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Pressure Transient Analysis as an Element of Permanent Reservoir Monitoring

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Abstract

Pressure transient analysis (PTA) is traditionally used to characterize well and reservoir parameters from well tests based on shut-in periods. PTA was widely used for reservoir management and decision making before reservoir simulation became the main tool. Presently more and more reservoirs are surveyed by permanent (downhole) gauges. These gauges provide vast amount of pressure transient and rate data which may be interpreted using improved PTA approaches to gain more knowledge on reservoir dynamics. This has opened new prospects for PTA applications in field studies.

Permanent pressure and rate measurements cover both well flowing and shut-in periods occurring during normal operations. These measurements allow for analysis of time-lapse pressure transients and comparative interpretation of flowing and shut-in periods. The analysis of time-lapse data provides time-dependent description of well-reservoir parameters. The comparative interpretation gives understanding of flowing reservoir properties which are often different from those estimated from well shut-in periods as in the classical PTA. These approaches provided basis for an improved methodology of interpreting permanent pressure measurements, where the scope of the standard PTA application may be extended to integrate new data sources.

Application of the developed methodology has been demonstrated with data from fields on the Norwegian Continental Shelf. For many wells the comparative interpretation revealed significant difference in well-reservoir parameters estimated from flowing and shut-in periods. It was also found that the flow regime near a well may vary. For example, the dominance of a hydraulic fracture observed during a shut-in period may be significantly reduced during the flowing period with simultaneous changes in reservoir conductivity. Dynamic behavior of natural and induced fractures due to pressure (stress) changes, wellbore cross-flows and variable contribution of reservoir layers are considered to be possible reasons for these effects. Analysis of time-lapse pressure transients provided description of long-term changes in well-reservoir parameters, e.g. reservoir conductivity, hydraulic fracture properties and boundary effects.

The key advantage of applying this methodology is characterization of the more representative flowing, rather than shut-in, well-reservoir parameters as well as their permanent monitoring during reservoir lifetime. The monitoring may reveal ongoing changes in the reservoir characteristics, production impairment risks etc. The methodology uses data readily available for many fields and provides an updated

description of well behavior and hydraulic reservoir properties. The reward may be improvement in everyday field operations and well performance optimization, reduced uncertainty of input to reservoir models and better decision making through enhanced model predictability.

Introduction

Installation of Permanent Downhole Gauges (PDGs) providing high quality pressure data for the whole well history is a good basis for gaining more knowledge about well and reservoir behavior comparing to well tests (Horne 2007). At the same time, interpretation of PDG measurements is challenging due to the vast amount of data, uncertainties with flow rates, well interference and dynamic changes of well and reservoir parameters. Horne (2007) has highlighted that although enormous amount of data now becomes available, there is a lack of interpretation techniques accounting for well conditions and reservoir properties changing with time that can deal with such data sets. Following the studies on PDG interpretation reviewed by Horne (2007), theoretical approaches were further developed (Zheng and Wang 2009, Kabir et al. 2012, Liu and Horne 2013) and many field applications were reported (BinAkresh and Rahman 2011, Stenger et al. 2011, Shuaili K. et al. 2012, Feitosa and Lucas 2012, Ugoala et al. 2013, Chang et al. 2014). While the PDG interpretation theory is under continuous development, the methods that are already available such as the classical PTA or recently progressed deconvolution method are widely applied to PDG data. It was reported that time-lapse fall-off testing of injection wells is an efficient approach to evaluate hydraulic fracture behavior (BinAkresh and Rahman 2011) including EOR applications (Shuaili K. et al. 2012), as well as to monitor well-reservoir parameters related to IOR (Stenger et al. 2011). A field example (Feitosa and Lucas 2012) has shown that interpretation of PDG data can help in estimating well and reservoir parameters, communication between wells and their evolution with time. In addition these estimates can improve history matching and predictability of reservoir models. Another example of a gas field (Ugoala et al. 2013) illustrated the value of time-lapse pressure build-up interpretations in evaluation of declining well productivity. The decline, in turn, was caused by compaction, increasing well skin-factor and multi-phase effects. Chang et al. (2014) used coupling PTA and PLT as an efficient way of estimating parameters of a multi-layer reservoir. A difference between conductivities of each layer of a multi-layer reservoir and conductivity of the whole reservoir estimated from PTA was found and analyzed.

In this paper, the methodology for time-lapse PTA is further developed and examples illustrating field applications on the Norwegian Continental Shelf are discussed. As a new feature of time-lapse interpretations, the necessity of analyzing both well flowing and shut-in pressure transients is substantiated. Integrating both types of pressure transients into analysis was suggested by Shchipanov et al. (2010) and further developed in this work. It is shown that estimates obtained for flowing and shut-in periods may be quite different. Ignoring well flowing periods may lead to misinterpretations and errors in estimates of well-reservoir parameters. Changes of these parameters with time are analyzed and possible reasons for these changes are presented.

A methodology of PDG interpretation focusing on both flowing and shut-in periods

Practical remarks on comparison of pressure transients and choosing a model

Comparison of different pressure transients is usually carried out based on plotting all the transients and derivatives on the same log-log plot. In practice a difference between time-lapse shut-in pressure transients does not necessarily indicate change in well-reservoir parameters, since such comparison is usually carried out for rate-normalized data with a chosen reference transient. The rate prior to the shut-in period of interest governs the pressure transient location on the log-log plot. An approximate value may be attributed to this rate due to averaging of flow data, while permanent (preferably downhole) rate

