

TITLE PAGE

**Modify & Extend Casing Plunger Technology to Tubing
Final Report**

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ABSTRACT

Gas wells drilled in formations that produce liquid in the form of oil, water, or condensate suffer a gradual decline in gas production as the liquid level increases and “chokes off” the gas inflow into the casing. The liquid shutting off the desired gas production must be removed from the well bore and surrounding areas to reduce the unwanted back pressure on the formation thus allowing an increase in gas production. There are many conventional artificial lift methods used to remove the restrictive liquid. Many producers use a tubing plunger to lift the column of fluid to the surface where it is expelled and placed in storage tanks for future disposal or sale. The current standard tubing plunger utilizes metal pads to contact the wall of the tubing to minimize the amount of gas leaking past the plunger as it is propelled up the tubing string at a high rate of speed lifting the liquid column above the plunger. The largest draw back to this mode of operation is the long shut-in-time necessary to allow the bottom hole pressure to build to a point where the plunger and liquid can be blasted to the surface when a surface valve is opened. This nonproductive shut-in time greatly reduces the overall gas production time and volume.

A tubing plunger designed using features found in casing plungers will replace the metal pads with rubber sealing elements or cups. When the plunger reaches the stop set at the bottom of the tubing the internal by-pass valve will be closed, the cups will be sealed, and the plunger will begin to rise in the tubing due to the inflow of gas thus lifting the column of liquid. No long shut-in-time will be required and the plunger will rise at a slower velocity than the conventional tubing plunger. Plunger velocity will be determined by gas inflow rate and the liquid load being raised. Because the casing style plunger makes more frequent trips it can carry a lower load and reduce formation back pressure which will allow more gas production.

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EXECUTIVE SUMMARY

Prior Reports

The PAL Tubing Plunger will use elastomeric sealing cups or elements rather than metal pads normally used by conventional tubing plungers. We have designed five styles of sealing cups for this plunger project. We have also designed molds to produce the two configurations which we judge to hold the most promise. The mold designs along with the designs for the metal plunger body components have been sent to a machine shop for cost estimates. The two cup configurations will be evaluated to determine minimum and maximum load carrying capabilities as well as their ability to resist abrasion under load conditions in various types of fluids. In addition multiple elastomer formulations will be evaluated to establish a cup-elastomer combination that will be satisfactory.

The first cup mold, valve seat mold, and plunger body were available for shop testing in late March. The initial cups and valve seat were molded using elastomers qualified by Pal during casing plunger cup evaluations. These elastomeric materials have proven to be serviceable in similar applications and environments. Materials necessary for the test set up were received in mid March, 2007. These materials include acrylic tubing allow viewing the actual operation of the plunger in our existing test tower. The first cup design to be evaluated is a conventional style cup with an open end on the lower side and having a flexible wall capable of deforming under a small load to create a seal with the tubing. The valve mechanism consists of a 440-C stainless steel ball and a metallic reinforced elastomeric seat. When the ball contacts the seat it is held tightly by an elastomeric skirt encircling the ball. This skirt and a small differential pressure will ensure that the valve will produce an effective seal and minimize the likelihood that gas will leak thru the valve mechanism.

In the initial tests performed in the acrylic tubing it was determined that the cup OD was too large to allow the plunger to consistently reach the lower stop and produce the desirable results. The cups were removed from the plunger body and the cup OD was reduced by sanding .030 inches from the diameter of the cup. This cup reduction produced more consistent ability to reach the lower stop; however, it produced a leakage around the cup. This leakage can partially be explained by the low load placed on the plunger by the small amount of fluid being lifted, heavier loads result in higher lifting pressures and subsequently higher sealing pressures. The valve mechanism performed as expected with no visible problems, and will require no modifications at this time. A second cup configuration using a modified expansion mechanism has been designed and a new mold will be produced to evaluate the concept.

