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DEPOSITS DETECTION USING PRESSURE PULSE TECHNOLOGY

Ormen Lange Pipelines Case Study Using Process Simulation Tools

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Preface

This project work has been done in connection with my in-depth study of petroleum production at NTNU, Trondheim. The work was carried out from September to December 2004.

I would like to thank Professor Jón Steinar Gudmundsson, of the Department of Petroleum Engineering and Applied Geophysics at NTNU, and Jon Rønnevig of Markland AS, who has been very helpful and cooperative.

Abstract

The subject of this work is a presentation of deposits detection on the Ormen Lange multiphase pipelines, using pressure pulse technology. The work has been conducted with the use of the process simulation tool, HYSYS. Special attention is paid to comparison of full and highly reduced multiphase production on the Ormen Lange field. A simulation process that is similar to the Ormen Lange field has been accounted for by the use of real data. The results from simulation without deposits have been checked by analytical methods. Deposits of 10, 50 and 100 millimetres thick, 100 and 1000 metres long have subject to investigation. As a quality check, simulations have also been performed by expert Jon Rønnevig at Markland AS. Pressure pulse is introduced as a deposit detection and leakage detection method. Discussion of the results obtained have been performed with emphasize on the pressure pulse technology.

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1 Introduction

Detection of deposits in subsea multiphase pipelines is a very important issue for the petroleum industry. As more and more of the fields offshore are developed subsea, it is important to develop reliable and precise methods to detect deposits in the pipelines which often are multiphase.

The Ormen Lange field which is under development is planned to have two multiphase pipelines each of 120 kilometres long. It is necessary to monitor and detect possible deposits in the pipelines. Pressure pulse technology, PressurePulse™, is patented by Markland AS and has been used with success on several fields in the North Sea to detect deposits.

In this work a simplified model of the Ormen Lange field has been built in HYSYS, data and values have been extracted to perform necessary calculations of pressure pulse to verify whether pressure pulse technology can be applied as detection method.

In this project assignment the challenge has been to detect deposits in the multiphase pipelines on the Ormen Lange field, using pressure pulse technology. The process simulation tool, HYSYS, has been applied.

2 Ormen Lange

The Ormen Lange field is located in the Norwegian Sea, approximately 100 kilometres northwest of the coast of Møre. With its 400 billion Sm^3 of gas, its Norway's largest gas field and it was discovered by Norsk Hydro in 1997. Production will begin in the 3rd quarter of 2007 and when the field reaches its maximum production, it will have the capacity to deliver 20 % of Great Britain's need for natural gas [1].

The reservoir is very characteristic. It covers an area of 10 by 44 kilometres; the depth of the reservoir varies between 2650 metres and 2915 metres beneath mean sea level. Initial reservoir pressure is about 290 bara and the temperature ranges from 86 to 96 ºC. The field is located within a prehistoric slide area, the Storegga slide, with water depths varying from 850 to 1100 metres in the planned development area. The Storegga slide is extremely irregular with soil conditions varying from very stiff clay with boulders to soft clay [2]. The Storegga slide has been thoroughly researched to find out whether such a slide could occur again, and the conclusion is that it requires a new ice-age [3].

2.1 Subsea development

Every installation on the Ormen Lange field is thought to be subsea. Initial development will consist of two 8-slot production templates (A & B), with approximately 4 kilometres between them [2]. Each template will have four 9 $^5/_8$'' and four 7'' wells [3]. The 9 $^5/_8$'' well will have a production capacity of 10 MSm^3/d and the 7'' will have a capacity of 6.4 MSm^3/d [4]. A well trajectory to one of the 9 $^5/_8$'' wells is shown in Figure 1.

Each of the production templates will have a 20'' production header which will be tied into the two 30'' multiphase pipelines by rigid spools. The two 30'' lines will be connected via a pipeline end termination system (PLET). Two main control umbilicals will link the onshore plant to the subsea production system; one will be connected to template A and the other to template B. For redundancy there will be a cross over control umbilical that'll interconnect the two templates and also a pigging loop will be installed

to secure the capability of round-trip pigging of the two 30'' multiphase lines. To prevent hydrate formation, all wells are continuously dosed with monoethylene glycol (MEG), supplied via two 6'' pipelines from the shore terminal, Nyhamna. They are connected in the same manner as the umbilicals and they also have a crossover interconnection [2].

A further development might be necessary depending on the production experience. One of the uncertainties is how many and if there is communication between the faults in Ormen Lange [3]. If more wells are required, one scenario is to add two 6-slot production templates (C & D). They will include two spare well slots that may be used for additional wells. Each of these production templates will produce gas through dual 12'' manifold headers and infield flowlines tied back to the 30'' PLET (valid for template C) and hot-tap tees in the 30'' lines (valid for template D). A new infield 6'' MEG line will be connected to each of the two future templates as extensions from the initial templates. The remaining well completions are assumed to be 7'' wells [2]. In the future it will be necessary to compress the gas, to increase the pressure. A pre-compression platform or a subsea compression unit, see Figure 2, is one of the possibilities considered by Norsk Hydro [3].

2.2 Pipelines

There are initially four pipelines which have to be laid to connect Nyhamna to the Ormen Lange field; two multiphase lines and two MEG lines.

As a base case, two multiphase pipelines with constant ID of 690 millimetres will be installed from the land terminal at Nyhamna to the field. These lines will be called Production Line A (PL-A) and Production Line B (PL-B). The governing design criteria for the 30'' pipelines depends on the water depth, location class and on the design temperature, Table 1 shows the selected wall thickness. To achieve stability of the pipelines, weight coating and additional intervention work is needed. The weight coating is mainly governed by the need for lateral stability in the operational phase [5].

The 6'' MEG pipelines will be installed from the land terminal at Nyhamna to each of the templates A and B. As for the multiphase pipelines the governing design criteria depends on the water depth and location class. Current calculations of lateral stability for the MEG pipelines during the installation show that the MEG line is partly unstable. Further engineering work will be undertaken to further evaluate the stability. However for the operational phase, the pipelines are fully protected by trenching or rock dumping [5].

To protect the pipelines from external corrosion, a combination of corrosion coating and sacrificial anodes will be applied. See Table 2 for full description. The first 33 kilometres of the multiphase pipelines will be installed from Nyhamna and out of the near shore area, Bjørnesundet, in 2005. The remaining part will be installed in 2006 together with the two main MEG pipelines. Since the templates (A & B) are located with approximately 4 kilometres apart, it allows for rig work, even with anchors, to be done at one template while marine activities can take place at the other. Base case is to install the multiphase pipelines by use of both S-lay and J-lay methods. For the MEG lines a reel vessel will be used, alternatively an S-lay or J-lay vessel can be used [5].

3 Pressure pulse technology

Since the early 1990's the pressure pulse technology has been developed, with basic research at the Norwegian University of Science and Technology (NTNU), further improvement and commercializing has been done by Markland^{TM}. Extensive field testing on several production platforms, has demonstrated the feasibility of pressure pulse technology for allocation testing and wellbore monitoring [7].

3.1 Principle of pressure pulse

The pressure pulse is obtained from pressure measurements at one location, immediately up-stream of a quick-acting valve [7]. The pressure pulse method is based on the combined effects of the water-hammer measured in a gas-liquid flow when a valve is closed quickly, the line-packing of the flow and the sound speed of the mixture in the pipeline [8].

When a quick-acting valve is closed, it will generate a pressure increase up-stream of the valve; this is referred to as the water-hammer. The water-hammer is given by the Joukowsky equation:

$$\Delta p_a = \rho u a \qquad \textbf{Equation 3.1}$$

Where Δp_a (Pa) is the water-hammer, ρ (kg/m^3) is the fluid density, u (m/s) is the homogenous fluid velocity and a (m/s) is the sound speed. To define a valve as quick-acting it has to close before a pressure pulse is reflected back from up-stream or down-stream. However the water-hammer is pressure increase is independent of the time it takes a quick-acting valve to close; provided it closes before any reflections arrive from up-stream or down-stream. Any reflections will affect the pressure increase during closing. An illustration of this phenomenon is shown in Figure 3. The pressure increase takes place from the valve is 80 % closed to its fully closed. Therefore most of the pressure pulse will be generated in the last 0.4 seconds if the valve's closing time is 2.0 seconds [8].

As the flow is brought to rest; line-packing occurs. The pressure up-stream will continue to increase with time, as shown in Figure 3, this pressure increase is called line-packing of the pipeline. In liquid-only flow the line-packing represents the frictional pressure drop with distance in the pipeline. The frictional pressure drop is given by the Dacy-Weisbach equation:

$$\Delta p_f = \left(\frac{f}{2}\right)\left(\frac{L}{d}\right)\rho u^2 \qquad \textbf{Equation 3.2}$$

Where f (-) is the friction factor, L (m) the length of the pipeline and d is the diameter of the pipe, the other variables are given above. Line-packing is more complicated in gas-liquid flow, due to its increase in water-hammer with up-stream distance [8].

The sound speed is the third effect in the pressure pulse technology. The sound speed in gas-liquid mixtures is much lower than the sound speed in single-phased flows [8]. Experiments shows that the sound speed for void fraction in the range 0.2 – 0.8 was in the range of 30 – 40 m/s for line pressure in the range of 1.4 – 1.6 bara. It was also shown that a homogenous sound speed model gave a good match with the experimental result [9].

The sonic velocity in gas-liquid mixtures is given by the Wood equation:

$$a = \frac{1}{A \cdot B} \qquad \textbf{Equation 3.3}$$

$$A = \sqrt{\alpha\rho_G + (1-\alpha)\rho_L} \qquad \textbf{Equation 3.4}$$

$$B = \sqrt{\left(\frac{\alpha}{\rho_G a_G^2}\right) + \left(\frac{1-\alpha}{\rho_L a_L^2}\right)} \qquad \textbf{Equation 3.5}$$

Where α (-) is the void fraction, and the subscripts G and L denotes gas and liquid respectively. In 1993 a computer program developed by Dong and Gudmundsson was used to estimate the speed of sound in the gas-oil mixture flowing at 60 bar and 90 bar in an offshore well on the Gullfaks B platform. The wellhead pressure was approximately 90 bars and the separator pressure about 60 bars. For two-phase mixtures the computer program gives the same result as Equation 3.3. Experiments show that the speed of sound

in pure liquids is high, but decreases dramatically with small amounts of gas. When the void fraction is in the range of 0.2 – 0.8 the sound speed remains relatively constant, but from 0.8 and to pure gas, the sound speed increases along with the pressure [8].

For any single phase fluid, gas or liquid the expression for sound speed is:

$$c^2 = \frac{\partial p}{\partial \rho_S} = \gamma \frac{\partial p}{\partial \rho_T}$$ **Equation 3.6**

The subscript S and T denotes isentropic and isothermal processes, and γ the ratio of specific heats. An expression for sonic velocity in multiphase mixtures has been developed by Dong and Gudmundsson which relates the sonic velocity of the mixture directly to the properties of the gases and liquids. Equation 3.6 can be rewritten by the use of isentropic, K^S, or isothermal, K^T, compressibility.

$$c^2 = \frac{1}{\rho K^S}$$ **Equation 3.7**

Or

$$c^2 = \frac{\gamma}{\rho K^T} = \frac{C_p}{C_v \rho K^T}$$ **Equation 3.8**

Where the superscripts S and T refer to an isothermal and isentropic process respectively, C_p is isobaric specific heat and C_v isochoric specific heat. As seen from Equation 3.8, the sonic velocity of any fluid or mixture can be related directly to its density, isothermal compressibility and specific heat. For a multiphase mixture these properties are functions of those of its constituent fluids. Therefore, its sonic velocity can be directly related to those of its pure constituents. Knowing those properties gives an opportunity to calculate the sonic velocity arithmetically instead of differentially [10].

3.2 Pressure pulse detection ability range

Pressure pulse detection ability range is calculated from Equation 3.9. This equation is obtained by comparison of $\Delta p_a = \Delta p_f$.

$$\rho u a = f \frac{\rho}{2} \frac{L_{max}}{d_i} u^2$$ **Equation 3.9**

If Equation 3.9 is rearranged with respect to L_{max}, it gives the expression to Equation 3.10

$$L_{\max} = \frac{2 \cdot a \cdot d_i}{f \cdot u}$$ **Equation 3.10**

Where L_{max} denotes the pressure pulse detection ability, d_i is the internal diameter; the other variables are given earlier [11].

3.3 Pressure pulse applications

The pressure pulse technology is versatile and can be applied in many areas, and in the petroleum industry it can be applied in pipelines, flow lines and wellbores.

Pressure pulse technology can be used to detect and monitor solid deposits. To illustrate how pressure pulse can be used to detect a reduction in diameter, see Figure 4. The diameter reduction is abrupt and significant and exists for some distance, until the diameter expands abruptly back to its original diameter. The pressure pulse goes back to its original gradient because of the pressure pulse that travels the opposite way and has the same value, only negative. The point A represents the distance from the quick-acting valve to the reduction in pipeline diameter, and the point B represents the distance from the valve to the resumption of full pipeline diameter. Such a reduction in pipeline diameter which occurs in the interval AB could originate from the deposition of solids in the particular interval.

An increase in friction factor will result in similar effects as a decrease in diameter, as evident from Equation 3.2. The increase in friction factor increases the frictional pressure gradient in the interval, as illustrated in Figure 5. The point C represents the distance from the quick acting-valve where friction increases, and the point D represents the distance from the valve where pipeline friction decreases. A complicating factor is that when the internal diameter is reduced from the depositions of solids, it may also be accompanied by a change in friction factor [7].

