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Gas Well Deliquification for Maximizing Recovery from Mature Gas Assets

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Abstract

VICO Indonesia operates the Sanga Sanga PSC in East Kalimantan which is on production since 1972. Reservoirs are mostly gas and depleted. Very Low Pressure compression “VLP” systems, which operate at 15–25 psig suction, are widely installed across all fields. As a result, flowing tubing head pressures in a large number of wells are in the order of 40 psi. Completion tubing sizes range from 2 3/8” to 4.5” with the majority being 3.5”. Despite this, a large proportion of VICO’s existing gas wells are subject to liquid loading, leading to premature abandonment of producing zones when the gas velocity in the tubing is lower than the critical velocity. This phenomenon is influenced by the tubing size, surface pressure and the amount of associated liquids produced with the gas. Historically, some temporary activities were carried out to overcome this problem. This included the reactivation of wells by flowing to flare and/or dropping foaming agents. The result of this type of “temporary” application was very variable and inconsistent.

In an effort to continuously optimize the system and reduce the abandonment pressures, a large scope deliquification project was launched in 2006. The project included the application of capillary strings for down-hole chemical injection, plunger lifts, and wellhead compressors. This program was applied across all fields in VICO. The results were very positive in bringing back the production strings previously considered marginal or not producing. The field wide implementation program for both capillary string units and well head compressors was conceived to allow periodic relocation and optimization of the units and the system. As a result, all these deliquification techniques have now become a core element of the Base Production System. They continue to be optimized on a day to day basis and as a whole they are responsible for approximately 10% of the total production from VICO.

Introduction

VICO has been continuously producing the Sanga Sanga PSC in East Kalimantan since 1972. Its production is primarily gas, which accounts for approximately 80% of the total. Currently the majority of this production comes from very depleted reservoirs. The bottom hole reservoir pressures are mostly within the range of 2 to 3 ppg, hence low surface pressures are required to produce these reservoirs. Very low pressure (VLP) compression systems have been installed at plant station across all fields. The suction pressures of these VLP compressors are usually within the range of 15 to 25 psi, thus the flowing tubing head pressure of most wells flowing to these VLP systems are in the order of 40 psi. This very low pressure system has been successful in maintaining the wells producing for long periods of time.

As time has passed, a large number of wells -even flowing to these VLP systems- started to suffer liquid loading problems. Liquid loading is usually influenced by the amount of liquids associated with the gas production, the tubing size, the surface pressure and, off course, the rate of production, which defines the velocity of both the gas and liquid inside the tubing.

This problem has been a focus area for VICO since a significant proportion of the remaining reserves are located in some of these large depleted reservoirs. In order to overcome these problems, several deliquification techniques have been introduced and implemented since 2001. However, since no systematic approach was initially applied, the results of most of the initial efforts were very variable, and limited success was achieved. Subsequently, a larger and more systematic approach was applied after 2006. This program is still the one being applied today and it is the one responsible for keeping about 10% of the total production from VICO.

Deliquification Techniques

Gas well deliquification, also referred to as “gas well dewatering”, is the general term for technologies used to remove water or condensate build-up in the wellbore when producing gas wells. In a condition where gas flows naturally and steadily, the gas has a velocity high enough to carry any liquids to surface. In this high velocity condition, liquids are finely dispersed into the gas stream resulting in a mist flow pattern. Consequently, a very low volume of remaining liquid is present in the production tubing and only a very low back-pressure is caused by the gravity effect acting on the flow stream. However, when the gas velocity in the production tubing decreases with time, the velocity of the liquids carried by the gas stream decrease even further, thus creating a very different flow pattern. The most common resulting patterns are annular or slug[2] (Fig 2). These patterns will cause the liquid to accumulate at the bottom and along the well. This phenomenon can reduce or even completely stop the gas production from the well altogether.

The source of liquid accumulation in the wellbore can either be from condensation -liquids carried in the gas stream- or direct liquid flow from the reservoir. Liquid loading in the wellbore will increase the pressure gradient in the production tubing and will restrict the reservoir drawdown. In the end, the gas production will be significantly affected.

Recognizing Liquid Loading

To choose the right candidates and technology for deliquification, it is very important to recognize the liquid loading indications in a gas well. The three most common ways to recognize liquid loading are: by observing the well’s production symptoms, namely fluid rates (gas & liquids) and pressures; by calculating its critical velocity, and, by doing standard nodal analysis.