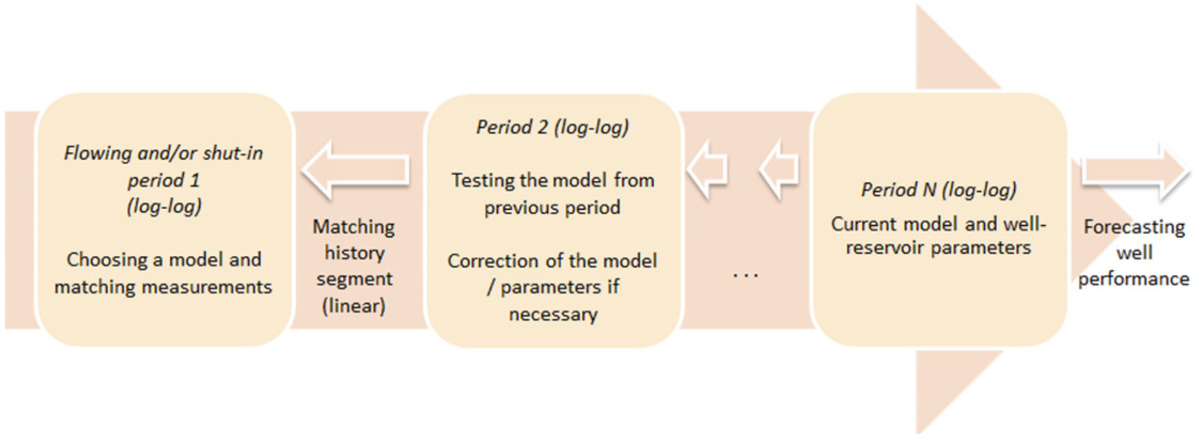

Figure 1—Workflow of the time-lapse pressure transient analysis.

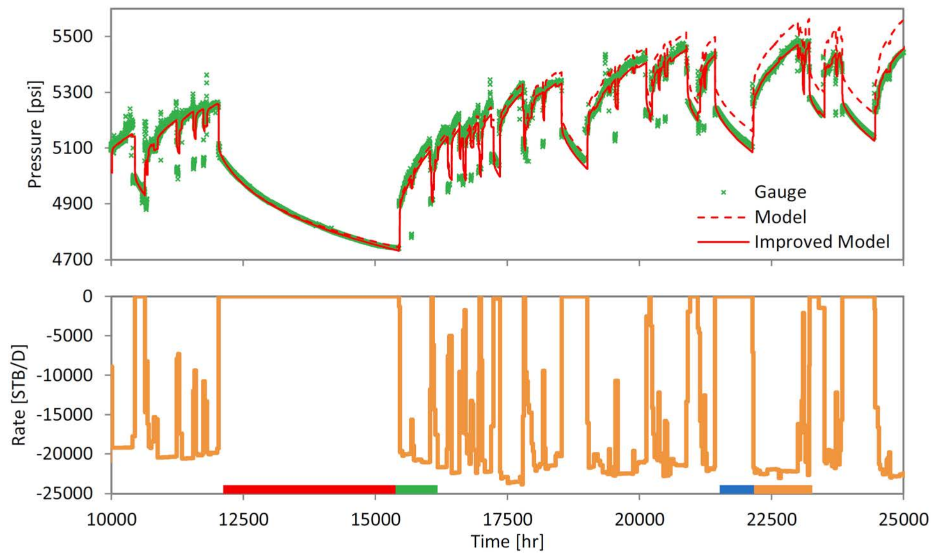

Figure 2—Injection history of well I-V with highlighted two pairs of sequential fall-off / injection periods (Fig. 3) and simulated pressure response with the model (Fig. 4).

measurements may help in reducing this uncertainty. Flowing pressure transients are usually normalized subject to variable rate during the flowing period. This makes comparison of these pressure transients more reliable.

Pressure derivatives are more representative in this sense, because well history prior to and during a pressure transient is accounted for via the superposition principle usually utilized for the derivative calculation (Bourdet 2002). At the same time, assuming radial flow as the main flow regime in the superposition calculation as well as averaging, cutting or possible errors in rate history prior to the pressure transient of interest may have an impact on the derivative trend, especially for late elapsed times and interpreting boundary effects. Simulation of the well history in the linear scale with the analytical model used for the pressure and derivative interpretations in the log-log scale improves reliability of the analysis. The simulated pressure response may help in evaluating the impact of superposition effects and in revealing changes in well-reservoir parameters. All described above leads to the conclusion that comparison of time-lapse pressure transients and derivatives may be used for diagnostics of changes in well-reservoir parameters, while only simulation of the well history or at least a part of the history would provide reliable conclusions on such changes.

Choosing a proper model to describe wellbore and well, reservoir and boundaries is crucial for the following analysis and forecasting as well as drawing conclusions. Suggestions for choosing relevant

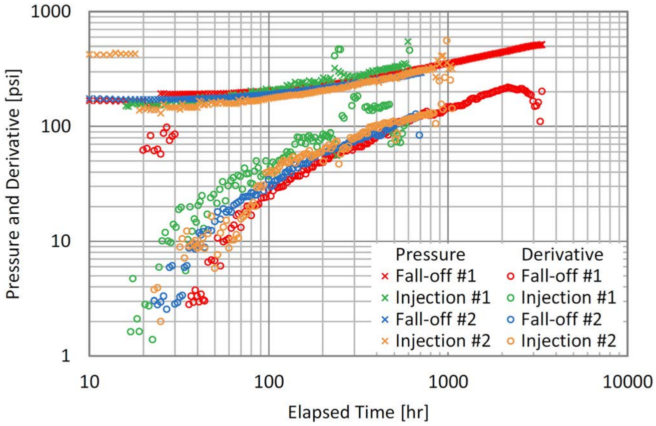

Figure 3—Pressure and derivative transients of time-lapse fall-off and injection periods observed in history of well I-V (Fig. 2).

