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Injection Testing to Determine Reservoir Properties

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Abstract

In many locations, totally evaluating the quality of a reservoir based on conventional logs alone is difficult. This difficulty is especially present in lower-permeability reservoirs. Often, conventional logs can allow the operator to pass up zones that may be more productive than indicated on a conventional porosity cutoff. In such cases, a zone is perforated and allowed to flow to get a better evaluation of the zone and its production potential. However, if the zone does not flow to expectations, the operator may face a real dilemma: is it a poor-quality reservoir, or is some sort of damage prohibiting flow? This question can be very daunting and may not be easily answered, especially if the well will not flow adequately for a buildup analysis within a reasonable time frame.

In this paper, the potential for using a small injection test and the subsequent pressure fall-off to analyze the reservoir pressure and permeability is evaluated. Many benefits could be derived from using an injection test for reservoir analysis. Some are obvious, such as the capability to determine permeability and reservoir pressure, but this test can also be advantageous because these properties can be determined without flowing the well (which in some circumstances may be difficult and/or costly).

In this paper, a deep Atoka Wash well in Western Oklahoma is evaluated. The results of the fracture injection test are discussed, as well as how these results compare with a conventional buildup analysis.

Introduction

Lately, the Atoka Wash in Western Oklahoma is highly sought after for gas production; however, it can also be a difficult formation to complete because traditional porosity cutoffs do not always clearly define which zones will be productive. These difficulties probably arise in part from the changing rock composition as well as the depositional environment of this formation, and a variety of methods have been employed to determine its potential pay zones. These techniques include

conventional logging, advanced logging techniques, and well testing, either through flow testing or buildup analysis. Although conventional log analysis works very well in some areas, defining a model that can adequately describe the formation with a conventional log analysis in the Atoka Wash formation is difficult. Although advanced logging tools can be employed to help describe the rock more completely, these logs may not be run for a variety of reasons and the operator may have very little information to use in choosing the overall completion strategy. Here, another tool or technique is needed during the completion so the operator can better characterize the reservoir and optimize the completion.

Often at the beginning of the completion stage, the operator has felt that there were only two options. They must perforate the well and then perform a flow test or a buildup analysis to more fully determine some of the formation characteristics, or just begin completing zones with little understanding of the reservoir characteristics.

In some locations, the flow tests or buildup analysis are relatively simple and inexpensive to perform after perforating because the well will flow easily and the process proceeds smoothly and at a relatively low cost. However, in many instances in this area, the ability to obtain the flow test or buildup analysis is much more complicated. Often the operator is faced with a well that will not flow on its own and they first try to break the zone down (i.e., initiate a fracture) to see if it will flow after the breakdown process. If it does not begin to flow, they may choose to bring in a coiled-tubing unit to unload some of the hydrostatic pressure off the zone until it will begin to flow.

However, in this case potential complications can still arise. What if the well does not begin to flow or flows at what appears to be an unproductive rate? At this point the operator may be faced with the choice of either abandoning the zone because of apparent poor reservoir quality or hoping that the zone is actually just “damaged” and that a fracture can bypass the damage. This situation is further complicated by the fact that each additional step in this process continues to raise the completion cost of a zone that may still have an unknown potential.

In this paper, the authors review their applications of another method of evaluating the reservoir quality: the After Closure Analysis (ACA) technique.¹⁻³ This method can be simpler and potentially less expensive than efforts to get the well flowing for either a flow test or buildup analysis. This method of determining reservoir properties has been well established in some areas,⁴⁻⁸ but has been a largely under-

utilized resource in evaluating the Atoka Wash in Western Oklahoma.

In an effort to better understand and characterize the Atoka Wash in this area, Dominion E&P has performed a variety of these pump-in and leak-off tests to determine reservoir properties. In some of these cases, they have performed both ACA and buildup tests to help validate the process. These tests were performed on a 16,000-ft Atoka Wash well in Beckham County Oklahoma. The well was perforated, a pump-in breakdown with leak-off analysis was performed, and then the well was jetted and allowed to flow before a buildup analysis was performed. The results of the two analyses on this well are compared in the following sections.