One typical symptom of liquid loading could be the slug type flow. This flow regime is typically recorded by the differential pressure on a gas chart (barton) or a cyclic type pressure behavior on any other type of recorder. This behavior indicates that liquid loading is either starting (if not noticed before) or is present, and could have been occurring for some time. A sharp, sometimes inexplicable, drop in the well’s production could also be a strong indication of liquid loading. On steady state flow conditions, a gas well decline curve should be smooth and gradual from a reservoir standpoint. Sharp drops in the decline curve and possible erratic surface pressures occurring on the tubing are strong indicators of problems related to liquid loading in the tubing. If available, a pressure gradient in the tubing would be one of the best indicators. A well without liquid loading should show a smooth gas gradient in the tubing. If liquids are accumulating in the well, a survey may show liquids that have fallen back and accumulate at the bottom of the well. Also if liquids are condensing in the tubing nearer the surface of the well, the area of high condensation could show a higher gradient than the rest of the tubing.

The critical velocity has been defined in the industry as a critical parameter of a well’s flow. If the well flows at a slower rate than its critical rate, liquids will begin to accumulate in the wellbore. That is, in a condition where the velocity of the fluids in the wellbore is lower than the critical velocity (below Turner and Coleman rates), then liquid loading in the wellbore will be started. The critical velocity is generally defined as the minimum gas velocity required to lift up the liquid. Turner define the formula to calculate critical velocity for gas wells with a wellhead pressure greater than 1000 psi as follow:

$$V_t = \frac{2.04\sigma^{\frac{1}{4}}\left(\rho_L - \rho_g\right)^{\frac{1}{4}}}{\rho_g^{\frac{1}{2}}}$$

where σ = surface tension, dynes/cm and ρ = density, lbm/ft^3

Coleman predicts that critical rate is 20% lower than Turner rate for gas wells with a wellhead pressure less than 1000 psi.

Nodal analysis can also be used to analyze the effects of several parameters in the inflow and outflow performance curve for the ability of gas to produce reservoir liquids. Therefore nodal analysis is one of tools to evaluate the flow conditions and the deliquification options.

Applications in VICO

To overcome the liquid loading problems several deliquification techniques have been developed by the industry through time. Initially, VICO’s approach to deliquification had been the low cost, low tech solutions, which had been previously tried. This included venting, cycling, HP gas injection, soap sticks and gas lift (in old oil wells with gas caps). The results of these applications were very mixed, and only limited success was achieved.

However, post 2005 after several VICO engineers participated in several BP deliquification forums, particularly in the North America region, a more rigorous and systematic approach to these technologies was considered and applied. Today, these technologies have been identified as a key focus area for VICO.

Capillary Strings

The use of capillary strings in VICO has grown significantly since its first application in 2006. This deliquification technique consists of a small size (1/4") tubing installed inside the well to allow the pumping of a foaming agent -liquid soap or surfactant- down to a certain depth inside the well. The foaming agent is usually pumped from surface using a standard chemical injection pump and storage tank at surface (Fig 3). Once in the well, the surfactant is sprayed through a nozzle at the end of the capillary string. The sprayed chemical mixes with the produced fluids and creates foam, which will reduce the surface tension and density of the fluids; hence the ability of the well to produce will significantly improve.

For VICO this capillary string chemical injection method was chosen due to its relatively simple application. It can be applied to a wide range of completion types. The other important reason was that the development cost of the project expansion was considered relatively low. Therefore, VICO can continue expanding its application at a moderate cost.

The most common method used to unload wells is by continuous foaming injection using capillary strings. This method has proven more successful than batch treatments, using" soap" sticks. The economic limit is a function of the chemical costs and equipment costs. Chemical costs are also proportional to the liquid (water) rate; therefore at very high levels of water production, not only the method will be less efficient but also chemical and pumping costs may exceed the benefits of the treatment.

The use of foaming agents could also generate some problems, particularly at locations where experience foam carryover and/or liquid emulsion treating problems become too severe to cope with. This also depends on the specifications and capacity of the surface equipment used to process the production fluids. Chemical selection was also important because formation water properties will vary between different fields.

