Well Construction; Possible Causes of Failure and Remedial Measures

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ABSTRACT

The last few years have seen the rapid development of the fracturing method of connecting two wells and utilizing the fracture for the purpose of circulating fluids to mine salt.

There have been some failures due to the fracture not intersecting the target well. The causes of these failures are both mechanical and from natural causes. Certain techniques in the well construction can lessen the chances of the mechanical failures and help secure the maximum cooperation from nature. All possible geological information is necessary to accomplish this.

There are five major causes of failure that, unless overcome, can cause the loss of a well or system. Each of these, in most cases, can be overcome by the application of certain remedial measures.

The primary consideration is the use of brine as the fracturing fluid, so that a cavity will not develop.

Close observation and certain information is required to be able to diagnose the cause of the failure. The remedial measures are variations of methods and techniques that have been utilized in well workovers for years.

INTRODUCTION

Perhaps the title of this paper should be rephrased something like this -- The possible causes of failure when attempting to connect two wells by fracturing, how this affects the well construction to avoid these possibilities and gain success and yet facilitate the application of remedial measures if necessary.

There are those failures caused by such things like a hole in the pipe, etc. The remedial measures are usually apparent in these cases and need no further discussion. This paper will confine its contents to those causes of failure that occur when well construction, regardless of method, has apparently been properly executed.

At the start of a new project, in the planning session, all available information must be studied in detail. Previous experience in the area is investigated and if there have been failures, what were the causes and how can they be avoided in the next attempt. If it is a new area where there is no previous experience, what can be expected to happen, what information is necessary and how can the well be constructed so that it will be favorable to avoid failure? Everything that can happen from the start to finish of a well will not be anticipated. Therefore, two things must be kept in mind. First, keep the outlined plan flexible so that the unexpected can be handled and, second, keep a complete well record from start to finish.

LOCATION OF WELLS

The location of the well or wells is determined by the following:

1. A geological study: The assumption must be made that the fracturing fluid will adopt some type of a horizontal radial pattern. It is believed that the pattern could be better described as having an elliptical shape with the long axis of the ellipse parallel to the strike of the formation.
2. The shape of the available land.
3. The position of the new location in relation to old wells if it is in an area that is presently being utilized as a brine field. The cavity development of the old wells will be up dip. This must be studied with two thoughts in mind. First, will the new well, while drilling, intersect the cavity of the old system at the top of the salt? Second, if it is desired to maintain the new well in a spearate system, can it be placed so that the cavity development will not join them at too early a date?
4. The spacing of wells to secure maximum economic recovery of the salt in place.
5. Plans for future development in the area.

It can be seen that several of the above are in conflict. Therefore, a decision is the result of the weighing of the factors to accomplish the objective of a specific case.

TYPE OF DRILLING EQUIPMENT

What type drilling equipment should be used, rotary or cable tools, is the next consideration. Apparently neither one of these have any material effect on the outcome of the success of the well. There are two items that govern the selection of the type drilling equipment -- time and economics. The first of these, time, is usually a decision of management based upon the urgency of the project. The second item, economics, cannot be discussed here. This has to be studied with a specific well location in mind.

When the drilling contractor has been selected he should be instructed about the following: First, a maximum deviation. Second, the size casing to be run. Third, in the case of rotary drilling, the mud program outlined. Outside of the saturated solutions required when drilling the salt, the mud requirements are those necessary to accomplish two different things. The first of these is to drill the well with a minimum of trouble. The second is to get the casing into the hole and properly cemented. For example, the viscosity and jel strength of the mud should be as low as possible, in keeping with good practices, while the well is being cemented.

WELL TO BE DRILLED FIRST

If a complete new system of two wells is to be drilled, then it is suggested that the prospective target well be drilled first. This will allow securing of information to have first priority so that it can be utilized to the fullest extent on the prospective fracturing well.

MINIMUM INFORMATION NECESSARY OF THE SALT SECTION

Close supervision should be initiated when the hole approaches the salt section and continued until final completion of the connection by fracturing. The following gives the minimum information necessary.

