FIELD DRIVEN INITIATIVE TO IMPROVE ARTIFICIAL LIFT EFFICIENCY AND RELIABILITY WITH AN ENGINEERED SUCKER ROD PUMP BALL VALVE INSERT

Corbin Coyes, TangentFlow Inc.
Randy Coyes , SAIT Polytechnic, MacPhail School of Energy, Instrumentation Technologies Flow Laboratory

ABSTRACT

To increase recovery rates – the greatest challenge facing the industry – operators must not only look to step-change technologies, but improvements to existing technology. Even incremental increases in recovery rates can impact economics when multiplied across numerous wells. For example, approximately two-thirds of onshore wells use beam operated pump jacks with reciprocating rod pumps. Our objective was to improve the efficiency and reliability of sucker pumps by engineering a new ball valve insert.

Prototype testing demonstrated that the lowest pressure drop was provided by an insert design with the tangent angle equal to Pi (3.14, π), as it forced the fluid into a spin. Based on a number of flow rates (including two phase flow) the TangentFlow insert decreased pressure drop by 40% on average resulting in 58% more flow than the bar-bottom inserts. In addition, compared to the bar-bottom inserts, which produced significant ball chatter, the TangentFlow insert had a consistently low decibel reading with increasing flow rates, as the ball remained stationary. This results in reduced gas breakout, which in turn further reduces pressure drop and pump damage.

One-year field results from 100 wells in the Red River reservoir of Montana and North Dakota demonstrate that the TangentFlow insert reduced pressure drop across both the standing and traveling valves to increase average surface flow by 8%. Considering the average water to oil ratio in the area, this provides an additional 3.1 bbl/day/well. This increase applied over 100 wells translates to approximately 109,206 bbl/year, or $7.3 MM in revenue at current oil prices.

The design of the TangentFlow insert improves the efficiency and reliability of sucker rod pumps by minimizing the effects of pressure drop, gas breakout, solids accumulation (wax), casing wear and ball wear, which together improve pump efficiency and production flow. Because the design enables the ball to remain stationary, smaller and lighter balls can be used, allowing for higher flowback solids and reduced cage wear, respectively. The TangentFlow insert is manufactured to replace conventional bar-bottom inserts without needing to change out the entire pump assembly, making them applicable to 90% of pumps presently used in the industry.

INTRODUCTION

Artificial lift is a process used on oil wells to increase pressure within the reservoir and encourage oil to the surface. When the natural drive energy of the reservoir is not strong enough to push the oil to the surface, artificial lift is employed to recover more production.

While some wells contain enough pressure for oil to rise to the surface without stimulation, most require artificial lift. 96% of the oil wells in the United States require artificial lift from initial production (RigZone). Even in wells that initially have adequate natural flow to bring oil to the surface, the reservoir pressure will deplete over time requiring artificial lift to continue production. Therefore, artificial lift is performed on all wells at some time during their production life.

Although there are several methods to achieve artificial lift, the most common type is beam, or sucker rod, pumping. In the US, the majority of wells (80-90%) employ a beam pump (Toma et al., 1995 & 1998; Cutler and Mansure, 1999). Consisting of a sucker rod string and a sucker rod pump, beam pumps are the familiar pump jacks seen on onshore oil wells (Fig. 1).

Issues with Conventional Ball Cage Insert:
Looking closer at the sucker rod mechanism, there are two ball check valves, a stationary valve at the bottom called the standing valve and one on the piston connected to the bottom of the sucker rod called the travelling valve (Fig. 1 – inset). Each valve contains a ball cage insert to regulate flow. A single bar bottom insert design (insert/ball/seat/cage) has been run in the majority of all the sucker rod pumps used in North America for over 50 years (Fig. 2).

A number of problems exist with the functioning of the bar bottom insert, including gas breakout, pressure drop, solids, ball wear and cage failure, which result in reduced pump efficiency (Cutler and Mansure, 1999).

Gas Breakout:
As fluid undergoes turbulence, the entrained gas breaks out from its solution form. When a fluid with entrained gas travels through a confined space, the gas is forced to instantly combine, creating a high pressure drop and gas breakout resulting in delayed ball seating and fluid pounding on the downstroke.

