THE STRESS IMPACT ON MECHANICAL PROPERTIES OF ROCKS IN HYDRO FRACTURING TECHNIQUE

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Abstract:
Ground water is considered to be the best safe protected drinking water source and bore wells are drilled in hard crystalline rock terrains for drinking water, irrigation and industrial purposes. Even after scientific location, some bore wells yield inadequate quantity of water or fail to yield. The success of bore wells depend largely on number, length, dilation and interconnectivity of fractures encountered on drilling. Considering the cost factor involved in drilling a new bore well, rejuvenation of failed bore well through some technique is thought off. The innovative technology of 'hydro fracturing' is a new interdisciplinary approach of Hydro mechanical to stimulate the bore well to improve the yield by applying water pressure into bore well by using a heavy duty mechanical compressor. The hydro fracturing technique was first used in oil well to increase oil and gas production. In this research paper, the hydraulic pressure applied increases with depth reflecting the rigidness, toughness of rock. The fracture development, propagation of fracture and stress behavior depends on the physical and mechanical properties of rocks. The hydro fracturing process has been conducted in three depth zones ranging from 8 m to 45 m below ground level in Annavasal union of Pudukottai district, Tamil Nadu, India. The Pressure application varies depending on the geological formations. This study pertains to a part of research work. The minimum and maximum pressures applied are 1 and 10 N/mm^2 respectively. The maximum pressure of 10 N/mm^2 has been recorded in the third zone, where the country rock is charnockite which is generally massive, compact and dense rock. Generally for the igneous rock in the third zone in the depth range of 40 to 50 m, more than 7 N/mm^2 of pressure has been applied indicating extremely strong nature with uniaxial compressive strength 100 – 300 N/mm^2, tensile strength 7- 25 N/mm^2. Out of 37 bore wells 32.4% of bore wells have shown 75% yield improvement, 40.5% have shown 50 to 75% improvement and 21.9% shown 25 to 50% improvement.

Keywords: Hydro Mechanical; Hydro fracturing; Fluid pressure; Stress.

1. Introduction

Hydro fracturing of new and existing water bore hole to increase yield is routinely carried out in the United States and has been successfully used in other parts of world including Scandinavia, South Africa, India and Australia. The Hydro Fracturing was first developed in India in early 1984 by a Non governmental organization in Madhya Pradesh [1]. The hydro fracturing technique acts to increase bore hole yield by injecting high pressure water into a bore hole to create and enlarge fractures in the surrounding rock. It does not increase the storativity of the aquifer but effectively widen the influence of the bore hole so that it draws water from a greater area of storage. The pressure required creating new fractures and the degree of yield improvement varies considerably according to the rock tensile strength, stresses and permeability. Studies have also concluded that improving bore hole yields by hydro fracturing is more cost effective than drilling new bore holes [2]. Hydro fracturing is carried out in the open uncased section of a bore hole below the casing and water table. The interval to be hydro fractured is hydraulically isolated using packers. The pressure varies from 3.5 N/mm^2 in soft rocks, to over 14 N/mm^2 in harder rocks [3]. Fracture opening causes a drop in the injected water pressure and increases flow of water into the rocks. After hydro fracturing the injected water is normally pumped or airlifted from bore together with any debris arising from the process.

2. The study area

The Annavasal union in Iluppur taluk of Pudukkottai district of Tamil Nadu, India lies between geographic co-ordinates North latitudes 10° 21’ 00’’ to 10° 36’ 00’’ and East longitudes 78º 34’ 00’’ to 78º 50’ 00’’ covering Survey of India toposheets 58/10, 11, 14 and 15. [Fig.1-2].

