# PERFORATING AND PRESSURE MEASUREMENT TECHNIQUES TO MAXIMIZE PRODUCTION AND WELLSITE EFFICIENCY

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**ABSTRACT**

Modern perforating techniques designed to maximize production seem as varied as the wells they are applied to. However they have one trait in common; an instantaneous pressure drawdown (reverse pressure) is applied to surge the perforations clean and create the highest effective shot density possible. The pressure drawdown lends itself to a pressure buildup test immediately thereafter. This paper discusses reverse pressure surging techniques with casing, thru-tubing, and tubing conveyed perforating guns along with a discussion of the capabilities and versatility of the Measurement While Perforating (MWP*) and Measurements After Perforating (MAP*) buildup testing techniques.

**INTRODUCTION**

Shown in Figure 1A is the typical appearance of a formation target immediately after being perforated. Note the perforation is filled with debris and surrounded by a compacted zone of about one half inch. Obviously this debris must be removed in order for the perforation to perform or flow efficiently (Figure 1B). Common experience with production and injection logs, pulsed neutron logs, and blast joints indicate that in many cases only a few perforations ever contribute to production. Many perforations remain plugged with debris for the life of the well and never contribute to production.

> The summation of all hard field evidence makes it difficult to accept any premise except one that presumes a small percentage of perforations open and working. Virtually nothing points to a preponderance of perforations being open and productive, except blind faith and hope.[1]

The rest of this paper will be concerned with perforating methods that maximize the number of perforations that actually clean up and perform properly and some methods of well testing that will give a near instantaneous indication of the success along with a measurement of other skin

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factors. Thus stimulation or additional perforating can be evaluated immediately after perforating.

**REVERSE PRESSURE SURGING TECHNIQUE**

It is of paramount importance in the natural completion that the debris filling the perforation be removed; however, the debris is often overlooked or ignored when any type of stimulation is performed on the well. Whenever possible any well should be backflowed by reverse pressure surging for the following reasons:

1. The debris in no way can aid in production.
2. The debris reduces the effective penetration. Common practice tells us that deeper penetrations require less pressure to breakdown which can help insure an effective completion in two ways:
   a. Reduces the risk of breaking down the cement column which mitigates potential problems of water production from nearby aquifers and the unnecessary loss of stimulation fluids to nonproductive zones.
   b. Reduces the horsepower required for pumping the stimulation and hence helps control completion costs.
3. If a reactive acid is placed at the perforation entrance to the casing, the reaction process itself will leave by-products in the tunnel entrance and thereby insulate the remaining solids from fresh reactive fluid.[2] (Figure 2)

Once a perforation is pumped into without backflowing first, any nonsoluble remnants will be compacted into the back of the perforation tunnel and there they will likely remain for the life of the well. The stimulation has created a path for flow that will never take advantage of the entire perforation tunnel.

Perforating underbalanced has been shown to be the most effective way of maximizing the number of perforations that are actually open and clean.[1,3,4,5] A reverse differential pressure is established that is comfortably in excess of that which is known to affect good perforation clean-up. The perforating gun is fired. All perforations are immediately subjected to a level of pressure in excess of that required to insure their initial clean-up, particularly those in the lower permeability intervals. Each perforation has the opportunity to become functional before the negative differential is reduced by well/tubing fill-up (Figure 3).

Contrast this with the overbalanced scenario. The well is perforated overbalanced and then swabbed in. During the process pressure changes are small. Visualize that suddenly a small percentage of the perforations begin to flow. Swabbing operations are suspended; the well flows through the few functional perforations, leaving the remainder plugged and nonfunctional at the operational drawdown pressure (Figure 4).

For methods that employ selective gun firing and/or multiple gun runs the well must be flowed in order to maintain a negative pressure differential. This can create a transient or disappearing underbalanced pressure differential during the late stages of perforating. Therefore, it is usually better to perforate the intervals with lowest permeability first, while the pressure differential is at a maximum.

Underbalanced Perforating Methods and their advantages and disadvantages are varied. Following are the most widely used methods and their advantages and disadvantages:

Conventional Thru-Tubing Perforating with carrier guns.