Pressure Drop:
Pressure drop is the difference in pressure between two points of a fluid in a pipe. Pressure drop occurs when the fluid inside the casing flows across a smaller cross sectional area of flow – i.e., areas between the ball and insert. A more constrictive path, additional ball vibration, and increased gas levels in the fluid all contribute to the pressure drop across the insert. A Pressure drop occurs inside the valve that causes a decrease in pump fillage every time the pump is stroked. Pressure drop occurs with frictional forces, caused by the resistance to flow, on a fluid as it flows through the insert. Pressure drop can cause scale and paraffin wax to build up minimizing the area for oil to flow.

Ball Wear and Cage Failure:
Ball wear and cage failure can occur as a result of the continuous pounding of the ball on the insert. These effects can also occur from the vibration (chatter) of the ball inside the insert. When the ball beats out, the pump can no longer create a proper seal.

Solids:
Solids can get lodged between the ball and the insert causing the ball to stick rendering the pump useless. Solids can also cause abrasion to the ball and the insert, which ultimately wears out the pump.

Objective:
Our objective was to design a fully optimized, universal ball cage insert to improve pump efficiency and reliability, enable application to all sucker rod pump ball valves, and make it cost effective for operators to replace the old bar bottom inserts without changing out the entire pump assembly.

TANGENTFLOW INSERT DESIGN OPTIMIZATION

A design prototype that provided the best flow compared with the conventional bar bottom insert in a laboratory apparatus was further optimized to minimize pressure drop and gas breakout, as well as for strength and reduced wear. The final design (Fig. 3) incorporated several improvements as detailed in (Figs. 4-6)

Finite Element Analysis:
The University of Calgary performed finite element analysis on the TangentFlow insert as a way to test the strength of the design (Fig. 7). This analysis determined that the 3 flanges of the TangentFlow insert provides superior structural stability compared to the 2 contact points of the conventional bar bottom

insert. The inherent strength of the design is further enhanced through the chosen metallurgy – a cobalt alloy with a high chromium content – as well as machining the top and bottom rings to within 0.001-in. parallelism.

Comparison of Optimized TangentFlow Insert to Conventional Bar Bottom Insert:
Detailed flow testing was performed at the Southern Alberta Institute of Technology (SAIT) laboratory using a flow apparatus consisting of two identical flow runs to specifically show the reduction in pressure drop and reduced ball chatter of the new design. The optimized TangentFlow insert provided a significantly lower average pressure drop compared to the bar bottom insert with and without gas in the system (Fig. 8). The average density of the water/gas fluid averaged 950 kg/m^3.

In addition, the optimized TangentFlow insert kept the ball perfectly stationary during the flow resulting in greatly reduced decibel values – close to ambient room levels – both with and without gas in the system (Fig. 9). The bar bottom insert readings were >90 dB – the point at which hearing protection must be worn in order to avoid permanent hearing loss. This movement negatively effects the structural stability of the flow run cage; therefore, the TangentFlow insert mitigates cage wear and eventual failure due to ball chatter.

FIELD APPLICATION FOR TANGENTFLOW INSERT

While there are a number of parameters that cannot be controlled for in a field situation, field applications have shown a production benefit with the TangentFlow insert. An operator working in the Red River formation in the Williston Basin of Montana and North Dakota wanted to maximize flow in their 8,300 – 9,300 ft total depth wells producing 10% oil under water flood (Table 1).

Standard one-piece full flow cages in fiberglass tubing were replaced with two-piece TangentFlow insert cages in over 100 wells. The cage sizes were 2.25-in. for the standing valve and 1.75-in. for the traveling valve. Installation of the TangentFlow inserts was the only variable modified and dynamometers were available on every well to measure flow changes.

On average, an additional 7-10 in. stroke length in the standing valves and 3-in. stroke length in the traveling valves for a total average difference of 11.5 in. was observed. Wells with the TangentFlow insert showed an average increase in surface flow rate of 31.2 bbl/day (Table 2). Therefore, the pressure drop reduction across both the standing and traveling cages increased surface flow by 8% on average. Based on the field average 90:10 water to oil ratio, this increase provides an additional 3.12 bbl/day or 1,092 bbl/year oil production per well. This increase applied over 100 wells translates to approximately 109,206 bbl/year, or $7.3MM in revenue at current oil prices.