When detection ability range has been determined for the pressure pulse, it is possible to detect leaks within this range. When leak occurs in the pipeline, some of the fluid escapes. When steady-state is achieved, a leak will result in a change in mass flow rate

and greater pressure drop in the pipeline. By applying pressure pulse technology it will be possible to detect where the leak is located [11].

4 Simulation program HYSYS

The process simulation program HYSYS is attributed Hyprotech, a subsidiary of Aspen Technology. The usability of the program is attributed to the following four key aspects of its design:

- Event driven operation
- Modular operations
- Multi-flowsheet Architecture
- Object oriented design

4.1 Basis environment

The basis environment contains the following environments:

- Simulation Basis Environment
- Oil Characterization Environment

When beginning a new simulation case, HYSYS automatically starts the program in the Simulation Basis environment where one can create, define and modify fluid packages for use by the simulation flowsheets. In general a fluid package contains a minimum of one property package and library and/or hypothetical components. Fluid packages can also contain information for reactions and interactions parameters. The oil characterization environment enables you to characterize petroleum fluids by creating and defining Assay and Blends, see Figure 6. This attribute has not been used in this project [12].

4.2 Simulation environment

The simulation environment contains the main flowsheet where the majority of the work, such as installing and defining streams, unit operations, columns and sub-flowsheets. This flowsheet serves as the base level or “main” flowsheet for the whole simulation case. Any number of sub-flowsheets can be generated from the main flowsheet, but there is only one main flowsheet environment. Each individual sub-flowsheet that is installed has its own corresponding sub-flowsheet environment; in Figure 7 the simulation environment is shown [12].

4.3 Objects

Objects are used to build your simulation within the Simulation environment. The objects in HYSYS are streams, unit operations or logical operations. To install objects in the simulation, use of the Object Palette is required. In the Object Palette it's possible to choose from these categories:

- Streams
- Vessels (2- and 3-phase separators, tank)
- Heat transfer equipment
- Rotating equipment (compressor, expander, pump)
- Piping equipment
- Solids handling
- Reactors
- Pre-built columns
- Shortcut columns
- Sub-flowsheets
- Logicals

[12]

5 Simulation of production without deposits

In the simulation program HYSYS, a simplified flowsheet of the Ormen Lange has been created. The simulation objects consist of four 9 $^{5}/_{8}$'' completed wells, one of the two 30'' multiphase pipelines and a separator at the end. As a base case the simulations have been done without any deposits, to verify that the system behaves similar to Norsk Hydro's description.

5.1 Reservoir gas saturated with water

The reservoir gas consists of 16 different components, see Table 3, this gas should be saturated with water. To create the desired wellstream in HYSYS, the gas stream is brought together with a water stream into a separator. From the separator two new streams emerge, vapour and liquid outlet. The vapour outlet becomes the wellstream, and the liquid outlet is not being used any further, see Figure 7 for details. The wellstream is a gas saturated with water; its composition is given in Table 4.

5.2 Production wells

Each 9 $^{5}/_{8}$'' completed well is supposed to have a capacity of 10 MSm^3/d of flow according to Norsk Hydro. In the simulation done in this project, the four wells have produced approximately 8.7 MSm^3/d, which is equivalent to 81 kg/s. For simplicity all the four wells have the same elevation profile [6], the elevation profile is shown in Figure 1. As mentioned the outer diameter is 9 $^{5}/_{8}$'', the internal diameter has been set to 8 $^{1}/_{2}$''. The formation temperature has been calculated from Equation 5.1:

$$T_{amb} = L_{interval} \cdot \frac{dT}{dL} \qquad \textbf{Equation 5.1}$$

Where T_{amb} is the ambient temperature, $L_{interval}$ is the vertical length of the interval in the formation and $\frac{\partial T}{\partial L}$ is the temperature gradient for the formation which has been set to 48.3 $^{C}/_{km}$ [16]. The heat transfer coefficient (HTC) for the well has been set to 4 $^{W}/_{m^2 °C}$ [16]. The reservoir temperature in the simulations is 96ºC, the calculated temperature at the top (sea bottom) is -1.2ºC, see Appendix A. When the surrounding temperature and reservoir is given as input HYSYS calculates that the wellflow has a temperature of

approximately 80ºC, see Figure 8. The pressure in the reservoir initially is 290 bars, this drop to 218 bars at the wellhead, due to the high flow, as showed in Figure 9.

5.3 Multiphase pipeline

In the simulation; only one of the two multiphase pipelines has been simulated. The pipeline's outer diameter is, as mentioned earlier, 30'' and its inner diameter is 27.17'' (690mm). The two pipelines together are supposed to have a production of 70 MSm^3/d. The pipeline is 121 kilometres long and the elevation profile is given in Figure 10. An overall HTC has been decided and set to 11 $^{W}/_{m^2 °C}$ [16], and the seawater temperature to 2.5ºC [16]. The inlet temperature is 80ºC, from Equation 5.2 the outlet temperature is calculated to be 7.0ºC., see appendix A.

$$T_2 = T + (T_1 - T)\exp\left[\frac{-U\pi d}{mC_p}L\right]$$ **Equation 5.2**

Where U is the overall HTC, m is the massflow, C_p is the specific heat capacity, T, T_1 and T_2 is the surrounding-, inlet- and outlet temperature respectively. The HYSYS simulation gives an outlet temperature of 3.8ºC which is close to the value expected by the analytical calculations, see Figure 11. The difference in temperatures is probably due to the expansion of the gas, which has been neglected in Equation 5.2. The total pressure loss in the pipeline is approximately 55 bars; this is shown in Figure 12.

5.4 Flow assurance

Several aspects of the flow had to be checked to verify that it was consistent with Norsk Hydro's information.

Water production is expected from the Ormen Lange field. The water-saturated gas should, according to the graph shown in Figure 13, contain approximately 3500 $^{mg\ water}/_{Sm^3\ of\ wet\ gas}$, result taken from the separator at the end of the multiphase pipeline, and basic calculations, see appendix A, show that amount of water is correct, this is also the amount of condensated water Norsk Hydro operates with. In this simulation, it has been assumed for simplicity to ignore the free water that is flowing in the reservoir; this should not have any considerable effect on the results [16].

The HTFS Homogenous Flow [16] has been selected as the pipe multiphase flow correlation in HYSYS, both in the wells and the multiphase pipeline. From pvt-data generated by HYSYS, it shows that there is two-phase flow after the first 100 metres of the well(s) and through-out the whole system, see Table 5 and Table 6.

Pressure losses associated with wellheads, valves and manifold have been ignored in the simulation. However this simulation has only implemented four wells, connected to the template, Norsk Hydro is planning to have seven wells on each template. Since the production in the simulation is just as high as the planned production, this will give a total pressure loss that probably is higher than what the pressure loss will be when production starts with seven wells at each template.

The multiphase pipelines are expected to form hydrates; obviously the production wells are not in the hydrate area. From the HYSYS simulation, it shows that after the first 50 kilometres the pipeline enters the hydrate formation area, without MEG injection; see Figure 14. The hydrate area in the simulation is probably a bit larger than what it is supposed to be, due to a lower inlet pressure to the multiphase pipeline in the simulation compared to real conditions. Norsk Hydro is planning to inject a substantial amount of MEG to avoid hydrates.

6 Simulation with deposits in the pipeline

The simulation has been performed with deposits in the pipeline, compared two cases; one with production flow and one where the flow has been reduced to $^{1}/_{10}$ of the original flow. Pressure curves have been extracted from HYSYS and sound velocity calculated. All the data that has been acquired in HYSYS have been extracted to Excel for further calculations.

To simulate deposits, a narrowing is created in the multiphase pipeline. Different deposit sizes have been tested; 10 mm and 50 mm. The deposits have been placed in the beginning of the hydrate area; this is without MEG injection, more exactly after 56 kilometres. This is based on the pressure and temperature equilibrium curve, and the hydrate area is for a pipe in production.

Simulation of these cases has also been done at Markland, by expert Jon Rønnevig. The pressure pulse was calculated with the custom designed program, PPsim™.

6.1 Sound velocity

The sound velocities calculations have been done with a simulation program called PPSound™ [14], for the two cases; production flow and reduced flow. The previously described model in chapter 3.1, has been tested, as mentioned it doesn't give the correct results at given places in the pipeline, however the mean sound velocity is quite close to the real mean sound velocity, sadly the mean velocity isn't very applicable for these calculations. The results from the calculations are shown in Figure 15 and Figure 16.

6.2 Deposit detection

Detecting deposits is based on the pressure pulse that is generated when the quick-acting valve is closed. Two conditions decide if the operation will be a success or not; the size of the pressure pulse and how fast the pressure pulse dies out. According to Equation 3.10 it is possible to calculate the distance the pressure pulse is capable of travelling. To acquire information with regards to friction, pressure and so on, it is necessary that the

pressure pulse can travel at least as far as to the areas where deposits will most likely develop; preferably throughout the whole pipe.

If the pressure pulse is capable of travelling the desired distance, the data the pressure pulse obtains can be used to detect deposits. When sound velocity has been calculated along the pipe it is possible to calculate the change in pressure vs. time, by creating a plot comparing the pressure pulses from pipe with and without deposits the deposits will result in an extra change in pressure starting where the deposits are, see Figure 17, the derivative curve makes it easier to spot the deposit.

6.3 Results

As mentioned, two cases, and two different deposit sizes have been tested, the calculations have taken into account that they are performed from the land facility, Nyhamna.

At full production, case one, the pressure pulse is relatively high, 3.84 bars, but the pressure loss due to friction is even higher and it is not possible to detect deposits any further than 12 to 13 kilometres from land (Nyhamna), see Figure 17. By looking at the derivative curve it is easy to see where the pressure pulse dies out. This distance is close to what is expected by using Equation 3.10. Considering that the hydrate area starts after approximately 50 kilometres (without MEG injection) from the wellheads it makes detection of deposits from land quite hopeless.

Case two where the production is $^{1}/_{10}$ of the original, the pressure pulse is only 0.46 bars but due to less flow, the pressure loss due to friction is very low and the pressure pulse travels throughout the whole pipeline. Deposits are detected by the pressure pulse at 56 kilometres from the wellheads, see Figure 18. The sizes on the deposits affects case one more than case two, assuming that the pressure pulse reaches the deposit in case one. It is easily shown when examining the derivative curves in the figures located in Appendix A.

Results from the Markland simulation confirm the results to some degree. However it shows that a deposition of only 100 metres long and 10 millimetres thick would be difficult to discover, even at a $^{1}/_{10}$ of the original rate, this due to disturbing factors that might reduce the signal. Simulation performed with deposition with a length of 1000 metres is detected by the pressure pulse, at the same rate.

6.4 Discussion

The pressure pulse technology is a clever and easy technology to use. However it has its limitations especially that it is not applicable to detect deposits longer than 12 kilometres from land during full production; solutions to this problem exists. The technology is also very dependent on having correct data on the examining pipes in "perfect" state; clean pipe.

One solution could be to install two or three quick-acting valves on each of the multiphase pipelines. This would create a pipeline system that would have the ability to detect deposits easily.

Another solution is to reduce the flow to increase the distance the pressure pulse can travel. This should be possible since the Ormen Lange will have two multiphase pipelines, one of the pipelines can produce at full capacity while the other is reduced for maintenance. However the pressure pulse generated at highly reduced flow is quite small and could be difficult to measure, considering that there are many disturbing factors in the Ormen Lange pipelines. If quick-acting valves are installed on the pipelines this could be combined with a reduction in flow. A complete detection control of the entire hydrate area would then be available with a production which only is reduced by 40%.

6.5 Conclusion

The use of pressure pulse technology would give the operators of the pipelines accurate information on where and how long deposits are. The technology is however dependent on a few key aspects; flow, number of quick-acting valves and historic data.

To achieve results from the pressure pulse one needs to; reduce the flow significantly, install a large numbers of quick-acting valves with full production or a combination.

Since the pipeline installation is in the starting phase, it should be possible to install quick-acting valves. If the pressure pulse technology is implemented at the start of the Ormen Lange project, one will have the possibility to gather data on how the pipeline acts when the flow is “perfect”. The comparison of measured data with data for a clean pipe is crucial for the pressure pulse technology, but if this is available then the technology works very well.

The best solution is most likely a combination of the alternatives. The installation of three quick-acting valves and a reduction of 40 % in flow will give a full monitoring of deposits in the multiphase pipelines.

