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Hydraulic Fracturing in Salt and Potash Formations

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ABSTRACT

Extensive development programs have been conducted for the past several years to devise techniques for the economical solution mining of potash from the deeper areas of the large Canadian potash deposit. Economic considerations indicate that mining procedures utilizing wells connected by hydraulic fracturing could be attractive. Initial attempts to establish a fracture communication between adjacent wells by initiating a fracture at the base of a potash seam were not productive. The communication appeared to be established momentarily, but it could not be maintained. The selected fracture point was a clay seam which, although thin, appeared to be continuous and to provide a weak plane in the deposit. Analysis of the experiment appeared conclusive in demonstrating that a fracture path along the clay seam was not established and consequently that these weakness planes were not suitable for fracture propagation.

A different technique was developed and applied successfully. This new technique offers a high probability of success in initial fractures and virtually guarantees a high percentage of successful fractures in a production well field. In addition to potash deposits, this technique should be applicable to salt deposits and most other soluble mineral deposits. The results of the experimental program and the development of the techniques are presented in this paper.

Hydraulic fracturing was originally developed as a technique for stimulating production of oil wells. The creation of a fracture by fluid injection enlarged the surface area exposed for oil flow, thus increasing the effective permeability and production rate of a given oil bearing formation.

The same basic technique was later applied to fracturing soluble salt formations, in particular to sodium chloride (rock salt) deposits. In contrast to oil field fracturing where the production of a single well is stimulated, these soluble mineral fractures require the establishment of a communication or flow path between two or more wells to allow dissolving or "solution mining" of the salt deposit. The hydraulic fracture technique has been utilized to establish this communication between wells.

Typical salt fracturing operations were described at the two earlier Salt Symposia (Gilbert, 1963; Jacoby, 1963; Mair, 1963; Shock, 1966). The fracturing procedure in rock salt mining invariably utilizes a salt-shale interface for a cleavage plane to initiate and propagate the fracture (Bays, U.S. Patent, Bays, 1960; Pullen, U.S. Patent; Redlinger, U.S. Patent). By following these salt-shale interfaces successful fractures are often obtained, and communication paths have been established between wells several hundred feet apart.

More recently the same fracture techniques have been applied to the creation of cavities for natural gas and other hydrocarbon storage (Shock, 1966; Shock and Davis, 1969), where the cavities are created by solution mining of a salt formation. Cavity volumes of 100,000 barrels and greater volumes have been established by this method. The general convenience of underground storage indicates these cavity storage systems will become even more common.

Potash formations.

The application of hydraulic fracturing to potash solution mining is also of considerable interest. One experimental program has been described (Davis and Shock, 1969) and other unpublished tests have taken place. Of particular interest are the deeper portions of the large Saskatchewan potash deposit where the rich ore zones are too deep for conventional shaft mining to be economical.

Interest in these deposits led to an experimental program to establish hydraulic fracture communication between potash solution mining wells. The initial program followed conventional procedures wherein a weak clay stratum was selected as the fracture point in the potash zone of interest. A well was drilled into the formation, cased, cemented and subsequently notched at the clay stringer. A second well which was cased only to the top of the ore zone, with an open hole extending well below the zone, was used as a target well.

After the completion of the injector well and notching of the casing, suitable pumping equipment and fluid reserves were established at the site. The injection of fluid was begun with the initial condition of the well as shown in Figure 1, and

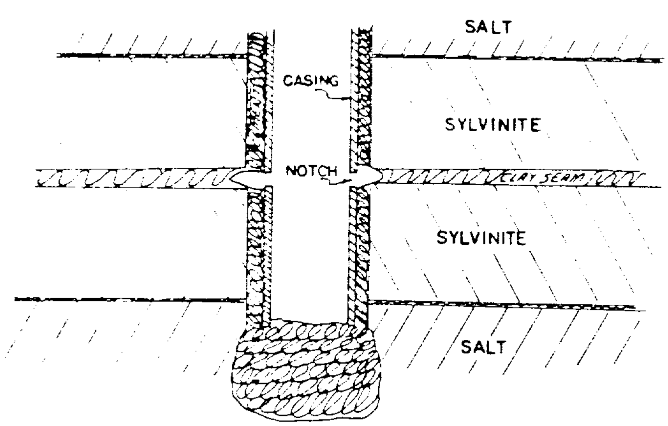

Figure 1. Initial well structure.

observation of injection pressure clearly indicated a positive fracture, as represented in Figure 2. The indicated thickness of the fracture was determined in retrospect rather than in initial estimates and planning.

