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Experimental Investigation on Sandstone Rock Permeability of Pakistan Gas Fields

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Abstract. Permeability is the ability of formation to produce hydrocarbon which is affected by compaction, pore size, sorting, cementation, layering and clay swelling. The effect of texture on permeability in term of grain size, sorting, sphericity, degree of cementing has been reported in literature. Also, the effect of permeability on capillary pressure, irreducible water saturation, displacement pressure and pore geometry constant has been studied separately. This preliminary study presents the experimental results of eight samples to understand the effect of similar factors of texture on permeability. With the knowledge of the results, it can be said that the effect of grain size, cementation, texture material, sphericity, and porosity can't be observed on permeability except sorting when less than ten samples are considered from different depositional environment. The results also show the impact of permeability on capillary pressure, irreducible water saturation, and displacement pressure and pore geometry index as similar as published in the literature.

1. Introduction

Permeability is a key petrophysical parameter that has the capability to conduit the fluid flow, which has been used as a vital factor in the development and management of petroleum reservoir [1, 2]. As a matter of fact, permeability is indicative of reservoir system quality. It generally ranges from 0.1 to 1000 mD or more [3]. Permeability depends on effective porosity of rock, whereas, it is also controlled by composition, texture and structure of rocks [4]. Texture of sandstone is different due to variation in depositional environment, and it consists of grain size, sphericity, sorting, porosity, texture material and textural maturity of formation. A number of researchers [5-7] reported grain size ranged from 0.125 mm to 2 mm. Furthermore, sandstone exists in a variety of colors ranging from white to black due to extensive fluctuation in depositional environment [8].

It has been shown by previous researchers that grain size, and sorting are fundamental variables which are controlling permeability in unconsolidated rocks. As better sorting steadily increases porosity as well as permeability. Other researchers [9, 10] also investigated the effect of grain size on permeability. Their common conclusion was that the increase in gravel and coarse grain size types of particle in sandstone causes an increase in permeability whereas reducing the porosity. Many relationships of permeability with the porosity; irreducible water saturation and sorting are presented in literature [10, 11, 12].

Also, as a result of the extensive research conducted to date on the subject of permeability, it has proved the effect of permeability on capillary pressure, displacement pressure, irreducible water saturation and pore geometry index. All these parameters except pore geometry index (λ) dramatically increase with the decrease in permeability due to squeezing of pore throat radius [13]. Whereas, pore geometry index (λ) which is a measure of the degree of pore sorting shows a direct relationship with permeability [14].

Recently, a comparative study of porous plate method, oil displacement method and centrifugation method have been presented to show that irreducible water saturation decreases with the increasing permeability [15]. Additionally, the impact of petrophysical control on irreducible saturation, displacement pressure and pore throat size distribution have also been investigated by centrifuge experimental displacement technique [16].

The objective of this experimental study is to provide a source review of key factors (grain size, cementation, texture material, sphericity, sorting and porosity) influence on permeability.

2. Materials and Methods

Eight driller's samples of different formations were obtained for this study as mentioned in table 1. Core fittings of 1.5-inch in the width and 3-inch in length were prepared to carry out necessary experiments (porosimeter, permeameter, forced injection and capillary pressure measurement) by following the standard procedure of apparatus [17, 18].

By means of Manual Dynoptic Polarizing Microscope (Model L.M. 1966) [19], rock texture of representative core samples was directly predicted visually on prepared thin sections as can be seen in figure 1.

Figure 1. Thin section films.

Direct effective pore volume of the same cores was measured by using a Helium Porosimeter, TPI-219 Cortest system [20]. In order to calculate the porosity, bulk volume was measured gravimetrically. Permeability was analyzed by Ruska Gas Permeameter-1011-801 [21]. In third place, core samples were 100% saturated using Manual Saturator-535 Coretest System [22] with prepared saline water (density of 1.01g/cc). Gravimetric capillary pressure system, TGC - 764 based on porous plate method [23] was used to determine primary drainage capillary pressure curve and the irreducible water saturation. The equipment used for air-brine porous plate method consisted of a pressure control system, a balance and a pressure vessel with a porous ceramic plate of 15 bar (threshold pressure). In addition, stable saturation was gravimetrically determined at different desaturation pressures to obtain capillary pressure curves.

