AL-AZHAR ENGINEERING FIFTH
INTERNATIONAL CONFERENCE
DECEMBER 19 - 22 , 1997

AEIC '97

المؤتمر العلمي الدولي الخامس
كلية الهندسة - جامعة الأزهر
من ١٩ - ٢٢ شعبان ١٤١٨هـ
من ١٩ - ٢٢ ديسمبر ١٩٩٧م

STIMULATION OF SANDSTONE FORMATIONS BY MUD ACID

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ABSTRACT

Hydrofluoric-hydrochloric acid mixtures have been widely used in stimulation of sandstone reservoirs. Hydrofluoric acid reacts with clays, sand, drilling mud, or cement filtrate to improve permeability adjacent to the wellbore. A series of experiments was run to determine the effects of HF concentration, volume of acid injected, differential pressure and temperature on the permeability of the sandstone core samples. The compressive strength of the samples was determined as well. Different pore volumes of acid were injected into each sandstone core. Volumes of injected acids were varied from one to 7 pore volumes. The differential pressure was varied from 150 to 500 psi.

The change in the permeability of tested core samples before and after acidizing was recorded. An overflush with kerosene as an inert liquid was tended to increase the effectiveness of acid treatment. It was found that injecting 7 pore volume of hydrofluoric-hydrochloric acid was completely removed the damage and restored the initial permeability in case of Man-made sandstone. Whereas additional improvement of 50 percent above the initial permeability value was achieved for Berea sandstone.

KEYWORD

Acidizing; stimulation; well treatment; hydrofluoric- hydrochloric acid.

INTRODUCTION

Hydrofluoric acid has been widely used in stimulation treatments since 1935. This acid was introduced to the petroleum industry by Wilson [1] to dissolve formation minerals and foreign material, such as drilling mud. Smith and Hendrickson [2] indicated that small amount of hydrofluoric acid reacts with sand grains, clays and calcite which are present in the formation. Clays are either located interstitially between sand grains in flow channels or in stringers. The acid would attack clay faster than the reaction with sand. The acid formulation generally used is a 12% hydrochloric acid and 3% hydrofluoric acid mixture. The normally used acidizing technique was classified by Williams et al. [3] into three categories: acid washing, matrix acidizing, and acid fracturing. Shaughnessy and Kunze [4] reported that afterflush volumes applied immediately after the HF-Hcl treatment would appear to be the safest procedure to prevent precipitation of colloidal silica Si(OH)4.

As stated by McLeod [5], and Watch et al [6] a successful matrix treatment depends on the favorable response of the formation to the treatment fluid. The sensitivity of a formation to a given fluid includes all the detrimental reactions that can take place when this fluid contacts the rock.

This paper reports some of the factors which control the reaction rates of Hydrochloric-Hydrofluoric acid with two types of sandstone cores.

ACIDIZING STIMULATION APPARATUS

Fig. 1 is a flow diagram of the experimental set up used in these experiments. It consists of high pressure Hassler cell, acid reservoir, kerosene reservoir, back pressure regulator, and nitrogen gas. The core sample (diameter = length = 1.38 in), was sealed into the core chamber by means of a rubber sleeve. Various acid mixtures were displaced through the sample, the pressure was applied by nitrogen gas. A back pressure device was placed on the core test apparatus to maintain the desired differential pressure. Treating temperature was also controlled. An overflush with kerosene as an inert liquid will tend to increase the effectiveness of acid treatment by increasing the penetration of the acid before it spends. The spend acid was collected in a graduated cylinder.

RESULTS AND DISCUSSIONS

The physical properties of rock samples namely, porosity, permeability and compressive strength were measured and tabulated in Tables 1 and 2.

Results of grain sizes distribution by sieving for Man-made and Berea sandstones were tabulated in Tables 3 and 4. These data were presented in Figs. 2 and 3.

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.

Man-made sandstone has 45% of grain sizes 250 rim and 45% of grain sizes of 90, 18O, and 50 μm. Berea sandstone cores are well sorted and 87% of the grain sizes are ranged from 63 to 500 μm.

The x-ray diffraction pattern of the studied samples were determined using Philips full automated x-ray diffraction spectrogroniometer equipped with PW730/10 generator.