The Procedure

The well was logged and potential pay zones were chosen by the normal methods of porosity cut-offs and gas shows on the mud log. As the completion operations began, the operator decided that this well would be a candidate to test the ACA, then compare it with a standard buildup analysis and determine whether any comparison could be drawn from the flowing data before the buildup analysis.

During the completion phase the well was loaded with KCl water and perforated. After perforating, the formation was broken down by injecting 30 bbl of KCl water and the pressure was monitored for an extended period of time (**Fig. 1**).

ACA can only be performed after the well has reached pseudoradial flow. As several authors have determined, the amount of time it takes to reach this state can be lengthy^{2,7,9-11} and depends on a variety of factors that include reservoir permeability, pore pressure, and the amount of fluid injected into the formation. Often, the formation can be very tight; therefore, the practice of shutting the well in for 24 hours with an electronic pressure gauge tied into the wellhead at the surface has been adapted. The gauge is retrieved the next day so the data can be analyzed. However, in this case the recorded pressure data shown in **Fig. 1** indicates that the pressure fall-off ended in just two hours.

After the gauges were collected, the job team began the process of analyzing the data for the ACA. However, at that time the operator also began to flow the well to obtain both a flowing test and subsequently a buildup analysis of the reservoir. After the operator got the well flowing, they prepared to perform a buildup analysis.

The ACA. After the data is collected from the electronic memory gauges used on location, it is merged with the data collected from the pumping service company. This merging process brings the treating pressure, treating rate, and gauge pressure into one file that can then be used for the analysis.

The first step of the analysis is to obtain an estimate of the reservoir pressure. During this analysis, the reservoir pressure could be determined and verified from three plots: a Horner plot (**Fig. 2**), a pseudolinear flow plot (**Fig. 3**), and a pseudoradial flow plot (**Fig. 4**).

From these three plots, the following estimates of reservoir pressure were obtained:

- Horner plot 7,789 psi
- Pseudolinear Flow plot 7,781 psi
- Pseudoradial flow plot 7,794 psi

This result is a nice agreement between these three methods and leads the authors to believe that the data is of good quality because each method is predicting a very similar value for reservoir pressure.

From this point, the pseudoradial flow plot (**Fig. 4**) can be analyzed and the permeability for the reservoir can be found. On this plot, a line is drawn through the straight-line section of data that represents the pseudoradial flow. From the slope of this line we can calculate the reservoir pressure and the intercept represents the reservoir pressure. (The actual calculations are not reviewed in this paper, but are covered extensively in a variety of existing papers.) The result is a kh of 8.39 md-ft, or a permeability of 0.419 md.

With this result obtained, the comparison against the results obtained from the flow test and subsequent buildup analysis can be performed.

The Buildup Analysis. As can be see in **Fig. 5**, the well was allowed to flow slightly over 20 hours before the pressure buildup analysis was performed. The well was then shut in for approximately 90 hours to obtain the data used in the pressure buildup analysis.

The permeability was calculated with two methods: striking a line on the semilog plot (**Fig. 6**) and using the derivative analysis (**Fig. 7**) assuming homogeneous reservoir plus skin. The semilog analysis returned a reservoir pressure of 7,120 psi, a permeability of 0.482 md, and a skin of 18. The derivative analysis returned a reservoir pressure of 7,153 psi, a permeability of 0.483 md, and a skin of 16.1.

Summary

A summary of the results obtained from these tests is shown in **Table 1**. In this table, both methods show a very close estimate of permeability, but a small spread in the reservoir pressure. It is possible that the radius of investigation explains the difference in the reservoir pressures and that surrounding production is actually drawing the reservoir pressure down. However, the data in **Fig. 7** also indicates that the amount of buildup time allowed was not sufficient to fully define the reservoir parameters of this well because the derivative was still changing when the data collection stopped. Even with this discrepancy, the tests are showing a very nice correlation between the reservoir pressures and permeabilities that each one has estimated.

