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Intelligent Integrated Dynamic Surveillance Tool Improves Field-Management Practices

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Abstract
This paper describes solutions developed using a dynamic surveillance tool to automate several workflow processes of the reservoir management, production engineering, and R&D Center at Saudi Aramco. The objective is to provide improved efficiency in field management practices, while enhancing collaboration between reservoir and production engineers; ultimately resulting in improved decision-making process.

The solutions provided include a combination of smart tools and automated workflows designed to improve reservoir management and surveillance processes. A candidate recognition system was developed to identify and flag problem wells that require immediate remediation. As new production and injection data become available, the system that is linked to the corporate database can automatically display these data for fast and rigorous validation. In addition, a formation damage indicator function is also calculated using field data and mapped to spot production problem areas and identify damaged wells. A daily surveillance tool, which compares the performance of individual wells to the average performance of a group of wells, is also provided to allow the reservoir and production engineers to easily identify under-performing wells, promptly intervene, and recommend best completion practices. Benefits include efficient well management and cost avoidance resulting from early intervention and remediation, while avoiding full-scale problem resolution.

Another dynamic surveillance tool was designed and views were developed to provide online access to the hydrocarbon phase behavior and petrophysical data for the R&D scientists and reservoir engineers. The tool allows integration of the hydrocarbon phase-behavior data and comparison of petrophysical data with historical production/injection data and production well logs, resulting in enhanced analysis, production optimization and data validation. Additional benefits of the smart tools and automated workflow processes include considerable timesavings, with pertinent data being automatically updated, validated and used in the analysis, leading to improved efficiency in field management practices.

Introduction
It is generally accepted that most of the reservoir and production engineers' time is spent in searching, collecting, checking, and integrating reservoir and production data. Less time is spent by engineers on analysis and interpretation. Each engineer uses different tools in gathering this data, resulting in less collaboration and possible repetition of tasks. One of the main objectives of the integrated dynamic surveillance tool is to reduce the spent time on data gathering; letting engineers focus on data analysis and interpretation rather than data collection, leading to more efficient use of their time and increased collaboration between reservoir and production engineers. In this paper, four sets of tools are provided to automate reservoir management and surveillance, monitor production data, provide an integrated online access to hydrocarbon phase behavior and petrophysical data, and to manage well test knowledge.

Reservoir Management and Surveillance Tools
One of the reservoir engineer's main tasks is to manage the reservoir as efficiently as possible in order to prolong the life of the reservoir, while maximizing hydrocarbon recovery. Our aim is to provide the engineer with the necessary software tools to automate their workflow processes, while integrating computing processes and data, based on multidisciplinary asset team approach. Some of the tools developed to aid in this task include a remedial well analysis tool, a water management tool, a heterogeneity index tool, a formation damage indicator, and an integrated reservoir analysis tool.

Remedial Well Analysis Tool
A candidate recognition system was developed to identify and flag problem wells that require immediate remediation. The system consists of various analysis tools that allow anticipating the onset of problems by leveraging existing knowledge from nearby wells. **Figure 1** shows a typical plot of the remedial well analysis tool. It summarizes the production performance of a well by tracking the oil and water production rates. These rates are then extended to forecast their future production using decline curve analysis. This allows early detection of mechanical and other problems such as high water cut, low productivity or injectivity. The tool also has the ability to identify the occurrence of production logs, workover and stimulation jobs. The occurrence of well pressure build-up and fall-off tests can also be identified. Also

included in the tool is the identification and explanation of well events that took place. This includes workover and/or stimulation jobs. Using this tool, the engineer can anticipate the onset of problems by leveraging existing knowledge from nearby wells. Benefits include cost avoidance resulting from early intervention and remediation, while avoiding full-scale problem resolution.

Water Management Tool

The integrated dynamic surveillance tool was also used to implement water management strategies for identifying and controlling high water producing wells and cyclic production wells. Based on reservoir management specified criteria, this application allows the reservoir engineer to rapidly screen the entire field for high water producing wells and recommend the best reservoir management practices for the candidate wells. These wells can be recommended for water shut-off, stimulation, rate restriction, and sidetracking. **Figures 2 and 3** show a field example of a carbonate reservoir with wells producing up to 22000 bbl/d, 90% water cut, and oil pay thickness ranging from 20 to 160 ft. Wells are screened by selected criteria based on reservoir performance. For example, in Figs. 2 and 3, the wells were screened based on arbitrary cut-offs of 50% water cut, 40 ft oil pay thickness, and 5000 bbl/d oil rate. Wells with low water cut (<50%) and high net pay thickness (> 40 ft) are considered as excellent wells. On the other hand, wells with high water cut (>50%) and high net pay thickness are prime candidates for workover, stimulation, and/or rate restriction.