The x-ray diffraction (XRD)results showed that the Berea sandstone samples are consisted of 6% clay, 85% a - quartz, 5% Feldspar and 4% clay [2]. While Man-made sandstone cores are mainly composed of quartz and traces of clay (10%) as shown in Fig. 4.

A series of experiments was run to determine the effect of HF concentration, volume of acid injected, differential pressure, and temperature on the permeability ratio of the core samples. Also the effect of acid concentration on the compressive strength of the core samples was studied.

1. The Effect of HF Concentration on Core Permeability

Fig. 5 illustrates the effect of hydrofluoric acid concentration on the permeability of Man-made sandstone cores. This figure shows that the higher HF concentration gives a greater initial permeability decrease. Tests with 3% HF - 12% Hcl give twice the permeability ratio of 10% HF - 12% Hcl at low pore volumes of acid injected. Upon continued injection of different volumes of HF-Hcl mixtures larger than 3 pore volume, permeability increases. The initial permeability reduction was caused by the partial disintegration of the sandstone matrix and immigration of fines that plug flow channels in the cores. Continued exposure of the fines to unspent HF was thought eventually to result in their dissolution. Therefore, the permeability increase was due to flushing the plugged pore channels with acid and the enlargement of other pore channels by the acid.

2. The Effect of Pressure Drop on Permeability

Fig. 6 illustrates the effect of various pressure drops across in Man-made sandstone cores on permeability. It shows that as the pressure difference across the core samples is increased (acid flow rate is increased), the initial permeability decline increases. Also greater quantities of acid are required to achieve a given permeability increase. The increased permeability decline may be caused by an increase in the quantity of fines released because of the increased drag forces at high differential pressures. Volumes of injected acid larger than 3 pore volume are required to achieve a given permeability increase because of the complete reaction of HF-Hcl acid.

3. The Effect of Matrix Composition on Permeability

The mineralogical composition of the sandstone matrix has a substantial effect on formations response to hydrofluoric acid. Berea sandstone, a relatively clean quartzitic material usually containing about 6% clay, was used for the tests. Man-made cores contain substantially more clay than Berea sandstone (10%) and show correspondingly greater loss in permeability on initial acid contact as it is shown in Fig. 7. Fig. 7 also shows the effect of various volumes of mud acid (12% Hcl - 6% HF) on Man-made cores. As the volume of injected acid is increased (higher than 3 pore volume) the permeability ratio increases.

4. The Effect of Temperature on Permeability

HF concentration of 3% HF - 12% Hcl was studied to determine the effect of temperature on the permeability of the core samples. The reaction taking place at 120°F is higher than that of the reaction taking place at 90°F as it is shown in Fig. 8 and consequently the permeability ratio increases.

5. The Effect of HF-Hcl Reaction on Core Mechanical Properties

Fig. 9 shows the effect of HF-Hcl reaction on Man-made cores mechanical properties. It shows that as the volume of acid injected is increased, the uniaxial compressive strength decreases until the sandstone is finally unconsolidated. Note that the compressive strength decrease correlates closely with the total dissolving power of acid injected. Cores treated with 3% HF possesses higher compressive strength than cores treated with 10% HF.

CONCLUSIONS

Based on the experimental results obtained in this study, the following conclusions were drawn out:

1. Highly concentrated hydrofluoric acids gives a temporary reduction in permeability as the acid enters the core. The permeability will increase with increase in HF acid concentration.

2. As the pressure difference across the sample is increased, the initial permeability decline increases because of the increased drag forces.

3. The uniaxial compressive strength of the tested rocks decreases as the volume of injected acid is increased.

4. Hydrofluoric-hydrochloric acid stimulation of sandstone cores can give production increase equal to or greater than the damage ratio.

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Table 1. Properties of Man-made sandstone cores.

Porosity	27.4%
Permeability	0.34 Darcy
Pore volume	11.4 cc
Compressive strength	4466 psi

Table 2. Properties of Berea sandstone cores.

Porosity	20%
Permeability	0.386 Darcy
Pore volume	8.04 cc
Compressive strength	3696 psi

Table 3. Granulometric analysis of Berea sandstone.

Mesh size	Diameter, (μm)	Weight (%)
20	1000	2.15
40	500	12.58
60	250	28.30
80	180	29.56
100	90	16.04
200	63	10.38
Pan	Pan	0.95

Table 4. Granulometric analysis of Man-made sandstone.