CONCLUSIONS

Both standard API and alternative (smaller ball size) TangentFlow inserts are currently being manufactured, cast, machined, and sold to distributors and pump shops in Canada and the US. Over the last 14 years, the TangentFlow insert has been run in 21,275 wells in sucker rod pump standing and travelling valves across North America. The variety of insert sizes (1.25-, 1.5-, 1.75-, 2.0- 2.25-, 2.75-in.) are made to fit multiple pump types making it extremely versatile and suitable for the majority of artificial lift applications.

The TangentFlow insert has been run in and out of a variety of wellbores with H_2S, pressure, solids and corrosive environments. The cobalt alloy with a high chromium content offers corrosion resistance while providing high fatigue strength to withstand the ball constantly beating against the upper flanges.

Unlike one-piece full cage vortex pumps, the optimized TangentFlow insert is designed to fit into any sucker rod ball valve and has a low cost of entry. Additionally, by optimizing fluid flow and thus pump fillage, fuel requirements are decreased, reducing costs and environmental impact of the resulting emissions. The TangentFlow insert is particularly suited to oil wells that require lower pressure drops across valves, experience gas influx, solids, casing failure and excessive ball and seat wear.

ACKNOWLEDGEMENTS

TangentFlow would like to thank the University of Calgary and the Southern Alberta Institute of Technology for their participation in the testing of the TangentFlow insert.

NOMENCLATURE

dB = decibels
GPM = gallons per minute
in. = inches
m = millimeter
m^3 = cubic meter
TVD = true vertical depth

REFERENCES

Cutler, R.P. and Mansure, A.J. 1999. "Fluid Dynamics in Sucker Rod Pumps." Report SAND99-0093C, Sandia National Laboratories, Albuquerque, New Mexico. Proc. 46th Annual Southwest Petroleum Short Course, Lubbuck, Texas. p. 1-24.

RigZone Training: http://www.rigzone.com/training/insight.asp?insight_id=315

Toma, P., Coates R. Nguyen, D., Ivy, R. and Good, W. 1995. Improved Design of Rod Pump Valves for Thermal and Horizontal Wells – Laboratory and Field Results. Paper PETSOC 95-99 presented at the 48th Annual Technical Meeting of The Petroleum Society of Canada in Calgary, Alberta, Canada, 7-9 June.

Toma, P., Coates R. Nguyen, D., Ivy, R. and Good, W. 1998. Improved Design of Rod Pump Valves for Thermal and Horizontal Wells – Laboratory and Field Results. Paper PETSOC-98-05-06 published in the Journal of Canadian Petroleum Technology, 1998. Vol 37, Issue 05.