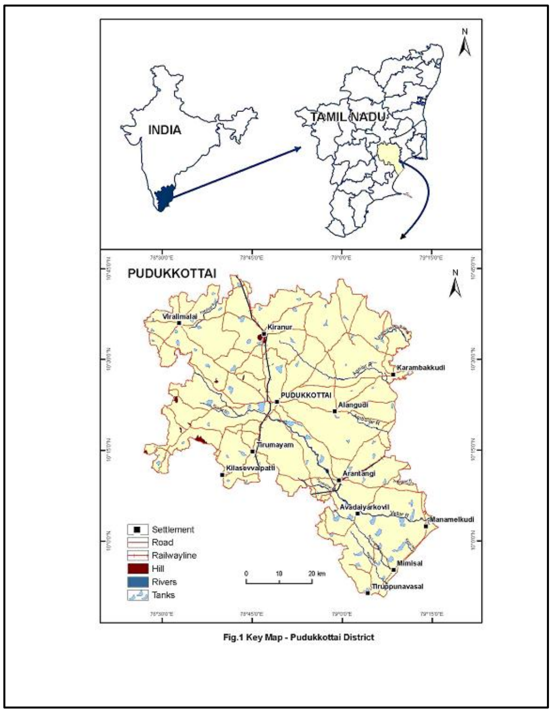


Fig. 1. Key map of Pudukkottai district

Fig. 2. Annavasal Block

3. Geologogy and hydrogeology of the area

The Annavasal block is a typical hard crystalline rock terrain, underlain by biotite gneiss and charnockite of Archean age and younger pink granites, pink gray granites and pink gray white granites. The rocks have a north east- south west trend with a steep north westerly dip. The thickness of weathered zone ranges from 0 to 12 meters. Vellar river passing in the southern parts drains the block. Hundreds of tanks smaller and bigger are scattered over the block. The major geomorphic units are deep buried and shallow pediments and the major land form is residual hills. The summer water level ranges from 4.69 to 7.13 m and the winter level ranges from 0.91 to 6.8 meters below ground level. The area experiences maximum rainfall during north east monsoon. The Annavasal union is categorized as safe.[7].

4. Rock mechanics

Rock Mechanics is an applied physics to study the rock materials. It deals with the properties of rocks and the relationships between forces and resulting structures. Mechanical properties such as tensile strength and compressive stress determine the strength of a rock. When exposing a rock for a pressure the reaction of the rock can be described in two principal manners. For high pressure the reaction will be plastic, while for moderate pressure the theory of elasticity can be applied to estimate the stress [8].

4.1. The physical and mechanical properties of rocks

The fracture development and the propagation of fractures are governed by the physical and mechanical properties of rocks. The important physical and mechanical properties that govern are density, porosity, hardness, abrassivity, coefficient of permeability, electrical resistivity uniaxial compressive strength, tensile strength, elastic modulus, Poisson’s ratio, strain at failure, point load index and toughness. Density and porosity often related to the strength of rock material. A low density and high porosity rock usually has low strength. Porosity is one of the governing factors for the permeability. High porosity naturally leads to high permeability. Hardness is the characteristic of a solid material expressing its resistance to permanent deformation. Hardness of a rock depends on several factors like mineral composition and density. Abrasivity measures the abrasiveness of a rock against other material for example steel. It is an important measure to estimate wear of rock drilling and boring. Abrassivity is highly influenced by the amount of quartz mineral in the rock material. The higher quartz content gives higher abrassivity. Permeability is a measure of the ability to transmit fluids. Most rocks including igneous and metamorphic rocks generally have very low permeability. Granites have low permeability [Table 1] [4].

Table 1. Physical properties of rocks

Rock	Dry density (g/cm^2)	Porosity (%)	Schmidt Hardness	Cerchar Abrasivity index	P-wave velocity (m/s)	S-wave velocity (m/s)	Coefficient of permeability (m/s)
Igneous							
Granite	2.53-2.62	1.02-2.87	54-69	4.5-5.3	4500-6500	3500-3800	10^{-14}-10^{-12}
Diorite	2.80-3.00	0.10-0.50		4.2-5.0	4500-6700		10^{-14}-10^{-12}
Gabbro	2.72-3.00	1.00-3.57		3.7-4.6	4500-7000		10^{-14}-10^{-12}
Rhyolite	2.40-2.60	0.40-4.00					10^{-14}-10^{-12}
Andesite	2.50-2.80	0.20-8.00	67	2.7-3.8	4500-6500		10^{-14}-10^{-12}
Basalt	2.21-2.77	0.22-22.1	61	2.0-3.5	5000-7000	3660-3700	10^{-14}-10^{-12}
Sedimentaary							
Condlomerate	2.47-2.76			1.5-3.8			10^{-10}-10^{-8}
Sandstone	1.91-2.58	1.62-26.4	10-37	1.5-4.2	1500-4600		10^{-10}-10^{-8}
Shale	2.00-2.40	20.0-50.0		0.6-1.8	2000-4600		
Mudstone	1.82-2.72		27				10^{-11}-10^{-9}
Dolomite	2.20-2.70	0.20-4.00			5500		10^{-12}-10^{-11}
Limestone	2.67-2.72	0.27-4.10	35-51	1.0-2.5	3500-6500		10^{-13}-10^{-10}
Metamorphic							
Gnesis	2.61-3.12	0.32-1.16	49	3.5-5.3	5000-7500		10^{-14}-10^{-12}
Schist	2.60-2.85	10.0-30.0	31	2.2-4.5	6100-6700	3460-4000	10^{-11}-10^{-8}
Phyllite	2.18-3.30						
Slate	2.71-2.78	1.84-3.64		2.3-4.2	3500-4500		10^{-14}-10^{-12}
Marble	2.51-2.86	0.65-0.81			5000-6000		10^{-14}-10^{-11}
Quartzite	2.61-2.67	0.40-0.65		4.3-5.9			10^{-13}-10^{-13}

