REDUCING WATER PERMEABILITY THROUGH THE APPLICATION OF A NEW AND UNIQUE RELATIVE PERMEABILITY MODIFIER

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ABSTRACT

The need to effect water production through the use of relative permeability modifiers is becoming an everyday reality in the oil and gas industry today. Rising exploration and development costs, along with ever-increasing water management costs, require that cost-effective methods of reducing unwanted water production be developed and implemented. To address this issue, a new relative permeability modifier system has been developed. It is designed to be placed into the matrix of sandstone or carbonate formations. The relative permeability modifier selectively reduces the permeability to water, without detrimentally affecting oil or gas permeability.

This new water management treatment approach provides simplicity in job application, is viable over a wide range of reservoir types, lithologies, and permeabilities, and can be employed in a broad range of job types, including matrix injection and hydraulic fracturing treatments.

INTRODUCTION

The concept of water control through the use of relative permeability modifiers (RPMs) is receiving increased attention among oil and gas operators. Escalating costs associated with the disposal of produced water necessitate the need for a new approach to restrict water production. It is estimated that the industry spends over $40 billion annually to manage water, with over $10 billion in the United States alone. In response, a new and unique relative permeability modifier system has been developed for a broad range of applications. It is designed to be placed directly into sandstone or carbonate reservoirs that are identified as having the potential to produce unwanted amounts of water. The placement of the RPM into water-bearing formations selectively reduces the effective permeability to water, without a corresponding reduction in either oil or gas permeability.

Historically, the ability to control water production has been achieved through selective perforating, or mechanical isolation techniques requiring costly well intervention. With respect to wells selectively perforated, subsequent stimulation processes utilizing acid or hydraulic fracturing often employ modified pumping techniques intended to maintain isolation of the producing interval from nearby water producing zones. However, such methods are not reliable. In many instances, the target reservoir is under-stimulated for fear of a detrimental increase in water production.

In order to address water control in a low-risk, intervention-less manner, a new versatile RPM system has been developed for matrix and fracture treatment applications.

RPM PROPERTIES

The new RPM is a moderate molecular weight hydrophilic synthetic ter-polymer (STP) based on acrylamide chemistry. The performance properties engineered into the STP W M include a high tolerance to brine fluids, particularly those having high concentrations of divalent cations (e.g., Ca^{+2} and Mg^{+2}). This hydrophilic characteristic, coupled with a unique chemical structure that allows the polymer to attach itself to rock, provides the basis for the polymer's performance. Once placed, it is believed that the RPM expands or extends in the presence of water and deforms in the presence of oil or gas. Gas has the additional ability to pass easily through RPM-treated pore channels.

Structural changes to the W M, initiated by the flow of water, cause a selective restriction in water-saturated pore throats. If the flow of fluids through a treated interval were to change over a period of time from entirely water to a fluid containing significant oil or gas, the modified structure of the RPM inside the porosity matrix would allow for a return to uninhibited flow.

Another advantage of the new W M is the packaging of the product. Many RPMs are packaged as dry powders and require sophisticated blending equipment to mix the treating fluid. This equipment is necessary to assure that the treating fluid is homogeneous and void of “fisheyes” that could detrimentally reduce hydrocarbon production. Other RPMs are packaged as invert polymer emulsions. These products readily disperse in the treating fluid to provide homogeneous solutions, but the emulsions are stabilized with non-ionic surfactants. These surfactants, dispersed in water, are notorious for forming emulsions with oil and can significantly reduce oil permeability.

The new RPM is packaged as a concentrated polymer solution having viscosity less than 6,000 cP as measured on a Brookfield with a #4 spindle at 60 rpm and 25°C. At this viscosity, the concentrate is easily pourable into the mix water used to prepare the treating fluid. The RPM concentrate is also packaged without any surfactants to avoid potential emulsion problems, although non-emulsifiers are added to the treating fluid as additional insurance that emulsions do not form down-hole. Consequently, the RPM treating fluid is operationally simplistic to prepare at the well site.

STUDY AREA – GEOLOGICAL DESCRIPTION

One study area where the RPM was utilized evaluated its performance in the Brushy Canyon formation of the Delaware Basin in Eddy County, New Mexico. The Brushy Canyon formation consists primarily of deep-water, fine grained, sandstones and siltstones that were deposited in the Delaware Basin during the Permian Era.[1,2,4] The lower, middle, and upper Brushy Canyon intervals that were completed in the study ranged from approximately 7,000 feet to 8,000 feet in depth.