Advantages:

1. Positive well control.
2. Cost competitive.
3. Selective perforating is optional.
4. Saves rig time.

Disadvantages:

1. Guns may swell or split if not shot in fluid.
2. Shallow penetration.

Semiexpendable Thru-Tubing Perforating

Advantages:

1. Penetration performance that rivals or exceeds that of many casing gun perforators.
2. Positive well control.
3. Charges are conveyed on a strip which is recovered.
4. Cost competitive.
5. Positive indication of all charges that fire.
6. Can be fired under the maximum differential pressure into a dry wellbore.

Disadvantages:

1. Leaves a limited amount of debris in the wellbore.
2. Limited select fire capability - 2 intervals per run.
3. Can cause some swelling in thin-walled unsupported casing.

Tubing Conveyed Perforating

Advantages:

1. Positive pressure control.
2. Allows for high density, phasing, and deep penetration.
3. Long intervals can be perforated at one time.

Disadvantages:

1. More expensive.
2. No means to accurately detect the number of shots fired without pulling the guns.
3. A lengthy and costly operation to retrieve misfired guns.

Other Methods involve the use of casing guns.

Underbalanced

1. If the productive interval is of low enough pressure and/or the produced fluid of high enough density, then the well will kill itself before flowing to the surface. There is no well control problem to deal with and a simple and effective underbalanced completion can be achieved with standard casing guns on wireline.
2. Run a permanent packer with a blanking plug in it, on wireline, under pressure to effectively kill the well.

Balanced

1. Shear discs such as the Positive Action Completion Technique (PACT*) tool can be run in the well with the packer and tubing assembly after perforating in a balanced or slightly overbalanced environment. The tubing is dry above the shear disc, and the shear disc is placed at whatever depth in the string is necessary for the reverse pressure desired. Once the packer is set and wellhead attached a drop bar is released which shears the disc and exposes all the perforations to a high pressure differential surging them clean.
2. By replacing the shear disc with a valve a cased hole drillstem test can be performed. When the valve is opened the perforations are surged clean. When the valve is closed the buildup begins. Whereas other methods minimize wellbore storage; this method has the advantage of eliminating wellbore storage completely making the buildup analysis simpler.

Differential pressures of 500 to 1500 psi have been employed with good success rates on liquid producing wells. In low permeability reservoirs these numbers roughly double, with

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some gas wells in stubborn sands completed with differential pressures in excess of 5000 psi.

## MWP AND MAP TECHNIQUES

In 1986 Joseph Ayoub[6] suggested a procedure in which permeability could be obtained from short term pressure information. Impulse testing differentiates itself from conventional pressure transient analysis in that the equations used for interpretation use a total volume flowed (barrels) rather than flowrate (barrels per day). This method has seen extensive use offshore in conjunction with drillstem testing tools and tubing conveyed perforating.

In 1988 Jim Campbell[7] showed that impulse analysis techniques could be used in conjunction with wireline perforating on land to obtain reservoir parameters. Historically, many of these wells are not tested due to low "KH" values (permeability - thickness product) and extensive wellbore storage. With impulse testing the wellbore fluid level is usually at or near the surface, which reduces wellbore storage to minimal levels.

MWP and MAP are the practical applications of impulse testing theory to wireline perforating techniques. MWP obtains bottomhole pressure (BHP) and transmits the data to surface via the perforating electric line in real time. MAP stores BHP data on a downhole memory gauge that is retrieved after the perforating electric line is returned to surface.

## TEST PROCEDURE

The procedure for wireline impulse testing can be broken down into three types: surface flow, slug flow, and compressive flow. Although all three are similar in that they measure bottomhole pressure after perforating this paper will only be concerned with the last two. Variations of these techniques will allow almost any well to be tested when an underbalanced condition exists at the time of perforating.

The slug flow procedure is designed for oil wells that will not produce (flow) to surface. Initially the well is swabbed down to an underbalanced condition. On the trip in the hole with the perforating guns and the pressure gauge the fluid level is noted and then the well is perforated. Bottomhole pressure is measured for approximately four hours, and on the trip out the new fluid level is found. From the changing fluid level the volume flowed is calculated.

In compressive flow the wellbore is filled with completion fluid and has a measurable air volume at surface. Prior to perforating, all surface valves are closed. After perforating, the air compresses, followed by compression of the completion fluid. The air compression acts as the flow period, because of its high compressibility; and conversely, the water compression acts as the buildup. Note that the well is never flowed at the surface.

For any MAP or MWP procedures it is recommended that the well be at least 500 psi underbalanced prior to perforating. The more underbalanced the well is the better the chance of a successful test.