VICO performed a capillary string pilot project in 2006 on 5 wells and the results were very encouraging. Prior to the implementation of the capillary strings, the wells were flowing very erratically at 1 – 1.5 mmscfd. After the cap string installation the well's production increased up to 4 mmscfd and then continued to flow steadily at 2 mmscfd (Fig 4). The key parameters on this successful pilot project were candidate selection and lab testing for chemical selection.

The successful pilot project brought VICO to continue the project for field wide implementation since 2007. Currently about 60 capillary strings have been installed across all fields and they continuously produce about 10 mmscfd (Fig. 5). These capillary strings are also easily relocated between wells when the production reaches its economic limit. Capillary strings have proven to be one of the critical activities in maintain existing production in VICO. They are a simple, fairly well tested technology that can be applied to similar mature fields with liquid loading problems.

Plunger Lift

Plunger lift is a method of removing liquids from a well which employs periods of flow and periods of no-flow for pressure build up. The objective of the plunger lift is to improve the gas flow using the well's own energy and keeping the wellbore free of liquids (Fig 6).

This method uses a free traveling plunger in the tubing to assist the gas in carrying liquid slugs to surface. The shut-in periods should be as short as possible to develop a 'continuous-like' gas well, if at all possible. This means that a balance should be achieved in terms of the falling time of the plunger, the pressure build up rate and the shut in time, the rate and flowing period, and very importantly, the performance and reliability of the equipment.

In VICO, in order to achieve a higher efficiency during the shut-in periods, a two-piece plunger was selected. The main advantage of this two-piece plunger is that reduces the shut in time required for the plunger to drop against the flow. It usually requires about 5 seconds of shut in time. It is also simple to operate. The surface equipment includes a lubricator (equipped with rod & spring inside), plunger lift controller, magnetic sensor, and solar panel as a source of power supply. The down hole equipments includes the plunger and the bumper spring (Fig 7).

The two-piece plunger works with the automation control valve that can adjust the setting time, when the control valve is closed for ~5 seconds. The cylinder will drop to the bottom then will make a seal with the ball, and will bring up the water to surface. On surface, the rod knocks down the ball to the bottom while the plunger stays on top and the gas is flowing for a period of time. This action will repeat several times depending on the control valve setting. By traveling up and down, the two-piece plunger will carry the liquids in the wellbore to surface and will reduce the back pressure to the reservoir, allowing the well to produce the gas. The well candidates for plunger lift should have a smooth inside diameter from the target depth to surface. This is required to allow the plunger an easy travel through the wellbore.

VICO performed an initial pilot project in 2006 by installing two plungers. The candidate selection for the trial was limited on the well stock since the inside diameter of a large number of wells at the time was not entirely smooth due to the completion jewelry. Two main candidates were identified and selected for the two-piece plunger pilot project.

The installation included wellhead piping modification (Fig 8) and setting the down hole equipment. The result was successful in re-gaining the production from the loaded-up wells (Fig 9). Based on this pilot project this technology was expanded to a total of 10 wells, most of which delivered as per the expectation. However, due to the limitations on the well stock candidates VICO has only applied this technology to a smaller number of wells. Currently this technology in VICO provides less production benefits compared to the capillary strings and only a few wells still use the plunger lift.

Wellhead Compressors

The existing VLP compressors at plant stations reduce flowing wellhead pressure as low as 40 psi. However, some of the wells which are flowing into these VLP systems still flow below the critical rate and are subject to liquid loading problems. In addition to the capillary string and plunger lift options, one alternative is to lower the flowing wellhead pressure even further to keep the well flowing above the critical rate for a longer period of time.

One method to reduce flowing wellhead pressure is put a compression system, which has a lower suction pressure, as close as possible to the wellhead. Wellhead compressors work by lowering the flowing wellhead pressure so that well production increases and the abandonment pressure reduces, hence adding reserves through the extension of a well’s life. The key considerations to be taken into account when looking for implementing well head compressors, such as capacity, suction and discharge pressures, are determined by the gas and liquid production parameters.

VICO purchase one wellhead compressor unit in 2005 (Fig 10). This was a trial to find out the optimum compressor system for wellhead compressor application. The compressor was designed to handle 2 mmscfd of gas and 2000 bpd of liquid at 0 – 5 psi flowing wellhead pressure and 110 psi discharge pressure. The pilot project proved the wells do respond to lower wellhead pressure (Fig 11) and provided support for the economics of the project.