Wikipedia: https://en.wikipedia.org/wiki/Pumpjack

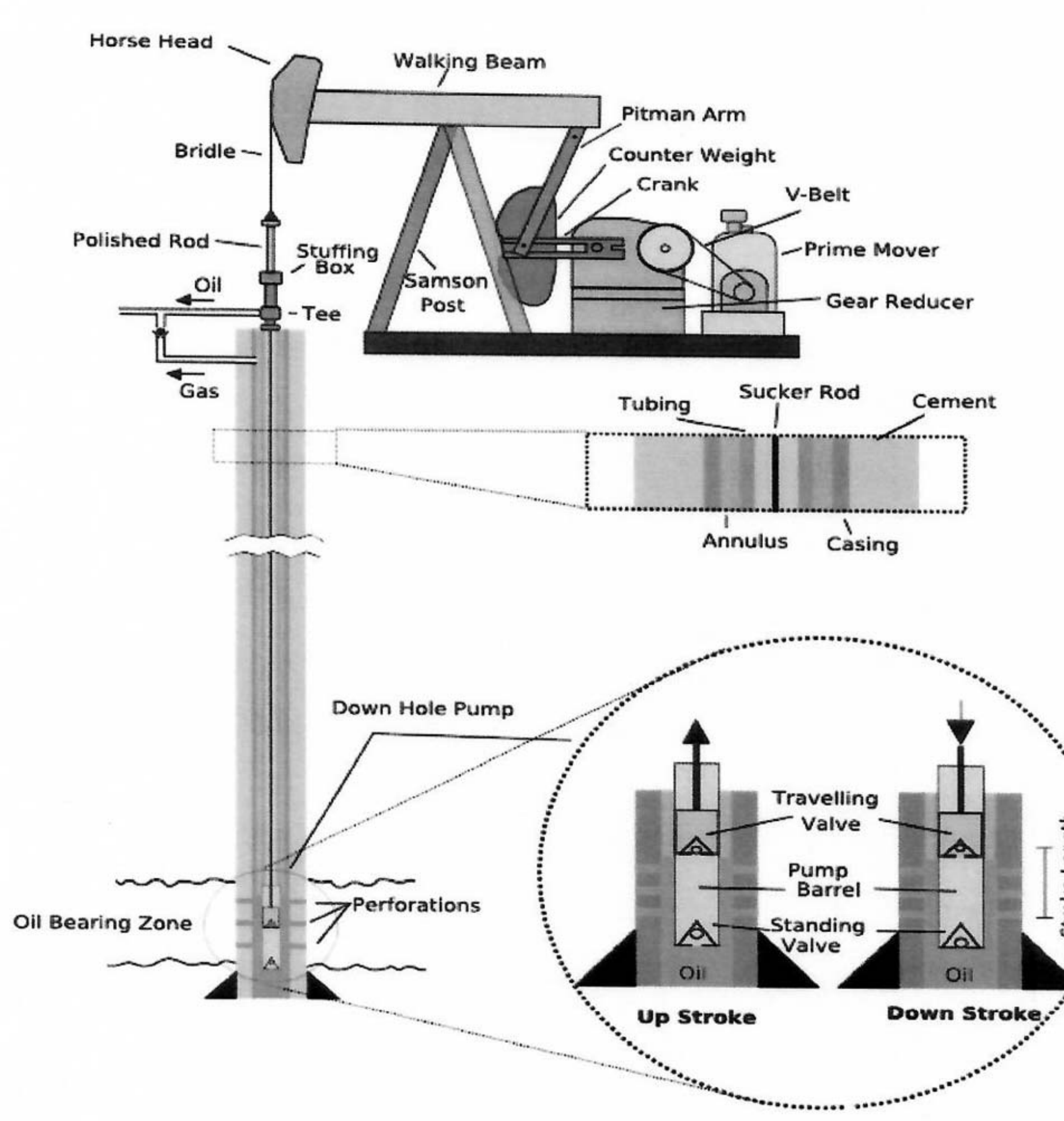

Figure 1—Diagram of pump jack and sucker rod pump mechanism including the travelling and standing value (Source: Wikipedia).

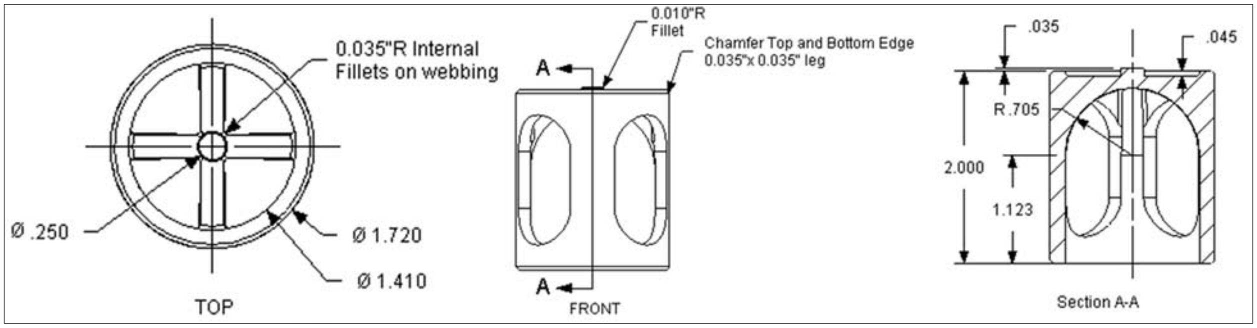

Figure 2—Bar bottom ball cage insert.

