HYDROFRACTURE: STATE OF THE ART IN SOUTH AFRICA

by

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ABSTRACT: During the past five years, the Department of Water Affairs and Forestry of South Africa have hydrofractured a large number of low yielding boreholes in different geological and geohydrological regimes. In the Swartwater study area (10 holes), the results indicate that boreholes that were scientifically sited in order to intersect geological features such as faults or contacts are the most likely to be successfully stimulated. In the case of random site selection, the success rate was extremely low.

By using the newly developed hydrofracture unit and carefully selecting the holes to be stimulated, a low-yielding water borehole can be successfully converted into a production hole for between 35 and 45% of the cost of drilling another borehole.

RÉSUMÉ: Au cours des cinq dernières années, le Département des Eaux et Forêts d'Afrique du Sud a procédé à la fracturation hydraulique dans un grand nombre de forages à faible rendement dans des situations géologiques et hydrogéologiques variées. L'étude de la région de Swartwater (10 forages) montre que les forages qui ont été positionnés rigoureusement de façon à recouper des discontinuités (failles, contacts, etc.) sont les plus susceptibles d'être améliorés. Dans le cas d'implantation au hasard, le taux de réussite est au contraire très faible.

La mise en oeuvre d'une unité de fracturation hydraulique nouvellement conçue et le choix convenable des puits à développer améliorent considérablement le rendement des forages pour un coût équivalent à 35 à 45% de celui d'un nouveau forage.

INTRODUCTION

In South Africa, as in many other water-poor countries, many unsuccessful boreholes are drilled each year. This is particularly true for boreholes drilled in fractured rock formations where, in the Republic of South Africa, the yields average <450ℓ/hr (0,125ℓ/s). As a result, these boreholes are usually considered to be "dry" and are abandoned. Often, another borehole will be drilled elsewhere in the immediate vicinity, generally with the same result.

In the mid 1980's hydrofracturing of low-yielding water boreholes was attempted by entrepreneurs. These attempts met with only limited success, due to the lack of the correct equipment and technical skills, in particular due to inadequate packers and high pressure pumping equipment.

In order to remedy the situation, the Directorate of Geohydrology of the Department of Water Affairs launched a pilot project in September 1987 designed to evaluate borehole stimulation in general, but in particular the use of hydrofracturing. The project had the following main objectives (Less 1989):

- Determine the viability of the technique;
- Test the capability and limitations of the equipment to be used;
- Determine the correct equipment to be used for this type of work;
- Apply the techniques elsewhere if successful;
- Ultimately establish a set of standards for the future.

Although the initial success rate was low, the results were sufficiently encouraging to go ahead with the development of a state-of-the-art unit and to commence a full scale test programme. The Republic of South Africa is divided into 16 domains with similar geological / geohydrological attributes, and results will in future be compared on a domain basis before the launching of a full scale hydrofracturing programme.

EQUIPMENT

Very early in the programme it became obvious that the initial equipment being used was not ideally suited for the task. Numerous problems with the pump unit and hydraulic packers were experienced leading to considerable delays. It was also time consuming and cumbersome to move the equipment between sites.

From using this early test equipment, we were able to design a unit ideally suited to our field conditions. After careful consideration of all options, a new unit was acquired from Kyle Equipment of Sterling, Massachusetts, USA. The new unit is compact, relatively light and mobile and can be operated by a two man crew. It consists of dual pumps (one for pressure and one for volume) and is capable of generating in excess of 130 KW of energy downhole when required. Flow rates of more than 15ℓ/s at a pressure of 80 bar are not uncommon after fractures have opened. Inflatable packers are used in either single or straddle configuration. The straddle packers allow the input energy to be concentrated in a particular fracture zone and for "hydrojacking" to occur. The term "hydrojacking" (Bill Williamson pers. comm.) stresses the fact that, in general, existing fractures are "jacked" open. Since the rate of energy delivery into the system is equal to the flow-rate (ℓ/s) times the pressure (MPa), it follows that high volumes of water delivered at high pressures will be the most effective.

Energy (KW) = Flow-rate (ℓ/s) x pressure (MPa)

The HF unit is mounted on a 1517 Mercedes Benz truck, together with test pumping equipment. Water for the treatments is transported in an 8000ℓ water tanker which also serves as the fracpipe carrier. The unit is capable of working to depths exceeding 300 m, although this is not usually necessary.

With this new unit the on-site time has been reduced to 12 hours maximum, including pre- and post-test pumping of up to 6 hours and four packer settings. Average time per site using the old equipment was 21 days, although it could have been as little as 3 days if all went well.

