Ascertainment of potential increase in production of RAG oil wells due to casing pressure drop

Diploma Thesis

Presented by

Nicole Engl

Prepared for

RAG - Rohöl-Aufsuchungs AG

Supervisor: Dipl.-Ing. Thanh-Huong Pham

University of Leoben

Department of Mineral Resources and Petroleum Engineering

Chair of Petroleum Production and Processing

Supervisor: Univ.-Prof. Dipl.-Ing. Dr.mont. Herbert Hofstätter

Leoben, November 2009

„Das Beginnen wird nicht belohnt, einzig und allein das Durchhalten.“

Katharina von Siena (14.Jhdt.)

AFFIRMATION

I declare in lieu of oath that I did this master´s diploma thesis in hand by myself using only literature cited at the end of this volume.

Nicole Engl

Leoben, November 2009

Acknowledgements

I would like to express my sincere gratitude to Univ.-Prof. Dipl.-Ing. Dr.mont. Herbert Hofstätter for his support during my thesis.

I would like to thank Dipl.-Ing. Thanh-Huong Pham, RAG – Rohöl-Aufsuchungs AG and Dipl.-Ing. Markus Seywald for their advice during the work on this diploma thesis.

Further I would like to thank Dipl.-Ing. Christoph Marshall for giving me the opportunity to write this thesis at RAG – Rohöl-Aufsuchungs AG, and Univ.-Prof Bergrat h.c. Dipl.-Ing. Dr.mont. Gerhard Ruthammer for his patronage regarding valuable contacts.

Additionally I would like to express my thanks to Dipl.-Ing. Thomas Wöhrer for his support during some measurements.

Special thank goes to Heinz Lederer and his team, but particularly to Wolfgang Windischbauer and Gerhard Moser for their great help and support during my thesis.

I dedicate this diploma thesis to my family.

Abstract

Ascertainment of potential increase in production of RAG oil wells due to casing pressure drop

Aim of this diploma thesis was to optimize production due to casing pressure drop for long standing oil fields which are on the decline by reason of decreasing reservoir pressure. When in an oil well a column of gas forms in the casing above the fluid level in the annulus, casing pressure is developed. Due to this fact the evolving pressure holds back the hydrocarbons flow into the well and so restricts the amount of oil and gas production. It is utile for the productivity of the well to lower the casing pressure and thus allow more hydrocarbons to flow into the wellbore. This major inflow increases the dynamic fluid level and thus advances production. In order to relieve the casing pressure and increase productivity, a specific and profitable method is the beam mounted gas compressor technology.

The principle is based on a big bicycle pump and draws the gas from the casing, compresses it and afterwards releases the gas into the flow line. A typical beam mounted gas compressor is attached on the walking beam of a pumping unit, and is operating either single-acting or double-acting.

For lower casing gas volume applications a single-acting device is assembled. It draws gas from the casing during one half of the pumping unit stroke cycle and releases it during the second half. The double-acting option is used to fit higher gas volume applications. It has two reservoirs that enable to draw gas in one reservoir and compress and release it in the other. This procedure takes place on the upstroke and the downstroke of the pumping unit.

A beam mounted gas compressor utilizes the pumping unit as its prime mover and energy source. By moving the gas up the casing and away from the down hole pump it results in increasing pumping efficiency and also prevents gas locking.

An outside of Europe manufactured beam mounted gas compressor is not permissible unless official approval has been obtained in Austria. According to ATEX-directive and CE-certification the BMGC has to be modified in some different regions.

An alternative to reduce the casing pressure for several oil wells is the application of a multiphase pump, but this option has exposed not to be economical for the analyzed oil wells.

In order to determine an appropriate well for a beam mounted gas compressor, different screening criteria were made. Subsequent some simulations were accomplished and the results could be verified with production tests.

Finally, it should be noted that for an optimum evaluated candidate, this technology is a promising and economic system with short payback time.

Kurzfassung

Potentialerhebung für mögliche Produktionssteigerungen bei RAG Ölsonden durch Druckabsenkung im Casing

In dieser Diplomarbeit wurde die mögliche Produktionssteigerung aufgrund einer Druckabsenkung im Casing speziell bei älteren, marginalen Ölfeldern mit geringem Lagerstättendruck näher durchleuchtet. Wenn sich in der Sonde im Casing Annulus eine Gassäule über dem Flüssigkeitsspiegel bildet, entsteht ein Druck im Casing. Dieser Druck mindert den Zufluss der Kohlenwasserstoffe aus der Formation und reduziert die Öl- und Gasproduktion. Um die Produktivität der Sonde zu erhöhen ist es vorteilhaft den Casing Druck zu entlasten und dadurch einen erhöhten Zufluss an Öl und Gas zu ermöglichen. Der gesteigerte Zufluss führt zu einem Anstieg des dynamischen Spiegels und verbessert die Produktion. Eine zielgerichtete Methode zur Druckentlastung und Erhöhung der Produktion stellt die Beam Gas Kompressor Technologie dar.

Diese basiert auf dem Prinzip eines Kolbenkompressors, der das Gas aus dem Casing ansaugt, verdichtet und anschließend ins Leitungsnetz einspeist. Ein herkömmlicher Beam Gas Kompressor wird an der Pferdekopfpumpe befestigt und kann entweder einfach wirkend oder doppelt wirkend ausgeführt werden.

Für geringer auftretende Gasmengen in der Sonde wird die einfach wirkende Variante eingesetzt, wobei jeweils nur während einer Hälfte des Tiefpumpenkreislaufes Gas angesaugt wird, sowie während der anderen dieses abgegeben wird. Die doppelt wirkende Arbeitsweise findet bei größeren Gasmengen Verwendung und komprimiert während eines vollständigen Tiefpumpenkreislaufes sowohl bei der Aufwärts- als auch bei der Abwärtsbewegung des Pumpenbockes.

Der Kompressor nutzt die vorhandene Energie des Pumpenbockes für die Gasverdichtung. Aufgrund der Absaugung des Casing Gases kann die Effizienz der Tiefpumpe gesteigert und ein sogenanntes Gas Lock verhindert werden.

Außerhalb Europas hergestellte Kompressoren haben den ATEX-Richtlinien und der CE-Zertifizierung zu entsprechen. Um in Österreich eingesetzt werden zu können, sind einige Modifizierungen vorzunehmen.

Eine Alternative zur Druckabsenkung in mehreren Sonden bietet die Multiphasenpumpe. Diese stellte sich jedoch für die untersuchten Sonden als unwirtschaftlich und somit irrelevant heraus.

Zur Ermittlung einer geeigneten Sonde für einen Beam Gas Kompressor wurden verschiedene Auswahlkriterien festgelegt und weiters Software Simulationen durchgeführt, deren Ergebnisse durch Produktionstests verifiziert werden konnten.

Abschließend ist festzuhalten, dass bei Evaluierung eines passenden Kandidaten diese Technologie ein vielversprechendes und wirtschaftliches System mit überaus kurzen Amortisationszeiten ist.

Index

1 Introduction

Rohöl-Aufsuchungs AG – RAG founded in 1935, is an oil and gas company with its headquarters in Vienna, Austria. The operations center which is responsible for drilling, production and underground gas storage is located in Gampern, Upper Austria and as well in Zistersdorf, Lower Austria.

Based on the domestic market the know-how of the RAG Company (Figure 1) is meanwhile also substituted in several European countries.

Due to the fact that many of the long standing RAG oil and gas fields are on the decline, it is necessary to optimize production much possible.

A critical factor for an effectual well is that its production pressure is greater than the pressure of the gathering system. [2]

Typically, a fluid column will build up above the formation, if a well is not pumped off. The fluid exerts backpressure on the formation in form of the hydrostatic head. In addition to the hydrostatic head of the fluid level, the surface casing pressure exerts backpressure on the formation. For this purpose, it could be inferred that an increase in backpressure on the formation will cause a decline in drawdown and accordingly reduce the productivity of the well. The ability for a well to increase production will be greater if the casing pressure is decreased. [2]

Moreover, if the casing pressure is high in relation to the bottom hole flowing pressure, some of the free gas enters into the pump barrel causing gas locks and thereby reduces the volumetric pump efficiency.

By reducing the casing pressure on wells with low bottom hole pressure, the volume of gas entering the pump barrel can be minimized. Thus, the gas lock problems are reduced in the pump. Afterwards, the free gas is diverted into the annulus and produced with the assistance of the Beam Mounted Gas Compressor (BMGC). A BMGC is mounted on the walking beam of a rod pumping unit. [2]

Additionally, the density of the fluid is reduced if the gas is allowed to enter the annulus and mix with the annulus fluid. A reduction in the fluid level density results in a reduction of back pressure exerted on the formation by the hydrostatic head of the annulus fluid column, and also results in an increased oil and gas production. [1]

Figure 1: Image brochure of RAG Company 2009 [3]

1.1 Conceptual Formulation

The main function of a Beam Mounted Gas Compressor is to draw gas from the casing side of an oil well and to discharge the gas into the flow line.

Furthermore, the BMGC reduces the back pressure on the formation face, thus allowing additional oil to enter the wellbore for production.

When selecting wells for BMGC applications it is necessary to have high casing pressure, low bottom hole pressure, size and condition of pumping unit, production rate and trend, and GOR. [1]

1.2 Objective Target

A Beam Mounted Gas Compressor has to be selected for an optimum candidate. The system installation of the BMGC, as well as the performance, results, technical and economical aspects, safety and maintenance requirements should be analysed. For a technical calculation a software tool like Prosper® should be used.

2 Basics

Oil wells which use pumping units (Figure 2) to artificially lift oil from the well are also wells that generally produce natural gas in addition to oil. When the oil formation conveys oil into the well bore, the formation also releases natural gas into the casing annulus if there is no packer in the well. The downhole pump forces the oil through the tubing up to the wellhead and then into the flow line away from the wellhead. The oil formation pressure moves oil from the formation into the wellbore. The released gas will fill the annulus all the way up to the surface casing head. When the casing head gas pressure becomes equal to or exceeds the flow line pressure, the gas leaves the casing head and enters the same flow line as does the wellhead oil. [4]

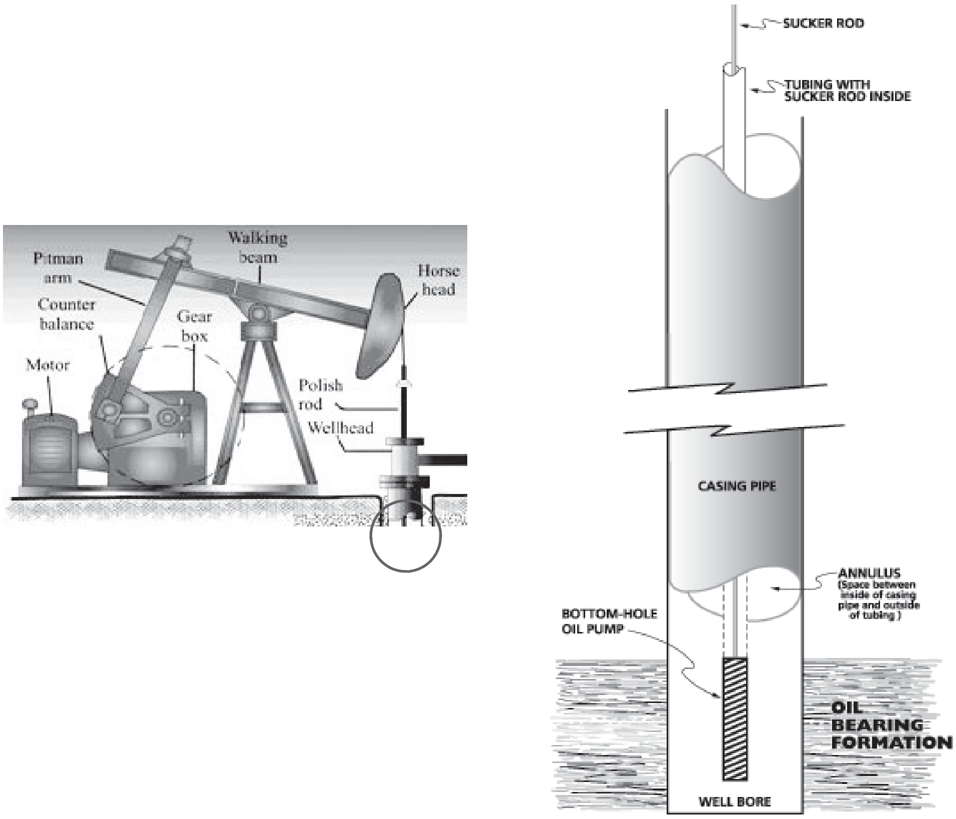


Figure 2: Pumping unit (left) and detailed view (right) [4]

During the life cycle of an oil well, the production over a proceeding time generally follows a typical scheme. An oil production chart for a well usually follows a decline curve.

After a long period of oil production, the decline in production could be so high that the production should be enhanced again. A possible procedure to raise the dropped production is to install a Beam Mounted Gas Compressor. [5]

An initial flush production of oil and gas occurs, when a BMGC is mounted on a walking beam. This flush increase is due to the fact that when the BMGC begins operation, the casing annulus is full of gas with the same pressure as at the flow line. The Beam Mounted Gas Compressor removes the gas at a rapid rate of discharge. During the gas removal based on BMGC, oil is released from the downhole formation by the sudden and significant drop in hydrostatic pressure. After the flush production period, the oil flow settles out at a different production level. [5]

The extent of the new production level is primarily a function of the permeability and porosity of the oil formation as well as the efficiency of the walking beam gas compressor. [5]

3 Beam Mounted Gas Compressor Technology

The technology of a Beam Mounted Gas Compressor is not a new one. BMGCs are in use for years now, but have often been saddled with maintenance and other performance issues that make them a risky investment. In recent years, new technology and operating strategies have been developed that easily overcome previous detriments to walking beam compressors. Nowadays, the design is intended to provide a very rugged, dependable, compressor for longevity by reliable operation.

3.1 Theoretical View

Pumping well productivity depends on different factors. [2]

Factors to be considered for Beam Mounted Gas Compressor installations include (a) pumping unit capacity, (b) downhole pump condition, (c) ability of the formation to give up fluids, (d) density and nature of the annulus fluid, and (e) location of annulus fluid levels. [2]

Factors a and b can be identified by running dynamometer surveys (the principle of dynamometer measurements is explained in Chapter 6.2.1) or by closing surface valves on the wellhead to allow the pump to run for a few minutes. [2]

An indicator that the downhole pump is in good condition is given by the fact that the tubing pressure increases with the pump strokes. If the tubing pressure does not build up, it indicates that the downhole pump is defective, a tubing leak exists, or a leak in the surface equipment subsists. [2]

Statement c is the domain of a Reservoir Engineer. It is more complex to ascertain whether a formation´s ability to give up fluids can be enhanced. Important information are delivered initial production tests. It can be established whether a well is capable of producing a certain volume of oil and gas. With preceding time, the production rate of a well could decline. If the well has been on production for five or more years, the rate of a pumping well could be determined by decline curve analysis. [2]

Ancillary, transient pressure surveys could be arranged to effectively determine the permeability thickness which is $(k * h)$. This value could be translated into recovery figures. [2]

Factors d and e are dependent, because the relationship between the annular fluid level and the density of the fluid is proportional to the magnitude of the back pressure exerted on the formation face. [2]

In a well, the fluid column exerts backpressure on the formation in form of hydrostatic weight. An increase in hydrostatic weight on the sand face will need an equal increase in the following bottom hole pressure (p_{wf}) to produce the same volume of oil and gas. The bottom hole flowing pressure is representing the pressure in the well at a point opposite the producing formation. See Figure 3. In the same way the surface casing pressure also exerts back pressure on the sand face. In most cases the casing pressure reflects the pressure of the gas column above the annular fluid level. Therefore, an increase in the backpressure on the formation will cause a decline in the drawdown and accordingly reduce the productivity of the well. [2] See Chapter 3.1.1.2.

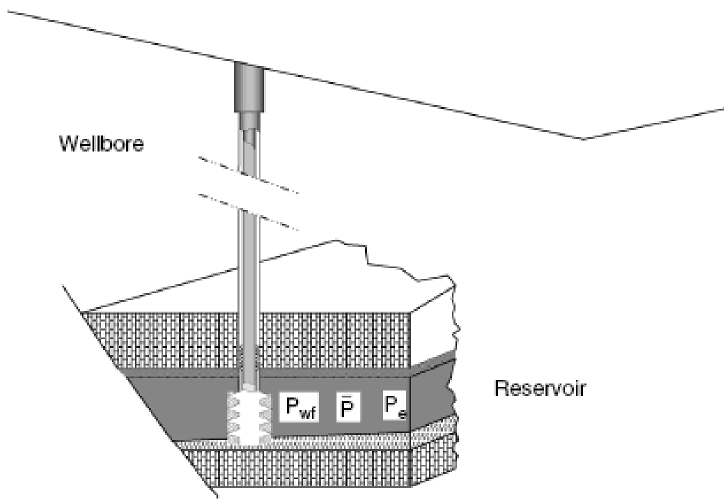


Figure 3: Schematic well with reservoir [9]

3.1.1 Reservoir Inflow Performance [7]

The Inflow Performance Relationship, called IPR, is used to define the relation between surface oil rate and the well flowing pressure. The term ´backpressure curve´ is used when giving attention to the productivity of gas wells. Bottom hole flowing pressure (p_{wf}) used in the IPR calculations is normally expressed at the depth of the mid perforation.

3.1.1.1 Single Phase Oil Flow IPR

The straight line is the simplest IPR equation, where the rate and the pressure drop (pressure drawdown) are in linear relationship. Today, the straight line IPR is only used for undersaturated oil reservoirs (single phase oil). The constant of proportionality is so called productivity index (PI or J). See Figure 4.

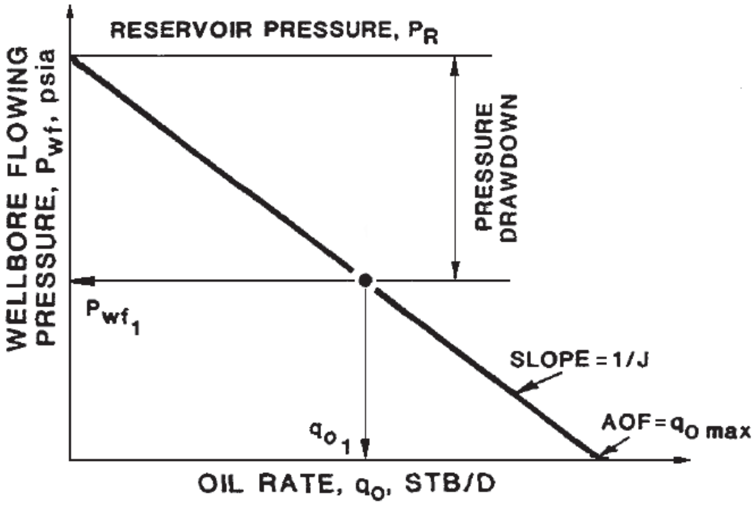


Figure 4: Straight-line IPR

3.1.1.2 Productivity Index

The productivity index is used to define the productivity of a well and is dependent on the drawdown. The drawdown is the difference between the average reservoir pressure and the pressure at the bottom of the tubing. This drawdown is a pressure drop and causes the production flow into the well from the producing formation. It is not constant but varies with production rate or pressure drawdown. In other words, it can be expressed; the more drawdown, the higher the production. The formula of the productivity index is mentioned below.

$$PI = \frac{q_o}{\overline{p_r} - p_{wf}} \qquad \text{......(1)}$$

Formula - Parameter		
Item	Explanation	Unit
PI	Productivity Index	(bbl/d)/psi
q_o	Oil production rate	bbl/d
$\overline{p_r}$	Average reservoir pressure	psi
p_{wf}	Bottom hole pressure	psi

3.1.1.3 Two-Phase Flow IPR

A standard equation for calculating the IPR in saturated oil reservoirs (gas is liberated or free when pressure drops below bubble point pressure) is derived by Vogel (1968). This is mentioned in Figure 5.

$$\frac{q_o}{q_{o\max}} = 1 - 0.2\left(\frac{p_{wf}}{p_r}\right) - 0.8\left(\frac{p_{wf}}{p_r}\right)^2 \quad ......(2)$$

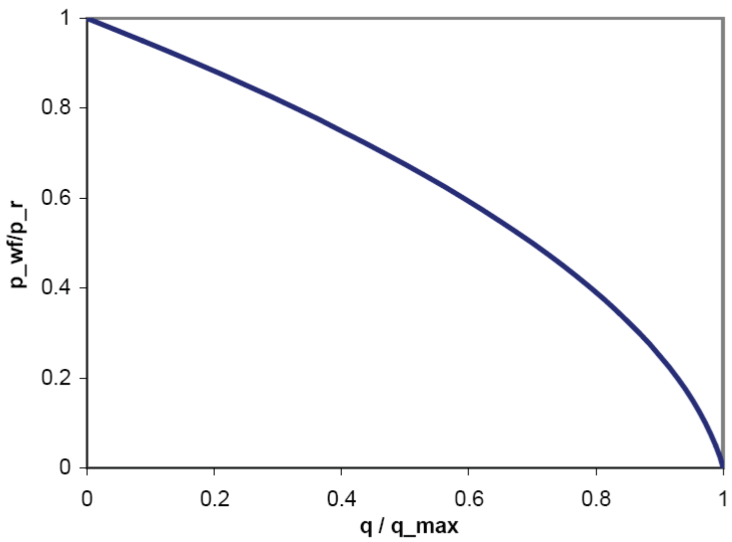


Figure 5: IPR for Solution gas drive reservoir (after Vogel)

The principal reason for the curved shape of the Vogel curve is the liberation of gas due to the decreased pressure in the vicinity of the wellbore. This effect creates an increasing gas saturation profile towards the well and coevally decreases the effective permeability to liquid. The liquid rate is also decreased.

The PI constant is not used for wells producing below the bubble point pressure p_b. Above the bubble point the IPR curve still appears as straight line which is mapped in Figure 6. At maximum production rate which is called the absolute open flow potential (AOF), the p_{wf} is zero. In case of reservoir pressures above the bubble point the reservoir pressure p_r has to be substituted by p_b.

$$q = q_b + (q_{\max} - q_b)\left[1 - 0.2\left(\frac{p_{wf}}{p_b}\right) - 0.8\left(\frac{p_{wf}}{p_b}\right)^2\right] \quad ......(3)$$

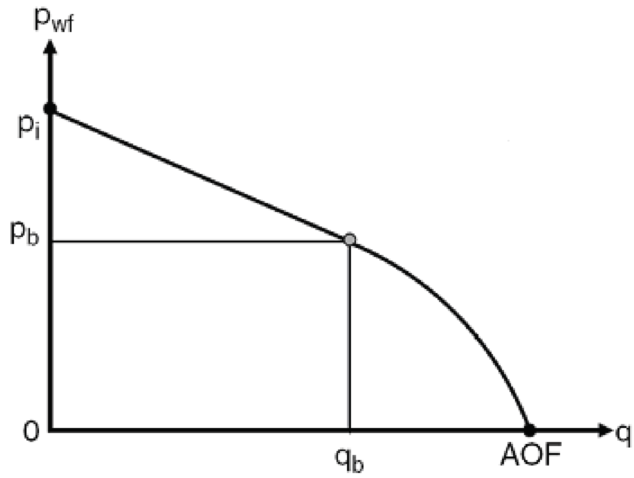


Figure 6: IPR-Curve with bubble point pressure

An increase in pressure drawdown increases the ability of the formation to produce fluid. The drawdown and the productivity of the well will be reduced, when the casing pressure implements sufficient backpressure on the formation,

If the p_{wf} is below the bubble point pressure of the fluids, the formation would tend to produce excess volumes of free gas equivalent to the formation gas liquid ratio multiplied by the volume of oil produced.

A high casing pressure compared to the bottom hole pressure, means that some of the free gas will enter the tubing and casing annulus and some gas will be forced into the pump barrel. This can cause gas locks and reduce the volumetric efficiency of the pump.

3.1.2 Casing Formation Backpressure in the Wellbore

Figure 7 shows the coherence of the casing formation back pressure and the flow of hydrocarbons into the wellbore.

The movement of gas in the reservoir stops when the pressure of reservoir gas is equal to the weight of the fluid column and the resistance in the separator and flow line. [6] The casing formation backpressure is holding back the hydrocarbons flow into the well.

Thus production of oil falls to zero. It becomes necessary to plug and abandon the well. Another way is to find a solution that will restore enough production to extend the producing life of the well. [6] So it is beneficial for the productivity of the well if the casing formation backpressure is as low as possible. On the other hand a particular pressure is needed to operate the separator at wellhead.

The Beam Mounted Gas Compressor relieves the backpressure from the formation and allows more hydrocarbons to flow into the wellbore and thus the dynamic level will rise. The production of the well will thereby increase.

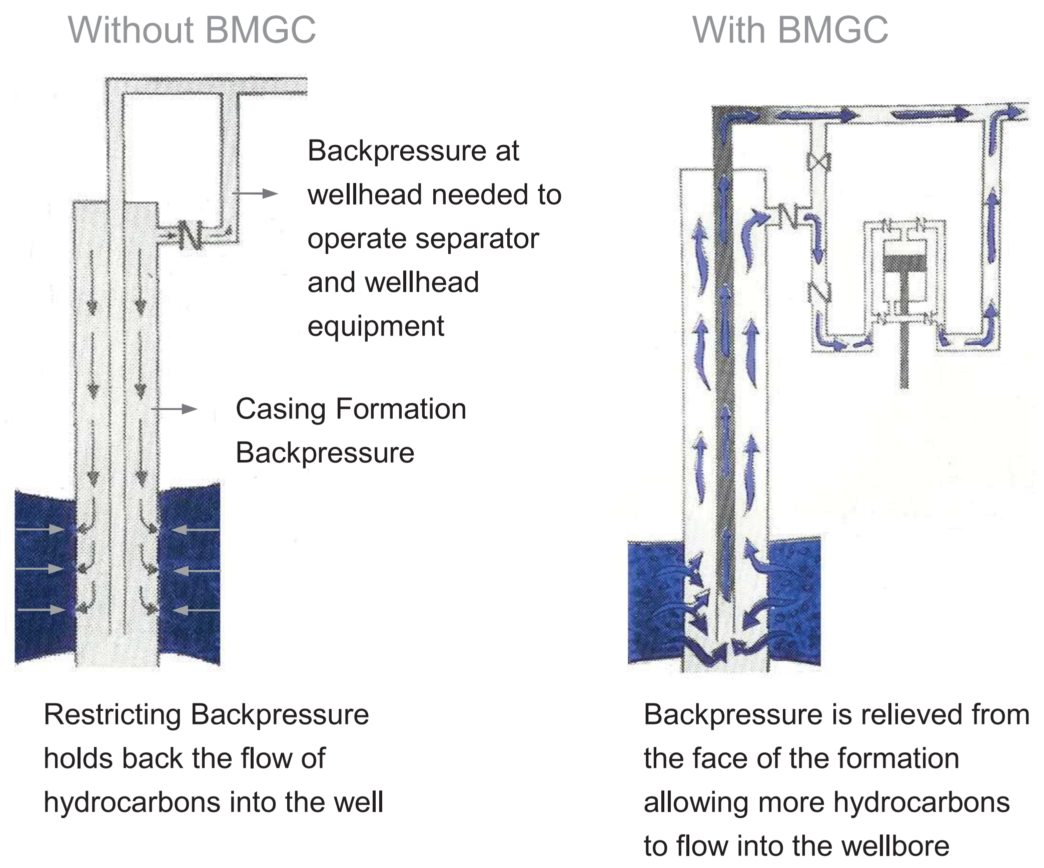


Figure 7: Backpressure in the wellbore [26]

3.1.3 API Standard Conditions for Flow Measurement

The volume calculation (Sm³/h) referred to API standard conditions (15/1013) is using ambient conditions of 15℃ and 1013 mbar or 6 0℉ and 14.7 psia. API stands for American Petroleum Institute. [11]

3.2 Principle of Operation

A picture of a typical Beam Mounted Gas Compressor is shown in Figure 9 and in more detail in Figure 10. More precisely, a BMGC is a simple device that resembles a big bicycle pump. Inside the body of this compressor a piston is attached to a rod which is driven by the walking beam of the pumpjack. [17] The walking beam is powered by the prime mover of the pumping unit. Figure 8 below shows the working principle of a sucker rod pump.

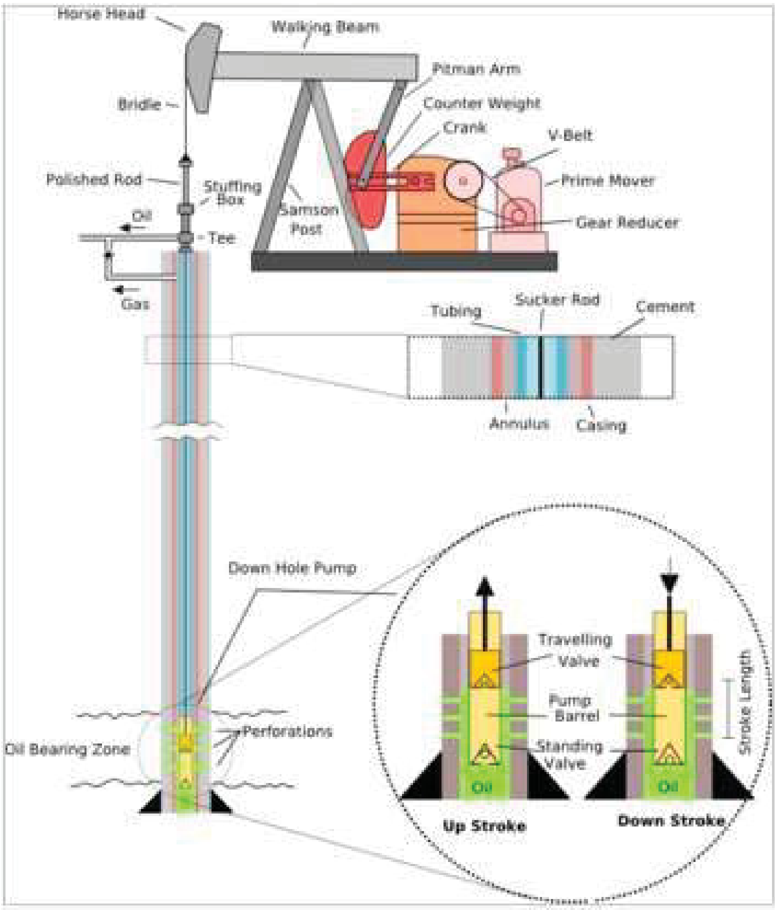


Figure 8: Walking beam with detailed description [14]

The Beam Mounted Gas Compressor draws gas from the casing, compresses it and releases it into the flow line. [13] On a pumping unit it is attached to the walking beam.

Figure 9: Beam Mounted Gas Compressor on a walking beam [20]

Figure 10: BMGC in more detail

3.2.1 Single-Acting

A BMGC is operating either single-acting or double-acting. The single-acting Beam Mounted Gas Compressor is used to fit lower gas volume applications. A single-acting option draws gas from the casing side of an oil well during one half of the pumping unit stroke cycle and releases it during the second half. One complete pumping unit stroke cycle is composed of an upstroke and a downstroke. During the upstroke, the walking beam moves upwards, whereby during the downstroke, the walking beam is moving downwards. Two check valves are used to direct the gas flow from the casing in the compressor (suction line) and out of the compressor to the flow line (discharge line). See Figure 11. If during BMGC operation the gas flow will increase, the Beam Mounted Gas Compressor can be activated as a double-acting system. [26]

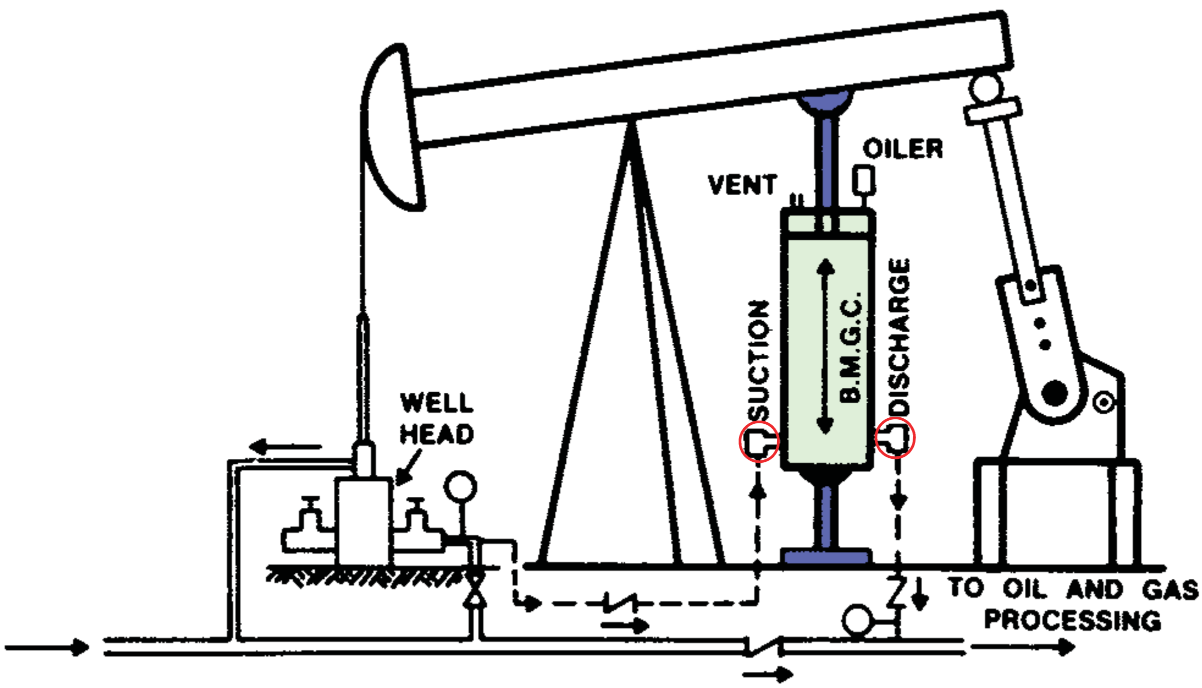


Figure 11: Single-acting Beam Mounted Gas Compressor [2]

3.2.2 Double-Acting

The double-acting Beam Mounted Gas Compressor is used to fit higher gas volume applications.

A double-acting BMGC has two reservoirs that enable it to draw gas in one reservoir and compress and release gas in the other. This procedure takes place on both the upstroke and the downstroke of the pumping unit. [13] It does not effect the counterbalance of the pumping unit, due to the fact that the Beam Mounted Gas Compressor requires the same amount of energy on the upstroke as well as on the downstroke.

For better understanding of how the operation of the compressor performs, a BMGC´s cycle can be categorized into four basic steps as seen in Figure 12. The double-acting compressor has two reservoirs with a suction and discharge line running to each. [13]

The first step, which occurs during the downstroke of the Beam Mounted Gas Compressor, has one reservoir (Reservoir ´A´) drawing in gas from the casing while the other (Reservoir ´B´) is compressing gas. Step II is at or near the bottom of the stroke when the gas being compressed reaches a pressure greater than the line pressure, thereby allowing it to be released into the discharge line. At the same time the other reservoir has completed filling. Step III, during the upstroke of the BMGC, has the piston reversing direction and as a result the reservoir that just completed compressing and releasing its gas, begins refilling while the reservoir that has been filled begins compressing gas. Finally, step IV occurs at the top of the stroke with one reservoir releasing and the other filling to complete the cycle. Throughout each pumping unit stroke this cycle is repeated. [13]

The result of the varying pressures in the compressor is a varying force on the walking beam at the point where the BMGC is attached. To determine the pressure gradient, either a pressure transducer can be installed and the pressure recorded during one cycle or it can be calculated. [13] The calculation method is described in more detail in chapter 3.6.