The rule of thumb for test times is "If you can't obtain the necessary data in four hours it probably can't be obtained in the context of an impulse test." Even for tight gas wells four hours is usually plenty of data.

Both bottomhole and surface pressure are generally recorded during MWP and MAP operations. The acquisition of both sets of pressure data aid the reservoir engineer when the data analysis is made particularly in the case of two phase flow.

**CASE HISTORIES**

The following examples show three different wireline perforating techniques along with three different pressure data acquisition systems. All yield excellent reservoir analysis. This flexibility allows a range of choices in perforating techniques and pressure recording devices depending on well conditions, cost considerations, and personal preference.

Example 1

This job was conducted using thru-tubing expendable guns with an electronic surface readout pressure gauge (MWP). The following well and reservoir conditions existed at the time of the test.

Casing ID: 4.276 in.
Perforated Interval: 13 ft
Shot Density: 4 spf
Perf Diameter: 0.21 in
Tubing ID: 1.995 in.

Figures 5 & 6 are the pressure transient analysis plots used to calculate the following reservoir parameters:

Permeability-Thickness: 3.13 md-ft
Skin Factor: -1.1
Radius of Investigation: 20 in.
Reservoir Pressure: 8205 psi

Example 2
This job was conducted using casing guns and a downhole electronic memory gauge (MAP). The following well and reservoir conditions existed at the time of the test.

Casing Size: 5 in., 18 lb/ft
Perforated Interval: 10 ft
Shot Density: 2 spf

Figures 7 & 8 are the pressure transient analysis plots used to calculate the following reservoir parameters:

Permeability: 0.04 md
Skin Factor: -1.0
Radius of Investigation: 20 ft
Reservoir Pressure: 4690 psi

Example 3
This job was conducted using thru-tubing semiexpendable guns and an Amerada mechanical pressure gauge run above the guns. The following well and reservoir conditions existed at the time of the test.

Casing Size: 7 5/8 in.
Perforated Interval: 40 ft
Shot Density: 2 spf

Figures 9 & 10 are the pressure transient analysis plots used to calculate the following reservoir parameters:

Permeability: 0.006 md
Skin Factor: 2
Radius of Investigation: 10 ft
Reservoir Pressure: 12,950 psi

## CONCLUSION

By using the proper technique, pressure surging the perforations can be accomplished by utilizing any of the standard perforating systems. Underbalanced perforating, shear discs, or cased hole drillstem tests can be combined with a pressure gauge to obtain BHP. Various pressure transient analysis techniques can then be used to yield reservoir parameters of permeability, skin, and pressure immediately after perforating. Thus allowing for a timely decision on additional perforating or stimulating.

Impulse testing is a fast and low cost method for the logical evaluation of production potential in conjunction with perforating. It can also allow the testing of low permeability wells which in the past went untested due to long test durations.

**References**

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3. W. White, T. Walker, and J. Diebold: "A Proven Gas Well Completion Technique for Higher Deliverability", JPT (June 1965).
4. W. T. Bell and R. M. Bell: "The Paradox of Gun Power Versus Completion Efficiency", 1981 Explosives Conference of the International Association of Drilling Contractors.
5. Stanley Locke: "An Advanced Method for Predicting the Productivity Ratio of a Perforated Well", SPE paper 8804, Bakersfield 1980.
6. Joseph Ayoub, D.P. Bourdet, and Y.L. Chauvel: "Impulse Testing", SPE Formation Evaluation (September 1988), 534-546.
7. Jim Campbell: "Impulse Analysis on Wireline", Schlumberger Well Services, 1988.
8. S.M. Tariq and L. Ayestaran: "Analyses and Applications of Pressure, Flowrate, and Temperature Measurements During a Perforating Run", SPE paper 15475, New Orleans 1986.