Grain sizes of all grains on thin sections were measured under attached microscopic scale with the lense during the examination and average grain size of samples were gotten by arithmetic mean as accounted for in table 1. Sorting and sphericity were visually examined and matched with the Ehlers & Blatt's sorting and sphericity classification [24]. Table 1 lists the results of texture obtained during microscopic analysis.

All the studied clastic rocks are classified as sandstone based on their textural parameters such as grain size, sorting & sphericity by using Ehlers & Blatt's [20] classification and the results are shown in table 1. As evident from the results that rock samples of different locality in this study have widely diversified rock texture.

Table 1. Summary of sandstones texture material description.

Sample ID	1	2	3	4	5	M-1	M-2	M-3
Formation	Mari	Mari	Mari	Dhandhot	Warcha	XYZ	XYZ	XYZ
Grain size (mm)	0.244	0.374	0.08	0.159	0.53	0.214	0.08	0.063
Texture material	Fine Sand	Med. Sand	Very Fine Sand	Fine Sand	Coarse Sand	Fine Sand	Very Fine Sand	Very Fine Sand
Cementing	No	Poor	Poor	Very poor	Highly	Poor	Very poor	Poor
Sphericity	Angular	Angular	Rounded	Sub Angular	Rounded	Very Angular	Rounded	Sub Rounded
Sorting	Poor	Very Poor	Well	Very Well	Well	Poor	Well	Well

Listed in the table 2 are the experimental outcome of parameters such as effective porosity, absolute permeability, irreducible water saturation and displacement pressure. The pore geometry index was determined by matching the measured capillary pressure data with the Brooks & Corey [25] calculated data.

Table 2. Summary of measured properties.

Sample ID	Porosity (%)	Permeability (mD)	Displacement Pressure (psi)	Pore Geometry Index	Irreducible Water Saturation (%)
1	13.4	4	14	1.64	59
2	9.3	0.4	19	1.5	84
3	21.6	26	9	1.824	47
4	17	60	6	2.32	36
5	9.3	30	9	1.94	40
M-1	12.8	2	18	1.63	75
M-2	18.9	25	9	1.8	47
M-3	20	20	9	1.79	50

3. Results Analysis

3.1. Factors Control the Permeability

All the rock texture factors were compared to know their influence on permeability. Texture material mainly varies from very fine grained (n=3) to coarse sand (n=1) and cementing ranges from none or very poor to high. The sphericity ranges between sub angular to rounded. Sample No# 3, 5, M-2 are textural mature. Almost all the samples are well sorted except Sample No# 1, 2 & M-1 as presented in table 1. Sandstone samples under study have porosity ranging from 9.3% to 21.6% and permeability ranging from 0.4 mD to 60 mD as given in table 2.

Figure 2 presents the variation in grain size as reported in table 1 which are plotted versus permeability as can be seen in figure 2. It was found that there is no influence exists on permeability. As described earlier [9] that grain size is a fundamental variable that control permeability in unconsolidated rocks. This contrast may be either due to less number of the samples or almost all the samples except S#1 are consolidated.

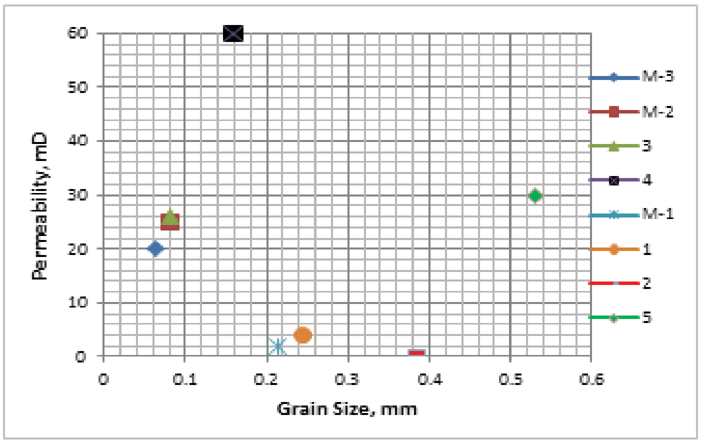

Figure 2. Plot of grain size versus permeability.

It can be seen in figure 3 that there is no positive relationship of the degree of cementing with the permeability if effect of all other parameters are assumed negligible. Albeit, there is no positive correlation exists, however, it can't be denied based on this study that there is no effect of cementing on permeability as it has been indicated earlier about the effect of cementation on permeability [3]. This unique behavior of cementing in sandstone sample can be due to type of texture material and the degree of sphericity in the samples.