The initial flow rate obtained on this well is also very interesting. From past experience, the flow rate of this well indicated that the well would be of commercial quality; however, it would not have the type of potential that is seen in

the permeability that each of the tests indicated. This discrepancy is caused by the skin that was measured in the buildup analysis; a determination of skin is not provided from the ACA technique.

In this case, the operator would not have skipped the zone based on the data obtained from the flowing test. However, potential exists to skip a zone based on the data obtained from a flowing test in some cases. Seeing the results from the tests performed on this well confirmed that the ACA contributes to understanding the reservoir and is a useful tool that can be used as part of the completion strategy.

Conclusions

Based upon the analysis presented in this paper, the following conclusions can be reached:

1. ACA can be applied to the Atoka Wash in Western Oklahoma to obtain reservoir properties comparable with those from a buildup analysis.
2. Many operators have a formation breakdown already included in their completion strategy. Adding the ACA to the completion adds very little to the completion costs and can provide valuable information.
3. Permeability can be difficult to determine in some zones based on the flow test after the breakdown. However, with the additional reservoir characterization that may be obtained from the ACA, the completion decisions may be greatly simplified.
4. Using ACA in the Atoka Wash could potentially save time and money if it is used as part of the overall completion strategy.

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Table 1—ACA and Buildup Analysis Results

	ACA	Buildup Test	
		Derivative	Semilog
Permeability, md	0.419	0.483	0.482
Reservoir pressure, psi	7,794	7,153	7,120
Skin	—	16.1	18

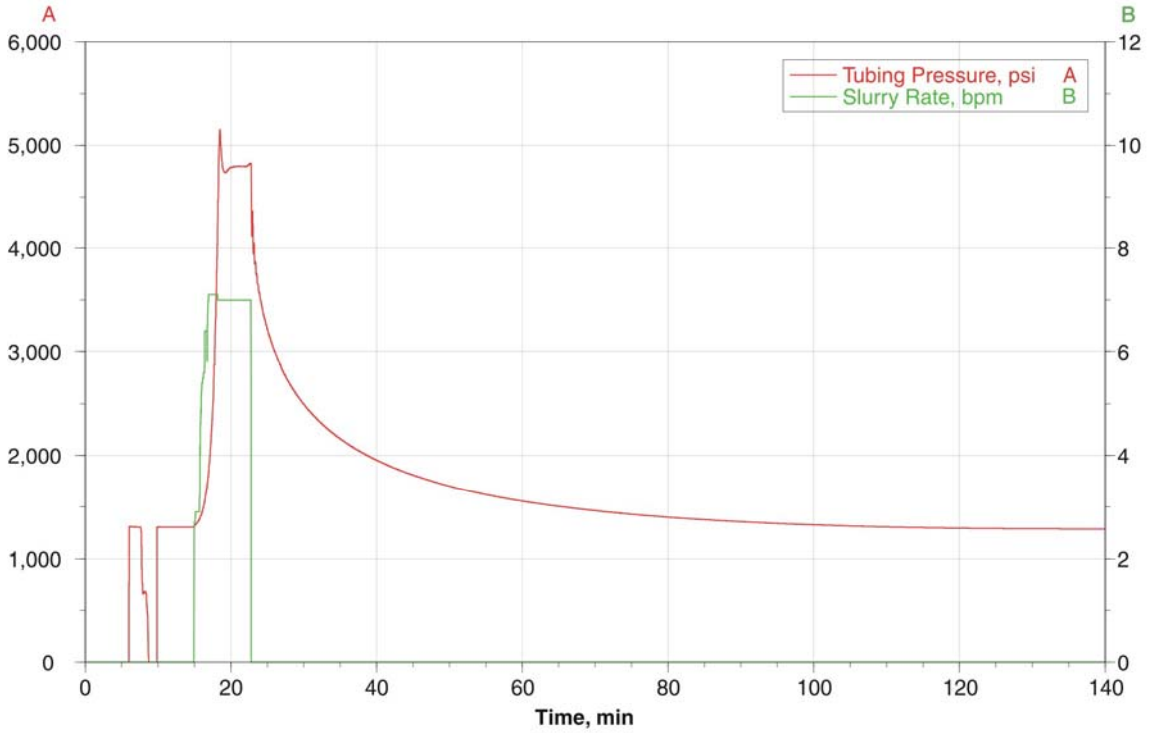


Fig. 1—Atoka Wash breakdown and leakoff.