The electrical resistivity of rock is the resistivity in Ohm.meters of a unit cube of material. The resistivity of geological formations is generally high under dry conditions and decreases in clayey rocks. The resistivity of geological formations will vary depending upon the lithology and more influenced by the presence, content and quality of water. The resistivity of granites – 3 x 10^2 -10^6 ohm-m, gneiss- 6.8 x 10^4 [wet]- 3 x 10^6 [dry]. [4]. Compressive strength is the capacity of material to withstand axially directed compressive forces. Usually the compressive strength of rock is defined by the ultimate stress. Young's modulus is modulus of elasticity and measuring of stiffness of a rock material. It is defined as the ratio for small strains of the rate of change of stress with strain. Similar to strength, Young's modulus of rock materials varies widely with rock types. For extremely hard and strong rocks Young modulus can be as high as 100000 N/mm^2. Poisson's ratio measures the ratio of lateral strain to axial strain at linearly –elastic region. Strain at failure is the strain measured at ultimate stress. Brittle rocks typically crystalline rocks have low strain at failure. Strain at failure sometimes is used as a measure of brittleness of rock. Most rocks including all crystalline igneous and metamorphic rocks behave brittle under uniaxial compression [5]. Tensile strength of rock material is normally defined by the ultimate strength in tension i.e the maximum tensile stress the rock material can withstand. Rock material generally has a low tensile strength. The tensile strength of the rock has great influence on the magnitude of the fracture initiation pressure when performing hydraulic fracturing. Shear strength is used to describe the strength of rock materials to resist deformation due to shear stress. Rock resists shear stress by two internal mechanisms, cohesion and internal friction. Point load [strength] is another simple index test for rock material. Fracture toughness of rock materials measures the effectiveness of rock fracturing. It is typically measured by toughness test. All these physical and mechanical properties of granites, gneiss and charnockite influence the fracture development and propagation. [Table-2] [6].

Table 2. Mechanical properties of rocks

Rock	UC Strength (MPa)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Poission's Ratio	Strain at Failure (%)	Point Load Index I s	Frature Mode I Toughness
Igneous							
Granite	100-300	7-25	30-70	0.17	0.25	5-15	0.11-0.41
Diorite	100-350	7-30	30-100	0.10-0.20	0.30		>0.41
Gabbro	150-250	7-30	40-100	0.20-0.35	0.30	6-15	>0.41
Rhyolite	80-160	5-10	10-50	0.20-0.40			
Andesite	100-300	5-15	10-70	0.2		10-15	
Basalt	100-350	10-30	40-80	0.1-0.2	0.35	9-15	>0.41
Sedimentaary							
Condlomerate	30-230	3-10	10-90	0.10-0.15	0.16		
Sandstone	20-170	4-25	15-50	0.14	0.20	1-8	0.027-0.041
Shale	5-100	2-10	5-30	0.10			0.027-0.041
Mudstone	10-100	5-30	5-70	0.15	0.15	0.1-6	
Dolomite	20-120	6-15	30-70	0.15	0.17		
Limestone	30-250	6-25	20-70	0.30		3-7	0.027-0.041
Metamorphic							
Gnesis	100-250	7-20	30-80	0.24	0.12	5-15	0.11-0.41
Schist	70-150	4-10	5-60	0.15-0.25		5-10	0.005-0.027
Phyllite	5-150	6-20	10-85	0.26			
Slate	50-180	7-20	20-90	0.20-0.30	0.35	1-9	0.027-0.041
Marble	50-200	7-20	30-70	0.15-0.30	0.40	4-12	0.11-0.41
Quartzite	150-300	5-20	50-90	0.17	0.20	5-15	>0.41

4.2. Gneisses

In gneisses where foliation is well developed, the general pattern of fractures will be more or less parallel. Two types of foliation occur, one is created perpendicular to the fold axis and one is parallel to foliation. These fractures have very little interconnectivity so even though the fractures contain water, it will form a poor aquifer [4].

4.3. Biotite Hornblende Gneiss

The rock belongs to the granodiorite which is expected to be a coarse grained rock. The size of the grains promise a good aquifer but this can be subdued by an eventual foliation. The rock can be expected to have a very varying ability for water supply [4].

4.4. Pink Granites

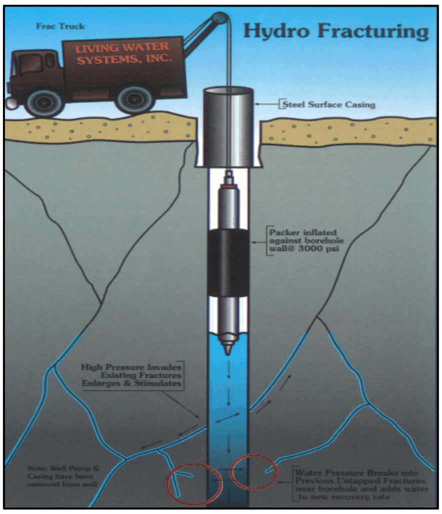
Pink granite is more fractured than other granites. The pink color indicates that the rock contains quartz and feldspars only. In rocks of quartz and feldspars without any weaker minerals, the fractures will be cleaner. Pink granite may be encountered generally in areas where the tectonic activity is high and therefore in general very well fractured [4].

