Bottom Hole Pressure Management in a Highly Permeable and Narrow Margin MPD Operation*

Ugochukwu Oseme[1], Ayodele Akinfolarin[1], Sunday Awe[1], Adeyemi Erinle[1], Timothy Ibrahim[1], and Vincent Roes[1]

Search and Discovery Article #42017 (2017)**
Posted February 20, 2017

*Adapted from extended abstract based on oral presentation given at AAPG/SPE Africa Energy and Technology Conference, Nairobi City, Kenya, December 5-7, 2016

[1]Shell Petroleum Development Company, Por Harcourt, Rivers, Nigeria (ugochukwu.oseme@shell.com)

Abstract

Application of Managed Pressure Drilling (MPD) technology with other techniques to maintain constant Bottom Hole Pressure (BHP) has been found to enhance drilling operations in applications where the margin between the pore pressure and fracture gradient is narrow and the reservoir permeability is high. Classic examples of such applications are deep water drilling, high pressure and high temperature (HPHT) regime, and depleted reservoir environments.

In the Niger Delta, HPHT reservoirs can be found in well depths up to 17,000 ftss with a drilling window range of 0.4 to1.6 ppg. Typical reservoir characteristics are formation permeability of 124-204 mD and reservoir mobility of 112-1000 mD/cp. Generally in this type of environment and essentially where there are high uncertainties in the reservoir pressures and formation characteristics, significant process safety incidents have been found to occur during flow-off events as a result of variations in BHP outside the allowable limits of pore pressure (lower limit) and fracture gradient (upper limit). The risks of exceeding the allowable limits are the possibility of taking significant influx volume if BHP falls below the pore pressure and loss of well bore integrity if the BHP exceeds the fracture pressure. Consequences of any of these events are high nonproductive time (NPT), well cost escalation and inability to achieve well objectives.

This article illustrates how in the recent HPHT exploration campaign carried out in Niger Delta, managing BHP was identified as a critical success factor. Hydrocarbon reserves of the exploratory objectives were successfully and safely unlocked by using MPD to maintain BHP within the allowable limits. This article also illustrates how MPD application was enhanced by the use of high resolution pressure while drilling (PWD) technology.

Introduction

During the high pressure and high temperature (HPHT) drilling campaign, expected reservoir pore pressures of Well X1 were in excess of 16.35 ppg with a depth range of 15,000-16,500ft (Figure 1). The primary objectives of this exploratory well were to prove reservoir presence and quality, establish hydrocarbon fill, and evaluate reservoir and fluid characteristics. Based on the pre-drilled subsurface data evaluations, the objective zones were expected to have a narrow drilling window with formation permeability of 124-204 mD and fluid mobility of 112-1000 mD/cp. The uniqueness of the high mobility ratio and the narrowness of the drilling window suggested a high potential for a process safety incident if variation of BHP, normally experienced while switching between the period when fluid is being circulated in the wellbore (flow-on) and when fluid is not being circulated in the well bore (flow-off), is not properly managed. During the planning phase of the well, MPD was identified as a key enabler to safely drill through the narrow window with the capacity to eliminate bottom hole pressure variations during different operation modes.

Due to the permeability and mobility characteristics of reservoirs in the Niger Delta, momentary marginal bottom hole pressure dips below the allowable threshold had resulted in significant influx volume in the past. The dips in bottom hole pressure values often occur during flow-off events such as when making drill pipe connections or taking surveys. To tackle this challenge in Well X1, the MPD system was used to control Bottom Hole Pressure (BHP) by providing surface back pressure (SBP) in addition to the hydrostatic mud column during flow-off events. The surface back pressure value applied by the MPD is based on predetermined BHP value for a particular interval. This BHP value can also be referred to as the “set point”. Depending on the specific wellbore conditions, application of back pressure with the MPD can be carried out in three different modes, namely, auto-mode, manual mode, and a combination of the auto and manual modes. Analysis of previous MPD application indicated that appropriate selection of the mode of back pressure application required proper understanding of the bottom hole pressure behavior during dynamic and static conditions. Consequently, the need to enhance performance of MPD in maintaining desired bottom hole pressure during flow-off and flow-on transition period was identified. This necessitated the deployment of high resolution pressure while drilling, PWD tool with capacity to provide flow-off pressure data on a time based scale. This made it possible to have a full realization of the well behavior statically or dynamically which helped to avoid wellbore instability and well control events that occurred in a previous HPHT well that was drilled.

Definitions

By IADC definition, MPD is an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore. The objectives are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly. MPD is intended to avoid continuous influx of formation fluids to the surface. Any influx incidental to the operation will be safely contained using an appropriate procedure. MPD process employs a collection of tools and techniques that may mitigate the risks and costs associated with drilling wells that have narrow downhole environmental limits by proactively managing the annular-hydraulic-pressure profile. This may also include control of back pressure, fluid density, fluid rheology, annular fluid level, circulating friction, and hole geometry.