STIMULATION DESCRIPTION

Hydraulic fracture treatments of the Brushy Canyon formation in the study area were performed with water-based fluids consisting of a refined natural guar gelling agent. In all of the treatments, a 30 ppt high-pH borate cross-linked fluid was chosen based on its ability to maximize retained proppant pack conductivity following fracture cleanup. The borate fluid system was cross-linked with an organo-borate complexor. A typical pH range of between 10.0 to 10.2 allowed for sufficient fracture fluid viscosity development, as well as satisfactory proppant transport capabilities. The organoborate cross-linked guar fluid contained a patented polymer-specific enzyme breaker system in all of the treatments.[3]

A typical Brushy Canyon fracture treatment consisted of a 30 to 40 percent pad volume, which would vary based on the total job size being pumped. Larger pad sizes were utilized in the smaller fracture treatments in order to develop sufficient fracture widths prior to the beginning of the proppant stages. The maximum proppant concentration attained was 6 psa. The proppants pumped consisted of Ottawa sand with curable resin-coated sand tail-ins to prevent proppant flowback. Total proppant volumes placed ranged roughly from 150,000 lb to 250,000 lb per well. The wells were fracture stimulated in 2 to 4 stages based on net pay development, and the location of individual pay intervals in each wellbore. The RPM was added to the fracture fluid system at a loading of 10 gpt, or 1 percent by volume, in the pad portion of the treatments only.

HYDRAULIC FRACTURE STUDY RESULTS

A drilling program with a total of 6 wells was started in 2002 to test the Brushy Canyon formation in Eddy County, New Mexico. It was decided that a RPM would be added to the fracture stimulations of five of the six wells in an effort to evaluate and quantify its effectiveness. The study area contained numerous previous completions that would prove to be an effective database for comparing oil production and water-cuts in the fields.

The first study (Study 1) comparison was made between a new well and an offset well completed in the same section in 1993 (Fig. 1). Following the first 120 days of production from the new well an evaluation was made of both wells over the same time period. The new well treated with the RPM had produced 1,963 more barrels of oil, and 4,315 less barrels of water. The RPM-treated well had a water-cut 9 percent lower than the untreated offset (Fig. 2). On a volume basis the new well was making 2.24 barrels of water for each barrel of oil produced at 120 days. The offset well at the same time in its life had made 3.60 barrels of water for each barrel of oil it produced. Comparing both wells water-to-oil ratios showed the untreated offset well had produced 61 percent more water per barrel of oil than the RPM-treated well. A look at average daily oil production over the first four successive months shows the new well to be producing twice the amount of oil after 120 days (Fig. 3). It should be noted that this production has come after the offset well has produced nearby for a full nine years.

A second study (Study 2) was conducted with four RPM-treated wells that were in close proximity to one another (Fig. 4). Those four wells were also in the vicinity of eleven earlier offset completions, all of which were less than one-half mile from a RPM-treated study well. An evaluation of the new wells versus the existing wells was made after 90 days of production had been attained. The average 90-day RPM-treated well had produced 3,115 more barrels of oil, and 2,197 less barrels of water. The average water-cut of the study wells was over 12 percent less than the average of the untreated offsets (Fig. *5)*. The average study well water-to-oil ratio was 1.08 barrels of water for each barrel of oil produced at 90 days. The water-to-oil ratio average for the offsets was 1.81 barrels of water for each barrel of oil produced. A comparison of average water produced per barrel of oil indicated that the untreated offsets were making 68 percent more water than the average of the RPM-treated wells. Average daily oil production over the first 3 successive months shows the RPM-treated wells to be producing an additional 33 percent more oil after 90 days (Fig. 6).