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"HYSYS 3.2 Documentation", 2003

[13] Reinertsen, Temadag Utmatting ved NTNU, 2004
"Utmatting av rørledninger på havbunnen- Ormen Lange- Ny guideline for multispenn"

[14] Jon Rønnevig, Markland AS, 2004. Performed Sound Speed calculations with PPSound™

[15] Jon Rønnevig, Markland AS, 2004. Performed Pressure Pulse calculations with PPSim™

[16] Jon S. Gudmundsson, NTNU, 2004. Private communication

[17] Gas Processors Association Handbook, 1980
"Engineering Data Book"

8 Tables

Table 1 Overview of pipeline specifications [5]

Pipeline Type	Pipe diameter [mm]	Design Pressure/ Reference Height [bara@m]	Design Temp. (min/ max) [°C]	Medium Density [kg/m³]	Design life [years]	Material
30" Multiphase PL-A	ID = 690.0	255 / 200 @ -890m	-20 / 80	80-200	50	X65 Carbon steel
30" Multiphase PL-B	ID = 690.0	255 / 200 @ -890m	-20 / 80	80-200	50	X65 Carbon steel
6 5/8" MEG-A	OD = 168.3	345 @ -890m	-10 / 50	1125	50	X65 Carbon steel
6 5/8" MEG-B	OD = 168.3	345 @ -890m	-10 / 50	1125	50	65 Carbon steel
6 5/8" MEG Crossover A-B	OD = 168.3	345 @ 30m	-10 / 50	1125	50	X65 Carbon steel
20" Multiphase Crossover spool	OD = 508.0	255 /200 @ -890m	-20 / 80	80-200	50	X65 Carbon steel

Table 2 Pipelines corrosion coating summary [5]

Pipe line	Coating	Material	Thickness (mm)	Density (kg/m^3)
Multiphase pipelines above ca. 550 m sea depth	Protection and weight	Reinforced concrete	45 - 65	2250 - 3400
	Anti-corrosion	Glass fibre reinforced Asphalt enamel	6	1300
Multiphase pipelines below ca. > 550 m sea depth	Protection and weight	Polypropylene + adhesive	7.7	900
	Anti-corrosion	Fusion bonded Epoxy	0.3	1450
MEG pipelines	Protection and weight	Polypropylene + adhesive	4.7	900
	Anti-corrosion	Fusion bonded Epoxy	0.3	1450
42" Gas Transportation Pipeline	Protection and weight	Reinforced concrete	50 - 75	2250 - 3050
	Anti-corrosion	Glass fibre reinforced Asphalt enamel	6	1300

Table 3 Gas composition [6]

Component	Mole Fractions
Nitrogen	0,0034
CO2	0,0042
Methane	0,9251
Ethane	0,0345
Propane	0,0121
i-Butane	0,0027
n-Butane	0,0032
i-Pentane	0,0015
n-Pentane	0,0013
Pseudokomp1*	0,0033
Pseudokomp2*	0,0041
Pseudokomp3*	0,0022
Pseudokomp4*	0,0009
Pseudokomp5*	0,0008
Pseudokomp6*	0,0003
Pseudokomp7*	0,0003

Table 4 Wellstream composition

Component	Mole Fractions
Nitrogen	3,39E-03
CO2	4,18E-03
Methane	0,920213159
Ethane	3,43E-02
Propane	1,21E-02
i-Butane	2,69E-03
n-Butane	3,19E-03
i-Pentane	1,50E-03
n-Pentane	1,30E-03
Pseudokomp1*	3,29E-03
Pseudokomp2*	4,12E-03
Pseudokomp3*	2,18E-03
Pseudokomp4*	8,98E-04
Pseudokomp5*	7,90E-04
Pseudokomp6*	3,41E-04
Pseudokomp7*	3,07E-04
H2O	5,25E-03

Table 5 Flow regime in the production wells

Length [m]	Flow Regime	Length [m]	Flow Regime
0	Vapour Only	3658	Two Phase
20	Vapour Only	3678	Two Phase
40	Vapour Only	3698	Two Phase
60	Vapour Only	3718	Two Phase
80	Vapour Only	3738	Two Phase
100	Two Phase	3758	Two Phase
393	Two Phase	3778	Two Phase
686	Two Phase	3798	Two Phase
980	Two Phase	3818	Two Phase
1273	Two Phase	3838	Two Phase
1566	Two Phase	3858	Two Phase
1859	Two Phase	3878	Two Phase
2152	Two Phase	3898	Two Phase
2446	Two Phase	3918	Two Phase
2739	Two Phase	3938	Two Phase
3032	Two Phase	3958	Two Phase
3125	Two Phase	3978	Two Phase
3218	Two Phase	3998	Two Phase
3312	Two Phase	4018	Two Phase
3405	Two Phase	4038	Two Phase
3498	Two Phase	4058	Two Phase
3518	Two Phase	4078	Two Phase
3538	Two Phase	4098	Two Phase
3558	Two Phase	4118	Two Phase
3578	Two Phase	4138	Two Phase
3598	Two Phase	4158	Two Phase
3618	Two Phase	4178	Two Phase
3638	Two Phase	4198	Two Phase

Table 6 Flow regime of the multiphase pipeline

Length [m]	Flow Regime	Length [m]	Flow Regime
0	Two Phase	74700	Two Phase
440	Two Phase	86600	Two Phase
880	Two Phase	98500	Two Phase
1320	Two Phase	98820	Two Phase
1760	Two Phase	99140	Two Phase
2200	Two Phase	99460	Two Phase
3920	Two Phase	99780	Two Phase
5640	Two Phase	100100	Two Phase
7360	Two Phase	100420	Two Phase
9080	Two Phase	100740	Two Phase
10800	Two Phase	101060	Two Phase
13620	Two Phase	101380	Two Phase
16440	Two Phase	101700	Two Phase
19260	Two Phase	103640	Two Phase
22080	Two Phase	105580	Two Phase
24900	Two Phase	107520	Two Phase
27720	Two Phase	109460	Two Phase
30540	Two Phase	111400	Two Phase
33360	Two Phase	113340	Two Phase
36180	Two Phase	115280	Two Phase
39000	Two Phase	117220	Two Phase
50900	Two Phase	119160	Two Phase
62800	Two Phase	121100	Two Phase

9 Figures

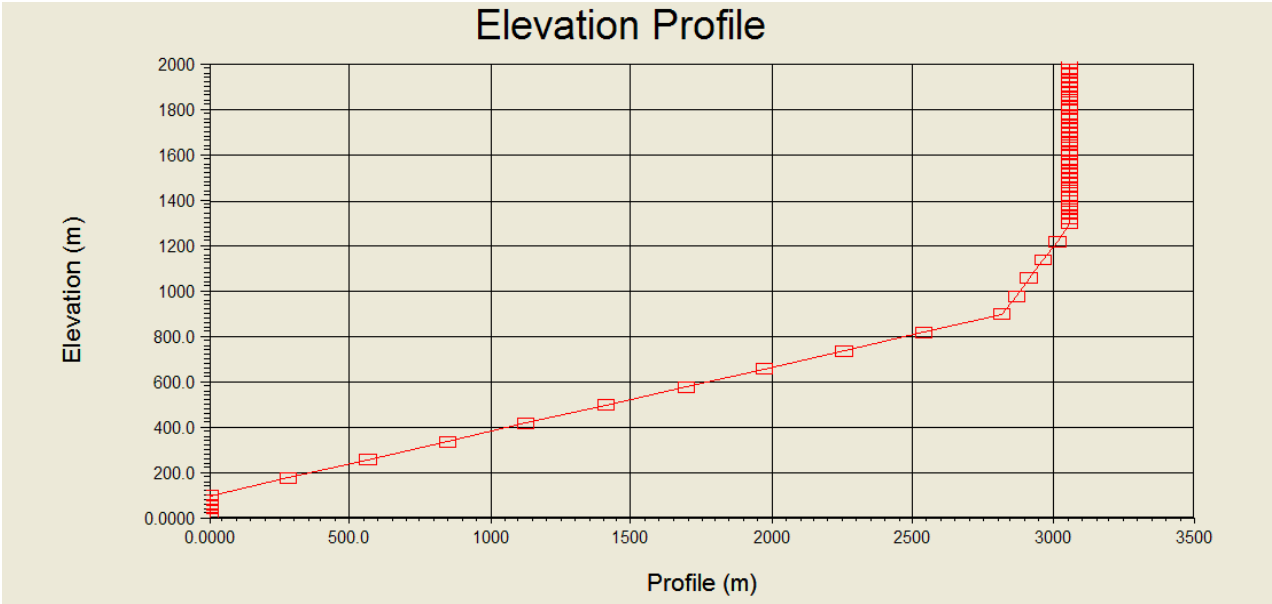


Figure 1 Graphical view of the elevation profile for one of the 9 5/8'' wells [6]

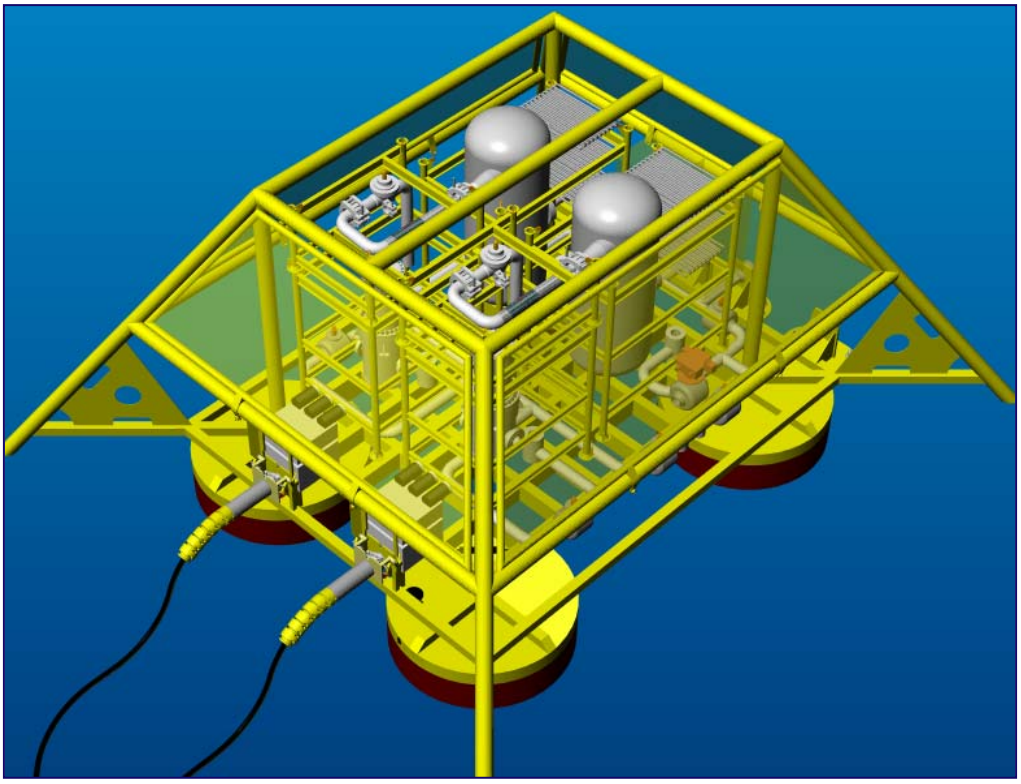


Figure 2 The Ormen Lange subsea compression pilot project: "Subsea Sputnik" [3]

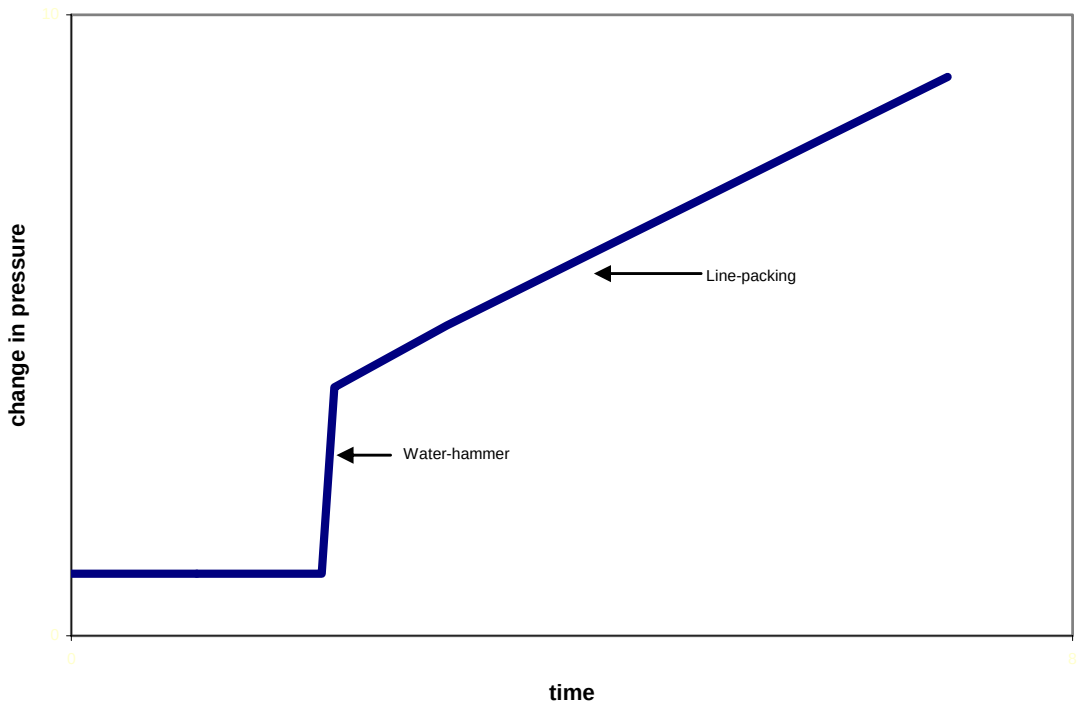


Figure 3 Graphical view of Water-hammer and Line-packing [7]

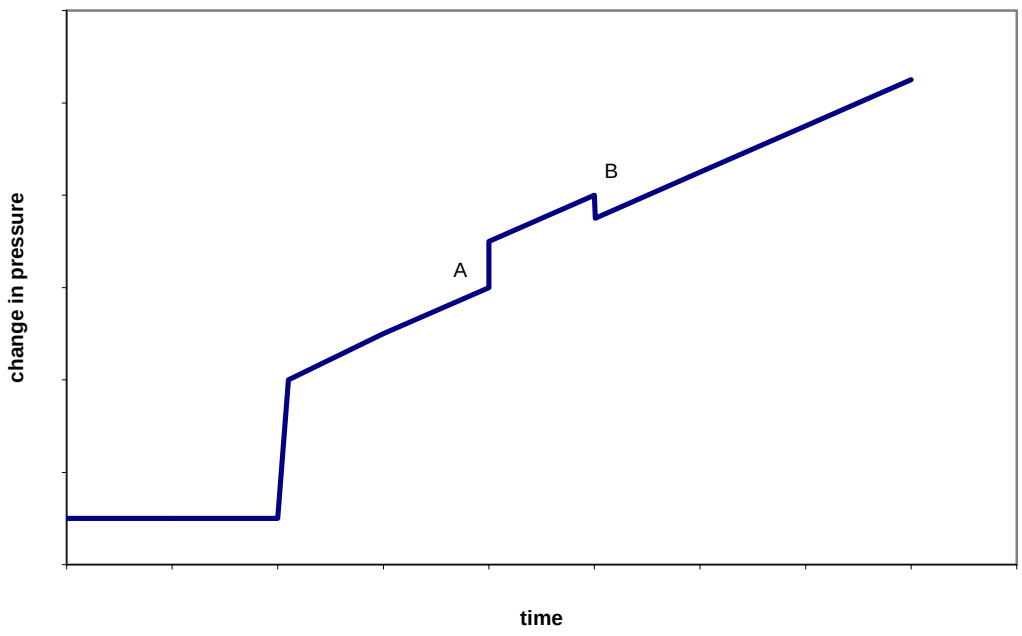


Figure 4 Pipeline diameter reduced in the interval A-B [7]

