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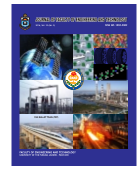

PHYSICAL AND INDEX PROPERTIES OF LATE PRECAMBRIAN AND CAMBRIAN SALT RANGE ROCKS OF PUNJAB

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Abstract

Thirteen rock types including Sandstone, Siltstone, Dolomite, Shale, Gypsum and Rock Salt, collected from five different formations of Salt Range area of Pakistan, were tested to assess their physical and index properties. Specific gravity, dry and wet unit weight, moisture content, porosity, water absorption and slake durability index were determined. Results indicate that most of the rocks have their specific gravity and unit weight values in the standard range. Higher durability indices and low water absorption values of sandstones and dolomite make them suitable as construction material. Assuming an appropriate seal, the higher porosity values of the Baghanwala sandstone, Lower Khewra sandstone and Upper Khewra sandstone indicate not only their potential to trap hydrocarbon but also as an ideal candidate for greenhouse gases sequestration in the subsurface.

Keywords: Physical Properties, Salt Range, Index Properties, Slake Durability, Porosity

1. Introduction

Physical and index properties along with mechanical properties of rocks are considered to be the most important components in any engineering project [1]. The response of rocks to applied load, water influx, temperature and tectonics stresses depends upon the physical and the geotechnical properties of those materials. For the safe and economical design of mining and civil engineering structures, adequate knowledge of technical properties of rocks is indispensable [2]. Moreover, petrophysical properties of rocks such as porosity and permeability are the prime indicators of quality and producibility of hydrocarbon reserves [3]. Some important engineering properties of rocks include specific gravity, weight density, , moisture content, degree of saturation, slaking, durability, porosity and permeability. These engineering characteristics of rocks depend on their intrinsic properties, such as, mineralogical composition, grain size and grain distribution (sorting). Furthermore, it also depends on time dependent parameters, like, degree of chemical alteration, weathering and deformation [1, 4]. In-addition to above mentioned factors, interaction of water with rocks has a marked effect on physical and mechanical properties of rocks, leading to the stability problems for engineering structures [5].

A rock mass is generally a mixture of several minerals having varying specific gravities, and its true specific gravity is the volumetric average of its mineral components. Specific gravity

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is used in computing other rock and soil properties e.g. porosity and unit weight. Unit weight of a rock is directly proportional to mineral weight; while it is inversely proportional to porosity. Therefore, in general sedimentary rocks are considered to be the one having least unit weight as compared to igneous and metamorphic rocks. In many mines and other underground works, rock is nearly saturated, resulting into leaky tunnels and water seeping into the opening and out of fractures, faults and/or joints. Fahimifar and Soroush [5] have proposed a new parameter, Moisture Index (Mi), that relates the sensitivity of a rock to its moisture content. This index is based on inherent parameters of rocks that control the physical, mechanical and physio-chemical properties of rocks.

In sedimentary rocks the porosity varies from zero (nearly) to 50% (n = 0.50) with 15% as a typical value for an average sandstone. Assuming similar grain sizes and distribution, porosity generally decreases with the age and burial depth. For example, a typical Cambrian sandstone has a porosity of 11% that is lower than 34% observed in Cretaceous sandstone. Similarly, a Pennsylvanian age shale from Oklahoma encountered at depth of 1000 ft (305 meter), 3000 ft (914 meter) and 5000 ft (1524 meter) had porosities of 16%, 7% and 4%, respectively. Furthermore, chalk is among the most porous of all rocks with porosities in some instances of more than 50% [2]. As described earlier, interaction of water with rocks and its effects on various properties of earth materials is of vital importance in geotechnical engineering. Water often reduces rock strength and leads to complicated problems in mining projects and geotechnical engineering structures, such as, dams, highways, caverns, canals and underground reservoirs, etc. How water affects a rocks depends on its mineralogy, effective porosity, water adsorption, grain size and microfissures. Clay minerals and evaporates such as carbonates, borates, nitrates, sulphates, and halides are more sensitive to water effects. As the percentage of these minerals in rocks increases, the deterioration effect of water also increases. Generally, strength of rocks decreases with increasing effective porosity, moisture contents of rocks and water adsorption. Grain size plays its role only in case of clastic sedimentary and pyroclastic rocks. The smaller grain sizes in these rocks often support the cementation, and hence increases the rock strength [5].