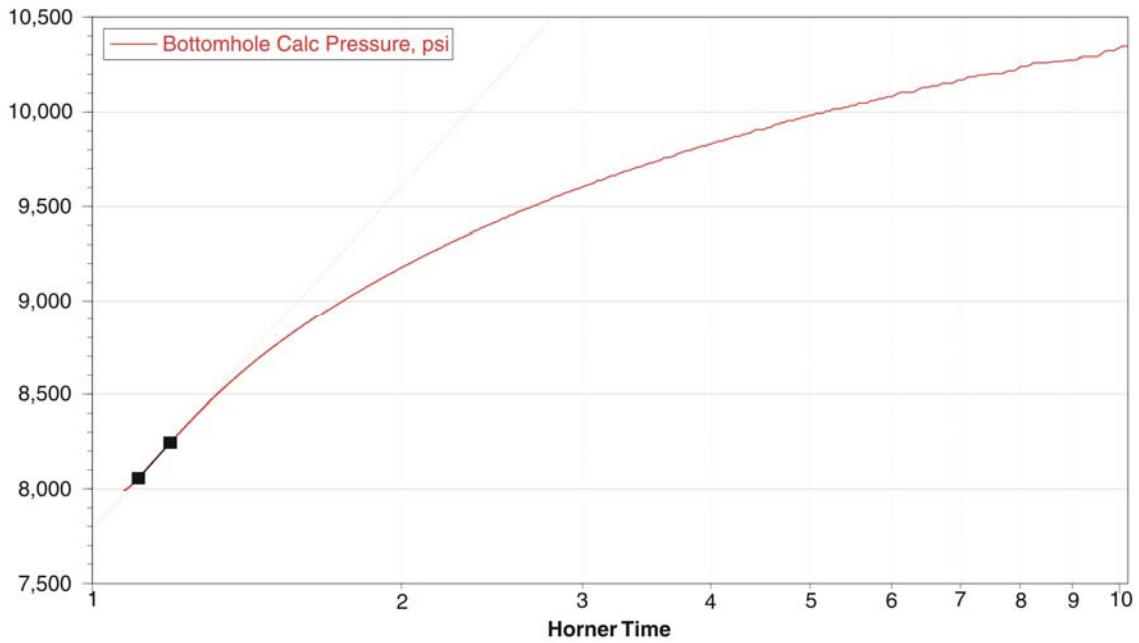


Fig. 2—Service-company pumping diagnostic analysis toolkit.

