Laboratory Analysis of the Z-Factor Pressure Theory for Down-Hole Rod-Drawn Oil Well Pumps

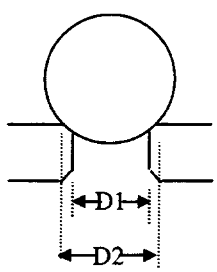
John Patterson, ARCO
Benny J. Williams, EVI Oil Tools

Abstract and Scope

The historical parameters, which have been used to calculate the sinker bar weight for artificially lifted rod-pumped wells, have been based on what is called the z-factor. This factor was derived using the physical dimensions of the lapped area of the sealing surface of the seat in the traveling valve of a rod-drawn pump. This paper describes testing which was done recently at EVI Oil Tools, Trico Industries, Inc. location, at San Marcos, Texas in the Hydraulic Test Lab.

History and Theory

Z-factor and rod buckling: The Z-factor theory states that the differential, lapped area of the seat requires an increase in static pressure below the traveling valve on the down stoke of the plunger, greater than the pressure above the traveling valve, before the traveling valve will open. The differential area is calculated based on diameter D_1 below the ball, and D_2 at the top of the lapped area. This differential pressure has been used to calculate an upward force on the downstroke, and then use this force to calculate the number of sinker bars needed to counteract this force.



$$F = Pd \times Dp^2 \times (PI/4) \times (Dr^2 - 1)$$

Where;
F= force needed to unseat the valve
Dp = barrel ID
Pd = pump discharge pressure
Dr = diameter ratio D2/D1

Laboratory Testing

Testing completed by Trico indicates that the differential or lapped area above and below the seating surface does not create a net upward force to open the traveling valve. It should be noted that these tests were static tests in that there was no plunger movement inside a barrel. Based on these tests it appears that the seal between a ball and seat corresponds to a line seal rather than an area seal equal to the lapped area of the seat.

This testing was conducted on a 1.75" traveling valve cage using a standard API ball and seat. The test procedure was straightforward in that the area above the valve was pressurized to 1000 to 2000 psi and then pressure was introduced under the seat and slowly raised to determine the differential pressure required to "lift" the ball off of the seat. A zero to 25 psi differential pressure gauge was used to measure the differential pressure. Historical theory suggested that about a 20% pressure differential would be necessary to lift the 15/16" ball used for an 1-1/2" seat.

Three tests conducted as follows:

1 - The 1.75" traveling valve (TV) cage was assembled with a standard API ball and seat and placed in the test apparatus. The top of the valve was pressured to 1000 psi and then the area below the seat was pressurized. As the pressure increased in the lower section it was noted that the pressure above the valve started increasing, but there was not any appreciable differential pressure recorded by the differential pressure gauge. The same test was repeated with a pressure of 2000 psi above the valve with the same results – no differential pressure was required to "lift" the ball. The increase of measured pressure above the ball was due to the valve opening when the ball was lifted off of its seat, thus equalizing the pressure above and below the seat when the ball was lifted.

2 - Based on the results using a standard ball and seat. The test ball was used to re-lap the seat to increase the sealing area. The ball used to lap into the seat was used in the test with the seat. The same results were obtained - no differential pressure was required to "lift" the ball.

3 - Next a seat was made with an o-ring groove machined into the seat sealing area (the former "lapped" area) and a standard ball was used in the test. The same results were obtained - no differential pressure was required to "lift" the ball. After the test, the seat was removed and the o-ring had conformed to the ball radius.

Analysis and Recommendations

Does this mean that the Z-factor is not real and does not impact rod compression on the down stroke? Remember that these tests were conducted in a static pressure environment. Several years ago The University of Tulsa Artificial Lift Project set up dynamic tests with a plunger operating inside a barrel and measured the pressure above and below the plunger during a pumping cycle with air. Their report did measure a instantaneous increase in the pressure in the barrel below the plunger which was higher than the pressure above the plunger on the start of the downstroke. However, this differential pressure was not proportional to the differential area of the seat and was slightly less than 50% of predicted. In summary it was stated that, *"The existing ball unseating concept has been tested with a limited number of real data collected from a field scale sucker rod facility. A large disagreement between the model's predictions and the actual data was observed. No definite conclusions could be drawn from this study. However, these tests raise the question of whether the present model really describes the actual physics of the problem."*

Combining the results of these two tests indicate that the differential pressure that occurs at the start of the downstroke is a dynamic force and the component of this force is still not understood. Should the Z-factor still be used to estimate the rod buckling force imposed on the rod string? These results indicate that Z-factor overestimates the force contributed from the differential pressure at the traveling valve and that sinker bar calculations using the Z-factor will be conservative (that is more sinker bars or large diameter rods will be used than necessary).

Contributors

Several people were involved in the test parameter development and testing program for this paper. We want to express our appreciation to Jim Curfew (ARCO), Trico Industries, Inc., Matthew Scott (Trico), Larry Rice (Trico), and Jim Lea (AMOCO.)