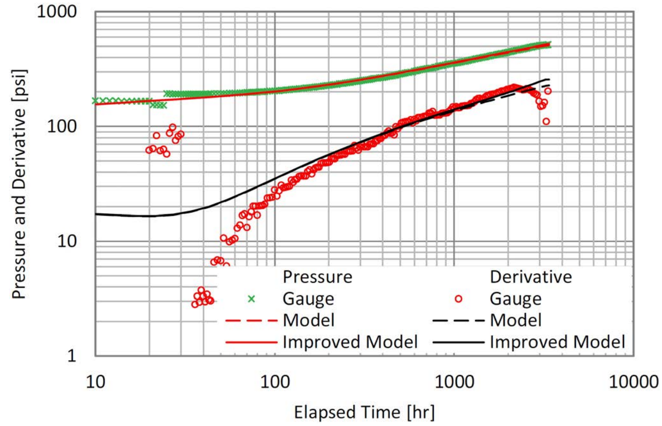

Figure 4—Pressure and derivative transients (gauge) and simulated response ('Model' and 'Improved Model') for the first pressure fall-off (Fig. 3).

model are well formulated in the literature (Bourdet 2002, Houze et al. 2011). The usual practice is that the chosen model should represent basic well and reservoir features which are known before the analysis, such as well type, reference fluid and stimulation performed, well environment including neighbor wells and faults. It should be noted that the same well may be described with different models, e.g. a hydraulic fracture may be modeled explicitly or implicitly via negative skin-factor. The same takes place for modeling reservoir and boundaries. Model refinement is usually governed by objectives and time limits of a study, while multi-model approach or testing and comparison of different models seems to be the most reliable way.

Comparison of time-lapse pressure and derivative transients

As a first stage of the analysis, time-lapse pressure and derivative transients may be extracted and plotted on the same log-log plot. Separate plots for well flowing and shut-in pressure transients are suggested, since these two types of transients may follow different trends. Comparison of time-lapse transients may serve as a first indicator of changes in well-reservoir parameters. Using the superposition principle for derivative calculations in combination with possible impact of dynamic boundary effects (e.g. neighbor wells) may lead to deviation of the pressure and derivative transients from each other. This means that the comparative analysis of time-lapse responses may be considered only as a preliminary diagnostics of changes in well-reservoir parameters.

Analysis of time-lapse responses focusing on both well flowing and shut-in periods

A second stage of the analysis is a step-by-step interpretation of each pressure transient or pair of transients (flowing and closest shut-in) according to historical data (Fig. 1). The value of comparison and interpretation of both flowing and shut-in transients was confirmed by Shchipanov et al. (2010) for the case of fractured reservoir. In general, a difference between flowing and shut-in responses may be related to many effects, e.g. opening / closure of natural and induced fractures, cross-flows observed during well shut-ins, boundary effects (e.g. impact of neighbor wells) etc. Starting from the first analyzable period of the well history, or even better from a flowing / shut-in pair, pressure transient analysis is carried out in the log-log scale. First, the shut-in response may be used for matching pressure and derivative with a chosen model, since this response is usually less noisy with clear indications of flow regimes. The model is further tested to be capable of matching the well flowing response. Modifications of the model parameters, or even the model itself may be necessary to fit the response. For example, in some cases an interference with a neighbor well may be interpreted from a flowing pressure derivative, while this is difficult to see from the shut-in derivative.

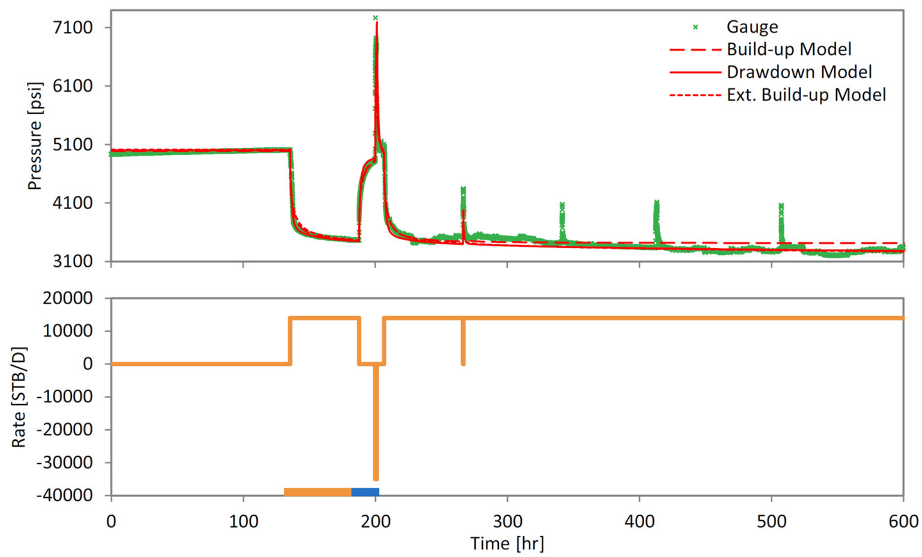

Figure 5—Segment of production history of well P-V with sequential production and shut-in periods (Fig. 6) and simulated pressure responses with the models (Fig. 7 and 8).

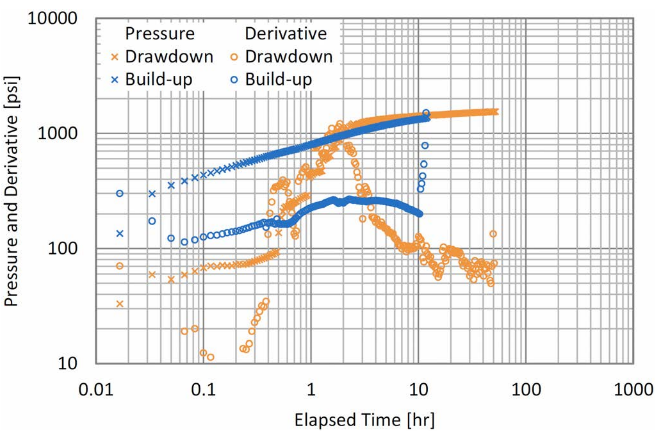

Figure 6—Pressure and derivative transients for sequential production and shut-in periods observed in history of well PV (Fig. 5).

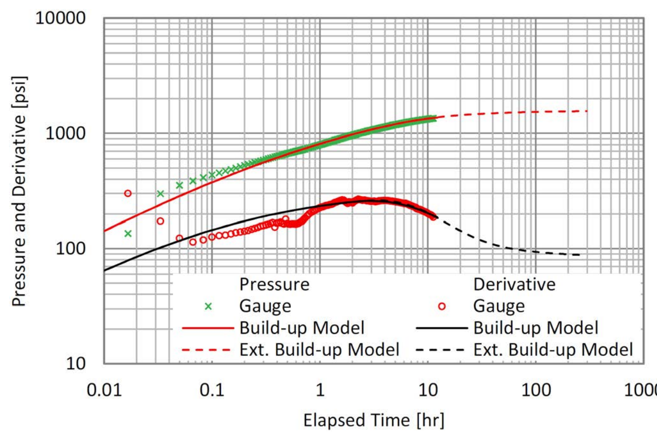

Figure 7—Pressure build-up and derivative (Gauge, from Fig. 6) and two simulated responses ('Build-up Model' and 'Ext. Build-up Model').