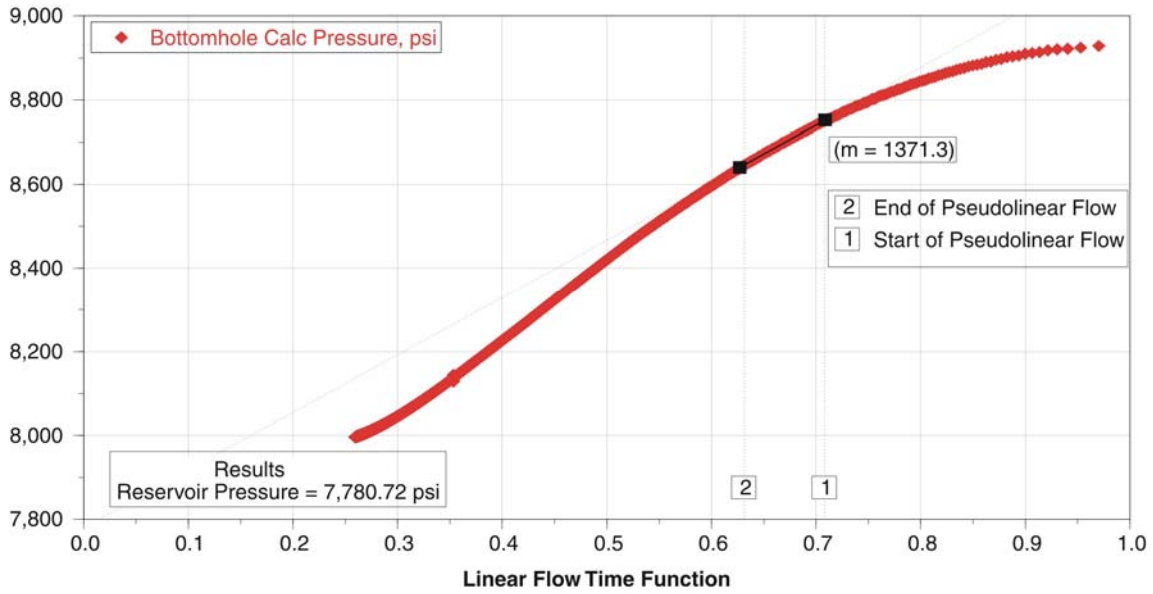


Fig. 3—Pseudolinear flow for Atoka Wash ACA.

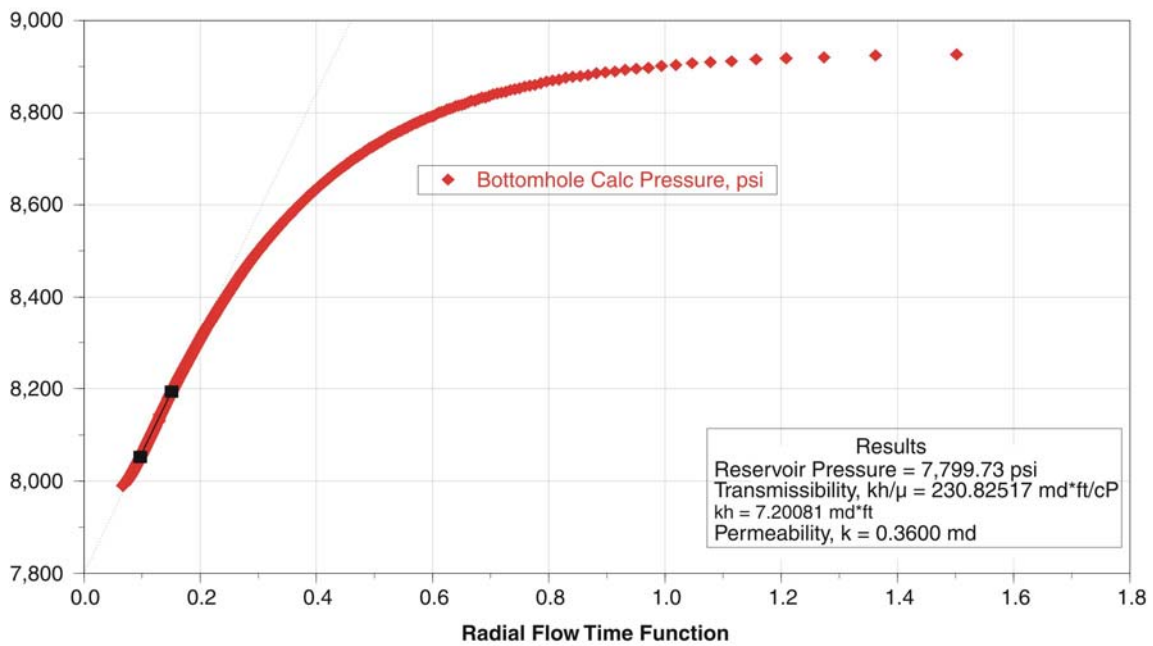


Fig. 4—Pseudoradial flow for Atoka Wash ACA.