In conventional drilling, BHP is controlled by hydraulic pressure and circulating annular friction pressure which are dependent on mud weight and pump speed applied during the drilling operation.

$$BHP = P_{\textit{hydostatic}} + P_{\textit{annular friction}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

In MPD drilling, the wellbore is a pressurized system. BHP can be controlled by applying surface back pressure, in addition to hydrostatic of the mud column and annular friction pressure (see Nomenclature section at end of this article).

$$BHP = P_{hydostatic} + P_{annular\ friction} + SBP \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The equivalent Static Density (ESD) is an expression of the hydrostatic pressure exerted by a static column of fluid. As the fluid density is affected by the formation pressure and temperature, the hydrostatic term calculation must be corrected using the variation in fluid density in order to obtain the real value of static bottom hole pressure (SBHP).

$$\rho_{ESD} = \frac{SBHP}{h}, ppg \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where h is the true vertical depth.

Equivalent Circulating Density (ECD) is the sum of the ESD of the drilling fluid and pressure loss in the annulus due to fluid flow.

$$\rho_{ECD} = \rho_{ESD} + \frac{\Delta P friction}{h}, ppg \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Higher formation temperature cause thermal expansion of the drilling fluid and in consequence lower ESD and ECD.

MPD System

The MPD system used to drill the target sand consists of mainly the Rotating Control Device (RCD), the automated choke manifold, the flow meter and other surface equipment to achieve control of the Bottom Hole Pressure while drilling and during connections (Figure 2). A communication protocol was established between the choke operators and the rig personnel for effective management.

RCD is equipment installed above the rig BOP stack to seal the annulus around the drill pipe providing a closed and pressurized system. By IADC/SPE, RCD is a drill through device with a rotating seal that contacts and seals against the drill string (drill pipe, casing Kelly, etc.) for the purpose of controlling the pressure or fluid to surface. RCD serves as a seal between the well and the rig floor enabling pressure containment. The automated choke manifold system consists of two drilling chokes and a mass flow meter. The chokes are used for the application of surface back pressure in the annulus with a redundant capacity, and the mass flow meter continuously measures the flow out of the well, fluid surface temperature, and drilling mud density.

MPD Operation

The drilling objective was to safely drill with MPD technology the 6” deviated hole section to Target Depth, TD at 15,921 ftah through a narrow operating window, maintained a near CBHP during dynamic and static conditions, perform dynamic LOT/FIT with MPD system after drilling out shoe at 14,192 TVD and mitigate swab effect when pulling out to prevent influxes.

Key planning activities before commencing drilling operation included:

- MPD Front End Engineering and Design
- Development of MPD Well Control Bow Tie
- HAZOP / HAZID for MPD deployment
- Preparation of the HPHT manual, MPD Manual and Program.
- MPD and HPHT training for Office and Rig based personnel

Finger Printing

HPHT and MPD system simulations were done at the 7 inch liner shoe with the drilling Bottom Hole Assembly (BHA) prior to drilling out the liner shoe. Simulations carried out included flow-back behavior analysis, mud compressibility evaluation, equivalent circulating density measurements, connection procedure optimization, and determination of trapped pressure effects. Calibration of the MPD system was carried out to establish the optimum pump rate and surface back pressure ramping schedule. During the finger printing exercise, it was noticed that the MPD operating system did not take into account the mud compressibility during static conditions, whereas during circulation the system factored it into the overall friction calculation. This was a significant observation because the mud compressibility under static conditions was measured to be ±0.250 ppg, and not taking this into account could result to the BHP going above the planned value

High Resolution PWD Data

The high resolution PWD tool deployed in the well operation is capable of providing 60 points of pressure time-series data over a period of any flow-off event. The 60 points data is capable of giving a better reflection of downhole ESD values during flow-off because the values are derived from time-based average measurements acquired by the tool. The time based resolution enabled the operations team to determine specific operation that could result to pressure dips or spike when switching from one mode of drilling operation to the other. This data set acquired at every connection enabled the MPD team to review each connection performance, fine tune the process and select appropriately MPD operating mode that gives the best chance of success.

A good example of the benefit of the high resolution PWD data was in the modification of surface facility for bleeding off pressure after bypassing mud flow from the standpipe during connection. It was observed that bleeding off Stand Pipe Pressure (SPP) during connections caused a decrease in Bottom Hole Pressure (BHP) approximately 300-400 psi, reducing the ESD during connections below the targeted set point. A choke was then installed on the rig stand pipe manifold as a replacement for the conventional bleed off valve and this enabled gradual bleed off the SPP during subsequent connections (Figure 4)

Optimization of Drill Pipe Connections

Continuous evaluation of the connections revealed that the combination of auto and manual MPD operation mode (Combine mode) gave the most desirable BHP values of ESD and it was adopted as the preferred mode. The process involved automatic back pressure application with flow rates above 50 gpm while back pressure ramping schedule between 0 and 50 gpm would be done manually by the choke operator by calculating pressure required to maintain a downhole static mud gradient of 17.12 ppg acquired during fingerprinting. Drilling of the exploratory sand was successfully carried out in the combined SBP mode applying maximum of 800 psi surface pressure during each connection and this resulted in an average min/max ESD for 17.6 / 18.2 ppg. The drill string was stripped out of the open hole to a safe depth maintaining 17.89 ppg EMW on bottom with 650 psi SBP.