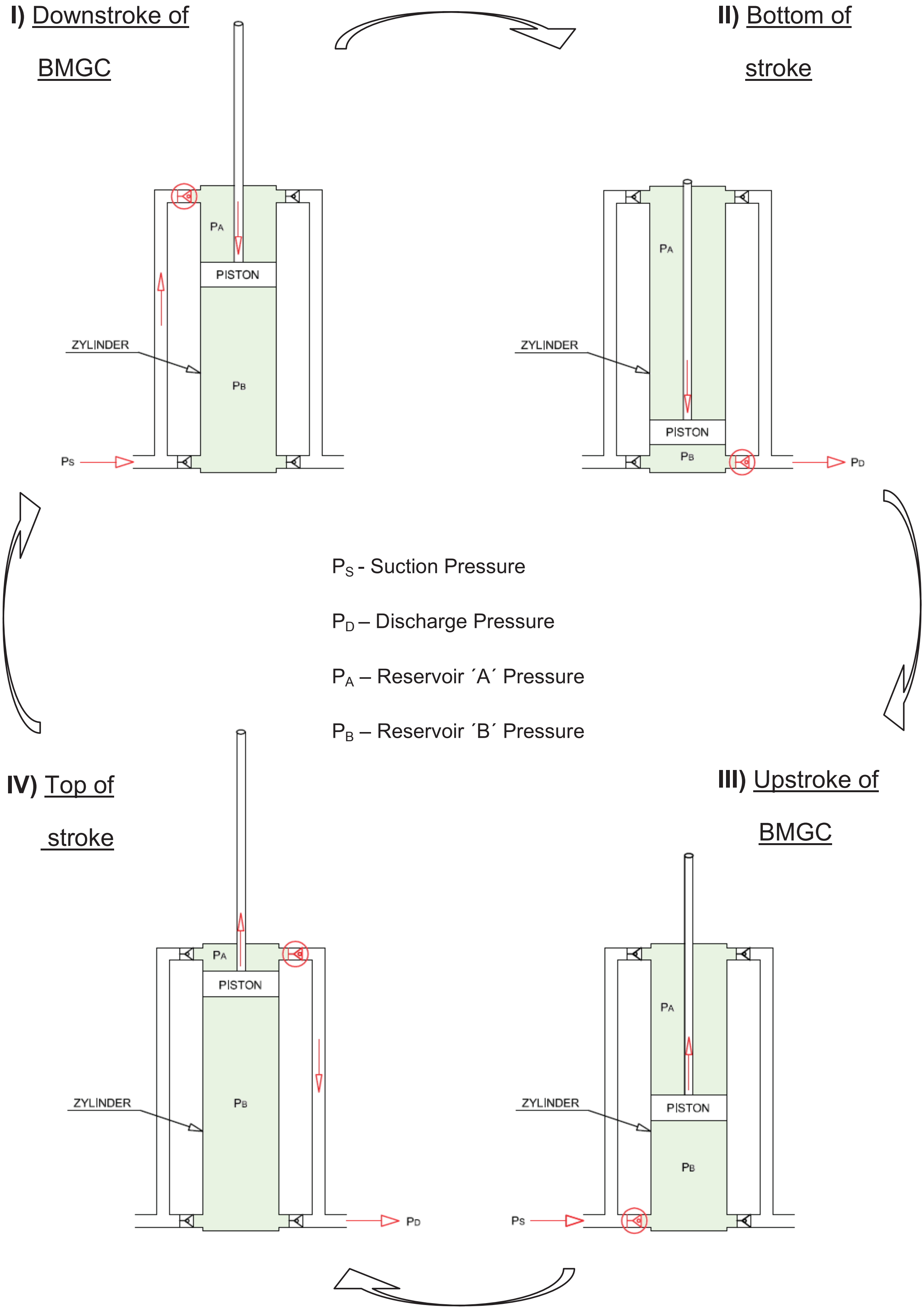


Figure 12: Double-acting Beam Mounted Gas Compressor – Cycle

3.2.3 System Installation

There are several opportunities of Beam Mounted Gas Compressor installation. Therefore it is important to distinguish between different kinds of pumping units. The RAG Company is using two different types, which are the Conventional Unit and the Mark II Unit. So the main focal point is on those types.

In general, the installation of the BMGC is very simple and does not require any welding on the wellhead or the pumping unit. [2]

On a Conventional Pumping Unit, the BMGC is attached to the walking beam between either the center and equalizer bearings or the center bearing and horsehead. [13] For better understanding, see Figure 13. There is a relationship between these two installation methods and the working cycle of the BMGC. If the compressor is mounted between the center bearing and the equalizer bearing during the upstroke of the pumping unit, the BMGC is forced to downstroke. During the downstroke of the pumping jack, the Beam Mounted Gas Compressor is forced to upstroke. If the BMGC is installed between the center bearing and the horsehead during the upstroke of the sucker rod pump, the BMGC is equally forced to upstroke. While the downstroke of the pumping unit, the Beam Mounted Gas Compressor is also forced to downstroke.

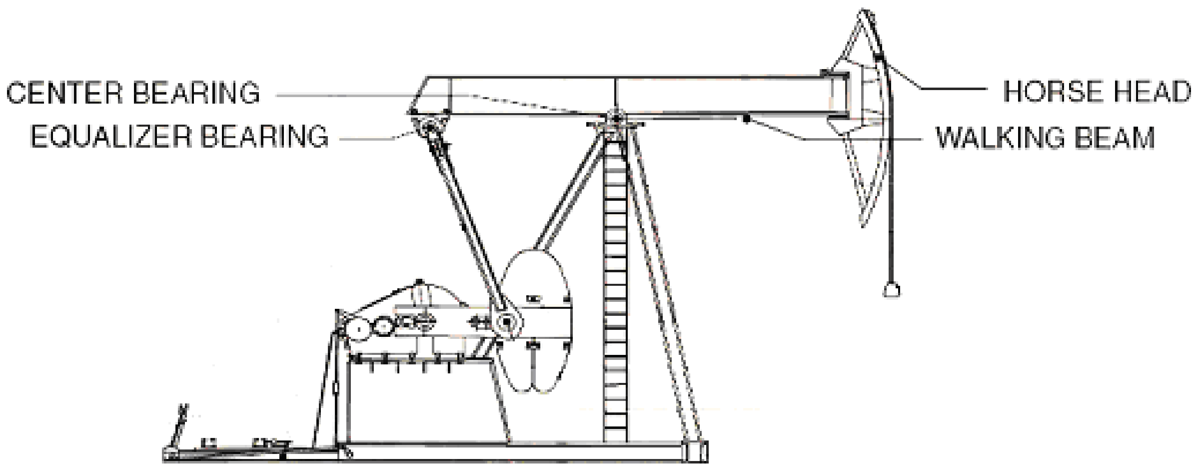


Figure 13: Conventional pumping unit with center and equalizer bearing [3]

Depending on whether the BMGC is installed on the front or the back side of the center bearing, the cylinder stroke of the BMGC is either upstroke or downstroke compared to the cylinder stroke of the pumping unit. If the BMGC is mounted between the center and equalizer bearing, the pumping unit is accomplishing an upstroke, while the Beam Mounted Gas Compressor is doing a downstroke. A complete cycle of a BMGC, mounted on the back side of the center bearing including the different pressure lines during an upstroke and a downstroke of the pumping unit is mapped in Figure 14 and Figure 15.

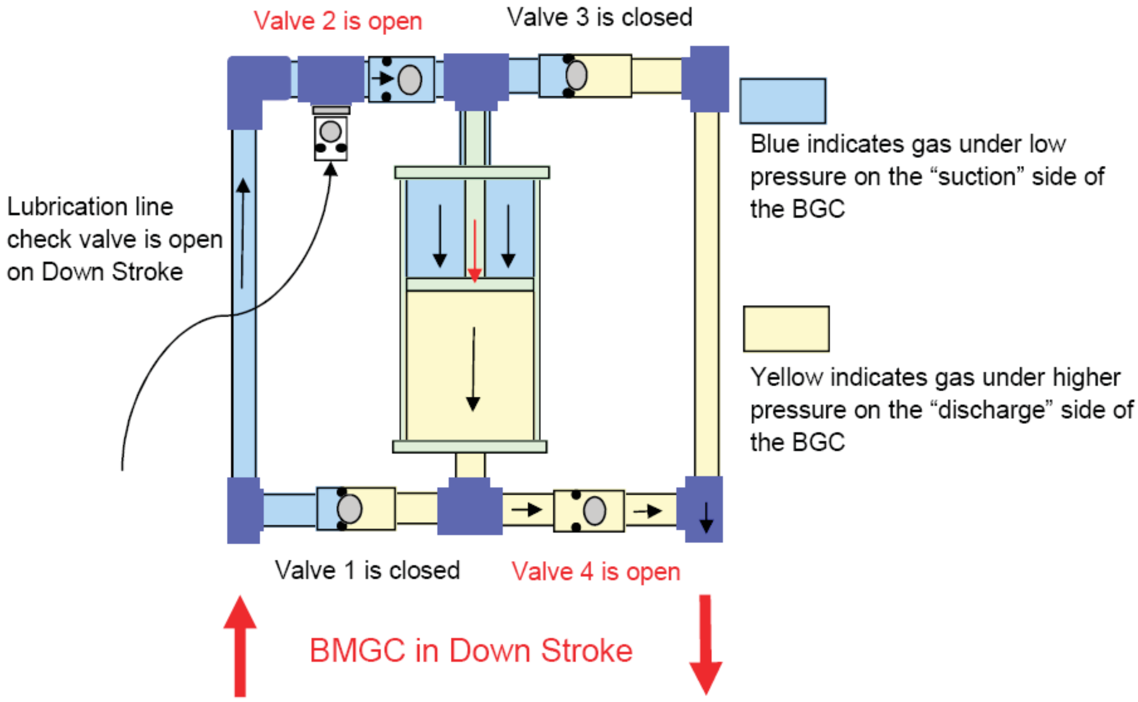


Figure 14: Upstroke of pumping unit [26]

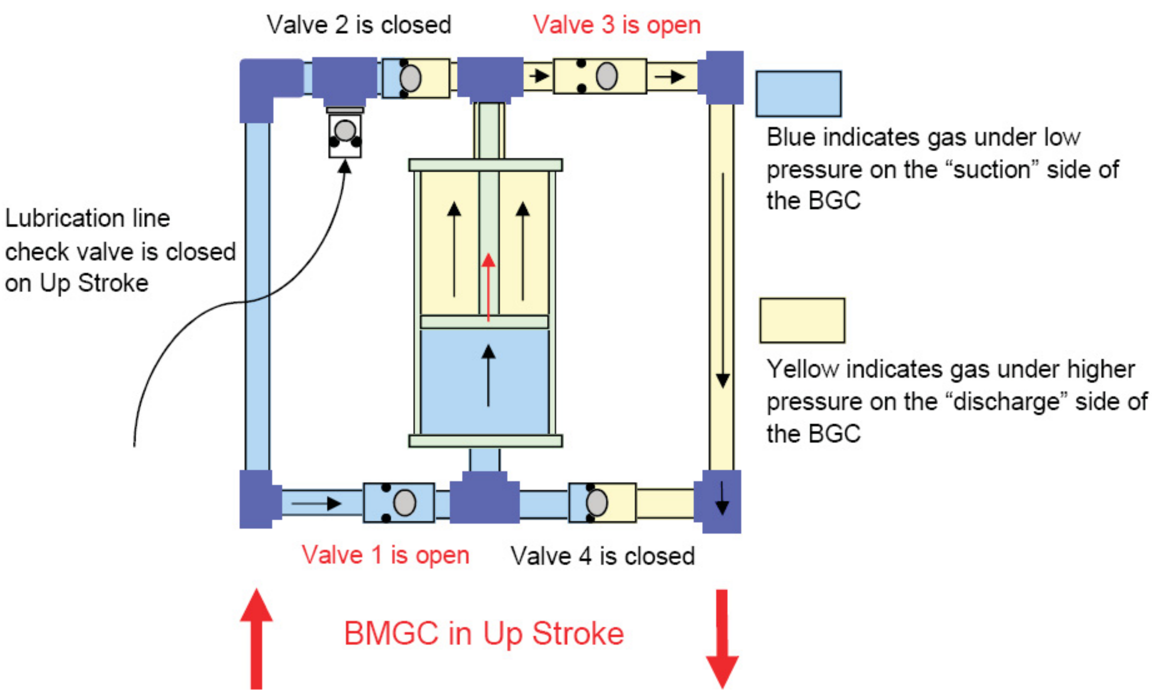


Figure 15: Downstroke of pumping unit [26]

On a Mark II Unit, the Beam Mounted Gas Compressor is either mounted on the back or in front of the walking beam. The different installation types are mentioned below.

- Conventional Pumping Unit – Skid mount installation, method 1:

The BMGC is mounted between the center bearing and the equalizer bearing. This is the most common installation method for Conventional Pumping Units. The BMGC is clamped to the walking beam and as already mentioned, welding is not required. The adjustable base mount is the part of the system that fills the space from the bottom of the BGC down to the position where it is clamped to the skid or the sampson post. Also, welding is not required to the pumping unit skid.

Figure 16 shows a BMGC which is mounted on a Conventional Unit.

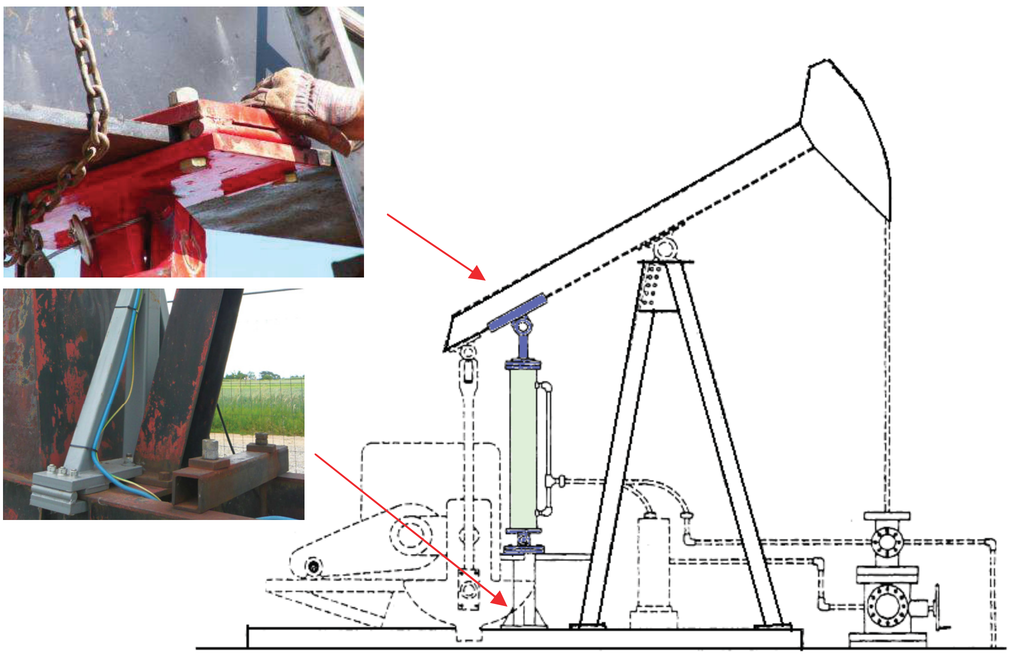


Figure 16: Conventional Pumping Unit with BMGC [19]

- Conventional Pumping Unit – Sampson post mount installation, method 2:

The BMGC is mounted on a sampson post of a Conventional Unit. See Figure 17. A sampson post mount is utilized where there is not adequate room to mount the BMGC between the gear box and the sampson post. The post mount installation can also be deployed to accommodate a shorter stroke BMGC cylinder. Equally, the sampson post clamp does not require welding. If bracing is required the braces are always welded to the BGC sampson post clamp.

Figure 17: Conventional Unit with BMGC on a sampson post [21]

- Conventional Pumping Unit – In front of sampson post installation method 3:

The Beam Mounted Gas Compressor is mounted in front of the sampson post on a Conventional pump jack (Figure 18). On pumping units where a large stroke length for the BMGC is needed, the BMGC can be mounted in front of the sampson post.

Figure 18: Conventional Unit with BMGC in front of the sampson post [22]

- Conventional Pumping Unit – Double Skid mount installation method 4:

Two Beam Mounted Gas Compressors mounted on a Conventional Unit working together as a two stage compressor for higher discharge pressure applications. See Figure 19.

Figure 19: Conventional Unit with two BMGC´s [21]

- Mark II Pumping Unit – Behind gear box installation, method 1:

When installing the BMGC System being driven by a Mark II Unit where the gas amount is low, a BMGC with a shorter stroke can be used and installed behind the gear box. A Beam Mounted Gas Compressor which is typically installed on a Mark II Unit, can be seen in Figure 20.

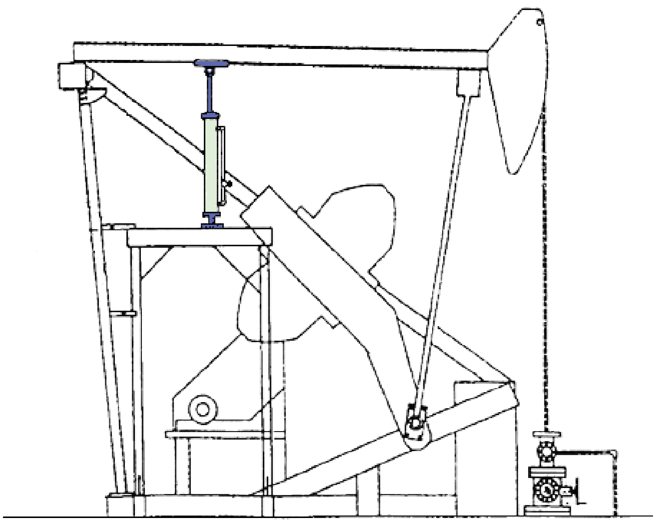


Figure 20: Mark Pumping Unit with BMGC behind the gear box [19]

- Mark Pumping II Unit – In front of gear box Installation, method 2:

Mounting in front of a Mark II Unit will accommodate a longer BGC compression stroke and is used for higher gas volume wells. A Beam Mounted Gas Compressor which is mounted in front of a Mark II Unit is mentioned below in Figure 21.

Figure 21: Mark II Pumping Unit with BMGC in front of the gear box [22]

3.2.4 Wellhead Connections

At a typical installation of a Beam mounted gas compressor on an oil well, the BMGC receives gas from the casing head into the suction (input) flex hose of it. The BMGC discharges the gas through the discharge (output) flex hose into the flow line or gas sales line. [4]

Figure 22 represents a typical wellhead configuration. During standard operation, pumped oil flows from the tubing through OV-1 (Oil Valve 1) and CV-2 (Check Valve 2), and enters the flow line to the separator. The existing casing gas flows through GV-1 (Gas Valve 1) and CV-1 (Check Valve 1), and enters the same flow line to join the oil in the separator. The secondary gas valve GV-2 is either closed, or is connected to a pressure gauge that indicates the casing head gas pressure. [4]

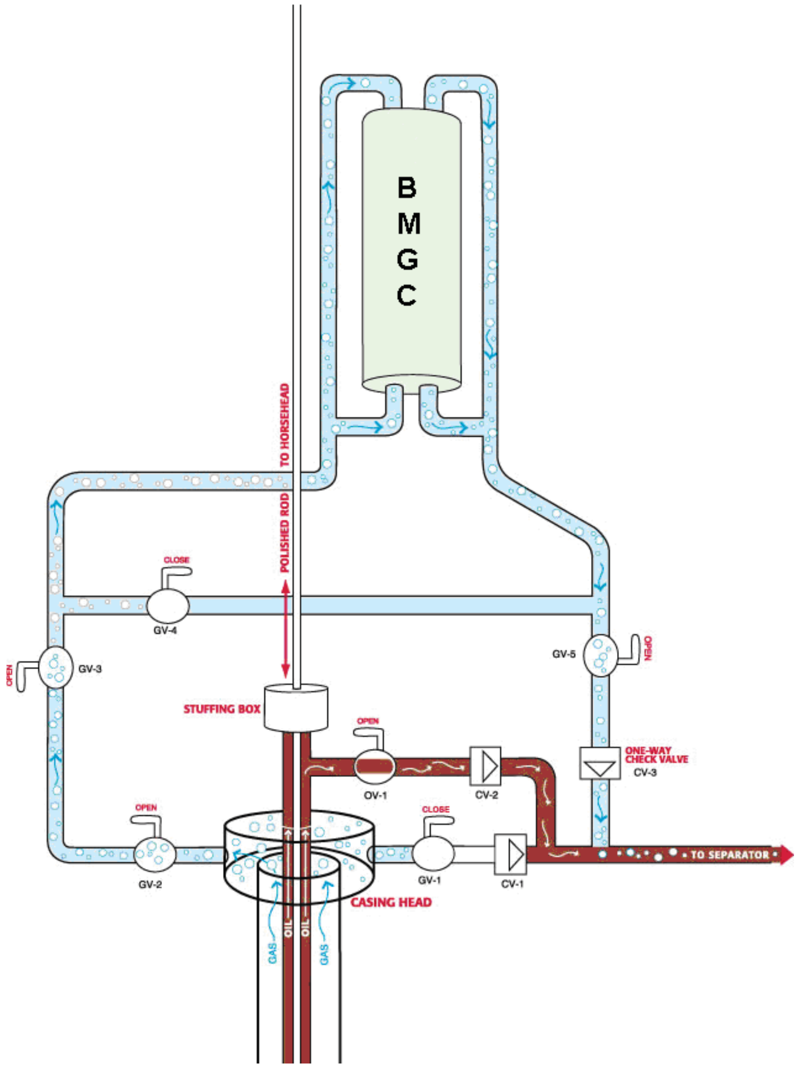


Figure 22: Wellhead configuration with BMGC in full functioning mode [10]

If a BMGC is installed, nothing changes with regard to the oil flow through OV-1 and CV-2. But with regard to casing head gas flow, piping is connected to GV-2 as shown in Figure 22. The gas valves GV-2, GV-4 and GV-5 are installed in the piping configuration in order to remove the function of the BMGC from the wellhead operation. This is important for chemical injection down the casing annulus, because the chemicals will not be drawn into and through the BMGC. Thereby, no harm will occur to the Beam Mounted Gas Compressor. [4]

When the BMGC function is active at the well, gas valve GV-1 is closed and GV-2 is open. The casing head gas is forced to enter the BMGC via GV-2. Furthermore, gas valves GV-3 and GV-5 are open, and GV-4 is closed. Gas flows from the casing head, through GV-2 and GV-3 into the BMGC. [4]

The discharged gas passes GV-5 and CV-3 and enters the same flow line to the separator. During this process, the BMGC has isolated the well head from the down stream flow line. Therefore, the casing head gas pressure can be reduced to the capacity of the BMGC (even into vacuum ranges), while the flow line pressure remains higher. The higher flow line pressure has no effect on the casing head gas pressure, and thus on the down-hole back pressure. The hydrostatic back pressure is then only a function of the Beam Mounted Gas Compressor. [4]

In Figure 23 gas valves GV-3 and GV-5 are closed, and GV-4 is open. During the pumping motion of the walking beam, gas within the BMGC solely circulates internally. If requested, GV-1 can be reopened in order to keep the casing head gas pressure not greater than the flow line pressure. [4]

When the BMGC function is again desired to be active, gas valves GV-3 and GV-5 are opened, and GV-4 and GV-1 are closed. [4]

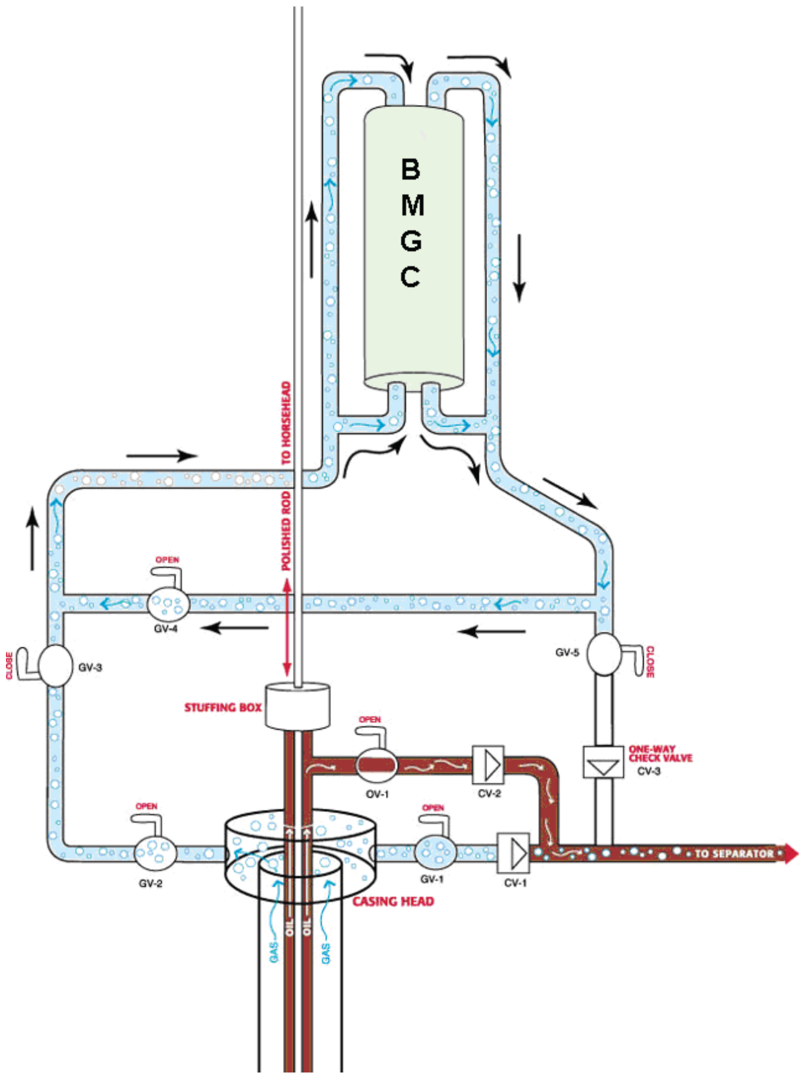
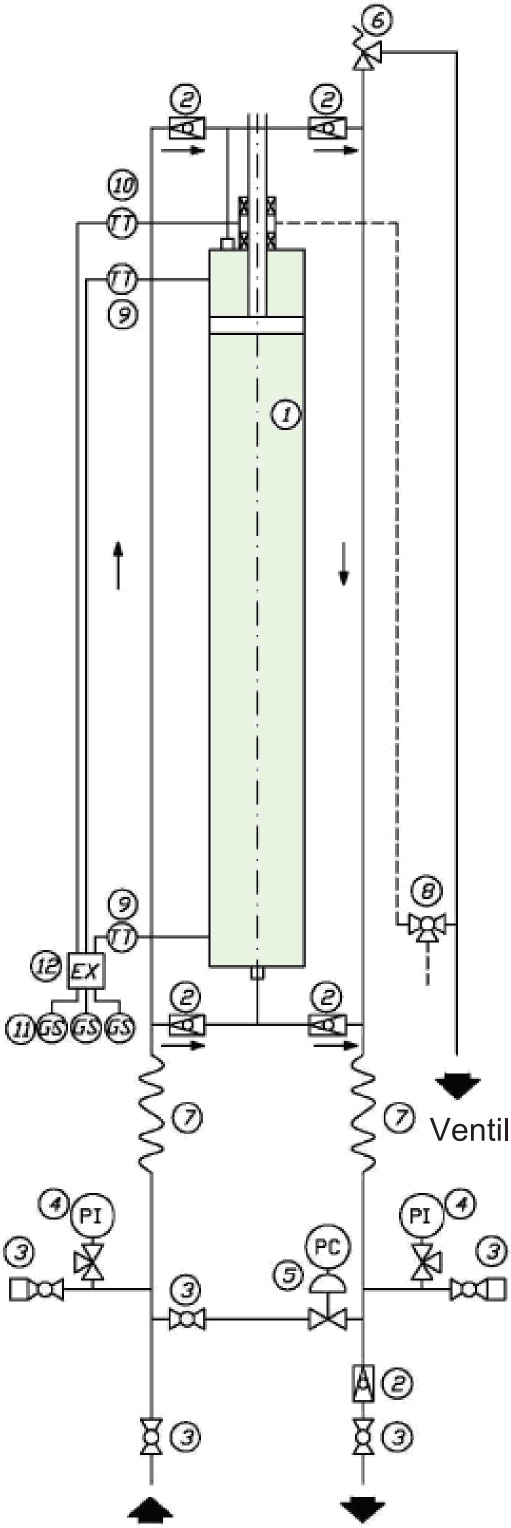


Figure 23: Well head configuration with BMGC in by-pass mode [12]

3.2.5 BMGC - Piping and Instrumentation Diagram/Drawing (P&ID)

A typical P&ID for upside-down-assembling of a double-acting Beam Mounted Gas Compressor is mentioned below in Figure 24.



1. BMGC double-acting
2. Check valves
3. Shut-off valves
4. Pressure gauge
5. Bypass regulator
6. Safety valve
7. Pressure hose
8. Bleeder valve to check stuffing box

---- Stuffing box – leakage line

9. Temperature sensor upper and lower gas compartment
10. Temperature sensor stuffing box
11. Temperature limit switch
12. Ex – electric panel

Pipeworks: ¾“

Figure 24: P&ID for upside-down-assembling of BMGC [26]

3.3 Sizing of a BMGC

A very important question is how to size a Beam Mounted Gas Compressor. The formula (5) calculates the volume in thousand cubic feet per day (MCFD) that a BMGC will compress. The BMGC should be sized to compress 10 to 20% more than the actual gas volume in order to be sure to have sufficient capacity in the BMGC system. The gas measured should be taken with the well at the same operating parameters the BMGC will be performing after installation.

Even though stroke lengths, piston diameters, and discharge pressures may vary, some typical sizes for BMGC are 5, 6, 8, 10, and 12 inch diameters with maximum discharge pressures of 300, 250, 200, 150, and 100 psi. All of them are available with 24, 36, or 48 inch stroke length. [13]

3.3.1 Sizing Charts

There are different sizing charts to calculate the casing pressure (psia) which will be obtained after installation of the BMGC (see Table 1, Table 2, and Table 3). First of all, the present strokes/minute of the pumping unit at the bottom line of the table has to be found. Then, it has to be followed the same column until the daily gas production figures (mcf/d) can be found. From that, it has to be moved across to the left side in order to find the casing (suction) pressure (psia).

If a different casing pressure is desired, the required pressure from the left column of the chart has to be located and the same procedure as explained above has to be done. In the opposite direction to determine the number of strokes/minute the pumping unit has to accomplish to reach the desired pressure.

Table 1: 6” BMGC with 48” stroke length and max service pressure: 1500 psig [24]

Suction Pressure PSIA (14)	Gas Volume (mcf/d)											
214	27.55	55.1	82.65	110.2	137.75	165.3	192.85	220.4	247.95	275.5	303.05	330.6
204	26.26	52.52	78.78	105.04	131.3	157.56	183.82	210.08	236.34	262.6	288.86	315.12
194	24.98	49.96	74.94	99.92	124.9	149.88	174.86	199.84	224.82	249.8	274.78	299.76
184	23.69	47.38	71.07	94.76	118.45	142.14	165.83	189.52	213.21	236.9	260.59	284.28
174	22.4	44.8	67.2	89.6	112	134.4	156.8	179.2	201.6	224	246.4	268.8
164	21.1	42.2	63.3	84.4	105.5	126.6	147.7	168.8	189.9	211	232.1	253.2
154	19.83	39.66	59.49	79.32	99.15	118.98	138.81	158.64	178.47	198.3	218.13	237.96
144	18.54	37.08	55.62	74.16	92.7	111.24	129.78	148.32	166.86	185.4	203.94	222.48
134	17.25	34.5	51.75	69	86.25	103.5	120.75	138	155.25	172.5	189.75	207
124	15.97	31.94	47.91	63.88	79.85	95.82	111.79	127.76	143.73	159.7	175.67	191.64
114	14.68	29.36	44.04	58.72	73.4	88.08	102.76	117.44	132.12	146.8	161.48	176.16
104	13.39	26.78	40.17	53.56	66.95	80.34	93.73	107.12	120.51	133.9	147.29	160.68
94	12.1	24.2	36.3	48.4	60.5	72.6	84.7	96.8	108.9	121	133.1	145.2
84	10.82	21.64	32.46	43.28	54.1	64.92	75.74	86.56	97.38	108.2	119.02	129.84
74	9.53	19.06	28.59	38.12	47.65	57.18	66.71	76.24	85.77	95.3	104.83	114.36
64	8.24	16.48	24.72	32.96	41.2	49.44	57.68	65.92	74.16	82.4	90.64	98.88
54	6.95	13.9	20.85	27.8	34.75	41.7	48.65	55.6	62.55	69.5	76.45	83.4
44	5.66	11.32	16.98	22.64	28.3	33.96	39.62	45.28	50.94	56.6	62.26	67.92
34	4.38	8.76	1314	17.52	21.9	26.28	30.66	35.04	39.42	43.8	48.18	52.56
24	3.09	6.18	9.27	12.36	15.45	18.54	21.63	24.72	27.81	30.9	33.99	37.08
14	1.8	3.6	5.4	7.2	9	10.8	12.6	14.4	16.2	18	19.8	21.6
Strokes per minute	1	2	3	4	5	6	7	8	9	10	11	12

Table 2: 8” BMGC with 48” stroke length and max service pressure: 1100 psig [24]

Suction Pressure PSIA (14)	Gas Volume (mcf/d)											
214	27.55	55.1	82.65	110.2	137.75	165.3	192.85	220.4	247.95	275.5	303.05	330.6
204	26.26	52.52	78.78	105.04	131.3	157.56	183.82	210.08	236.34	262.6	288.86	315.12
194	24.98	49.96	74.94	99.92	124.9	149.88	174.86	199.84	224.82	249.8	274.78	299.76
184	23.69	47.38	71.07	94.76	118.45	142.14	165.83	189.52	213.21	236.9	260.59	284.28
174	22.4	44.8	67.2	89.6	112	134.4	156.8	179.2	201.6	224	246.4	268.8
164	21.1	42.2	63.3	84.4	105.5	126.6	147.7	168.8	189.9	211	232.1	253.2
154	19.83	39.66	59.49	79.32	99.15	118.98	138.81	158.64	178.47	198.3	218.13	237.96
144	18.54	37.08	55.62	74.16	92.7	111.24	129.78	148.32	166.86	185.4	203.94	222.48
134	17.25	34.5	51.75	69	86.25	103.5	120.75	138	155.25	172.5	189.75	207
124	15.97	31.94	47.91	63.88	79.85	95.82	111.79	127.76	143.73	159.7	175.67	191.64
114	14.68	29.36	44.04	58.72	73.4	88.08	102.76	117.44	132.12	146.8	161.48	176.16
104	13.39	26.78	40.17	53.56	66.95	80.34	93.73	107.12	120.51	133.9	147.29	160.68
94	12.1	24.2	36.3	48.4	60.5	72.6	84.7	96.8	108.9	121	133.1	145.2
84	10.82	21.64	32.46	43.28	54.1	64.92	75.74	86.56	97.38	108.2	119.02	129.84
74	9.53	19.06	28.59	38.12	47.65	57.18	66.71	76.24	85.77	95.3	104.83	114.36
64	8.24	16.48	24.72	32.96	41.2	49.44	57.68	65.92	74.16	82.4	90.64	98.88
54	6.95	13.9	20.85	27.8	34.75	41.7	48.65	55.6	62.55	69.5	76.45	83.4
44	5.66	11.32	16.98	22.64	28.3	33.96	39.62	45.28	50.94	56.6	62.26	67.92
34	4.38	8.76	1314	17.52	21.9	26.28	30.66	35.04	39.42	43.8	48.18	52.56
24	3.09	6.18	9.27	12.36	15.45	18.54	21.63	24.72	27.81	30.9	33.99	37.08
14	1.8	3.6	5.4	7.2	9	10.8	12.6	14.4	16.2	18	19.8	21.6
Strokes per minute	1	2	3	4	5	6	7	8	9	10	11	12

Table 3: 10” BMGC with 48” stroke length and max service pressure: 900 psig [24]

Suction Pressure PSIA (14)	Gas Volume (mcf/d)									
114	43.32	86.64	129.96	173.28	216.6	259.92	303.24	346.56	389.88	433.2
104	39.52	79.04	118.56	158.08	197.6	237.12	276.64	316.16	355.68	395.2
94	35.72	71.44	107.16	142.88	178.6	214.32	250.04	285.76	321.48	357.2
84	31.92	63.84	95.76	127.68	159.6	191.52	223.44	255.36	287.28	319.2
74	28.12	56.24	84.36	112.48	140.6	168.72	196.84	224.96	253.08	281.2
64	24.32	48.64	72.96	97.28	121.6	145.92	170.24	194.56	218.88	243.2
54	20.52	41.04	61.56	82.08	102.6	123.12	143.64	164.16	184.68	205.2
44	16.72	33.44	50.16	66.8	83.6	100.32	117.04	133.76	150.48	167.2
34	12.92	25.84	38.76	51.68	64.6	77.52	90.44	103.36	116.28	129.2
24	9.12	18.24	27.36	36.48	45.6	54.72	63.84	72.96	82.08	91.2
14	5.32	10.64	15.96	21.28	26.6	31.92	37.24	42.56	47.88	53.2
Strokes per minute	1	2	3	4	5	6	7	8	9	10

These gas volumes in the tables above are all based on a 48” stroke length. A 36” stroke length will make up 75% of these volumes and a 24” stroke length 50%.

The flow line (discharge) pressure is the determining factor for selecting the appropriate model for each application. If the rod load created by the Beam Mounted Gas Compressor is too high, damages to the pumping unit will occur. [24]

3.3.2 Sizing Formula

By using the formula below, one can obtain the pressure (psia) that a BMGC will draw the casing pressure down to. [15]

$$P = \frac{M * 1600}{S * L * A} \qquad \text{......(4)}$$

Formula - Parameter		
Item	Explanation	Unit
P	Suction gauge pressure + Atmospheric Pressure of BMGC	psia
M	Gas volume (displacement)	mcf/d
S	Strokes per minute of Pumping Unit	strokes/min
L	Length of stroke of BMGC	ft
A	Cross-sectional area of the piston	in²

To calculate the gas volume (displacement) of the BMGC, for a single-acting system, the following formula as well as data is required [15]:

$$M = \frac{S * L * A * P}{1600} \qquad ......(5)$$

For a double-acting system the formula below is used:

$$M = \frac{S * L * A * P}{800} \qquad ......(6)$$

The main formula for the sizing is mentioned below: [15]

$$A = \frac{M * 1600}{S * L * P} \qquad ......(7)$$

The suction pressure can be either calculated for a determined gas volume as seen above in formula (4), or read out from the tables above. For better understanding, a calculation (Example 1, Example 2) was made for the suction pressure of the BMGC which is mentioned below. According to Table 1, a graphical evaluation was done to see the coherence between the values in the table and the calculation. This is pictured in Figure 25. The calculations in those equations are based on atmospheric pressure.