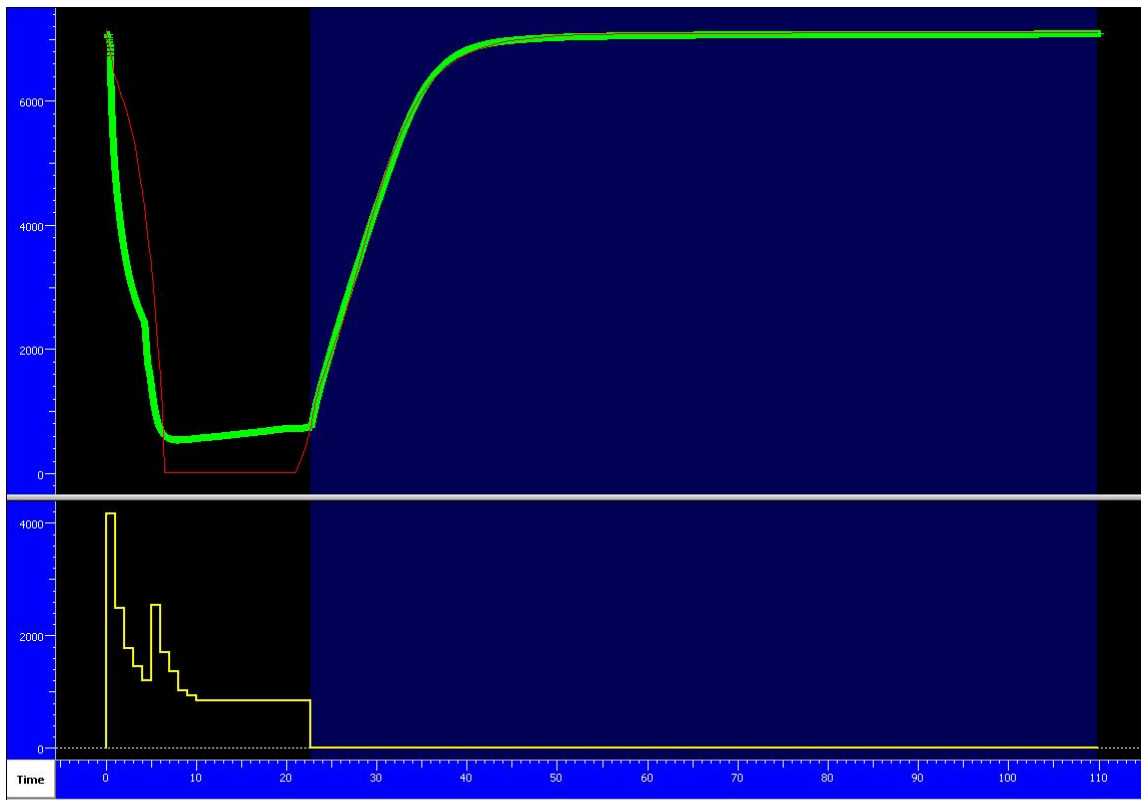


Fig. 5—History plot: (Pressure [psia], gas rate [Mscf/D] vs. Time [hr])