A total of 11 MPD Connections were made during drilling, including 1 dummy connection to determine the bottoms up gas at the desired ESD, and 1 Dynamic Flow Check. The MPD connections utilized the rig pump to circulate across the top of the well (160-260 gpm), while using the MPD choke to apply required surface backpressure and the flow out was monitored by Coriolis meter. A ramping sequence was used to schedule the diversion of fluid from drill string and simultaneous application of back pressure with the MPD choke (Figure 5). The applied back pressure enabled application of targeted set point thereby compensating for the loss of ECD during flow-off event.

Initially, the MPD team experienced some difficulty in achieving a steady BHP profile during start-up and shut-down of the pumps. When operating in Auto mode of annular pressure application during the first five connections, the MPD system software usually applied excessive surface back pressure of 300-700 psi with the intention to hold 17.3-17.7 ppg at the shoe and the bit, when shutting down (or starting up) the mud pumps (Figure 6). This was due to the fact that mud compressibility was not taken into account during flow-off. This phenomenon could potentially result in excessive BHP and fracture the formation. For the next 6 connections the combined mode (Figure 3) was adopted. When shutting down the pumps in the combined mode sequence, the MPD software was operated in Auto mode while diverting the flow through the string from normal circulating rates down to 50 gpm (10 spm), and then switched to manual mode of back pressure application by the choke operator from 50 gpm (10 spm) until zero flow through the string. The reverse sequence was applied when starting up the pumps. In this way, a much more steady BHP profile was achieved during connections.

Managing Connection Gas

Due to the narrow margin, uncertainty around the pressure regime and the high permeability of the formation, a single gas event was adopted for connection gas. This is a situation whereby deliberately or otherwise, whenever there is a flow-off event, the gas is circulated to surface before any other flow-off event. There must not be more than one pumps-off event in the well at any time. The first must always be circulated out prior to initiating another. Non adherence to this could result in reduction in BHP. During such dips in BHP, an influx can be taken if the BHP is below the Pore Pressure. Allowing multiple pumps-off events can cause multiple dips, the cumulative effect of which could result in an influx. This further enhanced the ability of the MPD to maintain required bottom hole pressure by eliminating any significant mud weight variation in the annulus.

Conclusions

Managing Bottom Hole Pressure using MPD technology and other well engineering techniques enabled safe drilling of a narrow margin well in a high permeable formation in the Niger Delta. This required MPD system modification for effective application of surface back pressure, finger printing exercise and compliance with single flow-off event so as to manage impact of gas inflow to the wellbore from highly permeable overpressure formations. The high resolution data from the PWD tool enhanced continuous evaluation and improvement of MPD connection technique. The reviews of bottom hole pressure behavior enabled the selection of the combined mode of back pressure application which eliminated the chance of fracturing the formation as a result of excessive bottom hole pressure on one hand and well control incident as a result of bottom hole pressure dipping below the pore pressure on the other extreme.

Acknowledgements

The SPDC HPHT drilling team and the service providers that made the MPD project a success are hereby acknowledged.

Nomenclature

BHA - Bottom Hole Assembly
BHP - Bottom Hole Pressure
BOP - Blow out Preventer
cp - centipoises
ρ - density
ppg - pounds per gallon
ECD - Equivalent Circulating Density
EMW - Equivalent Mud Weight
ESD - Equivalent Static Density
FG - Fracture Gradient
FIT - Formation Integrity Test
ftah - Feet along Hole
GPM - Gallons per minute
HPHT - High Pressure High Temperature
HAZID - Hazard Identification Studies
HAZOP - Hazard and Operability Analysis
h - height
IADC - International Association of Drilling Contractors
LOT - Leak off Test
mD – milli Darcy
PP - Pore Pressure

P&ID - Process and Instrumentation Diagram
PWD - Pressure While Drilling
ppg - pounds per gallon
RCD - Rotating Control Device
SBP - Surface Back Pressure
SPE - Society of Petroleum Engineers
spm - strokes per minute

Selected References

Arnone, M., and P. Vieira, 2009, Drilling wells with narrow operating windows applying the MPD constant hole pressure technology – How much temperature and pressure affects the operator's design: SPE/IADC #119882, Drilling Conference and Exhibition.