With this conventional procedure, all that remained to be done was to maintain the injection of fluid, and at the same time monitor the target well

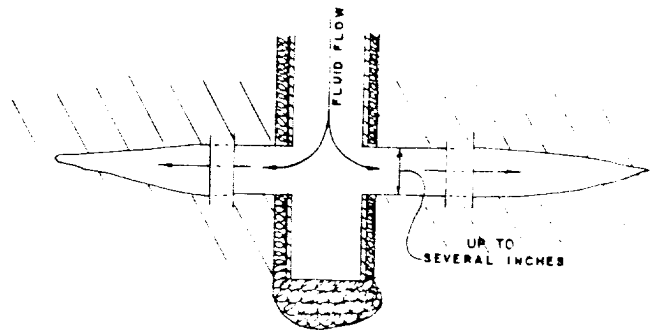

Figure 2. Fracture propagation.

for signs of success. These signs of success failed to appear, and after very large quantities of fluid had been injected and no communication had been established, fluid injection to the injector well was stopped. A further attempt to establish communication was made by injection into the target well with the original injector well serving as the target. This also failed to establish a successful communication. Additional manipulations were tried with additional lack of success in creating any flow between the wells.

Analysis of results.

The negative results of this fracture experiment, coupled with several observations of unusual and unexpected behaviour during and after the tests prompted a detailed evaluation and analysis of the procedure. The volume of fluid injected, and the known distance the fluid had not travelled in at least one direction, strongly suggested that the fracture thickness was of the order of inches as shown previously in Figure 2.

In contrast, most literature on hydraulic fracturing suggests that fractures are only a fraction of an inch thick. Results of some fracturing operations (Gilbert, 1963; Shock and Davis, 1969) confirm that the obtained fractures were only one or two tenths of an inch thick.

The thickness of a fracture clearly depends upon the mechanical properties of the target formation and the pressures used in the fracture operation. Initiation and propagation of a fracture can only be accomplished by applying and maintaining a pressure higher than the static formation (overburden) pressure. The excess pressure causes a compression of the formation to create the fracture opening. The thickness of this opening may be estimated from the formation mechanical properties and the pressures used in fracturing.

In a completely isotropic formation, a fracture should propagate equally in all directions, producing a circular envelope. It is well known, of course, that variations in the structure of geological formations (Jacoby, 1966) result in an areal propagation of a noncircular nature as represented in Figure 3. Fluid injected into the well will tend to follow the path of least resistance, and variable resistance of the formation results in the asymmetrical areal propagation.

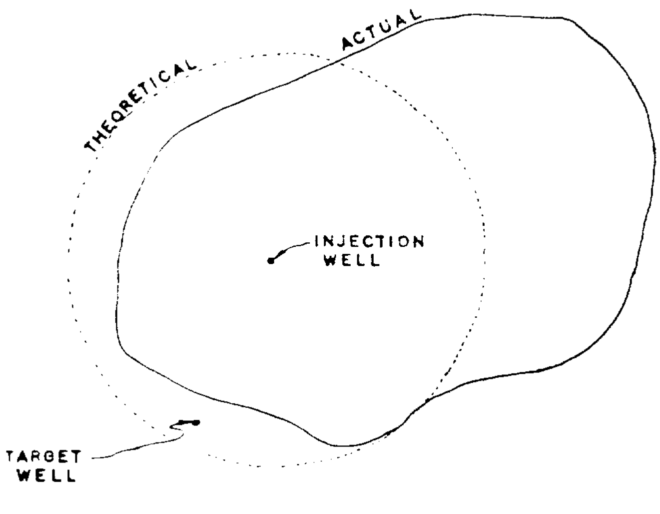

Figure 3. Areal propagation.