If the chosen model provides reasonable match of at least the flowing response, an attempt to match the well history (in the linear scale), or its segment, prior to the analyzed pressure transient may be made. Ideally the model should provide reasonable match of the whole well history. In practice, reasonable match may often be achieved only for the limited history segment containing the pressure transient of interest, while changes in well-reservoir parameters and presence of boundary effects varying with time may lead to deviations of the model response from the measurements. Nevertheless, matching of the well history segment containing both flowing and shut-in periods is necessary to get confidence in the chosen model and parameters.

Furthermore the model is tested for capability of reproducing next pressure transients chosen in the well history and modifications of the model parameters and probably the model itself may be performed. This step-by-step interpretation would result in a set of well-reservoir parameters changing with time (Fig. 1) providing history of such changes and the current status of these parameters, which is of special interest for well performance predictions. Possible reasons for these changes may be further analyzed, e.g. well

Table 1—Features of the analytical models utilized in interpretation of the pressure drawdown and build-up responses of well P-V (Fig. 7-9) and estimated parameters.

		Build-up	Drawdown	Ext. Build-up	Build-up
Model		Analyzed period			Previous
Reservoir		Homogeneous	Homogeneous	Composite	Composite
Boundary		One fault	Infinite	Infinite	Infinite
Parameter	Unit				
Total well skin (S_T)	dimless	-3.6	2.8	-3.6	-3.4
Conductivity (Inner, kh_1)	mD.ft	2000	7500	2000	2300
Conductivity (Outer, kh_2)	mD.ft	2000	7500	6700	5000

stimulations and treatments, evolution of bottom hole and reservoir pressure may be considered as driving factors.

It should be noticed that, due to the nature of the inverse problem, a fairly good match could often be achieved even under wrong concept or non-representative model. Analysis of available data on features and behavior of well and reservoir in the focus may help in choosing a relevant model, while multiple models provide assessment of the uncertainty usually present with any well.

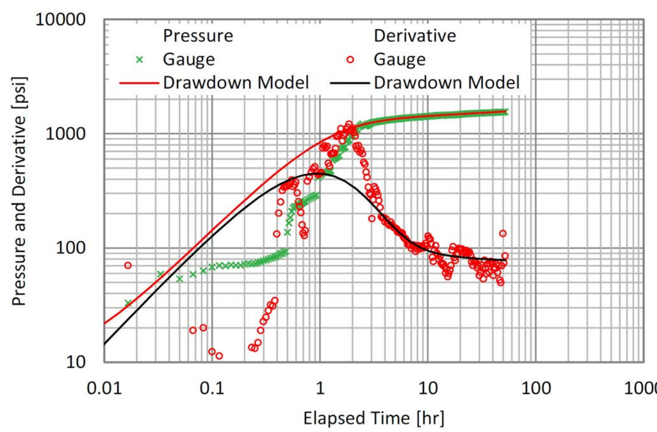

Figure 8—Pressure drawdown and derivative (Gauge, from Fig. 6) and simulated response ('Drawdown Model').

Application of interpretation results

The analytical or simplified numerical models applied in the interpretation process may be further used for prediction of well performance and behavior under different scenarios (Fig. 1). The models may be particularly useful for simulating short forecast scenarios, sensitivity studies and uncertainty analysis. The time-lapse PTA also provides additional input for reservoir simulation. Well connectivity and reservoir properties are reported as time- or pressure-dependent variables and may be directly used in reservoir models improving history matching and prediction capabilities of the numerical models.

The next section presents examples of application of this methodology to field data. Installation of PDGs at fields on the Norwegian Continental Shelf provided a good basis for application and further development of the methodology.

Field cases

Three field cases are presented to illustrate application of the methodology. The first case is a good example of classical PTA working perfectly, providing reliable estimation of well-reservoir parameters from a single well shut-in or flowing response. The second example shows the value of interpreting both flowing and shut-in responses with the advantage of using multiple shut-in pressure transients. The third and most complicated example illustrates all sides and advantages of the methodology applied.

An example of a single well injecting carbon dioxide into a saline aquifer

Injection of CO_2 into a saline aquifer is a good arena for efficient PTA application, especially if a single well starts to inject into a formation without earlier production / injection history. Advantages of using PTA in such a case are rather obvious. The CO2 plume remains near the injector for some period that is often confirmed by 4D seismic interpretations. In this case transient pressure response is mainly governed by the aquifer properties, similar to a composite reservoir with small area near the well. Low total

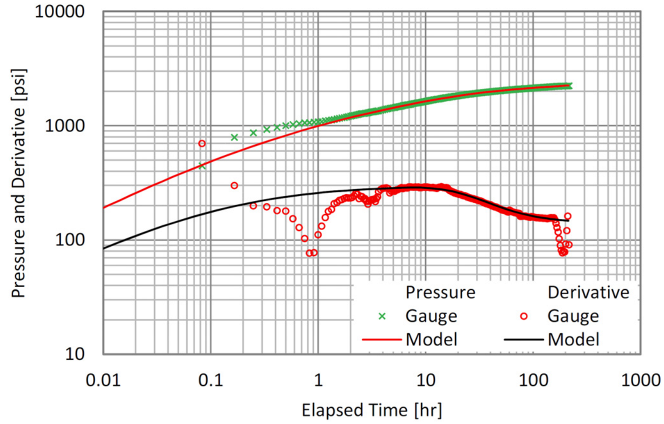

Figure 9—Pressure build-up and derivative (one year before the analyzed history segment, Fig. 5) confirming the extended build-up model (Fig. 7).