The third study (Study 3) included two newly drilled wells in which one well was treated with the RPM while its offset was completed without it. The wells were drilled in the same section so that direct comparisons between the two could be drawn (Fig. 7). Following the first 120 days of production for both wells, an evaluation of the RPMs effectiveness was examined. At this point the well treated with the RPM had a cumulative oil production that was 719 barrels less than the well that had not been treated with the RPM. A closer look at the first four months of production shows that the well treated with the RPM is indeed closing the gap on total oil production, and is on pace to surpass the other well in the near future (Fig. 8). A study of the average daily oil production over each successive month period also supports this conclusion (Fig. 9). The well treated with the RPM was stabilizing at 71 barrels of oil per day after 120 days of production, while the untreated well was producing at 51 barrels of oil per day and trending lower. The water production of the two wells illustrates a very clear comparison. The 120-day production of water from the RPM-treated well is 9,762 barrels less than the offset well (Fig. 10). This difference in water production relates directly to the fact that the RPM well has a water-cut more than 12 percent less than the untreated well (Fig. 11). The RPM study well has a water-to-oil ratio of 1.39 barrels of water for every barrel of oil produced. The offset well's water-to-oil ratio is 2.41 barrels of water for each barrel of oil produced. Comparing both wells on a barrel of water per barrel of oil basis shows that the well completed without the use of the RPM produced 73 percent more water per barrel of oil than the RPM-treated well produced. A look at the average daily oil production over the first four successive months shows the RPM-treated well to be producing 40 percent more oil after 120 days than the newly drilled offset well that did not contain the RPM (Fig. 9).

CONCLUSIONS

- A new synthetic ter-polymer relative permeability modifier (RPM) that reduces water permeability disproportionately relative to hydrocarbon (oil or gas) permeability without adversely affecting the hydrocarbon permeability has been developed and successfully tested in the field.
- The low-viscosity RPM can be applied in operationally simple, virtually risk-free treatments, including as an additive to fracturing fluids.
- Initial fracturing treatment field trials, in a fie-grained sandstone formation, successfully utilized the RPM as an additive to organo-borate cross-linked pad stages.
- Use of the new RPM to fracturing pad stages reduced post-stimulation water production, and enhanced oil production, in treated wells relative to comparable offset wells also fracture stimulated, but without the use of a RPM.

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4. Montgomery, S., Worrall, J., Hamilton, D.: "Delaware Mountain Group, West Texas and Southeastern New Mexico, A Case of Refound Opportunity: Part 1 – Brushy Canyon," AAPG Bulletin, v. 83, no. 12, Dec. 1999, p. 1901-1926.