Calculation of the suction pressure:

Data:

Diam. of Piston (in)	Area (in²)
6”	51.52
8”	95.48
10”	152.00

Example 1: (BMGC Model 6”, 48” stroke length)
S=6 strokes/min, L=4 ft, A=51.5 in², M=12mcf/d

$$P = \frac{12 * 1600}{6 * 4 * 51.5} = 15.5 \text{ psia}$$

Subtract absolute pressure (14.5038 psi) to get gauge reading

Example 2: (BMGC Model 6”, 48” stroke length)
S=6 strokes/min, L=4 ft, A=51.5 in², M=20mcf/d

$$P = \frac{20 * 1600}{6 * 4 * 51.5} = 25.9 \text{ psia}$$

Subtract absolute pressure (14.5038 psi) to get gauge reading

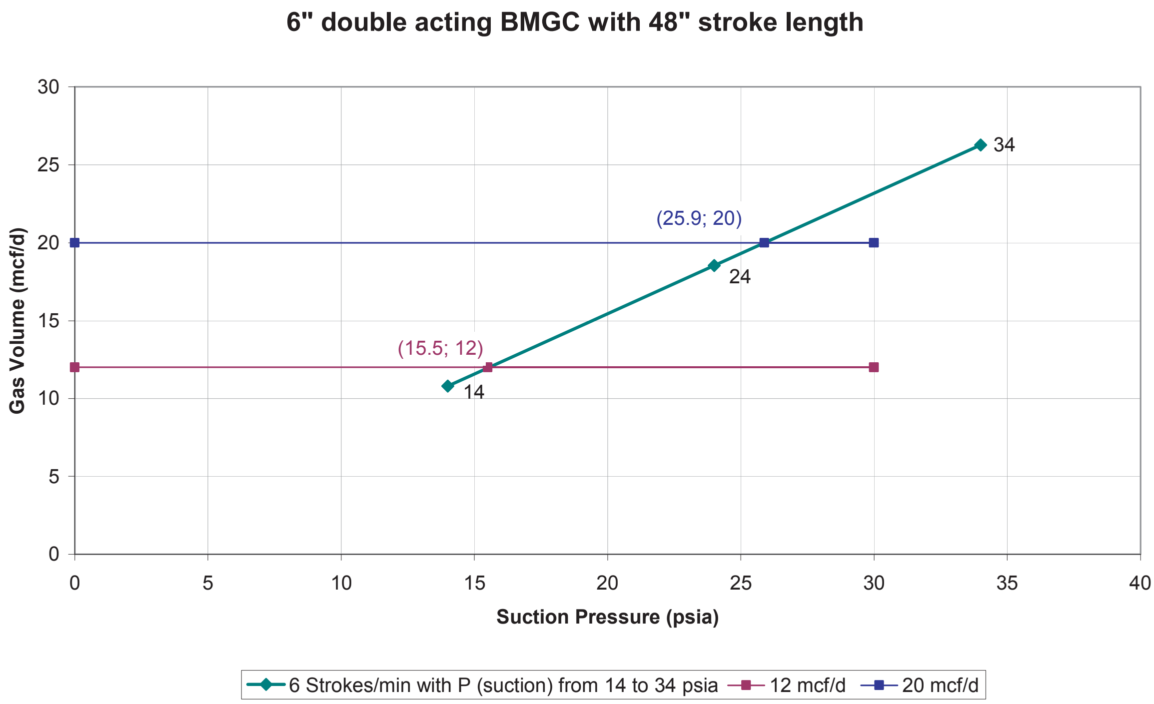


Figure 25: Graphical evaluation of suction (discharge) pressure at 6 strokes/min

The selective size of a Beam Mounted Gas Compressor specifies the area of compression piston as well as the single or double-acting execution. This is mapped in Table 4.

Table 4: Area of compression piston [13]

Cylinder	Area of compression piston (in²)		% more gas with double-acting BMGC
	Single-acting	Double-acting	
6”	28.27	51.52	82.3%
8”	50.26	95.48	90.0%
10”	78.54	152.00	93.6%
12”	113.01	221.00	95.6%

-

3.3.3 Types of BMGC

For preliminary sizing purposes, a “rule of thumb” can be assumed to help determining the size of compressor.[15]

The different sizes of BMGCs are featuring varying compression ratios, which are mentioned below:

- 5” bore compressors: 9:1 ratio
- 6” bore compressors 5:1 ratio
- 8” bore compressors 4:1 ratio
- 10” bore compressors 3:1 ratio

3.3.4 Size of Pumping Unit

The bigger the pump jack, the easier it can handle a bigger compressor size. However, the companies which are distributing Beam Mounted Gas Compressors, are working together with an engineering group to get a loading analysis, so they will be able to provide a proposal without overloading the pumping equipment. The standard procedure to order a specific BMGC for a determined well is to fill out a customer information sheet with the well data.

3.4 Application

The BMGC is installed on oil wells to relieve restricting back pressure caused by production facilities and sales line pressure. Back pressure in the casing restricts the oil and gas production of the formation. The BMGC is also used to increase gas sales on wells with low bottom hole pressures by forcing gas into the sales line. Further it is utilized to capture and compress vented gas into the sales line, allowing the operator to comply with EPA requirements (Environmental Protection Agency). EPA is valid for America. The Beam Mounted Gas Compressor is equally used to supply gas to operate lease equipment such as separators and natural gas engines. In the same way, it is used on rod pumping gas wells to increase gas production and sales by drawing the produced gas up the casing and into the flow line which relieves gas locking from the downhole pump. The BMGC makes marginal wells profitable where an increase in production could mean either profit or loss. The BMGC is manufactured to operate in extreme sour gas situations and is utilized in remote locations where dependable gas compression is required. [16]

In summary the Beam Mounted Gas Compressor is a dependable and reliable system and also profitable in various field applications.

The bottom line for using the walking beam operated Beam Mounted Gas Compressor is that operators can increase production and reduce operating costs on rod-pumping wells by drawing gas and thus gas pressure from the casing, relieving the problem of gas interference in the downhole pump. The BMGC is the solution to compressing casing head gas in fields where electricity is not available for conventional compression methods. Some operators experience increases of up to 40 bopd with associated high gas and compression expense savings. [18]

3.5 Advantages

One of the main advantages of the Beam Mounted Gas Compressor is that the compressor is easy and simple to install, because there are no complicated electrical controls or regulators. It is also beneficial that the BMGC utilizes the pumping unit as its prime mover and energy source. There are only a few moving parts to wear out and it has no gearbox or crankcase. Moreover, it requires almost no maintenance or adjusting. By moving the gas up the casing and away from the downhole pump an increase in pumping efficiency and also prevention of gas locking can be accomplished. Advantageous is the fact that the BMGC can be designed to operate in H_2S and other corrosive environments. In the same way, it moves liquid vapors down line with the gas and does not require a liquid dropout system during compression. At the point of the rod reversal the BMGC acts as a shock absorber for the rod pumping system. [21]

A typical Beam mounted Gas Compressor is very portable and can be moved to other pumping wells with little effort, assuming that the qualities of the BMGC are constant with the characteristics of the well.

Economically advantageous is the increasing cash flow and production on existing oil wells. The Beam Mounted Gas Compressor has a good history of quick payout ranging from less than one month to two years. This depends on what the formation can deliver by reducing the backpressure. [21]

3.6 Pumping Unit Forces

The varying pressures in the compressor result in a varying force on the walking beam at the point where the Beam Mounted Gas Compressor is attached to. The best way to determine the pressure gradient is to install a pressure transducer and to measure the recorded pressure during one cycle. The other way is to calculate the pressure gradient, which requires a mathematical relationship. For the sake of completeness, the mathematical background is mentioned below.

By assuming the casing gas behaves like an ideal gas, the following ideal gas relationship can be applied for a theoretical analysis of the BMGCs system [13]:

$$P_N (V_N)^K = const. = C$$ ......(8)

Formula - Parameter		
Item	Explanation	Unit
P_N	Pressure for any position ´N´	psi
V_N	Volume for any position ´N´	in³
K	Specific heat ratio	-

This relationship is used as a standard of performance for real processes. To determine this constant C for a particular unit, suction pressure, discharge pressure, and compressor stroke length has to be known. Additionally the point, where the gas is released during the stroke must be known. The suction and discharge pressure can be found from pressure gauges. They are located at the casing and at the flow line into which the gas is released. The stroke length can be determined by obtaining the difference in the compressor lengths from when it is fully extended to when it is completely retracted. To identify where along the stroke the gas is released, pressure gauges must be monitored at the discharge line to see when the flow line pressure is reached. At this point, the check valve is opening and the gas is released. Furthermore, it must be noted at which position during the stroke this happens. Typically, it is 50% to 100% into the stroke. This information is necessary for the following equation to determine the $P \times V$ value: [13]

$$C = P_D P_s \frac{\left(S * \% * D^2 * \pi * 0.005\right)^K}{P_D^{1/K} - P_S^{1/K}}$$ ......(9)

Formula - Parameter		
Item	Explanation	Unit
P_D	Discharge / Flowline pressure	psi
P_S	Suction / Casing pressure	psi
S	Compressor stroke	in
%	Percent into the stroke the gas is released	%
D	Piston diameter	in
K	Specific heat ratio: 1.26 for methane	-

From C, it is possible to determine the compressor volumes at the beginning and at the end of the compression cycle from the following [13]:

$$V_S = \left(\frac{C}{P_s}\right)^{1/K} \qquad ......(10)$$

$$V_D = \left(\frac{C}{P_D}\right)^{1/K} \qquad ......(11)$$

Formula - Parameter		
Item	Explanation	Unit
V_D	Volume at discharge	in³
V_S	Volume at beginning of cycle	in³

For an analysis of the pressure variation at the points between the beginning and at the end of the cylinder, the following equation can be used during the upstroke [13]:

$$P_N = \frac{C}{\left(V_S - \left(PRP_N * \pi * D^2 * S * 0.25\right)\right)^K} \qquad ......(12)$$

During the downstroke the following equation is used [13]:

$$P_N = \frac{C}{\left(V_S - \left(\left(1 - PRP_N\right) * \pi * D^2 * S * 0.25\right)\right)^K} \qquad ......(13)$$

Formula - Parameter		
Item	Explanation	Unit
P_N	Pressure in cylinder	psi
PRP_N	Polished rod position	in

Figure 26 shows a plot of the pressure during one cycle. The discharge pressure should be used instead of the calculated value, in case of P_N is larger than the discharge pressure. [13]

For a double-acting BMGC, the piston has pressure on its backside opposite the side compressing the gas. From Figure 26, one can see that the net reaction on the piston due to the pressure is the difference in the compression reservoir pressure and the suction reservoir pressure. The resulting force becomes: [13]

$$R = P_{NET} * \pi * D^2 * 0.25 \qquad ......(14)$$

Formula - Parameter		
Item	Explanation	Unit
R	Force of the walking beam	lbs
P_{NET}	Net pressure on piston	psi

To relate this force to more practical terms, it can be converted to an equivalent polished rod load (see Figure 27) by using the following equation: [13]

$$E = \frac{R * Q}{A} \qquad ......(15)$$

Formula - Parameter		
Item	Explanation	Unit
E	Equivalent polished rod load	lbs
R	Force on walking beam due to compression	lbs
Q	Perpendicular distance from force (R) to center bearing	in
A	Front working center of pumping unit	in

If the equivalent polished rod loads are plotted versus the position, they will increase proportionally as they did in the plot of the pressure in Figure 27. This leads to the analysis of the effects these forces have on the pumping unit. [13]

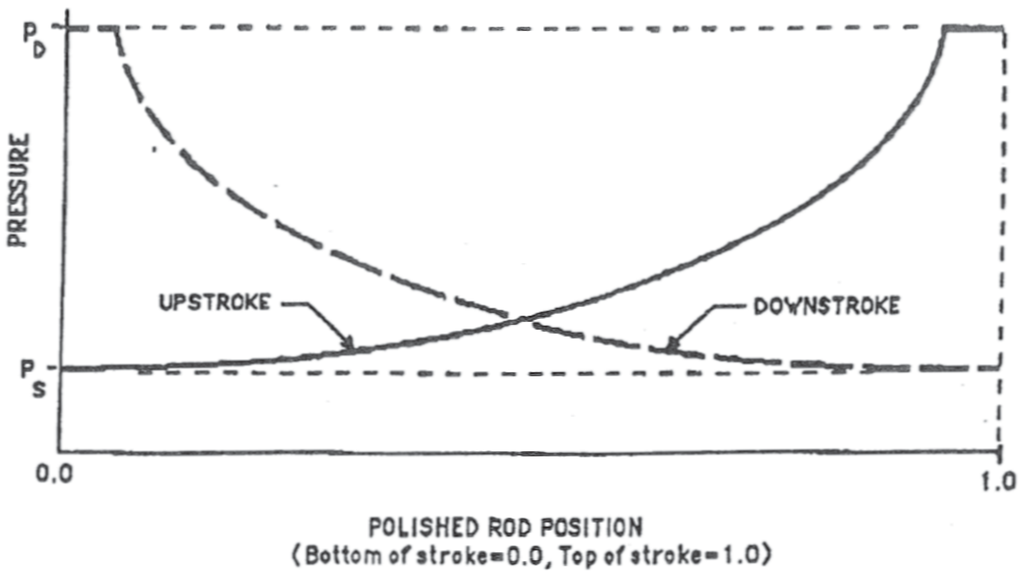


Figure 26: Pressure versus polished rod position [13]

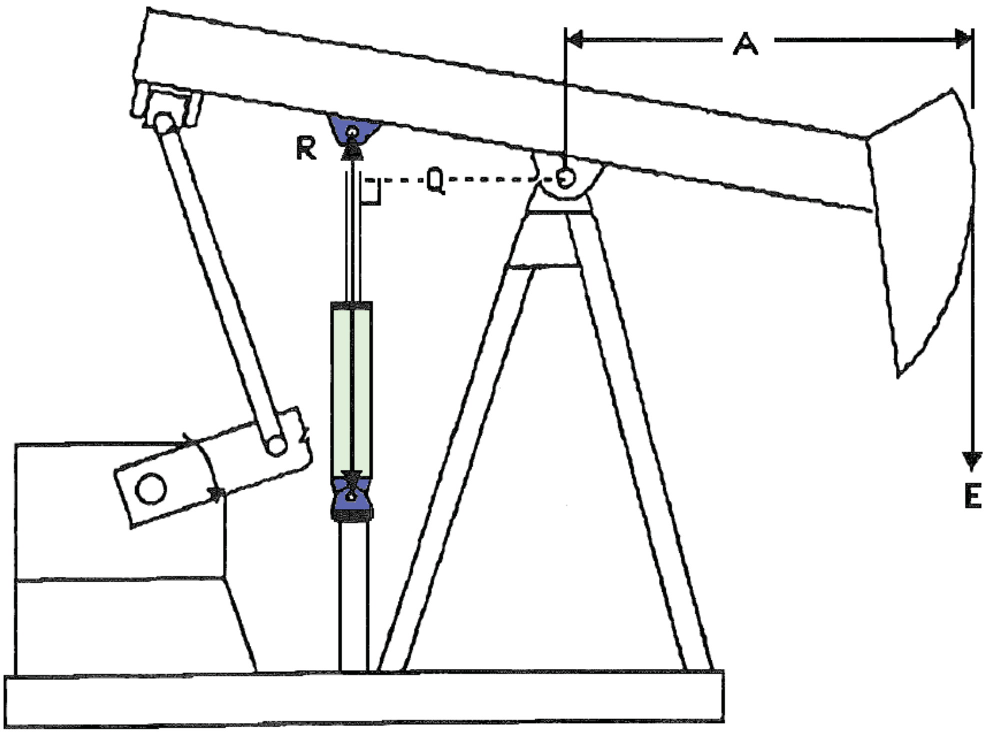


Figure 27: Pumping unit loading [13]

The peak forces created from the pressure in the cylinder can exceed 10000 lbs, with the peaks generally occurring near the end of the BMGC and pumping unit stroke, which in most cases keep the additional torque load to a minimum. [13]

3.6.1 Pumping Unit Loading

A double-acting Beam Mounted Gas Compressor works on both, the upstroke and downstroke. Therefore is always a load on the walking beam. If mounting between the center and the equalizer bearing, the force, as a result of the net pressure on the piston, during the upstroke is upward tending to push on the beam. This effects a moment on the walking beam at the center bearing in the same direction as a moment applied by a well load. During the downstroke of the pumping unit, the force is in the direction of the upstroke. The tendency of the compressor to pull down on the walking beam creates a moment in direction opposite the moment created by the well load. In effect, the upstroke loading appears as an increased well load to the reducer and on the downstroke as a decreased well load. With the equivalent polished rod loads for incremental positions of the pumping unit cycle, the next grade is to relate these loads to reducer torque. Polished rod load is typically converted to reducer torque by using the equation below. [13]

$$T_N = (W_N - SU) * TF_N \qquad ......(16)$$

Formula - Parameter		
Item	Explanation	Unit
T_N	Torque on reducer	in-lbs
W_N	Polished rod load	lbs
SU	Structural unbalance of pumping unit	lbs
TF_N	Torque factor of unit at the position being calculated	

Generally, well loads are taken from dynamometer cards at 15° increments and with the use of the torque equation they are converted to torque. In order to account for the torque caused by the BMGC, the equivalent polished rod loads from the compressor have to be added to the dynamometer card loads before the torque equation can be applied. A dynamometer card alone is not adequate for the torque analysis, because the card does not include the effects of the Beam Mounted Gas Compressor but only shows the well loads. To find the net reducer torque for a specific crank position, the counterbalance torque has to be accounted for by using following equation: [13]

$$T_{NET} = T_N - CBT_{90} * \sin(Q_N) \qquad ......(17)$$

Formula - Parameter		
Item	Explanation	Unit
T_{NET}	Torque on net reducer	in-lbs
CBT_{90}	Counterbalance torque at 90°	in-lbs
Q_N	Crank angle	°

To determine whether or not the reducer is overloaded, the torque should be calculated at 15° crank angle increments and the peak compared to the reducer rating. The loading on the center bearing tends to decrease on the upstroke of the unit and to increase on the downstroke. This is a result of the upward force applied by the BMGC partially negating the pitman and well loads on the upstroke. However, these loads are added on the downstroke. [13]

Whether or not the loading from the installation of a Beam Mounted Gas Compressor is detrimental to the pumping unit, can only be determined by a load and torque analysis of each unit. Thereby, variables that dictate the loads such as compressor size, its position, and the suction and discharge pressures can be accounted for and a thorough analysis can be made. It can be concluded that the loads tend to follow similar patterns. The loads become large near the end of the pumping unit stroke, and at this point little torque can be transmitted to the reducer. The loads on the walking beam are in a direction, which make them negligible to the center bearing. [13]

During one complete stroke cycle, a single-acting option draws gas from the casing side of an oil well during one half of the pumping unit stroke cycle and releases it during the second half. This has already been mentioned in previous chapters. On the basis of this fact, a single-acting BMGC does affect the counterbalance weights of the pumping unit. Therefore, no additional energy of the prime mover is needed to drive the Beam Mounted Gas Compressor, due to an adequate balance of the counterbalance weights. On the other hand, a double-acting BMGC has two reservoirs that enable it to draw gas in one reservoir and compress and release gas in the other. This procedure takes place on both, the upstroke and the downstroke of the pumping unit, which has also been adduced in this thesis. Hence, a double-acting BMGC does not affect the pumping unit's counterbalance and thus, additional energy of the prime mover is needed to force the compressor.

3.7 Evaluation of Installation Position

The correct evaluation of the BMGC installation position on the pumping unit is a substantial factor. Therefore, a predetermined procedure has to be deployed.

Initially, the pumping unit has to be shut down. Subsequently, it has to be measured from the center of the crank pin to the center of the wrist pin. This is section “B” which is mapped in Figure 28. The next step is to quantify the center of tail bearing to the center of the center bearing which is segment “A” in Figure 28. To determine the position of the upper mounting plate on the walking beam, it is necessary to take “A” multiplied by the stroke length of the BMGC and afterwards this term has to be divided by “B”. This will result in “C”, which is the center point of the upper mounting plate. Consequently, “C” is the distance from the center bearing to the center of the upper mounting plate. Subsequent to this the middle of the walking beam should be marked which will be the center of the upper mounting plate. Furthermore, has to be measured 4 ½ inches toward the “A” leg and drawn a line there. This line will be used to line up the outer edge of the mounting plate. From the center mark on the walking beam, has to be scaled down to the top of the I beam frame. This scaling has to be taken and the length of the BMGC unit compressed has to be subtracted. The difference of the two numbers will represent the height of the base, where BMGC is mounted. In the next step the size of the mounting plate should be measured which would be needed between the gear box and the bottom of the “A” leg. The plate has to be cut and then welded into place. After this it has to be dropped plumb bob down from the center mark on walking beam to the center point of the plate and marked. The pipe has to be cut to length and welded on the lower mounting plate. Then the pipe has to be tacked onto the plate. The upper mounting plate can be installed by bolting it to the walking beam. To install the BMGC unit, it has to be picked up and bolted to the mounting plates. [15]

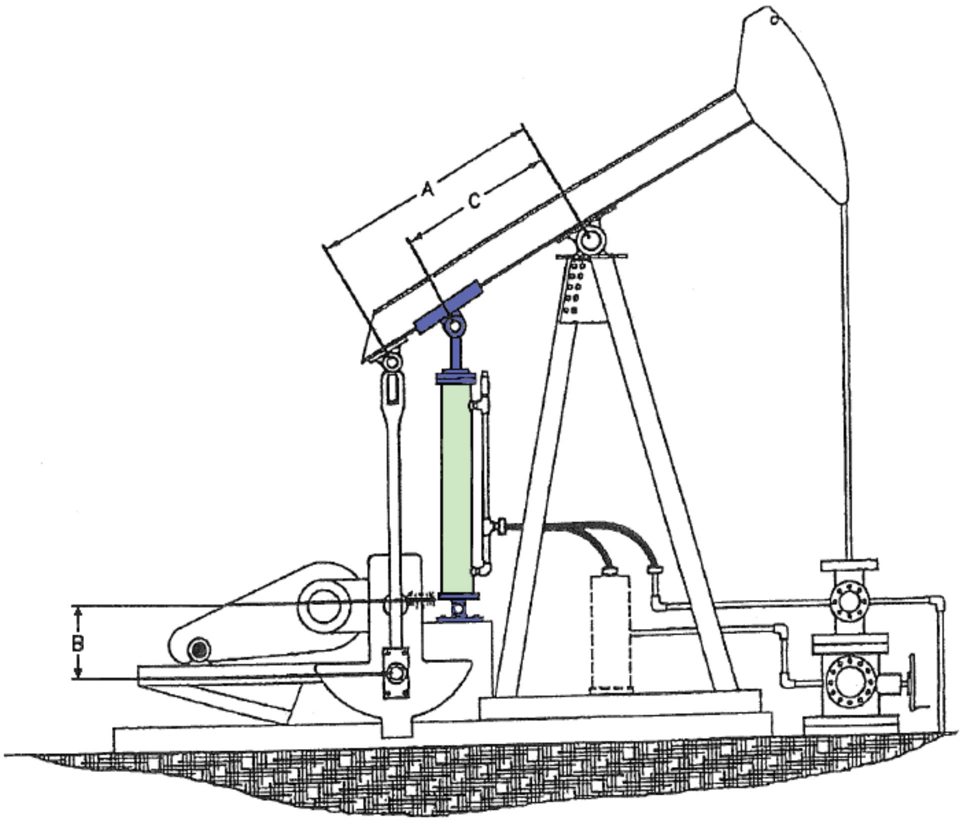


Figure 28: Pumping unit with evaluation of the BMGC installation position [15]

4 Operating Considerations

The durability of a Beam Mounted Gas Compressor is a contributing factor and therefore, all essential actions needed for maintenance should be taken. One of the most important selective measures is the regular maintenance which includes regular visual checks to secure a technically faultless operation.

4.1 Maintenance

In the following chapter, the production schedule for maintenance, as well as lubrication and several technical difficulties which can occur are elucidated.

4.1.1 Maintenance Schedule and Regular Visual Check [15]

DAILY:

The cylinder lubrication system and the lube pump have to be checked in case of any leaks they need to be repaired.

Further, the rod automatic greaser has to be controlled and refilled if needed.

It is important to remember that the suction and discharge pressure have to be recorded.

Moreover, the discharge temperature has to be recorded and should not exceed 107.2 degrees Celsius.

Similarly, steps should be taken to keep out fluids of the Beam Mounted Gas Compressor. These include chemical treatments, back side (casing) fluid flow, and flow line fluids backing up into the system during down time.

WEEKLY:

All mounting and adjustable base mount bolts have to be checked to see if they are working loose.

In the same way, all bearing points have to be controlled at the upper and the lower end of the Beam Mounted Gas Compressor, as well as the walking beam end and the bottom bearing mount.

Additionally, the adjustable base mount (ABM) as well as all welds on the mounting pedestal must be inspected.

Furthermore, it has to be assured that there is no movement of the sampson post during the compression cycle.

Moreover all hoses have to be supervised, including the lubrication hoses, to cocksure that they are operating clear of obstructions.

Important as well, is that all bearings have been greased where applicable. This is mentioned in chapter 7.1.2.

MONTHLY:

The rod packing nut has to be adjusted if necessary, to prevent leaking around the rod. After all the adjustments have been done, the rod packing will need to be replaced. This is defined in Chapter 4.1.2.

For well service, it is necessary that the suction line is protected from dirt, sand or any other materials, when the well is being serviced. Any foreign material allowed to enter the cylinder through the suction lines will damage the BMGC cylinder and the internals.

4.1.2 Replacing Piston Rod Packing

The first step is to shut down the pumping unit with piston rod inside the cylinder with approximately two feet of rod exposed. Second, the brakes have to be secured and locked out. Next, the suction and discharge valves have to be closed. Furthermore, the bleeder valves have to be opened and any pressure in the compression system has to be relieved. Afterwards, the piston rod has to be cleaned and all foreign material has to be removed because this will prevent contamination of the cylinder internals. The next step is to remove the automatic greaser from packing nut and posterior dispel packing nut. Subsequent to the old packing from the rod has to be cut and care should be taken not to damage the rod. The new packing has to be split at 45° angle. It is important to grease piston rod, packing gland and packing for easy assembling. The male member of the packing assembly has to be inserted first, with the flat side toward the compression chamber. Afterwards, the three V rings have to be inserted into the packing gland with the seal lips toward the compression chamber so as to connect with the already assembled male member. Then the female member of the packing assembly has to be inserted with the flat side facing away from the compression chamber. Posterior, the packing nut has to be replaced as well as the automatic greaser and refilled with grease. The suction and discharge bleeder valves have to be closed and after that the suction and discharge valves have to be opened. Finally, the pumping unit has to be rotated slowly and operation of unit has to be observed for several turns to assure all equipment is operating properly. It is advantageous to allow the unit to operate for several minutes, or until the new packing is seated and then to make a final adjustment on the packing nut. [15]

4.1.3 Technical Difficulties [15]

If the Beam Mounted Gas Compressor is not compressing gas, its compression has to be checked. Therefore, the discharge valve and the bypass valve have to be closed and accordingly the pumping unit has to be rotated to observe the gauges. The pressure should build on both the upstroke and downstroke. The safety valve is set to protect the pumping unit from damage. It is essential to know the set pressure of the relief valve. If the set pressure is exceeded any time during the operation, the unit should be shut down immediately and the relief valve repaired and reset to the original set pressure.

Another reason for not compressing gas could be worn out piston rings.

The BMGC gives maximum compression when it is installed with optimum head spacing. In such a way, a 60 inch stroke BMGC should be installed with 1 inch spacing on each end. A Beam Mounted Gas Compressor is designed to have one inch of head spacing from the top and bottom heads and still gives the full 60 inch compressor stroke. This procedure is the same with all BMGC models.

In case of any leaks the integrity of the discharge line should be checked. Moreover, the BMGC should run against a closed valve including the bypass valve, until a desired pressure in the discharge line is obtained.

The check valves in the BMGC manifold are numbered 1 through 4. The check valves on the rod end are suction valve 1 and discharge valve 2. The check valves on the bottom stroke are suction valve 3 and discharge valve 4. If the BMGC is not compressing on top up stroke (rod end) the check valves 1 or 4 should be controlled. If the BMGC is not compressing on the downstroke (bottom chamber) the check valves 2 or 3 should be checked. Any debris should be removed and the ball and seat should be checked for damage.

If the bypass regulator does not function properly it will allow the compressed gas to pass back to the suction side of the BMGC and prevent compressed gas to be discharged down the flow line.

The packing nut should only be snugged against the packing but not too tight. Only enough to prevent the top compression chamber from leaking around the rod. This should be adjusted to prevent a gas leak.

The piston seals are long life compression seals and are O-ring energized for compression efficiency. In case of piston seal damage the same procedure as for checking line leaks and check valve problems has to be used.

It is consequential to ensure a positive pressure supply of gas or air to the suction side of the BMGC during all checking procedures.

Precautions must be taken to prevent fluids from entering the compression chamber of the BMGC. Chemicals, treatment fluids and hot oiling fluids will damage the Beam Mounted Gas Compressor. When treating or hot oiling the well, the pumping unit should be taken out of service and the suction and discharge valves to and from the BMGC should be closed.

5 Candidate Evaluation

The Beam Mounted Gas Compressor technology is as discussed in a previous chapter an eminent method to release casing formation backpressure and so to increase production and make marginal wells profitable. But not every well is a candidate for a BMGC. Thus, it is fundamental to evaluate which wells are suitable for this technology. Several factors shall be contemplated, which are already discussed in chapter 3.1. Additionally, one of the most important conditions is that the well has to be equipped with a pumping unit because the BMGC is installed on the walking beam and equally is powered by the prime mover of the pump jack. Furthermore, some basic well data parameters have to be established to be able to screen the possible candidates for a Beam Mounted Gas Compressor. Afterwards the Inflow Performance Relationship - Curve (IPR-Curve) of the identified wells was simulated with the Petroleum Experts® Software which is called Prosper®. The IPR-models of the detected wells were used to define the production increase due to decreasing casing pressure.

5.1 Screening Criteria

The Screening Criteria for the candidate selection procedure were specified in the beginning. At first all oil wells which are equipped with a pumping unit had been picked out. From the remaining wells all candidates with a lower casing pressure than 5 bar and a lower production rate than 1 Nm³/d were eliminated. Those values were determined in collaboration with the Reservoir Engineering and Production Engineering department of the RAG Company. The assortment of wells was rechecked and curtailed to gain a commensurate quantity of candidates for the simulation process. This indicates high potential for several feasible wells which are suitable for the BMGC technology.

Moreover the remaining candidates were checked in reference to the solution gas oil ratio R_s and the gas oil ratio GOR. Wells with a higher GOR value in comparison with the R_s value were eliminated because of the additional gas deployment. The residual wells represent the candidates which are suitable for a potential increase in production due to Beam Mounted Gas Compressor technology.

5.2 Candidate Wells of RAG

The remaining candidates which arise from of the screening process are mapped in alphabetical order in Table 5. All these wells were simulated with the Prosper® software to achieve the IPR-Curves. The well data for simulation was extracted from

Prodcom® which is a data base programme from the RAG Company. Therefore, additional data such as formation pressure, formation temperature and solution gas oil ratio R_s were received from the Reservoir Engineering department of the RAG Company. The calculation of bottom hole flowing pressure ($p_{wf,}$) which is a necessary value for simulation, was similarly accomplished. This was done, due to the fact that actual measuring results were not available. The theory about the Inflow Performance Relationship is adduced in chapter 3.1.1. The data of simulated IPR-Curves were transferred into Excel® to construct the lowering pressure which results in increasing production. Data transfer is necessary on that account, because in Excel®, it is possible to construct and work on the graphic chart. Due to the fact that data output from Prosper® is only a fraction of values, the Excel® charts are not straightened well occasionally. But for this simulation the lot fraction defective is insignificant.

Table 5: Potential candidates for a BMGC

Well
HIER-001
HIER-002A
HIER-004
KTG-W-001
MDF-001A
OB-001
RA-002
SAT-002
SAT-006
SAT-007
SAT-023
V-016

5.3 Prosper®-Model of RAG Candidates

In the following chapter all above headed candidates are described in specific detail in terms of IPR-Curve Excel® Charts to display production increase due to lowering casing pressure. The Prosper® charts of all simulated wells are listed in the appendix. Casing pressure of all candidates was lowered down to 1 bar in the simulation process. This equates to application of a Beam Mounted Gas Compressor.

5.3.1 IPR-Curve [HIER-001]

Pressure in the casing of candidate HIER-001 is 5 bara and so the pressure drop is about 3 bara. The bottom hole flowing pressure calculation results in 104 bara which is mentioned below. Due to the pressure drop of 3 bara the increasing production (Δ q) results in 6.7 Sm³/day as can be seen in Figure 29.

Table 6: Calculation of bottom hole flowing pressure [HIER-001]

Bottom hole flowing pressure calculation:				
			Watercut:	0.07
Well:	HIER-001		Density: formation water:	0.97 kg/l
			Density: oil, gas, formation water:	0.74 kg/l
			Density: gas:	1 kg/m³
Prodcom data:	4/21/2009			
Casing pressure:	4 bar			
Atmosphere:	5 bara			
Dynamic level:	1097 m MD			1078.7 m TVD
Pump setting depth:	1354 m MD			1320.5 m TVD
Lower level of perforation:	2519 m MD			2414.8 m TVD
Pressure on dynamic level:	5.53 bara		p(Dynamic level) = p(Wellhead) + rho * g * h	
			Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	241.8 m			
p (hydr):	17.54 bar			
Distance-> Pump - Lower level of perforation:	1094.3 m			
p (hydr):	81.12 bar		Water content considered	
P_{wf}:	**104.19 bara**			

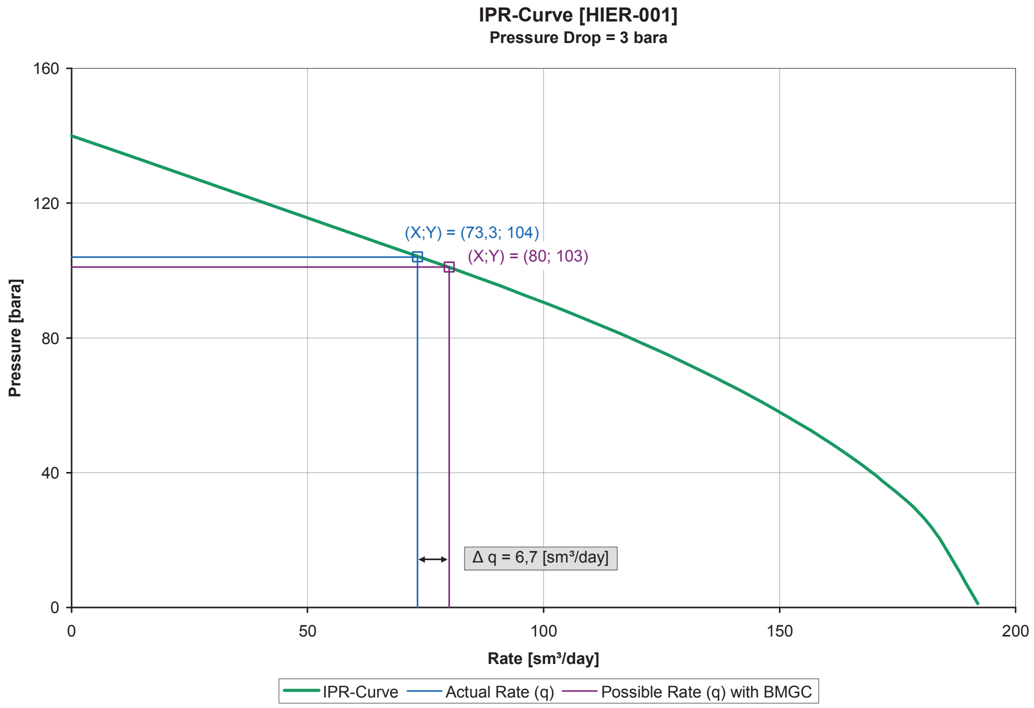


Figure 29: IPR-Curve Model [HIER-001] with increasing rate due to BMGC

5.3.2 IPR-Curve [HIER-002A]

Casing pressure of well HIER-002A is about 5.5 bara and the pressure drop is 3 bara. The result of the bottom hole flowing pressure calculation is 107.91 bara which is mapped in Table 7. The production increase because of pressure drawdown results in 7.5 Sm³/day. See Figure 30.

Table 7: Calculation of bottom hole flowing pressure [HIER-002A]

Bottom hole flowing pressure calculation:			
		Watercut:	-
Well:	HIER-002A	Density: formation water:	0.97 kg/l
		Density: oil, gas, formation water:	0.74 kg/l
		Density: gas:	1 kg/m³
Prodcom:	4/21/2009		
Casing pressure:	4.4 bar		
Atmosphere:	5.4 bara		
Dynamic level:	1061 m MD		1057.4 m TVD
Pump setting depth:	1362.2 m MD		1354.1 m TVD
Lower level of perforation:	2554 m MD		2462.7 m TVD
Pressure on dynamic level:	5.96 bara		p(Dynamic level) = p(Wellhead) + rho * g * h
			Gas: rho ~ rho(Standard conditions) * p
Distance-> Dynamic level - Pump:	296.7 m		
p (hydr):	21.53 bar		
Distance-> Pump - Lower level of perforation:	1108.6 m		
p (hydr):	80.43 bar		Water content neglectable
P_{wf}:	**107.91 bara**		

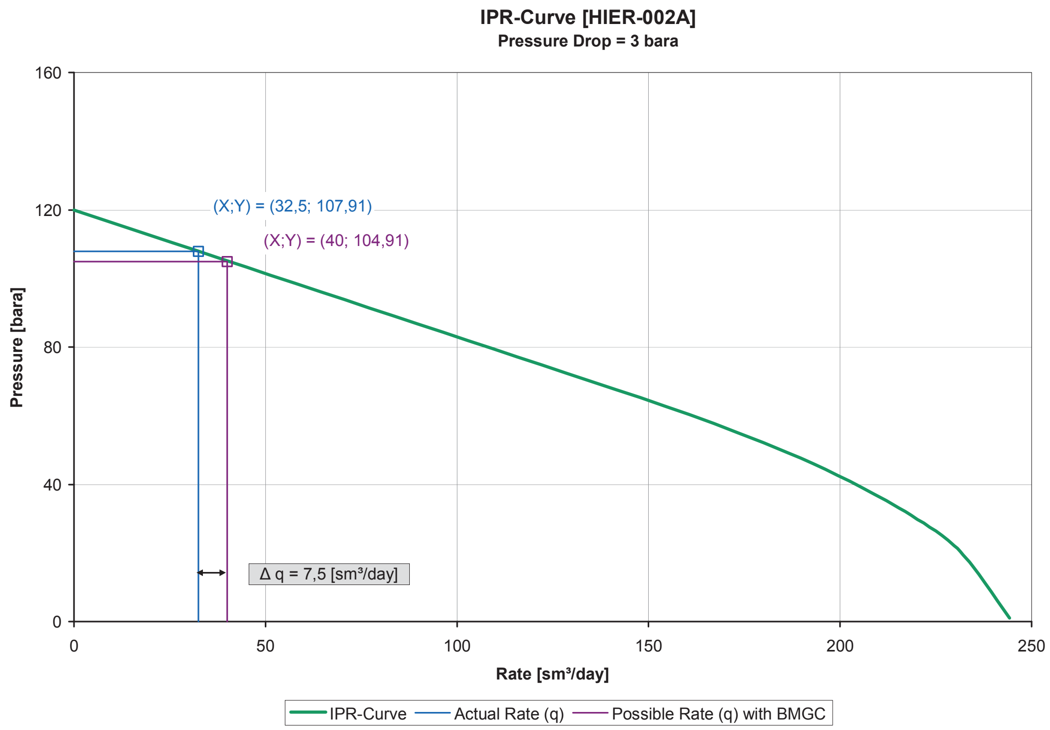


Figure 30: IPR-Curve Model [HIER-002A] with increasing rate due to BMGC

5.3.3 IPR-Curve [HIER-004]

The casing pressure of HIER-004 is, like candidate HIER-001, 5 bara and the resulting pressure drop is 3 bara. The outcome of bottom hole flowing pressure is 133.04 bara which is mentioned in Table 8. Because of pressure drawdown the outcome of increasing production (Δ q) is 27.6 Sm³/day. See Figure 31. This simulation result shows that increasing production does not depend instantaneous on the quantity of the pressure drop due to the fact that the characteristic of the IPR-Curve is the most contributing factor.