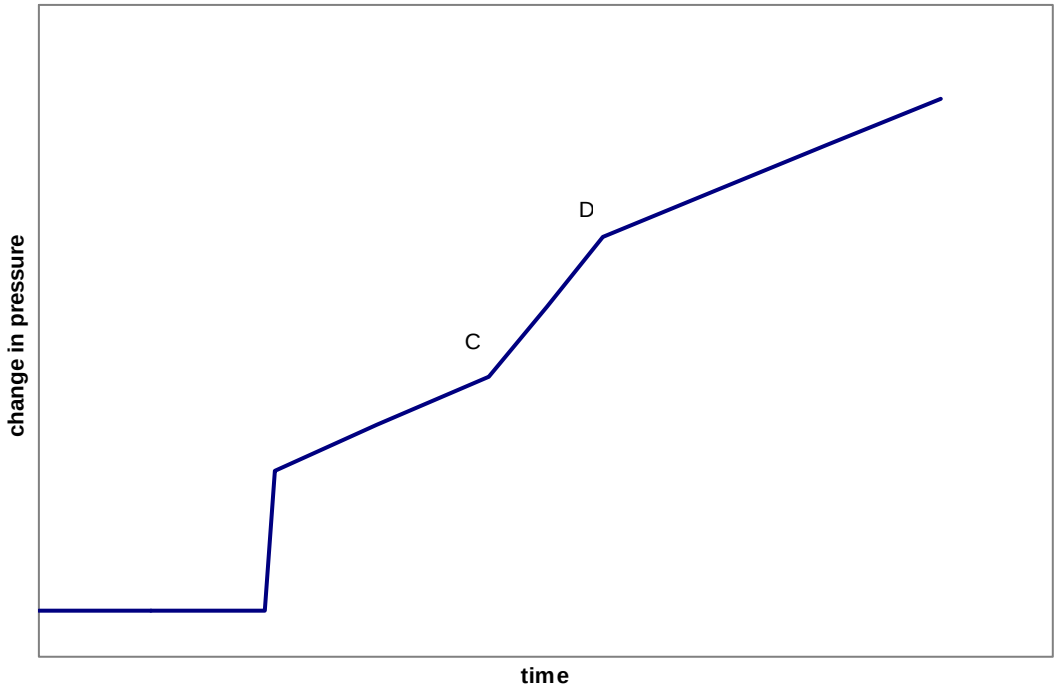


Figure 5 Friction increased in interval C-D [7]

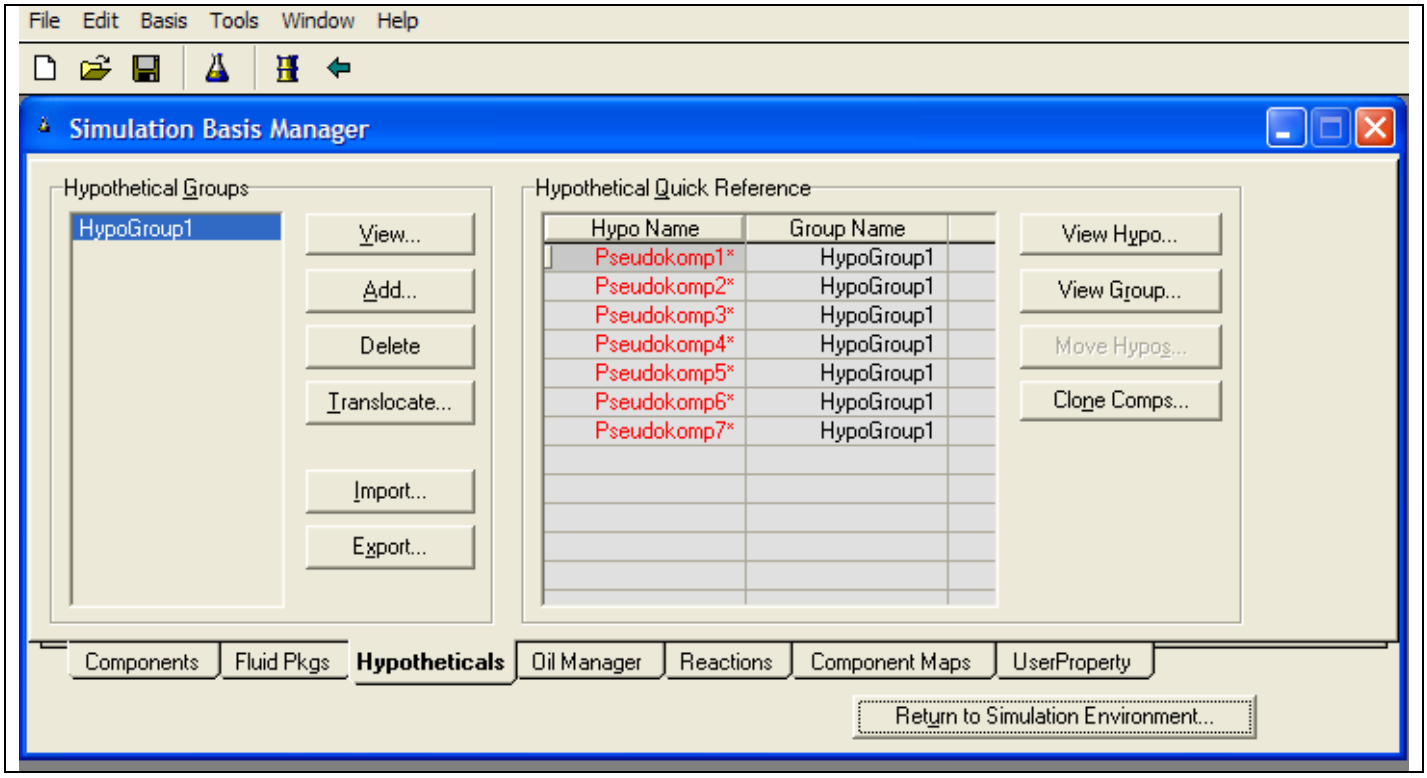


Figure 6 Shows the basis environment in HYSYS [12]

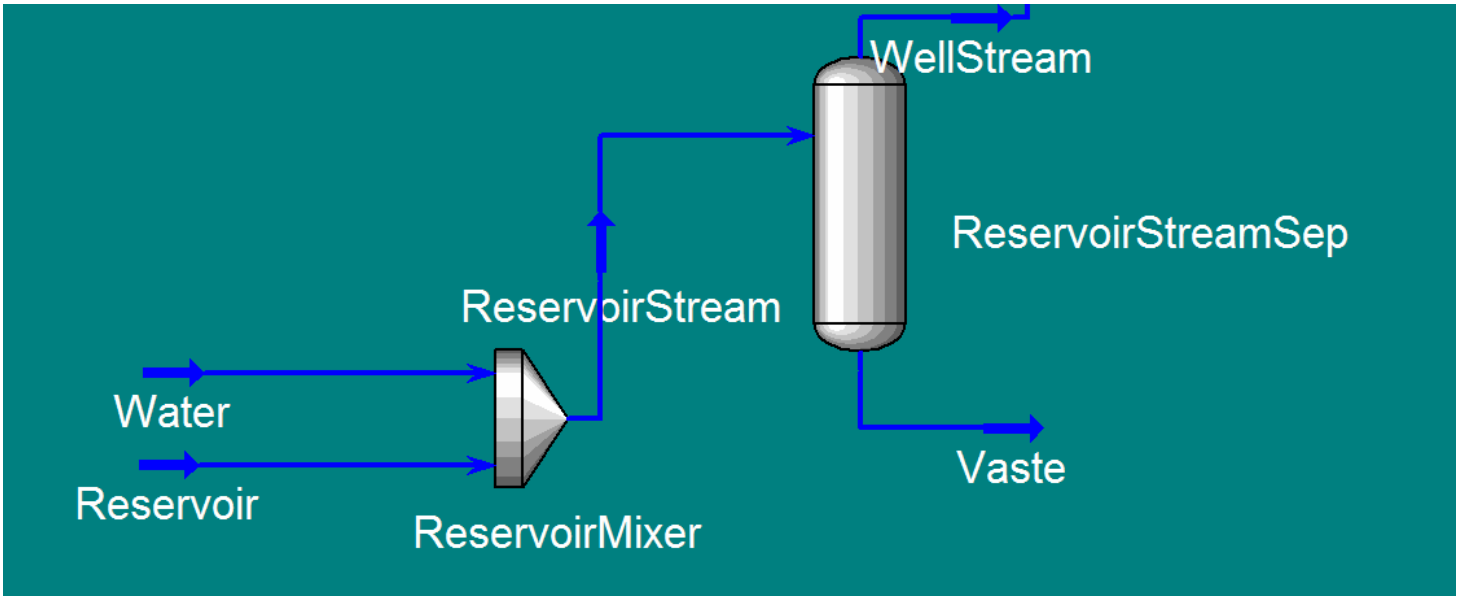


Figure 7 Shows how the reservoir gas is created in HYSYS [12]

