ELASTOMERIC COMPOUND SELECTION CRITICAL TO IMPROVED CASING PLUNGER SUCCESS

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ABSTRACT
The first ever actual field tests to evaluate well bore fluid's real time impact on elastomeric compounds used for casing plunger sealing cups led to major breakthroughs in the discovery of better sealing cup compounds, previously unavailable to the industry. The drastically improved performance of carefully formulated compounds, coupled with radical innovations in over-all casing plunger design, were major factors in the development of the first truly successful casing plunger, following decades of disappointment experienced with previous casing plungers on the market. Field data, photos, and procedures will be discussed and state of the art products presented.

HISTORY

Recent innovations and new patents available to the industry have successfully broadened the range of applications in which casing plungers can be used to remove well bore fluids from low volume gas wells unable to sustain the critical (entrainment) velocity necessary to remove fluids from deeper wells common in the industry. Patented improvements in the mechanical actuation, coupled with pneumatic expansion of sealing cups, are critical to the proper functioning of casing plungers, and have dramatically increased the reliability and opportunities for successful installations. These developments have been presented in this forum over the past several years. Additionally, advances in the formulations of compounds selected have produced elastomeric cups that react with more stability and longer wear in many applications. Field engineering procedures have obtained specific well bore data that have led directly to improvements in the engineering design of sealing cups with improved performance characteristics. The scope of this paper will provide a summary of the field testing procedures that evaluated the critical behavior of elastomers under actual field conditions that led to the selection of improved compounds and contributed to the successes experienced to date.

PROPERTIES OF ELASTOMERS, (RUBBER)

For the purposes of this paper, only those properties most critical to the successful performance of a casing plunger sealing cup in removing fluids from the well bore of producing gas wells will be discussed.

Over the past decades, various elastomeric compounds have been developed, primarily for packer sealing elements, swabbing cups, oil-saver packing, and similar applications. It is normal to expect that the early developments in casing plungers began using the compounds already in use in some of those applications. However, there was a vast difference in the requirements for good packer sealing elements and the requirements of fixed diameter sealing cups for the older style casing plungers. The current innovations in new casing plunger design required even more sophisticated elastormeric compounds. They have now been developed, tested, and have performed spectacularly in a broad range of applications. The critical properties of the elastomeric compounds in use were re-evaluated for tensile strength (measured in psi), elongation (measured in per cent), modulus (measured in psi), and durometer (measured by the Shore A scale (30-100) number). These critical properties are measured on carefully prepared dumbbell test specimens to ASTM specifications. A careful comparison of dumbbell test specimens of elastomers in common use were compared to proprietary compounds designed to address the evidence of sealing cup failures and frequently observed limitations. From that comparison came several new compounds for sealing cups now in successful use on the innovative new casing plunger.

TENSILE STRENGTH: Tensile strength is a term more often associated with metal objects, but is just as critical in the selection of a suitable elastomeric compound for a casing plungers sealing cup. Tensile strength is defined as the force per unit of original cross-sectional area which is applied at the time of rupture of the dumb bell specimen. It is calculated by dividing the breaking force, in pounds, by the cross-section of the unstressed specimen in square inches. In the new and radical design of casing plungers now proving to be successful in many varied field applications, the sealing cups must perform under forces of both compression and expansion. These forces occur over extended time periods and cycle back and forth from well conditions at reservoir pressure and temperature to surface pressure and temperature, where surface temperatures range from summer heat to bitter winter cold. Further, the proper selection of a successfully performing compound in one field, or even one well in the field, might not perform as well in another well or field. Consequently, a method for comparative evaluation of a selection of possible compounds would prove valuable in extending the range of successful casing plunger applications. Tensile strength is closely connected to elongation, another critical property of elastomers.