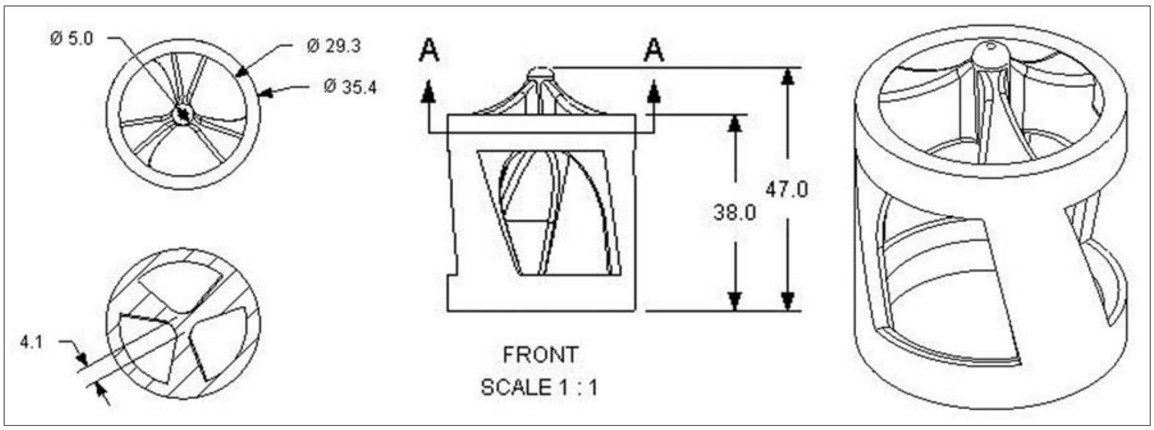

Figure 3—Optimized TangentFlow insert design.

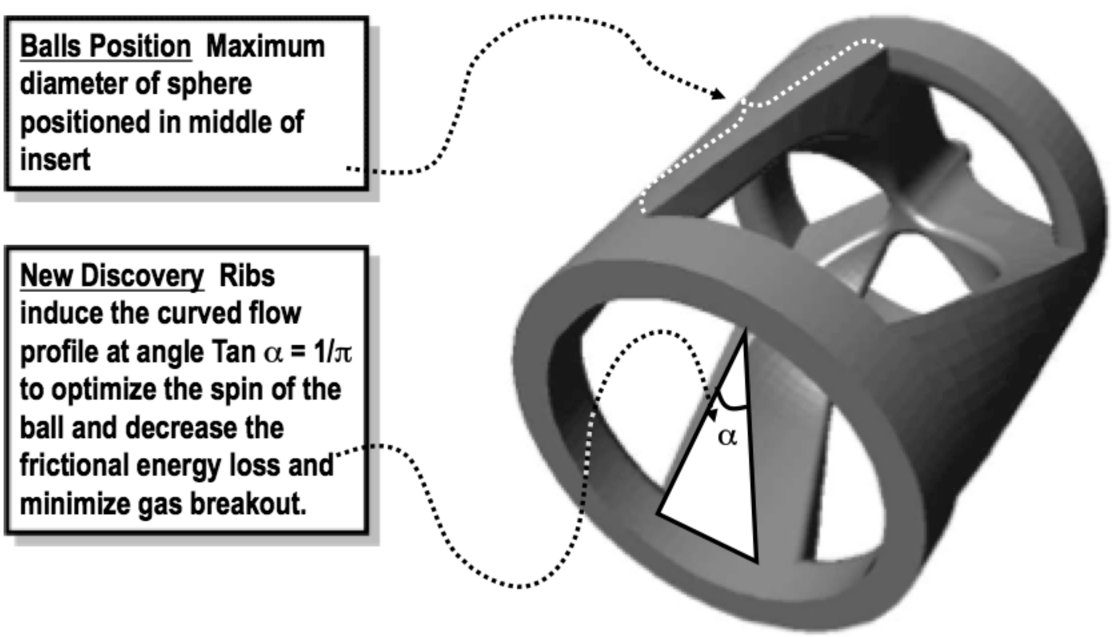

Figure 4—Optimization of flow angle and ball position to maximize flow rate and minimize gas breakout.