One of the good lesson learnt from the pilot project was that the compressor package should have a small footprint to enable easy relocation between wells. After all factors from pilot projects considered, the final package design for full scale project consisted of a wet screw type compressor. This was selected due to its high compression ratio, high reliability and minimum maintenance requirement. The chosen design was capable of delivering 0.5 – 1.0 mmscfd and contained gas-liquid separation system to handle 200 bpd of liquid. Sumaryanto et all[2)] explained more detail in compressor selection for mature field.

Currently VICO has 46 wellhead compressors on operations at all fields (Fig 12). Additional 10 units are expected to arrive in 2014. The compressors are handling 0.3 to 0.9 mmscfd per unit with total delivery of 20 mmscfd (Fig 13). Individual well incremental rate is 0.2 – 0.4 mmscfd of gas from reservoir pressure varying from 300 to 1000 psi. Regular optimization is carried out and compressor skids are relocated between wells when the economic limit is reached or the well ceases to produce.

Candidate Selection and Technology Implementation

In reference to the deliquification techniques above, VICO uses a simple, yet effective approach for selecting the right application to its well stock. The remaining reserves is the first important thing for candidate selection and technology implementation.The well location is also a very important parameter. The wells which penetrate the reservoir in the crestal area have proven to last longer than wells in the flank area. This is because water breakthrough will occur later in the crestal areas.

The completion type will have important roles as well for choosing the right deliquification technique to be implemented. Plunger lift requires a well with a smooth type of completion, preferably wells with no profile or ID changes in the tubing. There is no limitation for well with profile or ID changes for the capillary string installation.

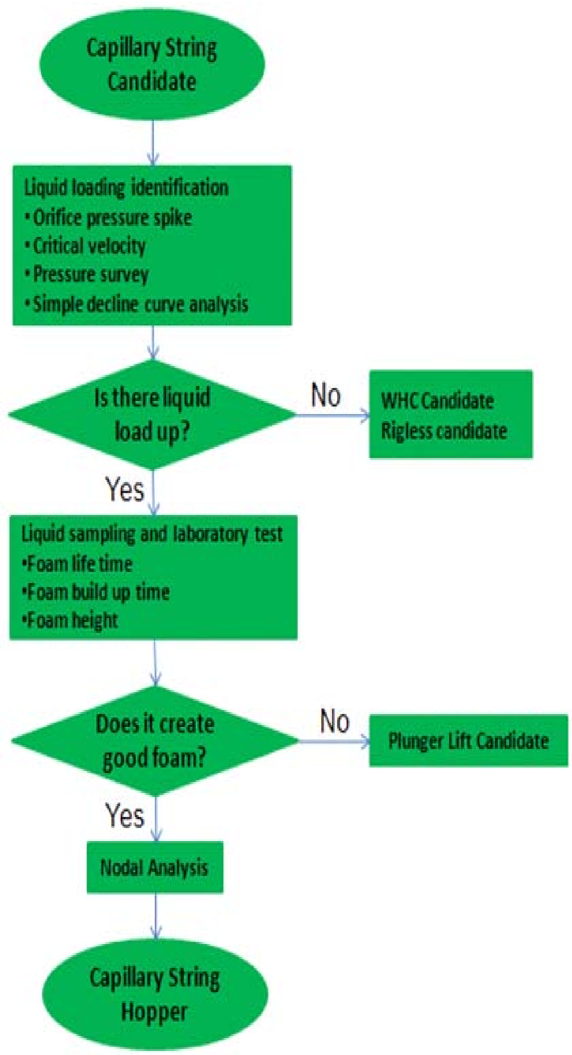
VICO uses a liquid loading spread sheet which was developed as the early part of the selection process for loaded up wells. The spreadsheet calculates the critical velocity for each well using the Turner and Coleman equations, and then compares with the well production history. The bottom hole survey (a static and flowing gradient survey) is then performed to confirm the capillary string candidates.

Screening candidates are then evaluated in more detail by running nodal analysis and material balance to forecast the production profile up to a certain abandonment pressure. The result of the analysis is used to determine the suitable techniques for each candidate.