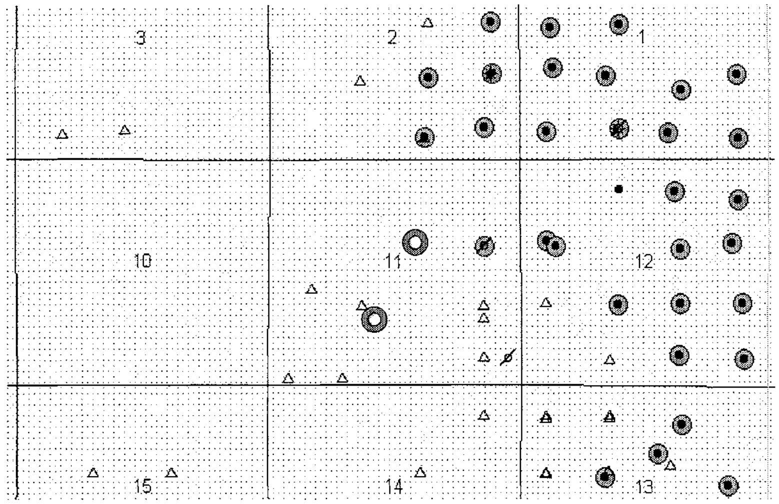

Figure 1 - Study 1 – Locations of RPM-treated Well and Untreated Offset

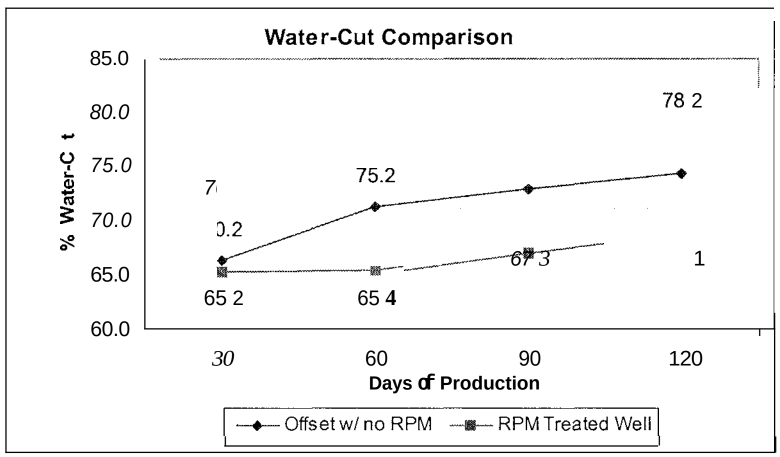

Figure 2 - Study 1 – Comparison of RPM-treated Well vs. Untreated Offset

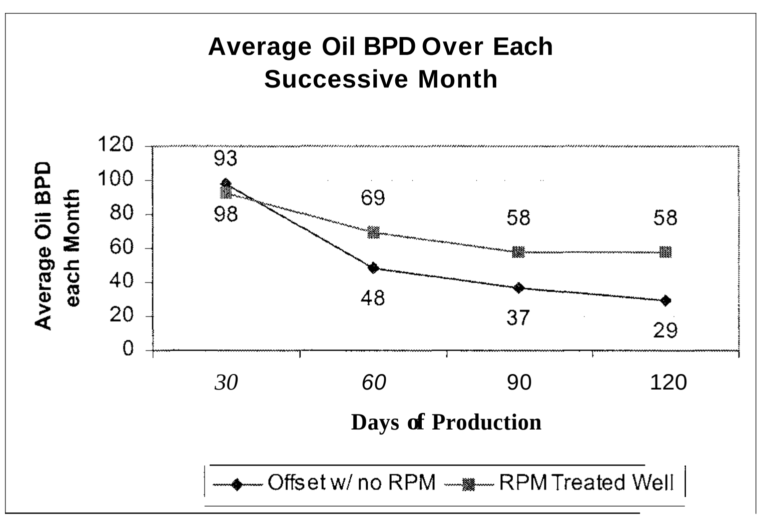

Figure 3 - Study 1 – Comparison of Oil Rates from RPM-treated Well vs. Offset

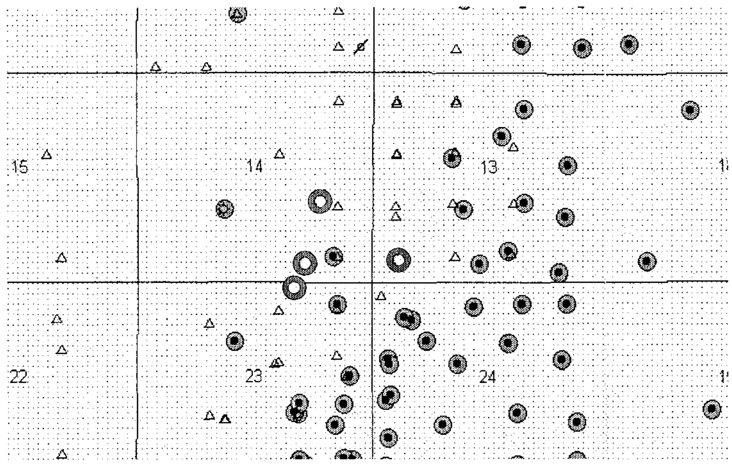

Figure 4 - Study 2 – Locations of 4 RPM-treated Wells Relative to Offsets