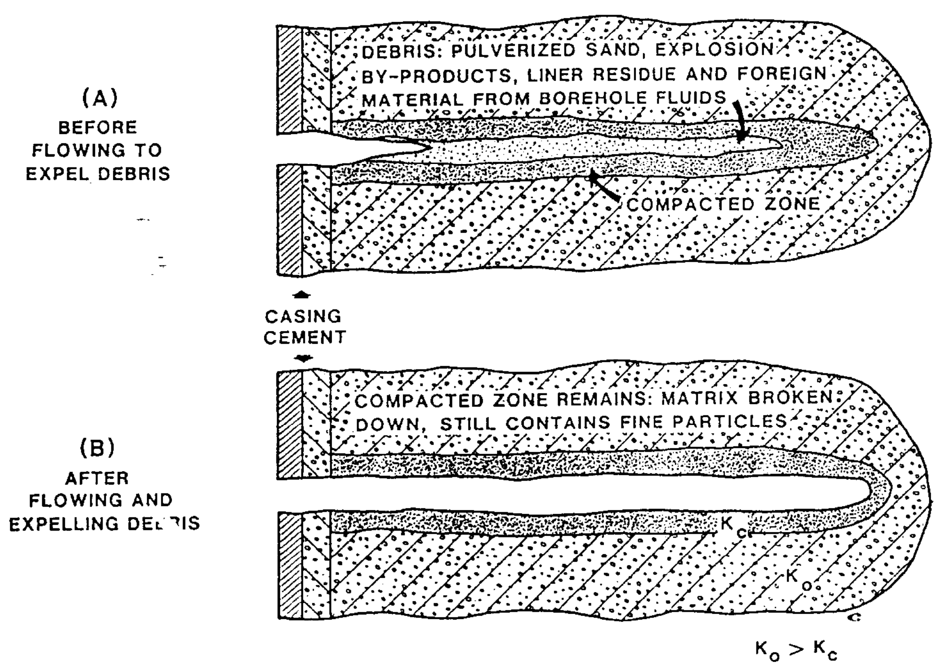


Figure 1 - Character of perforated hole made in Berea sandstone

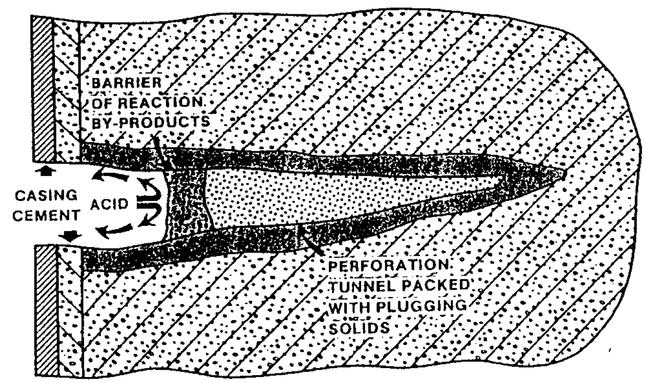


Figure 2 - Fluid acid "cleaning"