The path of least resistance will also tend to direct the fracture upward under average conditions. Again the lack of an isotropic structure may cause any given fracture to go upward, downward or horizontally. In the first fracture experiment, the extensive open hole section in the target well and later results of logging and other tests suggested that the established fracture had probably travelled upward from the initiation depth. There was no absolute evidence for this conclusion, but it appeared, as shown schematically in Figure 4, to be the most probable situation.

The "path of least resistance" principle further suggests that the drilling of the target well may be an invitation to failure. It is inevitable that the drilling process mechanically alters stresses in the formation around the well, and magnifies the disturbance by altering temperature profiles adjacent to the well. These disruptions may cause weakness paths which neatly circumvent the target well.

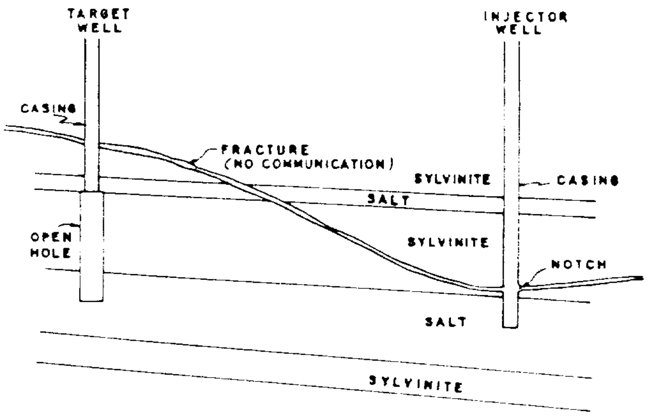

Figure 4. Fracture path and behavior.

One of the more interesting observations was the behavior of the injection well during and after the tests. When the well was shut in a pressure of about 2500 psi existed at the well head, corresponding to a pressure at the fracture depth of about 4500 psi. When the well head valve was opened there was an initial high flow of fluid from the well, but this slowed fairly quickly and within less than an hour had reduced to only a few gallons per minute. At first it was assumed the reduction in flow was due entirely to plugging of the well by material coming back out of the fracture. Subsequent injection and flow tests clearly demonstrated that the restriction only occurred on withdrawal of fluid and that reinjection encountered no similar flow resistance. The true behavior may be seen in Figure 5 which shows schematically the shut in condition, and in comparison the situation with the well head open. It may be noted that with a high flow rate from the

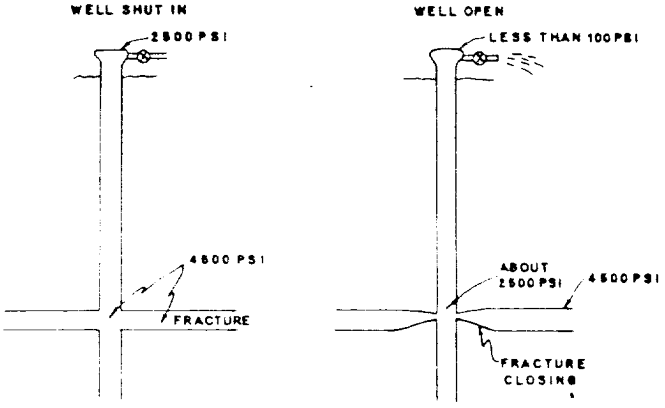

Figure 5. Behavior of well on pressure release.

well head, the down hole pressure near the fracture is reduced considerably, and in fact reduced below the level necessary to keep the fracture open. Consequently, the fracture starts to close in the vicinity of the well, reducing the flow rate. As the flow rate is reduced, the down hole pressure adjacent to the fracture is even further reduced, and eventually the flow out of the well head is slowed to a mere trickle.