METHODOLOGY

Since boreholes selected for treatment may have been completed several years before, there is very often no information available on the borehole construction or the formations which were intersected. As a result, all boreholes are routinely test pumped and geophysically logged in order to supply the information required to ensure the most effective hydrofracturing.

The geophysical logs include long and short normal resistivity, density, natural gamma, neutron, calliper and occasionally temperature. These logs provided information such as the diameter of the hole, the depth of the casing and hole, the depth of weathering, the depths and thicknesses of the various geological units (although it was very seldom possible to determine actual rock types), the depth to the static water level and the positions of any fractures or fracture zones, which are very important for placing/positioning the packer/s.

The test pumping provides important information on the aquifer itself, and is also used as a measure of the success of the hydrofracturing. Since the boreholes are mostly low yielding, the pump inlet is seldom placed deeper than 50 m below static water level (SWL). The water is then drawn down to this level, and the volume extracted and the rate of recovery are measured. This process is then repeated after the treatment (at the same pumping rate) and the success rate is then calculated as the percentage improvement in the volume extracted (Fig. 2). Due to the very low yield of the boreholes, it was too time-consuming to determine the specific capacities of the boreholes and it was thus decided rather that the measure of improvement would be calculated as above.

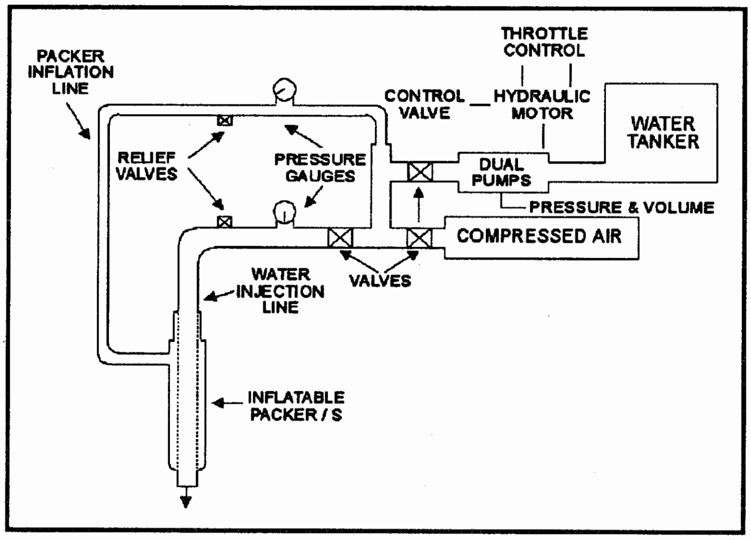


Figure 1. Example of typical hydrofracture equipment layout (after Waltz and Decker 1981)

Table 1. Percentage improvement vs number of boreholes

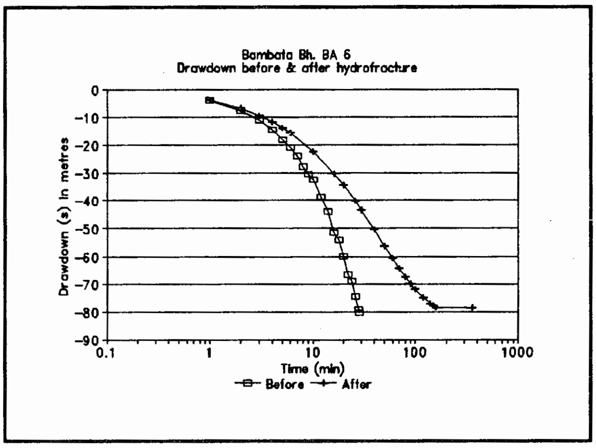
	Percentage Improvement						
	0-20	21-100	101-200	201-400	401-1000	1001-5000	5000+
No. of boreholes	91	32	5	20	8	9	5

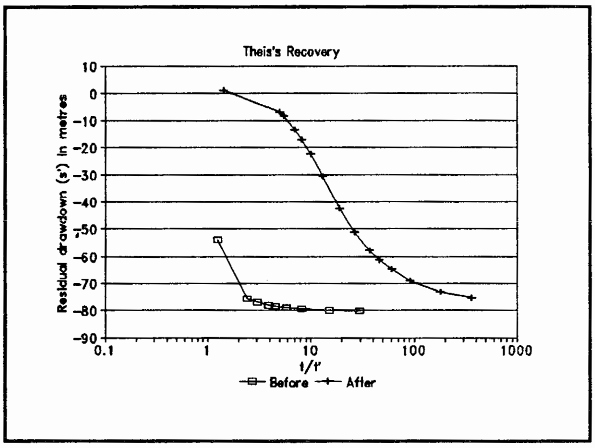
RESULTS

Since the new rig was commissioned in January 1990, to date (September 1992) a total of 170 boreholes have been hydrofractured in various geological and geohydrological domains. Randomly and scientifically sited boreholes in both sediments and crystalline rocks have been treated. Initial results indicate that boreholes in the crystalline rocks show the best improvement. There is also an indication in one area (Swartwater) that boreholes that were sited using sound geohydrological, geological and geophysical parameters (scientific siting) were the ones that were most likely to show the best improvements. Boreholes of up to 350 m depth with SWL's of 170 m have also been treated.