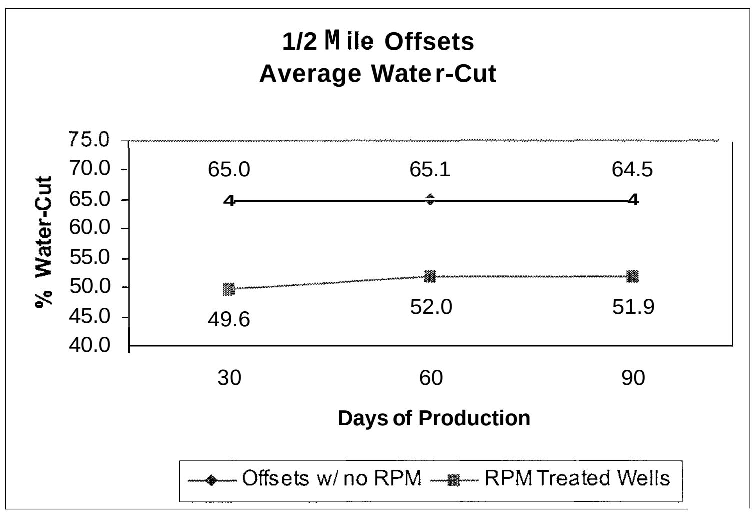

Figure 5 - Study 2 – Average Water-Cut – 4 RPM-treated vs. 11 Offset Wells

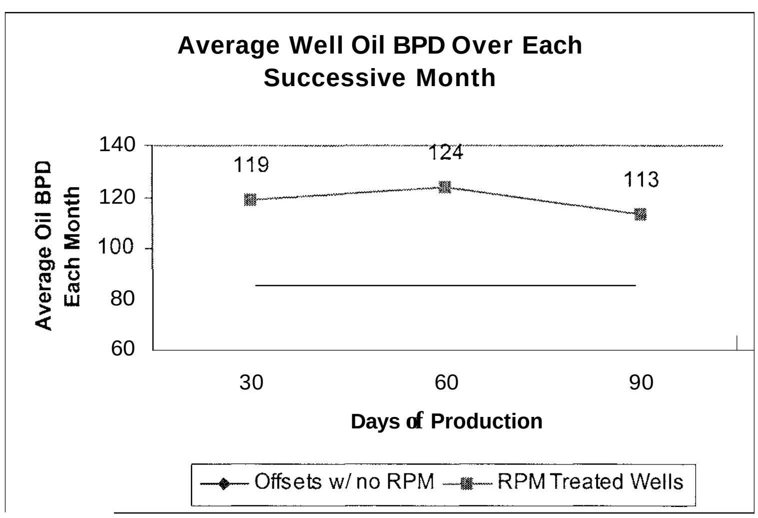

Figure 6 - Study 2 – Average Oil Rates – 4 RPM-treated vs. 11 Offset Wells

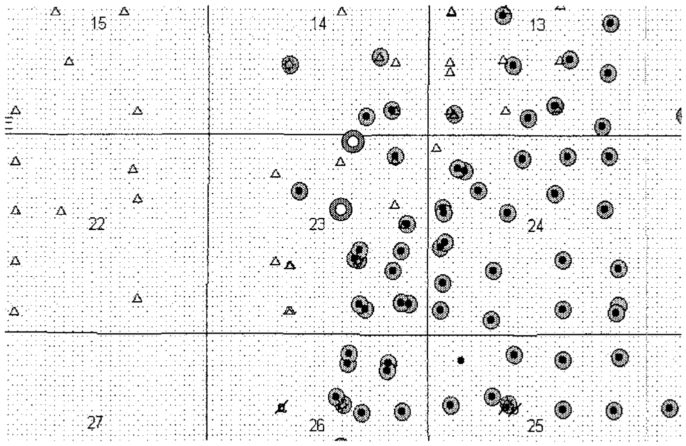

Figure 7 - Study 3 – Locations of RPM-treated Well and Untreated Offset

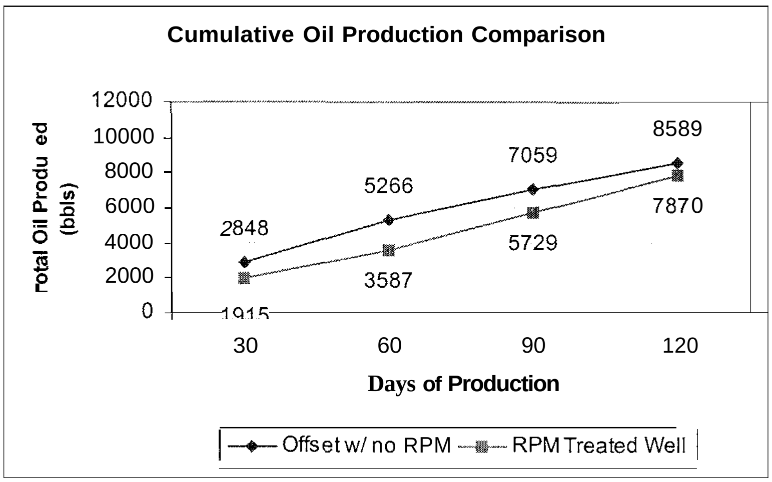

