Recent developments in the future potential for hydraulic fracturing in coalbed methane recovery in Australia

by

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ABSTRACT

Over the past 8 to 10 years, something resembling a drilling boom has occurred in many areas of the continental U.S. It has recently spread to Europe, and most recently the Far East. This boom or explosion in drilling and stimulation has occurred to take advantage of high BTU gas present in coal seams.

One of the most common completion techniques is the use of hydraulic fracturing with proppant. Although collapsing cavity techniques and natural completions have been successfully implemented in some areas, the most common technique to date has been hydraulic fracturing of coal seams, which have been isolated behind casing through perforations. Perhaps as never before, there is a tremendous amount of controversy on the design of hydraulic fracturing treatments of coal as well concerning whether or not viscosifiers such as linear gels, or crosslink gels or foams should be utilized in obtaining conductive flow paths into the coal seam cleat system. In our presentation, we will discuss various techniques utilized across the North American and European continents. We will, as best we can, objectively compare fracture design and fluid technologies.

INTRODUCTION

Hydraulic fracturing as a stimulation technique with proppant has been used for over 45 years. Greater than 90+ % of all research and study on hydraulic fracturing has been conducted in clastic reservoirs, such as sandstones, siltstones, and shales, or carbonate reservoirs, such as limestones and dolomite. Only just recently has any work been initiated evaluating the effects of hydraulic fracturing fluids in proppants and their interaction with the softer coal seam reservoirs.

With conventional reservoirs, the flow rate of the well typically is maximized early on with gradual decline of rate with time. With proper perforation placement, we feel that a single planar vertical fracture is created and almost without exception, the fracture height is solely dependent upon barrier stresses within the interval itself and bounding intervals.

In coal seams, particularly very permeable coal seams that are water saturated, gas production may be actually nil early on in the history of the well until sufficient water has been taken away from the formation to allow desorption of the gas. The primary mechanism of production in coal seams is through desorption of the gas from the cleat face. It should be noted, however, that there are many coal seam reservoirs which contain no water and maximum gas production actually occurs very early on in the history of the well with typical depletion curves as is seen in conventional reservoirs. Additionally, lower permeability coal seams are very quickly dewatered, even when saturated with water, and maximum production also occurs very early in the history of the well. The "classical coal seam production" as was seen in the very permeable, highly cleated areas in the overpressured San Juan basin have caused a tremendous amount of the confusion in the production of coal seam gas in most other areas of North America, in many areas in Europe, and for that matter coal seam basins throughout the world.

From the standpoint of fracture height growth, it has been found that relatively thin coal seams do not in most cases act as barriers to height growth, particularly when more than minimal rate and viscosity are utilized in the treatment. For very thick coal seams, those greater than 10-15 meters, with high permeability, it has been noted that the fractures initiated in the coal may in fact stay within the coal and one gets a very tortuous dindritic fracture network. As a general rule of thumb, it is noted that for many reasons which will be discussed later on, there are virtually very few situations where long conductive fractures can be created in the coal. It is for this reason that we state that at least moderate permeability is a necessity for economical production of gas from coal.

COAL SEAM FRACTURING

Although we have been studying coal seam fracturing for greater than 9 years, we have barely scratched the surface in truly understanding the mechanisms that take place and ways to optimize these techniques. There is indeed great controversy going on between major coal seam operators about types of fluids, fracture designs, and techniques. The major common denominator in the use of stimulation techniques is, in the writer's opinion, one of mass confusion.

A tremendous amount of hydraulic fracturing work has been conducted in San Juan, Black Warrior, Raton, San Wash, Green River, Powder River, and Appalachian Basins of the United States. Additionally, a great deal of work has been conducted in Canada and European basins. A great deal of conflicting evidence has been reported. In references 1 and 2, one major company states that any polymer used in fracturing fluid is detrimental. In reference 2, another company reports extremely successful fracture stimulation using not only polymer, but crosslinked high viscosity polymer, in stimulating coal seams.

To the people doing fracture designs in the coal, the first and most apparent difference is the large variance rock properties of the coal versus conventional rocks. Young's Modulus for coal, many times, is in the range of 400,000 psi versus 4-12 million psi for conventional limestone or sandstone rocks. The inherent butt and face cleats that exist in the coal seam matrix create a tremendous tendency for, not only high leakoff during the fracturing process, but also greatly enhance the possibility of creation of multiple "dindritic" fractures. To obtain successful fracturing of coal seams, there is basically one premise we follow. That premise is that we must create a conductive propped fracture that will interconnect the wellbore with the cleat system that exists within the coal seam matrix. It is our contention that if a very long propped fracture is required due to low permeability of the coal, that chances are very low that economical production can be obtained. We believe that coal seam fracturing is indeed a viable technique but if we apply the more conventional axioms that are used for tight reservoirs where hundreds of feet are required to achieve economic production, then indeed that is where economical coal seam stimulation will fail. Because of this particular premise, we feel that large proppants and excessively large treatments are not necessarily effective in obtaining economical coal seam stimulation. It is our premise that as long as we can maintain communication through a conductive prop fracture system and we can be assured that the fluids utilized have no detrimental effects upon conductivity of either the proppant pack or the coal itself, that indeed successful stimulation can be accomplished.

COMPLETION AND STIMULATION STRATEGIES

After several years of following coal seam stimulation, we have developed completion and stimulation strategies to be followed based upon the extent and lithology of not only the coal but bounding intervals, as well as depth, rock properties, etc. These completion and stimulation strategies are listed below:

1. A shallow coal seam where a horizontal fracture will be created.

2. A series of thin coal seams in the depth range where a single, planar, vertical fracture will be created.

3. A single thick coal seam where the hydraulic fracture will be confined entirely in the coal and a complex fracture system (multiple vertical or T shaped fractures) is created.