4.5. Charnockites

A coarse grained which should cause a good system of fractures, but if the charnockite is a high grade metamorphic rock it shows almost no fracturing. In general charnockites may be expected to be a poor aquifer. Generally the secondary porosities in hard crystalline rocks are formed due to tectonic activities and are influenced by geological structures like fold, faults, dykes, intrusive bodies, lineaments and geologic contacts [4].

5. Hydrofracturing process

The hydrofracturing is a process where by a hydraulic pressure is applied to an isolated zone of bore wells to initiate and propagate fractures and widen and extend existing fractures. The water under high pressure break up fissures, cleans away mud and other impurities leading to contact with adjacent water bearing bodies. The yield is improved since the fractures are exposed to larger catchments and aquifers. [Fig. 3-7]. In this research ASTM standard D4645-08 has been followed through out the investigation.



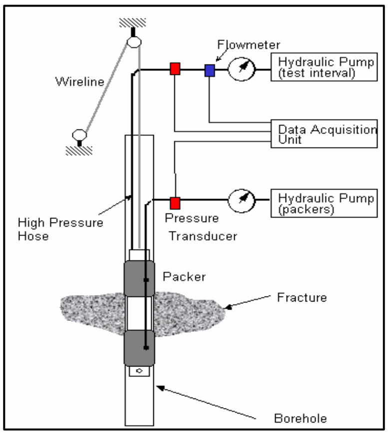


Fig. 3 and 4. Hydrofraturing Experimental setup and Equipment

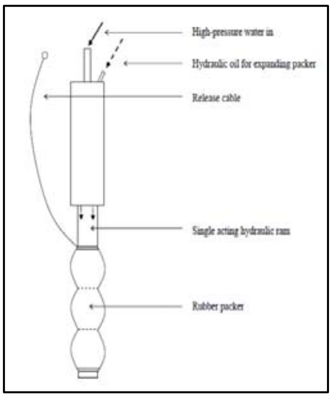


Fig. 5. Schematic of Packer

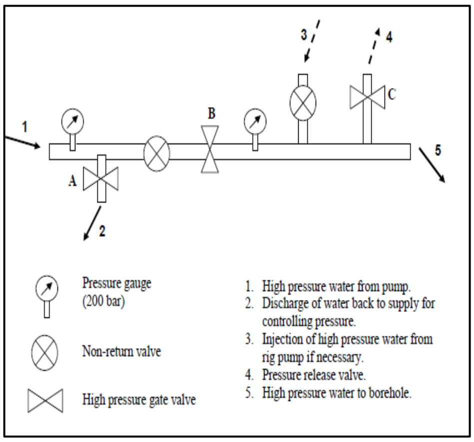


Fig. 6. Schematic of Hydrofraturing unit

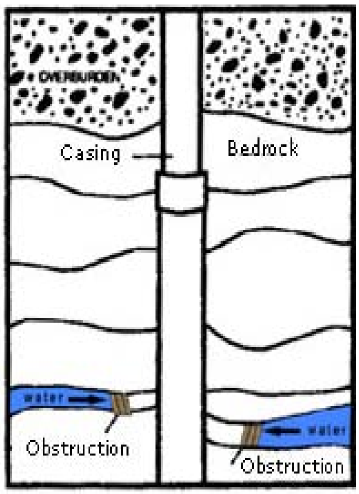


Fig. 7(a). Before Hydrofraturing

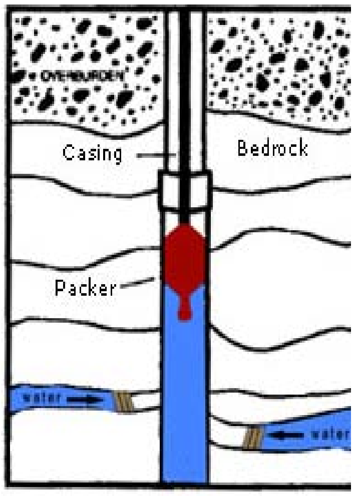


Fig 7(b).Packer and pressure application

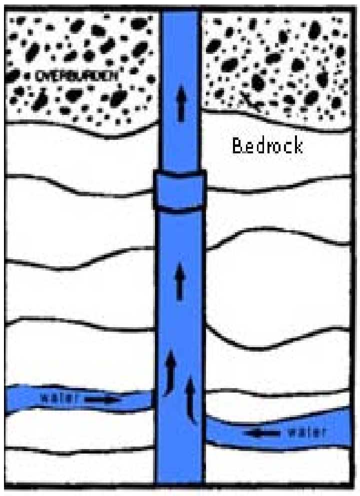


Fig 7(c). After Hydrofraturing

5.1. *Principle of hydrofracturing*

The hydrofracturing process works on the principles of Pascal's law which states that when the hydraulic pressure is applied in any closed body , it acts in all directions and is equal at all points. When high pressure water is injected in the isolated section, the hydraulic pressure acts equally in all directions. The injected water follows the least resistance paths and therefore the initiations of fractures or opening of the fractures takes place in the weathered zone**.**

5.2. Hydrofracturing procedures and operations

- Scientifically studying the lithology backed up with electrical logging.
- Demarcation of weathered zones and the aquifers.
- Measurement of static water level and yield of well before fracturing.
- Lowering of packer to the selected depth and fixing by applying hydraulic pressure.
- Opening the booster pump and injection pump to inject water in the isolated down the hole section.
- Noting the minimum and maximum pressure during hydrofracturing shut.
- Measuring water intake during operation.
- Releasing the packer and setting down in the next selected section.
- Carrying out hydrofraturing at number of selected.sections
- Pumping out the water intake and measuring the post fracturing yield.
- Entering all these field data
- Conducting electrical logging after fracturing to study the effect of hydrofraturing.