Table 8: Calculation of bottom hole flowing pressure [HIER-004]

Bottom hole flowing pressure calculation:				
			Watercut:	-
Well:	HIER-004		Density: formation water:	0.97 kg/l
			Density: oil, gas, formation water:	0.74 kg/l
			Density: gas:	1.00 kg/m³
Prodcom:	4/21/2009			
Casing pressure:	4	bar		
Atmosphere:	5	bara		
Dynamic level:	658	m MD		653 m TVD
Pump setting depth:	1352	m MD		1324.4 m TVD
Lower level of perforation:	2513.6	m MD		2413.4 m TVD
Pressure on dynamic level:	5.32	bara	p(Dynamic level) = p(Wellhead) + rho * g * h	
			Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	671.4	m		
p (hydr):	48.71	bar		
Distance-> Pump - Lower level of perforation:	1089	m		
p (hydr):	79.01	bar	Water content neglectable	
P_{wf}:	**133.04**	**bara**		

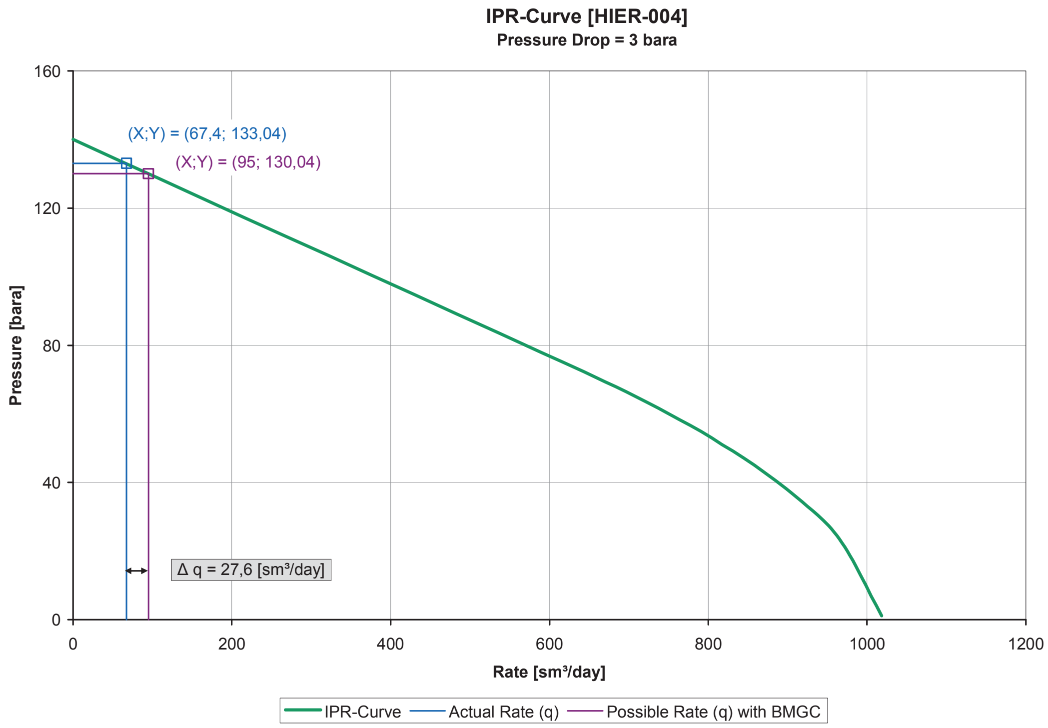


Figure 31: IPR-Curve Model [HIER-004] with increasing rate due to BMGC

5.3.4 IPR-Curve [KTG-W-001]

Pressure drop of KTG-W-001 is about 5 bara which is resultant of the casing pressure of 7.5 bara. See Table 9. The calculated bottom hole flowing pressure shows 103.59 bara and because of pressure drawdown the Δ q yields to 38 Sm³/day. This is a high Δ q value and mapped in Figure 32.

Table 9: Calculation of bottom hole flowing pressure [KTG-W-001]

Bottom hole flowing pressure calculation:			
		Watercut:	0.93
Well:	KTG-W-001	Density: formation water:	0.97 kg/l
		Density: oil, gas, formation water:	0.74 kg/l
		Density: gas:	1 kg/m³
Prodcom:	4/21/2009		
Casing pressure:	6.5 bar		
Atmosphere:	7.5 bara		
Dynamic level:	822 m MD		821.9 m TVD
Pump setting depth:	901 m MD		900.9 m TVD
Lower level of perforation:	1861 m MD		1860.6 m TVD
Pressure on dynamic level:	8.10 bara	p(Dynamic level) = p(Wellhead) + rho * g * h	
		Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	79 m		
p (hydr):	5.73 bar		
Distance-> Pump - Lower level of perforation:	959.7 m		
p (hydr):	89.75 bar	Water content considered	
P_{wf}:	103.59 **bara**		

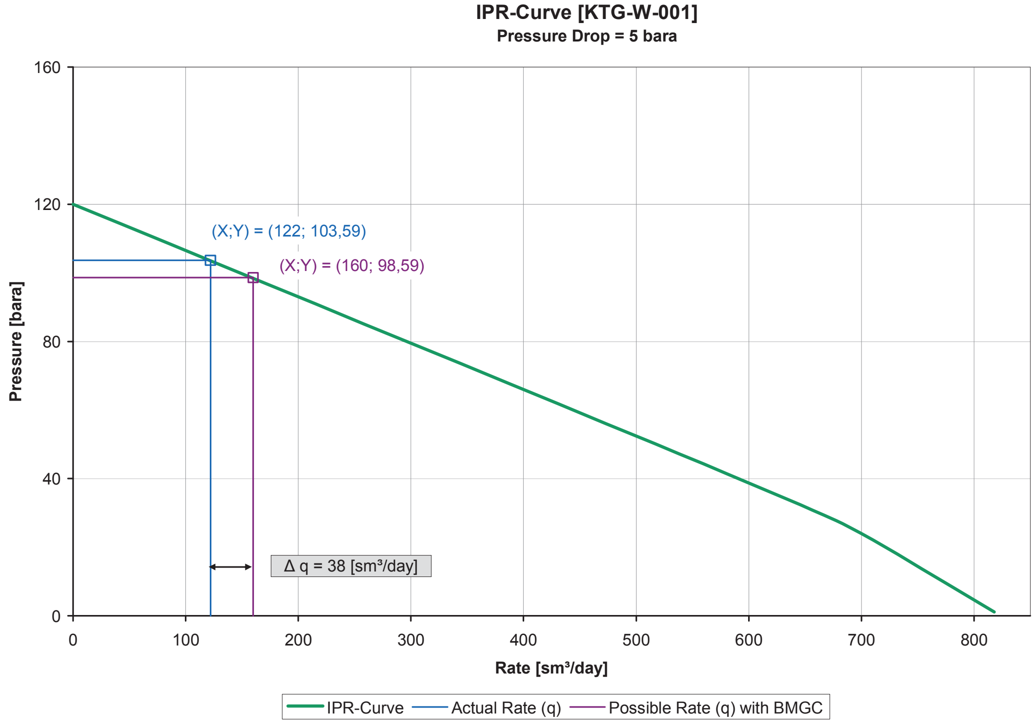


Figure 32: IPR-Curve Model [KTG-W-001] with increasing rate due to BMGC

5.3.5 IPR-Curve [MDF-001-A]

Candidate MDF-001-A has a casing pressure of 11 bara and the resulting pressure drop is about 9 bara. Table 10 shows the result of p_{wf} – calculation which is 15.69 bara and the resulting increased production is 0.45 Sm³/day. The IPR-Curve in

Figure 33 undulates because of data transfer from Prosper to Excel®. Due to small unit steps on the abscissae the quantity of data points is too few and the missing curve stretching in the Excel® program leads to this wavelike curve.

Table 10: Calculation of bottom hole flowing pressure [MDF-001-A]

Bottom hole flowing pressure calculation:

		Watercut:	-
Well:	MDF-001-A	Density: formation water:	0.97 kg/l
		Density: oil, gas, formation water:	0.74 kg/l
		Density: gas:	1 kg/m³
Prodcom:	4/21/2009		
Casing pressure:	10 bar		
Atmosphere:	11 bara		
Dynamic level:	2240 m MD		2204.9 m TVD
Pump setting depth:	2342.9 m MD		2207.4 m TVD
Lower level of perforation:	2377 m MD		2236.7 m TVD
Pressure on dynamic level:	13.38 bar	p(Dynamic level) = p(Wellhead) + rho * g * h Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	2.5 m		
p (hydr):	0.18 bar		
Distance-> Pump - Lower level of perforation:	29.3 m		
p (hydr):	2.13 bar	Water content neglectable	
P_{wf}:	**15.69 bara**		

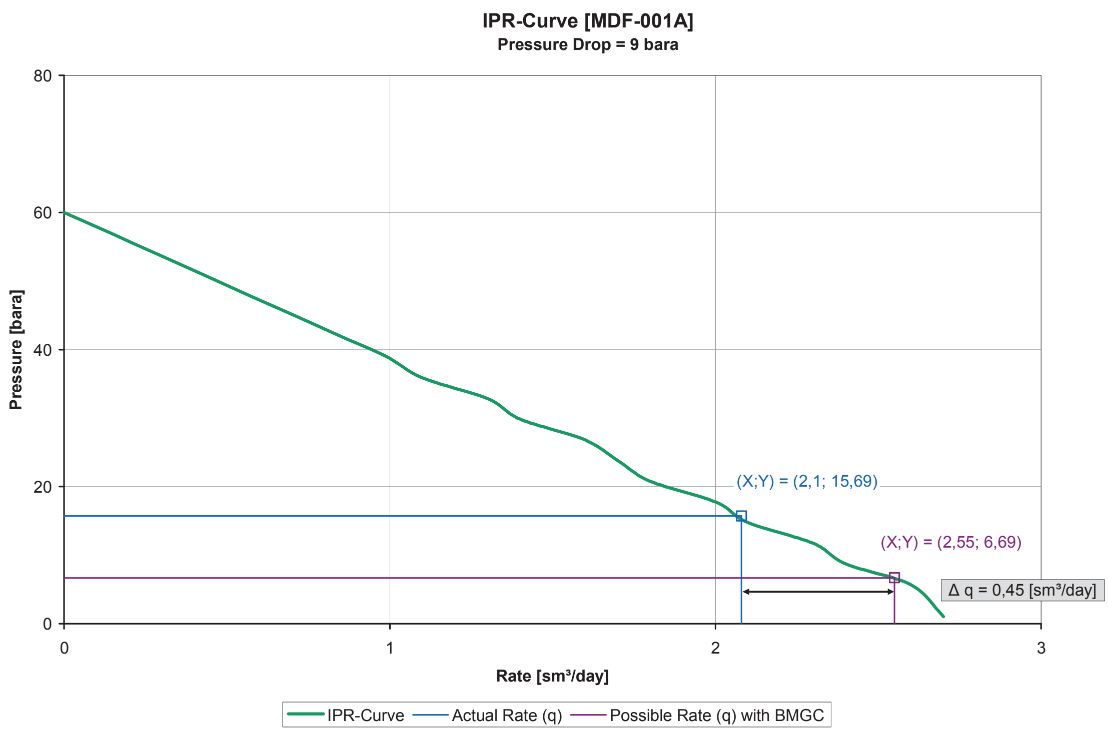


Figure 33: IPR-Curve Model [MDF-001A] with increasing rate due to BMGC

5.3.6 IPR-Curve [OB-001]

Casing pressure of OB-001 is 8 bara and the pressure drawdown is about 6 bara. The outcome of bottom hole flowing pressure is 59.75 bara. See Table 11. The increasing production is 3.9 Sm³/day which is mentioned in Figure 34. Even though pressure drop is relatively high the resulting production increase is not that high than expected. As noted above, in chapter 5.3.3, the characteristics of the IPR-Curve is the determining factor.

Table 11: Calculation of bottom hole flowing pressure [OB-001]

Bottom hole flowing pressure calculation:				
			Watercut:	0.93
Well:	OB-001		Density: formation water:	0.97 kg/l
			Density: oil, gas, formation water:	0.74 kg/l
			Density: gas:	1 kg/m³
Prodcom:	4/21/2009			
Casing pressure:	7	bar		
Atmosphere:	8	bara		
Dynamic level:	1420	m MD		1419.8 m TVD
Pump setting depth:	1456	m MD		1455.8 m TVD
Lower level of perforation:	1970	m MD		1969.3 m TVD
Pressure on dynamic level:	9.11	bar	p(Dynamic level) = p(Wellhead) + rho * g * h Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	36	m		
p (hydr):	2.61176471	bar		
Distance-> Pump - Lower level of perforation:	513.5	m		
p (hydr):	48.02	bar	Water content considered	
P_{wf}:	**59.75**	**bara**		

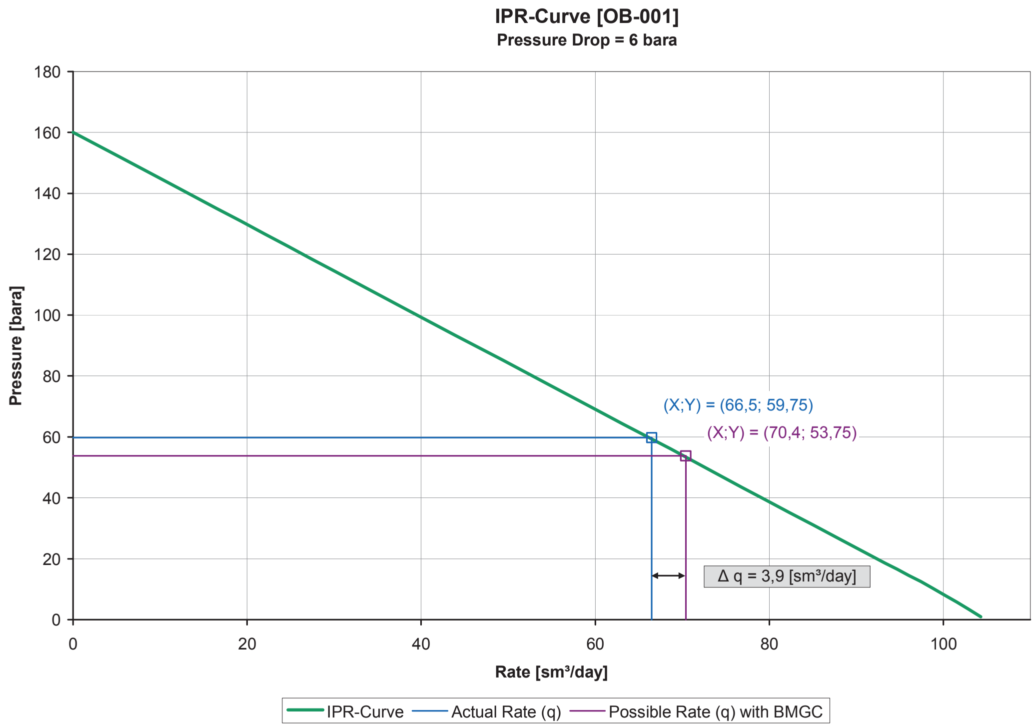


Figure 34: IPR-Curve Model [OB-001] with increasing rate due to BMGC

5.3.7 IPR-Curve [RA-002]

Pressure in the casing of candidate RA-002 is 7 bara and the pressure drop is 5 bara. Calculated bottom hole flowing pressure is 9.65 bara which is matched in Table 12. Production increase due to pressure drop equals 0.04 Sm³/day. This is pictured in Figure 35 and as well as candidate MDF-001 the IPR-Curve has small steps of unit on the x- axis and so the quantity of data points is too few to picture a stretched curve in Excel®. Due to the low Δ q this is negligible.

Table 12: Calculation of bottom hole flowing pressure [RA-002]

Bottom hole flowing pressure calculation:			
		Watercut:	-
Well:	RA-002	Density: formation water:	0.97 kg/l
		Density: oil, gas, formation water:	0.74 kg/l
		Density: gas:	1 kg/m³
Prodcom:	4/21/2009		
Casing pressure:	6 bar		
Atmosphere:	7 bara		
Dynamic level:	1605 m MD		1604.2 m TVD
Pump setting depth:	1608.3 m MD		1607.4 m TVD
Lower level of perforation:	1625.5 m MD		1625.5 m TVD
Pressure on dynamic level:	8.10 bar	p(Dynamic level) = p(Wellhead) + rho * g * h Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	3.2 m		
p (hydr):	0.23 bar		
Distance-> Pump - Lower level of perforation:	18.1 m		
p (hydr):	1.31 bar	Water content neglectable	
P_{wf}:	**9.65 bara**		

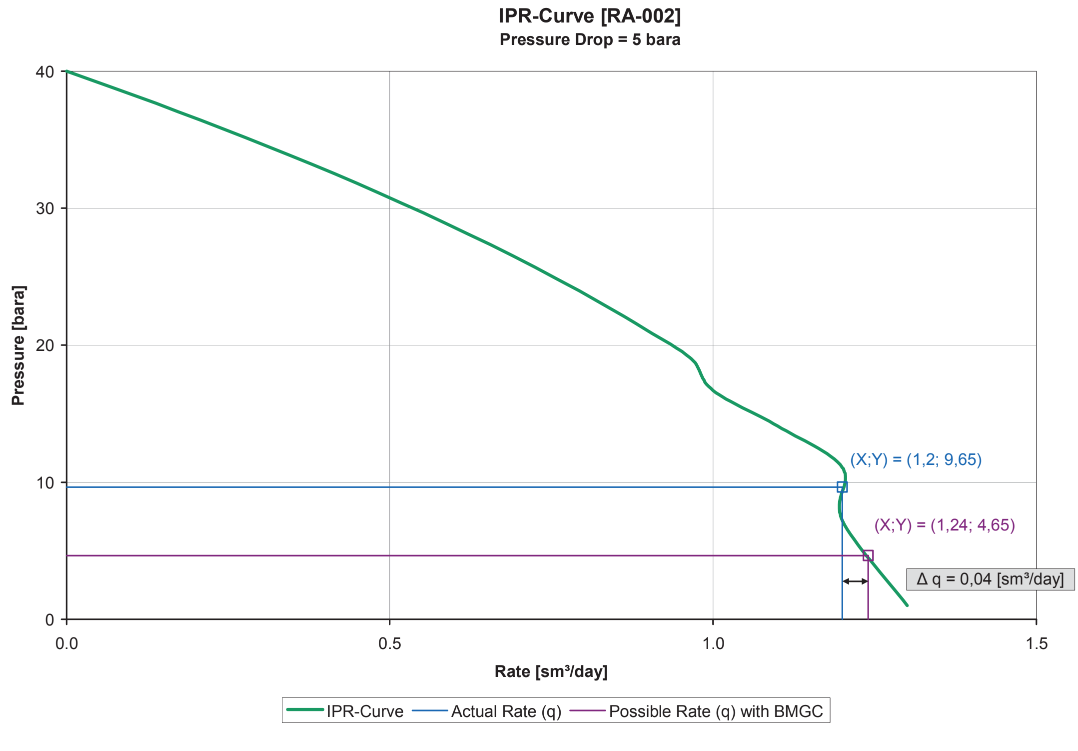


Figure 35: IPR-Curve Model [RA-002] with increasing rate due to BMGC

5.3.8 IPR-Curve [SAT-002]

The casing pressure of SAT-002 is about 8 bara and the pressure drawdown is 7 bara. Calculated value for p_{wf} is 12.16 bara which is matched in Table 13. The resulting production increase is 0.2 Sm³/day and pictured in Figure 36.

Table 13: Calculation of bottom hole flowing pressure [SAT-002]

Bottom hole flowing pressure calculation:			
		Watercut:	-
Well:	SAT-002	Density: formation water:	0.97 kg/l
		Density: oil, gas, formation water:	0.74 kg/l
		Density: gas:	1 kg/m³
Prodcom data:	4/21/2009		
Casing pressure:	7 bar		
Atmosphere:	8 bara		
Dynamic level:	1670 m MD		1654.3 m TVD
Pump setting depth:	1676 m MD		1660.2 m TVD
Lower level of perforation:	1710.2 m MD		1693.7 m TVD
Pressure on dynamic level:	9.30 bara	p(Dynamic level) = p(Wellhead) + rho * g * h Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	5.9 m		
p (hydr):	0.43 bar		
Distance-> Pump - Lower level of perforation:	33.5 m		
p (hydr):	2.43 bar	Water content neglectable	
P_{wf}:	**12.16 bara**		

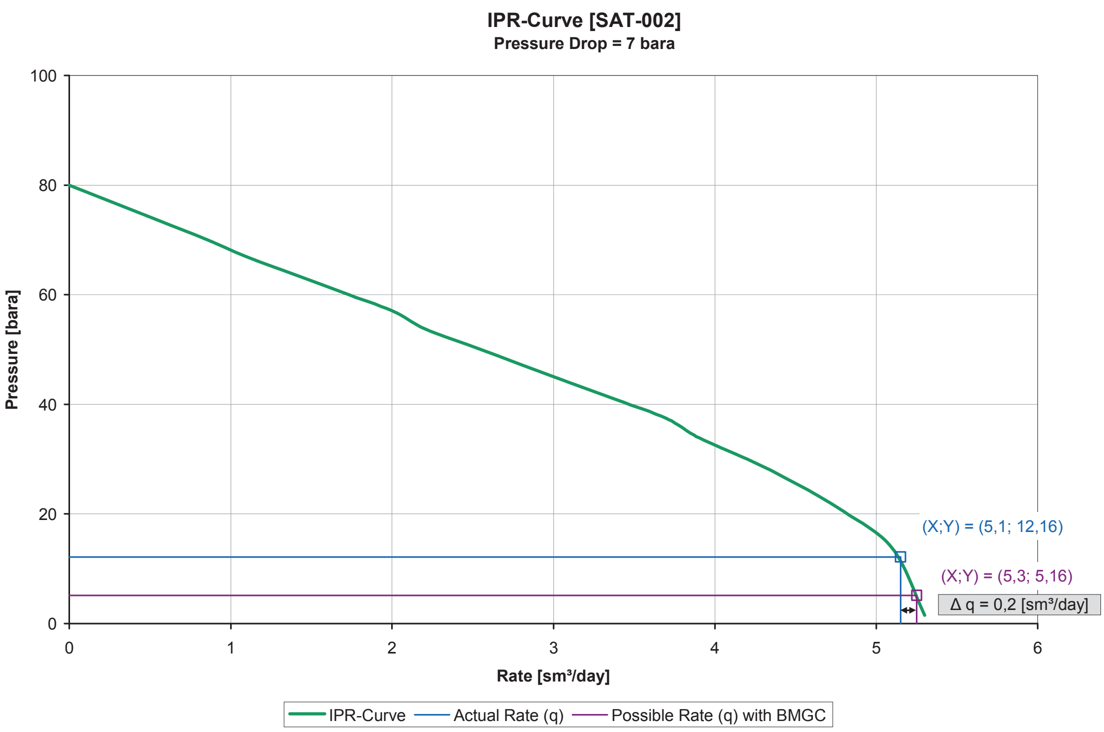


Figure 36: IPR-Curve Model [SAT-002] with increasing Rate due to BMGC

5.3.9 IPR-Curve [SAT-006]

Candidate SAT-006 has a casing pressure of 10 bara and the drawdown is about 8 bara. The calculated bottom hole flowing pressure is 21.48 bara. See Table 14. Production increase due to pressure drop is 3.0 Sm³/day (Figure 37).

Table 14: Calculation of bottom hole flowing pressure [SAT-006]

Bottom hole flowing pressure calculation:			
		Watercut:	-
Well:	SAT-006	Density: formation water:	0.97 kg/l
		Density: oil, gas, formation water:	0.74 kg/l
		Density: gas:	1 kg/m³
Prodcom data:	4/21/2009		
Casing pressure:	9 bar		
Atmosphere:	10 bara		
Dynamic level:	1618 m MD		1617.8 m TVD
Pump setting depth:	1731 m MD		1730.7 m TVD
Lower level of perforation:	1754.5 m MD		1754.1 m TVD
Pressure on dynamic level:	11.59 bara		p(Dynamic level) = p(Wellhead) + rho * g * h
			Gas: rho ~ rho(Standard conditions) * p
Distance-> Dynamic level - Pump:	112.9 m		
p (hydr):	8.19 bar		
Distance-> Pump - Lower level of perforation:	23.4 m		
p (hydr):	1.70 bar		Water content neglectable
P_{wf}:	**21.48 bara**		

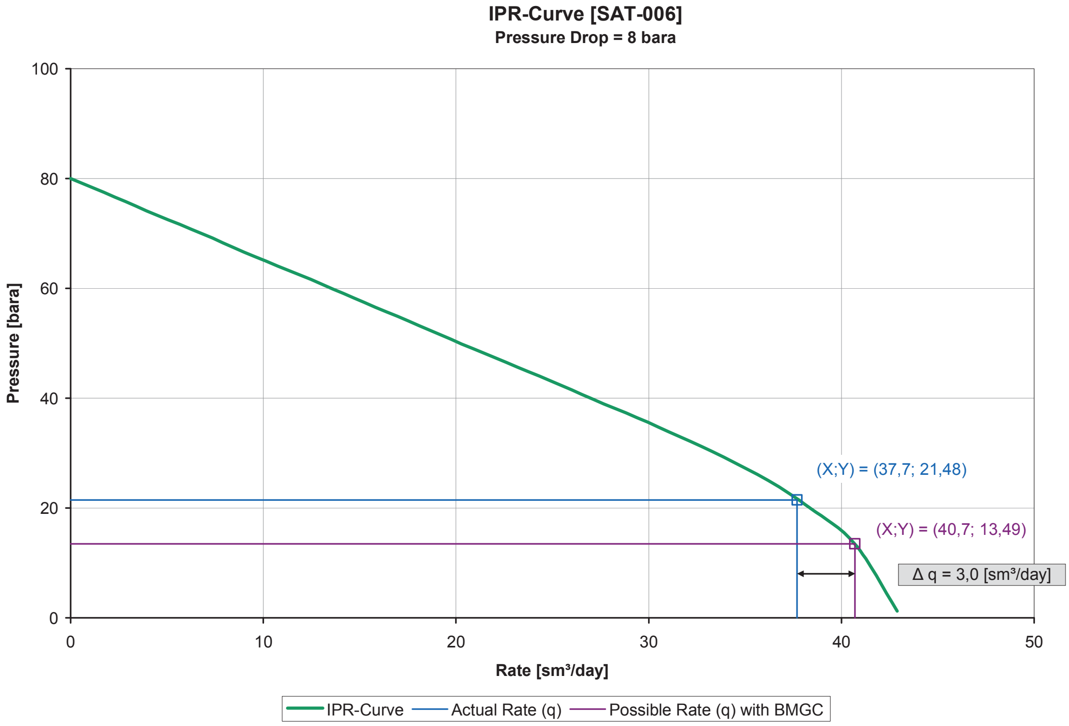


Figure 37: IPR-Curve Model [SAT-006] with increasing rate due to BMGC

5.3.10 IPR-Curve [SAT-007]

Casing pressure of well SAT-007 is about 9 bara and the resulting pressure drop is 7 bara. The calculated bottom hole flowing pressure shows 22.53 bara which is mapped in Table 15. Because of pressure drawdown the increasing production is 0.35 Sm³/day. See Figure 38.

Table 15: Calculation of bottom hole flowing pressure [SAT-007]

Bottom hole flowing pressure calculation:			
		Watercut:	0.66
Well:	SAT-007	Density: formation water:	0.97 kg/l
		Density: oil, gas, formation water:	0.74 kg/l
		Density: gas:	1 kg/m³
Prodcom data:	4/21/2009		
Casing pressure:	8 bar		
Atmosphere:	9 bara		
Dynamic level:	1598 m MD		1597.9 m TVD
Pump setting depth:	1743.2 m MD		1743 m TVD
Lower level of perforation:	1765.1 m MD		1764.9 m TVD
Pressure on dynamic level:	10.41 bara	p(Dynamic level) = p(Wellhead) + rho * g * h	
		Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	145.1 m		
p (hydr):	10.53 bar		
Distance-> Pump - Lower level of perforation:	21.9 m		
p (hydr):	1.59 bar	Water content considered	
P_{wf}:	**22.53 bara**		

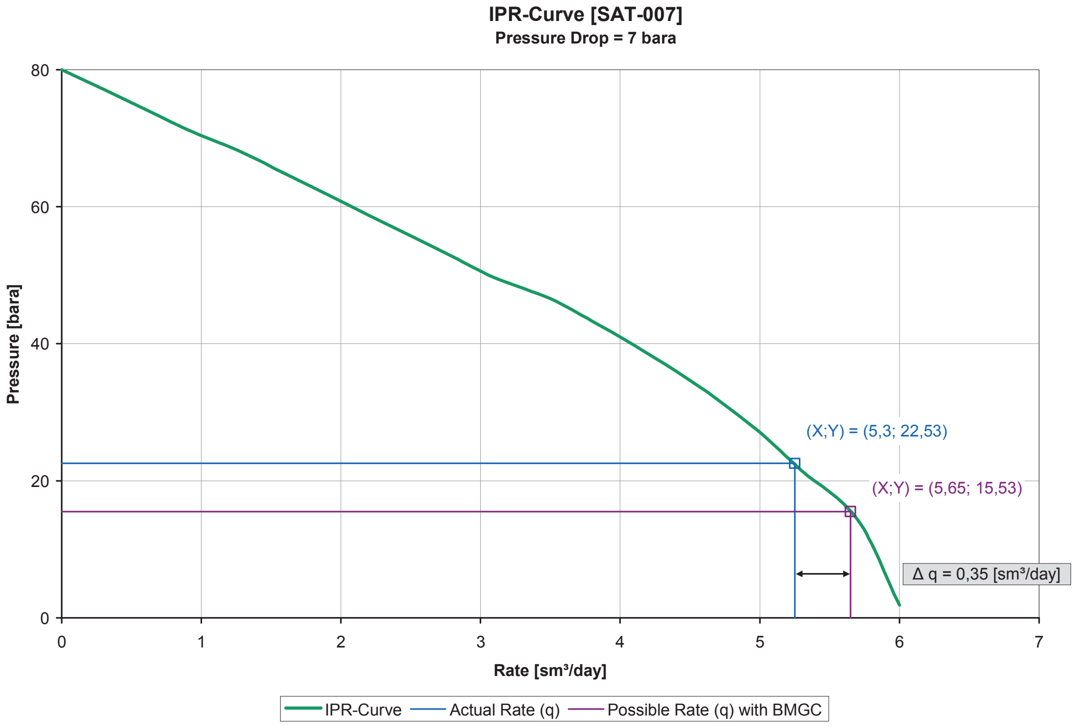


Figure 38: IPR-Curve Model [SAT-007] with increasing rate due to BMGC

5.3.11 IPR-Curve [SAT-023]

SAT-023 has a casing pressure of 7.5 bara and the resulting pressure drawdown is 5 bara. In Table 16 is mentioned the calculated bottom hole flowing pressure which is 31.01 bara. Figure 39 shows IPR-Curve with an increase in production of 2.5 Sm³/day.

Table 16: Calculation of bottom hole flowing pressure [SAT-023]

Bottom hole flowing pressure calculation:			
		Watercut:	-
Well:	SAT-023	Density: formation water:	0.97 kg/l
		Density: oil, gas, formation water:	0.74 kg/l
		Density: gas:	1 kg/m³
Prodcom data:	4/21/2009		
Casing pressure:	6.5 bar		
Atmosphere:	7.5 bara		
Dynamic level:	1450 m MD		1411.3 m TVD
Pump setting depth:	1672 m MD		1629.4 m TVD
Lower level of perforation:	1766 m MD		1721.1 m TVD
Pressure on dynamic level:	8.54 bara	p(Dynamic level) = p(Wellhead) + rho * g * h	
		Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	218.1 m		
p (hydr):	15.82 bar		
Distance-> Pump - Lower level of perforation:	91.7 m		
p (hydr):	6.65 bar	Water content neglectable	
P_{wf}:	**31.01 bara**		

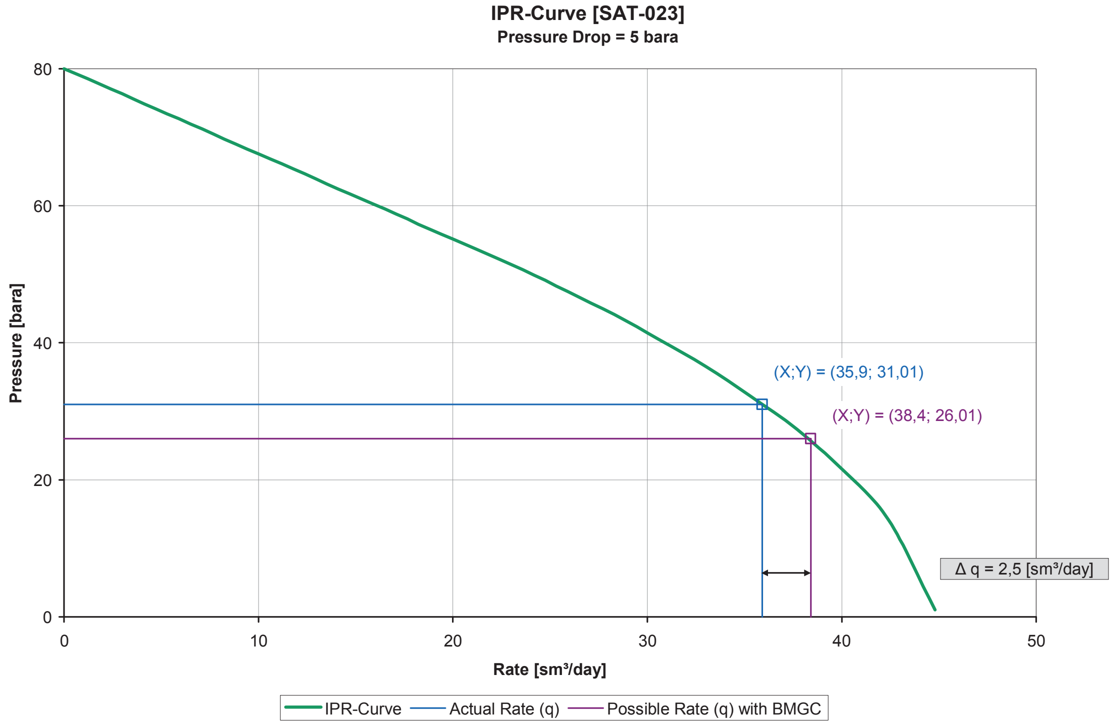


Figure 39: IPR-Curve Model [SAT-023] with increasing rate due to BMGC

5.3.12 IPR-Curve [V-016]

The pressure in the casing of well V-016 is about 14 bara and the pressure drawdown is 12 bara. Calculated bottom hole flowing pressure p_{wf} is 97.79 bara and the resulting increasing production rate is 11.0 Sm³/day.