Based on the VICO experience and for the specific field conditions, some key points in determining the best solution for each well could be mentioned. These are:

- Capillary strings can maintain rates of up to 700 bpd. The foam life is only 30 minutes and only works at formation with depths of less than 11,000 ft.
- Plunger needs higher bottom hole reservoir pressure to push the plunger to surface along with the liquid
- Wellhead compressor design is 0.5 mmscfd in order to have small footprint. The liquid maximum capacity is 200 bpd

The general workflow for candidate selections for each deliquification techniques is as follow:



The following table shows a general overview of the deliquification techniques that have been implemented in VICO:

POINTS	**Capillary String**	**Well Head Compressor**	**Plunger Lift**
Total cost	Medium	High	Low
Installation and modification on surface	1 day	~ 3weeks	~ 2 weeks
Formation liquid type	Water (min BS&W: 80%)	Water or Condensate	Water or Condensate
Tubing clearance	Depend on the size of injector head	Suitable for all	Need special clearance

Conclusion

The application of the deliquification technologies in liquid loaded wells has proven to be an economical approach to extend the well life and maximize the recovery. In some cases, the wells that have been treated as cyclic have been successfully transformed into continuous producers.

A deliquification implementation study should be carried on before the field reaches its mature or declining stage. The earlier the study the more it will help to choose the right completion and potential future technology to solve the liquid loading problems.

Capillary strings and wellhead compressors have become very important activities to maintain the base production in VICO. It is also believed that these technologies will be equally applicable to other gas fields running its mature and declining stage.

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Nomenclature

BPD	Barrel per Day
ft	Feet
FTHP	Flowing Tubing Head Pressure
HP	High Pressure
ID	Inside Diameter
MMSCFD	Millions Cubic Feet per-Day
PSC	Production Sharing Contract
VLP	Very Low Pressure

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2. Sumaryanto et al, “Optimizing Well Productivity and Maximizing Recovery from a Mature Gas Field: The Application of Wellhead Compressor Technology”, SPE 132855 (2010)
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Fig. 1 VICO Area of Operations