1. A core must be taken and examined for the following:
   a. Identify every lens of impurity such as anhydrite.
   b. Examine the interfaces between the lenses and the salt, and determine if they are clean positive interfaces or are they transitional zones.
   c. Examine the formation immediately below the salt. Eight to ten feet of this formation should be cored to determine if it has either permeability or vertical fractures.

Figure 1 is a picture of a core that was taken from a well in Canada. There is a vertical fracture present in the dolomite below the salt. This fracture has a secondary deposition of salt in it. To go into little detail on this well, the initial attempt at fracturing was a failure. It is believed that this fracture or a similar one in the vicinity was opened and the fluid escaped straight down. This well utilized fresh water as the fracturing fluid in the initial attempt.

After examination of the core the initial fracturing point, with alternatives can be selected. The initial fracturing point is the one closest to the bottom of the section that has passed inspection. If this one fails then another one is selected up the hole that will cause the minimum loss of salt.

2. The salt section should be time drilled while taking the core. It is recommended that the engineer in charge do this. The reason for this is that when he drills the second well he can stop the drilling at the appropriate place. Time drilling, along with the other items that follow, will make it unnecessary to core the second well drilled.
3. A caliper should be run, it will allow the computation of fill-up of cement. It will, also, help identify the zones of impurities.
4. A gamma neutron log should be run. It will give a picture of the entire section and later in the life of the well help identify cavity development. Generally speaking, from a gamma neutron log, a 2 or 3 foot zone of impurity cannot be decisively identified. However, if the section has been cored, time drilled and calipered, each zone can be identified on the log.

CASING AND CASING POINT

The decision on the weight and type of casing is made prior to starting drilling operations. However, since this is when it appears in the actual well construction it is discussed at this time. Surface pipe is not discussed because it will be governed by local conditions and sometimes law. The selection of the weight of the casing that should be purchased is governed by the use of the following formula. Economics generally suggest that casing capable of withstanding anticipated pressures be run rather than the use of a retrievable retainer and tubing to protect the casing from the pressure required to break the well down.

Expected break-down surface pressure (psi) = depth x 1.2 plus 600 minus hydrostatic head.

The formula given is peculiar to this particular area. There are other areas where the factor instead of being 1.2 is as low as 0.6.

The 600 psi, or the pressure break which is for the want of a better term called the tensile strength of the rock, may run as high as 12 to 14 hundred psi. In most cases it will fall between 400 and 800 psi.

The hydrostatic head will be helped if brine is used instead of water.

It is recommended that the initial fracturing point be completed in open hole. The pipe should be set 3 to 5 feet above the selected fracturing point.

In many cases it is advantageous to set casing 10 or 15 feet above the salt in the target well. The main advantage of this method of completion is that it gives the biggest possible target. If it becomes necessary to fracture from this well, then a balloon type packer can be used.

As a general rule pressures run higher through perforations than in open hole. Therefore, if the pipe is set through and then perforated 500 to 1000 psi should be added to the expected break-down pressure. Actually the figure cannot be calculated.

CEMENTING THE CASING

Saturated brine with 5% excess salt should be used with the cement. In some cases the excess salt is added only in the last of the cement, so that only that part that will set in the salt section has the added protection.