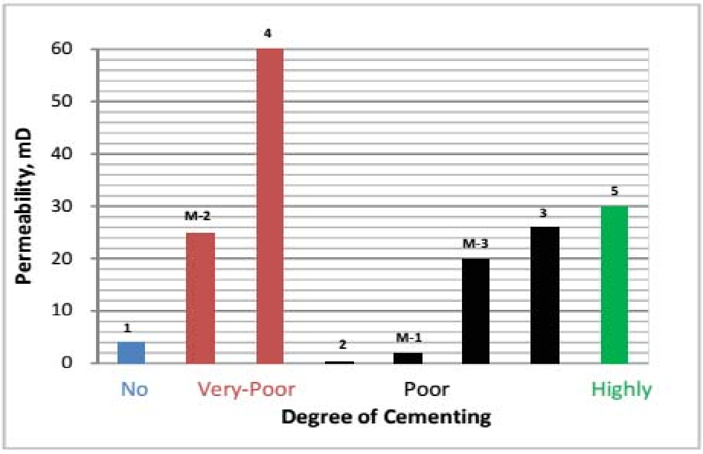

Figure 3. Plot of degree of cementing versus permeability.

Similar to previous described trends, the particle type (very fine sand to coarse sand) doesn't show any remarkable relationship with permeability individually as seen in figure 4.

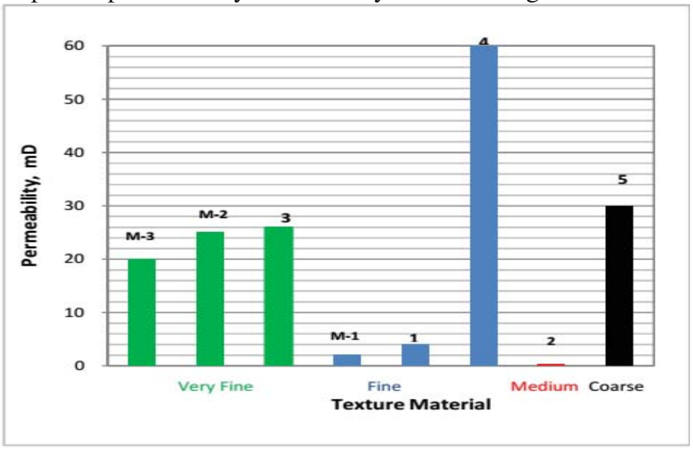

Figure 4. Plot of texture material versus permeability.

Also, with the increase in degree of roundness, permeability doesn't show a positive trend to call it a relationship that can be seen in figure 5. Clearly, permeability is increasing linearly with the degree of sphericity from sub rounded to round grains. Particularly, samples with more angularity showing very less permeability than rounded grain samples.

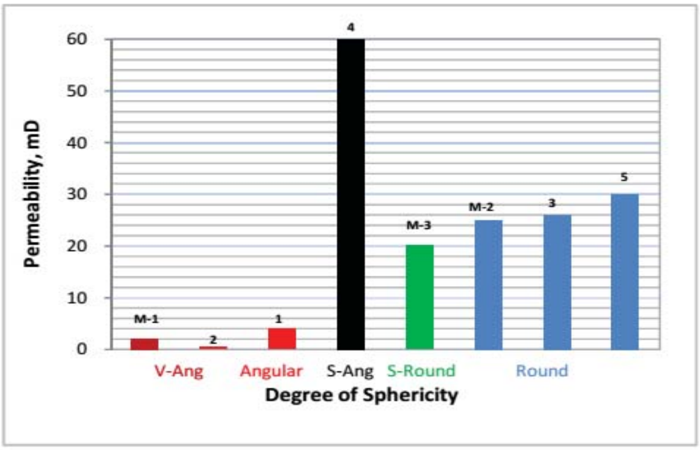

Figure 5. Plot of degree of sphericity versus permeability.

A clear trend can be observed between permeability and level of sorting such that permeability decreases with the decrease in degree of sorting as shown in figure 6. Hence, it can be concluded without any hesitation that individual parameters of texture except sorting don't have any positive impact on the permeability in this study. In fact, this study is not denying the secondary integrated effect of size, shape of grains and the degree of cementing on permeability but it is worth noting that sorting is a major controlling factor in comparison to other factors in consolidated sandstone which even shows positive relation independent of number and locality of the samples. Since, sedimentation process control sorting, therefore, sorting has an influence on the permeability as well as in relationship with it [10].