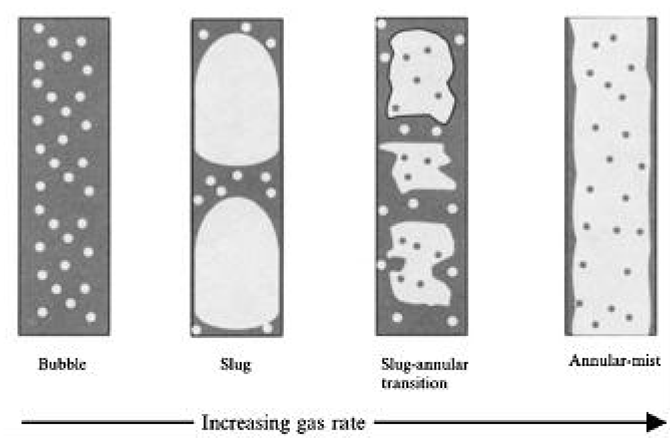

Fig. 2 Flow regimes in vertical multiphase flow2

Fig. 3 Capillary String Application

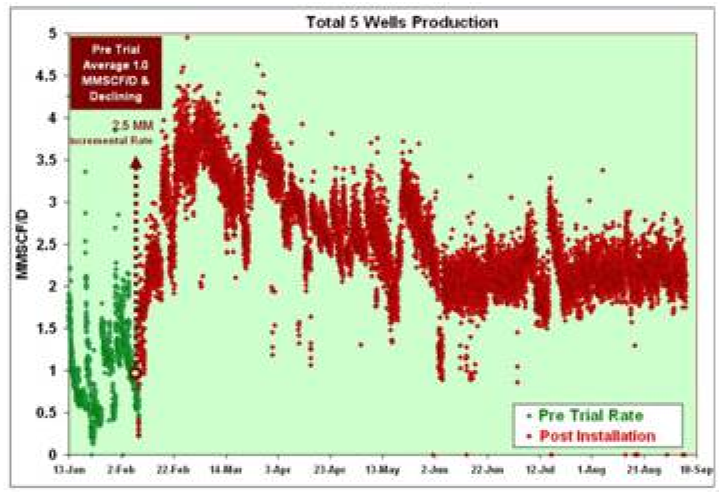

Fig 4 Capillary String Pilot Project Result

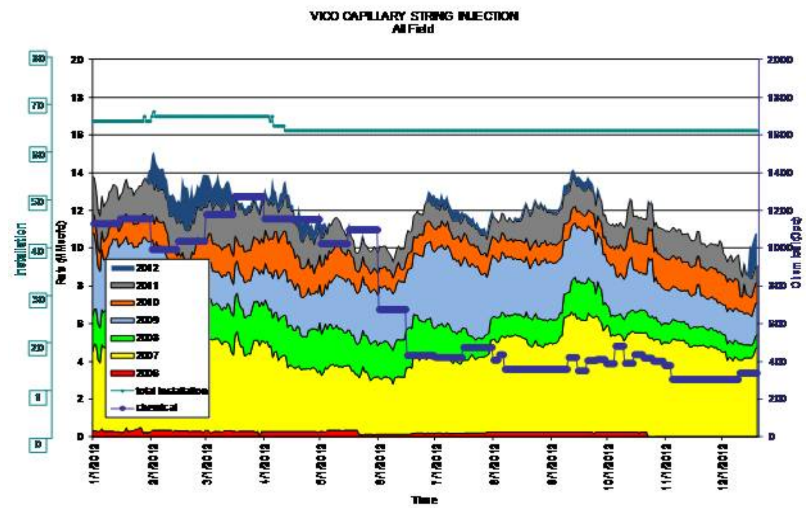