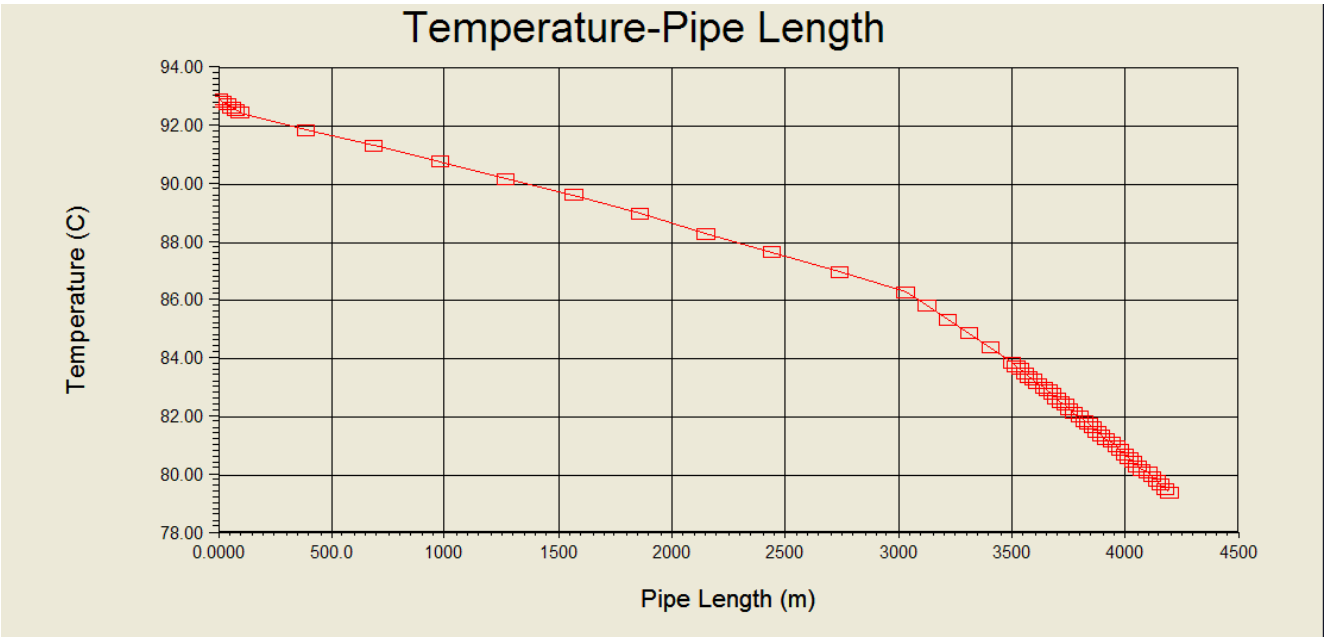


Figure 8 Shows how the temperature changes in the production wells

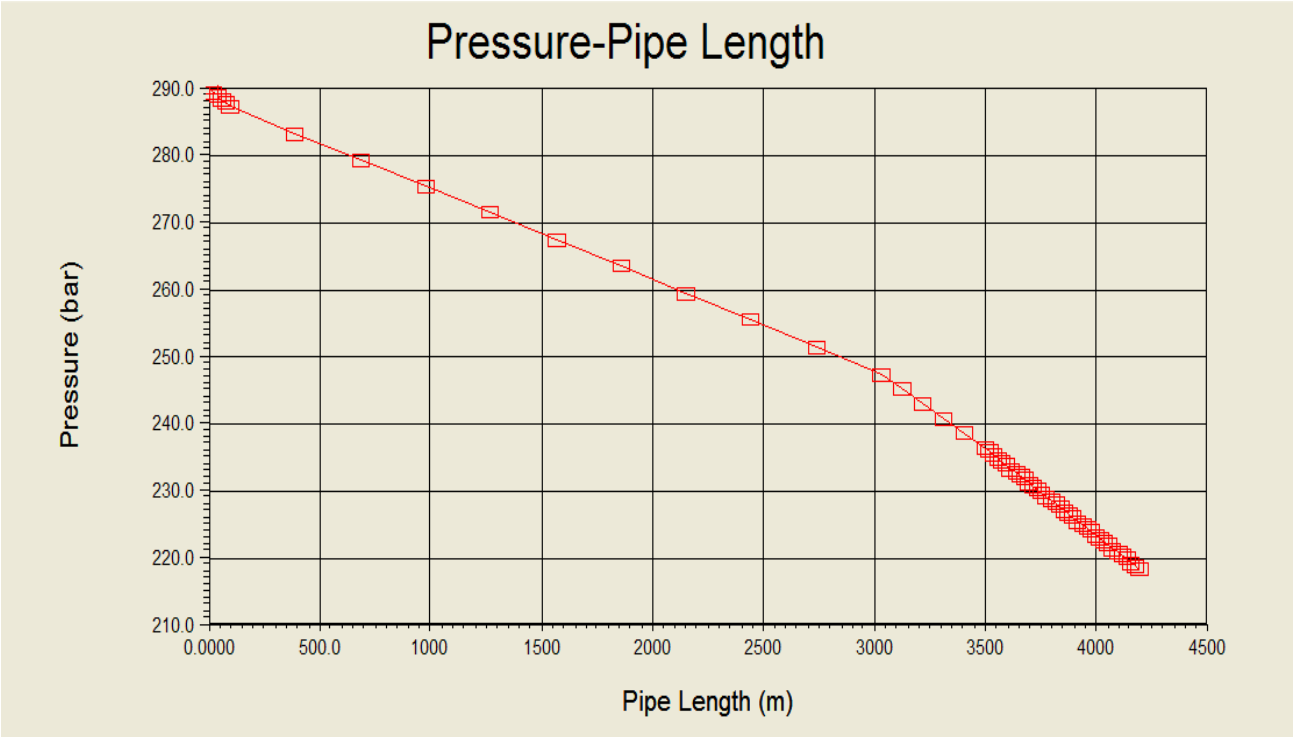


Figure 9 Shows the pressure drop in the 9 $^{5}/_{8}$'' wells

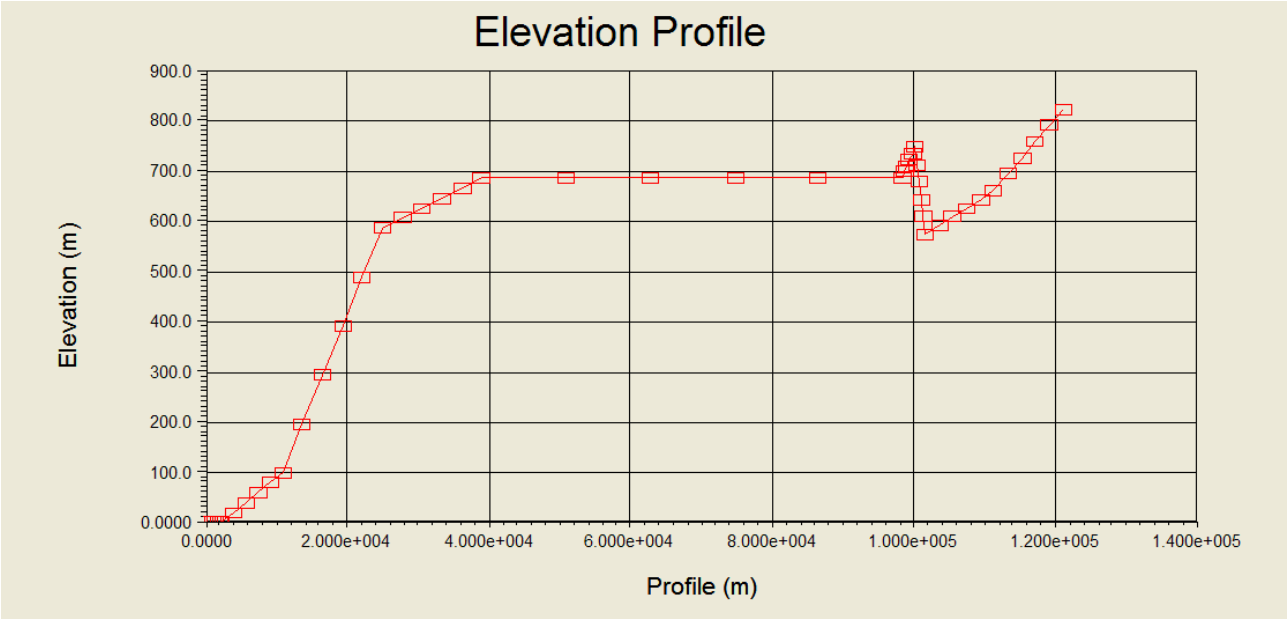


Figure 10 is a graphical display of the elevation profile to the multiphase pipeline [13]