Final Report

Lab testing of multiple cup designs in various materials with modified external and internal dimensions continued into the summer and fall of 2007. Major concerns surfaced between the lab results and the initial unsuccessful lab results using oil field tubing with scale

and rough surfaces. Cups that worked in smooth wall acrylic tubing used in the lab would not affect a consistently suitable seal in the 10 feet long section of used oil field tubing. This observations and results obtained indicated the need for a different approach to cup profile and sealing parameters. The weight of a tubing plunger slightly more than 5 pounds was insufficient to fall in tubing with normal surface conditions such as paraffin and scale and at the same time maintain a cup dimension that would fall through the tubing and seal at the tubing stop in the same manner as a fifty pound casing plunger. The initial cup configuration was determined to be inconsistent in the test lab and suggested modifications were in order.

The second cup design already mentioned with mold modifications was completed. In the process of design modifications, other viable designs were considered and appropriate molds were machined.

The second cup design was a short, disk style design with a thin contact edge and providing a convex/concave profile. The convex profile described the outer or top shape of the cup and the concave profile described the internal profile. This design profile would, hopefully, provide less contact with the rough tubing wall anticipated and then flex upward, increasing the outside diameter of the cup contact surface and thereby affect a seal under gas flow and liquid loading to rise to the surface with plunger and fluid during gas flow. The notable difference with this cup design from the casing plunger sealing cup is that with loss of gas flow, this second cup design would begin descent due to gravity. The initial cup design was intended to maintain a constant seal with the tubing wall. This deviation in the design of the second cup would provide the choice of either using an assembly of multiple cups as the sole sealing design or to be used in connection with an expandable sealing cup, much like on the casing plunger, adding a vertical force to assist in sealing the expandable cup.

The third, and subsequent, cup designs used various external profiles, with sealing capability to the plunger provided by mechanical sealing bands, and a transfer of internal well bore pressure through ports into the interior of the sealing cup, thereby expanding the outer diameter of the cup to affect a constant seal with the tubing wall, as in the casing plunger.

The third cup design employed an elliptical external profile, similar to the shape of a football. The internal profile produced a uniform wall thickness to the exterior profile which could, with minor mold modifications, be altered to provide more or less flexible expansion under pressure. This cup design would be inflated to seal with the tubing wall with internal well bore pressure and a suitable fluid load.

The fourth cup design employed a conical external profile with a short cylindrical section at the mid-point of the cup to provide a contact area, approximately 1/2 inch in length, with the tubing wall. The concave internal profile, tapered to the mid-point of the internal wall of the cup with a small radius at the point of intersection, was also designed to be inflated to seal with the tubing wall with internal well bore pressure and a suitable fluid load.

The fifth cup design employed a cylindrical profile to provide a contact area of 1 1/2 inch with the tubing wall. The internal profile, tapered to the mid-point of the internal wall of the cup

with a small radius at the point of intersection, was also designed to be inflated to seal with the tubing wall with internal well bore pressure and a suitable fluid load.

The required molds to accomplish these various features were machined and test cups were molded from two different compounds.

The first compound for testing was selected based on the results of field tests performed to determine the suitability of various compounds available to the stripper well industry successfully determined in the results of Sub-Award 2934-PAAL-DOE-2098.

The second compound was a typical compound frequently found in the oil and gas industry with decades of use in multiple applications. It was selected because it provided a lower durometer, compound which would produce a somewhat softer cup for testing and comparison.

Both compounds, nitrile based, met the parameters of this project and offered reasonable promise for success. It was expected that the final selection would lean more favorably to the compound proved successful in the prior investigation. These two compounds would allow the testing of harder and softer cups helpful in the determination of a suitable selection for further testing.

The progression of the design from a skirted cup to a concave wafer disc type cup to a cup with a tubular inflatable configuration enables the combination of one or more of these designs to work in conjunction with a higher probability of success. At each step, concerns with the potential difficulties with the various designs were carefully evaluated. After evaluation of the various cup designs, the necessary molds were drawn and machined. Subsequently, cup models were molded and tried on the mechanical portion of the tubing plunger. Throughout the lab testing, the mechanical plunger design continually performed satisfactorily. This indicates that a casing plunger style tubing plunger for 2 7/8 inch tubing should be relatively straightforward. Therefore, the major concern centered on the cup design that would fall in tubing with a five to ten pound plunger weight and seal at the tubing stop and carry fluid to the surface with gas flow.