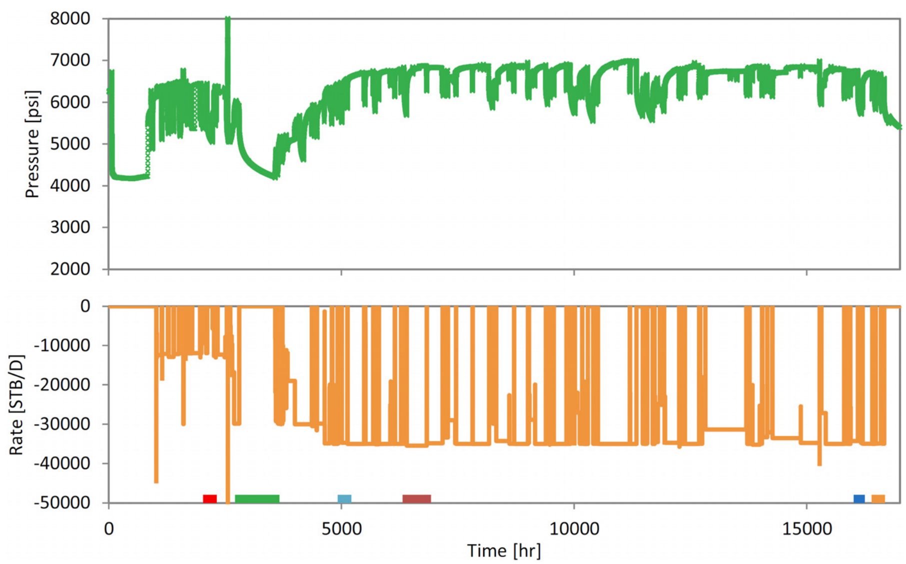

Figure 10—Injection history of well I-H with sequential pressure fall-off (Fig. 11) and injection (Fig. 12) periods.

compressibility leads to fast pressure evolution in the injection site, approaching boundaries like faults, while testing the first injector drilled in an aquifer provides pure in-situ reservoir response, not disturbed by other wells.

Application of the time-lapse PTA methodology may be illustrated with the data from a vertical CO2 injector which is referenced to as ‘well I-V’ (Fig. 2-4). This injector was drilled in a fault block confined by faults on three sides. The injection history segment (Fig. 2) contains two pairs of sequential fall-off / injection periods (Fig. 3). The flowing pressure responses are noisy comparing to the shut-in responses, but all follow the same trend indicting rather small difference between all the responses. The longest fall-off response was used as a reference for the interpretation (Fig. 4). The analytical model used in the interpretation was that of a vertical well with skin (accounting for CO2 plume around the well) in a reservoir confined by faults on three sides (U-shaped).

The interpretation confirmed that the faults were sealing (Fig. 4). Matching any of the pressure derivative trends of both the shut-in and the flowing periods (Fig. 3, except noisy derivative of injection #1) would result in such a conclusion. In other words, the short pressure transients (fall-off #2 and injection #2) indicate sealing boundary conditions. A hint on possibility of a distant constant pressure boundary (e.g. pressure backing from a neighbor reservoir block) may be found in the late response of the

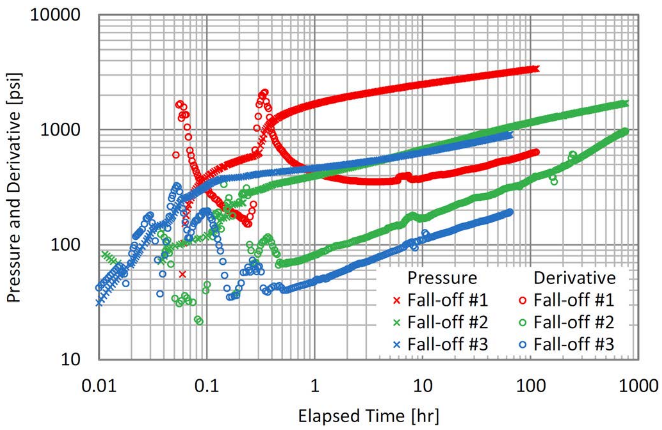

Figure 11—Time-lapse fall-off responses (pressure and derivative) observed in history of well I-H (Fig. 10).

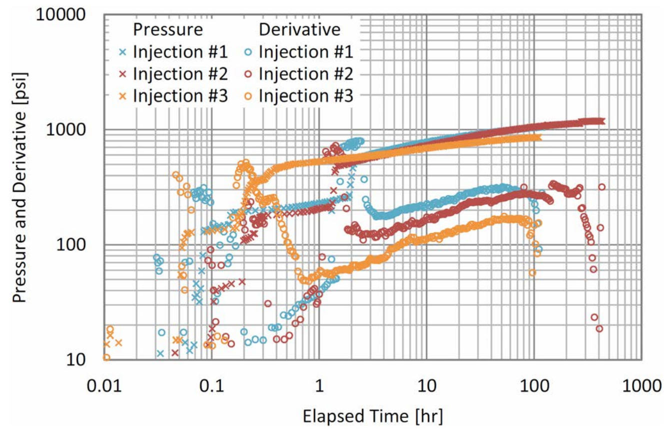

Figure 12—Time-lapse injection responses (pressure and derivative) observed in history of well I-H (Fig. 10).

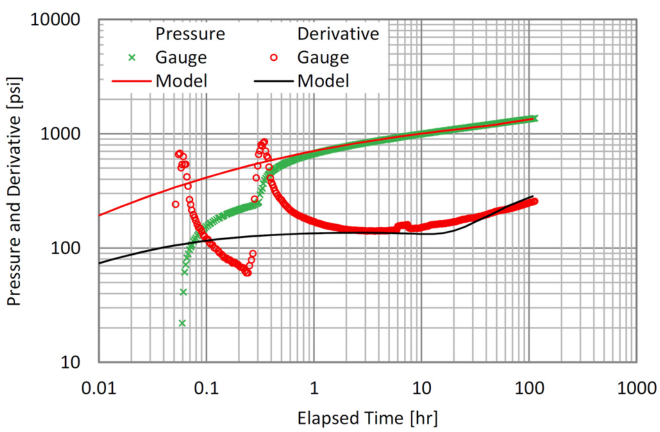

Figure 13—Pressure response interpretation, fall-off #1 (Fig. 11).