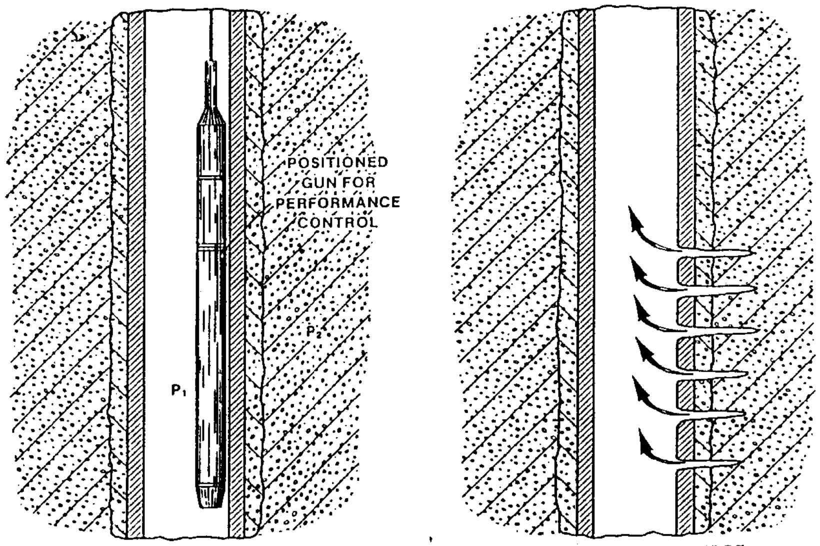


Figure 3 - Effects of reverse pressure perforating

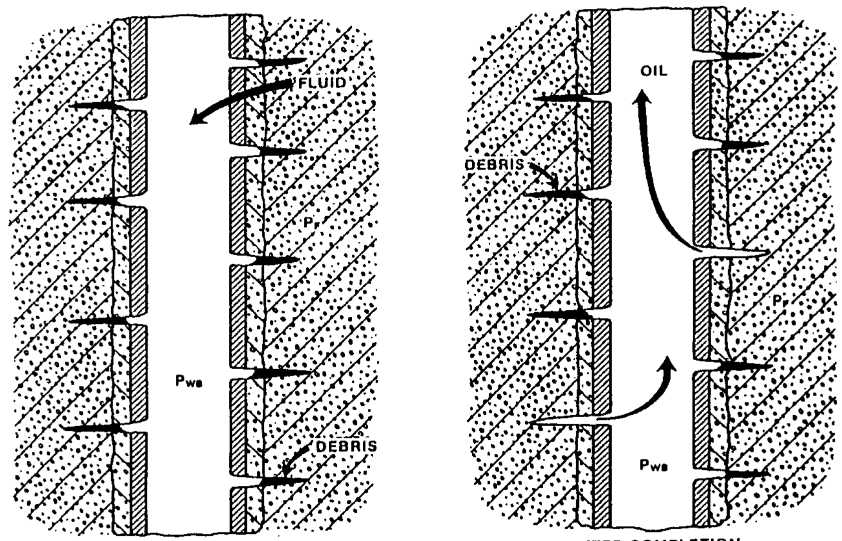


Figure 4 - Flow restrictions created by overbalanced perforating