5.3. *Hydrofracturing unit*

The hydrofrac unit mounted on a carrier is provided with equipment intended to carry out two types of processes in the field specifically hydrofrac treatment [aquifrac] and yield test [aquitest] of bore well. In addition the water tanker is provided to transport and store the water**.**

5.4. *Pressure application*

The water injection pump plays a prime role in hydrofracture process. The water pump is intended to initiate the fractures overcoming the insitu stresses of rock formations. The field studies reveal that the breakdown pressure of granite is about 15 N/mm^2. Therefore it is obvious to select the positive displacement pump with high pressure head of 17.5 N/mm^2. The discharge rate of the pump and treatment time controls the fracture length. In short the reciprocating pump with a minimum discharge rate of 350 lpm at given RPM and maximum pressure of 17.2 N/mm^2 should be selected for hydrofracturing operation. Pumping can be defined as a process of imparting mechanical energy to a liquid and converting this mechanical energy into hydraulic energy. The hydraulic energy obtained may be in the form of either pressure head or Kinetic head. In all the 37 bore wells hydrofracturing has been done at three depth zones below ground level from top to bottom in the depth range of 8 to 45 meters. Only single packer has been used. The hydraulic pressure behaviour is noted in particular the maximum and minimum pressures during hydrofracturing. Shut in pressure is noted. The water in take during operation is measured with the help of quantity meters and the time duration for each depth zone is recorded.

5.5. Stress behaviour analysis

I. Zone-I:

In the first depth zone the minimum and maximum depth are 9 and 30 meters respectively. The minimum and maximum duration of hydrofracturing are 5 and 9 minutes respectively. The minimum pressure applied is nil except in bore wells and the maximum pressure applied is 3 N/mm^2. The average maximum pressure is 1.3 N/mm^2 [Fig. 8].

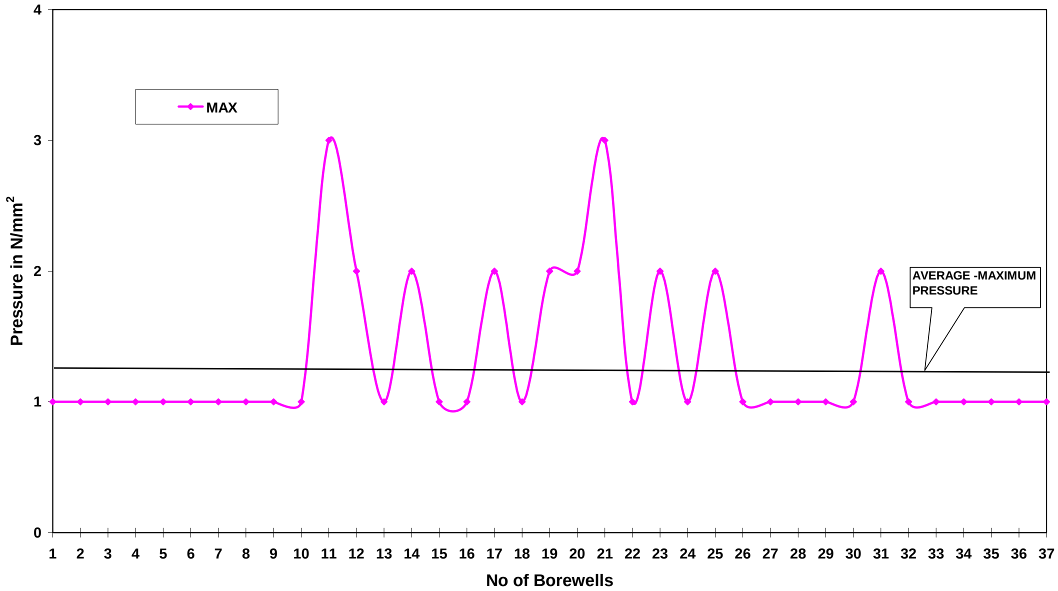


Fig. 8. Depth zone-I -Maximum pressure applied

II. Zone-II:

The minimum and maximum depth zones are 12 and 36 meters respectively. The minimum and maximum duration are 4 and 9 minutes. The minimum and maximum pressures applied are 1.0 N/mm^2 and 7.0 N/mm^2. The average minimum and maximum pressure applied are 1.16 N/mm^2 and 5.4 N/mm^2 respectively [Fig. 9].