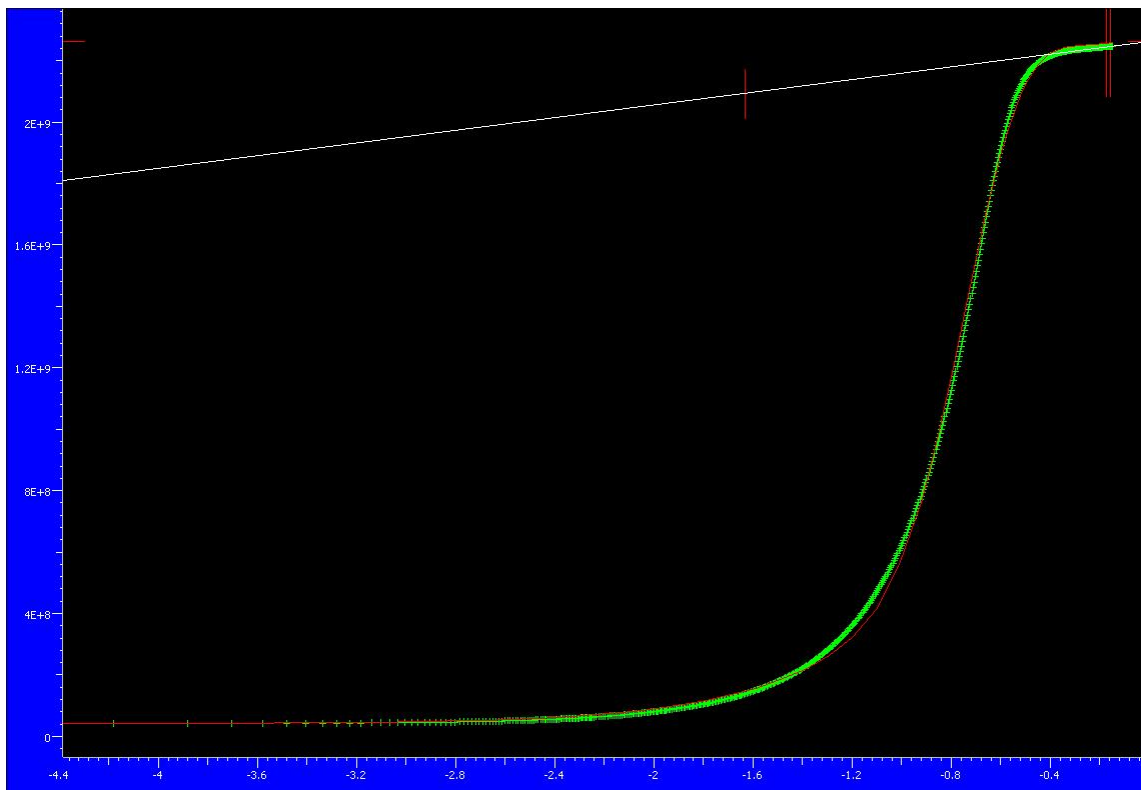


Fig. 6—Semilog plot: $m(p)$ [psi^2/cP] vs. superposition time.

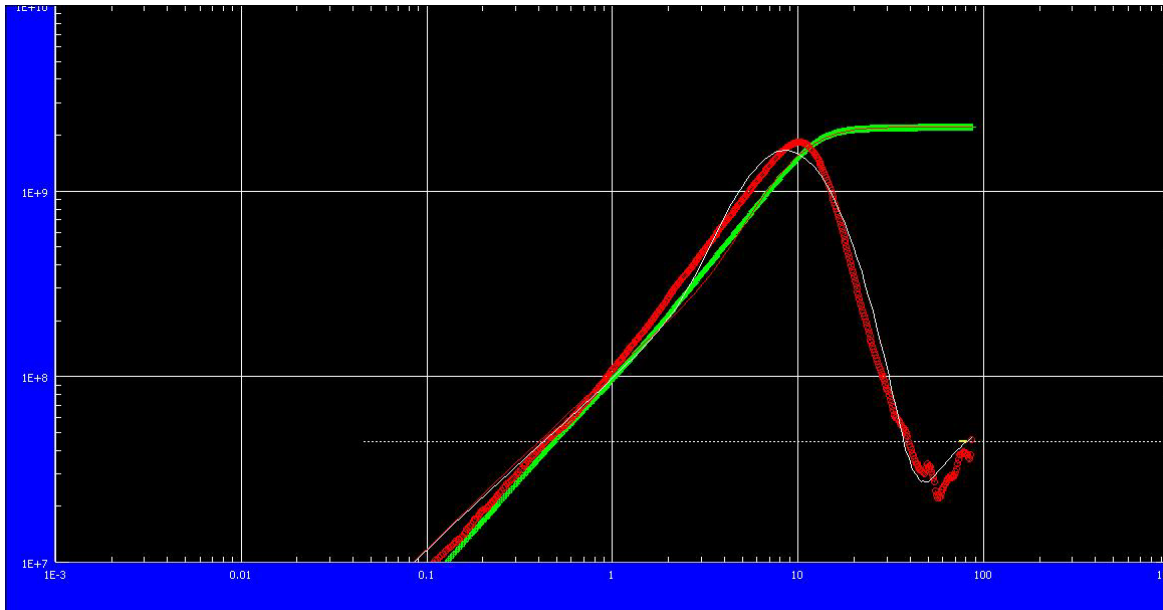


Fig. 7—Log-log plot: $dm(p)$ and $dm(p)'$ [psi^2/cP] vs. dt [hr].