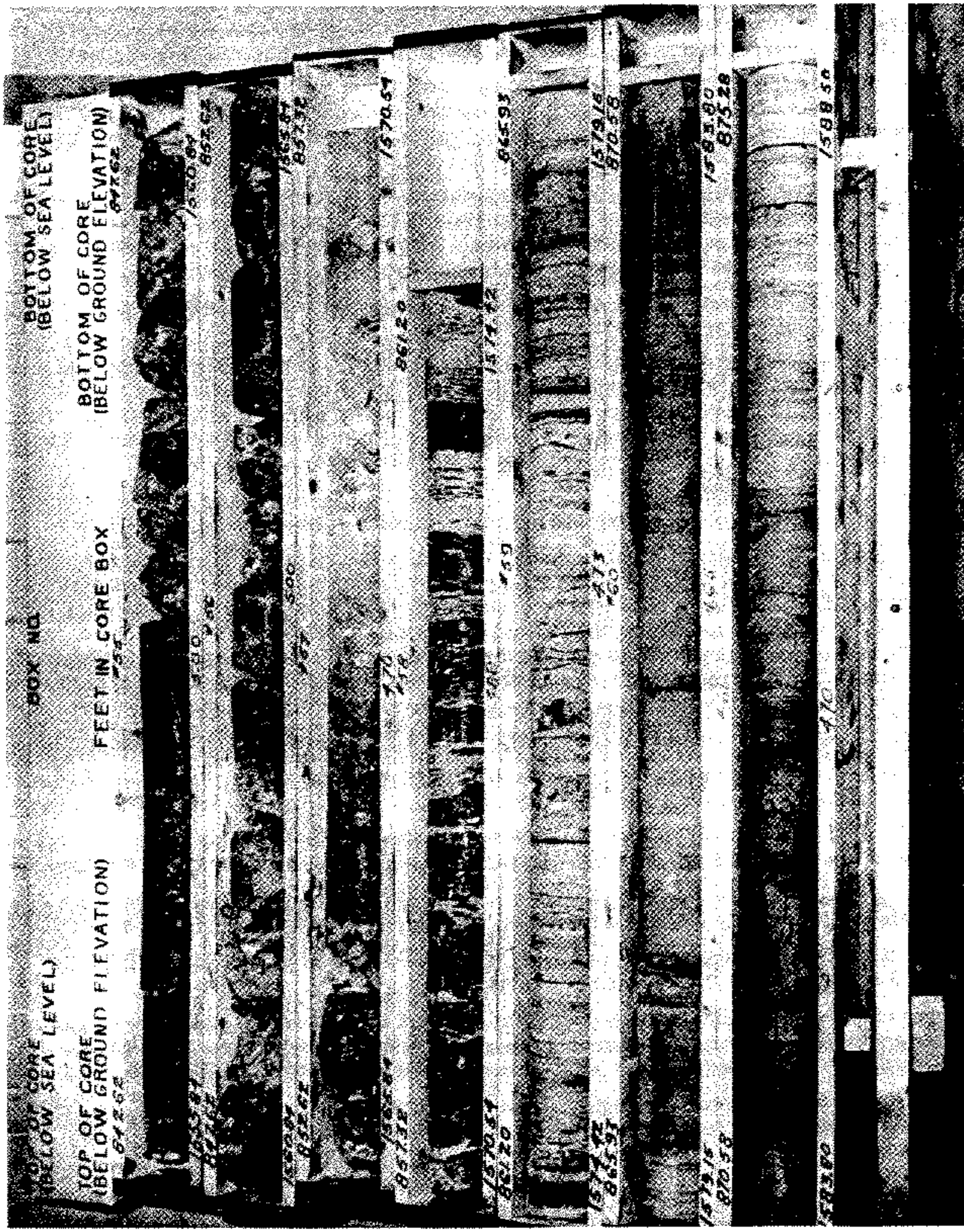
TOP OF CORE (BELOW SEA LEVEL)
TOP OF CORE (BELOW GROUND ELEVATION)
BOX NO.
FEET IN CORE BOX
BOTTOM OF CORE (BELOW SEA LEVEL)
BOTTOM OF CORE (BELOW GROUND ELEVATION)

Figure 1.

In the cementing program there are two things that must be considered. First, the possibility of not getting cement returns in one stage. This must be given consideration in a new area or in an area where previous experience shows that the added weight of the cement will break down some formation and cause returns to be lost. In such an area jels should be utilized to lighten the cement column. In addition the jels will do other things. It will increase the viscosity of the cement. This will tend to cause a better interface between the mud and the cement. If no jel is added the relatively thin cement will finger up into the more viscous mud creating the start of a bad cement job. Also, jels will absorb some of the excess water necessary to make the cement pumpable and cut the amount of shrinkage.

In severe cases it may be necessary to run a multiple stage cementing collar.