Mesh size	Diameter, (μm)	Weight (%)
20	1000	18.004
30	600	7.9537
50	300	38.3947
60	250	6.435
80	180	9.3275
100	90	12.2921
200	63	4.049
Pan	Pan	3.543

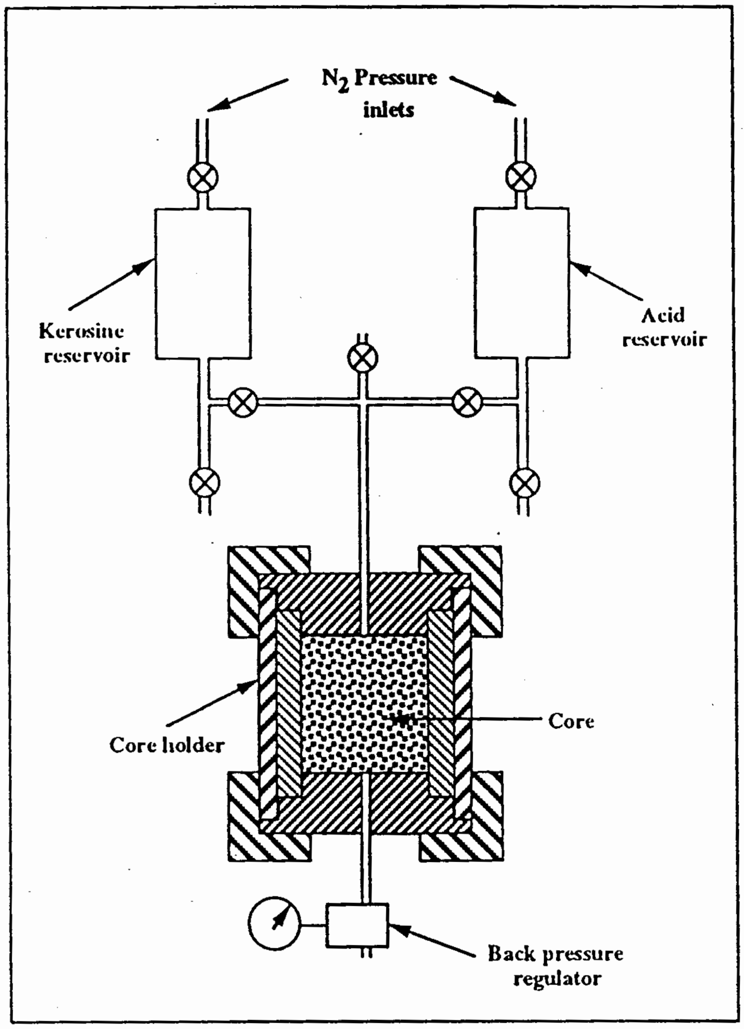


Fig. 1 A schematic diagram of the HP-HT acidizing cell.