Table 17: Calculation of bottom hole flowing pressure [V-016]

Bottom hole flowing pressure calculation:			
		Watercut:	0.98
Well:	V-016	Density: formation water:	0.97 kg/l
		Density: oil, gas, formation water:	0.74 kg/l
		Density: gas:	1 kg/m³
Prodcom data:	4/21/2009		
Casing pressure:	13 bar		
Atmosphere:	14 bara		
Dynamic level:	1211 m MD		1209.4 m TVD
Pump setting depth:	1389 m MD		1387.2 m TVD
Lower level of perforation:	2123.5 m MD		2118.7 m TVD
Pressure on dynamic level:	15.66 bara	p(Dynamic level) = p(Wellhead) + rho * g * h	
		Gas: rho ~ rho(Standard conditions) * p	
Distance-> Dynamic level - Pump:	177.8 m		
p (hydr):	12.90 bar		
Distance-> Pump - Lower level of perforation:	731.5 m		
p (hydr):	69.23 bar	Water content considered	
P_{wf}:	**97.79 bara**		

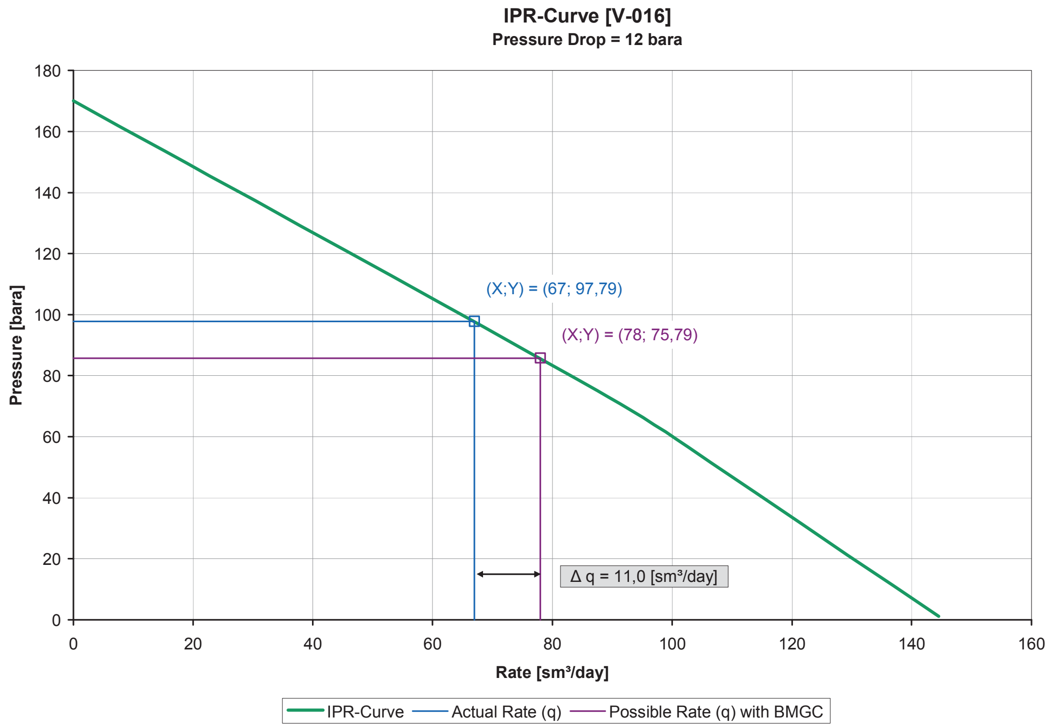


Figure 40: IPR-Curve Model [V-016] with increasing rate due to BMGC

5.4 Appropriate Candidate for Production Tests

After finishing the Excel® charts to devise production increase $\Delta\ q_{oil}$ an appropriate candidate for production tests has to be determined.

The results of the chosen candidates which were simulated with Prosper® and further treated with Excel® are listed in downward order of $\Delta\ q_{oil}$. This is mapped in Table 18. As aforementioned, the quantity of the pressure drawdown can not be equated with an increasing production. Self-evident it has to be aspired to a maximal pressure drop, but the critical factor is the Inflow Performance Relationship-Curve.

The wells from the Hiersdorf field are the most abundant candidates but the Asset Management of the RAG Company decided to exclude the wells from Hiersdorf of the BMGC project.

Candidate KTG-W-001 is as well a promising candidate but this well is rather strong diluted. So the decision was made not to carry out production tests of this well by reason of that some operators of the RAG Company made bad experiences with diluted wells (80% upwards) in combination with a BMGC. Formerly, the RAG Company already tried to establish the BMGC technology in an oil field in Zisterdorf. But at that time the compressors were not technically sophisticated and ATEX-certified, such as the present one. Therefore, this attempt failed. Later on in this thesis some experts for BMGC technology disclosed that this point is not a decisive factor. It should be kept in mind that this has to be tested to become an enlightening response. So, the well KTG-W-001 is an appropriate candidate for a BMGC installation.

Next beneficial candidate is MDF-001A. This would be an appropriate candidate for the BMGC but at that time the planned production tests had to be called off because downhole pump was broken down.

Candidates OB-001, RA-002, SAT-023 and V-016 were as well as KTG-W-001 under the directive of high dilution not propounded for production tests at that time.

The remaining candidates from the Sattledt field are SAT-002, SAT-006, SAT-007. From this follows that SAT-007 was chosen for production tests, due to the fact that the two other candidates are completed with tail pipes which are about 100 meters or longer. Therefore, the RAG Company decided not to select those wells. Candidate SAT-007 is also completed with tail pipes but these are only 22 meters long.

A tail pipe may be included in a completion design for several reasons. It can provide a facility for plugs and other temporary flow-control devices, improve downhole hydraulic characteristics, and as well provide a suspension point for downhole gauges and monitoring equipment. [31]

Table 18: Increasing liquid rate Δq_{liquid} and oil rate Δq_{oil} due to pressure drop

Well	Δq liquid [Sm³/day]	Δq oil [Sm³/day]	Pressure drop [bar]
HIER-001	6.70	6.28	3
HIER-004	3.60	3.55	3
HIER-002A	2.90	2.89	3
KTG-W-001	38.00	2.85	5
MDF-001A	0.45	0.44	9
V-016	11.00	0.25	12
SAT-023	2.50	0.20	5
OB-001	3.90	0.18	6
SAT-006	3.00	0.16	8
SAT-002	0.20	0.15	7
SAT-007	0.35	0.12	7
RA-002	0.04	0.04	5

6 Production Tests and necessary Measurements

The utilized production tests and also necessary measurements in the course of this thesis are introduced in the following chapter.

6.1 Production Tests of RAG Candidate SAT-007

Production tests should be conducted to verify simulation results. After well screening and simulation process, the evaluated candidate for production tests is SAT-007. Two different production tests were accomplished. On the one hand the tank test and on the other hand the well checker test. In the following, these tests are described in specific detail.

6.1.1 Tank Test

The procedure of a tank test is to simulate how much oil and water a well is producing during a predetermined time period. Therefore a plastic tank which is pictured in Figure 41 is used to produce the oil from the tubing of the well into the tank, instead into the flow line. Oil transportation into the tank takes place by means of a hydraulic hose which is connected with the tank and the tubing line. The advantage of a tank test is its simplicity and flexibility. The tank is easy to transport and the test equipment can be installed within short time. A big handicap of this test is the marginal significance because of the short time period due to limited tank capacity. Accessorily disadvantageous is the fact that there is no possibility to separate the phases of oil and water during test phase.

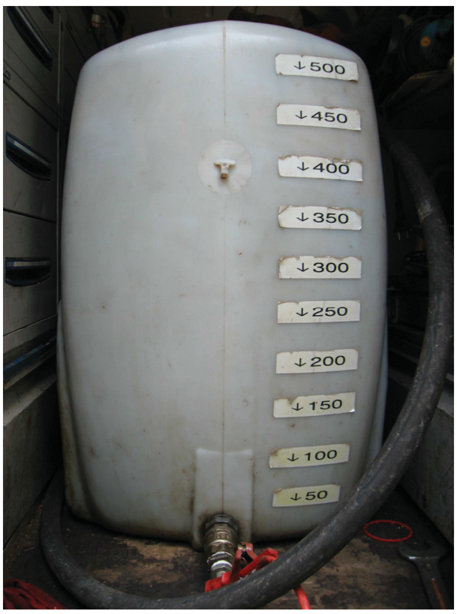


Figure 41: Tank for the tank test

6.1.2 Well Checker

A test with a well checker is to carry out long time period production tests. The major advantage compared to the tank test is to get more meaningful results due to a longer test period. As well, expedient is the separation of the phases representing oil and water. A well checker ascertains gross production rate and furthermore the fraction of oil and water production. The production from tubing is redirected via a hydraulic hose into the well checker. The operating principle of a well checker is based on the separation of oil and water. Gross production from tubing and separated amounts of oil and gas are measured and afterwards are mixed together and pipelined into flow line. Due to the fact that production rate from tubing is bypassed over the well checker and back into the flow line, the test period of a well checker test can be freely timed. Consequently test durations about one week are common and provide as already mentioned above meaningful results.

Figure 42: Well checker at well SAT-007

6.2 Dynamometer Measurements

Dynamometer measurements are used to determine the load of sucker rod pumping systems. Therefore a dynamometer is latched to the travelling polished rod and registers the actual cyclic fluctuations of pump loading within minutes without disturbance of subsurface conditions. This instrument records the polished rod load throughout the working cycle of a downhole pump and produces a continuous plot of polished rod load vs. a complete stroke cycle – the so called dynamometer card. A dynamometer provides accurate information about pump efficiency and based on that, the expected production. It also allows recognizing the onset of pump failures, such as plunger or barrel wear. [27]

Figure 43 shows an ideal dynamometer card. At point a the upstroke begins and the polished rod load gradually increases as the rods stretch until at point b the polished rod supports the weight of the rods in the fluid and the weight of the fluid. Until the downstroke begins at point c, the load remains constant. At this time, the rod load decreases while the rods recoil. At point d, the polished rod supports only the weight of the rods in the fluid. The load remains constant until another cycle begins at point a. In reality dynamometer cards are not as perfect as in the figure below. [25]

The RAG Company applies two different types of dynamometers which are on the one hand mechanical dynamometers and on the other hand digital dynamometers. They are explained in specific detail in the following chapter.

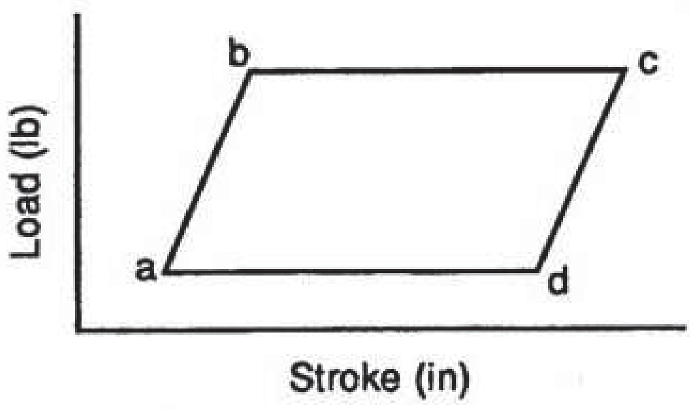


Figure 43: Ideal dynamometer card [25]

6.2.1 Mechanical Dynamometer

A mechanical dynamometer employs a steel ring as its load measuring device, which, being placed between the carrier bar and the polished rod clamp, carries the full polished rod load. The deflection of the ring is directly proportional to the load applied, which is recorded on paper attached to a rotating drum. [28] Mechanical direct-reading dynamometers do not allow the user to view the data while the unit is running, but they are a particularly favourable method to analyse beam pumped wells. See Figure 44.

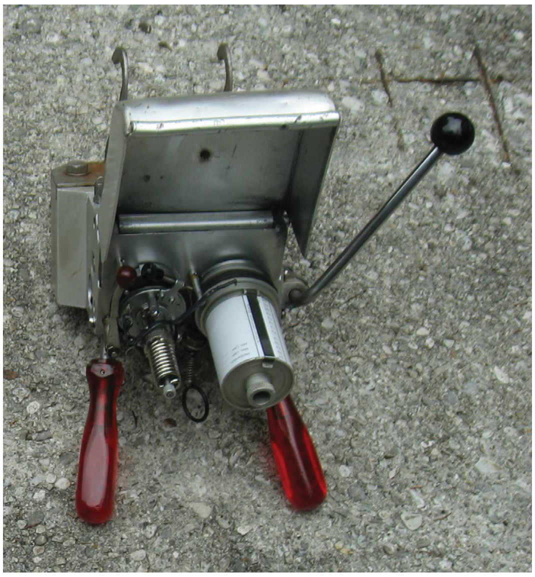


Figure 44: Mechanical dynamometer

6.2.2 Digital Dynamometer

Electrical dynamometers need more skill in use and are more time-consuming and more elaborate than mechanical ones. The dynamometer (see Figure 45 and Figure 46) is connected with the data acquisition unit and allows the operator beside load analysis to record valve checks, counterbalance, and perform pump leakage calculations. The data are saved and collected. They can be taken to the office and transferred to a desktop computer with specialised software for a more detailed analysis and for developing a pump card to analyse possible downhole problems.

Figure 45: Digital dynamometer (le.) and digital dynamometer during operation (ri.)

Figure 46: Data acquisition unit with laptop

6.3 Sonolog Principle

In this thesis, the acoustic method of a sonolog is described as per particulars given below. The acoustic liquid level tool is a precision instrument for determination of the fluid level in the casing of a pumping well. The pressure pulse gas gun of this instrument which is mentioned in Figure 47 (right) sends a gas pressure or acoustic pulse down the annulus of the well. This pressure pulse is reflected from each tubing collar and the fluid as it travels down the well. The unit, which is pictured in Figure 47 (left) stores all reflections and plots them on a paper tape. [29] This is called fluid level diagram and is mapped in Figure 48. The fluid level diagram shows at the beginning an initial kick from the gun blast. Furthermore follows a series of small kicks which indicates the tubing collars. At the end, a low frequency kick from liquid level is logged. The recorded signal trace corresponds to the pulse which is travelling from the gun´s microphone to the liquid level and then back to the surface. [30] A simple count of tubing collars determines the distance to the liquid. [29]

Figure 47: Acoustic liquid level tool (le.) and pressure pulse gas gun (ri.) [30]

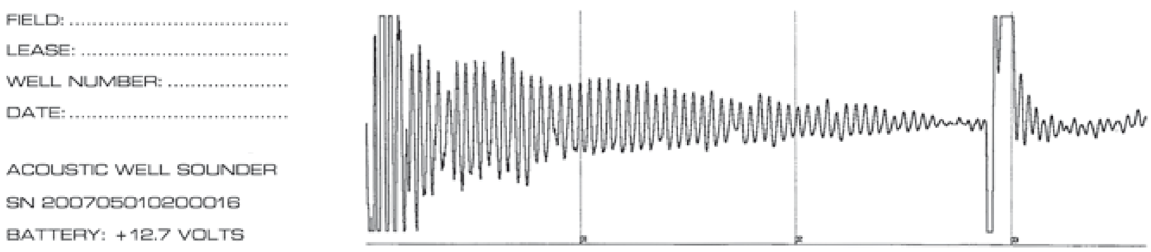


Figure 48: Fluid level diagram; paper tape [29]

7 Certification

Due to the fact that the BMGC equipment is not manufactured in Europe, a certification is necessary. Otherwise it is not permissible unless official approval has been obtained in Austria.

The Beam Mounted Gas Compressor has to be assembled in explosive areas of Zone 2 whereas explosion hazard is emanating from oil and gas. Explosion-proof requirements are temperature Class T3 and explosion Group IIB. According to directive 94/9EG (ATEX-directive) the BMGC must correspond with Group II of devices and equipment Category 3. The national engineer standards for installation of explosion-proof are to maintained (Austria ÖVE/ÖNORM E 8065). [26]

Marking according to ATEX is in the following: **Ex II 3 G cb T3** Also CE-certificate exists. A representative type plate of a double-acting BMGC is mentioned in Figure 49 and the type designation code is exemplified below.

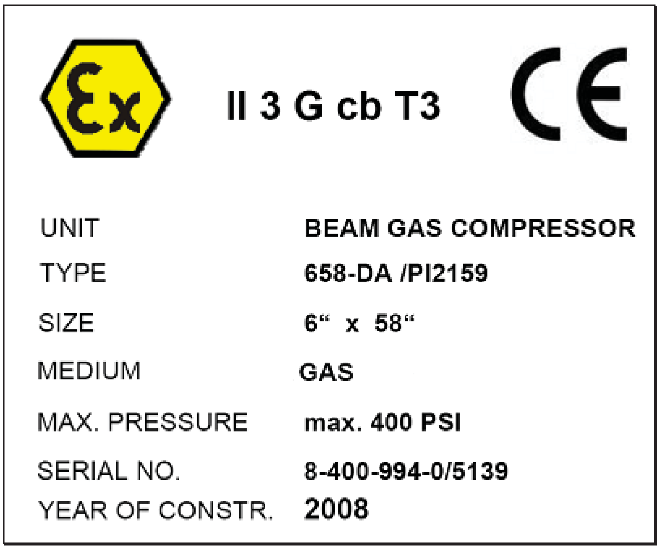


Figure 49: Type plate of a double-acting BMGC [26]

Type designation code [26]:

f.e.: **6 58-DA/material number**

double-acting (S - for single-acting)

stroke length in inch

cylinder diameter

7.1 Equipment

According to ATEX-directive the BMGC has to be modified in some regions and therefore three main points have to be converted. First of all, temperature must be monitored at several points of the Beam Mounted Gas Compressor. The stuffing box and the piston within the compressor have to be lubricated and the stuffing box has to be protected against gas leakage. This is defined in specific detail in the following chapter.

7.1.1 Temperature Monitoring

Automatic temperature monitoring is a result from the so-called T-sensors which are mounted on the BMGC. There are a total of three T-sensors, one is respectively mounted on both, the upper and lower gas compartment. The third is installed on the stuffing box. This is mentioned in Figure 50 and Figure 51. The measuring results are relayed to the electric panel and when adjusted limiting values are exceeded, the sucker rod pump is automatically stopped.

Shutdown temperature should be selected +20℃ above the actual operating temperature but should constitute max.100℃. [26]

7.1.2 Lubrication

The piston within the BMGC is automatically lubricated by means of a grease line which is mounted on the compressor. See Figure 50. This automatic piston lubrication system also lubricates the stuffing box and the system has to be controlled weekly as mentioned in chapter 4.1.1.

7.1.3 Stuffing Box Leak Line

Formation gas could escape in the case of leakage in the stuffing box. Escaped gas represents according to ATEX-directive Group I of devices. Due to the fact that BMGC is Group II of devices, the gas has to be transferred into the well cellar which stands for Group I of the devices. Therefore, a leakage line from the stuffing box is installed for ventilation into well cellar.

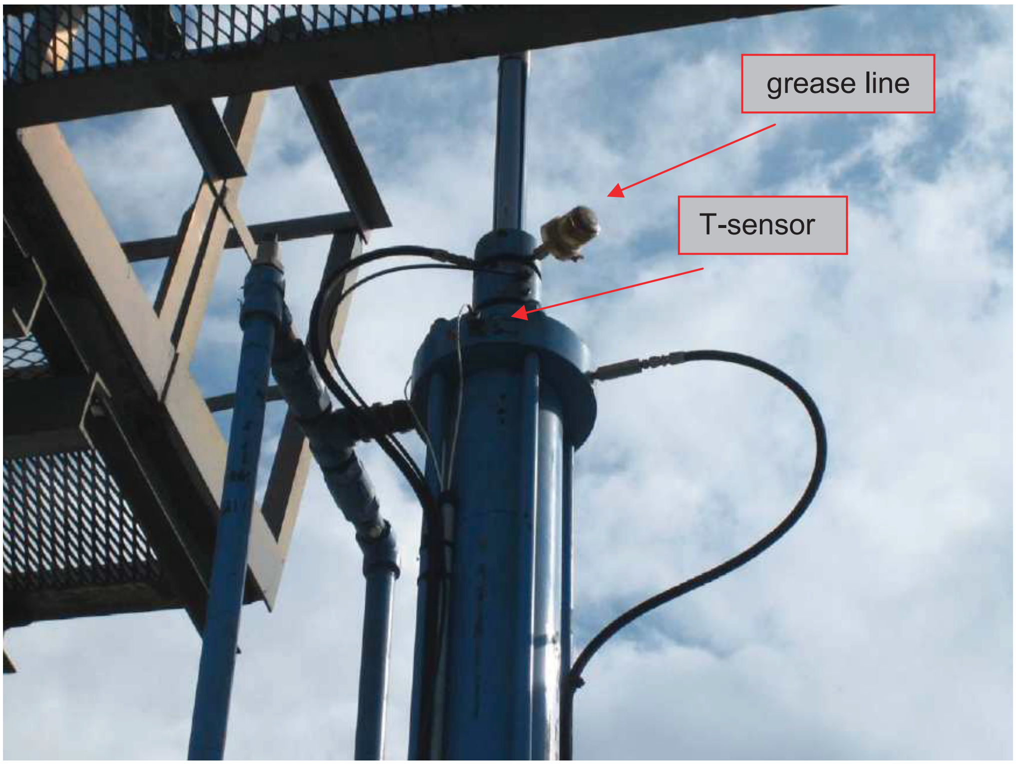


Figure 50: Upper end with T-sensors and grease line [20]

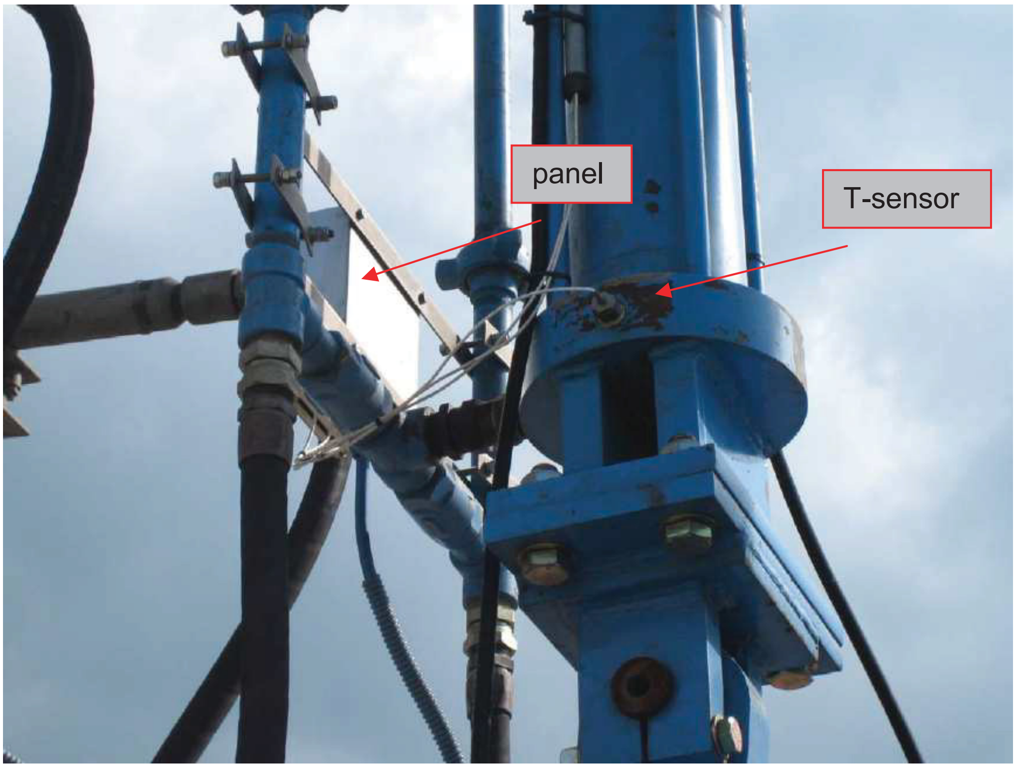


Figure 51: lower end with T-sensor and electric panel [20]

8 Economics

The economical aspect of the Beam Mounted Gas Compressor is considered in specific detail in this chapter.

8.1 Equipment Availability

The contemplated contractors, which are responsible for technical sales and distribution of the BMGC equipment are situated in Austria and Canada. Due to the fact that generally, the BMGC is manufactured overseas, some modifications have to be done according to ATEX-directive which has been already abovementioned.

8.2 Case Studies

To demonstrate the economical success of the BMGC, some case studies are adduced below. A special focus should be placed on the short payback times, which are not at least an aspect of the low CAPEX costs. Even if the Beam Mounted Gas Compressor should not be successful on the selected well, it can be easily moved to other pumping wells with little effort, assuming, that the qualities of the BMGC are constant with the characteristics of the well.

In the Indian Basin, New Mexico, most of the wells were in the later stages of productivity curves and the operating company was looking for a BMGC system to maximize the life and production of their wells. The BMGC Units were installed without any concern or stress carried to the Pumping Unit which greatly pleased the operating company The following are specific cases that had some or all of the problems associated with rod pumping wells- back pressure and gas interference in the downhole pump. In these case studies the production before and after the installation of the Beam Mounted Gas Compressor system is mentioned. Pay out is based on Oil = $65.00 and Gas = $ 4.00. Current pricing are different but the percentage increases are typical. [23]

8.2.1 Case Study 1

The data for case study 1, which is mapped in Table 19, shows a Total Annual Increase of $ 187,380.00 and the yearly expense for the BMGC is about $9,870.00. Due to the fact that no CAPEX costs are known, it was not possible to calculate the actual payback time, but it can be estimated at less than two months. Figure 52 is mentioned below and demonstrates the production rate of oil, gas, and water before and after the BMGC installation. Because of insufficient data, the fluctuations in the production can not be interpreted more accurately.

Table 19: Case study 1 [23]

Indian Basin	Parameter	Before BGC	After BGC	Increase	Increase in Annual Revenue
	Casing PSIG	40	0		
	Oil, BPD	2.5	8.6	6.1	$ 142,740.00
	Gas, MCFD	122	153	31	$ 44,640.00
				Total Annual Increase	**$ 187,380.00**

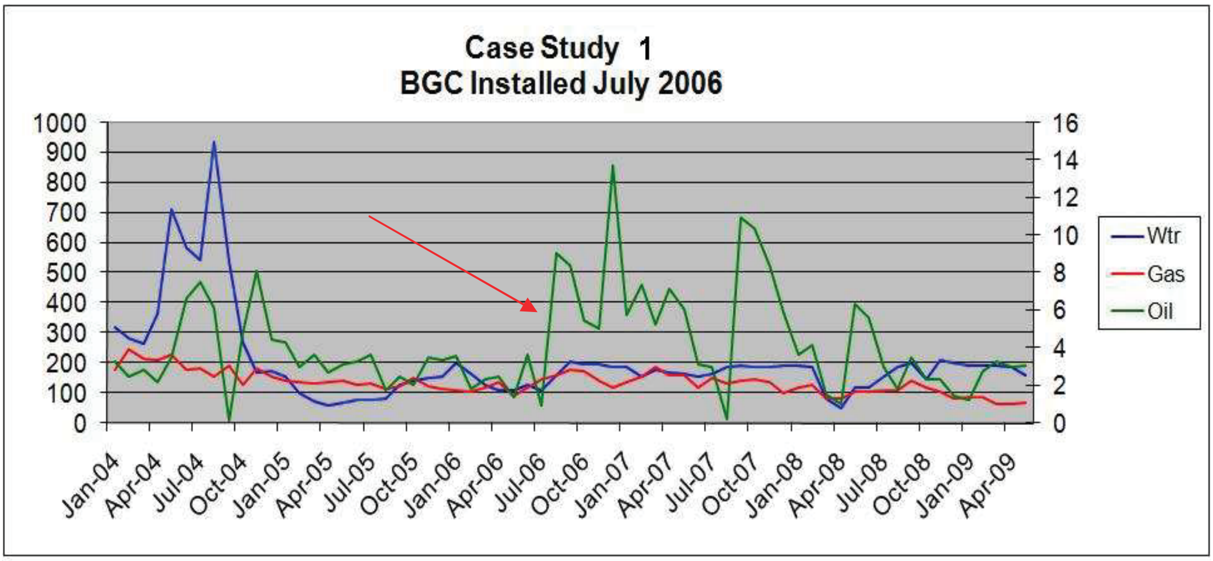


Figure 52: Case study 1 – production rate before and after BMGC installation [23]

8.2.2 Case Study 2

Case study 2, including fundamental data, is pictured in Table 20. The Total Annual Increase amounts $235,800.00 and the yearly expense for the BMGC is about $10,607.28. As well the CAPEX costs are not known in this case, so it was not possible to calculate the actual payback time, but it can also be estimated at less than two months. The production rate of oil, gas, and water before and after the BMGC installation is represented in Figure 53. Because of insufficient data, the fluctuations in the production can not be interpreted more accurately.

Table 20: Case study 2 [23]

Indian Basin	Parameter	Before BGC	After BGC	Increase	Increase in Annual Revenue
	Casing PSIG	40	2		
	Oil, BPD	5	12	6.1	$ 163,80.00
	Gas, MCFD	165	215	31	$ 72,000.00
				Total Annual Increase	**$ 235,800.00**

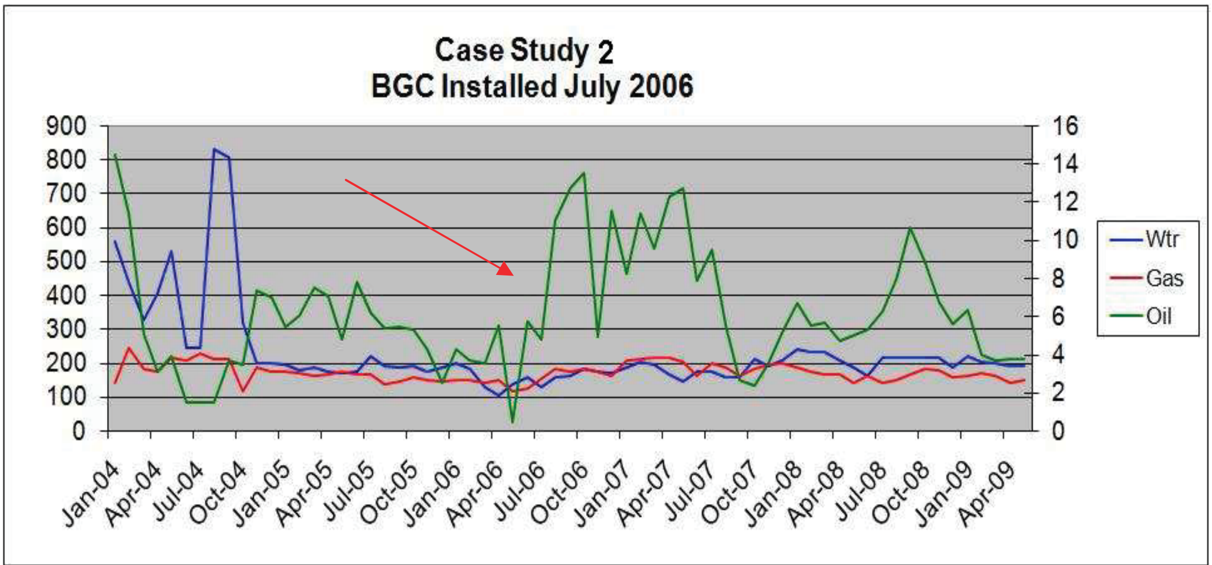


Figure 53: Case study 2 – production rate before and after BMGC installation [23]

8.2.3 Production Examples

At present in Austria, there are approximately twenty BMGC in the field. Table 21 shows three different examples of BMGC installations in this country. Particularly noteworthy is example C, due to the enormous increase in gas production rate. There are also no additional data available to interpret these examples in specific detail.

Table 21: Production rate examples of BMGC installations in Austria [20]

BMGC	Liquid Rate without BGC [m³/d]	Liquid Rate with BGC [m³/d]	Gas Rate without BGC [Nm³/d]	Gas Rate with BGC [Nm³/d]
A	11,4	16,8	256	425
B	1,7	5,8	143	535
C	0	0	20	1500

8.3 Costs

Due to the fact that the Asset Oil Management of the RAG Company has not approved the wells from Hiersdorf field for a BMGC installation, the well KTG-W-001 was selected as an appropriate BMGC candidate. Therefore an economic calculation was made for the wells KTG-W-001 and MDF-001A.

CAPEX costs consist of the BMGC unit, including hoses, pressure valves, and safety valve. Further, the costs for the mounting brackets, the lubrication pump, the ATEX-Conformity Equipment, and the ATEX-Equipment installation are contained. Additionally, the working time (3 men – 8 hours) and the crane costs (8 hours) are included.

OPEX costs consist of working time for maintenance, material costs for maintenance, stuffing box lubrication, and the amount of oil for lubrication. OPEX costs are calculated per year.

For calculating payout time, an actual oil price of $77.29 per barrel, and a current gas price of 0.2 €/Nm³ was determined. A 6" double-acting BMGC system for candidate KTG-W-001 shows a calculated payout time of 1.3 months. Assuming 50 percent increase in gas production, the payout time is diminished to 1.25 months. This is mentioned in Table 22. Additional, some workover modifications have to be done at this well. These modifications are not further mentioned in this thesis. However, the RAG Company, these modifications are known. The expected costs, amount from 20,000€ (best case) up to 70,000€ (worst case). But even if the worst case should happen, the BMGC would still have a payout time of 3.74 months.

A 5"single-acting BMGC system for candidate MDF-001-A results in a payout time of 7.93 months. Assuming 50 percent increase in gas production the payout time is 7.79 months. (see Table 23) The increasing gas production is not a determining factor for this candidate, because the actual gas rate of 9 Nm³/d is very low.

Table 22: Payout time calculation KTG-W-001

Payout Calculation:			
CAPEX costs	28762	€	
OPEX costs	7740	€	
Gas Price	0.2	€/Nm³	
Oil price	325.1	€/Nm³	assuming 77.29 USD/bbl-> €/m³
Payout oil	338156.5	€/a	
Payout gas	12775	€/a	assuming 50% increase in gas production
Payout (oil and gas)	350931.5	€/a	
Payout time (oil)	1.30	Months	
Payout time (oil and gas)	1.25	Months	

Table 23: Payout time calculation MDF-001-A

Payout Calculation:			
CAPEX costs	26762	€	
OPEX costs	7740	€	
Gas Price	0.2	€/Nm³	
Oil price	325.1	€/Nm³	assuming 77.29 USD/bbl-> €/m³
Payout oil	52206.6	€/a	
Payout gas	949	€/a	assuming 50% increase in gas production
Payout (oil and gas)	53155.6	€/a	
Payout time (oil)	7.93	Months	
Payout time (oil and gas)	7.79	Months	

8.4 Economic Appraisal

The adduced case studies possess very short payout times and as well the payout time calculation for the selected candidate is extremely short. This follows from very low CAPEX costs. The annual OPEX costs are similarly low and approximately 27 percent of the CAPEX costs. So, the BMGC technology is an acutely dependable and highly economic method to increase production rate in the RAG oil fields.

9 Alternatives

An alternative to reduce the casing pressure for several oil wells is the application of a Multiphase Pump (MPP). This pump has been employed to increase the production rate by lowering the back pressure on wells and further to consolidate surface facilities. It can boost pressure without the need to separate the phases. Another possibility for an application of a multiphase pumping unit is the economic development of marginal oil and gas fields.

Due to the fact that multiphase pumps require large investments costs, it was decided not to consider this alternative for the RAG Company because the project would not amortize. Additionally, it is a precondition that several oil wells should be linked together on a multiphase pump. In Upper Austria, there are no promising possibilities to link together several oil wells or an oil field on a multiphase pump. The RAG Company acquired a MPP several years ago in Zistersdorf, but the oil wells there, are located close together compared to Upper Austria. A picture of the multiphase pump in Zistersdorf is shown in Figure 54.

Figure 54: Multiphase pump of RAG in Zistersdorf

10 Results

In this chapter the results of the accomplished production tests from well SAT-007 were compared with the simulation results. Prosper® simulation results of all simulated wells are listed in the Appendix.

10.1 General

After the simulation process the decision was made to run production tests for the well SAT-007. The accurate decision making process for the appropriate candidate is adduced in chapter 5.4. Table 24 shows the simulated increase of production rate which can be reached due to a BMGC installation. Noticeable is that a high magnitude of pressure drop is not decisive for a high increase of production rate. Self-evident it has to be striven to a maximum pressure drop, but the determining factor is the distribution of the IPR-curve. This progress depends on several factors, see chapter 3.1.

Table 24: Increasing oil rate Δq_{oil} [Sm³/day] due to BMGC

Well	Gross Rate (q) [m³/d]	Net Rate (q) [m³/d]	Percentage of oil [%]	Δq_{liquid} [Sm³/day]	Δq_{oil} [Sm³/day]	Pressure drop [bar]
HIER-001	73.30	68.68	93.70	6.70	6.28	3
HIER-004	67.38	66.37	98.50	3.60	3.55	3
HIER-002A	32.50	32.50	99.70	2.90	2.89	3
KTG-W-001	122.00	9.15	7.50	38.00	2.85	5
MDF-001A	2.13	2.10	98.82	0.45	0.44	9
V-016	67.03	1.54	2.30	11.00	0.25	12
SAT-023	35.90	2.87	8.00	2.50	0.20	5
OB-001	66.50	2.99	4.50	3.90	0.18	6
SAT-006	37.70	2.04	5.40	3.00	0.16	8
SAT-002	5.10	3.77	73.90	0.20	0.15	7
SAT-007	5.30	1.80	34.00	0.35	0.12	7
RA-002	1.24	1.23	99.60	0.04	0.04	5

10.2 Prosper® Simulation of Candidate SAT-007

In Table 25 the output data for the IPR calculation of the Prosper® simulation is mapped. These data were transferred into Excel® to construct the exact reducing pressure which results in increasing production. This is adduced in specific detail in chapter 5.2. Figure 55 which is mentioned below shows the IPR plot of the Prosper® simulation of candidate SAT-007. The blue mark stands for the actual bottom hole flowing pressure in bara. The required data for Prosper® simulation process are similarly discussed in chapter 5.2.