Slake durability of rocks is an essential property for assessment of engineering behavior of earth materials in geotechnical practice [6, 7, 8, 9]. It is an important engineering consideration in relation with slope stability, underground opening stability and embankment failure [10]. Franklin and Chandra [6] have reported various factors that affect the slaking of rocks. These include resistance of a rock against swelling and disintegration, porosity and permeability of rock, shape of the rock pieces, nature of the testing fluid, number of wetting-drying cycles and conditions of sample storage. Furthermore, it is also dependent on rock type, texture and mineralogical composition of rock, grain size and degree of weathering. Some researchers [11, 12] have described porosity, grain binding strength, physical properties and degree of breaking as decisive parameters in terms of their influence on slake durability of rocks.

Kolay and Kayabali [11] have investigated the effect of aggregate shape and surface roughness on slake durability. They reported that slake durability index of round surface is relatively low as compared to angular and sub-angular particles. Moreover, rough surface increases the surface area of particles resulting in more interaction with the fluid, which in turn increases proneness of the rock to slaking.

These rock properties, their various affecting parameters and relationships among each others have been investigated by numerous researchers [1, 10, 11]. In this study physical and index properties of the Late Precambrian and Cambrian rocks of Salt Range area (Punjab) have been evaluated. For this purpose, total thirteen rock types were collected from five different formations and their specific gravity, dry and wet unit weight, moisture content, water absorption and slake durability index were determined.

2. Materials and Methods

2.1. Sample collection

The rock samples were collected from the Salt Range area shown in Figure 1. A total of thirteen rock types from five different rock formations were sampled and tested during this research. Rock samples were gathered from different areas of Salt Range starting from Baghanwala village to Khewra Village. The rock types, age, formation names and their descriptions are given in Table 1.

2.2. *Test procedures*

Physical properties such as specific gravity, dry and wet unit weights, moisture contents and water absorption of the sampled rocks were determined according to the test procedures laid down by ISRM [14]. Slake durability indices of rock samples were found according to the method developed by Franklin and Chandra [6] and recommended by the International Society of Rock Mechanics [14] and standardized by American Standards of Testing and Materials [15]. The apparatus consists of a drum 140 mm in diameter and 100 mm long with sieve mesh forming the cylindrical walls (2 mm opening). About 500 gm of rock is broken into 10 lumps, each having a mass of 40 – 60 grams. The prepared lumps are loaded inside the drum that is then rotated at a speed of 20 rpm in a water bath. The drum was half immersed in water bath at 20° C. After 10 minutes of this slow rotation, the percentage of rock retained inside the drum, on a dry weight basis, is reported as the slake durability index (Id).

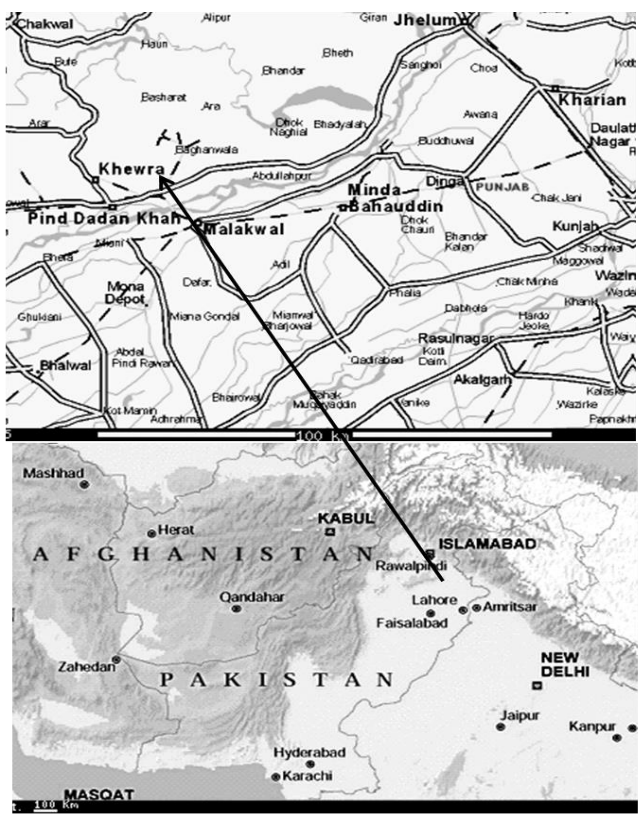

Figure 1. Location map of study area [13]