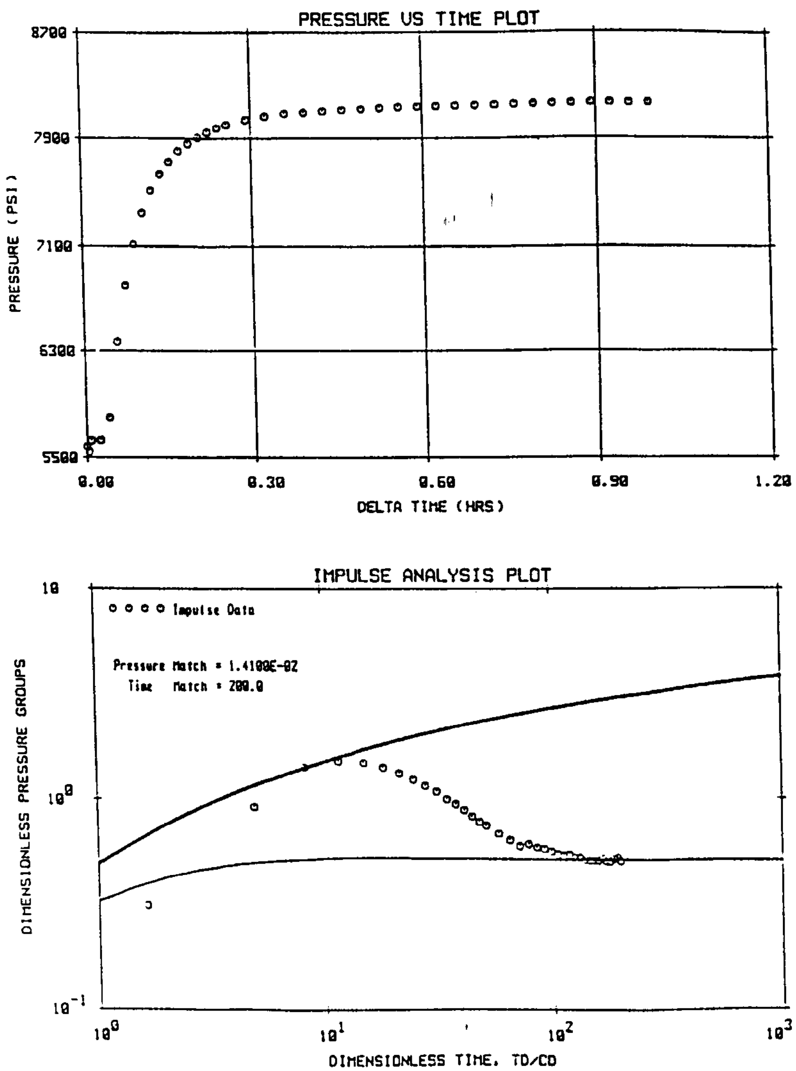


Figure 5 - Impulse test validation

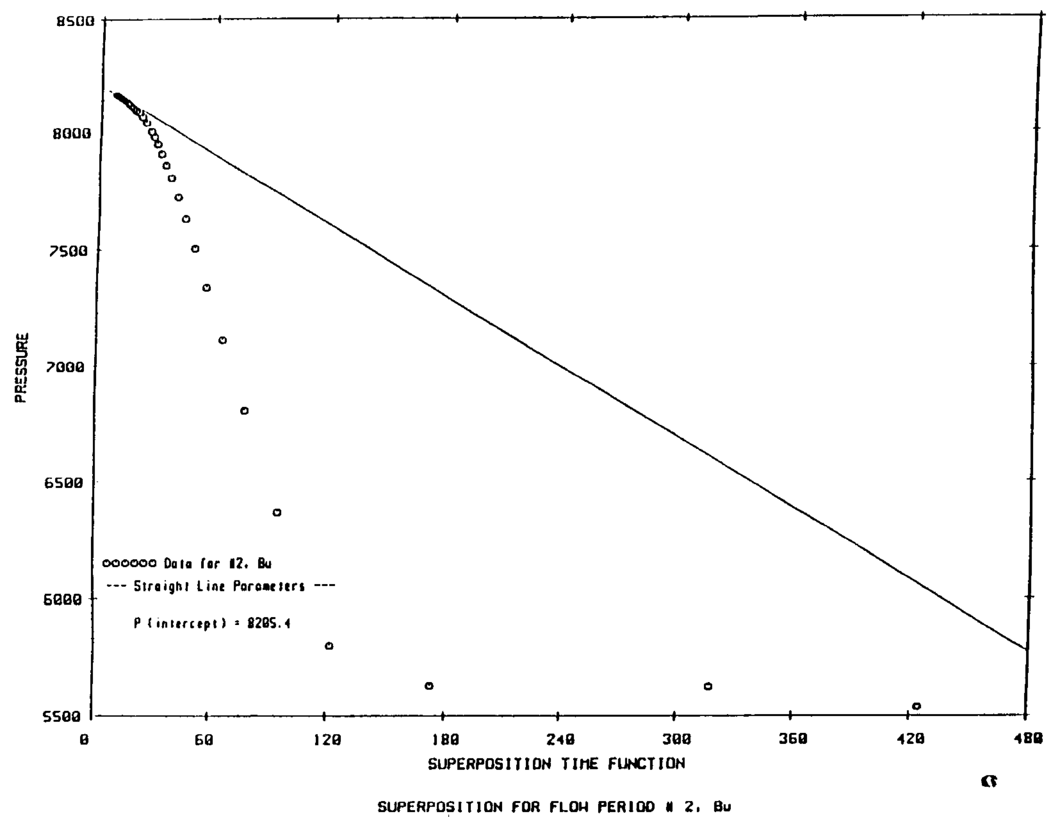


Figure 6 - Generalized Horner plot–reservoir pressure extrapolation