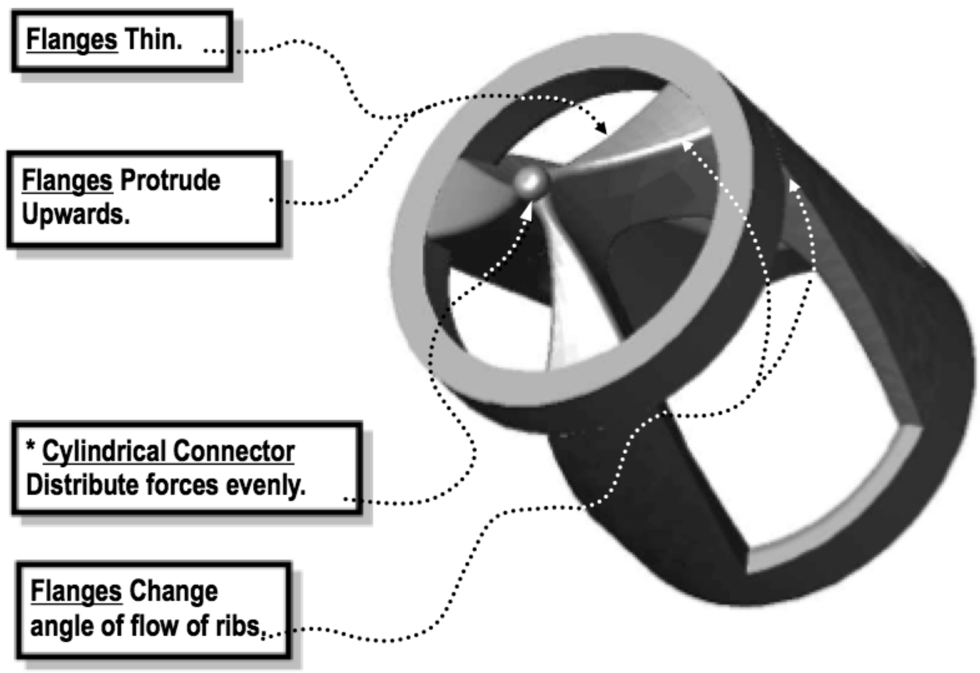

Figure 5—Optimization of force distribution and reduction of pressure drop.