ELONGATION: Elongation in elastomers is used to describe the ability of rubber to stretch without breaking. To describe this property as measured, it is more accurate to refer to it as “ultimate elongation,” since its value, expressed as per cent of the original length, is taken at the moment of rupture. Typically, a sample of a known compound is molded into a sheet of pre-determined thickness. A standard ASTM dumbbell die is used to cut several precisely measured samples of fixed dimensions from the sheet. These uniform samples can then be tested for tensile strength and elongation in their cured state and used as a benchmark for later comparisons to the effects of various well bore fluids and conditions. Additional samples can then be subjected to any number of other environments, fluids, solvents, temperatures, etc, and tested to determine any detrimental effects compared to the benchmark samples.. The elongation is measured by inserting the dumbbell into a tensometer, a lab instrument that stretches the dumbbell to rupture and records tensile forces at the moment of rupture. If the stretch goes from the “at rest” length of 1 inch to 2 inches, the elongation is measured as 100%. If the “at rest” length of 1 inch goes to 3 inches, the elongation is measured as 200%. And so on. At some point of stretch, the dumbbell sample will snap in failure. The tensile force point at which failure occurs is recorded as the “tensile strength” of that particular elastomeric compound and the elongation at rupture is recorded as the per cent increase over the 1 inch “at rest” starting point. Packer elements will typically have an elongation in the range of 100% to 300%. An elastomeric compound for, say an old fashioned slingshot, would have an elongation of 800% to 1000%. A rubber band in your desk might have an elongation of 600%. The elongation is a critical property of elastomers, somewhat inversely related to the modulus, another critical property of elastomers.

MODULUS: Modulus, or stress, is a term used to express the amount of pull in pounds per square inch required to stretch the test specimen to a given elongation. It expresses resistance to extension, or stiffness in the elastomer. The higher the modulus, the more resistance to stretch and greater resistance to deformation under loading. The modulus is measured at 100%, 200%, 300%, or until rupture. The modulus is critical to insure a specific desired performance under a given set of conditions. An application might require some elongation, but satisfactory performance would demand that the part would not extrude under pressure, such as an O-ring, a packer cup, or inflatable packer. Modulus is closely related to the durometer, or hardness, another critical property of elastomers.

DUROMETER: Durometer as applied to elastomeric (rubber) materials, implies resistance to indentation, or hardness. Hardness is expressed as a number referring to the scale of the instrument by which it is measured. The Durometer hardness scale runs from zero for full extension to 100 for zero extension. Shore Durometers are frequently used for routine measurements of hardness. The Shore A Durometer is used for soft rubber testing, and the Shore D Durometer is used for harder products. One of the essential properties of a sealing cup is the cup life wear rate. The wear rate of sealing cups is highly influenced by the frictional contact with the casing wall and the presence of abrasive elements and/or lubricants within the fluid medium. Consequently, the abrasion resistance of the sealing cup compounds is carefully controlled for the overall satisfactory performance of casing plungers.
All of these critical properties of elastomers must be carefully evaluated and combined in exacting proportions for each well application in order to optimize performance of casing plunger sealing cups under the well conditions they encounter.

The “art” of custom elastomer molding of compounds for casing plunger sealing cups can only be obtained through years of experience. The basic compounds, coupled with the various fillers in precise proportions, result in a sealing cup that provides the tensile strength, elongation, modulus, and durometer for superlative performance. Once a suitable compound has been developed, the critical properties of tensile strength, elongation, modulus, and durometer must be closely monitored and maintained over time to insure repeatable and reliable performance of sealing cups in well bore applications. Furthermore, the suitability of these properties must be evaluated over the production life of the well.

THE IMPORTANCE OF FIELD TESTING CRITICAL PROPERTIES:

Historically, compatibility of elastomeric compounds to oil field conditions has been determined by obtaining well head fluids for transport to a lab for testing. The compounds under consideration would then be exposed to the well head fluids under roughly simulated well conditions. While this method certainly eliminated many compounds, it did not provide the benefits of testing the compounds under actual well conditions. Consequently, many of the lighter hydrocarbons in the well head fluids would flash off, either in the capture of the sample, or in the simulation in the lab. These lighter hydrocarbons were likely the more critical factors controlling the suitability of the elastomer under evaluation for the specific application. Furthermore, some of the detrimental effects of the well head fluids on the elastomers under evaluation became less obvious during the transport time and delays in lab evaluations.