Table 25: Prosper® output data of IPR calculation

++++++++++++++++++++++++++++++
+ IPR Calculation Results +
++++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)
----------	--------
0.00015899	80.00
0.31432	76.97
0.62849	73.93
0.94266	70.90
1.3	67.87
1.6	64.84
1.9	61.80
2.2	58.77
2.5	55.74
2.8	52.71
3.1	49.67
3.5	46.59
3.8	43.32
4.1	39.81
4.4	36.01
4.7	31.81
5.0	27.06
5.3	21.48
5.7	14.35
6.0	1.86

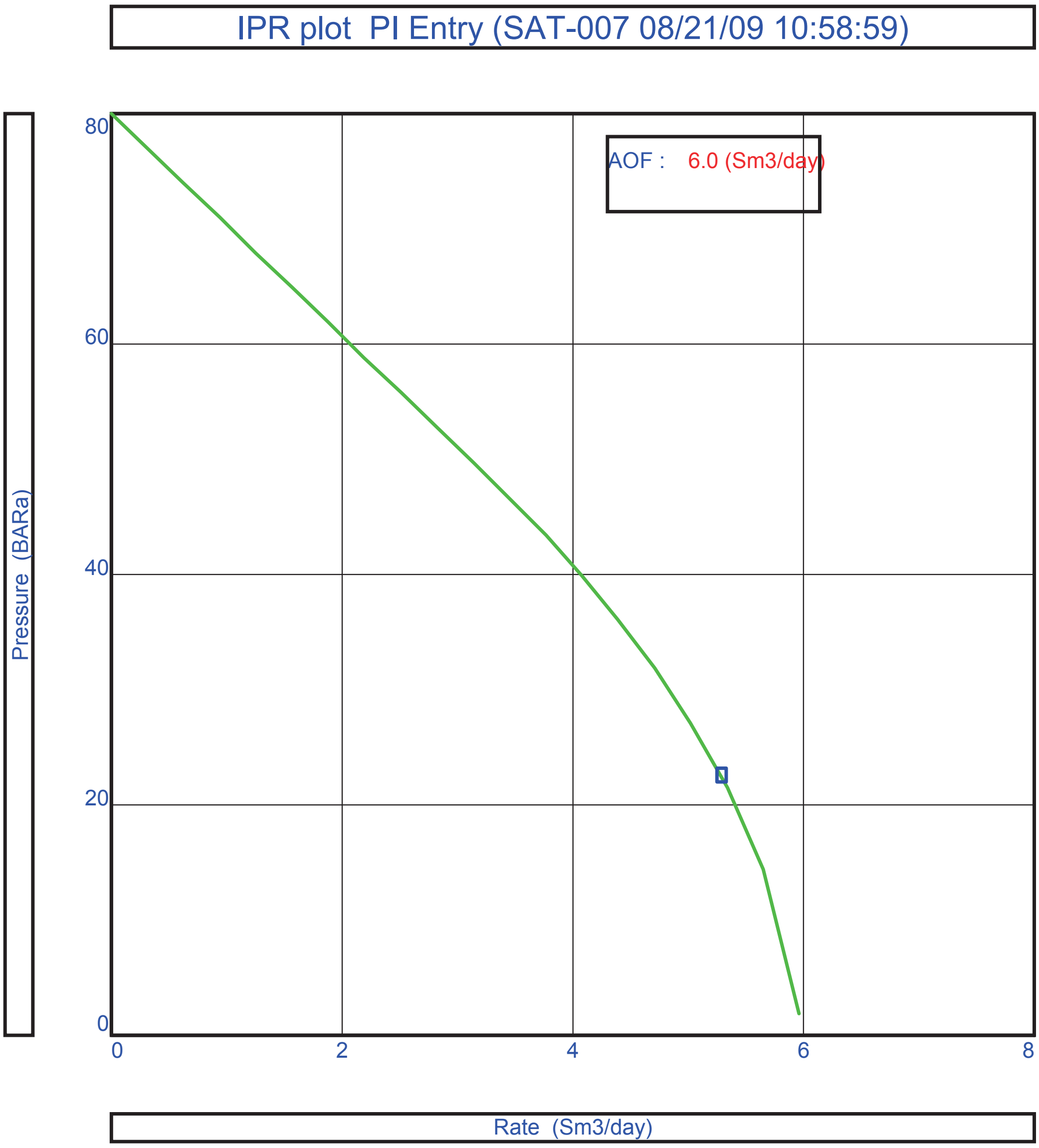


Figure 55: IPR plot modelled with Prosper®

10.3 Dynamometer Cards of Candidate SAT-007

Dynamometer measurements were accomplished with both, a mechanical and a digital dynamometer unit. The principle of this method is described in chapter 6.2.

10.3.1 Mechanical Dynamometer Cards

Two measurements were made with this unit. At first, the well was measured with a casing pressure of 9 bar. This was the actual pressure, the well had at that time. Figure 56 shows this dynamometer card. For better perspective of the dynamograph, a rating scale is added. The shape of the dynamograph indicates fluid pound. This means that the pump displacement rate is higher than the formation of potential liquid production rate. The fluid pound effect is essential for the installation of a BMGC, to ensure that the pumping unit has the efficiency to produce the potential increase of production

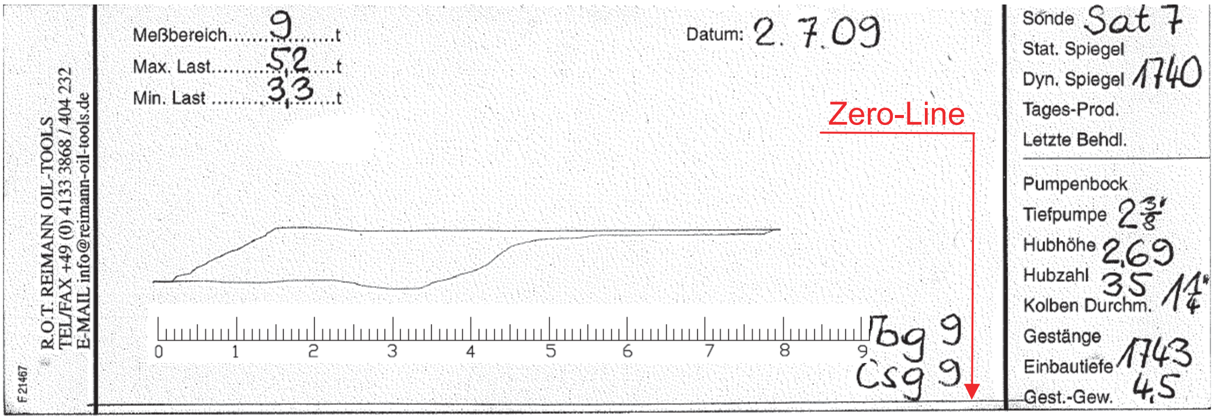


Figure 56: Dynamometer card with 9 bar casing pressure

Figure 57 reflects the dynamometer card with a casing pressure of 0 bar. The added rating scale shows a modicum increase of the dynamograph.

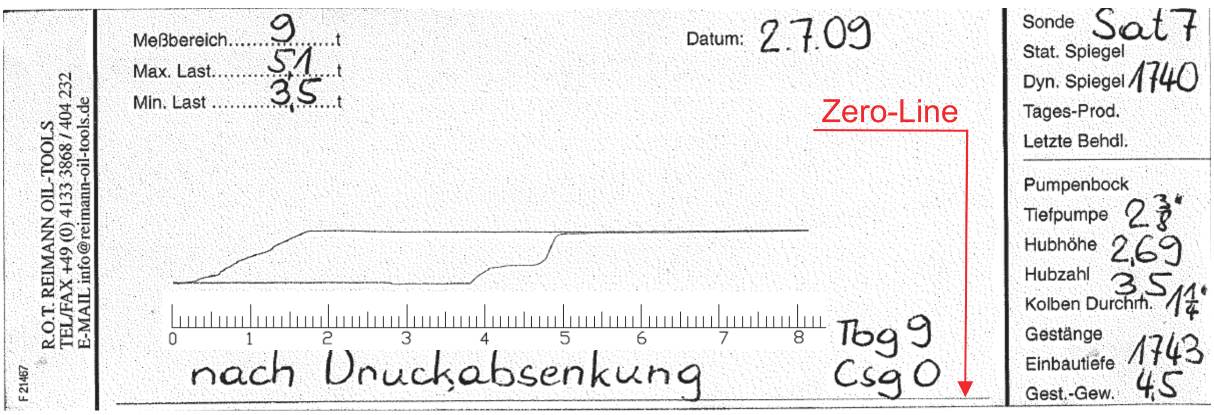
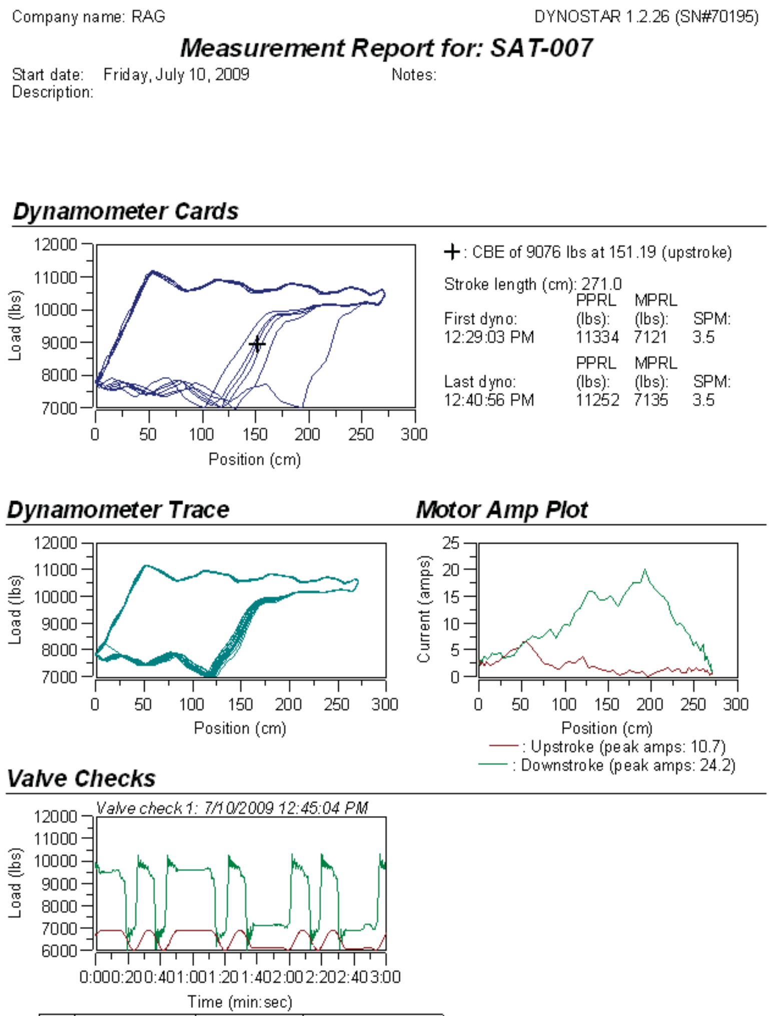


Figure 57: Dynamometer card with 0 bar casing pressure

10.3.2 Digital Dynamometer Report

As well two measurements were run with the digital unit in order to compare and confirm the simulated results. The measuring report was taken with 9 bar casing pressure (see Figure 58). The nomenclature in this figure, called ´Dynamometer Cards´ means temporarily memorized cards during the measuring process. The dynamograph card shows that the well is pumped off. This is already explained in chapter 10.3.1. The ´Dynamometer Trace´ signifies the average distribution. Additionally, the ´Motor Ampere Plot´ is mapped in this Figure, which is useful for correct balancing of the counterbalance weights. In this case the plot shows that the counterbalance weights of the pumping unit are not correctly equilibrated. For accurate balancing, the peaks have to be equally high. Similarly, the chart for the ´Valve Checks´ is mentioned to control the leak tightness of the travelling and standing valve. This picture shows that the travelling and standing valves are tight.



	Avg. Load (lbs)	Position (cm)	Leakage (lbs/sec)
TV	10579	260	0
SV	7876	19	-5

Figure 58: Digital Dynamometer card with 9 bar casing pressure

Figure 59 shows the measuring report of SAT-007 with a casing pressure of 0.6 bar. It can be seen, that there is a modicum increase of the dynamograph card at 0.6 bar compared to the dynamograph card with 9 bar casing pressure. An increase of the dynamograph card implies an increase of production rate. Additionally the ´Motor Ampere Plot´ is mapped in this Figure, which has already been explained above.

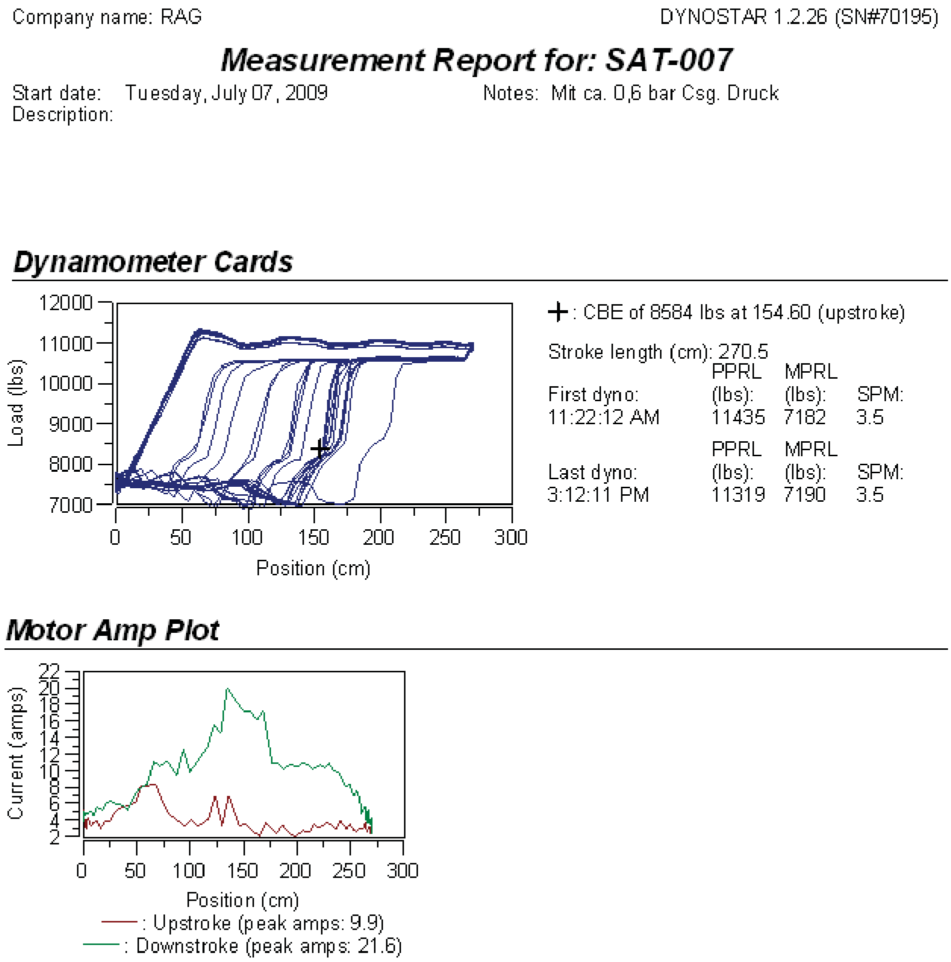


Figure 59: Digital Dynamometer card with 0.6 bar casing pressure

10.4 Tank Test of Candidate SAT-007

A tank test was accomplished for the well SAT-007 to probe the Prosper® simulation results. The procedure of a tank test is adduced in chapter 6.1.1. The test duration was about two hours. First, the production at a casing pressure of 9 bar was done. Afterwards, the casing pressure was decreased to 0.6 bar and the test was repeated. The results of this test are mapped in Table 26. It turned out that the production increase due to casing pressure drop was 6.77 %. In fact this is a percentage increase, but it did only approximately match with the simulation results. But, as already described in chapter 6.1.1, the handicap of this test is the marginal significance because of the short test period.

Table 26: SAT-007 Tank test

Tank test well: SAT-007				
T= 28℃				
time [h]	**casing pressure [bar]**	**Ø production [l]**	**increasing production [l]**	**increasing production [%]**
2	9	384	-	-
2	0.6	410	26	6.77

10.5 Well Checker Test of Candidate SAT-007

For better significance a well checker test was made at well SAT-007. The procedure of a well checker test is mentioned in chapter 6.1.2. Test duration was about 4.5 days. At the beginning the casing pressure was dropped to 0 bar. Primary, the well was tested with 0 bar casing pressure and the oil production rate, water production rate and gross production rate was recorded over time. Afterwards the casing valve was closed and the build-up of casing pressure was initiated again. The average results over time of the well checker test are mapped below in Table 27. Average oil production rate is due to 0 bar casing pressure 1.93 m^3/day. The original oil production rate at 9 bar casing pressure is 1.8 m^3/day which is already mapped in Table 24. The outcome of the well checker test is an increase in production of 0.13 m^3/day. In comparison with the simulated Prosper® models the production increase results in 0.12 Sm^3/day (see Table 24). Both deliverables the simulated Prosper® results as well as the well checker results, agree.

For completeness, the average oil production rate (Table 27) of the well checker test with increasing casing pressure is also mentioned. This value is lower than the original oil production rate of 1.80 m³/day. Due to the fact that the build up of the casing pressure was recorded from 0 bar up to 9 bar, this average value of 1.71 m³/day is subject to fluctuations of the reservoir and therefore not meaningful. Accomplishing a well checker test to verify the simulation results was only possible for well SAT-007 because the well checker was utilized for other important projects of the RAG fields.

Table 27: SAT-007 Well checker test

Well checker test well: SAT-007					
stroke number: 3.5 stroke length: 2.69 m dynamic level: 1740 m					
date	**time [h]**	**casing pressure [bar]**	**Ø oil production rate [m³/d]**	**Ø water production rate [m³/d]**	**Ø gross production rate [m³/d]**
4.07.-7.07.	68.5	0	1.93	3.39	5.32
7.07.-9.07.	48	0 - 9	1.71	3.43	5.14

11 Conclusions and Outlook

Due to the fact that many of the RAG oil fields have been producing for a long period of time and most oil wells are on the decline. So, one main focus of attention for the RAG production engineers is to increase, respective perpetuate production rate. A potential increase in production due to casing pressure drop was scrutinized in this thesis and could be verified. The Beam Mounted Gas Compressor technology was described in specific detail, and proven that it is a promising and reasonable method to diminish casing pressure and subsequently increase the production rate. In particular, it is economical with regard to marginal oil wells with a decreasing production rate or oil wells that are uneconomic to produce. Alternatively, the multiphase pump was taken into consideration, but this could not be found as an economically potential solution for the RAG oil fields in Upper Austria.

11.1 General Annotations

The idea of conducting Prosper® simulations to create IPR-curves, was a correct approach for getting constructive information about the performance of the well and thereby be able to assess a potential BMGC installation. Realized production tests, first and foremost the well checker test for the selected candidate SAT-007 corresponds with the results of Prosper® simulation. Hence follows, that this approach to determine optimum candidates for a BMGC installation can be implemented from the RAG Company.

It has to be mentioned, that during the screening criteria process, the assortment of wells was rechecked and curtailed to gain a commensurate quantity of candidates for the simulation process. This indicates high potential for several wells of the RAG oil fields which are suitable for the BMGC technology.

Generally, it can be assumed, that the best candidates for a BMGC are marginal oil wells where the casing gas in the annulus is not able to flow into the flow line because the pressure too low. This is an important factor because a specific wellhead pressure is needed to operate the separator. Even if the oil production rate can not be substantially increased due to a BMGC, the increment of gas production is decisive. Therefore, oil wells with high gas oil ratios and equally, wells with a high gas production rate should be taken into consideration. The potential increase of production rate depends on the distribution of the IPR-curve. It has been pointed out that a high magnitude of pressure drop in the casing is not the determining factor for a large increase in production rate. As a matter of course, a maximal pressure drop has to be aspired, but the critical factor is the distribution of the Inflow Performance Relationship-Curve, as already mentioned.

Similarly, wells which show low bottom hole pressure and good productivity index are good candidates. Gas wells, which were not part of this thesis, should have good permeability and low formation pressure. It is also important to mention that oil wells with high dynamic fluid level and a properly operating downhole pump are not potential candidates, because increasing production raises the fluid level and can overload the downhole pump efficiency. Therefore, it is advantageous and necessary to review downhole pump condition and run dynamometer measurements to verify the actual pump efficiency. In addition, it is necessary to increase the number of strokes of the Pumping Unit with increasing production.

The Beam Mounted Gas Compressor can also be installed on rod pumping gas wells to increase gas production and sales by drawing the produced gas up the casing and into the flow line which relieves gas locking from the downhole pump. One of the main advantages for such an application within the RAG fields is that the compressor is easy to install and there are only a few moving parts to wear out and thus the maintenance costs are very low.

A benefit for the RAG Company is that the BMGC technology provides short payout time due to low CAPEX costs. Generally, the Beam Mounted Gas Compressor is a reliable and highly economic system and profitable in various field applications of the RAG Company.

11.2 Backside Auto Injection System

During the diploma thesis concept an interesting system came across which shows great promise as an alternative to a downhole pump. This method should be tested in more detail and represents a topic for a different diploma thesis.

The principle of a Backside Auto Injection System (BAIS) is mentioned in Figure 60. The core of this system is a compressor (see Figure 61) which injects gas through the casing and is u-tubing it up through the tubing. No valves are used as with conventional gas lift systems.

BAIS should increase production and extend the economic life and recoverable reserves of marginal oil fields. This could be achieved with 2 pilot-operated valves sensing the tubing pressure – one valve normally opened on the discharge – and the other normally closed going to the casing. When the tubing pressure falls below the required set point – in order to provide maximum MCFD flow up the tubing, the normally closed valve running to the casing starts to open while the normally opened valve to the sales simultaneously closes. They will remain in this position until the tubing pressure rises above the required set point. [32]

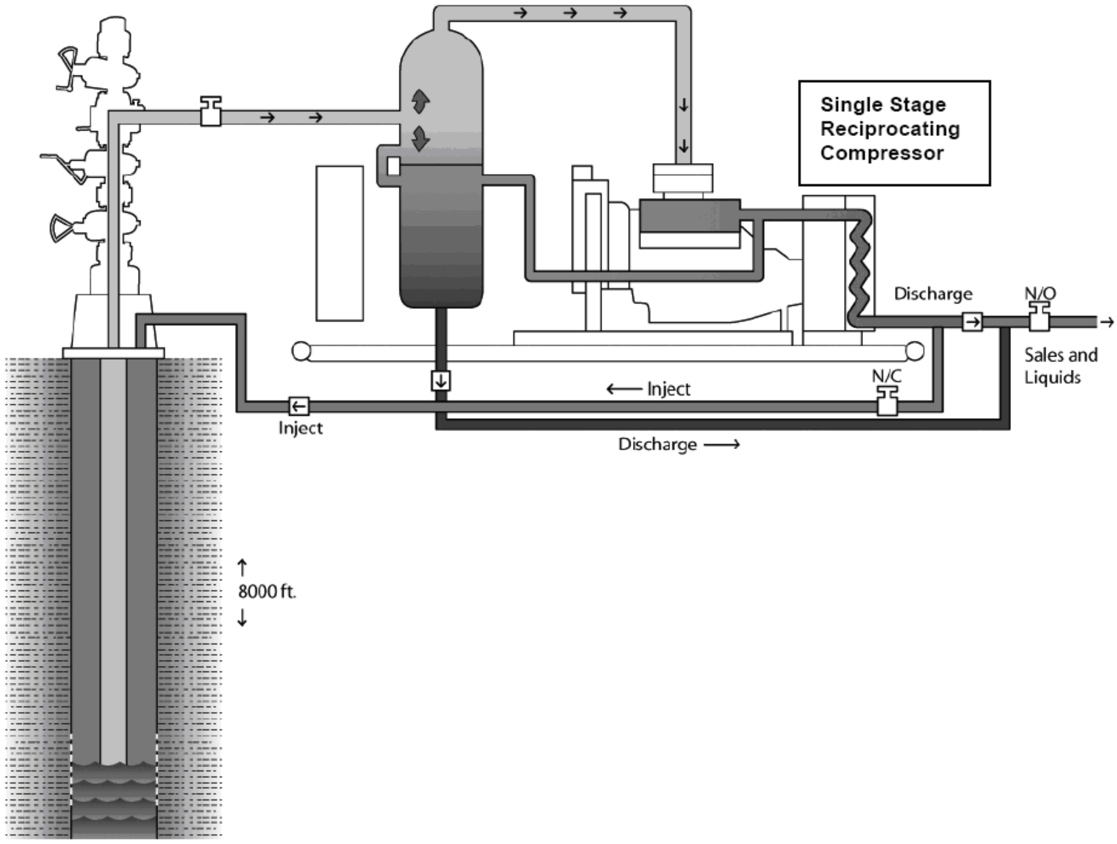


Figure 60: Backside Auto Injection System [32]

Figure 61: BAIS Compressor

11.3 Outlook

On the basis of simulated candidates, the well KTG-W-001 and MDF-001-A are recommended for a Beam Mounted Gas Compressor installation. The existing pump jack type on both wells can easy handle the compressor size without overloading the pumping equipment.

Once, the BMGC is installed, it is absolutely necessary to comply with the maintenance schedule, otherwise, the compressor will rapidly break down. The maintenance instructions are mentioned in this thesis. For further evaluation of the BMGC project, it is important to record the gross production rate as well as the oil production rate, gas production rate and water production rate. But this is already executed by dint of the Prodcom® database, for all wells of the RAG Company. Essential is the comparison of production data before and after the BMGC installation. From this follows valuable clues to future BMGC installations.

Moreover, it is statutory for a Beam Mounted Gas Compressor installation in Austria to comply with ATEX and CE regulations. The ATEX-directive is as well adduced in this thesis.

In the course of this thesis, the economic aspect was likewise observed. The CAPEX costs were considered for two different contractors. Particular mention deserves the huge divergence of CAPEX costs. It should be noted that from one contractor CAPEX is twice as high as from the other one. Nevertheless, the recommendation is made for the more expensive one, due to the fact that the provided system is more technically matured. The popular-priced provider is using a steel cylinder which is due to corrosion problems extremely maintenance intensive. Even if the inner cylinder is coated with chromium, the chromium surface will be porous due to the moisture. This will give rise to serious corrosion problems. The high priced provider is utilizing a fiberglass cylinder, with no corrosion problem. By reason of a short payback time, the higher CAPEX costs are not so portentous. A dependable system for the RAG Company is more essential than a bisection of payback time.

In former times, the RAG Company already tried to establish the BMGC technology in an oil field in Zisterdorf. This trial collapsed, because of the fact that then in several wells Ligroin was used as measure to combat paraffin. This led to a break down of the BMGC due to compressor overheating. It should be taken into account that nowadays, according to ATEX-directive, the BMGC has been modified in some regions. Automatic temperature monitoring is one of those regulations.

In conclusion, the BMGC technology is an acutely reliable and highly economic method to increase the production rate due to casing pressure drop, which can be well established in the RAG fields. The oil well KTG-W-001 and MDF-001-A emerged as appropriate candidates for this project. A detailed production rate analysis should be contrasted before and after the BMGC installation. This provides the basis for future economic Beam Mounted Gas Compressor installations.

12 Directories

12.1 References

[1] http://www.ironhorsecompression.com/jacgas-theory.html: Homepage: Iron Horse 30.03.2009

[2] A.M. Al-Khatib, Mobil Oil Corp.: “Improving Oil and Gas Production With the Beam-Mounted Gas Compressor”, SPE paper 11573 presented at the Production Operation Symposium in Oklahoma City, Ok, February 27 – March 1, 1983.

[3] Source by RAG, accessed September 2009

[4] http://www.globaloilflow.com: Homepage: Global Oil Flow, 06.04.2009

[5] http://www.basilinternational.com/w_cmpr.htm: Homepage: Basil International 06.4.2009

[6] http://www.ok.gov/marginalwells/documents/C-15.B-Primary%20Recovery.pdf, 20.9.2009

[7] Ruthammer Gerhard: Petroleum Production Engineering II; University of Leoben, Leoben 2003, page 7-8

[8] http://www.freeimagehosting.net/uploads/92762de7f5.jpg, 20.09.2009

[9] Guo, Boyun; Lyons, William C.; Ghalambor, Ali: Petroleum Production Engineering, A Computer-Assisted Approach; Elsevier Science & Technology Books, Louisiana 2007, page 1/4

[10] http://www.basilinternational.com/works_o.htm: Homepage: Basil International, 06.04.2009

[11] http://www.test-therm.com.pl/pdf/pf-300_dtr_en.pdf; 19.11.2009

[12] http://www.basilinternational.com/works_c.htm: Homepage: Basil International, 06.04.2009

[13] Kent R. Neuvar, Lufkin Industries, INC.: “Effects of a Beam Mounted Gas Compressor on a conventional pumping unit“, accessed March 2009

[14] http://www.geomore.com/Completed%20Well.htm, 21.04.2009

[15] Source by Normec Oilfield Products, accessed May 2009

[16] http://www.beamgascompressor.com/applications.htm: Homepage: Permian Production Equipment, Inc., 30.03.2009

[17] Joy Castro, University of Alberta: “Beam Mounted Gas Compressor: An Alternative to Booster Compressor”, SPE paper presented at the Annual Technical Conference an Exhibition in Houston, Texas, October 3 – 6, 1999

[18] http://findarticles.com/p/articles/mi_m3159/is_9_224/ai_n27653771, 21.03.2009

[19] http://www.ironhorsecompression.com/jacgas-platforms.html: Homepage: Iron Horse, 16.04.2009

[20] Source by OMV, accessed May 2009

[21] http://www.beamgascompressor.com: Homepage: Beam Gas Compressor, 08.04.2009

[22] Source by Permian Production Equipment, Inc., accessed March 2009

[23] Source by Permian Production Equipment, Inc., accessed November2009

[24] http://www.annugas.com/technical-info.htm#engineereddesign: Homepage: Annugas Compression Consulting Ltd, 21.04.2009

[25] Ruthammer Gerhard: Petroleum Production Engineering II; University of Leoben, Leoben 2003, page 84

[26] Source by Premaberg, accessed May 2009

[27] http://www.leutert.com/docs/oilgas/Dynamometer_DYN77.htm: Homepage: Leutert, 08.07.2009

[28] Takacs Gabor: Sucker–rod pumping manual: Penn Well Corporation; Oklahoma 2003, page 322

[29] http://www.leutert.com/docs/oilgas/downloads/db_awsex.pdf: Homepage: Leutert, 18.11.2009

[30] Source by Echometer, accessed July 2009

[31] DeGeare, Joe; Haughton, David; McGurk, Mark: The guide to oilwell fishing operations: tools, techniques, and rules of thumb; Gulf Professional Publishing, USA 2003, page 197

[32] http://www.compressco.com/Brochure.shtml Homepage: Compressco GasJack Compressors; 18.06.2009

12.2 List of Abbreviations

AOFP	absolute open flow potential
ABM	adjustable basemount
A	area
Ø	average
ATEX	Atmosphère explosible
BAIS	Backside Auto Injection System
bar	bar
bara	bar absolute
BMGC	Beam Mounted Gas Compressor
p_{wf}	bottom hole flowing pressure
p_b	bubble point pressure
CAPEX	capital expenditure
°	celsius, fahrenheit
CE	Conformité Européenne
m^3	cubic meter
d	day
D	diameter
p_d	discharge pressure
EPA	Environmental Protection Agency
GOR	gas-oil-ratio
h	hour
H	hydrogen
“	inch
IPR	inflow performance relationship
K	kelvin
kg	kilogram
l	litre
max.	maximal
m	meter
MPP	multiphase pump
Nm^3	norm cubic meter
OPEX	operational expenditure
%	percent
p	pressure
q	production Rate
PI	productivity index
RAG	Rohöl - Aufsuchungs AG
p_r	reservoir pressure
RPM	round per minute
s	second
R_s	solution gas oil ratio
m^2	square meter
Sm^3	standard cubicmeter

s	strokes per minute
p_s	suction pressure
S	sulphur
t	temperature
mcfd	thousand cubicfeet per day
vs.	versus
V	volume

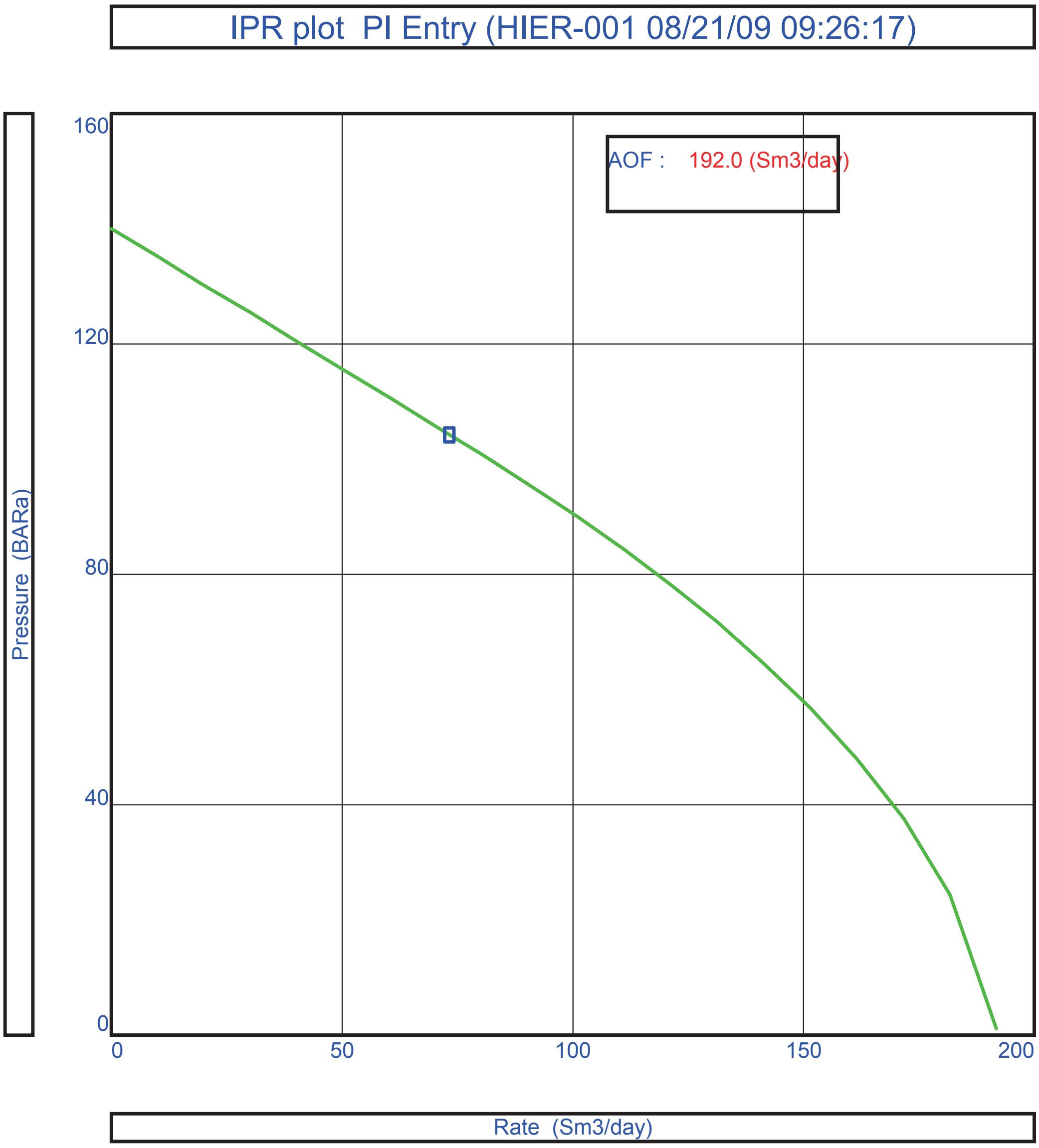
12.3 List of Tables

12.4 List of Figures

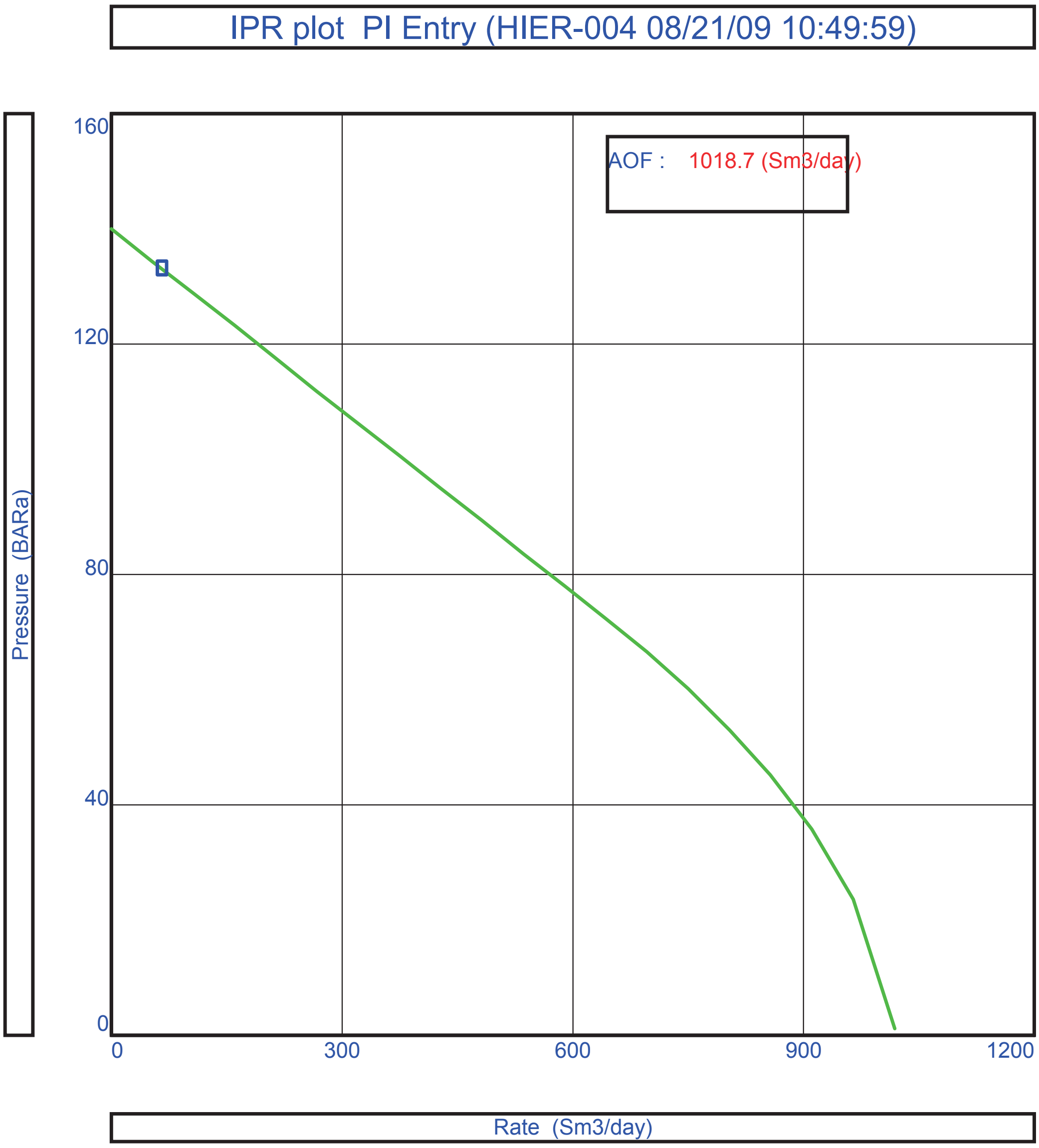
Appendix

The Appendix contains:

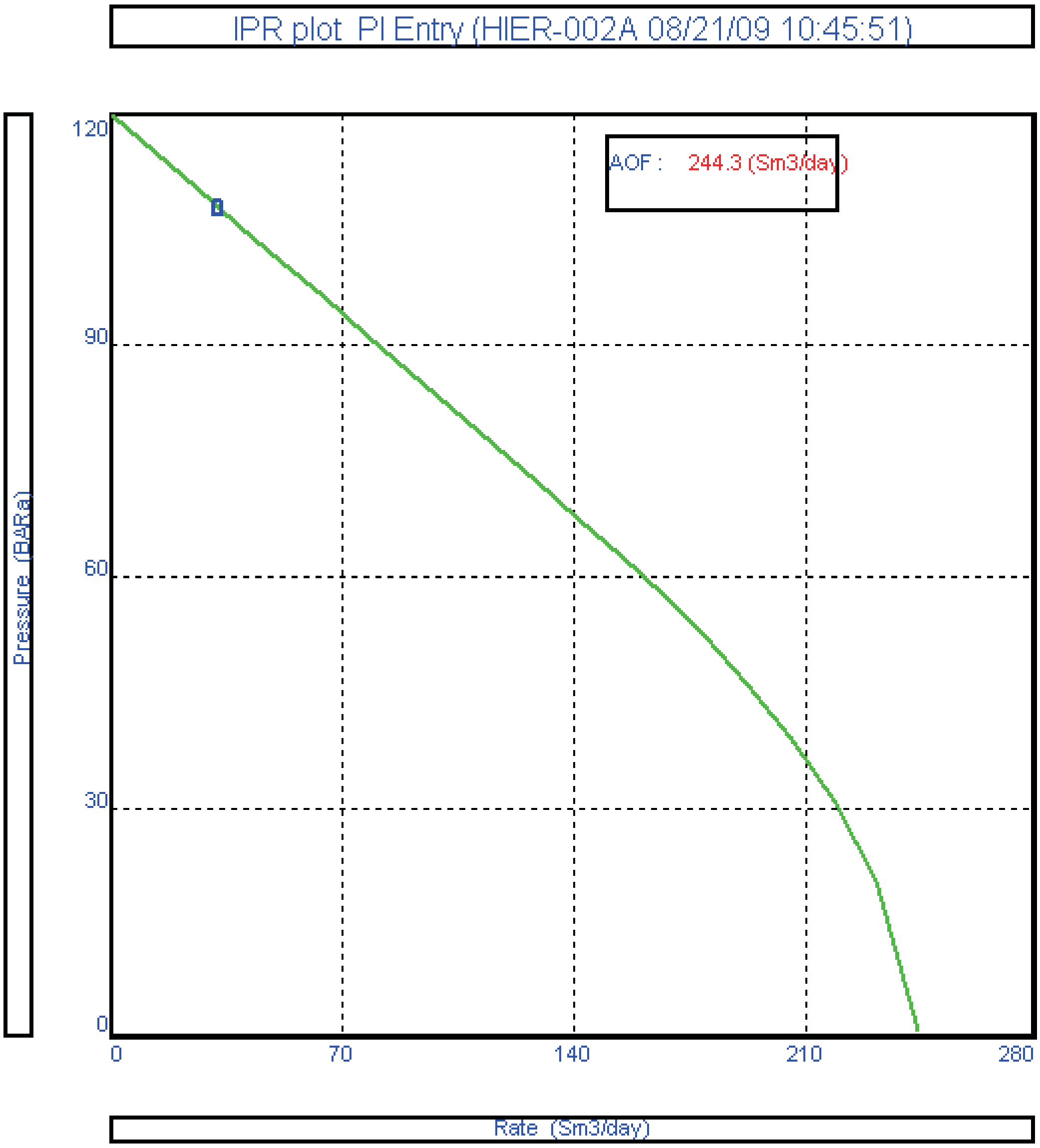
- IPR-Prosper® Models, dated 21.8.2009
- IPR-Calculation Results from Prosper®, dated 21.8.1009
- Mechanical Components a of BMGC (sheet 1-3) [26]
- Features of a BMGC [26]



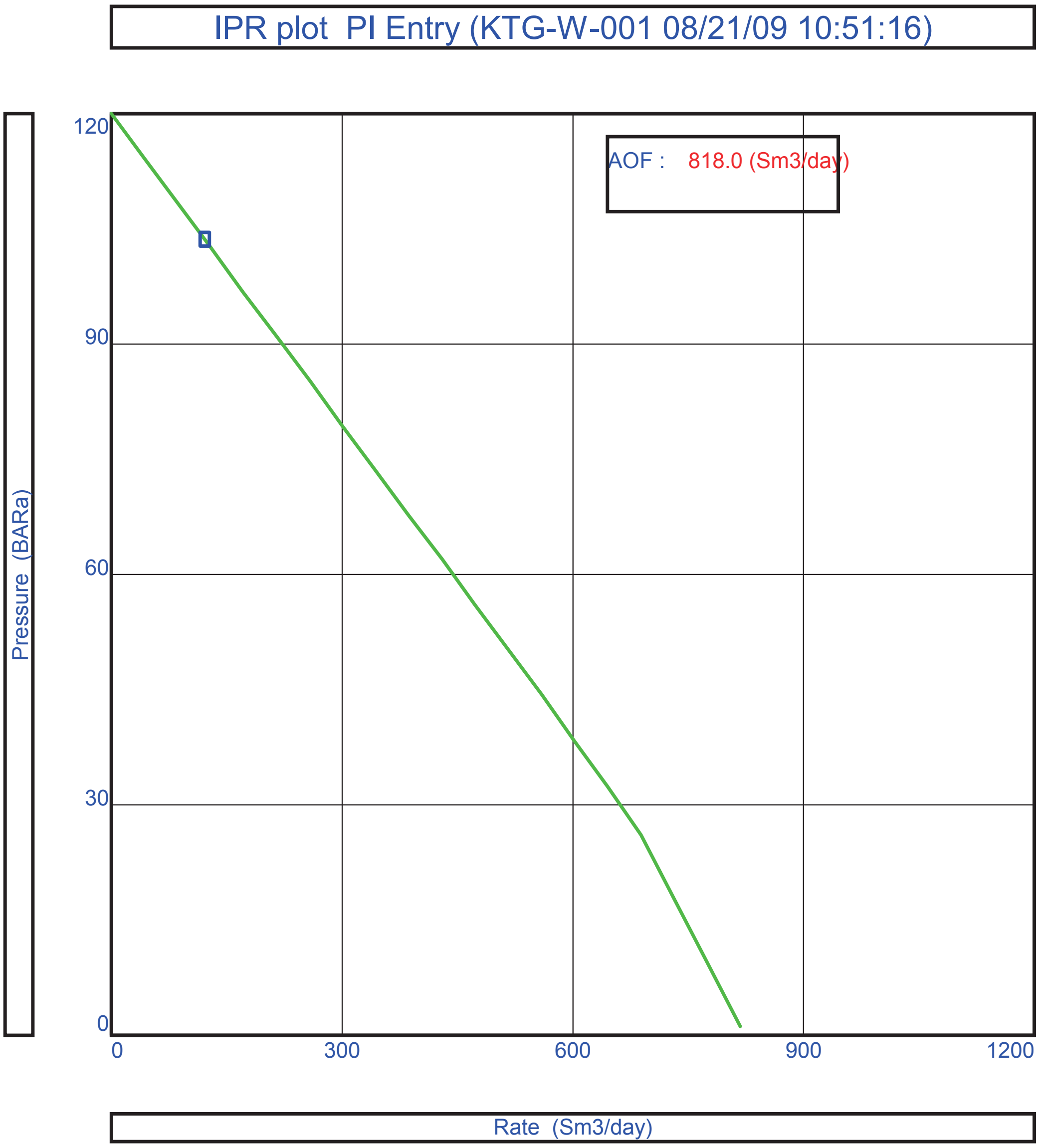
A-Figure 1: IPR-Prosper® model of HIER-001



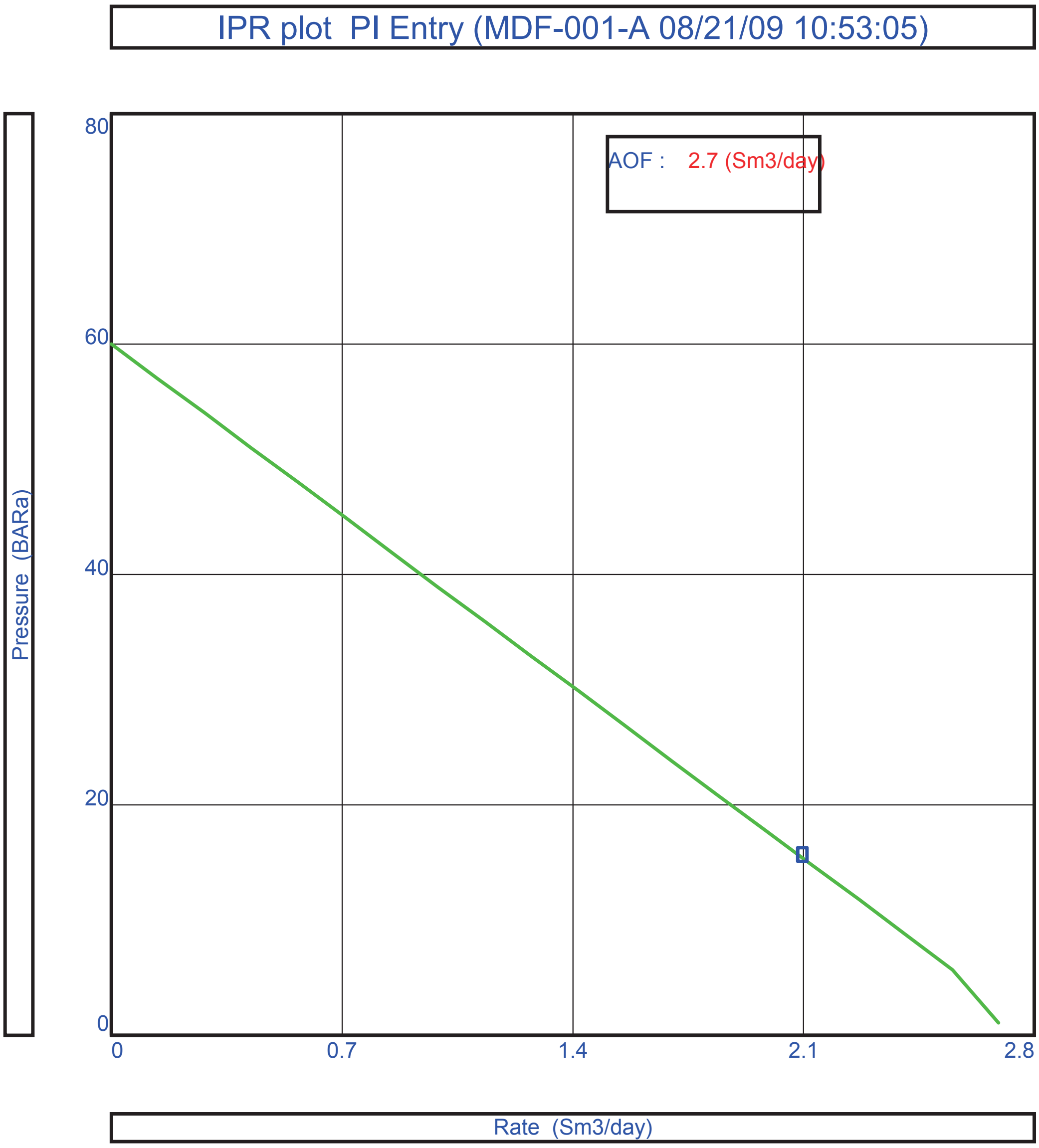
A-Figure 2: IPR-Prosper® model of HIER-004



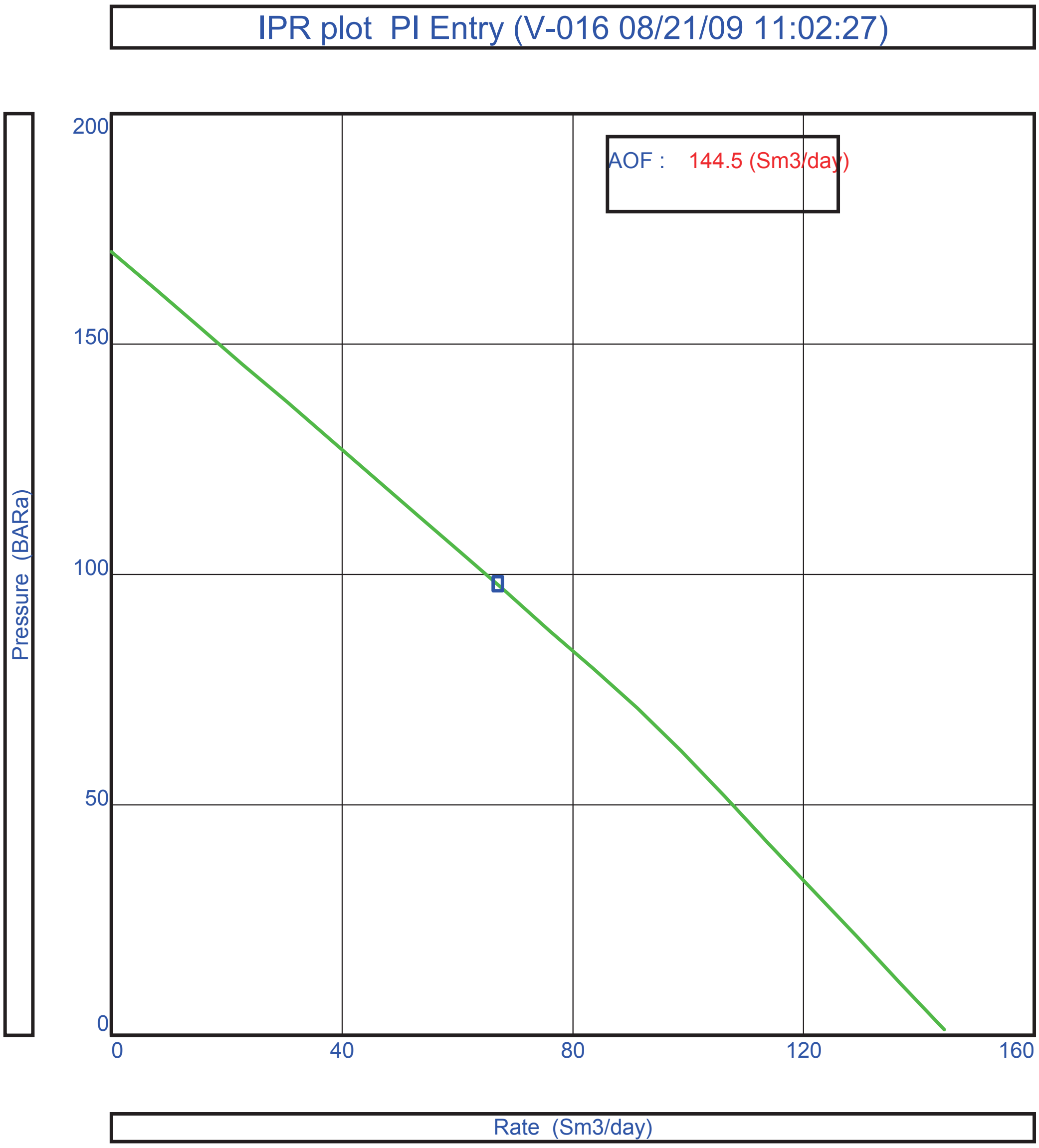
A-Figure 3: IPR-Prosper® model of HIER-002A



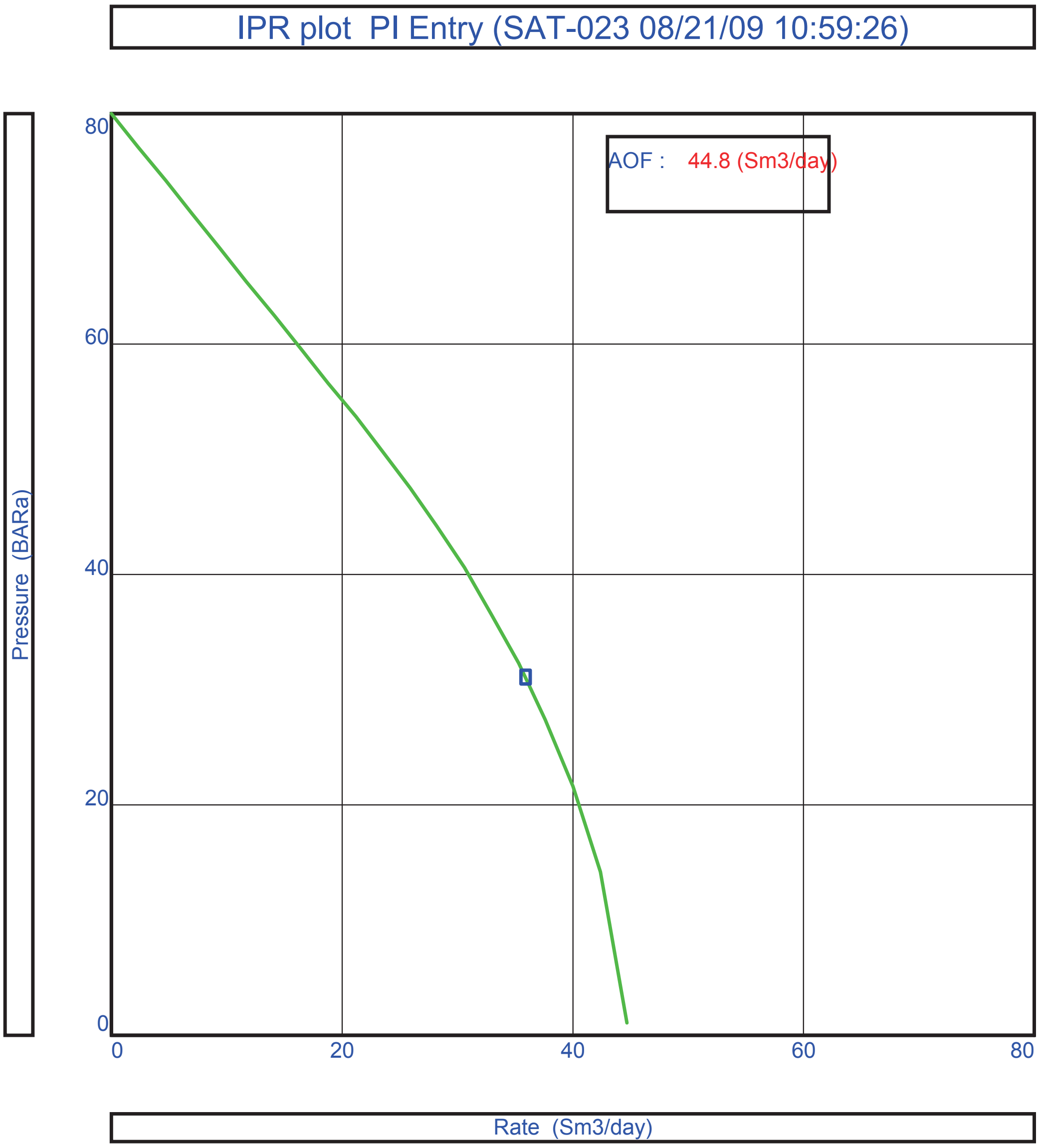
A-Figure 4: IPR-Prosper® model of KTG-W-001



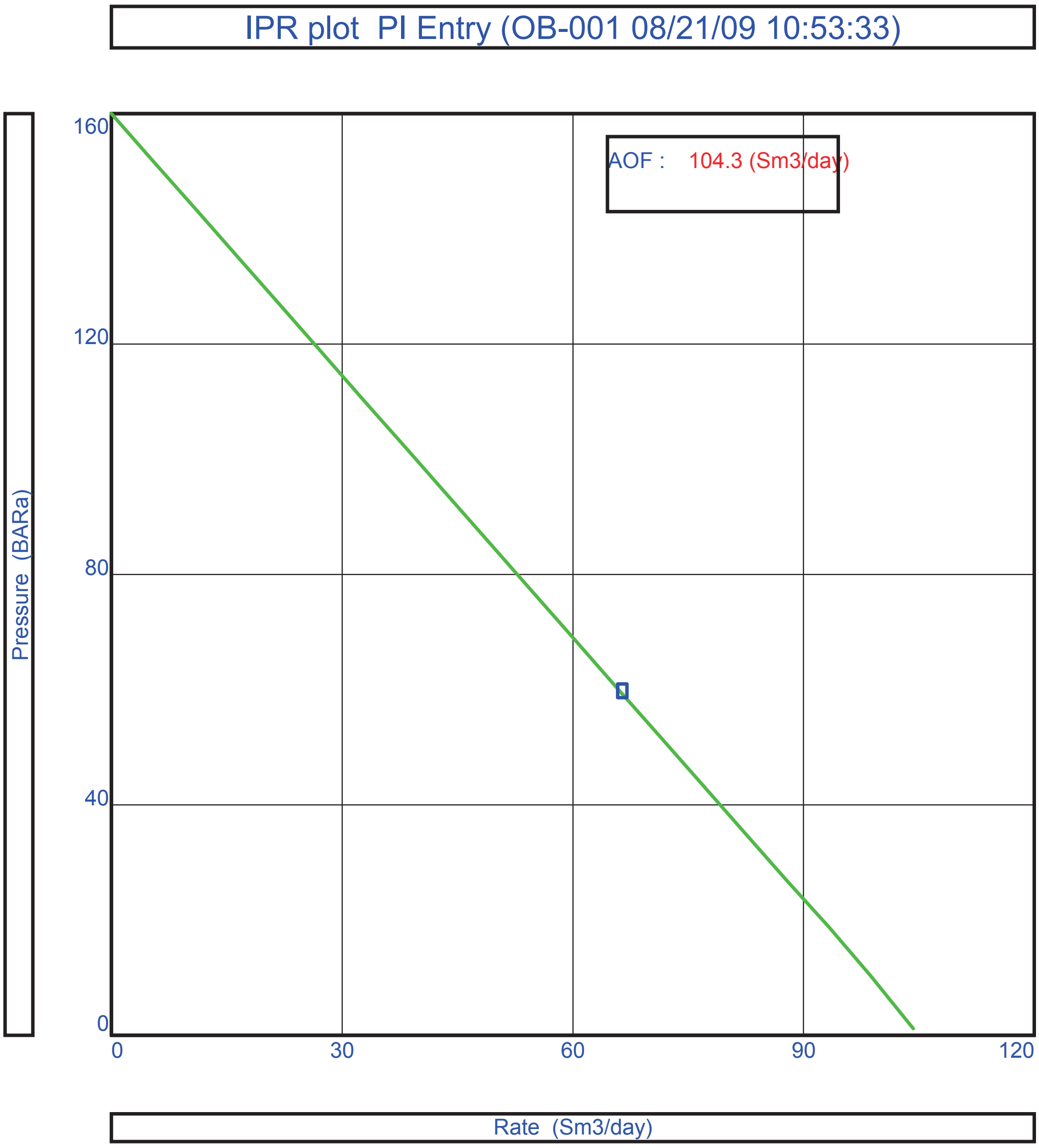
A-Figure 5: IPR-Prosper® model of MDF-001



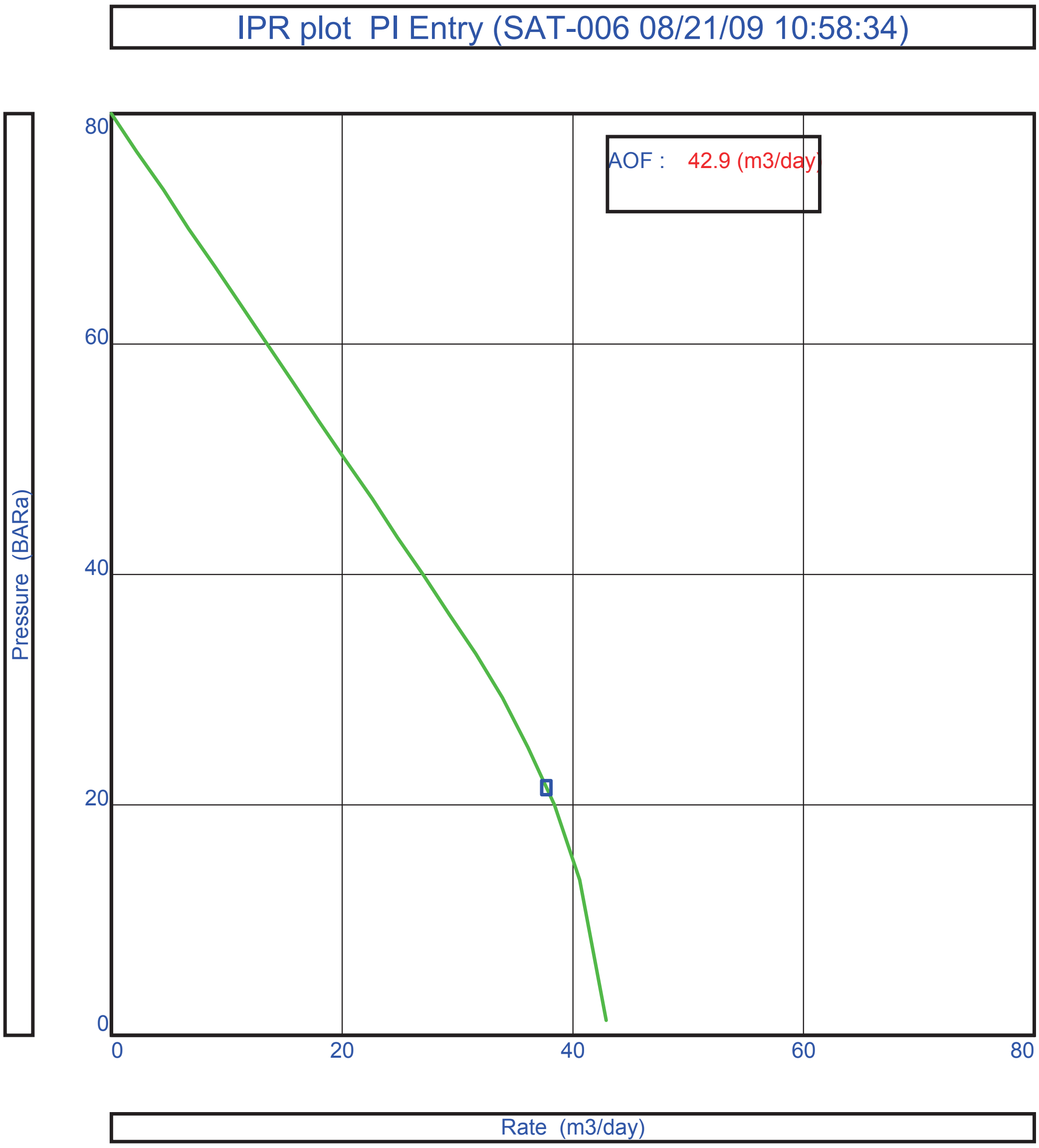
A-Figure 6: IPR-Prosper® model of V-016



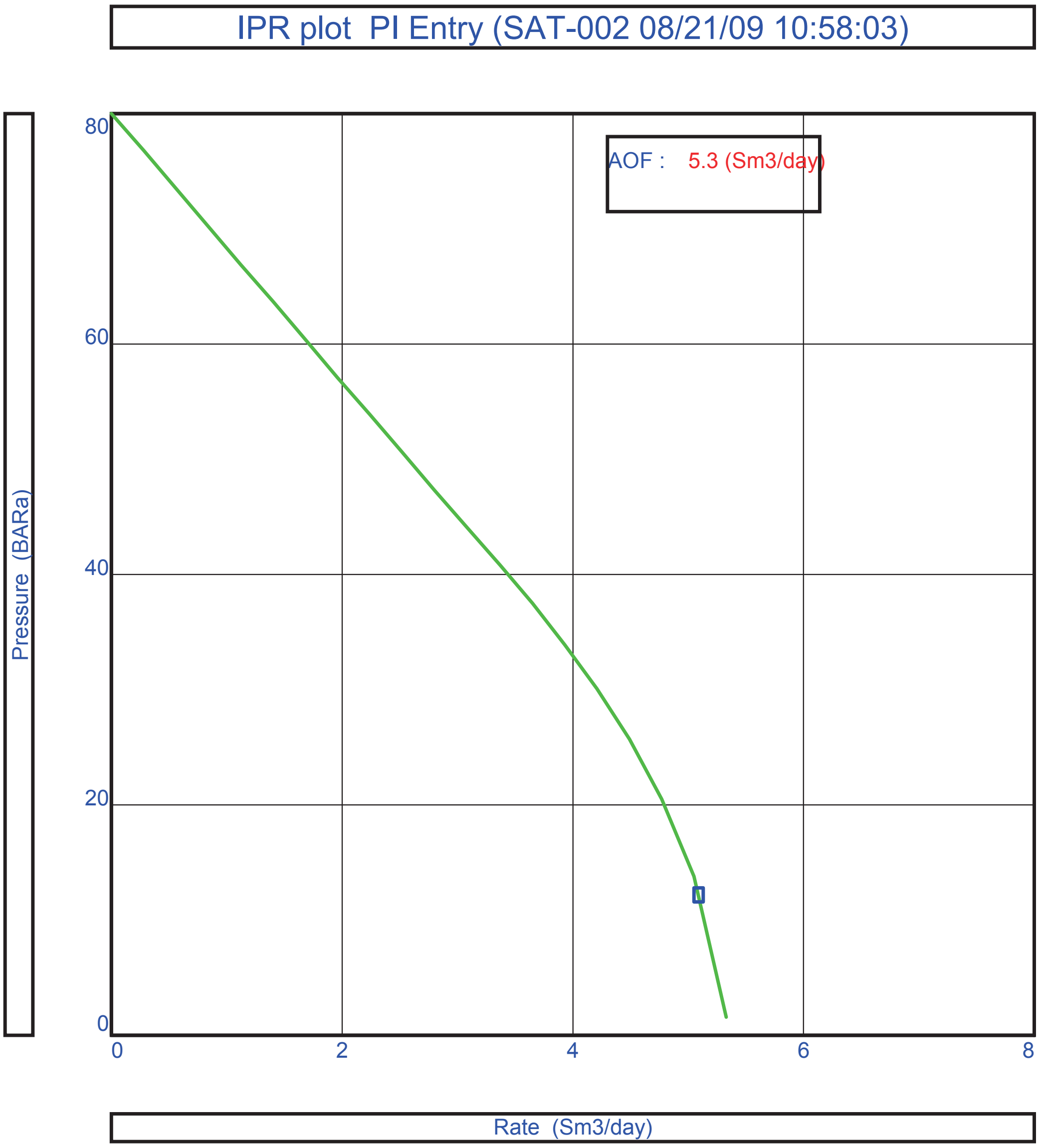
A-Figure 7: IPR-Prosper® model of SAT-023



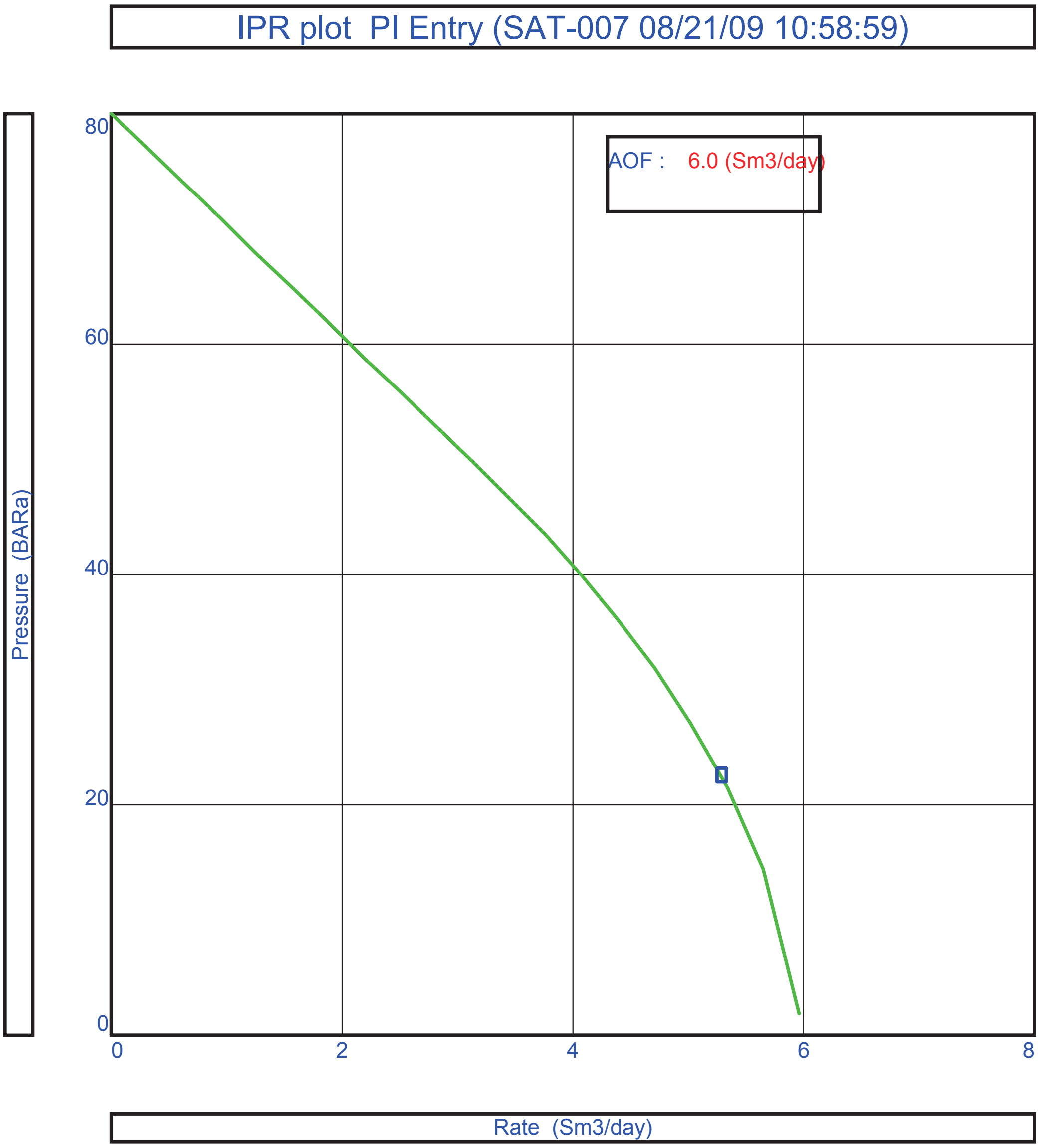
A-Figure 8: IPR-Prosper® model of OB-001



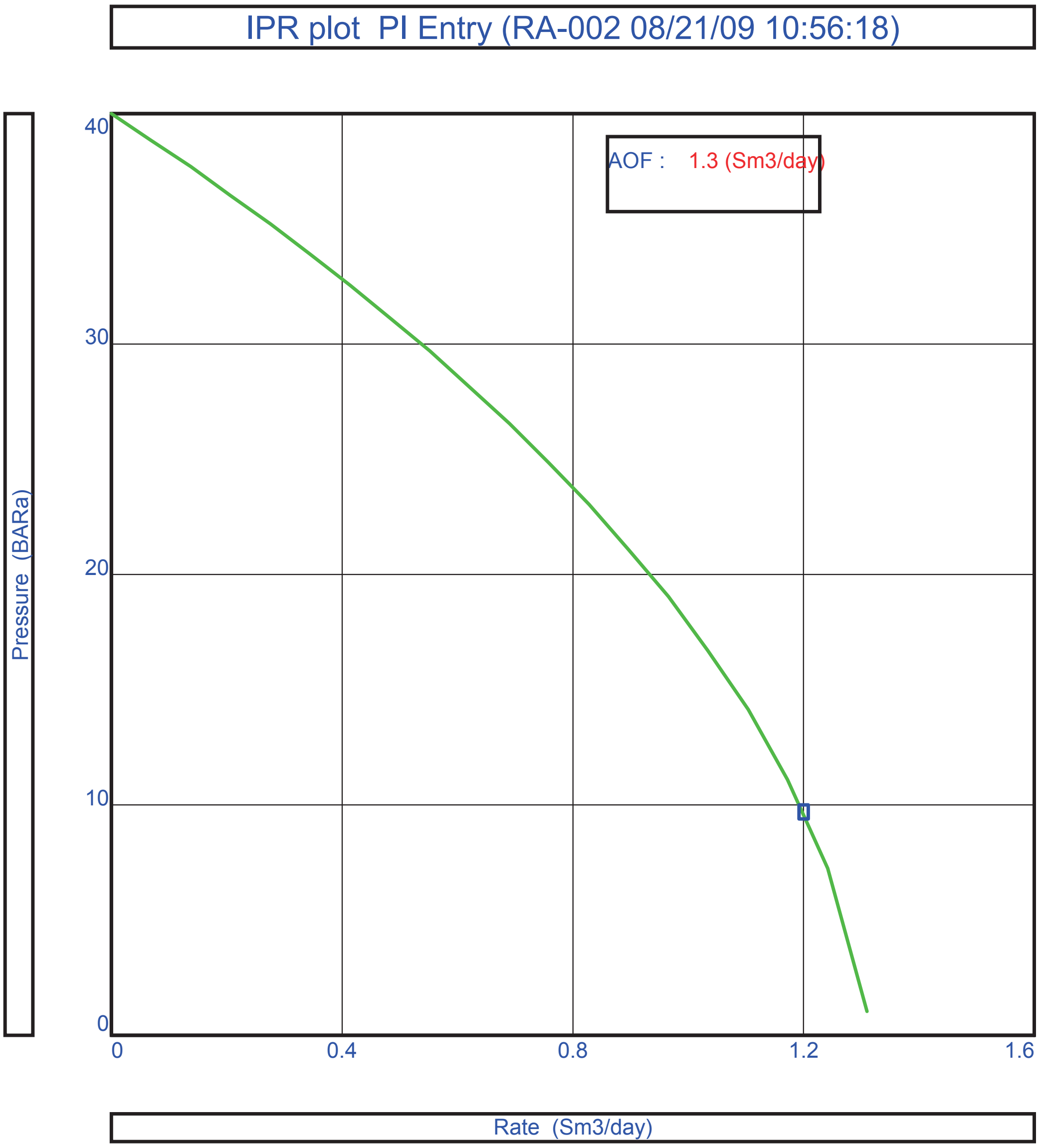
A-Figure 9: IPR-Prosper® model of SAT-006