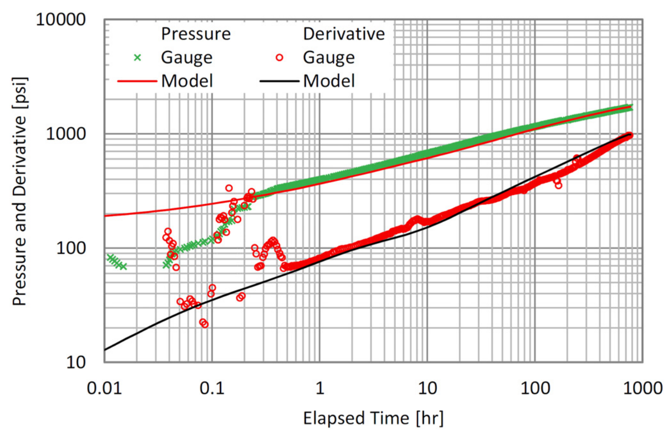

Figure 14—Pressure response interpretation with the detailed model, fall-off #2 (Fig. 11).

long fall-off #1 (Fig. 3, 4). The model fitting the pressure responses from these three periods (dash-line 'Model', Fig. 4) may be improved using this hint (solid-line 'Improved Model', Fig. 4). Introducing such a distant boundary resulted in better match of the historical data (Fig. 2). At the same time, it was difficult to reproduce this boundary effect in the pressure derivative trend (Fig. 4). Bringing the boundary closer to the well, thereby improving the match in the log-log scale (the derivative) led to some mismatch in the linear scale (the history), that may be related to the limitations of the simplified model used for this analysis.

This example is a good illustration of the cases, where well-reservoir parameters remain nearly invariable with time which is often assumed in the classical PTA. Nevertheless such a conclusion should be generally verified via plotting and comparing both flowing and shut-in pressure transients and derivatives as well as reproducing history on the model. As a practical result of the aquifer characterization, even interpretation of the short pressure transients (Fig. 2, 3) gave reasonable evaluation of the potential site capacity and prediction of the injection performance with a small error (about 7%) in pressure build-up forecast. On the other hand, if sealing boundary configuration and distances to a well are known (e.g. from interpretation of seismic data), this knowledge may be used for improving estimation of total compressibility, which is one of the governing factors in evaluating injection site capacity.

A vertical well with commingled oil production from a two-layer reservoir

An oil producer ('well P-V' in the figures and table below) was perforated in two reservoir layers with different properties and reservoir pressure dynamics governed by injection and production of neighbor

Table 2—Well-reservoir parameters estimated for three sequential shut-in and the last injection periods, well I-H (Fig. 13-16, 19).

Parameter	Unit	Fall-off #1	Fall-off #2	Fall-off #3	Injection #3
All models		Pre-	Post-Stimulation		
Boundary		Infinite	Infinite	Infinite	Producer
Conductivity (kh)	mD.ft	120	200	550	700
Model with skin					
Total well skin ($S_T = S_g + S_f$)	dimless	-8.06	-8.23	-8.1	-8.02
Geometrical skin (S_g)	dimless	-7.92	-7.92	-7.92	-7.92
Skin due to induced fractures (S_f)	dimless	-0.14	-0.31	-0.18	-0.1
Horizontal well skin ($S(H_f)$)	dimless	-2.1	-4.7	-2.8	-1.6
Model with fractures and skin					
Total well skin (S_T)	dimless		-8.22	-8.09	
Number of fractures			18	18	
Fracture half-length (X_f)	ft		40	40	
Fracture height (H_f)	ft		200	160	
Fracture skin (S_f)	dimless		0.02	0.13	

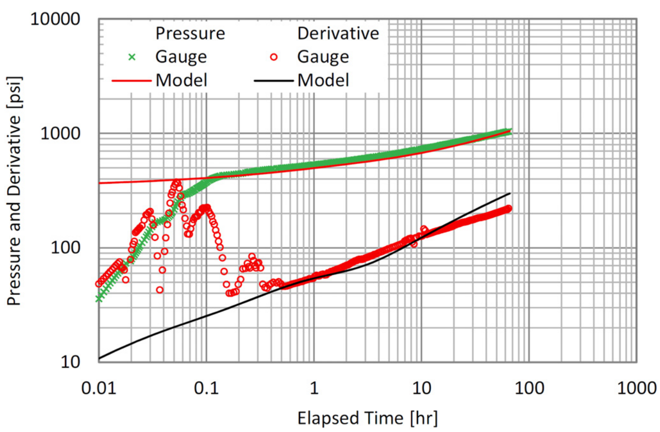

Figure 15—Pressure response interpretation with the detailed model, fall-off #3 (Fig. 11).

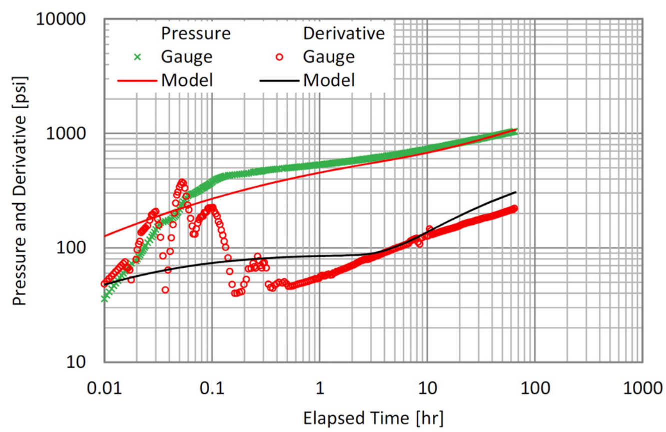

Figure 16—Pressure response interpretation with the simple model, fall-off #3 (Fig. 11).

wells. Production logging confirmed intensive cross-flows between the layers through the wellbore during well shut-in. The analyzed segment of the well history (Fig. 5) contains sequential production and shut-in periods. Pressure transients and derivatives were found to be quite different for the flowing and shut-in periods (Fig. 6). A smooth derivative curve may be calculated from the pressure build-up response (Fig. 6) and well-reservoir parameters estimated from this curve provided reasonable match of the measurements in both log-log (Fig. 7) and linear (Fig. 5) scales. The late build-up derivative response (Fig. 7) may be interpreted as an effect of a constant pressure boundary (Table 1). At the same time, the drawdown period is longer and the drawdown pressure derivative seems to have a transition to late radial flow, while pressure boundary effect is not observed (Fig. 6). Interpretation of the drawdown response (Fig. 8) resulted in higher reservoir conductivity (Table 1), which provided reasonable match of both the pressure transient (Fig. 8) and the history segment (Fig. 5). Analysis of the drawdown derivative helped to modify the initial build-up model by assuming composite reservoir with inner and outer areas of different conductivity ('extended build-up' model in Fig. 7).