Table 1. Sampled rock types and their description

Rock type	Age	Formation	Rock description
Sandstone (lower)	Cambrian	Khewra	Purple to brown, yellowish brown, fine grained, thick bedded to massive
Sandstone (middle)	Cambrian	Khewra	Purplish to brown, medium to coarse grained, well bedded
Sandstone (upper)	Cambrian	Khewra	Yellowish brown, glauconitic, conglomeritic
Dolomite	Cambrian	Kussak	Light grey, oolitic arenaceous
Siltstone	Cambrian	Kussak	Greenish grey
Sandstone	Cambrian	Kussak	Greenish, glauconitic, micaceous
Sandstone (lower)	Cambrian	Jutana	Light green, fine grained, hard, massive dolomitic
Sandstone (middle)	Cambrian	Jutana	Bluish-gray, maroon and purple, shaly
Sandstone (upper)	Cambrian	Jutana	Light green to dirty white, fine grained, thick bedded to massive dolomitic
Sandstone	Cambrian	Baghanwala	Pinky gray and bluish green, flaggy
Shale	Cambrian	Baghanwala	Maroon, bright red to purple, variegated
Gypsum	Late Precambrian	Salt Range	White to light grey, flaggy, cherty, Massive
Salt	Late Precambrian	Salt Range	Various shades of pink color, thick bedded

3. Results and Discussions

3.1. Specific gravity and unit weights

The results of specific gravities and unit weights of the thirteen different samples of the Salt Range region are given in Table 2. The mean specific gravities of tested sandstones are 2.62, 3.34, 2.52, 2.77, 2.73, 2.65, 2.84 and 2.68. These mean values show that the specific gravities of sandstone are little higher than that of the standard range i.e. 1.91 – 2.58 [16]. The mean values of shale and salt e.g. 2.85 and 2.23 respectively are also a little higher than the standard specifications for shale i.e., 2.0 – 2.40 and for salt it is 2.16 [16]. This is probably due to the differences in mineralogical composition,porosity, cementation fraction and degree of compaction associated to different rocks tested. However, the mean values of gypsum (2.20) and dolomite (2.84) are exactly within the standard range which is 2.20-2.40 and 2.80-3.00 for gypsum and dolomite respectively [16].

The wet unit weight was found higher than the dry unit weight of the rocks e.g. the mean values of the dry and wet unit weights of Khewra sandstone (lower) are 2.6 gm/cm3 and 2.76 gm/cm3 respectively. Mean values of dry and wet unit weights of Kussak sandstones are 2.58 gm/cm3 and 2.72 gm/cm3 respectively. Similarly, the mean values of dry and wet unit weights of Gypsum are as 2.46 gm/cm3 and 2.56 gm/cm3 respectively. This increase in weight is due to the presence of pores that are later filled with water in wet rocks. When these pores are filled with water, their weights increase and hence their wet unit weights also increase. It is clear that the mean values of most of the sandstones are within the standard range which is 1.99 – 2.58 [16]. However, the dry unit weights of Baghanwala shale and Kussak dolomite are exactly within the range given i.e. 2.0-2.4 and 2.8-3.0 respectively [16].

Table 2. Specific gravity and unit weights of Salt Range rocks

Sr. No.	Sample description	Specific gravity (mean value)	Dry unit weight (gm/cm^3)	Wet unit weight (gm/cm^3)
1	Khewra sandstone (lower)	2.62	2.6	2.76
2	Khewra sandstone (middle)	2.34	2.42	2.39
3	Khewra sandstone (upper)	2.52	2.39	2.44
4	Kussak dolomite	2.84	2.96	2.98
5	Kussak siltstone	2.51	2.56	2.68
6	Kussak sandstone	2.77	2.58	2.72
7	Jutana sandstone (lower)	2.73	2.81	2.59
8	Jutana sandstone (middle)	2.65	2.63	2.47
9	Jutana sandstone (upper)	2.84	2.71	2.65
10	Baghanwala sandstone	2.68	2.13	2.32
11	Baghanwala shale	2.85	2.40	2.33
12	Gypsum (Salt Range)	2.20	2.46	2.65
13	Salt (Salt Range)	2.23	2.07	2.06

3.2. *Moisture contents*

The results of percentage moisture content are given in the Table 3, which shows that the percentage moisture content of the given rock samples ranges between zero and less than 1%. The moisture content of less than 1% is due to the compactness of grains in the rocks.