Table 1 gives the results from 170 boreholes hydrofractured up to September 1992. The top row indicates the percentage improvement in each category and the lower row the number of boreholes which achieved those values. Results indicate that 46.47 % of all boreholes treated responded positively (> 20 % improvement). Of the 91 boreholes that did not respond to treatment, 15 already produced usable quantities of water varying from 0.5ℓ/s to 3.0ℓ/s. If these boreholes are excluded, the success rate goes up to about 55 %.

These statistics can further be improved if those boreholes that were randomly sited are excluded. One such study has been completed in the Swartwater area, where the boreholes that had been hydrofractured were studied in order to determine if there were any patterns in the success of the hydrofracturing with respect to the geology at the borehole site. As this sort of study requires a fairly large data base to be statistically meaningful, only preliminary comments can be made; only 10 boreholes have been hydrofractured in the study area. However, one can see from the data presented in Table 3 that boreholes that were drilled close to favourable geological structures are the most likely to have improved yields after hydrofracture.





Initial water level:	**14.17 m (below collar)**	
Discharge rate:	**$Q_{initial\ (av.)}$**	**0.968 ℓ/s**
	Q_{final}	**0.748 ℓ/s**
Pump intake:	**94.5 m (below collar)**	
Depth of hole:	**99 m**	
Volume extracted (ℓ) for a 78 metre drawdown	**Before 1590 (in 27 min)**	**After 7740 (in 155 min.)**
Recovery rate in (m/min)	**Before 0.239**	**After 1.729**
Improvement	**387%**	

Figures 2a and 2b; Table 2. Example of test pumping before and after treatment.
Note change in recovery rate.

ECONOMIC BENEFITS

With the earlier unit, hydrofracturing a hole took from 3 to 21 days and cost between 170 % and 250 % of the price of drilling another borehole. Since commissioning the new unit 2½ years ago, the overall operational efficiency has improved considerably and it now takes 12 hours maximum to complete the treatment and the costs are between 35 % and 45 % that of the original borehole.

This makes the technique all the more attractive in the difficult areas where a farm may have as many as 150 dry boreholes, the total cost of which would probably exceed R 1,500,000 (US$ 560,000). The success of the hydrofracturing in a particular hole cannot be guaranteed (as is often done in the USA), due to the many variables involved, but if holes are selected on sound geological reasoning then the success rate should be high.

In future drilling programmes where the sites are scientifically selected, low production boreholes should be hydrofractured immediately. This will lead to a greater chance of success with considerable cost saving to the whole programme.

Table 3. Results of hydrofracturing of boreholes in Swartwater

Farm	Borehole	% Improvement	Geological comments
Selous	SL13	1753	Fault and amphibolite close to borehole
Benedict	BT3	35	No fault evident but close to amphibolites
Oxton	ON1	29	No fault evident but on meta-sedimentary contact
Bambata	BA6	387	Borehole drilled close to NNE trending fault
Klipfontein	G37747	Nil	No evidence of faulting or presence of meta-sedimentary rocks
Holdrift	G37770	14	No evidence of faulting or presence of meta-sedimentary rocks
Melkbosch	G37768	Nil	No evidence of faulting or presence of meta-sedimentary rocks
Daantjies-laagte	DL7	12	No evidence of faulting or meta-sedimentary rocks
De Hoek	DH9	6155	Borehole sited near a NNE trending fault
Paddysland	DP9	86	Borehole sited near a NNW trending fault

CONCLUSIONS

- The objectives of the original project have been met and suitable equipment has been designed for South African conditions.
- From the results to date it is evident that boreholes that have been sited using sound geological, geohydrological and geophysical parameters are the most likely to produce the best results on hydrofracturing.
- In the light of the Swartwater results, it is not always necessary to drill new boreholes when hydrofracturing of existing, suitably geologically located boreholes would be more expedient.
- In future, boreholes will have to be more critically selected for hydrofracture, thus improving the overall success rate.

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