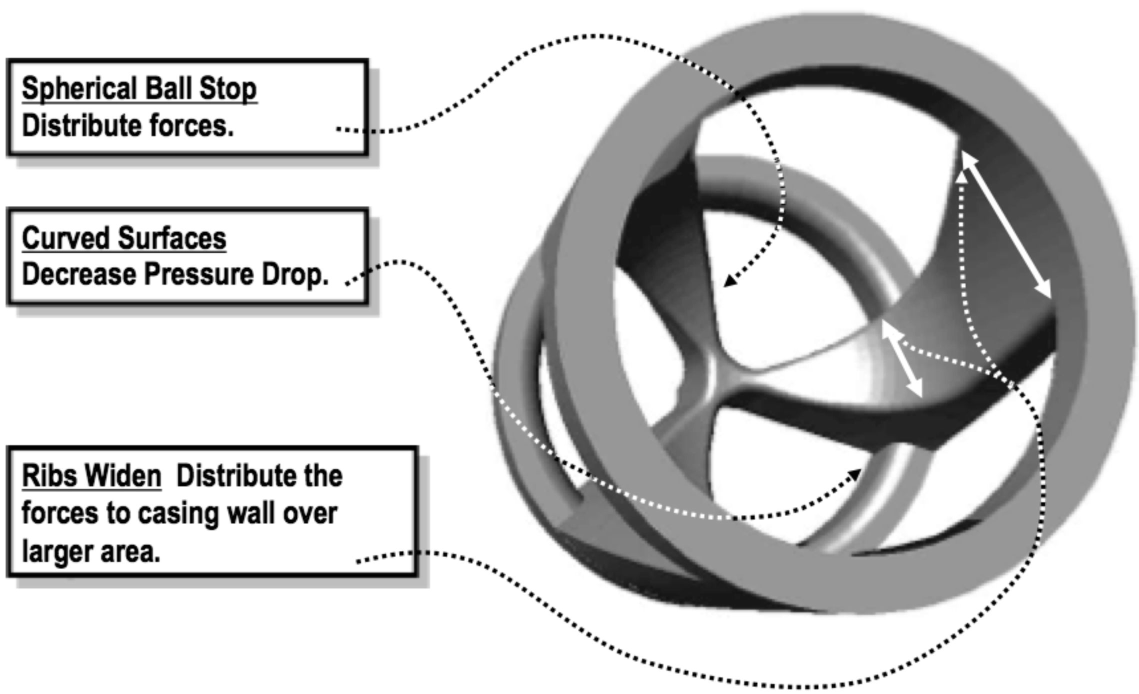

Figure 6—Optimization of flanges and cylinder to improve flow rate and evenly distribute forces for reduced fatigue and casing failure.

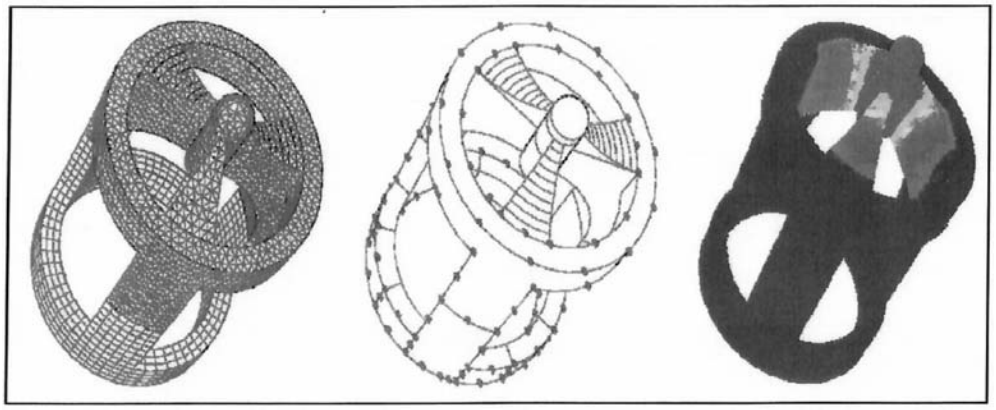

Figure 7—Finite element analysis images of meshing, boundary conditions and total displacements.