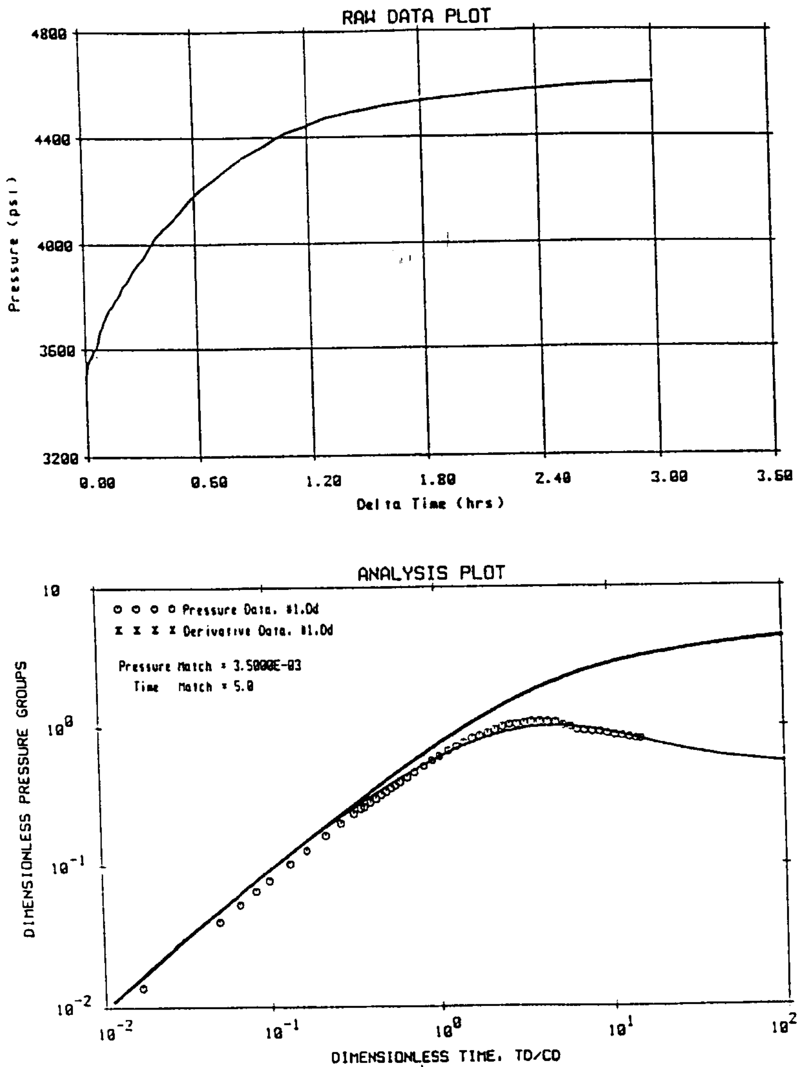


Figure 7 - Impulse test validation plots

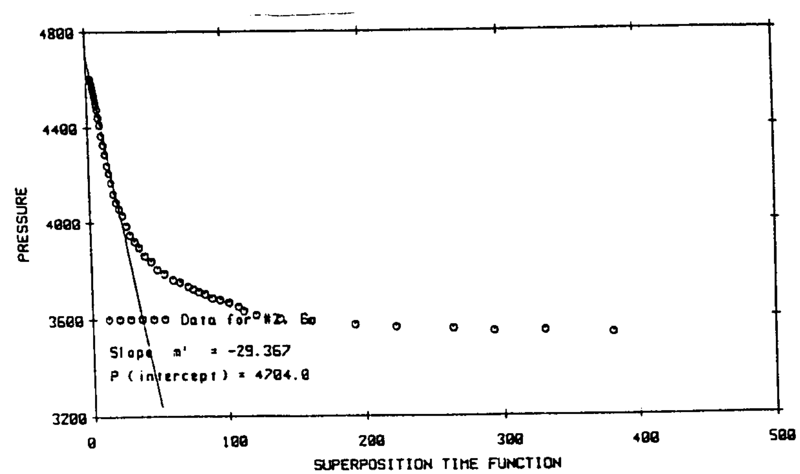


Figure 8 - Analysis: superposition plot for flow period #2, Bu - infinite-acting radial flow

