, micro-fractures may be initiated and erroneous results are obtained. In this test a heavy duty compression machine was used. Samples with length to diameter ratio of 2.0 to 2.5 : 1 were used. Each sample was placed vertically in the compression machine and the load was increased until failure was noticed. The compressive strength was then calculated as follows [7]:

$$\sigma_c = L_1 / A \quad (2)$$

Table 2. Liquid permeability data of the man-made sandstone.

Sample no.	Length, cm	Sample Diameter, cm	Dry weight, gm	Confining pressure, Kg/sq. cm	Porosity, %	Average permeability, Darcy
B1	9.00	3.81	184.65	71.50	21.20	0.02136
B2	8.43	3.81	180.59	71.50	20.65	0.19325
B3	7.93	3.81	167.28	71.50	22.32	0.62958
B4	7.83	3.81	165.14	71.50	19.80	0.65529
B5	7.84	3.81	174.69	71.50	20.01	0.09223
B6	8.06	3.81	183.38	71.50	21.03	0.03438
B7	8.34	3.81	186.54	71.50	22.10	0.08183
B8	7.80	3.81	170.22	71.50	20.10	0.05558
B9	7.07	3.81	152.92	71.50	19.21	0.04190

Tensile strength was measured using the indirect method (Brazilian tensile test) [7]. In this test samples of diameter to length ratio of 1 : 0.5 were used. The samples were loaded diametrically in the compression machine and the load was increased until failure was noticed. The tensile strength was then calculated as follows [7]:

$$\sigma_t = [2 L_2] / [\pi D t] \quad (3)$$

This indirect measurement technique is based on the theory which states that both direct and indirect measurements of the tensile strength give the same value of the direct tensile(direct pull) strength of a material [7].

3. RESULTS AND DISCUSSION

In this study man-made sandstone was tested for its potential use in petroleum engineering research activities. The properties of this sandstone were compared with that of the commonly used sandstones namely ARAMCO, Al-Khafji and Berea sandstones. Mineralogical analysis of the man-made sandstone was investigated using an x-ray diffractometer and the results are shown in Fig. 1 It is clear that this sandstone is mainly composed of quartz and negligible amounts of clays. Table 1 and Fig. 2 show the grain size distribution of the man-made sandstone as well as the three natural sandstones. Fig. 2 shows that the grain sizes of the four sandstones are uniformly distributed. Six samples of the man-made sandstone were tested for their uniaxial compressive and tensile strengths. This was done to examine the samples ability to withstand the applied confining pressure during the permeability tests. The results obtained from the mechanical tests are tabulated in Table 3 and are plotted in Fig.3. To investigate the man-made sandstone permeability nine core plugs are tested using liquid permeameter (see Fig. 4) and the results are tabulated in Table 2. A 1% sodium chloride solution (NaCl) was used in the permeability tests. Based on the above results, it can be concluded that the man-made sandstone has negligible amounts of clays. Large amounts of clays in the sandstone cores can affect the permeability due to its swelling ability. When clays swell they close a large portion of the fluid passing conduits (pores). The man-made sandstone is able to withstand high compressive and tensile loads induced by the confining pressure during the permeability tests. Porosity of the four sandstones comparable as shown in Table 2. The absolute permeability of the man-made and Berea snadstones are identical and are smaller than that of the Al-Khafji and ARAMCO sandstones as shown in Table 4.

Table. 3 Mechanical properties of man-made sandstone.

Sample no.	Length, cm	Diameter, cm	Indirect uniaxial tensile strength, Kg/ sq. cm	Uniaxial compressive strength, Kg/ sq. cm
C1	8.09	3.81	-	218.3
C2	8.09	3.81	-	282.0
C3	8.38	3.81	-	278.0
C4	8.42	3.81	-	273.4
C5	1.9	3.81	20.30	-
C6	1.9	3.81	30.21	-
C7	1.9	3.81	22.50	-
C8	1.9	3.81	26.50	-

Table 4. Petro-physical properties of the tested sandstones.

Sample	Diameter cm	Length, cm	Dry weight, gm	Porosity, %	Average Absolute permeability, Darcy
Saudi man-made sandstone	3.81	8.03	174	20.82	0. 2006
Berea sandstone	3.81	8.79	195	20.35	0.320*
Saudi ARAMCO sandstone	3.81	7.76	163	19.90	0.105*
Al-Khafji sandstone	3.81	7.60	186	16.43	0.386*

* Computed from reference [4]

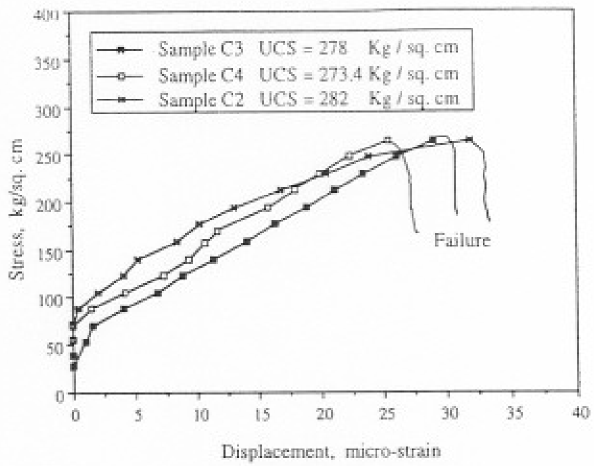

Fig. 4. Stress-strain relationship of the man-made sandstone.

4. CONCLUSION

From the experimental work performed in this study, we can draw the following conclusions:

1- X-ray analysis shows that the man-made sandstone is mainly composed of quartz and negligible amounts of clays.

2- Sieving analysis shows that the grain sizes distribution of the man-made sandstone is uniformly distributed.

3- Mechanical tests show that the man-made sandstone is able to withstand high loads throughout the confining pressures range normally applied during permeability tests.

4- Porosity of the man-made sandstone and the other three natural ones (Berea, Al-Khafji, and ARAMCO sandstones) are comparable.

5- Liquid permeability of the man-made cores is similar to that of Berea sandstone, therefore, it can be used in permeability related tests.

6- The man-made sandstone can provide a good substitute to the Berea sandstone and the other two Saudi natural sandstones (Al-Khafji and ARAMCO sandstones).

7- Further investigation of the applicability of the use of this man-made sandstone in secondary and tertiary oil recovery experiments is necessary.

5. NOMENCLATURE

A	= Sample cross sectional area, sq. cm.
D	= Sample diameter, cm.
k	= Permeability, Darcy.
L	= Sample length, cm.
L_1	= Compressive load, Kg/sq. cm.
L_2	= Tensile load, Kg/sq. cm.
q	= Flow rate, cc/sec.
t	= Sample thickness, cm.
UCS	= Uniaxial compressive strength, Kg/sq. cm.
μ	= Viscosity, cp.
ΔP	= Pressure drop, atm.
σ_c	= Uniaxial compressive strength, Kg/sq. cm.
σ_t	= Indirect tensile strength, Kg/sq. cm.

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