4. A hydraulic fracture where the fracture is initially confined within a single coal seam, but during the later portion of the treatment, the fracture begins to propagate vertically into the boundary layers.

5. A high permeability (highly cleated/fractured) coal seam that does not require stimulation.

Under Scenario 1, where one sees relatively thin individual coal seams at relatively shallow depths, one must create multiple horizontal fractures using either limited entry methods or mechanical diversion. We typically recommend linear fracturing fluids with moderate to small size pad volumes to fracture treat these intervals. During these treatments, we typically note bottom hole treating pressure greatly in excess of 1 psi/foot. We have noted complex (multiple) fracture systems being created if bottom hole pressures increase substantially during the treatment. In fact, in one case in point, we have seen, through using tilt meter measurements during the actual treatment, a fracture go from multiple horizontal to a vertical fracture orientation during the treatment.

Under Scenario 2, which is very common across many basins of the world, we see multiple thin seams existing at moderate to great depths. These types of fracture treatments are quite similar to conventional fracturing done in conventional reservoirs in that we see very little increase in net pressure during the treatment, indicating a great deal of fracture height growth, typically in a radial mode. Typically fracture gradients are considerable less than 1 psi/foot and what is seen as shown in Scenario 2 is a single fracture covering multiple coal seams. It should be noted that excellent success has in fact been achieved not perforating within the coals but rather perforating between the coals and creating a fracture that goes through multiple coal seams above and below the perforated interval. This technique, we believe, is a good approach where one has a competent wellbore and a competent place for the proppant to be near the wellbore rather than within the coal.

Scenario 3 is a situation where one has a thick coal seam with a complex hydraulic fracture contained entirely in the coal. This is the scenario that indeed makes for exciting fracture treatments. High injection rates are required to take care of very excessive leakoff. Typically, operators have either used high viscosity crosslinked gel or alternatively, no viscosifier at all, utilizing only water as a carrying agent. It should be noted that both types of fluids have been used successfully, particularly if intense quality control is utilized in the application of the high viscosity fluids. It should be noted that under this particular scenario, that it is highly unusual to achieve any great distance from the wellbore due to the creation of multiple fractures.

Scenario 4 is a situation where one starts out with initiated fracture within a relatively thick coal seam, i.e. 10 meters or greater, and the fracture treatment for a large portion of the job or some portion of the job is contained within the coal. During the treatment, there is a breakout of the fracture to boundary layers, resulting in a precipitous drop in treating pressure and net pressure. This type of treatment has been quite often noted in relatively thick coal seams in the San Juan basin as well as in some of the thicker coal seams that exist in Germany and France. The major consideration in this particular scenario is being able to get the well flushed prior to screenout, if it is late in the treatment, or reinitiating pad and starting the treatment over if this breakout occurs early in the treatment.

Scenario 5 involves quite thick high permeability coal seams not necessarily requiring hydraulic fracturing. Drilling and completion techniques are such that either no damage or minimal damage is accomplished during the drilling operation or a completion technique is utilized to remove the damage that is done during the drilling phase. A major example of this type of scenario exists in the overpressured, high permeability, and relatively thick, coal seams existing in the San Juan basin.

The typical scenario involved in completion procedure for the collapsing cavity techniques is to drill down to just above the top of the coal section, cement casing and then drill out below the casing with air or foam in an underbalanced state. In some situations, while drilling underbalanced, large volumes of coal are actually produced during the drilling operation. In other situations, the coal is more competent and a fairly gage hole will result. If very little collapsing or inflow of the coal is seen during drilling, a technique whereby the zone is pressured up with air and then quickly released, is used to achieve cavitation of the coal. Coal seams that will collapse creating the cavity typically allow fairly high production rates as there is nothing to restrict gas flow production to the wellbore. Once this cavitation is achieved, the well is typically cleaned out and a slotted or perforated liner is lowered into the hole to assist in minimizing coal fines production throughout the life of the well. Typical problems which have occurred because of this technique are excessive coal fines production but universally where this technique has been applied, very high production rates have been achieved compared to offset wells that have been hydraulicly fractured conventionally. It is the contention of the writer that this scenario is a classic example of a very high permeability reservoir which truly requires no stimulation. It is one of our major contentions that unless very strong control exists in the execution of hydraulic fracture treatments, particularly in under pressured coals, that more damage can be done by the fracturing fluids themselves than can be overcome with even high concentrations of proppant in a potentially productive proppant pack.

FRACTURE DESIGN PROCEDURES

The frac design procedure which has been followed in design of coal seam treatments is very similar to that for conventional fracture treatments. Basically, there are controlled and estimated parameters. Examples of controlled parameters are tubular goods, viscosity of the fluid, fluid loss additives, injection rates, volume, proppant scheduling, etc. Parameters which we must measure are such items as insitu stress, reservoir porosity, pay thickness, created fracture height, etc. What is involved in the fracture design process is to pick out the particular scenario described earlier in the paper, i.e. a shallow horizontal fracture, contained fracture, or a radial fracture scenario, utilize the controlled and measured parameters and iterate upon them. It is very important, obviously, for those that do fracture design, to change one parameter at a time in the design mode. It is certainly an understatement to say that fracture design in coal seams which have truly unique rock properties, is a challenging process. This particularly is the case for thicker seams or where there are multiple coal seams with 3-10 meters thickness in trying to estimate what indeed is fracture height when one is not at all sure how many actual inechelon or dindritic fracture systems are present.