Typical pressure behavior at the well head is shown in Figure 6. Here the well, initially shut in,

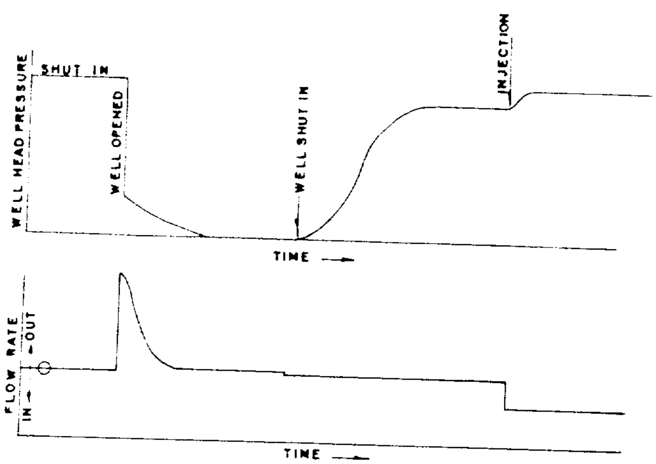

Figure 6. Well pressure behavior.

is at a static pressure sufficient to keep the fracture open. When the well head is opened there is an immediate drop in pressure, followed by a more gradual decrease to nearly zero pressure at the well head. Correspondingly when the well head is opened there is initially a high flow rate, which soon decreases to a level just above zero. If the well is then shut in, the pressure will return nearly to the original pressure indicating that conditions in the fracture and the well are again stabilized. At this point the well could be opened again, and a repetition of the initial behavior will be obtained. Alternately, further injection could be carried out, with only a small increase in the well head pressure required to obtain significant injection flow rates.

The well and fracture system is thus analogous to a balloon which may, within reasonable limits, be blown up or let down at will. What has actually been established underground might best be described as a "fracture pool." This fracture pool is a reservoir from which fluid may be withdrawn, or which may be extended by the injection of additional fluid.

New fracturing procedure.

Careful consideration of all the above factors suggested a very different approach to establishing communication between wells (Manker, Garrett, and Wachtell, 1967). This procedure is based upon establishing a fracture pool, then either estimating or measuring the shape and extent of the fracture pool and subsequently drilling a well communicate with the pool. What must be done is simply blow up a balloon within the deposit and then direct one or more darts into the balloon.

Since the initial experiment had established a very significant fracture pool within the potash deposit, that portion of the procedure was already accomplished. What remained was to determine the location of the pool, and then drill a well into it. The areal extent of the established pool could be estimated. It is also quite probable that injection to establish the fracture pool creates disruptions which are transmitted to the ground surface where they could be measured. Since "tilt meter" instruments capable of measuring extremely small angular deflections are available, the progression and extent of the "fracture pool" probably could be determined by surface measurements. This, however, had not been done during the initial experimental program, so the existing fracture pool was estimated. Calculations indicated its radius should be approximately twice the well spacing used in the initial test. It, therefore, seemed almost certain that a well drilled with the same well spacing (more than 300 feet) would intersect the fracture pool and establish the desired communication.

It was anticipated that when the new well intersected the fracture pool, the high pressure in the pool (compared to the fluid head in the well) would cause the well to "blow-in." This "blow-in" would, of course, be short-lived since the low pressure at the well head would lead to the previously noted constriction of the fracture adjacent to the well, and a corresponding reduction in flow from the well.

A new well was drilled and encountered the fracture pool exactly as anticipated. After the fracture pool was encountered, flow from the well subsided as predicted and a successful communication had been established. The initial path between the wells was sufficiently clear that only 50 psi differential was required to obtain flow rates in excess of 125 gallons per minute through the fracture. It is certain that additional wells could be communicated with the same fracture pool and injector well with a high degree of success.

This new and relatively simple procedure is summarized in Figure 7 where, after selection of a desired well spacing and some basic calculations are made, the fracture is initiated and fluid is injected to establish the desired pool. Either surface deflection observations or a calculated injection volume may be used to establish the size of the pool. A second well is drilled into the pool to complete the communication. The fracture pool can, if desired, be extended by drilling additional wells in the pool, so that a multi-well operation can be established on a given pool. Occasionally new wells may not intersect the pool, but they can, of course, be used as injector wells to establish additional pools adjacent to the original pool. Alternately they may, when fluid is injected, communicate with the original pool. Thus, the number of successful fracture completions in a well field operation can exceed 90%.