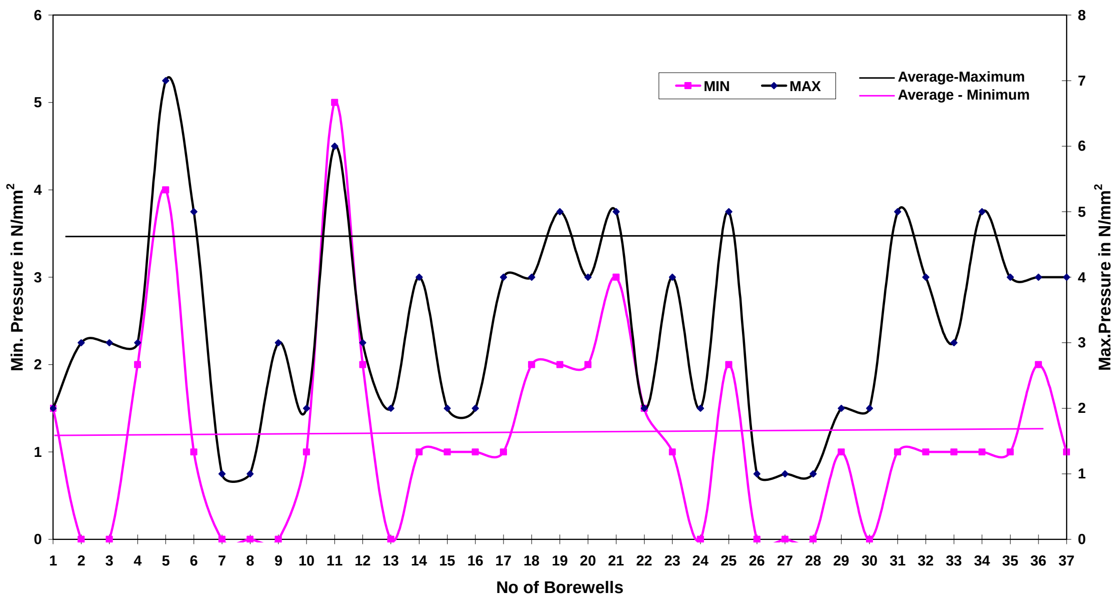


Fig. 9. Depth zone-II, Minimum & Maximum pressures

III. Zone-III:

The minimum and maximum depths zones are 15 and 45 meters below ground level. The minimum and maximum duration are 3 and 8 minutes. The average minimum and maximum pressures applied are 6.05 N/mm^2 and 6.16 N/mm^2 respectively. A maximum pressure of 10.0 N/mm^2 at the depth of maximum depth of 39 meters has been recorded in the bore well number 1188 at Goldennagar of Vellanur panchayat and the lithology is charnockite [Fig. 10].

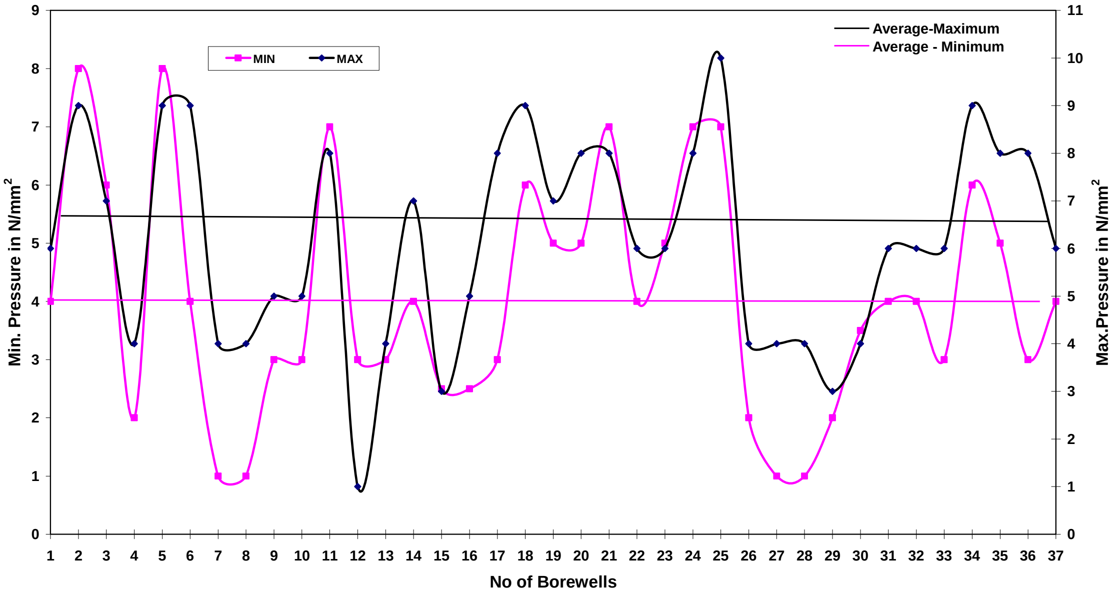


Fig. 10. Depth zone-III, Minimum & Maximum pressures

5.6. *Stress and yield correlation*

The average pressure applied in all the three zones of hydrofracturing and the yield after hydrofracturing has been correlated. The minimum and maximum pressures applied are 1.4 N/mm^2 and 5.8 N/mm^2 respectively. The minimum and maximum yields after hydrofracturing are 15 and 117 liters per minute respectively. The average yield after hydrofracturing is 52.816 liters per minute [Fig. 11].