Aggregates in cement can be a much needed help. There are three different types in common usage and easily obtainable. The first of these is perlite. Common construction perlite is not a proper type and should not be used; it has an excess of fines. Second is gilsonite. Gilsonite is a weathered asphalt and it serves as an excellent aggregate. Another is cut cellophane. What these aggregates do is put into the cement a lost circulation material. Most causes of cement failing to return to the surface is the increased weight of a column of cement causing the formation to break down and the cement escaping into the formation through a fracture. If the formation breaks down during the cementing operation and aggregates are contained within the cement they will seal the break and force the cement to continue to the surface.

The second consideration is the securing of a good bond between the cement and the pipe and the cement and the formation. Cement is perhaps the poorest sealing material that can be used. However, economics, availability, and adaptability make it the only material to use except in extreme cases.

There are several things that can be done to increase the efficiency of the operation:

1. Centralizers should be placed every joint across the salt and every other joint for a couple hundred feet above the salt.
2. Remove the mill varnish from several of the bottom joints of pipe before introducing it into the hole.
3. Place the cement at high enough rates to establish turbulent flow.
4. The more cement moved around the bottom of the casing has a better chance of scrubbing out pockets and/or fingers of mud.
5. When the plug is in place, and the float valve is holding, release all captured pressure in the casing.

SELECTION OF THE FRACTURING POINT

The fracturing point is selected on the basis of nature providing that plane that will give the best controlled path to the target well. It should be a clean interface between the lens of impurity and the salt. Every point in the well where a successful fracture can be expected is noted, starting at the base of the salt and working up. The pipe is set so that the lowest of these points is left exposed in the open hole. The open hole is kept to a minimum, allowing only that amount necessary for measurement errors and possibly 2 feet of cement sheath.

ITEMS CONTRIBUTING VITALLY TO A SUCCESSFUL FRACTURE

There are 3 items that are vital to the execution of a successful fracture:

1. Open hole completion: There is only one purpose in this type of completion. It is to make as sure as possible that the selected fracturing point is exposed to the hydraulic pressure. It is possible that perforating can fail to expose this point even though measurements are correct. The use of a notching procedure requires an exactness in measurements that is very hard to obtain.

2. Use of brine as the fracturing fluid: This is a very important point. It prevents the development of a cavity so that remedial measures and alternate fracturing points can be utilized. The use of water will destroy the salt around the casing so that upper layers of lenses cannot be utilized as future fracturing points.

3. The initial fracturing pressure: The formula or experience will give an expected break-down pressure. If, when the fracture is initialed, the pressure varies materially either up or down from the expected then the pressure should be relieved and the well examined for a cause of the variation.

FIVE MAIN REASONS FOR FAILURE

There are five main reasons for failure:

1. A poor primary cement job.
2. A fracture initiated in the crystalline structure of the salt and thereby causing the fluid to follow an indiscriminate path.
3. A path of weakness in the fracture pattern that causes the fluid to take an unwanted direction.
4. Natural vertical fractures, generally in the formation immediately below the salt, allowing the fluid to escape into a heavily fractured or permeable formation.
5. The fracturing well being at a different geological depth than the target well.

In discussing the first of these, a poor primary cement job, the best possible remedial measure can be explained by that old cliche "an ounce of prevention is worth a pound of cure." Every effort should be concentrated on using the proper equipment, materials, technique, etc. If, however, a cement failure does occur and the fracturing fluid selects a path of traveling up and/or down the pipe, then it must be repaired.

There are two approaches to this problem if brine has been used as the fracturing fluid. The first, and also the cheaper, is the use of temporary plugging materials to block the channel and force the fracture to occur along the desired path. The second, and the better, is to cement squeeze and thereby seal off the channel giving a permanent repair to the failure. This calls for drilling out and sometimes under-reaming to re-establish contact with the virgin formation. Experience has taught that about 35 sacks of cement are required to fill up after each 100,000 gallons of brine that have been pumped.

In regard to No. 2 failure, that of creating a fracture in the crystalline structure of the salt: Here again the best procedure is in preventative measures. This failure is caused generally by one of two reasons. First, a mistake in measurements when perforating or notching. Second, an erratic pattern in the perforating may not expose the chosen fracturing point, thereby diverting the hydraulic pressure into the crystalline structure. The two above are the main reasons that open hole completions are recommended. The best procedure that can be adopted in this case is to cement squeeze, drill out and re-perforate.