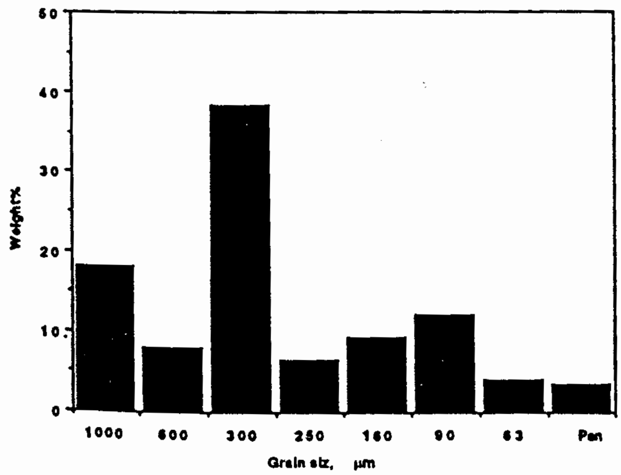


Fig. 2 Granulometric analysis of man-made sandstone

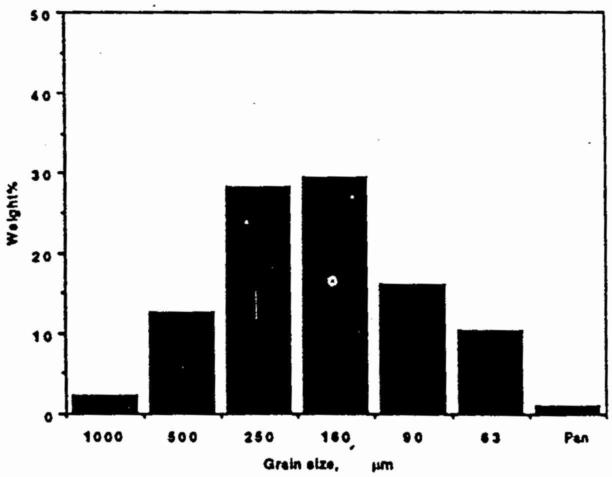


Fig. 3 Granulometric analysis of Berea sandstones

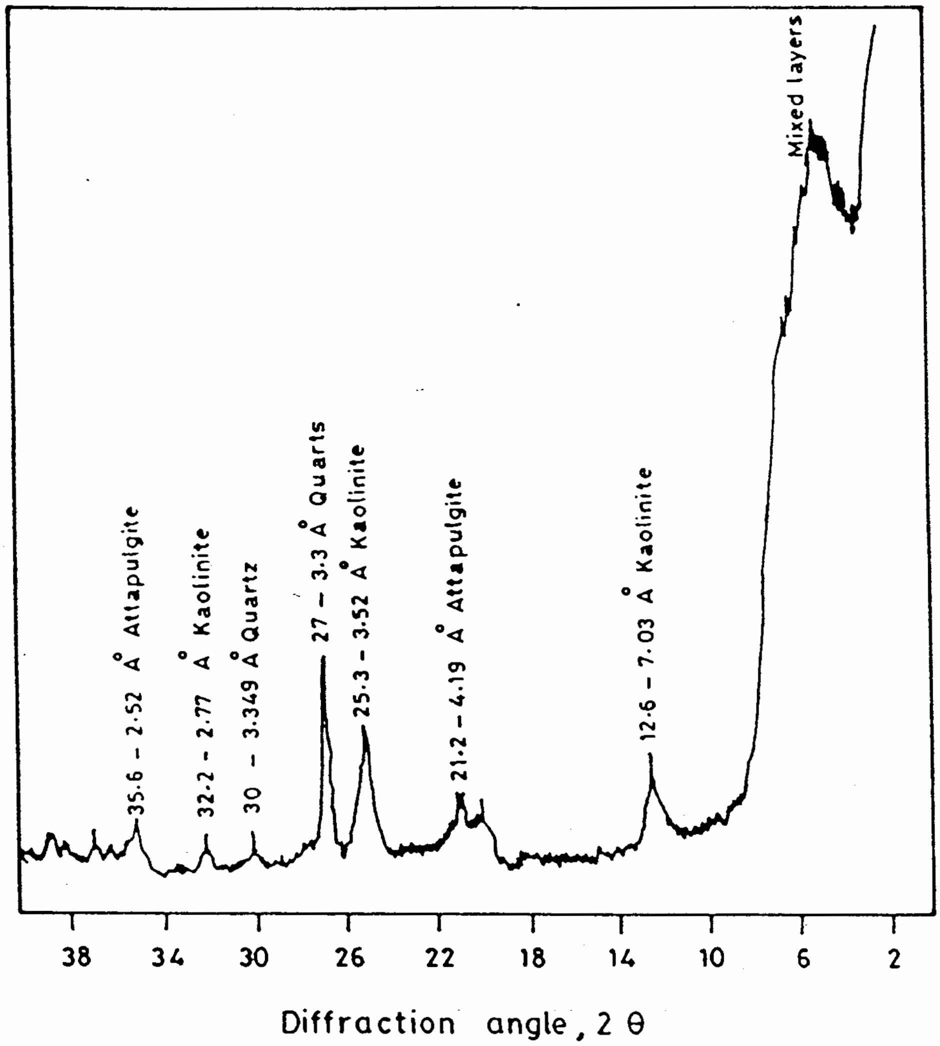


Fig. 4 X-ray diffractogram of the Man-made sandstone.