A-Figure 10: IPR-Prosper® model of SAT-002



A-Figure 11: IPR-Prosper® model of SAT-007



A-Figure 12: IPR-Prosper® model of RA-002

+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	140.00	0	0	0
10.1	135.07	0	0	0
20.2	130.14	0	0	0
30.3	125.21	0	0	0
40.4	120.28	0	0	0
50.5	115.35	0	0	0
60.6	110.42	0	0	0
70.7	105.50	0	0	0
80.8	100.54	0	0	0
90.9	95.38	0	0	0
101.0	89.97	0	0	0
111.2	84.25	0	0	0
121.3	78.16	0	0	0
131.4	71.64	0	0	0
141.5	64.55	0	0	0
151.6	56.74	0	0	0
161.7	47.92	0	0	0
171.8	37.54	0	0	0
181.9	24.28	0	0	0
192.0	1.11	0	0	0

A-Figure 13: Prosper® IPR Calculation results of HIER-001

+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	140.00	0	0	0
6.9	134.36	0	0	0
13.9	128.71	0	0	0
20.8	123.07	0	0	0
27.8	117.42	0	0	0
34.7	111.78	0	0	0
41.7	106.14	0	0	0
48.6	100.49	0	0	0
55.5	94.85	0	0	0
62.5	89.20	0	0	0
69.4	83.56	0	0	0
76.4	77.92	0	0	0
83.3	72.27	0	0	0
90.2	66.40	0	0	0
97.2	60.03	0	0	0
104.1	52.99	0	0	0
111.1	45.02	0	0	0
118.0	35.62	0	0	0
125.0	23.52	0	0	0
131.9	1.01	0	0	0

A-Figure 14: Prosper® IPR Calculation results of HIER-004

+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	120.00	0	0	0
12.9	115.24	0	0	0
25.7	110.48	0	0	0
38.6	105.71	0	0	0
51.4	100.95	0	0	0
64.3	96.19	0	0	0
77.1	91.43	0	0	0
90.0	86.67	0	0	0
102.9	81.90	0	0	0
115.7	77.14	0	0	0
128.6	72.38	0	0	0
141.4	67.62	0	0	0
154.3	62.82	0	0	0
167.1	57.71	0	0	0
180.0	52.17	0	0	0
192.9	46.04	0	0	0
205.7	39.12	0	0	0
218.6	30.95	0	0	0
231.4	20.44	0	0	0
244.3	1.10	0	0	0

A-Figure 15: Prosper® IPR Calculation results of HIER-002A

+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	120.00	0	0	0
43.1	114.18	0	0	0
86.1	108.36	0	0	0
129.2	102.55	0	0	0
172.2	96.73	0	0	0
215.3	90.91	0	0	0
258.3	85.09	0	0	0
301.4	79.27	0	0	0
344.4	73.46	0	0	0
387.5	67.64	0	0	0
430.5	61.82	0	0	0
473.6	56.00	0	0	0
516.6	50.17	0	0	0
559.7	44.30	0	0	0
602.7	38.36	0	0	0
645.8	32.31	0	0	0
688.8	25.98	0	0	0
731.9	17.95	0	0	0
775.0	9.52	0	0	0
818.0	1.09	0	0	0

A-Figure 16: Prosper® IPR Calculation results of KTG-W-001

++++++++++++++++++++++++++++++
+ IPR Calculation Results +
++++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	60.00	0	0	0
0.14195	56.98	0	0	0
0.28375	53.96	0	0	0
0.42554	50.95	0	0	0
0.56734	47.93	0	0	0
0.70913	44.91	0	0	0
0.85093	41.90	0	0	0
0.99273	38.88	0	0	0
1.1	35.86	0	0	0
1.3	32.84	0	0	0
1.4	29.83	0	0	0
1.6	26.81	0	0	0
1.7	23.79	0	0	0
1.8	20.78	0	0	0
2.0	17.76	0	0	0
2.1	14.74	0	0	0
2.3	11.73	0	0	0
2.4	8.71	0	0	0
2.6	5.69	0	0	0
2.7	1.01	0	0	0

A-Figure 17: Prosper® IPR Calculation results of MDF-001A

+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	170.00	0	0	0
7.6	161.82	0	0	0
15.2	153.65	0	0	0
22.8	145.47	0	0	0
30.4	137.29	0	0	0
38.0	129.09	0	0	0
45.6	120.88	0	0	0
53.2	112.65	0	0	0
60.8	104.39	0	0	0
68.4	96.09	0	0	0
76.0	87.75	0	0	0
83.7	79.33	0	0	0
91.3	70.77	0	0	0
98.9	61.60	0	0	0
106.5	51.51	0	0	0
114.1	41.43	0	0	0
121.7	31.35	0	0	0
129.3	21.26	0	0	0
136.9	11.18	0	0	0
144.5	1.09	0	0	0

A-Figure 18: Prosper® IPR Calculation results of V-016

+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	80.00	0	0	0
2.4	77.07	0	0	0
4.7	74.15	0	0	0
7.1	71.22	0	0	0
9.4	68.29	0	0	0
11.8	65.37	0	0	0
14.1	62.44	0	0	0
16.5	59.51	0	0	0
18.8	56.59	0	0	0
21.2	53.66	0	0	0
23.6	50.66	0	0	0
25.9	47.49	0	0	0
28.3	44.12	0	0	0
30.6	40.50	0	0	0
33.0	36.57	0	0	0
35.3	32.24	0	0	0
37.7	27.34	0	0	0
40.0	21.57	0	0	0
42.4	14.19	0	0	0
44.8	1.01	0	0	0

A-Figure 19: Prosper® IPR Calculation results of SAT-023

```
++++++++++++++++++++++++++++++
+  IPR Calculation Results  +
++++++++++++++++++++++++++++++
```

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
----------	--------	-----	-----	----------
0.00015899	160.00	0	0	0
5.5	151.68	0	0	0
11.0	143.37	0	0	0
16.5	135.05	0	0	0
22.0	126.73	0	0	0
27.4	118.42	0	0	0
32.9	110.10	0	0	0
38.4	101.78	0	0	0
43.9	93.47	0	0	0
49.4	85.15	0	0	0
54.9	76.83	0	0	0
60.4	68.51	0	0	0
65.9	60.20	0	0	0
71.4	51.88	0	0	0
76.8	43.56	0	0	0
82.3	35.25	0	0	0
87.8	26.93	0	0	0
93.3	18.61	0	0	0
98.8	10.30	0	0	0
104.3	1.01	0	0	0

A-Figure 20 Prosper® IPR Calculation results of OB-001

```
++++++++++++++++++++++++++++++
+  IPR Calculation Results  +
++++++++++++++++++++++++++++++
```

Rate (m3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	80.00	0	0	0
2.3	76.65	0	0	0
4.5	73.30	0	0	0
6.8	69.96	0	0	0
9.0	66.61	0	0	0
11.3	63.26	0	0	0
13.6	59.91	0	0	0
15.8	56.56	0	0	0
18.1	53.21	0	0	0
20.3	49.87	0	0	0
22.6	46.52	0	0	0
24.9	43.17	0	0	0
27.1	39.82	0	0	0
29.4	36.47	0	0	0
31.6	33.04	0	0	0
33.9	29.27	0	0	0
36.2	25.00	0	0	0
38.4	19.95	0	0	0
40.7	13.45	0	0	0
42.9	1.22	0	0	0

A-Figure 21: Prosper® IPR Calculation results of SAT-006

+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	80.00	0	0	0
0.28113	76.72	0	0	0
0.5621	73.45	0	0	0
0.84306	70.17	0	0	0
1.1	66.90	0	0	0
1.4	63.62	0	0	0
1.7	60.35	0	0	0
2.0	57.08	0	0	0
2.2	53.80	0	0	0
2.5	50.53	0	0	0
2.8	47.25	0	0	0
3.1	43.98	0	0	0
3.4	40.70	0	0	0
3.7	37.41	0	0	0
3.9	33.89	0	0	0
4.2	30.00	0	0	0
4.5	25.60	0	0	0
4.8	20.42	0	0	0
5.1	13.75	0	0	0
5.3	1.52	0	0	0

A-Figure 22: Prosper® IPR Calculation results of SAT-002

++++++++++++++++++++++++++++++
+ IPR Calculation Results +
++++++++++++++++++++++++++++++

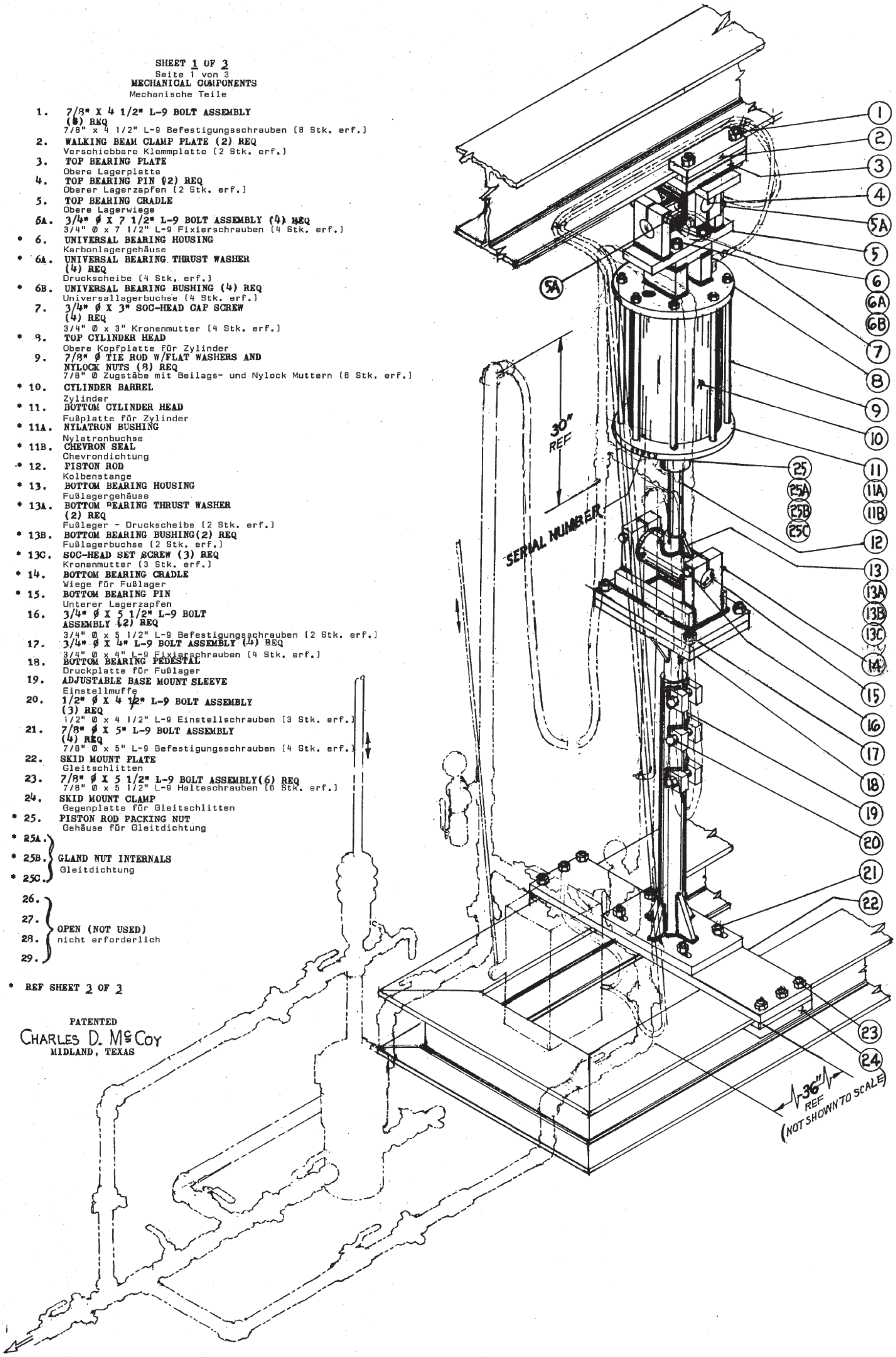
Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin
----------	--------	-----	-----
0.00015899	80.00	0	0
0.31432	76.97	0	0
0.62849	73.93	0	0
0.94266	70.90	0	0
1.3	67.87	0	0
1.6	64.84	0	0
1.9	61.80	0	0
2.2	58.77	0	0
2.5	55.74	0	0
2.8	52.71	0	0
3.1	49.67	0	0
3.5	46.59	0	0
3.8	43.32	0	0
4.1	39.81	0	0
4.4	36.01	0	0
4.7	31.81	0	0
5.0	27.06	0	0
5.3	21.48	0	0
5.7	14.35	0	0
6.0	1.86	0	0

A-Figure 23: Prosper® IPR Calculation results of SAT-007

+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (Sm3/day)	Pressure (BARa)	dP Total skin (bar)	Total skin	dP Completion Skin (bar)
0.00015899	40.00	0	0	0
0.069176	38.84	0	0	0
0.13819	37.65	0	0	0
0.20721	36.43	0	0	0
0.27623	35.17	0	0	0
0.34524	33.86	0	0	0
0.41426	32.51	0	0	0
0.48328	31.11	0	0	0
0.55229	29.65	0	0	0
0.62131	28.12	0	0	0
0.69032	26.52	0	0	0
0.75934	24.83	0	0	0
0.82836	23.03	0	0	0
0.89737	21.10	0	0	0
0.96639	19.00	0	0	0
1.0	16.70	0	0	0
1.1	14.10	0	0	0
1.2	11.06	0	0	0
1.2	7.21	0	0	0
1.3	1.01	0	0	0

A-Figure 24: Prosper® IPR Calculation results of RA-002


SHEET 1 OF 3
Seite 1 von 3
MECHANICAL COMPONENTS
Mechanische Teile
1. 7/8" X 4 1/2" L-9 BOLT ASSEMBLY (8) REQ
7/8" x 4 1/2" L-9 Befestigungsschrauben (8 Stk. erf.)
2. WALKING BEAM CLAMP PLATE (2) REQ
Verschiebbare Klemmplatte (2 Stk. erf.)
3. TOP BEARING PLATE
Obere Lagerplatte
4. TOP BEARING PIN (2) REQ
Oberer Lagerzapfen (2 Stk. erf.)
5. TOP BEARING CRADLE
Obere Lagerwiege
5A. 3/4" Ø X 7 1/2" L-9 BOLT ASSEMBLY (4) REQ
3/4" Ø x 7 1/2" L-9 Fixierschrauben (4 Stk. erf.)
* 6. UNIVERSAL BEARING HOUSING
Karbonlagergehäuse
* 6A. UNIVERSAL BEARING THRUST WASHER (4) REQ
Druckscheibe (4 Stk. erf.)
* 6B. UNIVERSAL BEARING BUSHING (4) REQ
Universallagerbuchse (4 Stk. erf.)
7. 3/4" Ø X 3" SOC-HEAD CAP SCREW (4) REQ
3/4" Ø x 3" Kronenmutter (4 Stk. erf.)
* 8. TOP CYLINDER HEAD
Obere Kopfplatte für Zylinder
9. 7/8" Ø TIE ROD W/FLAT WASHERS AND NYLOCK NUTS (8) REQ
7/8" Ø Zugstäbe mit Beilags- und Nylock Muttern (8 Stk. erf.)
* 10. CYLINDER BARREL
Zylinder
* 11. BOTTOM CYLINDER HEAD
Fußplatte für Zylinder
* 11A. NYLATRON BUSHING
Nylatronbuchse
* 11B. CHEVRON SEAL
Chevrondichtung
* 12. PISTON ROD
Kolbenstange
* 13. BOTTOM BEARING HOUSING
Fußlagergehäuse
* 13A. BOTTOM BEARING THRUST WASHER (2) REQ
Fußlager - Druckscheibe (2 Stk. erf.)
* 13B. BOTTOM BEARING BUSHING(2) REQ
Fußlagerbuchse (2 Stk. erf.)
* 13C. SOC-HEAD SET SCREW (3) REQ
Kronenmutter (3 Stk. erf.)
* 14. BOTTOM BEARING CRADLE
Wiege für Fußlager
* 15. BOTTOM BEARING PIN
Unterer Lagerzapfen
16. 3/4" Ø X 5 1/2" L-9 BOLT ASSEMBLY (2) REQ
3/4" Ø x 5 1/2" L-9 Befestigungsschrauben (2 Stk. erf.)
17. 3/4" Ø X 4" L-9 BOLT ASSEMBLY (4) REQ
3/4" Ø x 4" L-9 Fixierschrauben (4 Stk. erf.)
18. BOTTOM BEARING PEDESTAL
Druckplatte für Fußlager
19. ADJUSTABLE BASE MOUNT SLEEVE
Einstellmuffe
20. 1/2" Ø X 4 1/2" L-9 BOLT ASSEMBLY (3) REQ
1/2" Ø x 4 1/2" L-9 Einstellschrauben (3 Stk. erf.)
21. 7/8" Ø X 5" L-9 BOLT ASSEMBLY (4) REQ
7/8" Ø x 5" L-9 Befestigungsschrauben (4 Stk. erf.)
22. SKID MOUNT PLATE
Gleitschlitten
23. 7/8" Ø X 5 1/2" L-9 BOLT ASSEMBLY(6) REQ
7/8" Ø x 5 1/2" L-9 Halteschrauben (6 Stk. erf.)
24. SKID MOUNT CLAMP
Gegenplatte für Gleitschlitten
* 25. PISTON ROD PACKING NUT
Gehäuse für Gleitdichtung
* 25A. * 25B. * 25C. GLAND NUT INTERNALS
Gleitdichtung
26. 27. 28. 29. OPEN (NOT USED)
nicht erforderlich
* REF SHEET 3 OF 3
PATENTED
CHARLES D. McCOY
MIDLAND, TEXAS
30" REF
SERIAL NUMBER
36" REF (NOT SHOWN TO SCALE)
1
2
3
4
5A
5
6
6A
6B
7
8
9
10
11
11A
11B
12
13
13A
13B
13C
14
15
16
17
18
19
20
21
22
23
24
25
25A
25B
25C

SHEET 2 OF 3

GAS PLUMBING

- * 30. 1 1/4" NPT HYD NIPPLE (2) REQ
- * 30A. 1 1/4" NPT 90° F TO M SWIVEL ELL (2) REQ
- * 30B. 1 1/4" NPT COMMON T (5) REQ
- * 30C. 1 1/4" NPT BALL CONE CHECK VALVE (4) REQ
- * 30D. 1 1/4" NPT COMMON EL
- * 30E 1 1/4 NPT CLOSE NIPPLE (8) REQ
- * 30F. 1 1/4" NPT STRAIGHT SWIVEL, F TO M (4) REQ
- * 30G. 1 1/4" NPT PRESSURE RELIEF VALVE
- * 30H. 1 1/4" FLEX HOSE W/1 1/4" NPT TERMINALS (2) REQ
- * - THESE DETAILS SHIPPED ASSEMBLED TO CYLINDER

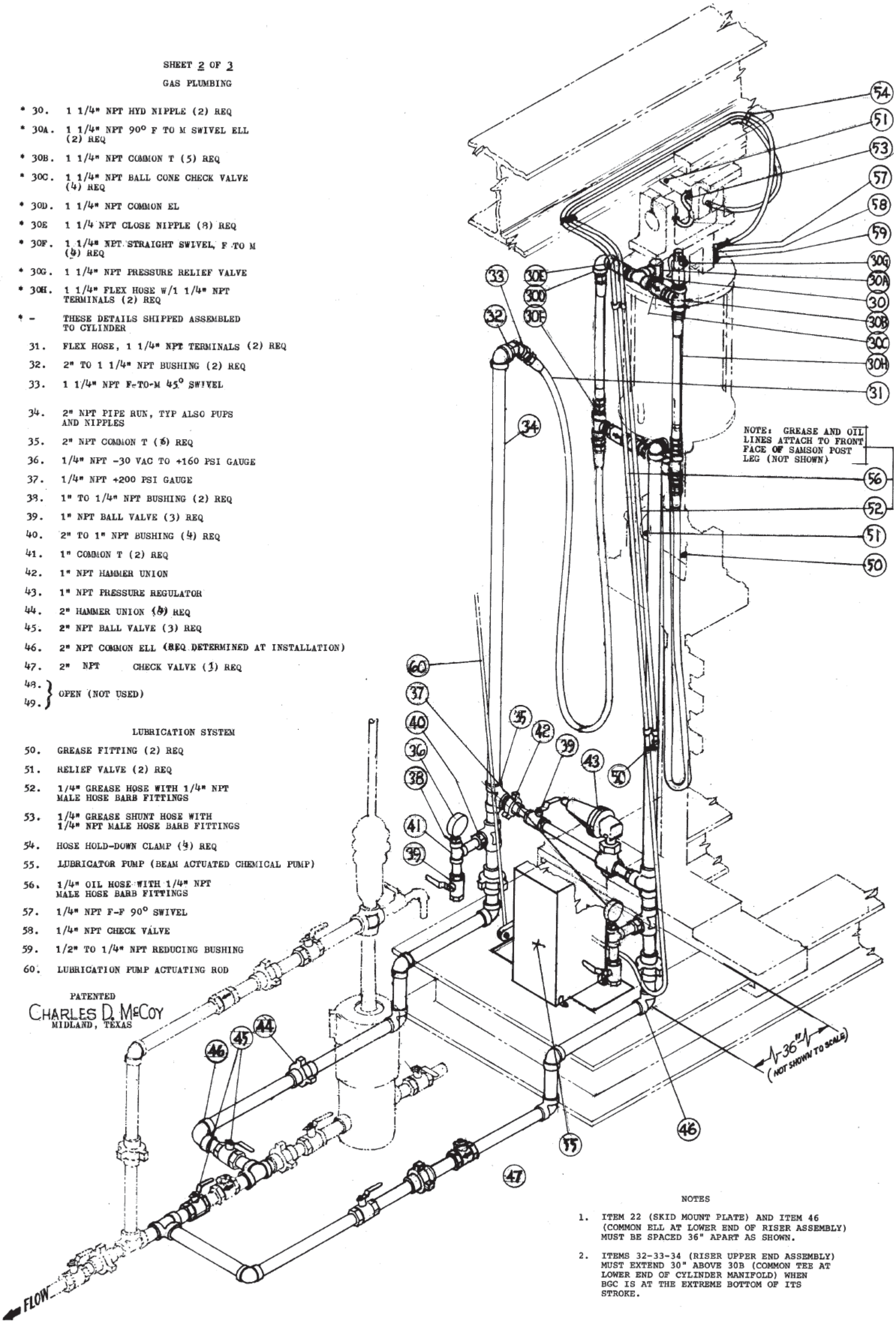
31. FLEX HOSE, 1 1/4" NPT TERMINALS (2) REQ
32. 2" TO 1 1/4" NPT BUSHING (2) REQ
33. 1 1/4" NPT F-TO-M 45° SWIVEL
34. 2" NPT PIPE RUN, TYP ALSO PUPS AND NIPPLES
35. 2" NPT COMMON T (6) REQ
36. 1/4" NPT -30 VAC TO +160 PSI GAUGE
37. 1/4" NPT +200 PSI GAUGE
38. 1" TO 1/4" NPT BUSHING (2) REQ
39. 1" NPT BALL VALVE (3) REQ
40. 2" TO 1" NPT BUSHING (4) REQ
41. 1" COMMON T (2) REQ
42. 1" NPT HAMMER UNION
43. 1" NPT PRESSURE REGULATOR
44. 2" HAMMER UNION (6) REQ
45. 2" NPT BALL VALVE (3) REQ
46. 2" NPT COMMON ELL (REQ DETERMINED AT INSTALLATION)
47. 2" NPT CHECK VALVE (3) REQ

48. } OPEN (NOT USED)
49. }

LUBRICATION SYSTEM

50. GREASE FITTING (2) REQ
51. RELIEF VALVE (2) REQ
52. 1/4" GREASE HOSE WITH 1/4" NPT MALE HOSE BARB FITTINGS
53. 1/4" GREASE SHUNT HOSE WITH 1/4" NPT MALE HOSE BARB FITTINGS
54. HOSE HOLD-DOWN CLAMP (4) REQ
55. LUBRICATOR PUMP (BEAM ACTUATED CHEMICAL PUMP)
56. 1/4" OIL HOSE WITH 1/4" NPT MALE HOSE BARB FITTINGS
57. 1/4" NPT F-F 90° SWIVEL
58. 1/4" NPT CHECK VALVE
59. 1/2" TO 1/4" NPT REDUCING BUSHING
60. LUBRICATION PUMP ACTUATING ROD

PATENTED
CHARLES D. McCOY
MIDLAND, TEXAS



NOTES

1. ITEM 22 (SKID MOUNT PLATE) AND ITEM 46 (COMMON ELL AT LOWER END OF RISER ASSEMBLY) MUST BE SPACED 36" APART AS SHOWN.
2. ITEMS 32-33-34 (RISER UPPER END ASSEMBLY) MUST EXTEND 30" ABOVE 30B (COMMON TEE AT LOWER END OF CYLINDER MANIFOLD) WHEN BGC IS AT THE EXTREME BOTTOM OF ITS STROKE.

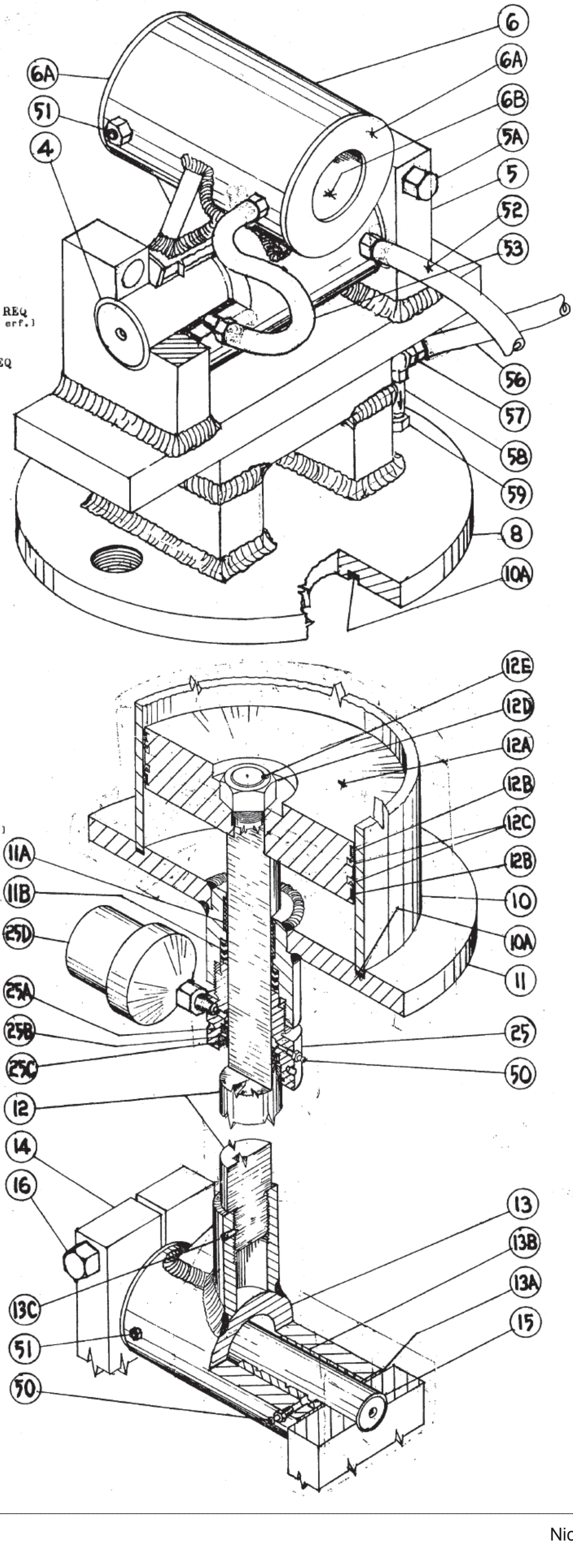
SHEET 3 OF 3
Seite 3 von 3
CYLINDER AND BEARING INTERNALS
W/REFERENCE DETAILS
Details für Zylinder und Auflager

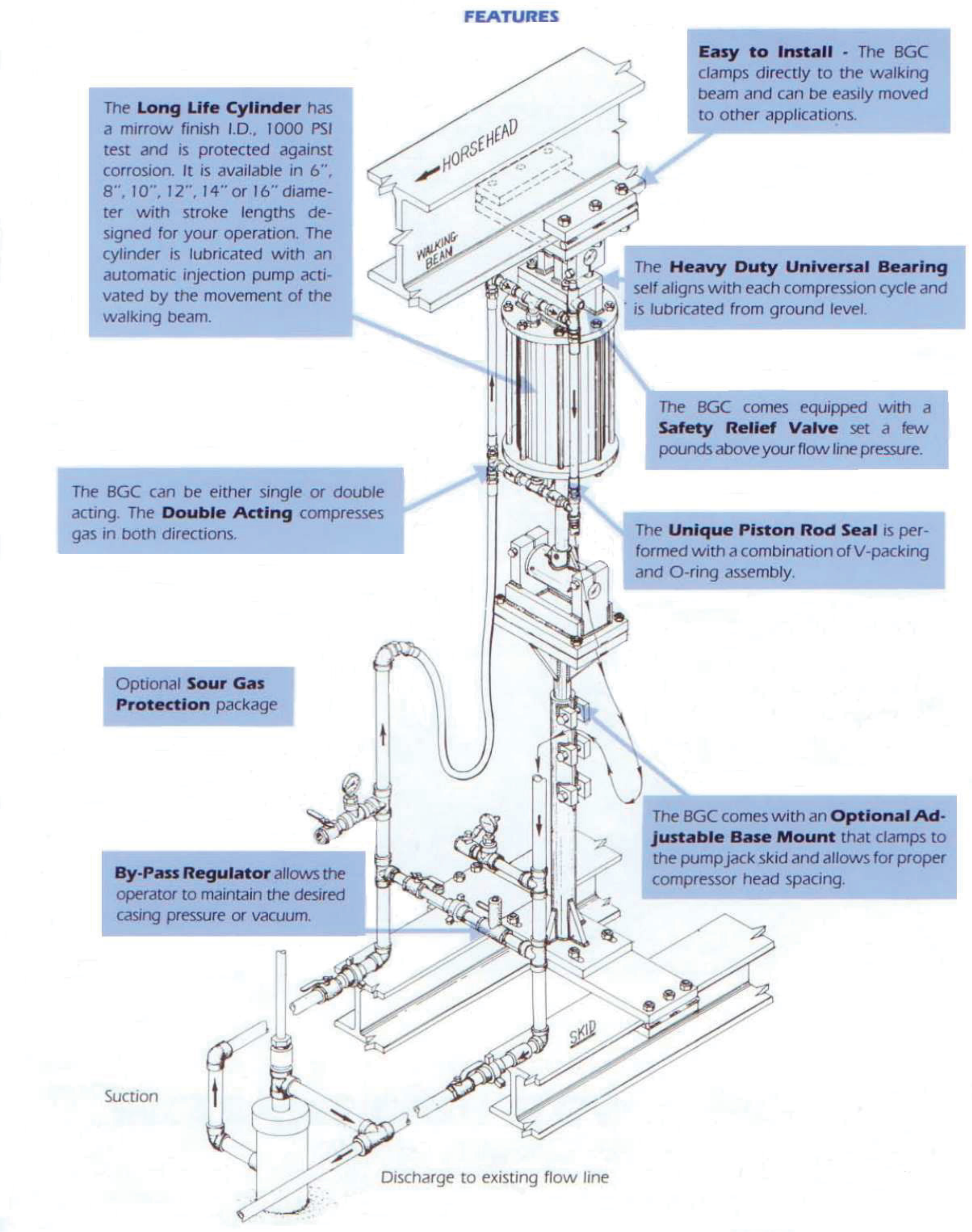
4. TOP BEARING PIN (2) REQ
Oberer Lagerzapfen (2 Stk. erf.)
5. TOP BEARING CRADLE
Obere Lagerwiege
5A. 3/4" Ø X 7 1/2" L-9 BOLT ASSEMBLY (4) REQ
3/4" Ø x 7 1/2" L-9 Satz Fixierschrauben (4 Stk. erf.)
6. UNIVERSAL BEARING HOUSING
Karbonlagergehäuse
6A. UNIVERSAL BEARING THRUST WASHER (4) REQ
Distanzscheiben für Lagergehäuse (4 Stk. erf.)
6B. UNIVERSAL BEARING BUSHING (4) REQ
Buchse für Lagergehäuse (4 Stk. erf.)

8. TOP CYLINDER HEAD
Obere Endplatte (Kopfplatte)
10. CYLINDER BARREL
Zylinder
10A. CYLINDER-TO-HEAD SEAL (2) REQ
Zylinderkopfdichtung (2 Stk. erf.)
11. BOTTOM CYLINDER HEAD
Fußplatte
11A. NYLATRON BUSHING
Nylatronbuchse
11B. CHEVRON SEAL
Chevrondichtung
12. PISTON ROD
Kolbenstange
12A. PISTON
Kolben
12B. BEARING RING (2) REQ
Kolbenring (2 Stk. erf.)
12C. COMPRESSION SEAL (2) REQ
Dichtring (2 Stk. erf.)
12D. ROD NUT
Fixiermutter für Kolbenstange
12E. ROD NUT LOCK SCREW
Drehsicherung für Fixiermutter
13. BOTTOM BEARING HOUSING
Gehäuse für unteres Lager
13A. BOTTOM BEARING THRUST WASHER (2) REQ
Druckscheibe für unteres Lager (2 Stk. erf.)
13B. BOTTOM BEARING BUSHING (2) REQ
Buchse für unteres Lager (2 Stk. erf.)
13C. SOCKET HEAD SET SCREW (3) REQ
Einstellschrauben für Kolbenstange (3 Stk. erf.)
14. BOTTOM BEARING CRADLE
Unteres Lagergehäuse
15. BOTTOM BEARING PIN
Unterer Lagerzapfen
16. 3/4" Ø X 5 1/2" L-9 BOLT ASSEMBLY
3/4" Ø x 5 1/2" L-9 Befestigungsschrauben

25. PISTON ROD PACKING NUT
Packung für Stoßstange
25A. GREASE SEAL
Schmierdichtung
25B. WIPER SEAL
Abstreifer
25C. SNAP RING
Seegerring
25D. AUTOMATIC GREASE DISPENSER
Automatische Schmierung
50. GREASE FITTING
Schmiernippel
51. RELIEF VALVE
Überdruckventil
52. GREASE HOSE
Schmierschlauch
53. SHUNT
Zwischenverbindung
56. OIL HOSE
Rücklauf
57. 1/4" Ø NPT F-F 90° SWIVEL
1/4" Ø NPT 90° Eckstück
58. 1/4" NPT CHECK VALVE
1/4" NPT Rückschlagventil
59. 1/2" TO 1/4" NPT REDUCING BUSHING.
1/2" auf 1/4" Reduzierstück

PATENTED
CHARLES D. McCOY
MIDLAND, TEXAS




FEATURES
Easy to Install - The BGC clamps directly to the walking beam and can be easily moved to other applications.
The Long Life Cylinder has a mirrow finish I.D., 1000 PSI test and is protected against corrosion. It is available in 6", 8", 10", 12", 14" or 16" diameter with stroke lengths designed for your operation. The cylinder is lubricated with an automatic injection pump activated by the movement of the walking beam.
HORSEHEAD
WALKING BEAM
The Heavy Duty Universal Bearing self aligns with each compression cycle and is lubricated from ground level.
The BGC comes equipped with a Safety Relief Valve set a few pounds above your flow line pressure.
The BGC can be either single or double acting. The Double Acting compresses gas in both directions.
The Unique Piston Rod Seal is performed with a combination of V-packing and O-ring assembly.
Optional Sour Gas Protection package
The BGC comes with an Optional Adjustable Base Mount that clamps to the pump jack skid and allows for proper compressor head spacing.
By-Pass Regulator allows the operator to maintain the desired casing pressure or vacuum.
SKID
Suction
Discharge to existing flow line