Bybee, Karen, 2010, Using MPD to drill wells narrow operating windows: Pressure and temperature effects: JPT, February.

Fadlin, Ali, Ray Usmar, Fikri Irawan, and Ardia Karnugroho, 2015, Successful application of Constant Bottom Hole Pressure (CBHP) MPD in offshore East Kalimantan, Indonesia: Proceedings, Indonesia Petroleum Association, Thirty-Ninth Annual Convention & Exhibition.

Fredericks, P.D., L. Smith, and K.J. Moreau, 2011, ECD management and pore pressure determination with MPD improves efficiency in GOM well: SPE/IADC #140289, Drilling Conference and Exhibition.

Riddoch, James, Chad Wuest, Julmar Shaun, and S. Toralde, 2016, Managing constant bottom hole pressure with continuous flow system: OTC-26752-MS, Offshore Technology Conference.

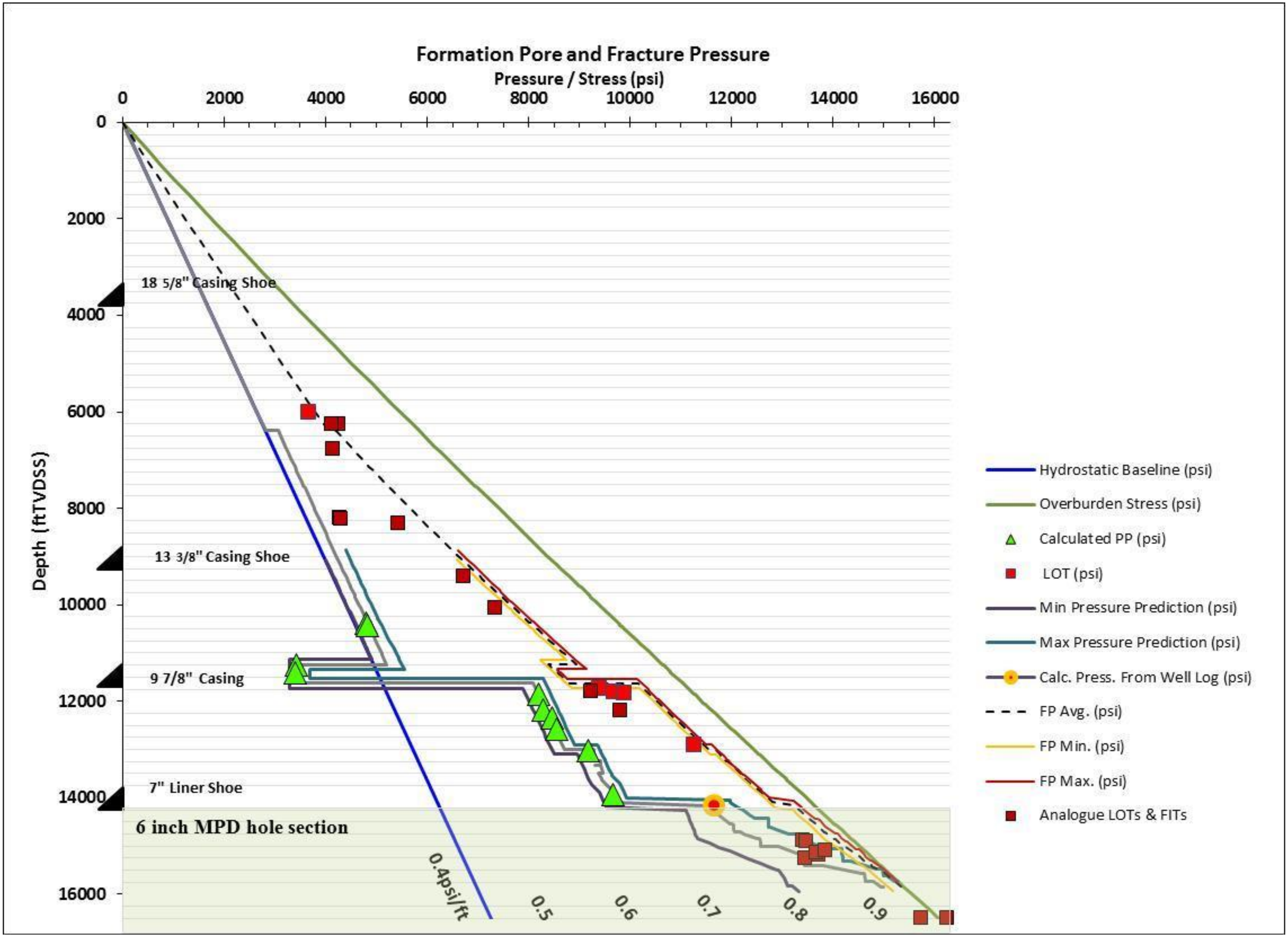

Figure 1. Pore pressure/fracture gradient profile for planning MPD operation.