The third cause of failure, a path of weakness causing the fracture pattern to take an unwanted direction. This is one failure cause over which apparently there is no control. Mother nature has predetermined it. Frankly, personal experience has never found this to be the case. There have been times when it was thought to be the trouble, however, in every case, with the possible exception of one, when the trouble was finally overcome it was found to be one of the others.

If it is the case, there are two possible remedial measures. First, go to the other well and fracture back. Second, move up the hole to another fracturing zone. If the second above is done, the old zone should be cement squeezed to rebuild the support removed by the old fracture and thereby help prevent the new fracture from taking the old direction.

The fourth reason, the escape of the fracturing fluid into a fractured or permeable zone. This culprit is suspicioned to be the cause of more failures than all the others. It is also, the most difficult to overcome without sacrificing some of the salt zone. The only preventative measure is to select a fracturing point above the base of the salt if examination of the formation below reveals vertical fractures. The absence of a fracture in the core does not mean that within 100 inches or 100 feet such a vertical fracture exists. Of course experience in a given area will indicate whether or not this is a cause of failure to fear. By the same token just because a pair of wells have been successfully fractured does not mean that an offsetting pair could not encounter the trouble.

There is only one remedial measure to take if a vertical fracture is encountered and necessity dictates that every effort be made to accomplish a fracture at the base of the salt. It is a method that has been successfully used in oil formations, whether it has been used in salt is not known. It is the use of fluid loss agents. Fluid loss agents are used to seal off permeability and thus extend fractures. Increased injection rates should supplement the fluid loss agents. The only other alternative is to move up the hole to another fracturing point. If this is done the old fracture must be squeezed to rebuild the formation support. The larger the layer of salt between the old fracture and the new selected point the better. This will afford greater protection from the vertical fractures in the formation below.

The fifth cause of failure is that the two wells are at different geological depths. This can cause a truly successful fracture to be judged a failure. There is one case where the fracturing well was four feet deeper geologically than the target well. The result would have been written off as a failure if the fracture had not passed under the target well and connected to another well 800 feet beyond. Water was introduced and the resulting dissolving removed the four feet of salt and connected to the original target well. Emphasis must be placed on a thorough geological study including pinch-outs and comparing the original dip when the salt was laid down with the present dip.

Here again the best remedial measure is the preventative measure of prior study and planning. However, if it does occur a restudy is in order and when it is discovered the remedial measure is apparent.

REMARKS ON GENERAL SUBJECTS

Perhaps remarks should be made regarding the use of the temporary plug as a diverting agent. It has been used successfully in oil formations many years. It is agreed that its percentage of success is going to be limited. However, its cost compared to the other remedial measures is substantially lower, thereby making it an item worth consideration. There can be some situations where it is the only solution to a given problem.

Some remarks might be made regarding vertical fractures. In this writer's opinion a vertical fracture in salt could better be described as a fracture in the crystalline structure of the salt. It may be vertical at a given point but when it reaches a point of distortion of the crystals or a lens of impurity its attitude might change altogether; it could become horizontal. This should be classed as an indiscriminate fracture rather than a vertical fracture.

No direct discussion has been made about going to the target well and working back. This, of course, is excellent procedure when the target well is in a proper condition and will multiply all remedial measures by two.

One more remark is in order. Experience has shown that wells four to seven hundred feet apart can be expected to be connected when 30,000 to 60,000 gallons of brine have been pumped. With pumping in excess of this amount chances of a successful connection are rapidly diminishing. Therefore, to give a sufficient safety margin a rule of thumb of 24 hours of pumping is established. If at the end of this time no connection has been established, stop pumping and determine what is wrong, and adopt the proper remedial measure. Of course if a connection has been made, switch to water and start dissolving for a low pressure connection.

CONCLUSION

In conclusion it is emphasized to include remedial measures in your prior planning. Do not base all hopes on a one shot proposition and quit when it fails.

With proper planning and application it is hard to visualize a system that cannot be successfully connected economically.