FRACTURE FLUID SELECTION

We basically break down available fracturing fluids for coal into the following:

- Fresh water
- Linear gel (30-40 lbs viscosifier/1000 lbs)
- Foams or energized non-crosslinked fluids
- Blade crosslink fluids or shear stable fluids such as borate crosslinked polymers

One of the major areas of conflict and controversy in our industry is the contradictory evidence put out by Amoco indicating severe damage by polymer when treating coal seams and also a great deal of information showing excellent stimulation results using polymers in the same field and coal seam reservoirs. It is the contention of the writer that the major problem with utilization of any polymeric material with water is the lack of intense quality control to be assured that the polymers completely degrade back to near water viscosity. Typically, coal seams are very susceptible to what is termed preferential viscosity damage. The filtration of polymer into cleat systems, the extreme low pressure that is involved or differential pressures that are involved, and the low temperatures involved all lead to severe problems if extreme care is not taken during complete polymeric degradation. We believe, through the use of intense quality control, that one can be assured of excellent success through the use of viscosified fracturing fluids. We feel that fresh water basically has its major application in very shallow reservoirs, particularly in the area where horizontal fractures occur. The author has designed several treatments with and without polymer pad and only water as the carrying fluid in shallow or Arkoma basin wells both in Oklahoma and southeastern Kansas. The major disadvantage of water relates to its inability to suspend and transport proppant and there is always a possibility where one has a vertical height growth, that the majority of the conductive proppant with end up outside of the zone of interest. It is indeed, I believe, a sad state of affairs when one has to select a very poor fracturing fluid as the only means to be assured that the well will clean up. It has been our experience that by working closely with the service company, and in utilizing intense quality control, that very successful fracture treatments can be conducted with both linear and crosslinked gel systems.

We have had excellent success with moderate to low viscosity fracturing fluids utilizing linear gel systems to transport high concentrations of proppant and by also utilizing forced closure techniques, combining proppant reverse gravel packing and enhanced fracture closure, one can achieve good proppant distribution with moderate to low viscosity fluids.

Although many operators have utilized foams or energized non-crosslinked fluids for stimulation in the coal, we have found little true rational for these fluids. Obviously, we are not dealing with water sensitive formations. There is perhaps some rational in assisting clean up in coal seams where there may be little water production. It is our major contention that money would be better spent on additional proppant than on the energizing mode in coal seams.

The authors have had a tremendous amount of success utilizing crosslink fluids throughout the treatment or as pad fluids ahead of viscous fingering treatments in coal seams. It does require excellent quality control or "intense quality control" techniques but there has been excellent success achieved in areas where multiple seams have to be treated simultaneously.

In reference to specifics of fracture design, we basically utilize a minimal amount of pad volume for horizontal frac designs. When utilizing linear gels, pad volumes are typically in the range of 25% for contained fractures in high permeability coal seams whereas with crosslink gel our pad volumes may be 40-60% of the fracture treatment. As stated earlier, we have reinitiated the pad where the fracture breaks out of the zone during the treatment.

We feel quite strongly that rather than utilizing very fine particular materials such as silica flour or plastering materials in the coal, that we will compensate for high leakoff with higher pump rates. We do feel strongly that the use of smaller proppant as bridging material, such 100 mesh or even larger proppant has many advantages in fracture design and implementation. Figures 1 through 15 are examples of various frac designs.

PRESSURE ANALYSIS TO EVALUATE PERMEABILITY OF COAL SEAMS

It has been our experience that the simplest, most straight forward pre production analysis techniques that have been utilized have indeed been pump-in fall off analysis techniques. The key to these procedures is maintaining a constant pump rate in the coal seam below fracturing pressure. Secondarily, one must pump sufficient fluid to be able to evaluate a significant portion of the cleat system with the analysis technique. We have found good success in predicting permeabilities of coal seam systems utilizing the procedure. The biggest mistake that we have found have been individuals who refuse to believe that indeed their coal seam reservoirs are low permeability and there is little chance of success. On many occasions we have submitted our analysis which indicated a very low permeability system to operators and yet they moved ahead with large stimulation projects.

Quite obviously, pressure buildup analysis techniques can be used where the wells are overpressured or where there is little or no water production. History matching of production is another technique whereby one can very accurately determine permeability. Some operators have had a great deal of success shooting water levels in wells to determine permeability post stimulation. It has been our experience, however, that there is little or no substitute for truly controlled pump in fall off analysis procedures with good bottom hole pressure readout devices. Techniques which will greatly assist in analysis are downhole shut in devices and tools which give pressure recordings at least once a second.

PROPPANT SELECTION

Our major hypothesis of what is important in hydraulic fracturing of coal seams is that we are interconnecting the wellbore to the cleat system. We do not feel that high conductivity is the most important criteria, and therefore use of large proppants is not necessary. There had been a contention by some authors that one should use large proppants so that coal fines could go through the proppant pack. We feel that movement for the coal fines is detrimental and that stopping the movement of coal fines, not assisting them is important. Movement of material through the proppant pack will inevitably lead to plugging of the proppant pack. We have seen excellent success in control of fines and in achieving enhanced conductivity by suing 100 mesh and 40/70 proppant. We do recommend, where logistically possible, running stages of smaller proppants, grading up to 20/40. We have seen little or no benefit in going to larger proppants such as 12/20, although as you have seen earlier, we have shown designs using larger proppants because of operator preference. A typical design that we do in coal seams today uses a large portion of 100 mesh sand in 2,4, and 6# stages, followed by 20/40 sand. We have had good success with this technique, not only in controlling coal fines production but also in excellent sustained production rates. We have seen some good success utilizing curable resin coated sand in controlling sand production when the well has been perforated over long sections, however intense quality control is very important to be sure that any affects of the curable resin coat on breakers are addressed by the addition of more breaker.