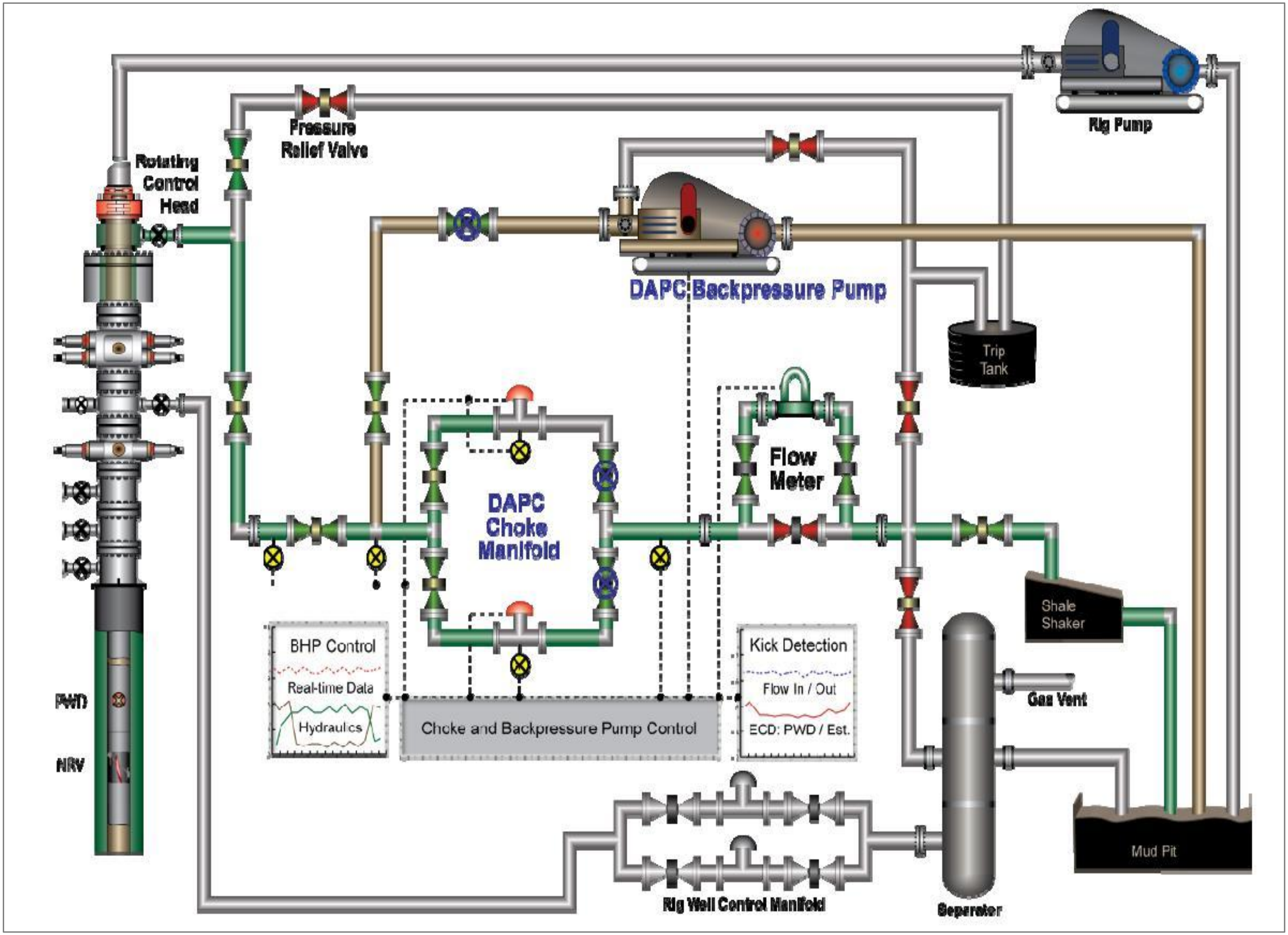

Figure 2. P & ID - process and instrumentation diagram of an MPD system.