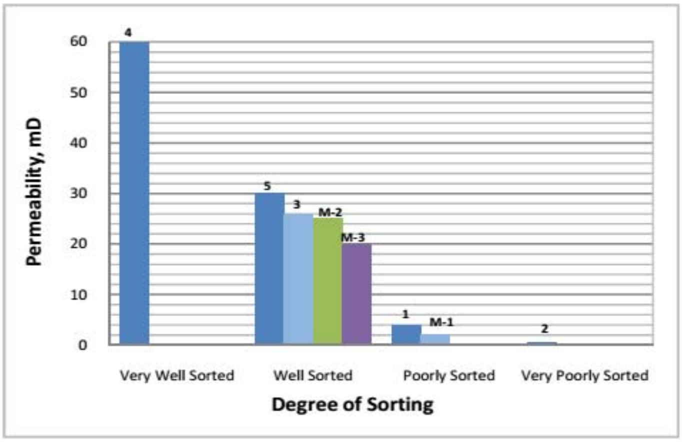

Figure 6. Plot of degree of sorting versus permeability.

As evident from figure 7 that porosity cannot manifest any relationship with permeability in this study. It can be because of a wide variety of fabrics and less number of samples.

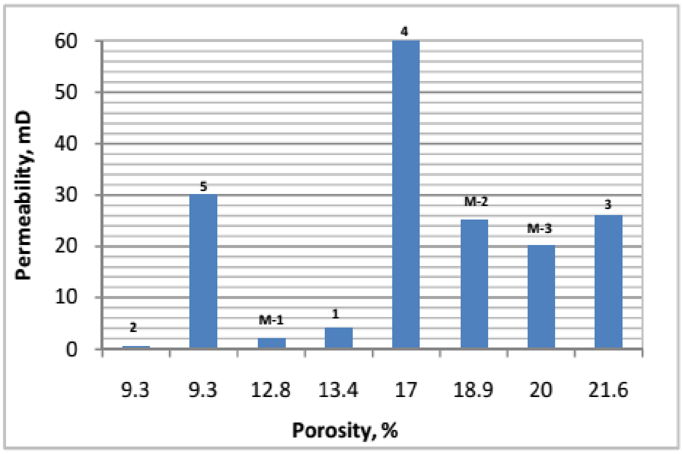

Figure 7. Plot of permeability versus porosity.

3.2. Effect of Permeability on Capillary Pressure, Irreducible Water Saturation, Pore Geometry Index and Displacement Pressure

Although, permeability effects a number of parameters, but capillary pressure, irreducible water saturation, pore geometry index and displacement pressure are considered in this study.

A trend can be observed between permeability and capillary pressure as presented in figure 8. It was found that with a decrease in permeability, the capillary pressure curve is shifting towards right implying increase in irreducible water saturation (S_{wir}); and implying an upward increase in displacement pressure (p_d) and its curvature is decreasing implying broader pore size distribution. The net effect is that as permeability is decreasing, capillary pressure became higher at a given value of saturation. Thus, the study confirms the established behavior of capillary pressure curve changes with the permeability as currently published [13]. A change in capillary pressure curve due to a change in sorting is analogous to changes in permeability because permeability itself is related to sorting as described earlier [10].

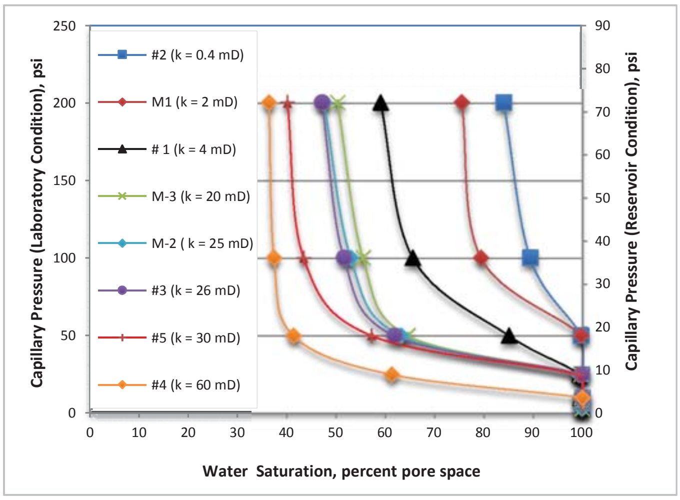

Figure 8. Plot between water saturation versus capillary pressure.