CONCLUSIONS

1. Successful fracture stimulation requires propped fractures interconnecting the wellbore to the cleat system.

2. Fracture fluid selection is critical to stimulation success.

3. Operator experience has yielded several scenarios to plan fracture treatment on coal seam lithology.

4. Much more research is required.

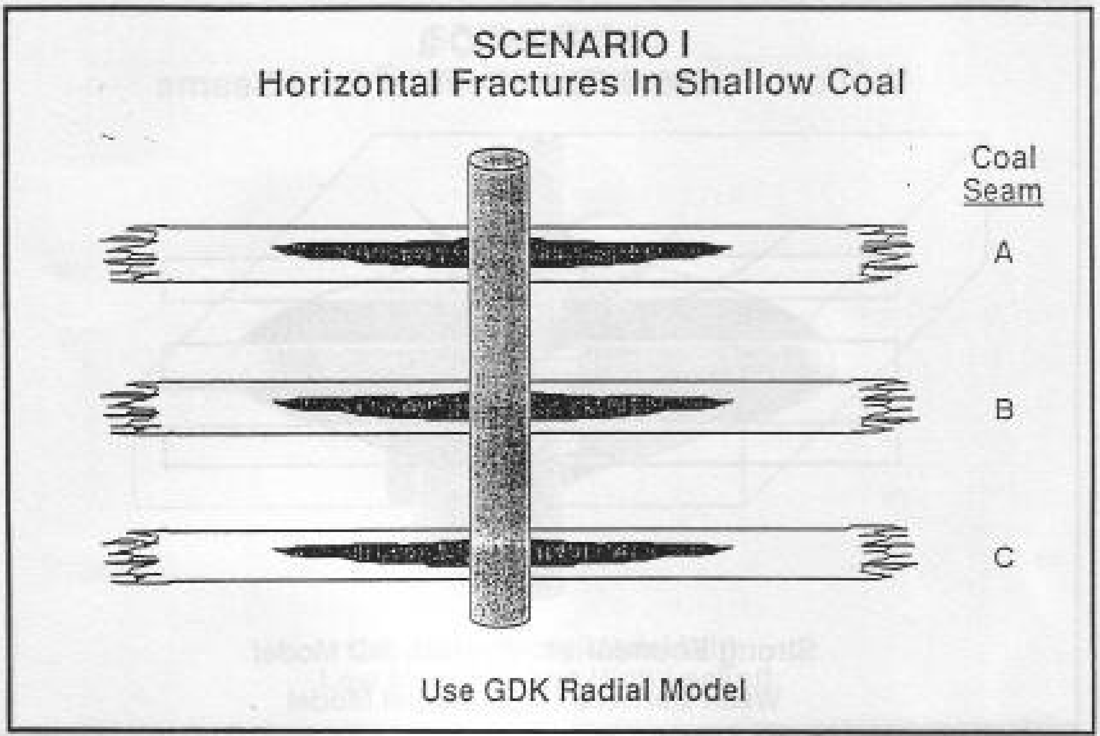
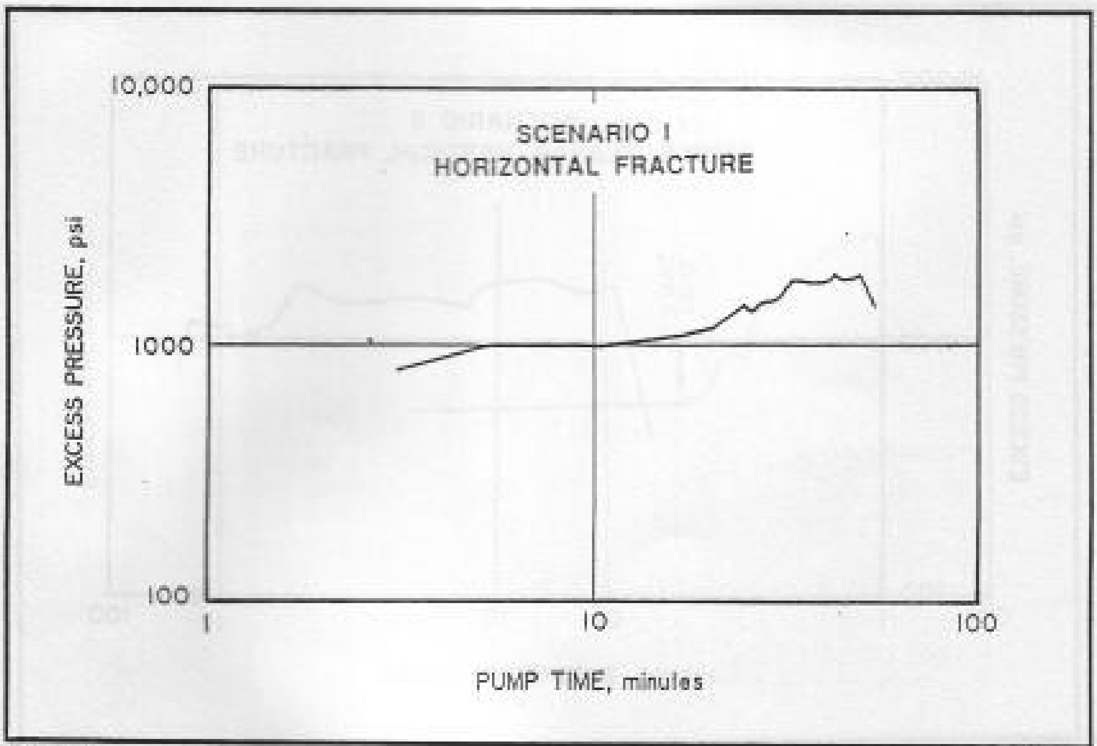


Figure 1.