During the process of evaluating the compounds being used for casing plunger sealing cup applications, the authors observed the differences in the appearance of sealing cups at the well head and the appearance of the same sealing cups days later. The authors' experience with sealing cups under actual field conditions clearly revealed the differences in cup performance from one well to the next well due to different well bore fluids and well conditions. These variations in cup performance led to the conclusion that standard lab test procedures were insufficient to fully evaluate the suitability of particular compounds to actual well conditions.
The need for more reliable test data for sealing cup compounds was presented to the Stripper Well Consortium for a cost-share funded project and approved for funding.

Thanks to the ongoing development of computers, the formerly large and immobile laboratory, tensometers became available in sizes small enough to be transported to the field and still provide reliable data. With the reduction in size, a corresponding reduction in price made the use of a portable tensometer a viable consideration. With the aid of laptop computers, the tensometer data could be obtained at the well head. The time-lag between the old method of catching well head samples, transporting them back to a lab, then testing various specimens, provided insufficient and/or inaccurate data for analysis of suitability of compounds for sealing cups. A field test procedure was developed that would allow compounds to be tested simultaneously within the same set of well conditions and to be exposed to the same environment experienced by the sealing cups. These specimens could then be removed from the well environment and tested within minutes of removal from the well. Specimen appearance could be documented and tested for comparison from formulated compound to formulated compound.

FIELD TEST PROCEDURE

Standard lab models of tensometers were roughly the size of a large single door refrigerator and cost up to $200,000. The development of a portable tensometer about the size of a 4 drawer file cabinet and costing less than $15,000 was evaluated for data accuracy and chosen for use in field testing. Further, it could be powered by converting 12VDC auto power. It also provided a laptop interface that would enable immediate data transfer in the field.

Five wells, equipped with successfully running new casing plungers, were chosen to represent different types of well conditions with various flow rates, well bore fluids, depths, and gas compositions. The casing plungers were modified to provide a chamber into which standard dumbbell specimens of the same compound of the sealing cup being used, as well as 6 to 8 other compounds with a range of critical properties could be placed and exposed to the exact same well environment experienced by the sealing cups.

A rather common malady of previous casing plunger designs was the successful run time of a plunger for a short period of time followed by erratic performance and failure. Retrieval of the plungers would indicate a failure of sealing cups such as swelling, blisters, or loss of modulus. In the old style plunger with fixed diameter cups, swelling would prevent the plunger from falling to bottom. Excessive cup swelling would also affect the performance of the radical new style casing plunger, but to a somewhat lesser degree. It was determined that the time period of testing should be chosen to represent a one week test, a two week test, and a four week test.

At the conclusion of each test period the specimens were retrieved and tested immediately at the well head for tensile comparison to the benchmark specimens. Visual inspection of the various compounds confirmed the test results. Those specimens that exhibited an increased overall length represented compounds susceptible to gas impregnation and exhibited substantial loss of tensile strength. The compounds that retained more of their critical properties were chosen for use as sealing cup compounds. Three substantially improved sealing cup compounds were formulated and are now in use. Furthermore, the industry standard compound used by other casing plunger manufacturers graded poorly in this comparative test program.

An observation from an elastomer compounding company was both revealing and complimentary: “No one has ever tested the compounds at the well head before. Your data is remarkable”.

Loading ASTM dumbbells of the cup compound with various compounds for comparison

Locking canister with samples for deployment into well bore.

Canister locked and samples ready for testing.

Samples retrieved from timed exposure to well bore fluids.

Portable tensometer under field power with laptop data download.

Samples tensile tested within minutes of removal from well.