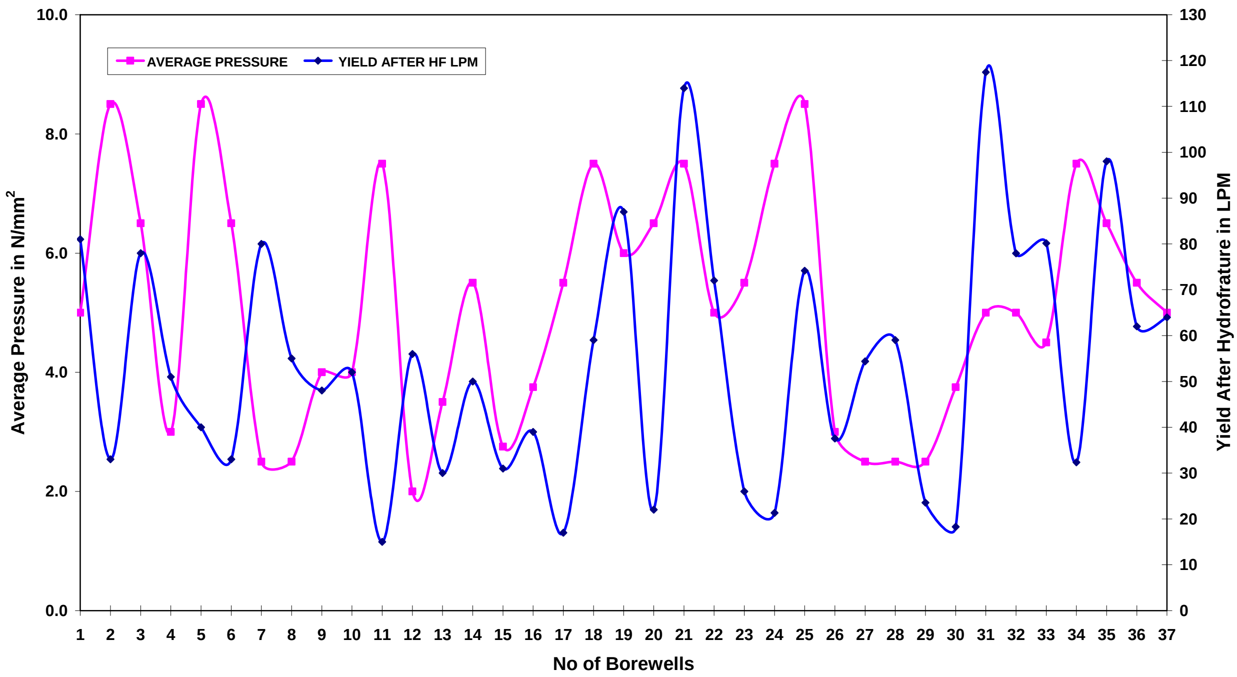


Fig. 11, Yield versus Pressure.

5.7. *Yield improvement analysis*

The yield before and after hydrofracturing has been correlated and analyzed. The minimum and maximum yields before hydrofracturing are 8 and 60 liters per minute. The minimum and maximum yields after hydrofracturing are 15 and 117 liters per minute respectively. Out of 37 bore wells fractured 12 bore wells have shown more than 75% yield increase, 15 bore wells 50 to 75% yield increase and 10 bore wells with 25 to 50% yield increase [Fig. 12& 13].