1. SELECT DESIRED WELL SPACING
2. ESTIMATE FRACTURE THICKNESS
3. DETERMINE FLUID VOLUME REQUIRED
4. INJECT AND OBSERVE SURFACE DEFLECTIONS
   OR
   INJECT TO CREATE ABOUT TWICE DESIRED RADIUS
5. DRILL SECOND (AND ADDITIONAL) WELLS TO COMPLETE THE COMMUNICATION
6. ESTABLISH ADDITIONAL "FRACTURE POOLS" AND WELL FIELDS AS DESIRED

Figure 7. Establishment and location of fracture pool.

At the same time, the controllability of the method assures that a relatively high percentage of any given surface area can be mined by this technique. Figure 8 shows the application in a fixed surface area. An initial fracture pool is established in the area, and intersection wells are drilled. Additional pools are created as desired, and based on data from earlier wells, their behavior can readily be predicted. In some cases it would be desirable to establish a large initial pool, and if the pool was following desired strata, simply extend the single pool toward the area boundary. The major advantages of the procedure are summarized in Figure 9.

The procedure offers several economies beyond good controllability and a high degree of success. Establishment of the fracture pool can be done with conventional pumps since the pool can be

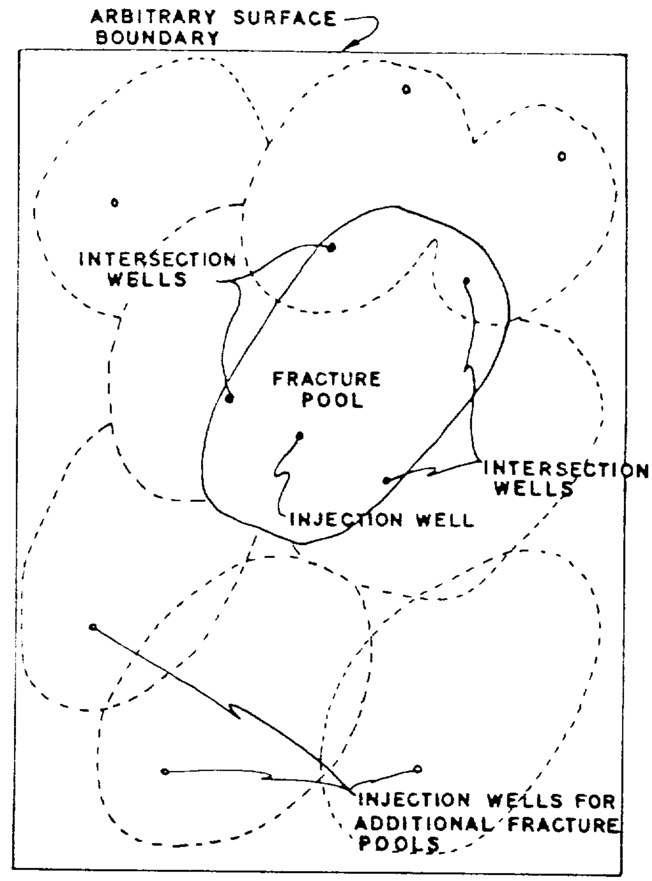

Figure 8. Mining in a fixed surface area.

easily maintained during any necessary pump shutdown. Intersection wells may be drilled as convenient and scheduled according to specific production requirements. Reduced costs for intersection wells will normally be obtainable because of reduced well logging costs and because casing and cementing does not need to be designed for high fracturing pressures.

1. CONTROLLED OPERATIONS
2. NO ABSOLUTE LIMIT ON WELL SPACING
3. SUCCESSFUL COMMUNICATIONS CAN EXCEED NINETY PERCENT
4. HIGH PERCENTAGE OF GIVEN SURFACE AREA CAN BE MINED

Figure 9. Advantages of procedure.

Beyond its demonstrated applicability to potash deposits, this new procedure is particularly applicable to salt solution mining, and for establishing underground storage cavities in salt formations. It can also be applied, with the use of suitable solvents, as a mining method for a wide variety of underground mineral deposits.

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