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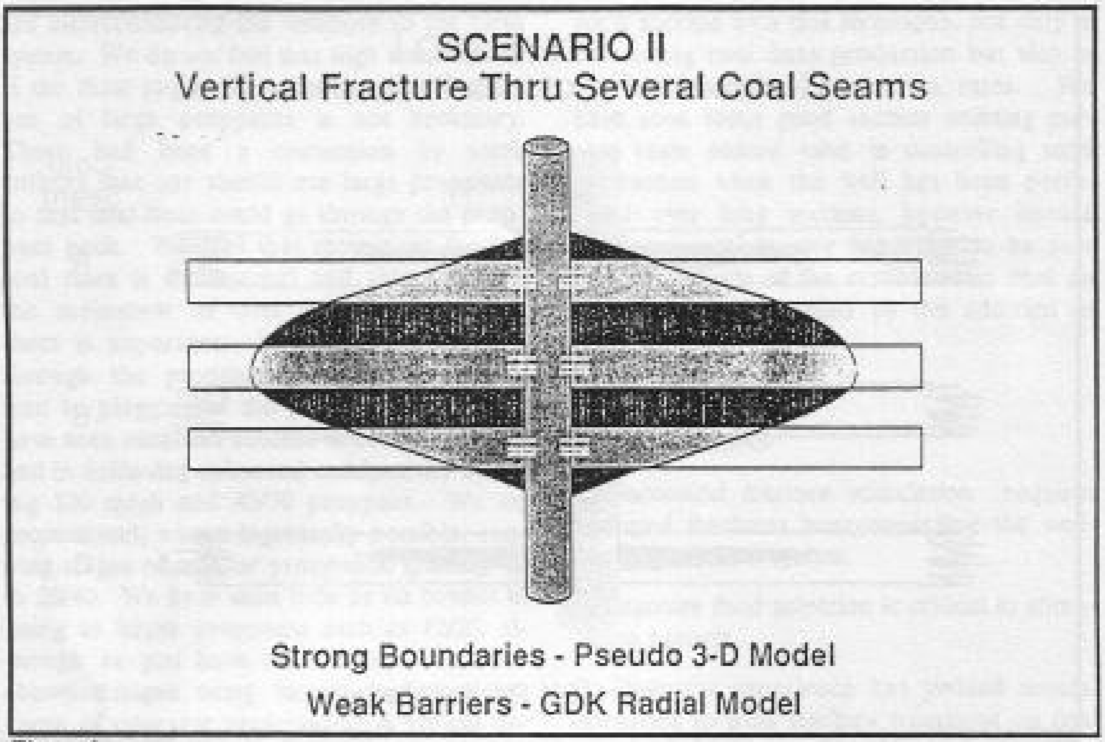

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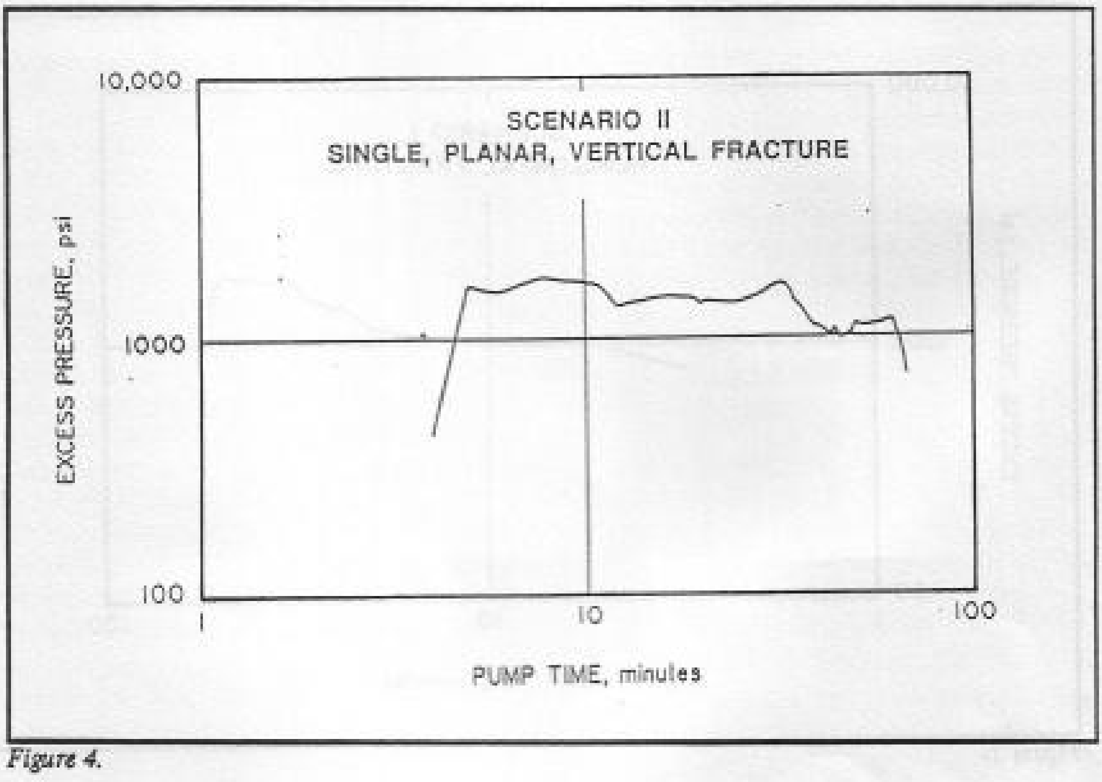