Fig 5 Capillary String Production

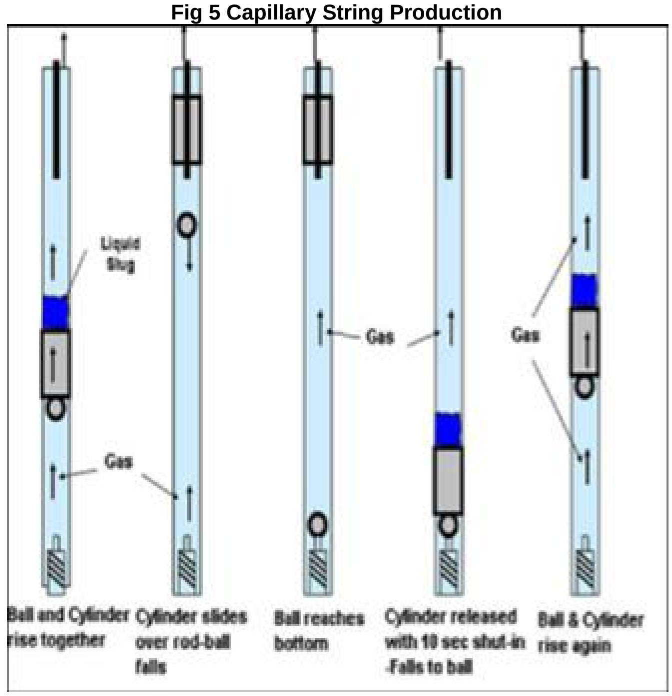

Fig 6 Plunger Lift Method

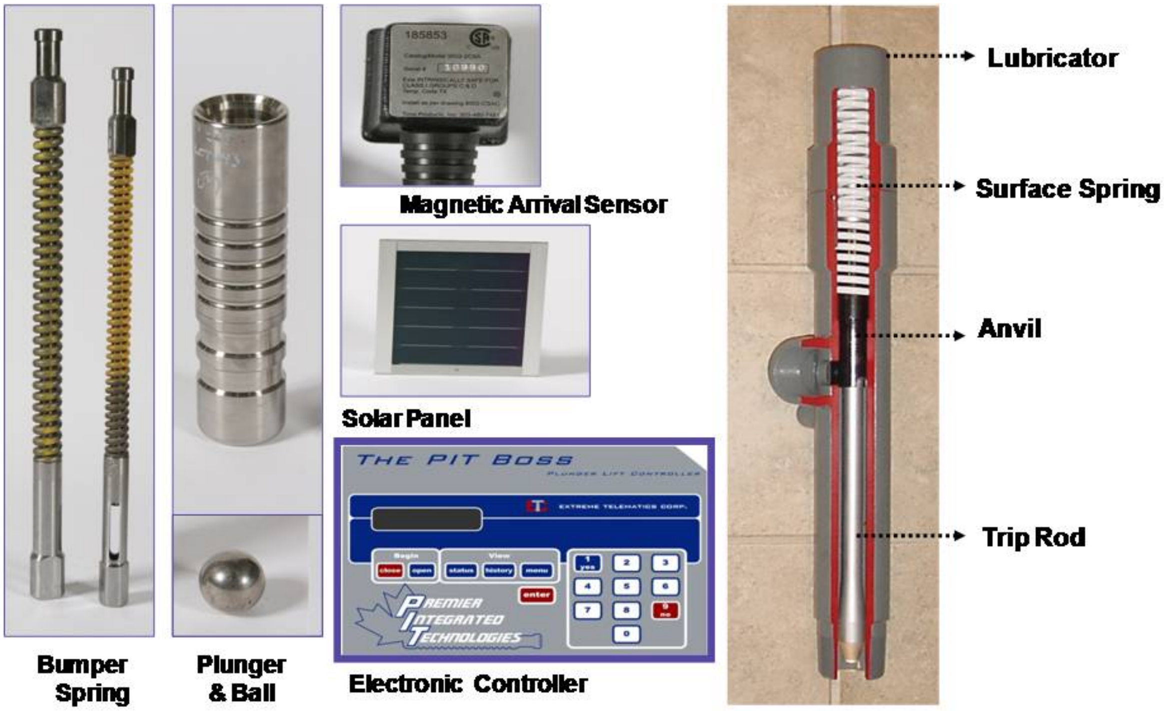

Fig 7 Plunger component

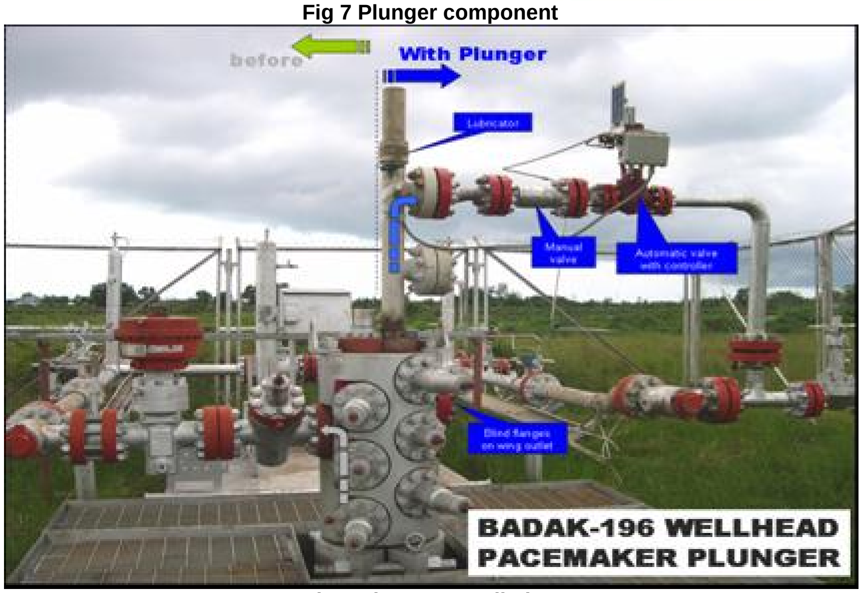

Fig 8 Plunger Installation

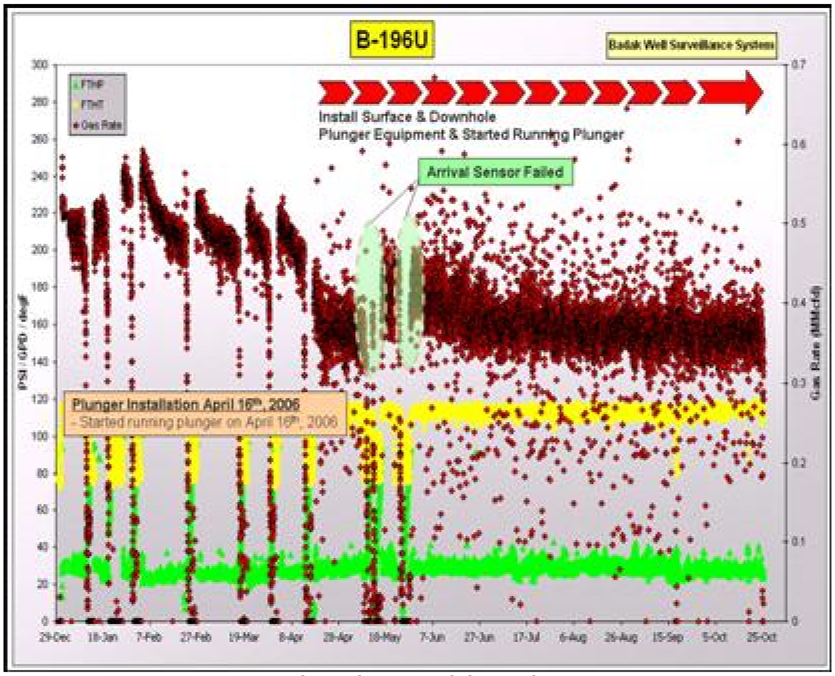