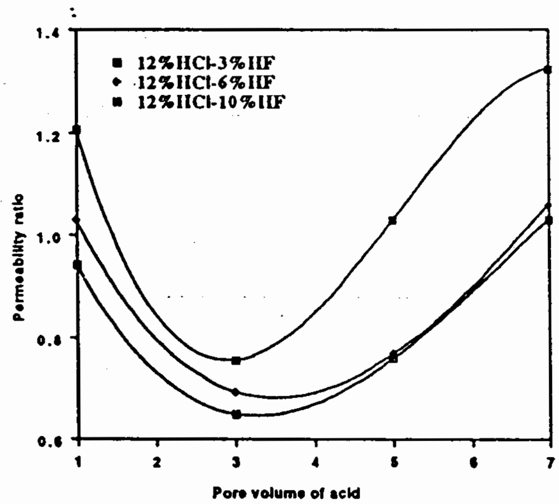


Fig. 5 Effect of HF concentration on Man-made sandstone core permeability at (ΔP=300 psi, T=90 °F).

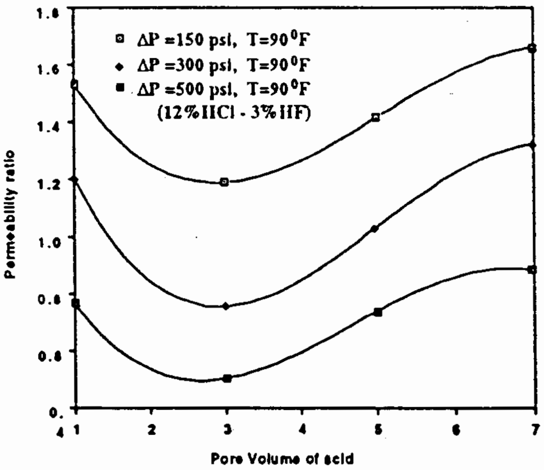


Fig. 6 Effect of differential pressure on Man-made sandstone core permeability.

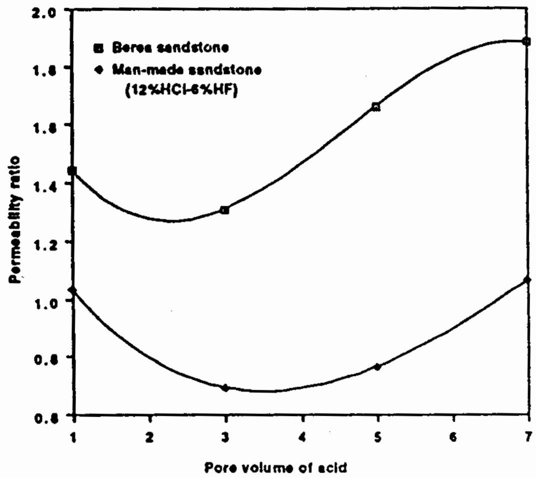


Fig. 7 Effect of acid volume on permeability of tested sandstone cores at ΔP=300 psi and T=90 °F.

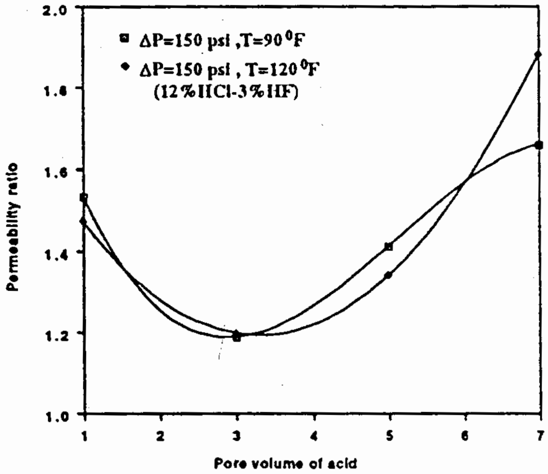


Fig. 8 Effect of temperature on Man-made sandstone core permeability.