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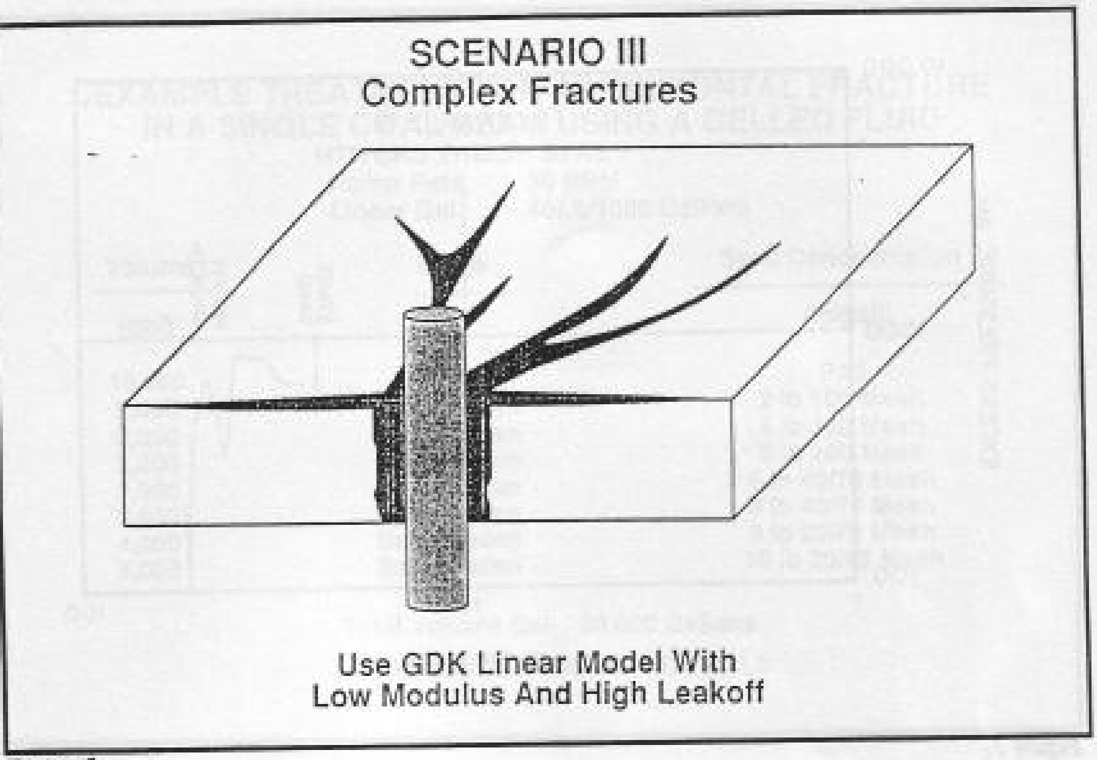

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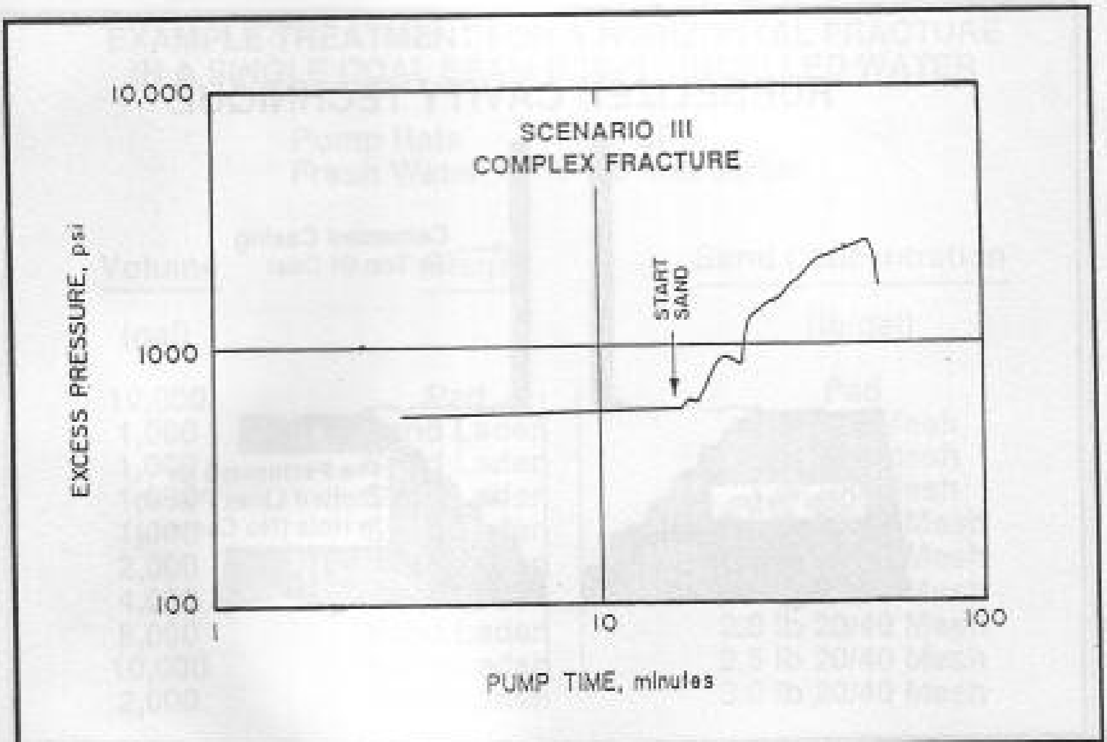