Throughout the summer and fall of 2007, PAAL, LLC. was engaged in the successful expansion of PAL PLUNGERS into a marketing and manufacturing agreement to manufacture, sell, install and service casing plungers in western Canada.

Even though we were involved with expanding our market base, we continued to work on the tubing plunger application. Five different cup molds were machined covering three distinctively different cup concepts. Each mold was designed and machined to permit modifications to sealing surfaces to perform under field conditions encountered. It was determined that a 10 feet tall test tower was insufficient to properly test the fall capability using actual oil field tubing. A 25 feet tower was obtained to permit a 30 feet test stand to assist in the final design features suitable for normal field conditions.

We have determined that the three distinctly different cup designs may work independently or in various combinations with each other to provide the effective seal required.

To be determined in further testing in the lab and in the field are the final dimensions necessary for success. Always at our disposal is the option to manufacture sealing cups of various compounds offering multiple advantages.

Although the project time period has expired, it seems worthwhile and efficient to continue to evaluate the concept of a tubing plunger for 2 3/8 inch tubing that will offer the production advantages of a casing plunger. A project time extension was requested to utilize unexpended funding, however, the necessary paperwork was never completed. We still would like to obtain permission to use the remaining funds not yet expended for further lab and field testing on these concepts. Perhaps an approved time extension is justified. We continue to believe that success is near and would like to pursue this project further.

EXPERIMENTAL

Using the success of the PAAL casing plunger in various field applications and the results of determining more suitable elastomeric compounds in actual well bore parameters, the initial design of a tubing plunger utilizing those same concepts commenced. The API standard 5CT was used as a reference to gather information on specifications of various weights of tubing.

The initial mechanical design concern was the much lower weight of a tubing plunger compared to a typical casing plunger weighing 35 to 65 pounds. Further concerns in tubing consist of many known and unknown parameters. Among the known concerns are scale and paraffin. Additionally, rod wear in tubing can be expected in many applications. The presence of unknown corrosion and surface roughness can equally affect the sealing capabilities of light weight tools in contact with the tubing walls. The essential requirement of a by-pass valve in a tubing plunger with sealing cups in contact with the tubing wall was easily accomplished using experience and skills developed over decades. Further lab tests have verified both the function and suitability of such a design in tubing plungers. This same design was incorporated into the PAAL casing plunger and has continually performed successfully.

The initial skirted cup design was selected in an attempt to insure that a five pound tubing plunger would fall in tubing of unknown surface roughness. The heavier casing plunger would gain the benefit of a higher pressure acting upon the cross-sectional diameter providing a more efficient sealing mechanism. In the much lighter weight of the tubing plunger, less force would be exerted on the sealing mechanism. This suggests that wall clearance on descent and wall contact on ascent will be critical.

The initial skirted cups provided 0.010 inch diametrical clearance for descent and relied on gas flow to expand the lower skirt of the cup to affect a seal with the tubing wall during ascent. Lab tests indicated the diametrical clearance was insufficient and the plunger would not consistently fall. The presence of fluid did not improve the reliability for falling and sealing. The clearance was enlarged to 0.030 inch which permitted descent, but would not seal under low pressure and light fluid loads of 4 feet in the lab test stand.

The normal procedure in molding elastomeric compounds to precise dimensions is to start with a cavity that is undersized. After molding several parts and evaluating their performance, final adjustments can be more precisely made to the molds. The mold cavity can be more easily enlarged than reduced. Further, the molding of elastomeric compounds is typically a series of mold dimensions compared to molded parts with adjustments made to the mold to modify the desired dimensions of the finished parts. Molding elastomeric compounds are subject to a broader range of tolerances for the finished parts.

In this regard, the initial mold designs available for testing have only gone through the first step of design and comparison to molded parts. Even though, the initial design was

perceived to be correct for all considerations, one or more cycles of mold modification and molded dimensions of finished parts are warranted before an actual field test in well bore conditions is appropriate.