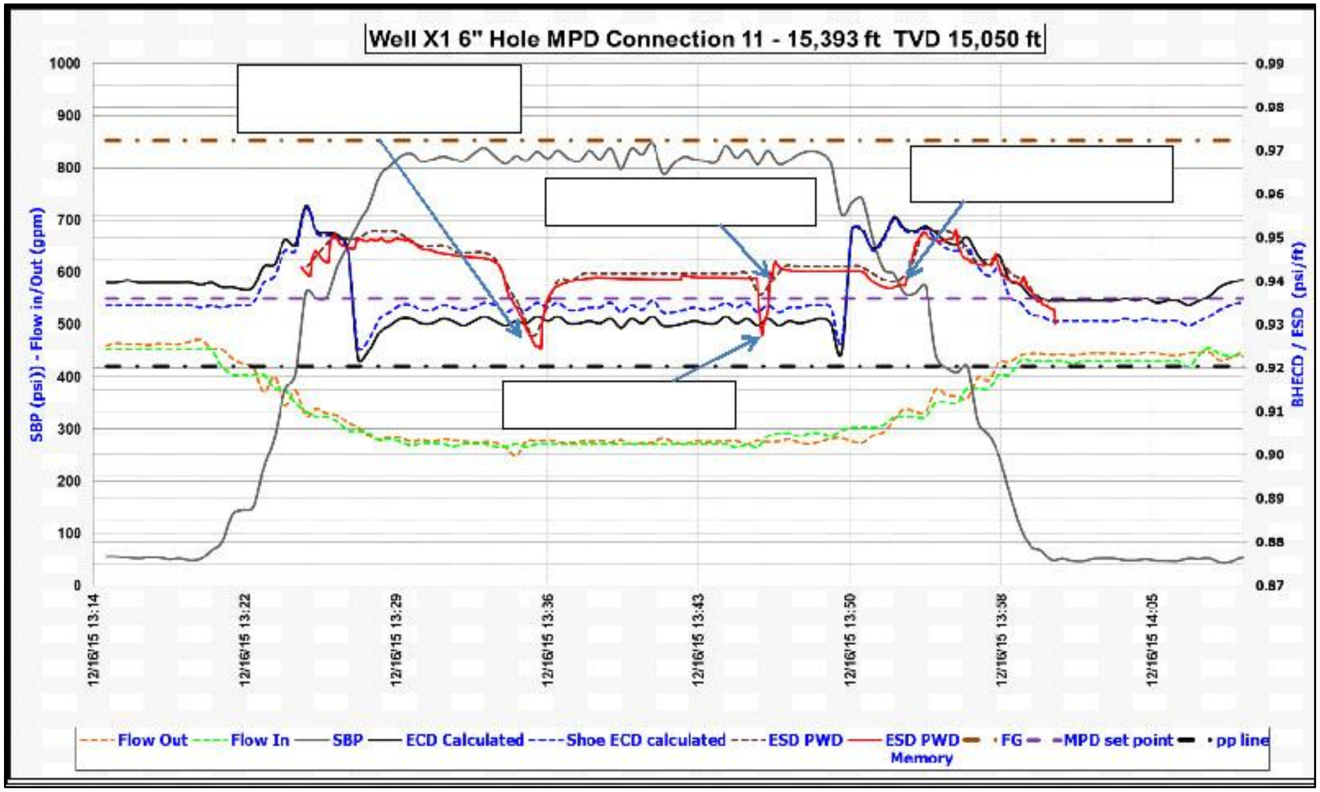

Figure 3. MPD connection in combined auto and manual modes of back pressure application.