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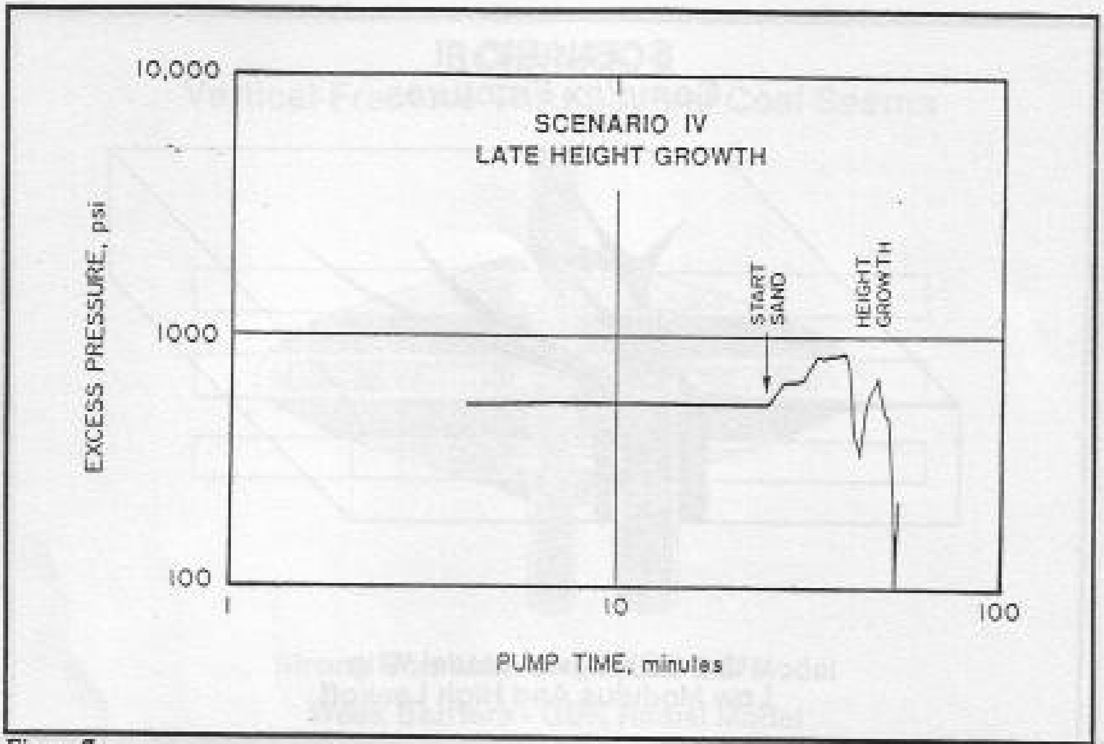

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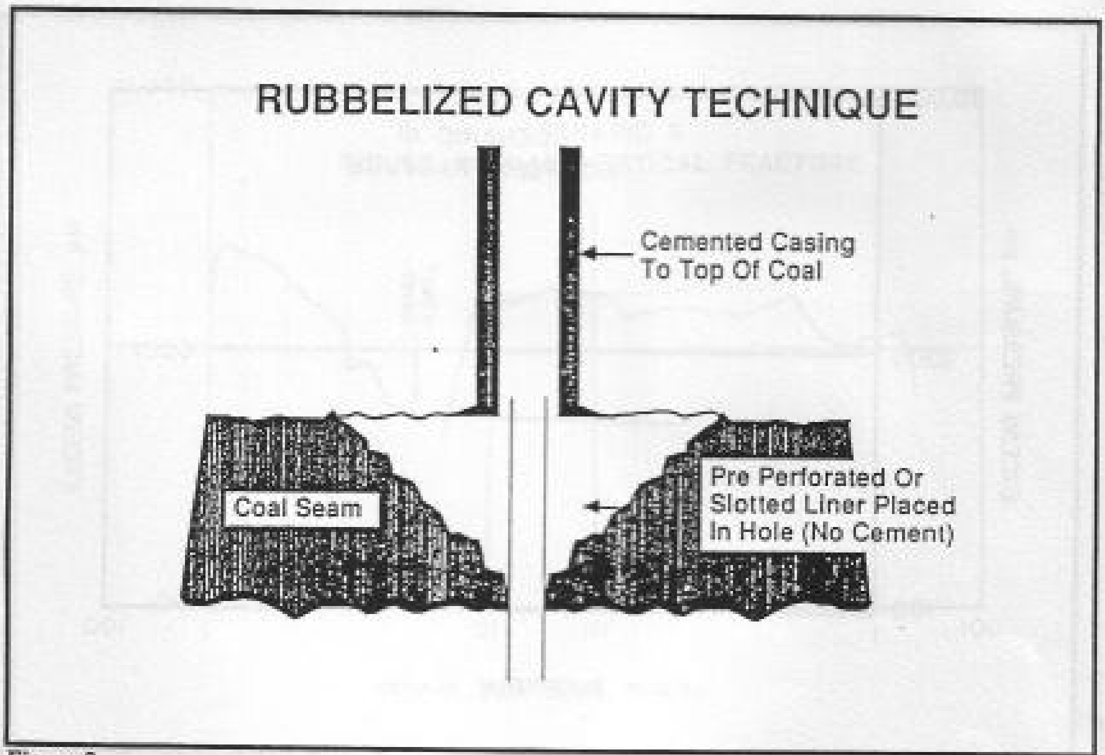

Figure 8.

EXAMPLE TREATMENT FOR A HORIZONTAL FRACTURE IN A SINGLE COAL SEAM USING A GELLED FLUID

Pump Rate 30 BPM
Linear Gel 40Lb/1000 Gallons

Volume (gal)	Stage	Sand Concentration (lb/gal)
10,000	Pad	Pad
2,000	Sand Laden	2 lb 100 Mesh
2,000	Sand Laden	4 lb 100 Mesh
2,000	Sand Laden	6 lb 100 Mesh
2,000	Sand Laden	6 lb 40/70 Mesh
3,000	Sand Laden	8 lb 40/70 Mesh
4,000	Sand Laden	8 lb 20/70 Mesh
5,000	Sand Laden	10 lb 20/40 Mesh

Total Volume Gel 30,000 Gallons

Total Proppant Pumped 152,000 Lb

Figure 9.