Fig 9 Plunger Trial Result

Fig 10 Wellhead compressor trial

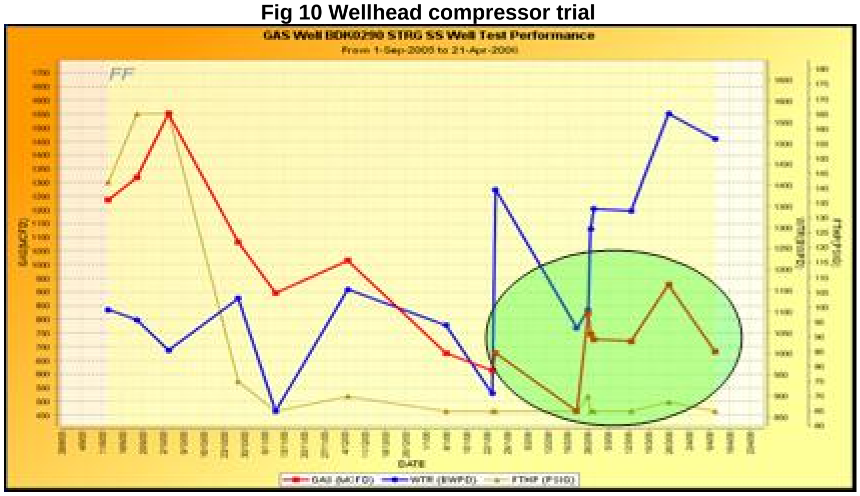

Fig 11 Wellhead compressor trial result

Fig 12 Wellhead Compressor

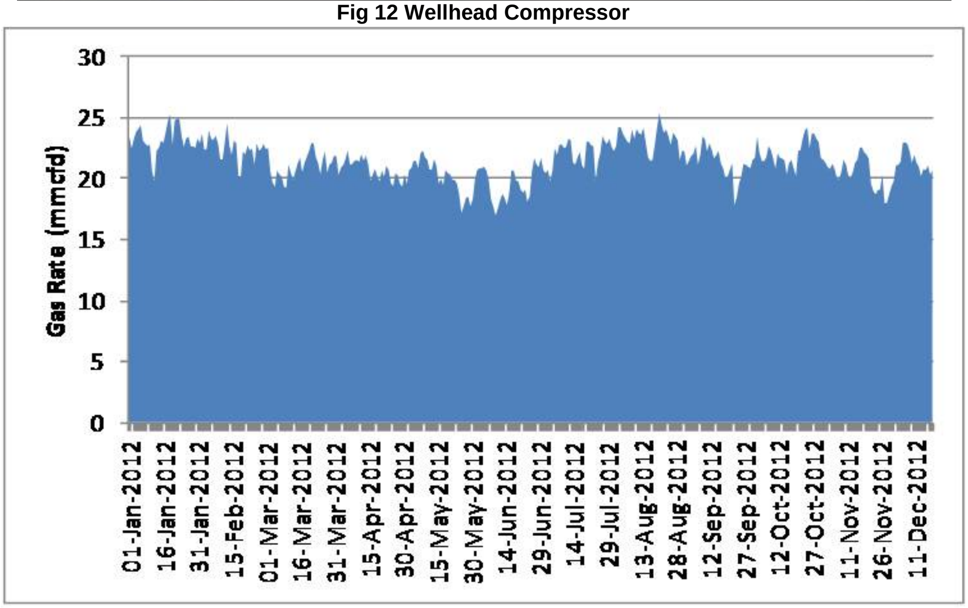

Fig 13 Wellhead Compressor Rate