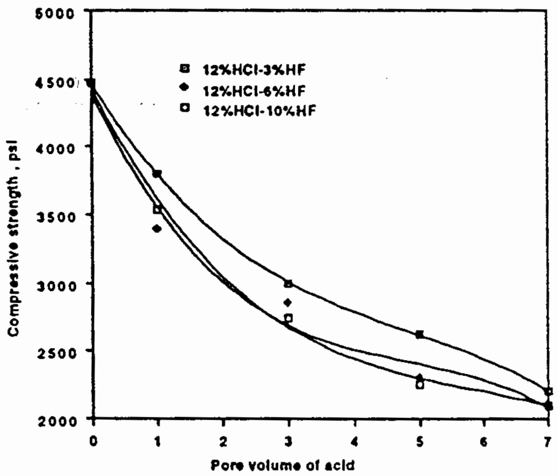
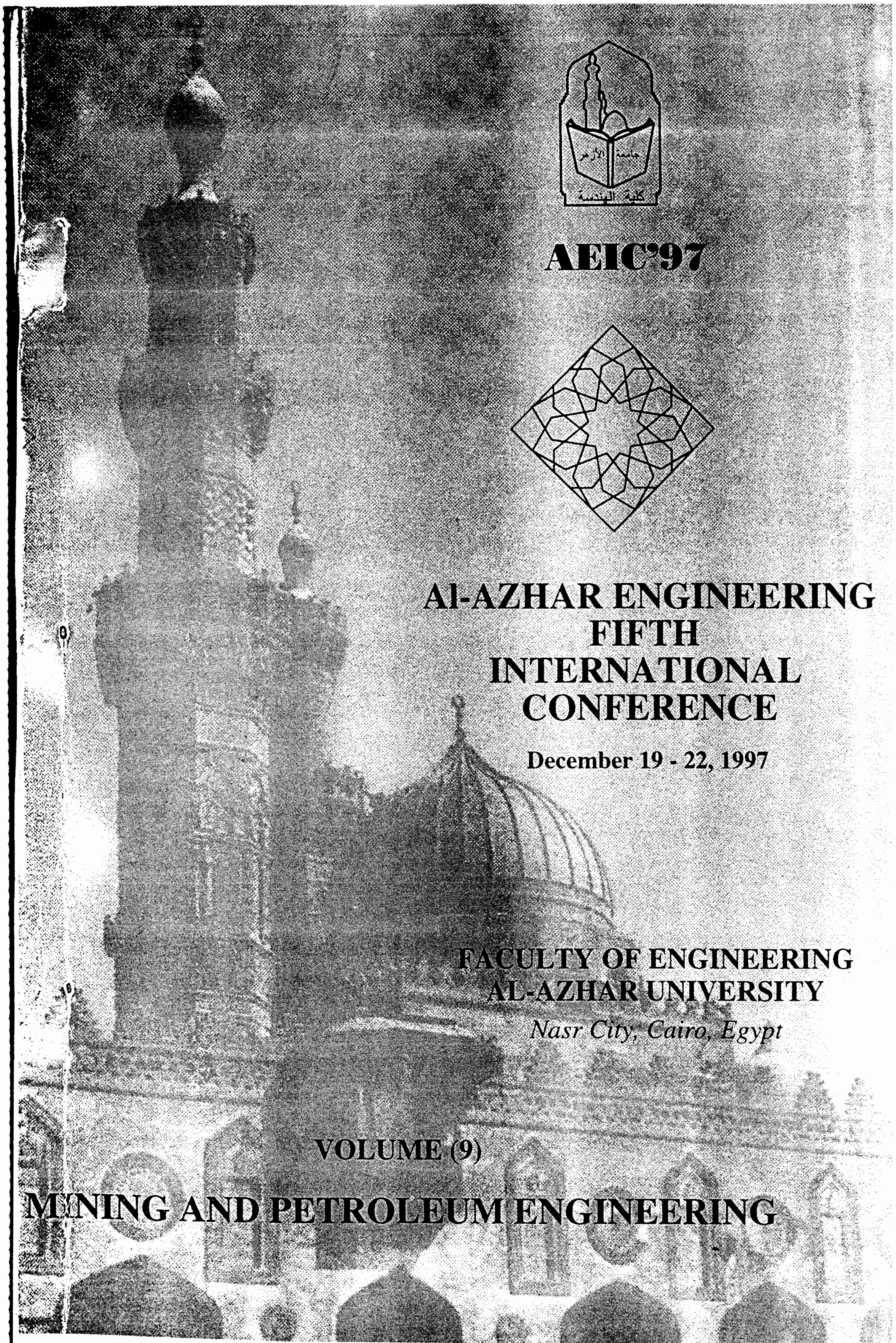


Fig. 9 Effect of acid volume injected on Man-made sandstone formation compressive strength.



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VOLUME (9)

MINING AND PETROLEUM ENGINEERING