Using different elastomeric compounds in the same mold does not always produce the same dimensional finished part. Consequently, extreme caution and experienced judgment is required to select an initial mold cavity that will likely produce similarly dimensional parts from different elastomeric compounds. Even though the dimensional difference might be rather small, such differences can have a profound effect on the suitability of a specific part molded from one compound compared to another compound.

From our experience in PAAL casing plunger cup wear and performance, cup wear with tubing plungers may be even more critical.

The various cup designs considered, molded and described herein, are shown in an attachment at the end of this report.

RESULTS and DISCUSSION

The initial concept of this project was to apply the technological advances that had been accomplished in using a PAAL casing plunger in varied well bore conditions to extend to tubing conditions in which a typical tubing plunger failed to perform satisfactorily. Even though many improvements and greater efficiency were found in the PAAL casing plunger, reducing the size of the plunger to a weight of 5 to 10 pounds was recognized to be, and still is, a formidable task. The many applications which exist in 2-3/8 inch and 2-7/8 inch tubing in which a constant sealing plunger lifted more by pressure than gas velocity holds great excitement in so called "tubingless" well bores and wells with casing leaks isolated with packers which must produce without the benefit of an annulus to accumulate gas under pressure necessary for most tubing plunger applications. The technology, though similar between casing plungers and tubing plungers, is substantially more complicated due to weight and dimensional constraints.

This project envisioned the extension of casing plunger technology to tubing plunger applications, but it must be remembered that the current state of the successful PAAL casing plunger has occurred over the past 9 years. Utilizing our experience, much less time will be required to apply the technology to tubing plunger applications and determine potential marketability.

The success of the PAAL casing plunger in determining more suitable elastomeric compounds for anticipated well bore parameters narrowed the initial selection for elastomeric compounds suitable in the design of a tubing plunger utilizing those same concepts. The advantages of a much heavier casing plunger are not available in a tubing plunger. The wall clearance to the sealing cups would also be greatly reduced. The lighter tubing plunger weight would not be sufficient to mechanically expand the lower sealing cup employed in the casing plunger. A by-pass valve in any tubing plunger design was absolutely essential. The design chosen has been tested in various oil and gas field applications over many years and was incorporated into the PAAL casing plunger and has worked very successfully for 9 years.

The initial skirted cup design was selected in an attempt to insure that a five pound tubing plunger would fall in tubing of unknown surface roughness. The heavier casing plunger would gain the benefit of a higher actuating force due to pressure acting upon the cross-sectional diameter providing a more efficient sealing mechanism. In the much lighter weight of the tubing plunger compounded by a much smaller cross-sectional area, less force would be exerted on the sealing mechanism. This suggests that wall clearance on descent and wall contact on ascent will be critical.

The first test was performed in two inch ID acrylic tubing to evaluate the operation of PAAL's first generation tubing plunger. This plunger was designed with a body length that would accept varying cup configurations and combinations, allowing evaluation of many designs. The first cup was designed to be approximately .010" under tubing ID. Set up with five

cups on the plunger body there was too much friction (plunger weight 5.1#) to allow the tool to drop in the dry tubing. Wetting the tubing with clear water helped the plunger to fall: however, the operation was erratic and unpredictable. To help make the operation more predictable the cups were removed from the plunger and approximately .030" was sanded from the cup OD. This allowed the plunger to operate in a more predictable manner but air was observed escaping around the cup OD. The combined weight of the plunger and the fluid being lifted is not enough to resist plunger movement and allow pressure to build under the tool and increase the cups ability to effectively seal to the tubing. The test equipment is being modified to allow additional fluid to be placed on top of the plunger producing a more realistic test condition

The initial skirted cups provided 0.010 inch diametrical clearance for descent and relied on gas flow to expand the lower skirt of the cup to affect a seal with the tubing wall during ascent. The mold was machined and the first cups molded were tested in the 2 inch acrylic lab test stand. Erratic performance indicated the diametrical clearance was insufficient. The plunger would not consistently fall to the bottom and close the by-pass valve. Adding water and water with soap as a well bore fluid did not improve the reliability for the plunger falling and sealing. The diametrical cup clearance was enlarged to 0.030 inch which permitted descent and closed the by-pass valve. However under pressure and low flow rate, the plunger cups would not seal with the acrylic wall dry or with light fluid loads of 4 feet in the lab test stand.