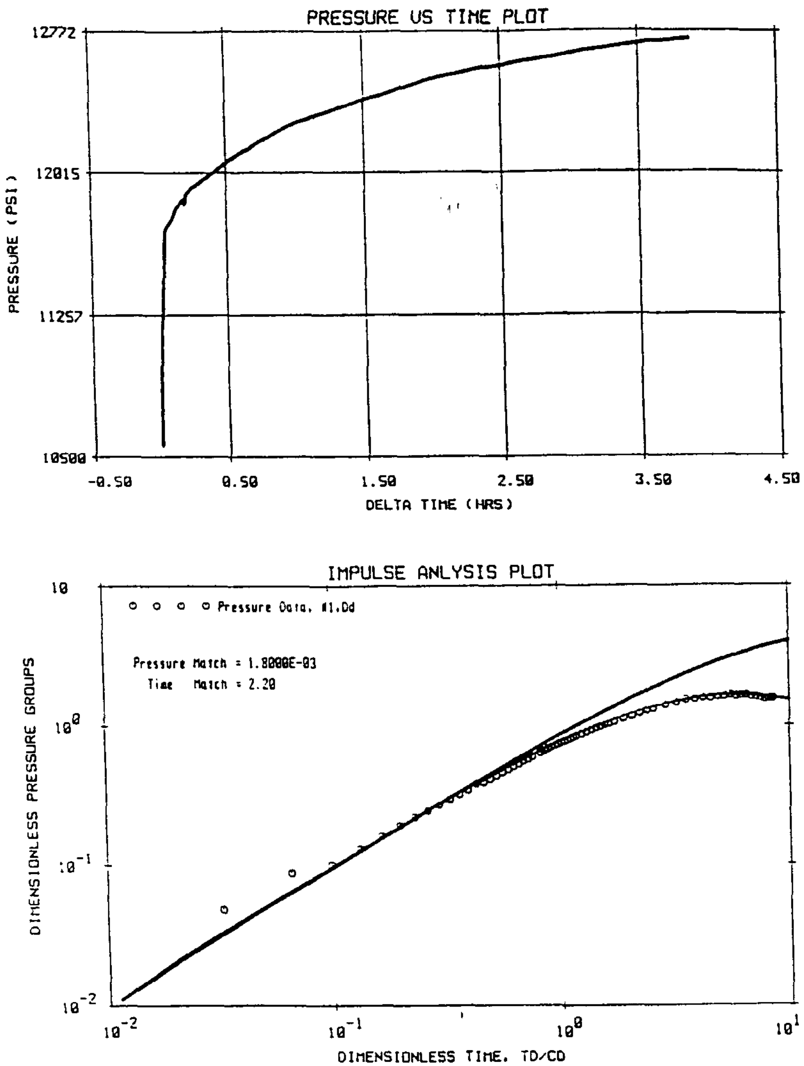


Figure 9 - Impulse test validation

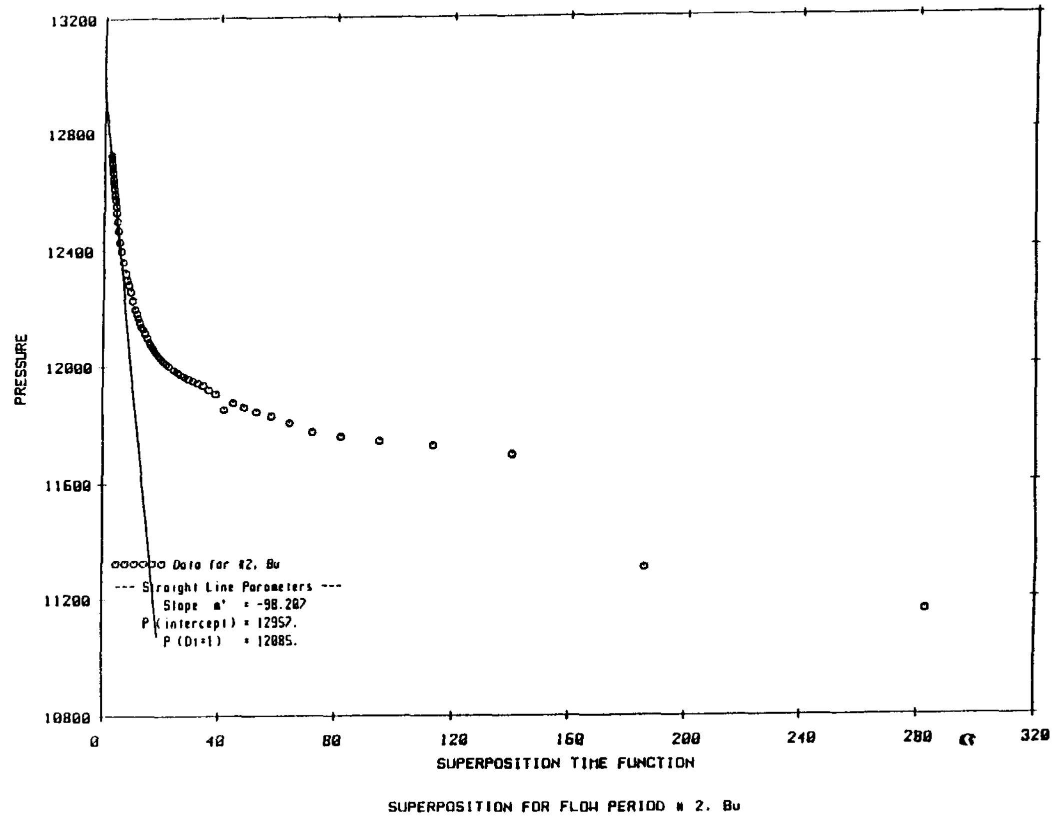


Figure 10 - Generalized Horner plot–reservoir pressure extrapolation