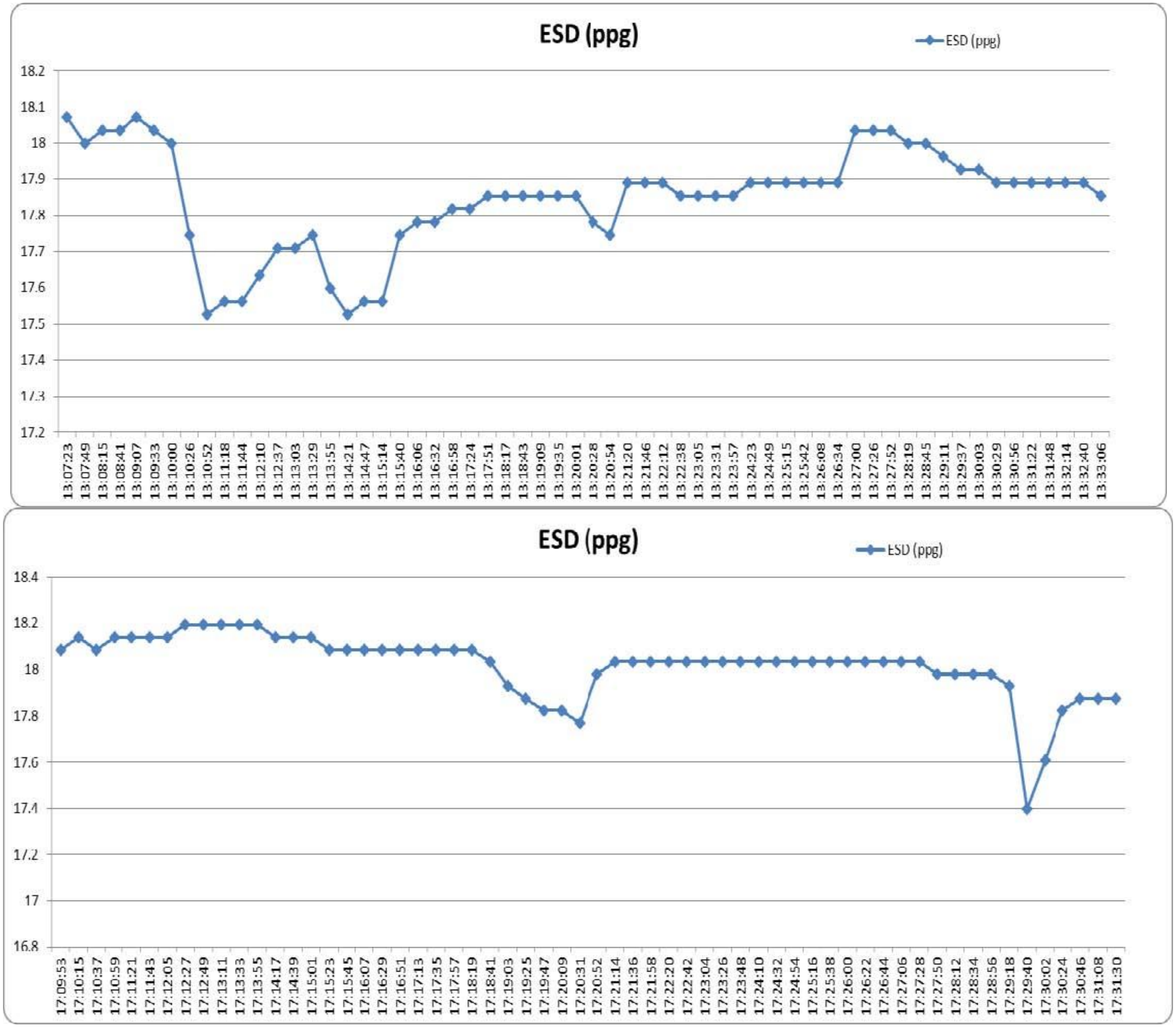

Figure 4. Effect of bleeding off with valve versus choke on ESD.