3.3. Water adsorption

Water adsorption means full saturation of voids of the rock samples with liquid. The rock material is oven dried at 40°C for 12 hours and weight of water adsorption is determined after immersing the rock material in water for a time period of 24 and 48 hours, respectively.

The results of the water adsorption tests are shown in Table 4. The difference between the water absorption measured after 24 hours and 48hours immersion is negligible. This suggests that rock samples were almost completely water saturated within 24 hours. The water adsorbed by Khewra sandstone ranges between 2.00 – 7.50%. The percentage water absorbed by Kussak dolomite is between 0.50 – 3.00% while the water absorbed by Jutana sandstone and Baghanwala shale ranges between 0.50 – 2.50% and 3.0 – 6.00% respectively.

Table 3. Moisture contents in Salt Range rocks

Sr. No.	Sample description	Range of percentage moisture contents	Mean moisture content percentage
1	Khewra sandstone (lower)	0.00 – 0.53	0.40
2	Khewra sandstone (middle)	0.06 – 0.40	0.33
3	Khewra sandstone (upper)	0.00 – 0.90	0.19
4	Kussak dolomite	0.00 – 0.63	0.13
5	Kussak siltstone	0.00 – 0.41	0.08
6	Kussak sandstone	0.00 – 0.07	0.01
7	Jutana sandstone (lower)	0.00 – 0.71	0.34
8	Jutana sandstone (middle)	0.00 – 0.38	0.08
9	Jutana sandstone (upper)	0.00 – 0.07	0.01
10	Baghanwala sandstone	0.00 – 0.07	0.02
11	Baghanwala shale	0.00 – 0.02	0.00
12	Gypsum (Salt Range)	0.00 – 0.03	0.01
13	Salt (Salt Range)	0.00 – 0.07	0.03

It is seen that Khewra sandstone and shale has the greatest percentage absorption while the Jutana sandstone has absorbed the least. Therefore, it is concluded that Khewra sandstone and shale are highly porous whereas the Jutana sandstone is compact and has lesser pores.

Table 4. Results of water adsorption of thirteen rock types of Salt Range

Sr. No	Sample description	After 24 hours		After 48 hours	
		Range of water absorption percentage	Mean water absorption percentage	Range of water absorption percentage	Mean water absorption percentage
1	Khewra sandstone (lower)	4.04 – 5.23	4.70	5.18 – 7.04	5.76
2	Khewra sandstone (middle)	2.16 – 3.58	2.82	2.02 – 3.91	3.05
3	Khewra sandstone (upper)	1.70 – 3.44	2.63	3.36 – 4.07	3.84
4	Kussak dolomite	0.28 – 2.79	1.06	0.58 – 2.79	1.12
5	Kussak siltstone	1.31 – 2.18	1.77	1.66 – 2.18	1.84
6	Kussak sandstone	0.28 – 0.61	0.37	0.35 – 0.91	0.63
7	Jutana sandstone (lower)	0.50 – 1.02	0.63	0.67 – 1.02	0.80
8	Jutana sandstone (middle)	0.41 – 2.38	1.24	0.41 – 2.40	1.28
9	Jutana sandstone (upper)	0.81 – 1.55	0.96	0.82 – 1.55	0.98
10	Baghanwala sandstone	2.64 – 4.15	3.16	2.65 – 4.15	3.16
11	Baghanwala shale	3.35 – 5.12	4.28	3.35 – 5.78	4.52

3.4. Porosity

Liquid saturation method was used to measure the porosity of the rock samples. Bulk volume of each sample was first determined by displacement of liquid. Pores of the prepared samples were filled with water and percentage porosity (n) was determined by the following formula [2]:

$$\gamma_{dry} = G\gamma_w (1-n) \qquad (1)$$

Putting γdry = Ws/V and re-arranging,

$$n = \frac{V - \left(\frac{W_s}{G\gamma_w} \right)}{V} \qquad (2)$$

Where;