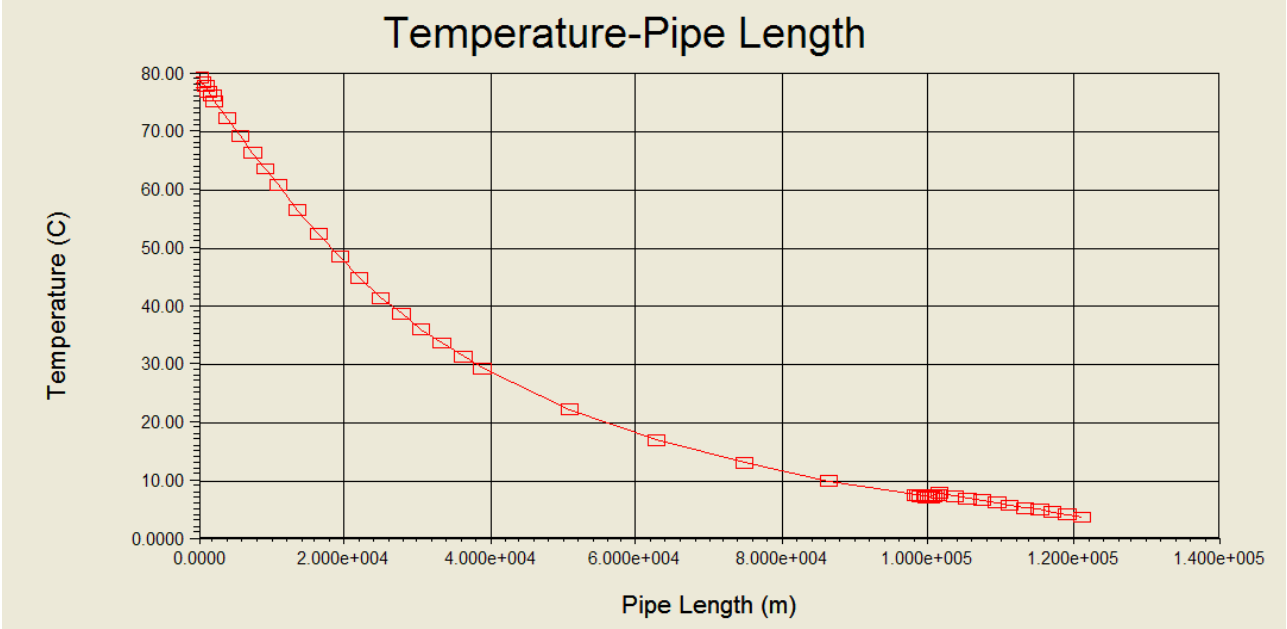


Figure 11 Shows how the temperature changes in the multiphase pipeline

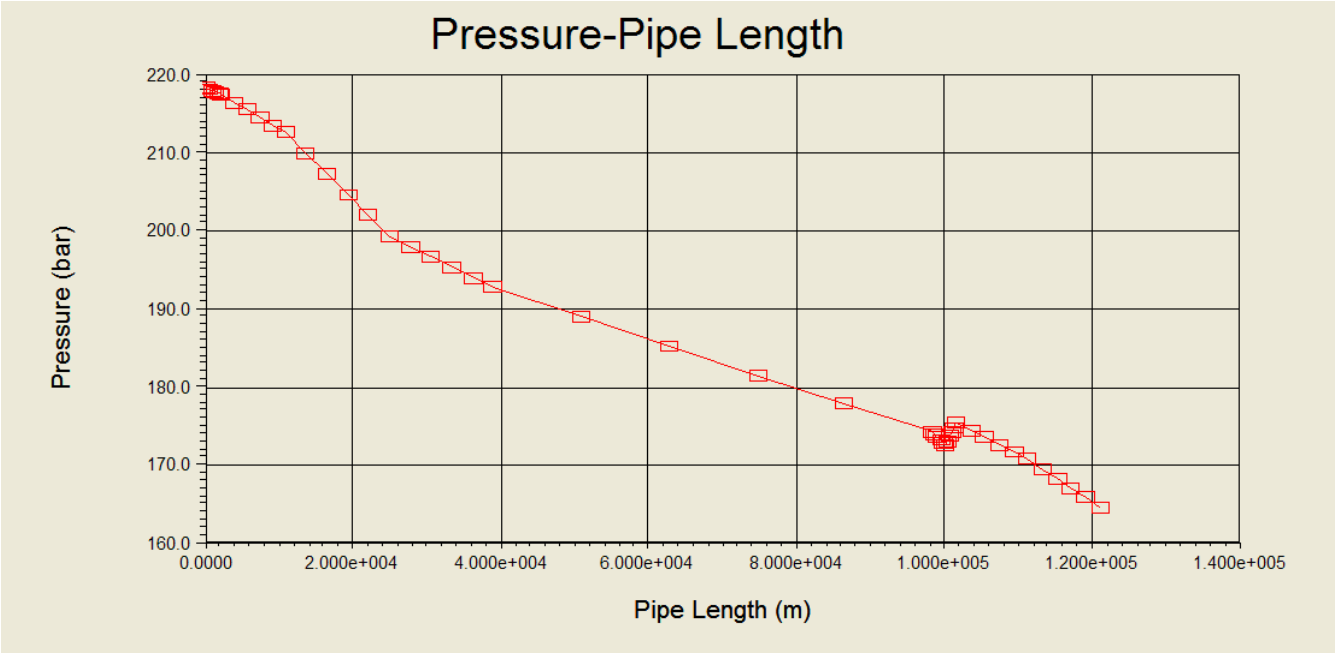


Figure 12 Displays how the pressure changes in the multiphase pipeline

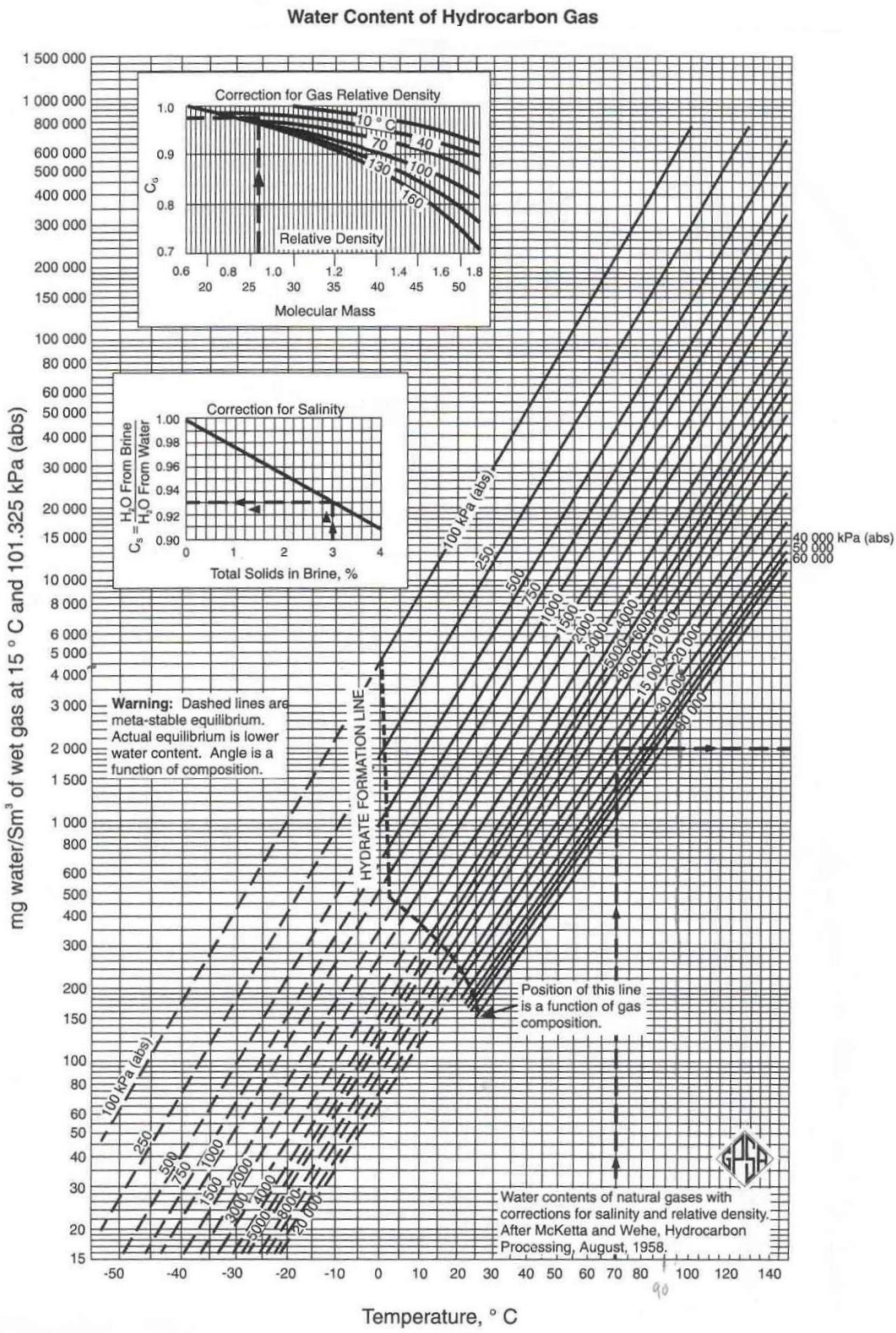
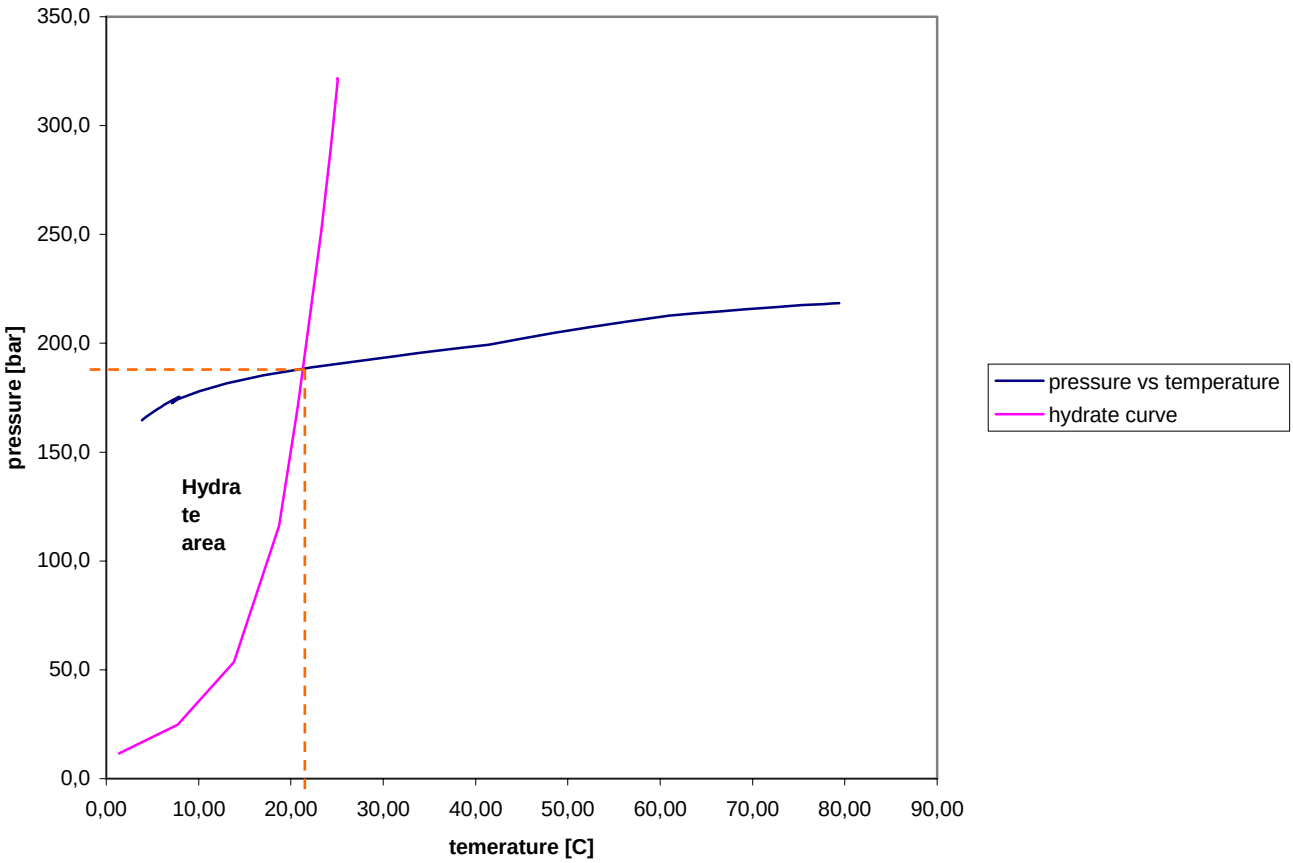


Figure 13 Water content of hydrocarbon gas [17]



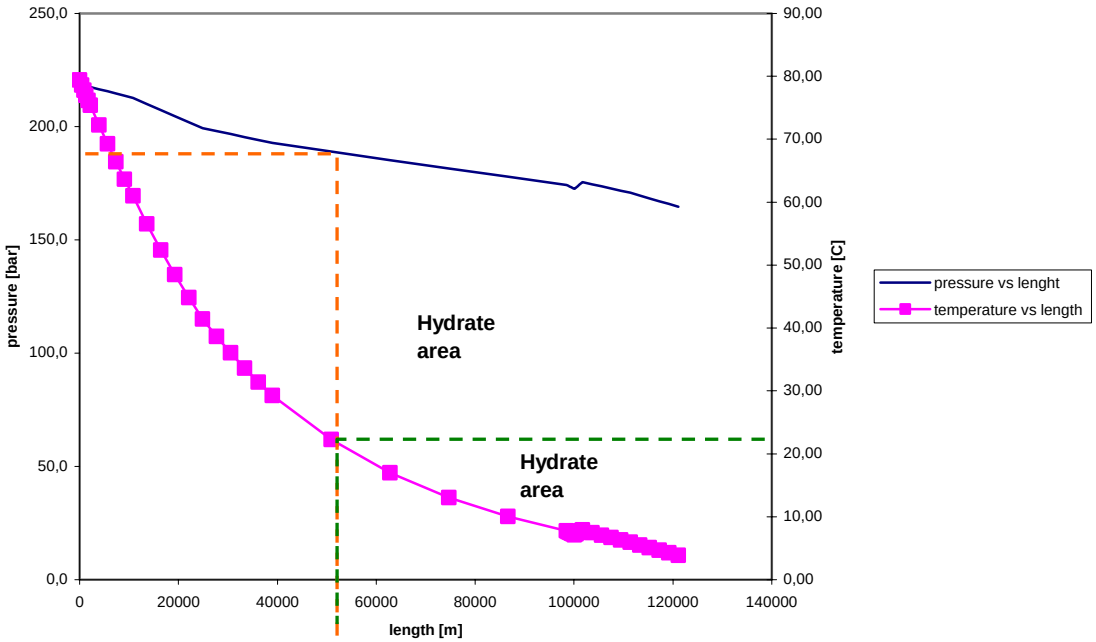


Figure 14 Shows the hydrate area of the multiphase pipeline without MEG injection

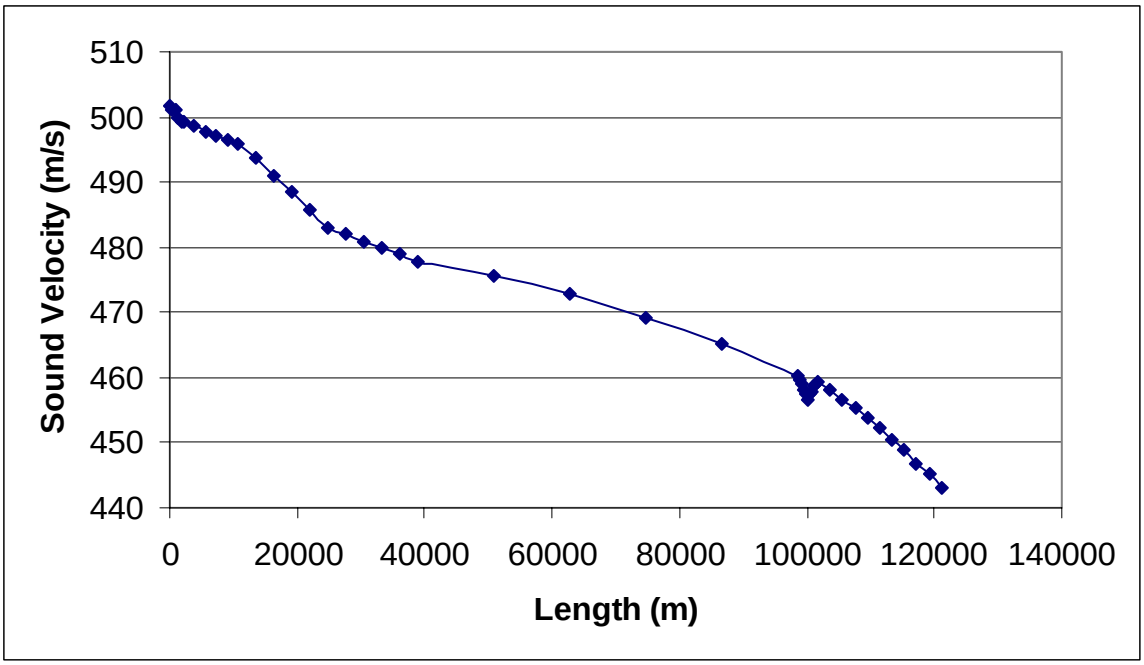


Figure 15 Sound velocity for case one, full production [14]

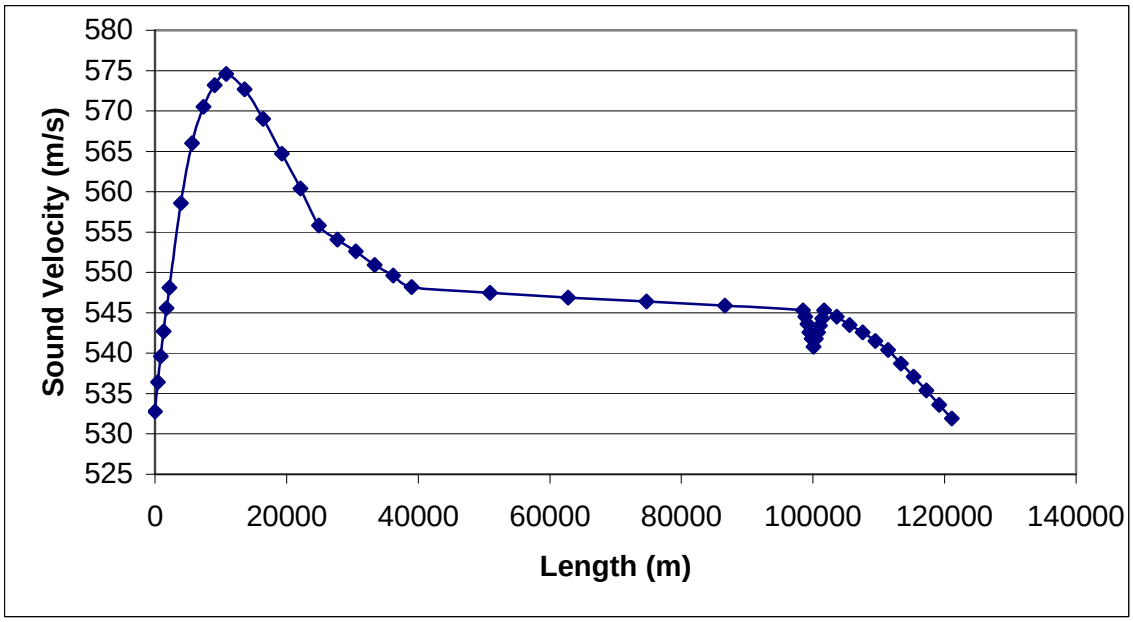


Figure 16 Sound velocity for case two, reduced production [14]