Figure 8 - Study 3 – Cumulative Oil Production – RPM-treated Well vs. Offset

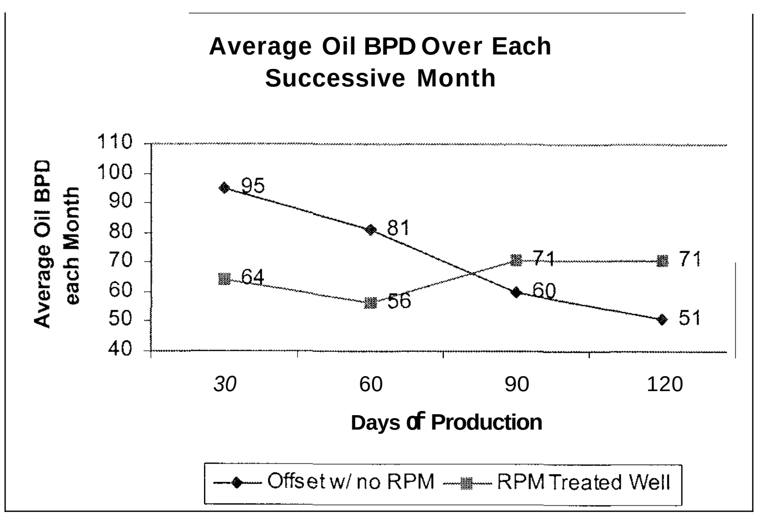

Figure 9 - Study 3 – Comparison of Oil Rates from RPM-treated Well vs. Offset

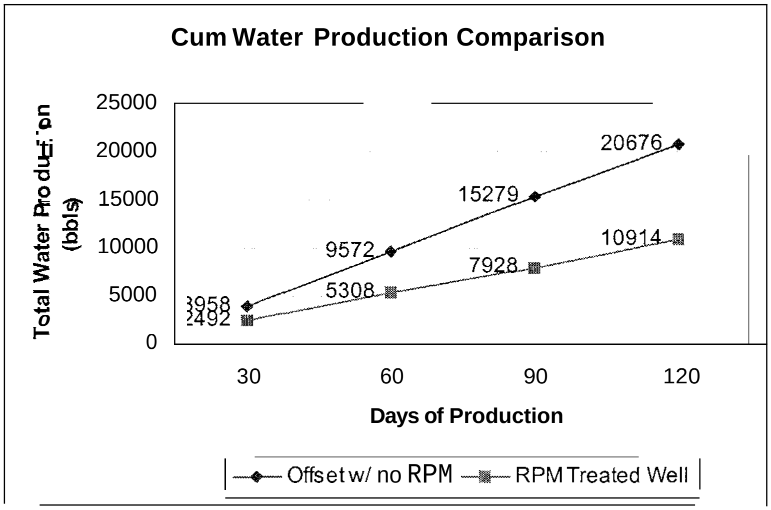

Figure 10 - Study 3 – Cumulative Water Production – RPM-treated Well vs. Offset

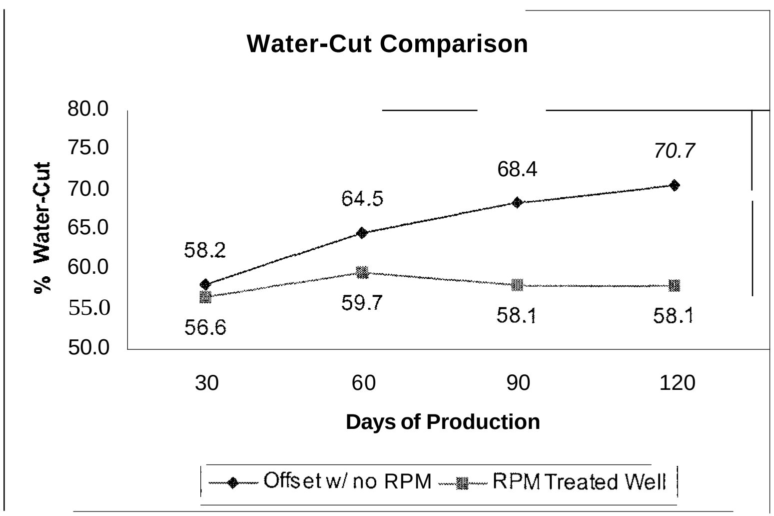

Figure 11 - Study 3 – Comparison of RPM-treated Well vs. Untreated Offset