V = Total volume of rock specimen

Ws = Dry weight of the rock solids

G = Specific gravity of rock

γw = Unit weight of water

γdry = Dry unit weight of rock

In order to determine dry weight, the rock solids were dried in an oven at a temperature of 110 °C for at least 24 hours and their masses were determined. By using these masses and total bulk volume, the dry weights were determined. Table 5 shows the values of porosity of the given rock samples. Upper and lower Khewra sandstone, Baghanwala sandstone and Baghanwala shale show the highest values of porosity i.e. 14.43 %, 11.67%, 14.85% and 22.33% which indicate them as the potential petroleum reservoirs that can be confirmed by geophysical exploration and drilling exploratory wells. Khan et al. [3] have also predicted the upper Khewra sandstone as potential source of petroleum production on the basis of its porosity value. Higher the porosity, higher will be the storage capacity. So, more volume of hydrocarbons will be present in such reservoirs making the drilling and exploration projects more promising for exploration and production purposes. Similarly, in high porosity reservoirs representing higher pore volume sequestrated greenhouse gases can be injected for storing purposes for a longer period provided that such formations have proper cap rocks for sealing. To make such projects economically more feasible, gases like carbon dioxide can be injected in oil bearing formations to enhance their production. [17, 18].

The porosity values of Kussak Sandstone, Kussak dolomite, Salt Range gypsum and lower Juatana sandstone are lying in the intermediate range while upper and middle Jutana sandstone, middle Khewra sandstone and Kussak siltstone have the least values.

Table 5. Porosity of the Rocks of Salt Range region

Sr. No.	Sample Description	Mean Porosity (%)
1	Khewra sandstone (lower)	11.67
2	Khewra sandstone (middle)	4.85
3	Khewra sandstone (upper)	14.43
4	Kussak dolomite	7.23
5	Kussak siltstone	3.26
6	Kussak sandstone	9.16
7	Jutana sandstone (lower)	6.61
8	Jutana sandstone (middle)	4.59
9	Jutana sandstone (upper)	4.83
10	Baghanwala sandstone	14.85
11	Baghanwala shale	22.33
12	Gypsum (Salt Range)	6.53

3.5. Slake Durability Index

Table 6 shows the result of slake durability tests. Almost all the rock samples show good values of slake durability index even after two cycles of wetting and drying i.e. > 95%, which indicate the durability of these rocks under wet conditions. However, Salt Range gypsum, lower and middle Khewra sandstone show relatively smaller values but still these are greater than 90%. The higher values of the Khewra Salt Range rocks can be due to their compactness and mineralogical composition. The age factor is also important in this regard, as all the rocks belong to the Cambrian age except the Salt range gypsum. The higher values of slake durability indices of these rocks categorized them into strong and competent materials which may be utilized for construction purposes.

Table 6. Slake durability indices of the Salt Range rocks

Sr. No.	Sample description	1st cycle	2nd cycle
1	Khewra sandstone (lower)	96.77	94.95
2	Khewra sandstone (middle)	96.88	94.26
3	Khewra sandstone (upper)	98.60	97.90
4	Kussak dolomite	99.11	99.01
5	Kussak siltstone	97.30	96.40
6	Kussak sandstone	98.89	98.59
7	Jutana sandstone (lower)	99.11	98.71
8	Jutana sandstone (middle)	98.51	98.12
9	Jutana sandstone (upper)	99.01	98.72
10	Baghanwala sandstone	99.20	99.00
11	Baghanwala shale	98.20	97.59
12	Gypsum (Salt Range)	96.17	94.85

4. Conclusions

Various physical and index properties such as specific gravity, dry and wet unit weights, moisture contents, water absorption, porosity and slake durability of different types of rocks of Khewra region, Punjab were determined. It was observed that most of the rock samples have their specific gravities, dry and wet unit weights in the standard range of such rocks except few ones. The Khewra region rocks contains very little or negligible moisture contents. Baghanwala shale, upper and lower Khewara sandstone, Baghanwala sandstone show enough values of porosity which indicates their potential for hydrocarbon reservoirs and/or for greenhouse gases sequestration. Higher values of slake durability index of upper Khewra sandstone, Kussak dolomite, Kussak sandstone, Baghanwala sandstone and Jutana sandstone make them suitable for construction materials. Water absorption values of these rocks also confirm their suitability as construction materials.

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