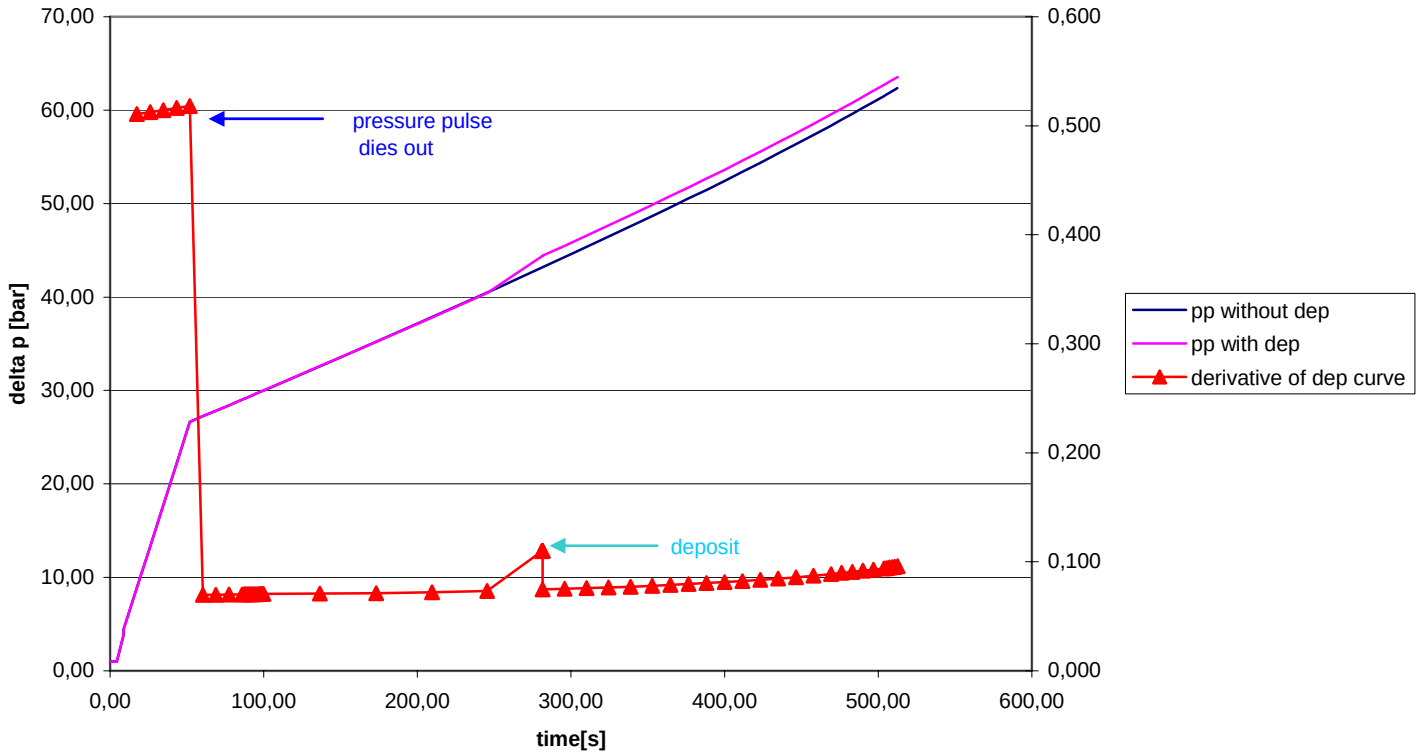


Figure 17 Pressure pulse at full production

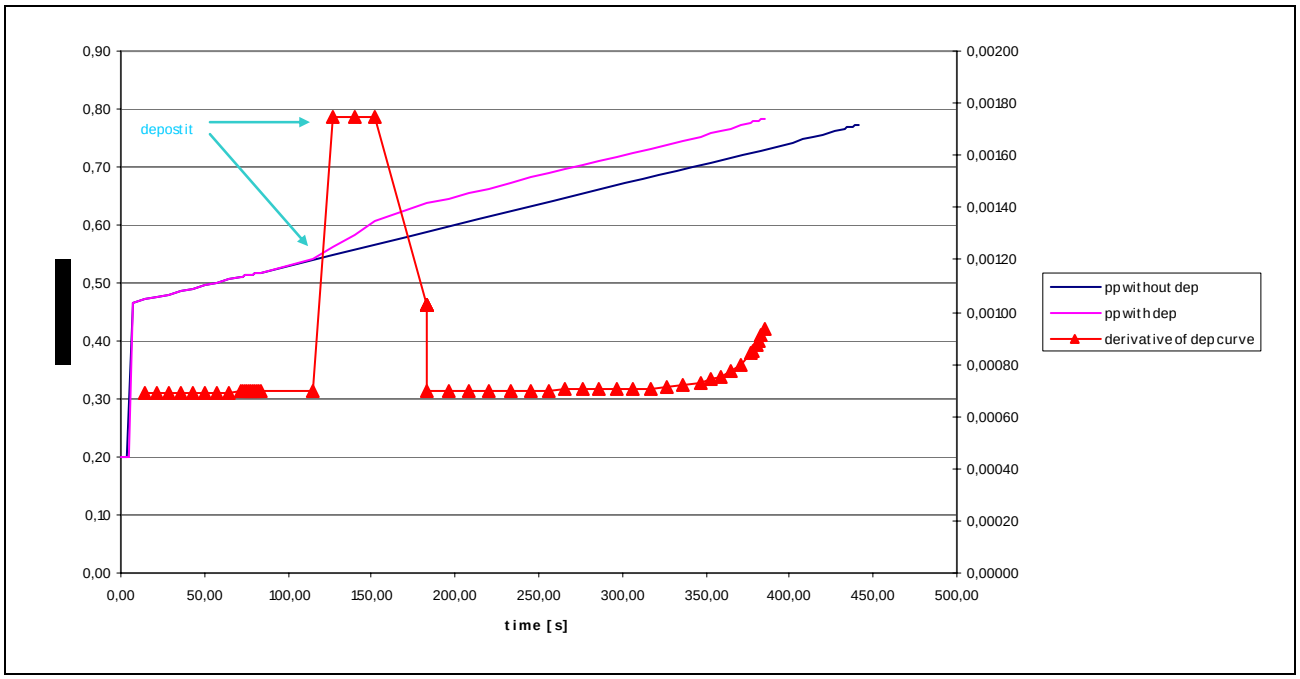


Figure 18 Pressure pulse with reduced flow

A. Calculations

a. Temperature Calculations

Surrounding temperature in the formation:

	Depth [m]	Temp [C]
Temperature @ sea level	900	-1,2
Temperature @	2700	86
Temperature @	2913	96

Temperature gradient 3 48,3C/km

Depth [m]	T_{amb} [C]
900	-1,2
1000	3,6
1100	8,4
1200	13,3
1300	18,1
1400	22,9
1500	27,8
1600	32,6
1700	37,4
1800	42,2
1900	47,1
2000	51,9
2100	56,7
2200	61,6
2300	66,4
2400	71,2
2500	76,1
2600	80,9
2700	85,7
2800	90,5
2900	95,4
2913	96,0

Temperature multiphase pipeline:

T surrounding	2,5 C
T inlet	80 C
U	11 W/(m2-C)
ID	690 mm
L	121,1 km
m	17,19 kmol/s
Cp	58,97 kJ/(kmol-K)
T outlet	7,0C

$$T_2 = T + (T_1 - T)\exp\left[\frac{-U\pi d}{mC_p}L\right]$$

$T \rightarrow$ Surrounding Temperature

$T_1 \rightarrow$ Inlet Temperature

$T_2 \rightarrow$ Outlet Temperature

b. Water amount

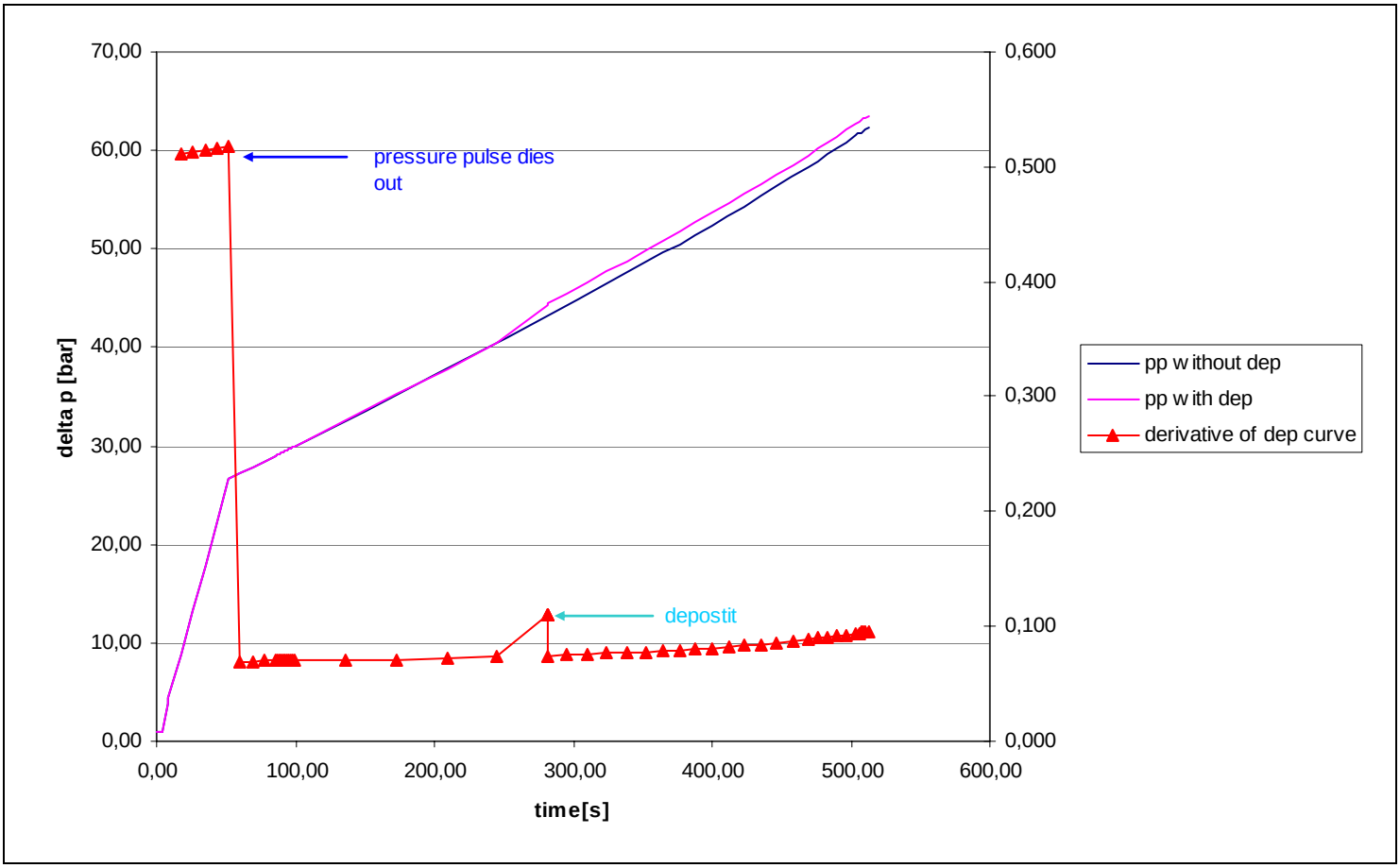
Amount of water from HYSYS	1,6kg/s	
Expected amount of water from graph from each well	3500mg water/Sm3 gas equivalent to	0,36kg/s
4 wells	1,43kg/s	
deviation of	11 %	

The simulation has a water amount which is 11 % higher than what is expected from the theoretical graph.

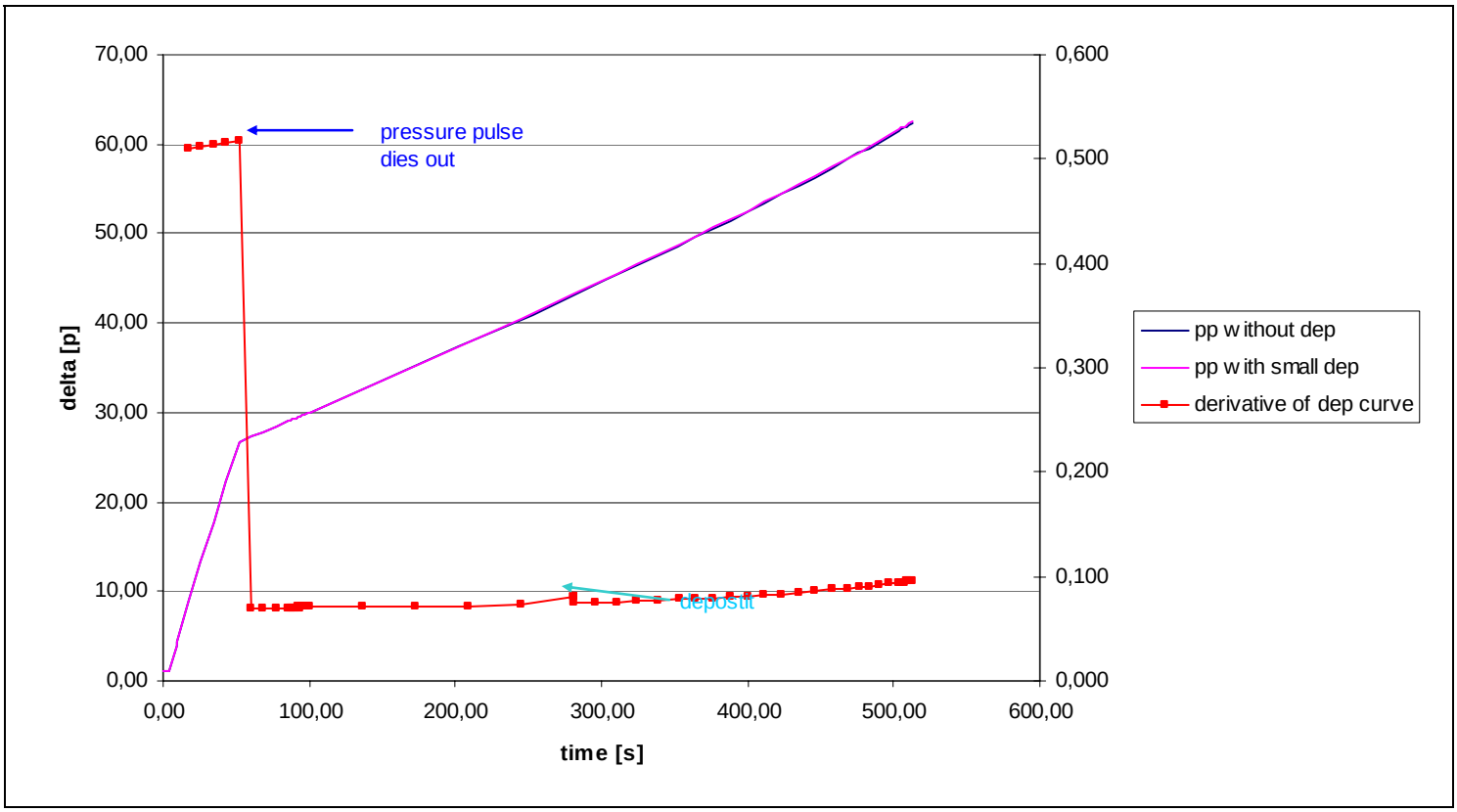
c. Pressure pulse

Calculations performed with HYSYS extracted data:

Normal flow:

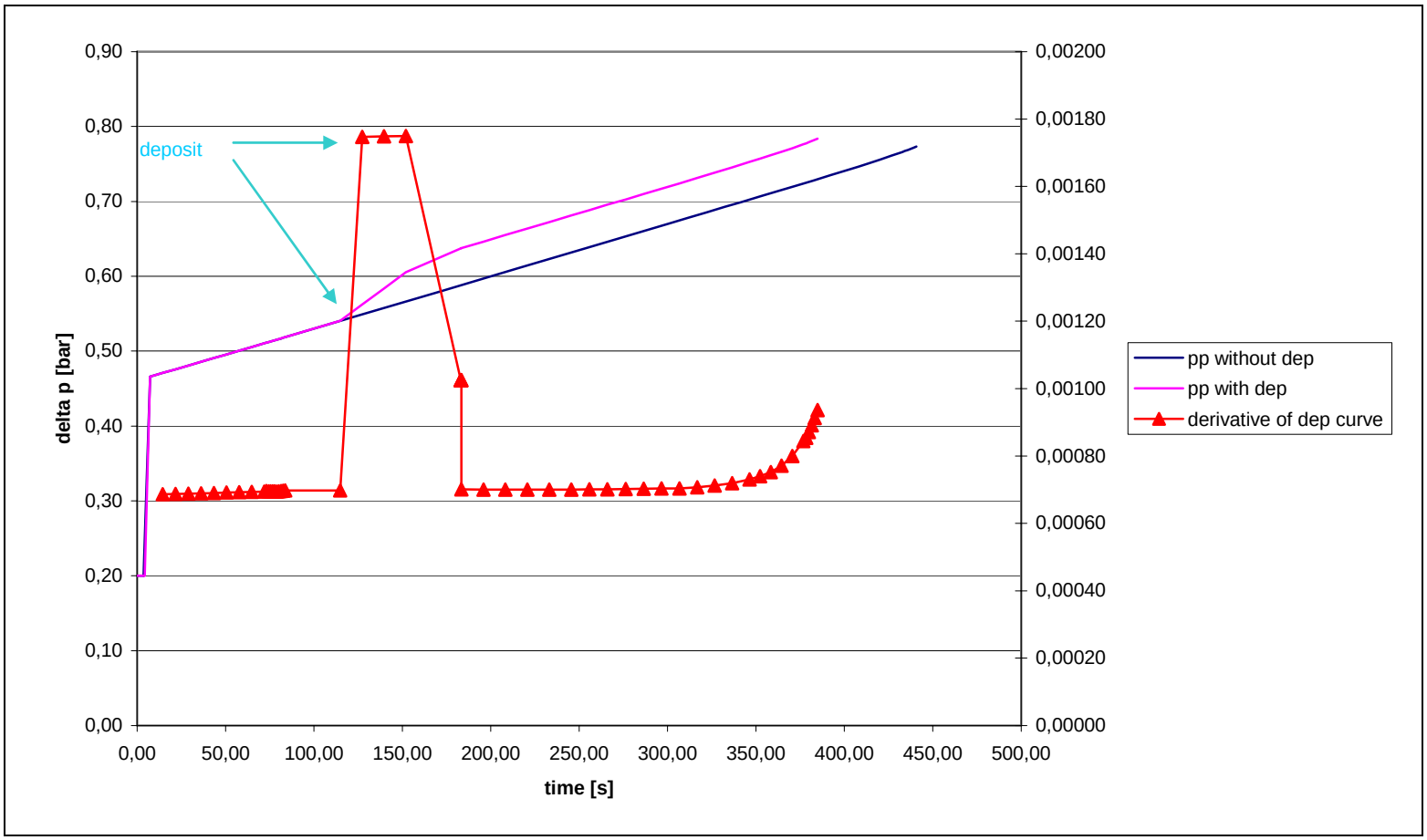


Pressure pulse with 50 mm deposit

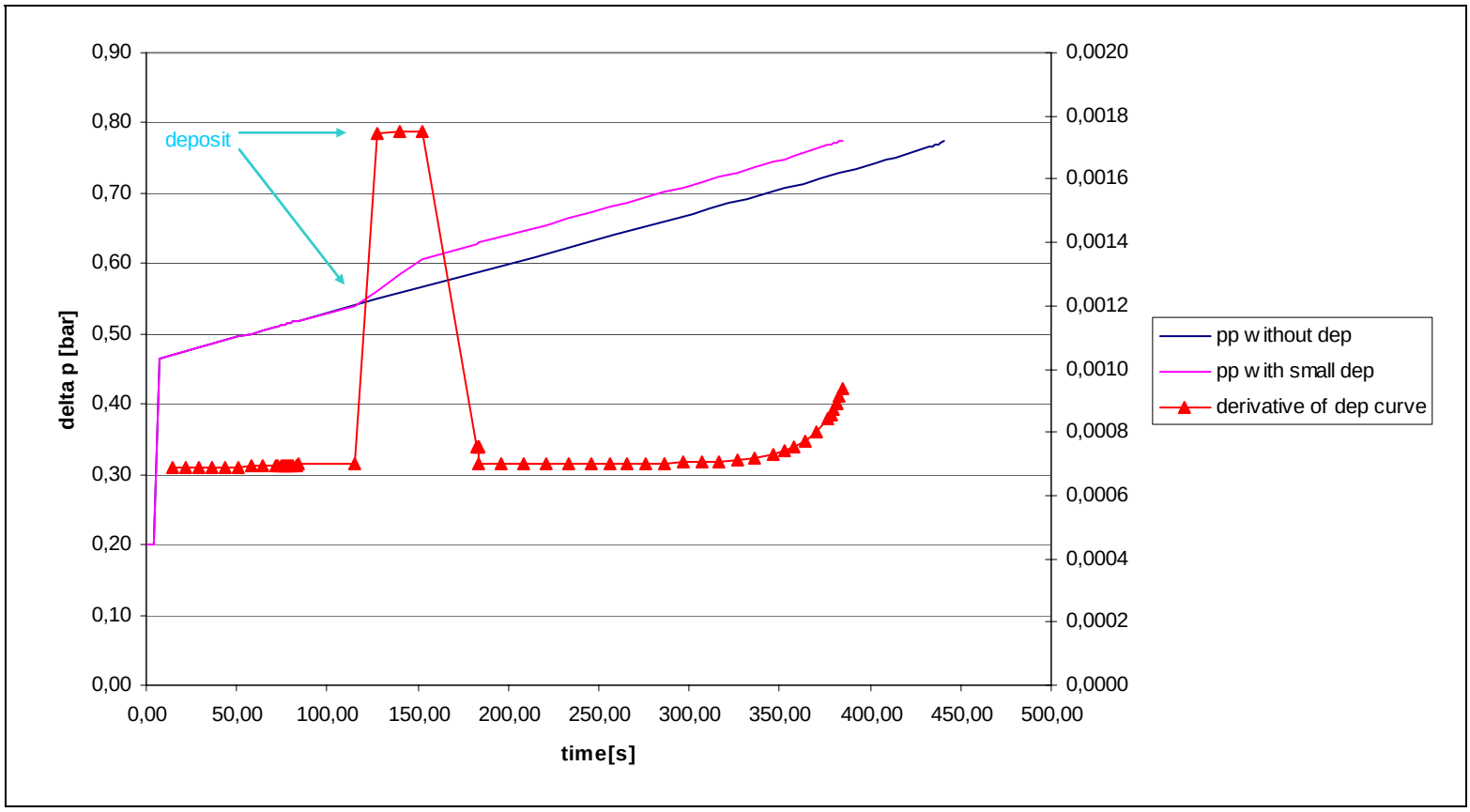


Pressure pulse with 10 mm deposit

90 % reduction in flow:



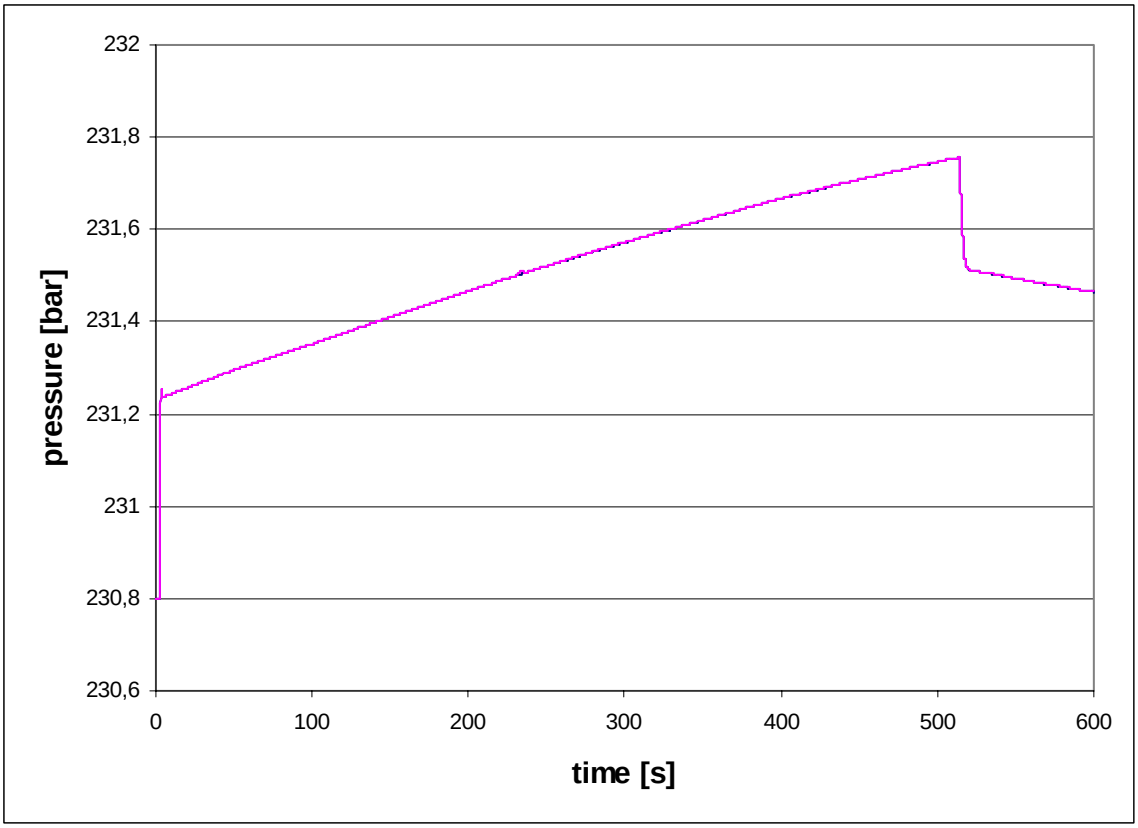
Pressure pulse with 50 mm deposit



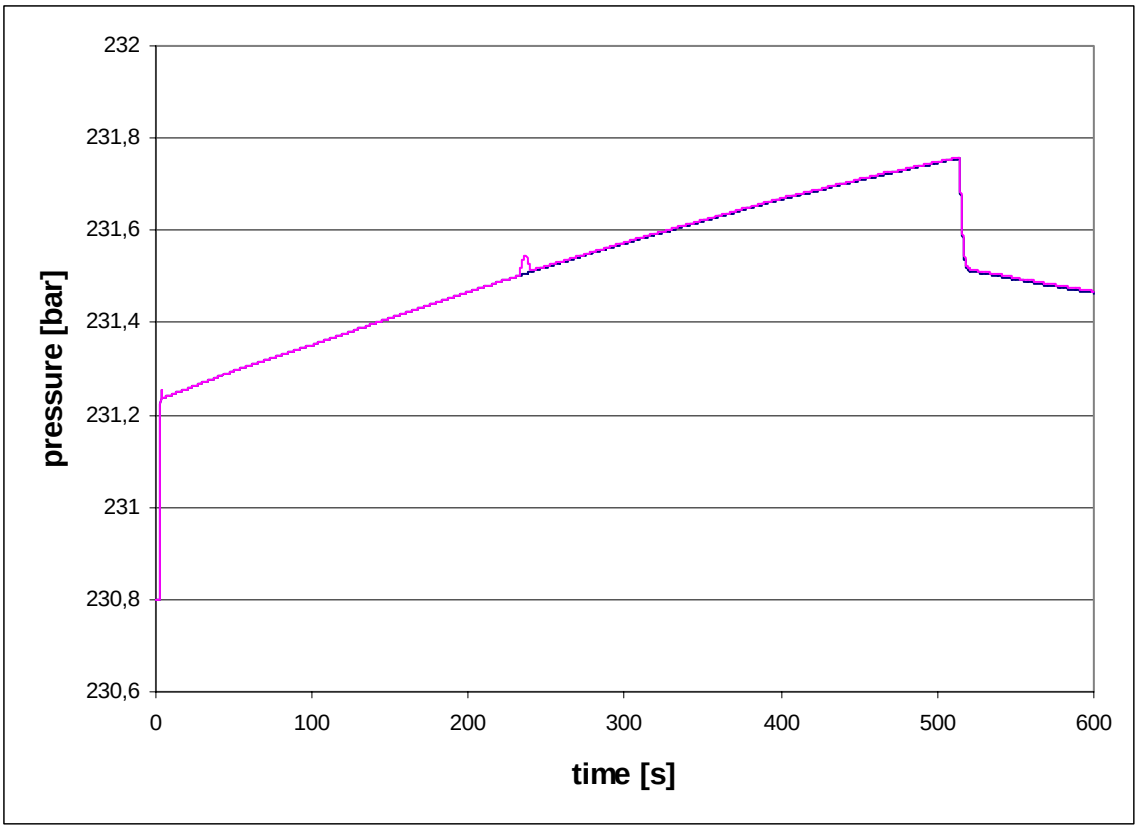
Pressure pulse with 10 mm deposit

Calculations performed with PPSim™:

<u>90 % reduction in flow:</u>



Pressure pulse with 100mm deposit, 100 metres long [15]



Pressure pulse with 100mm deposit, 1000 metres long [15]