The results of the initial lab tests indicated other cup designs of differing concepts should be evaluated. Two different concepts were considered: disk style and inflatable sleeve type.

The second cup design was a short, disk style design with a thin contact edge and providing a convex/concave profile. The convex profile described the outer or top shape of the cup and the concave profile described the internal profile. This design profile would, hopefully, provide less contact with the rough tubing wall anticipated and then flex upward, increasing the outside diameter of the cup contact surface and thereby affect a seal under gas flow and liquid loading to rise to the surface with plunger and fluid during gas flow. The notable difference with this cup design from the casing plunger sealing cup is that with loss of gas flow, this second cup design would begin descent due to gravity. The initial cup design was intended to maintain a constant seal with the tubing wall. This deviation in the design of the second cup would provide the choice of either using an assembly of multiple cups as the sole sealing design or to be used in connection with an expandable sealing cup, much like on the casing plunger, adding a vertical force to assist in sealing the expandable cup.

The third, and subsequent, cup designs were of the inflatable sleeve type. Various external and internal profiles with sealing capability to the plunger provided by mechanical sealing bands define the basic style considered. The transfer of internal well bore pressure through ports into the interior of the sealing cup expanded the outer diameter of the cup to affect a constant seal with the tubing wall. This concept is basic in the PAAL casing plunger. The following discussion will outline the various combinations of external to internal profiles and wall thickness in contact with the surface of the tubing wall. Consideration was given to contact area and inflation response in maintaining a consistent seal with the tubing.

The third cup design employed an elliptical external profile, similar to the shape of a football. The internal profile produced a uniform wall thickness to the exterior profile which could, with minor mold modifications, be altered to provide more or less flexible expansion under pressure. This cup design would be inflated to seal with the tubing wall with internal well bore pressure and a suitable fluid load.

The fourth cup design employed a conical external profile with a short cylindrical section at the mid-point of the cup to provide a contact area, approximately 1/2 inch in length, with the tubing wall. The concave internal profile, tapered to the mid-point of the internal wall of the cup with a small radius at the point of intersection, was also designed to be inflated to seal with the tubing wall with internal well bore pressure and a suitable fluid load.

The fifth cup design employed a cylindrical profile to provide a contact area of 1 1/2 inch with the tubing wall. The internal profile, tapered to the mid-point of the internal wall of the cup with a small radius at the point of intersection, was also designed to be inflated to seal with the tubing wall with internal well bore pressure and a suitable fluid load.

The required molds to accomplish these various features were machined and test cups were molded from two different compounds.

The first compound for testing was selected based on the results of field tests performed to determine the suitability of various compounds available to the stripper well industry successfully determined in the results of Sub-Award 2934-PAAL-DOE-2098.

The second compound was a typical compound frequently found in the oil and gas industry with decades of use in multiple applications. It was selected because it cured with a lower durometer reading indicating a compound which would produce a somewhat softer cup for testing and comparison.

Both compounds, nitrile based, met the parameters of this project and offered reasonable promise for success. It was expected that the final selection would lean more favorably to the compound proved successful in the prior investigation. These two compounds would allow the testing of harder and softer cups helpful in the determination of a suitable selection for further testing.

The progression of the design from a skirted cup to a concave wafer disc type cup to a cup with a tubular inflatable sleeve configuration enables the combination of one or more of these designs to work in conjunction with a higher probability of success. At each step, concerns with the potential difficulties with the various designs were carefully evaluated. After evaluation of the various cup designs, the necessary molds were drawn and machined. Subsequently, cup models were molded and tried on the mechanical portion of the tubing plunger. Throughout the lab testing, the mechanical plunger design continually performed satisfactorily. This indicates that a casing plunger style tubing plunger for 2 7/8 inch tubing should be relatively straightforward. Therefore, the major concern centered on the cup design that would fall in tubing with a five to ten pound plunger weight and seal at the tubing stop and carry fluid to the surface with gas flow.