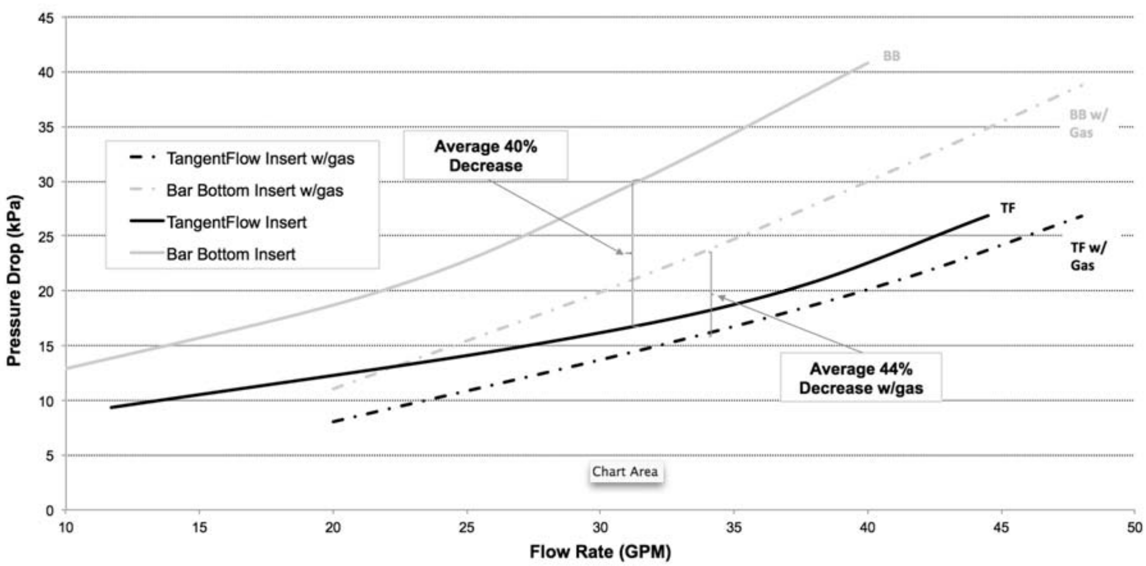

Figure 8—Average pressure drop versus flow rate with and without gas.
https://www.youtube.com/watch?v=6SjwLtFXj7s

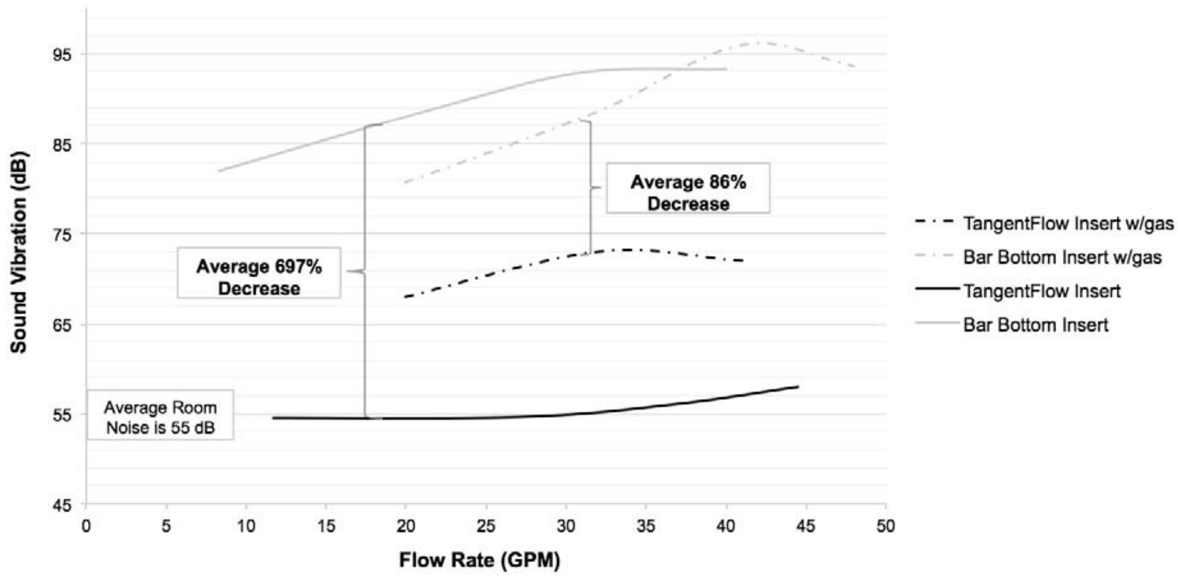

Figure 9—Ball vibration versus flow rate with and without gas.

Table 1. Red River Field Application of the TangentFlow Insert

PARAMETER	VALUE
Formation	Red River Dolomite
API of Oil	29 - 41
Permeability	1-97 mD
Avg. Temperature	220 - 250°F
H_2S	25 - 400,000 ppm
CO_2	3 - 33%
Air	Injecting air converts to N_2 and CO_2
Corrosion	CL (9,000 - 72,000 mg/L)
Inhibitors	Cap rings to inject wide range of corrosion inhibitors
Gear Box Size	640, 912, 1120 all sizes
Injection	Air and water
Plunger Size	Short, 3 - 4 ft grooved
Deviation	60 degrees into horizontals
Gas Separator	Downhole
Ball Type	Tungsten carbide
Compression	Lots of compression on string design
Fines	Fines are an issue in most areas

Table 2. Average Results from 100-Well Red River Field Application

WELLS	STROKE LENGTH (in.)	PUMP COEFICIENT	STROKES/MIN	FLOW RATE (bbl/day)
Standard cage	147	0.357	7.6	398.8
TangentFlow insert cage	158.5	0.357	7.6	430.0
Difference	11.5			31.2