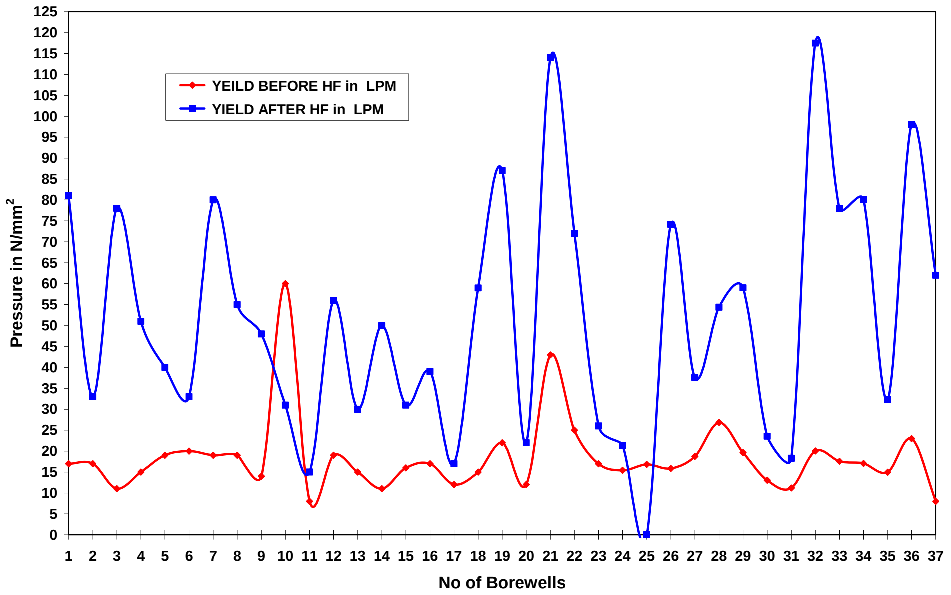


Fig. 12. Correlation of Yield before after Hydrofrature

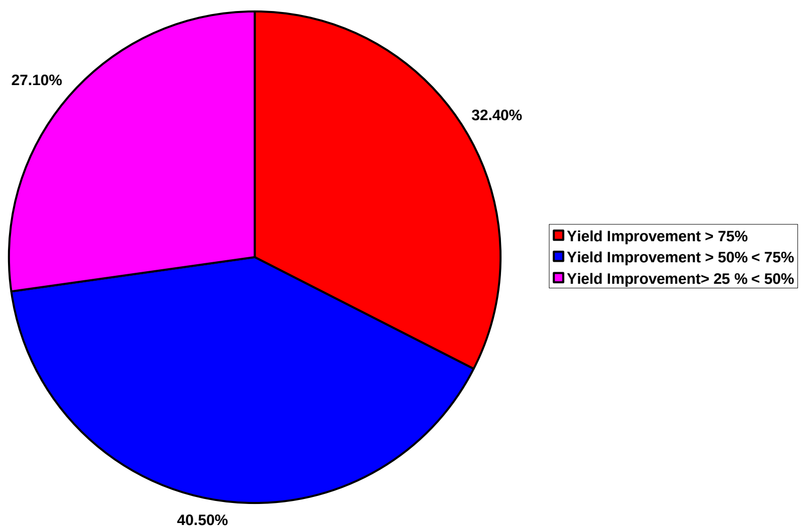


Fig. 13. Yield improvement

6.0 Results and discussion

The hydrofracturing has been conducted in 37 bore wells of 150 mm diameter. The minimum and maximum depths of bore holes are 75 and 120 meters respectively. The minimum depth zone fracking is 9 meters below ground level and the maximum depth zone is 45 meters below ground level. The least hydraulic pressure applied is 1.0 N/mm2 and the maximum pressure is 10.0 N/mm2 in the third depth zone in bore well number 1188 at Goldennagar. The minimum duration of fracking is 4 minutes and the maximum is 9 minutes. The lowest quantity of water injected is 400 liters and the maximum is 3000 liters. The minimum and maximum yields before hydrofracturing are 8 and 60 liters per minute. The minimum and maximum yields after hydrofracturing are 15 and 117 liters per minute respectively. The mean yield after fracking is 52.816 liters per minute. Out of 37 bore wells fractured 12 bore wells have shown more than 75% yield increase, 15 bore wells 50 to 75% yield increase and 10 bore wells with 25 to 50% yield increase. In total all the 37 bore holes which have been fractured has shown an increase in the yield.

7.0 Conclusion

Hydro fracturing techniques have been carried out with single packer in 150 mm diameter water supply bore wells below water table at 37 villages of Annavasal union in Iluppur taluk of Pudukkottai district of Tamilnadu. The terrain is a hard crystalline rock with lithological units of pink granite, biotite gneiss, charnockite, pink grey granites and pink grey white granites. The thickness of weathered zone ranges from 0 to 12 meters below ground level. Out of 37 bore holes fractured all the 37 bores have shown an increase in the yield. 12 bores have shown more than 75% yield increase, 15 bores have shown more than 50 to 75% yield increase and 10 bores have shown more than 25 to 50% yield increase. The metamorphic gneissic rocks show good yield improvement than igneous rocks. A maximum hydraulic pressure of 10.0N/mm^2 has been applied at Goldennagar bore hole in the third zone at a depth of 45 meter below ground level, where the lithology being igneous [charnockite] rock. Generally the igneous rocks in the third depth zones, more than 7.0N/mm^2 of pressure has been applied invariably in all bore holes indicating extremely strong nature of bed rock. The hydraulic pressure applied increases with depth reflecting the rigidness, toughness and strength of rock. The uniaxial compressive strength and tensile strength of igneous rocks are 100 to 300 MPa and 7- 25 MPa. The compressive and tensile strengths of metamorphic gneissic rock are 100-250 MPa and 7-20 MPa respectively. The fracture development and propagation of fracture depend on the physical and mechanical properties of rocks.

8.0 Acknowledgement

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