The initial mold designs available for testing have only gone through the first step of design and comparison to molded parts. Even though, the initial design was perceived to be correct for all considerations, one or more cycles of mold modification and molded dimensions of finished parts are warranted before an actual field test in well bore conditions is appropriate.

Using the two different elastomeric compounds in the same mold did not always result in the same dimensional finished parts. Consequently, extreme caution and experienced judgment is required to modify the designs of the mold cavities that will likely produce similarly dimensional parts from different elastomeric compounds. Even though the dimensional differences were rather small, those differences have not been fully evaluated to determine the effect, if any, on the suitability of a specific part molded from one compound compared to another compound.

From our experience in PAAL casing plunger cup wear and performance, cup wear with tubing plungers may be even more critical.

The various cup designs considered, molded and described herein, are shown in an attachment at the end of this report.

The mechanical design offers the benefits that were deemed to be desirable for this application. Three distinctively different cup profiles have been designed, molded and tested. Further testing and modifications of dimensions and compound materials are necessary to make the final determinations of the most suitable design and compound for field use. The mechanical design and various cup configurations have worked in the lab. These parameters need additional testing in the lab and subsequently need actual field testing for final assessment.

CONCLUSIONS

As expected, the extension of PAAL casing plunger technology to tubing plungers for 2-3/8 inch and 2-7/8 inch tubing has been challenging. The most difficulty encountered is activating the cup sealing process with the tubing wall. This difficulty centers primarily on the very light weight of a tubing plunger compared to the much heavier weight of a casing plunger. In many cases, the inside surface of the tubing may present irregular surfaces as the result of scale, paraffin, or rod wear. Any one or a combination of these conditions will make the efficient sealing of the cup and wall surface more difficult and unpredictable. Very few reasonable options exist to determine the surface roughness of the tubing. Essential to any plunger design for this application is a reliable by-pass valve to allow the plunger to fall through a flowing gas column and close and seal upon landing on the tubing stop. While the mechanical design for this feature has been somewhat simple and found in similar applications in the industry and in PAAL casing plungers, the cup design has been significantly more challenging.

The initial skirted cup design was selected in an attempt to insure that a five pound tubing plunger would fall in tubing of unknown surface roughness. The heavier casing plunger would gain the benefit of a higher actuating force due to pressure acting upon the cross-sectional diameter providing a more efficient sealing mechanism. In the much lighter weight of the tubing plunger compounded by a much smaller cross-sectional area, less force would be exerted on the sealing mechanism. This suggests that wall clearance on descent and wall contact on ascent will be critical. The first tests performed on this new style tubing plunger confirmed the by-pass valve was, as expected, functional and reliable. The cup design, as expected, confirmed that wall clearance was indeed a critical factor. The cups had more wall contact friction than the plunger had weight to consistently fall to the bottom of the test stand and close the valve. Adding fluid to the test stand did not materially change the results. The outside diameter of the cups was reduced which allowed the plunger to fall consistently and close the valve. However, pressure and low flow rate were insufficient to lift the plunger. The clearance that allowed the plunger to fall without restriction was too great to provide a cup to tubing wall seal and lift the plunger and fluid. The lab test stand is too short to experiment with fluid head greater than 6 feet. A taller test stand of 25 feet was obtained, but time expired on this project prior to evaluating it for testing.

The internal by-pass valve consisted of a 440-c stainless steel ball and a metallic reinforced elastomeric seat along with an elastomeric skirt encircling the ball. When the plunger lands on the plunger stop, the weight of the plunger positions the ball in contact with the skirt and causes the ball to circumferentially stretch the skirt until a seal is formed and the ball is mechanically held in place by the increasing pressure differential. The seal formed will hold pressure from a fraction of a pound per square inch upward. In all of the testing performed thus far the valve mechanism has performed satisfactorily.