EXAMPLE TREATMENT FOR A HORIZONTAL FRACTURE IN A SINGLE COAL SEAM USING UNGELLED WATER

Pump Rate 30 BPM
Fresh Water No Viscosifier

Volume (gal)	Stage	Sand Concentration (lb/gal)
10,000	Pad	Pad
1,000	Sand Laden	1 lb 100 Mesh
1,000	Sand Laden	2 lb 100 Mesh
1,000	Sand Laden	3 lb 100 Mesh
1,000	Sand Laden	0.5 lb 20/40 Mesh
2,000	Sand Laden	1.0 lb 20/40 Mesh
4,000	Sand Laden	1.5 lb 20/40 Mesh
8,000	Sand Laden	2.0 lb 20/40 Mesh
10,000	Sand Laden	2.5 lb 20/40 Mesh
2,000	Sand Laden	3.0 lb 20/40 Mesh

Figure10.

EXAMPLE TREATMENT FOR A HORIZONTAL FRACTURE OF FOUR ZONES SIMULTANEOUSLY. FOUR THIN ZONES ARE PERFORATED IN LIMITED ENTRY AND THE PUMP RATE IS DESIGNED TO INJECT FLUID IN ALL FOUR ZONES

Pump Rate 40-50 BPM
Linear Gel 40 Lb/1000 Gallons

Volume (gal)	Stage	Sand Concentration (lb/gal)
30,000	Pad	Pad
2,000	Sand Laden	2 lb 100 Mesh
3,000	Sand Laden	4 lb 100 Mesh
5,000	Sand Laden	6 lb 100 Mesh
5,000	Sand Laden	6 lb 40/70 Mesh
5,000	Sand Laden	8 lb 40/70 Mesh
10,000	Sand Laden	8 lb 20/40 Mesh
10,000	Sand Laden	10 lb 20/40 Mesh

Figure 11.

EXAMPLE TREATMENT FOR A SINGLE VERTICAL FRACTURE THROUGH MULTIPLE SHALLOW COAL SEAMS USING UNGELLED WATER

Pump Rate 60 BPM
Fresh Water Friction Reducer

Volume (gal)	Stage	Sand Concentration (lb/gal)
5,000	Pad	Pad
5,000	Sand Laden	1 lb 100 Mesh
5,000	Sand Laden	2 lb 100 Mesh
5,000	Sand Laden	3 lb 100 Mesh
5,000	Sand Laden	0.5 lb 20/40 Mesh
10,000	Sand Laden	1.0 lb 20/40 Mesh
20,000	Sand Laden	1.5 lb 20/40 Mesh
30,000	Sand Laden	2.0 lb 20/40 Mesh
20,000	Sand Laden	2.5 lb 20/40 Mesh
10,000	Sand Laden	3.0 lb 20/40 Mesh

Figure 12.

EXAMPLE TREATMENT FOR A SINGLE VERTICAL FRACTURE PROPAGATING THROUGH MULTIPLE SHALLOW COAL SEAMS USING GELLED FLUID

Pump Rate 40 BPM
Crosslinked Borate Gel 35 Lb/1000 Gallons

Volume (gal)	Stage	Sand Concentration (lb/gal)
10,000	Pad	Prepad
15,000	Sand Laden	Pad
2,000	Sand Laden	2 lb 20/40 Mesh
2,000	Sand Laden	4 lb 20/40 Mesh
5,000	Sand Laden	6 lb 20/40 Mesh
5,000	Sand Laden	8 lb 20/40 Mesh
6,000	Sand Laden	10 lb 20/40 Mesh
6,000	Sand Laden	10 lb 12/20 Mesh
7,000	Sand Laden	12 lb 12/20 Mesh

Total Fluid Volume 58,000 Gallons Plus Flush

Total Proppant Pumped 286,000 Lb

Figure 13.

EXAMPLE TREATMENT FOR VERTICAL FRACTURING OF A RELATIVELY THICK COAL SEAM WITH THE FRACTURE CONTAINED WITHIN THE COAL. COMPLEX (MULTIPLE VERTICAL OR T-SHAPED) FRACTURES ARE EXPECTED FOR THIS EXAMPLE

Pump Rate 50-60 BPM
Crosslinked Borate Or Delayed Crosslink Gel 35-45 Lb/1000 Gallons

Volume (gal)	Stage	Sand Concentration (lb/gal)
15,000	Prepad	Prepad
40,000	Pad	Pad
2,000	Sand Laden	2 lb 100 Mesh
4,000	Sand Laden	4 lb 100 Mesh
6,000	Sand Laden	6 lb 100 Mesh
8,000	Sand Laden	6 lb 40/70 Mesh
10,000	Sand Laden	6 lb 20/40Mesh
4,000	Sand Laden	8 lb 20/40 Mesh
6,000	Sand Laden	10 lb 20/40 Mesh

Total Fluid Pumped 95,000 Gallons Plus Flush

Total Proppant Pumped 244,000 Lb

Figure 14.

EXAMPLE TREATMENT FOR A VERTICAL FRACTURE THAT IS INITIALLY CONTAINED WITHIN A COAL SEAM, BUT BREAKS OUT OF ZONE DURING TREATMENT

Fluid Used Is 35# Borate

Volume (gal)	Stage	Sand Concentration (lb/gal)
15,000	Prepad	Prepad
40,000	Pad	Pad
2,000	Sand Laden	2 lb 100 Mesh
4,000	Sand Laden	4 lb 100 Mesh
6,000	Sand Laden	6 lb 100 Mesh
3,000	Sand Laden	6 lb 40/70 Mesh
20,000	Pad	Pad
2,000	Sand Laden	2 lb 40/70 Mesh
2,000	Sand Laden	4 lb 40/70 Mesh
3,000	Sand Laden	6 lb 40/70 Mesh
2,000	Sand Laden	6 lb 20/40 Mesh
6,000	Sand Laden	8 lb 20/40 Mesh
6,000	Sand Laden	10 lb 20/40 Mesh
4,000	Sand Laden	12 lb 20/40 Mesh

Figure 15.