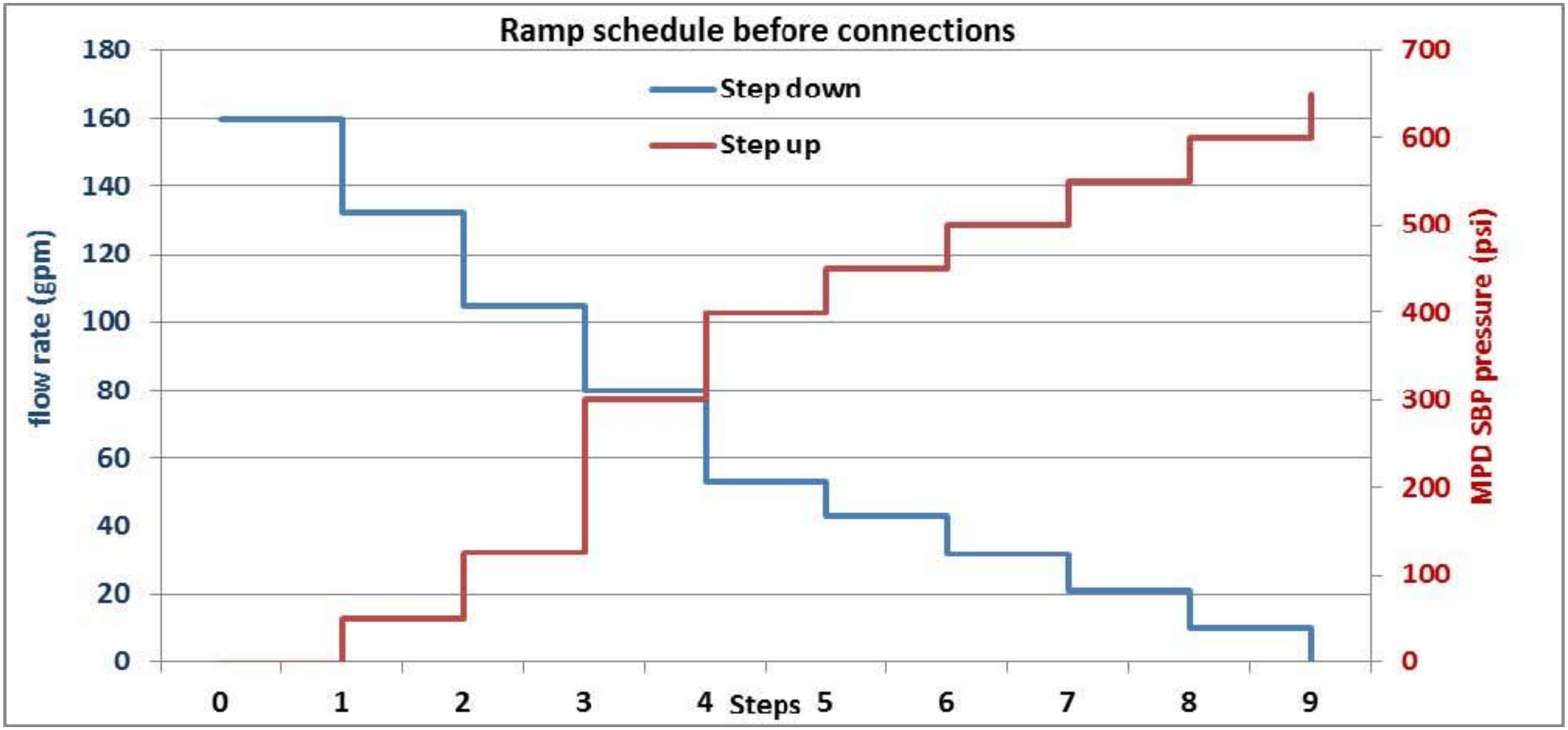

Figure 5. Pressure ramp up schedule.

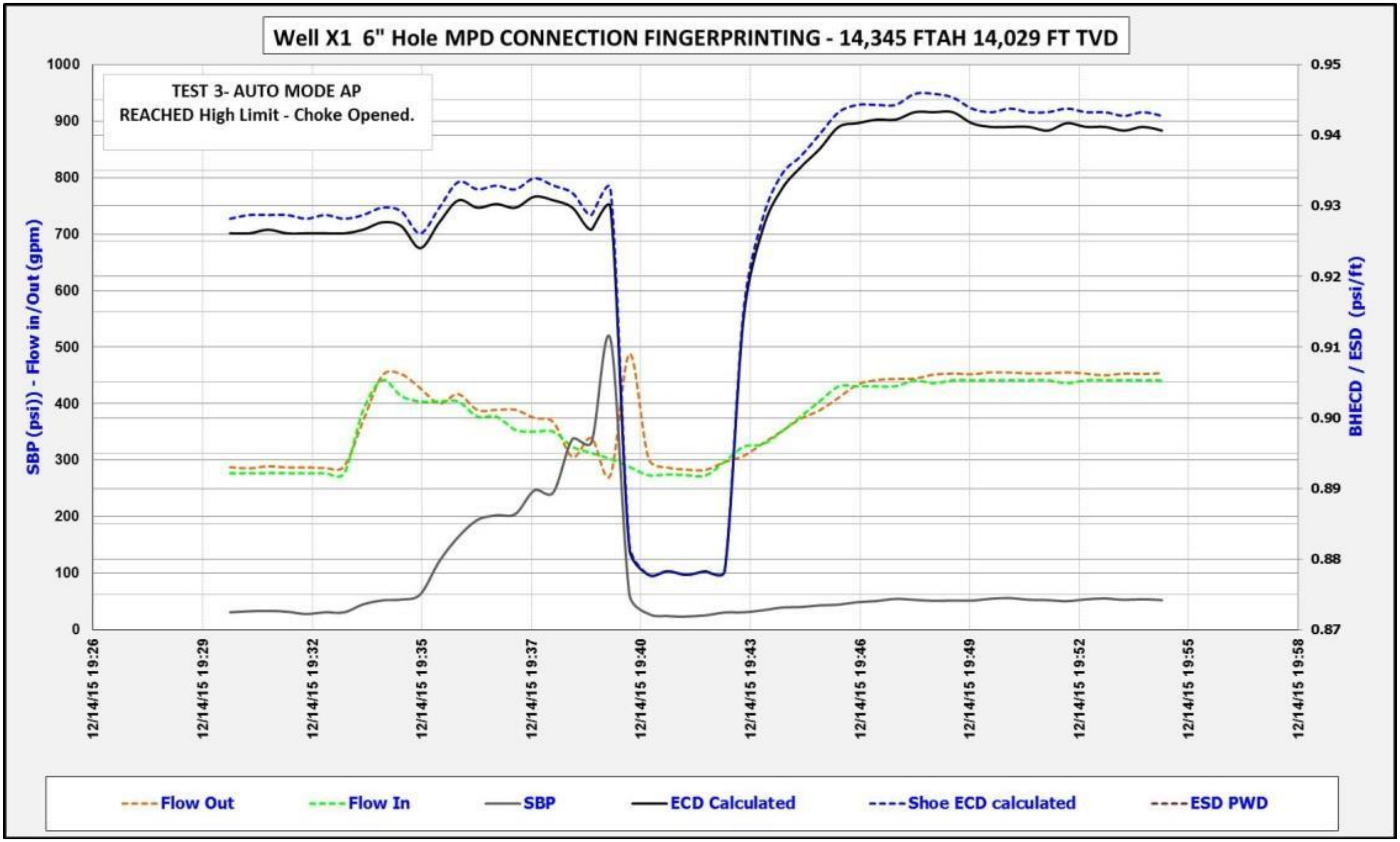

Figure 6. MPD connection in auto annular mode**.**