The initial skirted cups provided 0.010 inch diametrical clearance for descent and relied on gas flow to expand the lower skirt of the cup to affect a seal with the tubing wall during ascent. The mold was machined and the first cups molded were tested in the 2 inch acrylic lab test stand. Erratic performance indicated the diametrical clearance was insufficient. The plunger would not consistently fall to the bottom and close the by-pass valve. Adding water and water with soap as a well bore fluid did not improve the reliability for the plunger falling and sealing. The diametrical cup clearance was enlarged to 0.030 inch which permitted descent and closed the by-pass valve. However under pressure and low flow rate, the plunger cups would not seal with the acrylic wall dry or with light fluid loads of 4 feet in the lab test stand.

The results of the initial lab tests indicated other cup designs of differing concepts should be evaluated. Two different concepts were considered: disk style and inflatable sleeve type.

The second cup design was a short, disk style design with a thin contact edge and providing a convex/concave profile. The convex profile described the outer or top shape of the cup and the concave profile described the internal profile. This design profile would, hopefully, provide less contact with the rough tubing wall anticipated and then flex upward, increasing the outside diameter of the cup contact surface and thereby affect a seal under gas flow and liquid loading to rise to the surface with plunger and fluid during gas flow. The notable difference with this cup design from the casing plunger sealing cup is that with loss of gas flow, this second cup design would begin descent due to gravity. The initial cup design was intended to maintain a constant seal with the tubing wall. This deviation in the design of the second cup would provide the choice of either using an assembly of multiple cups as the sole sealing design or to be used in connection with an expandable sealing cup, much like on the casing plunger, adding a vertical force to assist in sealing the expandable cup.

The third, and subsequent, cup designs were of the inflatable sleeve type. Various external and internal profiles with sealing capability to the plunger provided by mechanical sealing bands define the basic style considered. The transfer of internal well bore pressure through ports into the interior of the sealing cup expanded the outer diameter of the cup to affect a constant seal with the tubing wall. This concept is basic in the PAAL casing plunger. The following discussion will outline the various combinations of external to internal profiles and wall thickness in contact with the surface of the tubing wall. Consideration was given to contact area and inflation response in maintaining a consistent seal with the tubing.

The third cup design employed an elliptical external profile, similar to the shape of a football. The internal profile produced a uniform wall thickness to the exterior profile which could, with minor mold modifications, be altered to provide more or less flexible expansion under pressure. This cup design would be inflated to seal with the tubing wall with internal well bore pressure and a suitable fluid load.

The fourth cup design employed a conical external profile with a short cylindrical section at the mid-point of the cup to provide a contact area, approximately 1/2 inch in length, with the tubing wall. The concave internal profile, tapered to the mid-point of the internal wall of the cup with a small radius at the point of intersection, was also designed to be inflated to seal with the tubing wall with internal well bore pressure and a suitable fluid load.

The fifth cup design employed a cylindrical profile to provide a contact area of 1 ½ inch with the tubing wall. The internal profile, tapered to the mid-point of the internal wall of the cup with a small radius at the point of intersection, was also designed to be inflated to seal with the tubing wall with internal well bore pressure and a suitable fluid load.

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Both compounds, nitrile based, met the parameters of this project and offered reasonable promise for success. It was expected that the final selection would lean more favorably to the compound proved successful in the prior investigation. These two compounds would allow the testing of harder and softer cups helpful in the determination of a suitable selection for further testing.

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Our mechanical design has proven to be satisfactory to meet the requirements of this application. Continued lab and field tests need to be conducted to determine the final configuration and dimensions of suitable sealing cups.

Although the project time period has expired, it seems worthwhile and efficient to continue to evaluate the concept of a tubing plunger for 2 3/8 inch tubing that will offer the production advantages of a casing plunger. A project time extension was requested to utilize unexpended funding, however, the necessary paperwork was never completed. We still would like to obtain permission to use the remaining funds not yet expended for further lab and field

testing on these concepts. Perhaps an approved time extension is justified. We continue to believe that success is near and would like to pursue this project to completion.

REFERENCES

None cited.

ATTACHMENT