All three models: 'build-up', 'drawdown' and 'extended build-up' provided reasonable match of the transient responses and the history segment (Fig. 5). However, the first and third models are quite different in terms of outer reservoir description. This is a good example of ill-posed inverse problem having an infinite number of possible solutions providing reasonable match of measurements. Another build-up

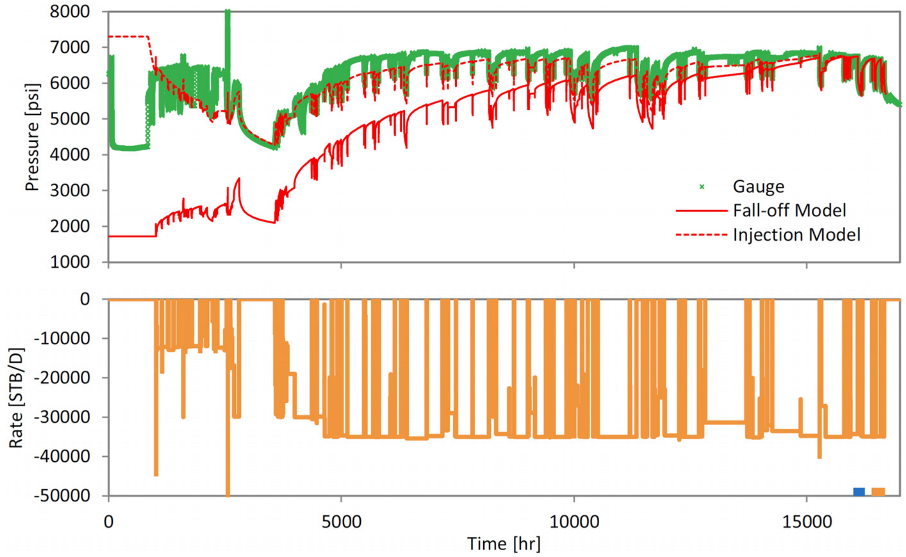

Figure 17—Simulation of well I-H history (Fig. 10) with the simple model ('Fall-off Model', Fig. 16) and with the same model accounting for interference with neighbor producer ('Injection Model', Fig. 19).

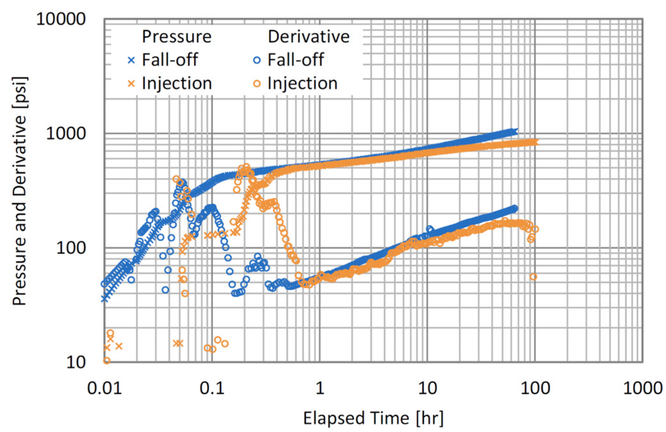

Figure 18—Comparison of pressure responses from fall-off #3 and injection #3 periods (Fig. 11 and 12).

response was found a year before the analyzed history segment (Fig. 9), that allowed to use advantage of time-lapse PTA. The derivative trend from the 'extended build-up' model (Fig. 7) is similar to this actual build-up (Fig. 9). This supported the reliability of the 'extended build-up' model. It should be noted that the composite reservoir model was used to mimic transient behavior during well shut-in periods, and may therefore not represent actual reservoir features. The reduced conductivity interpreted from the build-up responses may be related with reducing pay thickness and permeability as well as cross-flows through the wellbore.

The comparative analysis of both flowing and shut-in pressure transients was fruitful, since quite different well responses were revealed. This example illustrates the value of analyzing well flowing periods, not just shut-in interpretations as in the classical PTA. Using only the build-up (Fig. 7) interpretation results, the reservoir conductivity may be significantly underestimated (Table 1). Comparison of the build-up and drawdown responses (Fig. 6) gave knowledge of different pictures of near well flow during flowing and shut-in periods and provided reliable estimation of actual (flowing) reservoir conductivity (Table 1). On the other hand, reliability of conclusions and estimations drawn from analysis of one combination of drawdown / build-up responses was limited. Integration of additional pressure transients, such as the other build-up period, can help to reduce uncertainty and to improve reliability of interpretation results.