Permeability is plotted versus irreducible water saturation in figure 9. It shows that with the increase in permeability resulting in the decrease in irreducible water saturation. Since, permeability is related to capillary pressure, the irreducible water saturation also relates with capillary pressure. Hence, this trend confirms the concept as published in literature [13, 15, 16].

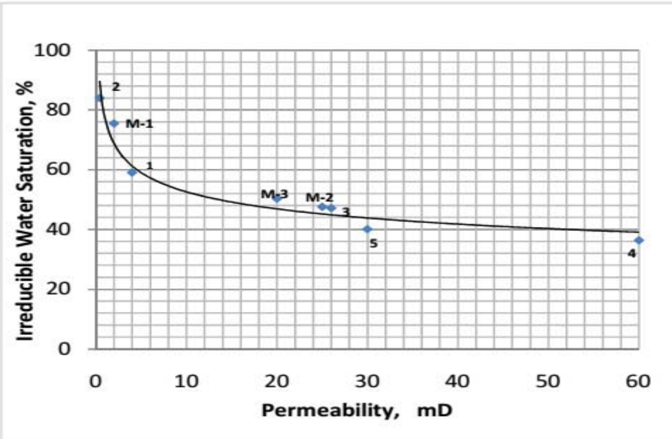

Figure 9. Plot of permeability versus irreducible water saturation.

Figure 10 is a plot of permeability against the pore geometry index. The pore geometry Index (pore sorting) is directly related to the arrangement of grains. It is endorsed that the increase in permeability represents well connected pore geometry as presented earlier [14].

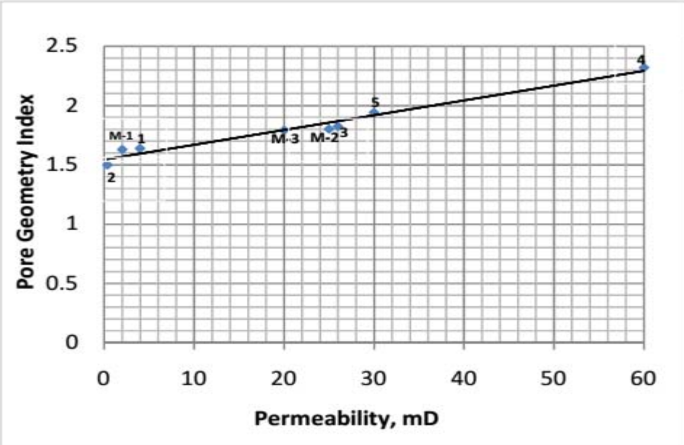

Figure 10. Plot of permeability versus pore geometry index.

Displacement pressure is directly linked to large pore throat radius which can be seen in figure 11. The trend shows that an increase in permeability causes a decrease in displacement pressure due to availability of large pore throats so verified researcher's findings on displacement pressure [13, 16].

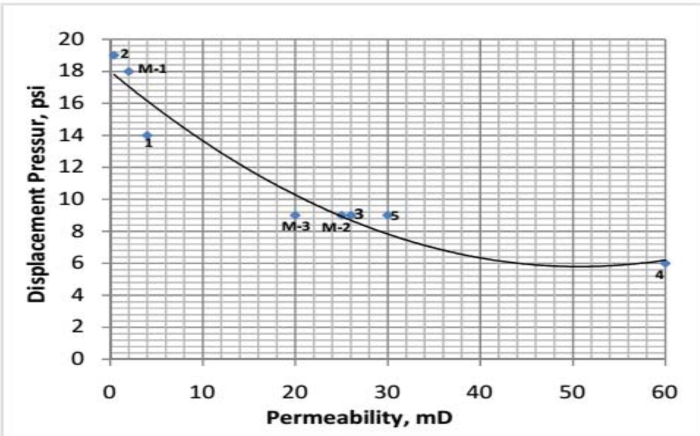

Figure 11. Plot of permeability versus displacement pressure.

4. Conclusion

Sorting is the only parameter of rock texture that is in positive correlation with the permeability. With the increase in degree of sorting from very poor sorted grains to very well sorted grains results increase in sample permeability. Parameters such as grain size, degree of cementing, texture, degree of sphericity and porosity have integrated influence on variation of permeability but any particular relationship with permeability can't be observed with the few numbers of samples. Variation in permeability has great influence on capillary pressure, irreducible water saturation, pore geometry index, displacement pressure.

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