A horizontal water injector with multiple induced fractures

The third example describes the most complicated well case: a horizontal injector in naturally fractured reservoir, stimulated with multiple hydraulic fractures ('well I-H' in the figures and table below). The installation of PDG provided permanent observation of downhole pressure from the beginning of injection, and frequent water rate measurements are also available (Fig. 10). This provided vast amount

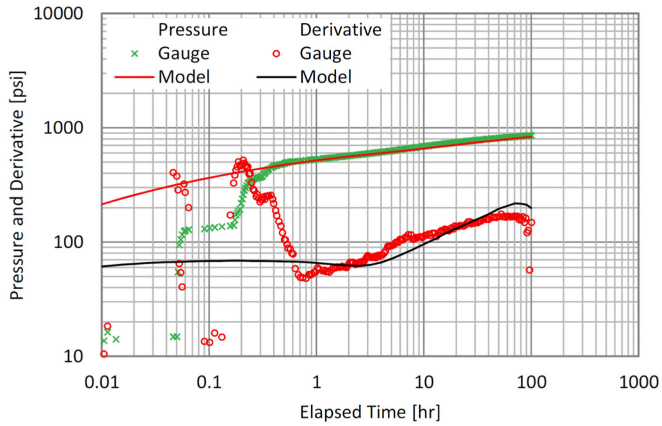

Figure 19—Pressure response interpretation with the simple model accounting for interference with neighbor producer, injection #3 (Fig. 12).

of high quality data to be analyzed. The most representative pressure transients were chosen for time-lapse PTA (Fig. 10). Following the concept of using both flowing and shut-in responses, three fall-off (Fig. 11) and three injection (Fig. 12) periods were compared. Both families of fall-off and injection pressure transients revealed the same dynamic trend: shifting down pressure and derivative with time (Fig. 11, 12). At the same time, there is significant difference in the late derivative behavior: all injection responses clearly demonstrate a boundary effect (similar to constant pressure boundary or a neighbor producer), which is not observed in any of the fall-off responses.

The step-by-step interpretation of these fall-off and injection responses was carried out starting from the fall-off data (Fig. 11). The first response (Fig. 13) was registered before the well was stimulated. This gave a chance to estimate reservoir conductivity from the constant derivative period (radial flow to horizontal wellbore). It is difficult to get a second chance to deal with (late) radial flow when analyzing a long horizontal well surrounded by other wells. The fall-off interpretation (Fig. 13) resulted in reservoir conductivity and horizontal well skin factor of 120 mD-ft and -2.1 (Table 2). The second fall-off (Fig. 14) was registered right after the stimulation and showed its efficiency: early derivative indicates linear flow to induced fractures and lower skin of -4.7, the reservoir conductivity seems to increase to 200 mD-ft (Table 2). Here a detailed model was used for the interpretation (Fig. 14) accounting for the first linear flow regime (induced fractures) followed by the second linear flow regime (horizontal well). The same model may be used to match the next fall-off response (Fig. 15). Further increase of the reservoir conductivity is necessary to achieve agreement with the measurements (Table 2). Using a simple interpretation model is often reasonable in field studies, when a result should be quickly achieved. In this case skin-factor may be sufficient model to describe well-reservoir connectivity. Such a model may also be used to match the same fall-off response (Fig. 16), resulted in the same conductivity and similar total skin (Table 2), where the latter accounts for the induced fracture impact. At the same time, it is obviously difficult to match the early derivative response governed by linear fracture flow using the simple model.

Moving step-by-step from one fall-off to another, a picture of dynamic changes of well-reservoir parameters is composed (Table 2). However, testing the last fall-off model resulted in significant mismatch of the history prior to the shut-in period (Fig. 17). It seems that the boundary condition (infinite reservoir) imposed in the fall-off models was far away from the reality. At the same time, there is no clear signature of boundary effects in the fall-off responses (Fig. 11). Such a signature is observed only in the injection responses (Fig. 12). Comparison of the fall-off and injection responses in the log-log scale (Fig. 18) illustrates difference in the late derivative behavior. Constant pressure boundary and accounting for neighbor producer impact were tested to match the injection response (Fig. 19) with the model used in the fall-off interpretation (Fig. 16). Introducing neighbor producer gave reasonable match of both the injection response (Fig. 19) and the history (Fig. 17).

The time-lapse PTA provided well-reservoir parameters which are changing during the well history (Table 2). Enhancement of the effective permeability of natural fracture networks due to reservoir pressure build-up is supposed to be one of the reasons for the reservoir conductivity increase. On the other hand, this conductivity increase was estimated under the assumption of constant fluid properties and effective well length as well as single-phase flow. However, different factors like variation of fluid viscosity due to changing reservoir temperature and multi-phase flow effects may have an impact on the interpretation results. Analysis of uncertainties related to these factors may be accounted for in the well performance forecast. Another effect observed is moderate growth of the skin-factor (Table 2) that may be related with some decline of fracture flow performance.

The well-reservoir models resulted from the time-lapse PTA may be further utilized to forecast well performance under different scenarios giving fast and reliable short-term prediction. The well-reservoir parameters estimated from the time-lapse PTA may be used to improve reservoir simulation, which may help to deal with effects uncovered by PTA and to forecast reservoir performance in the long-term perspective.

Conclusions

Advantages of the time-lapse PTA were confirmed with the field examples, providing estimation of well-reservoir parameters evolving with time, improving reservoir description via focusing on flowing reservoir properties and understanding difference between near well flow and boundary effects during flowing and shut-in periods.

Application of the described methodology improves the PTA reliability and extends its scope, namely:

› Analysis of sequential pressure transients provides basis for isolating reservoir effects from measurement noise, since repeatability of the same or similar pressure derivative behavior confirms the reservoir response.
› Comparison and interpretation of both flowing and shut-in pressure responses would give complete picture of the well behavior with estimates of flowing well-reservoir parameters. These parameters are more relevant for reservoir simulation and well performance predictions compared to the shut-in estimates.
› Representation of well-reservoir parameters evolving with time is now feasible task through available PDG data and interpretation approaches continuously progressed.

As practical guidelines for time-lapse PTA applications the following may be suggested:››

› Using both well flowing and shut-in pressure transients.
› Analyzing sequential flowing / shut-in periods in well history to confirm repeatability (static well and reservoir conditions) or to reveal changes in well-reservoir parameters.
› Matching both pressure transient responses (the log-log scale) and history or its segments (the linear scale).

Interpretation models used for the time-lapse PTA are capable of reproducing both pressure derivative transients and well history or at least its segments. Matching the derivative provides better description of reservoir features which are often uncovered by usual (pressure and rates) history matching. Therefore the interpretation models are good candidates for short-term predictions of well performance. On the other hand, the time-lapse PTA providing input data for reservoir simulation improves its prediction capabilities and reduces uncertainty in well-reservoir parameters.

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