Another water diagnostic technique[1] was also implemented to help identifying and controlling high water producing wells. **Figure 4** illustrates the use of this technique that employs both water/oil ratio and water cut derivatives with respect to producing time. Using this tool, the source of excessive water production can be identified due to either channeling, water coning, or high oil production, and best reservoir management practice is recommended.

Heterogeneity Index

This tool provides a convenient means of comparing the performance of individual wells to the average of a group of wells. This daily surveillance tool allows the engineer to rapidly identify over- and under-performing wells, and recommend the best completion practices. The heterogeneity index[2,3] (HI) is defined as

$$HI = \frac{Value_{well}}{Value_{avg\ wells}} - 1 \quad \text{.................................} \ (1)$$

One is subtracted from the ratio to normalize the heterogeneity index to zero, i.e. the average of all the wells is equal to zero. Wells performing above the average will have a value of HI that is larger than zero. HI values below zero indicate wells performing below the average. HI can be calculated for any dynamic variable such as production rate and water cut. HI calculated from production rates could be very noisy and hard to analyze. Therefore, a cumulative HI is introduced to smooth the production rate HI as follows:

$$Cum\ HI = \sum HI \quad \text{...................................... ...} \ (2)$$

Figure 5 shows a scatter plot of the heterogeneity index based on cumulative production rates and another scatter plot showing the well locations. Wells falling in the lower-right quadrant of the HI plot are strong performers, with higher than average oil rates and lower than average water rates. Analysis of cumulative HI with time includes not only the relative position of the point but also the slope of the curve (trend analysis). This heterogeneity index should not be confused with the formation heterogeneity.

Formation Damage Indicator

The use of the formation damage indicator is to spot production problem areas and identify damaged wells. Calculation of the skin factor can easily indicate which wells have formation damage problems using steady state flow equation.

$$q = \frac{0.007078 kh \Delta p}{\mu_o B_o \ln\left(\frac{r_e}{r_w} + s\right)} \quad \text{......................................} \ (3)$$

However, some of the fields have limited pressure data. Therefore, by rearranging the equation, we can correlate it with the formation damage index[3] (FDI).

$$FDI = \frac{q}{kh} = \frac{0.007078 \Delta p}{\mu_o B_o \ln\left(\frac{r_e}{r_w} + s\right)} \quad \text{............................} \ (4)$$

The numerator is the production rate that represents the capacity of a well to produce. The denominator is the product of the permeability and the pay zone thickness. It represents the storage capacity of the formation to deliver. If a well has formation damage problems, then it will produce at a low rate even though the formation has a high storage capacity to deliver. Hence, the formation damage index will be a low value. **Figure 6** shows a grid map of the formation damage index. Areas colored in dark red have a high formation damage index, while areas in yellow have low damage. The green-colored areas have moderate damage. With this tool the engineer can quickly and easily identify and quantify all damaged wells of a given field with much less time and convenience than the traditional way.

Integrated Reservoir Analysis Tool

An integrated reservoir analysis tool was also developed, detailing the workflow process carried out by a reservoir engineer in analyzing reservoir performance and production data. **Figure 7** shows a field example of several well analyses tools integrated into single dynamic surveillance application. The integrated reservoir analysis tool allows engineers and geoscientists to view, report, map, and analyze reservoir performance and production data with ease and convenience. Among other applications, the integrated analysis tool was used to analyse reservoir performance through historical production/injection data, production forecast using decline curve analysis, single and multiple production well logs, stratigraphic cross sections, well deviations, and wellbore schematics of any particular well or a group of wells in a given field.

The integrated tool can also be used as a useful means of characterizing the field in a macroscopic scale. The base map of a field includes the original oil-water contact, gas-oil contact, faults, fractures, and geological structures of th field. The integrated reservoir analysis tool was also used in the waterflood management by monitoring the floodfront movement, and studying the water encroachment through mapping the fluid contact movement with time and the geochemical water analysis. Additional analyses to study the water encroachment in oil producing wells at the crest of the field include mapping and displaying of flowing wellhead pressure, flowing wellhead temperature, cumulative water cut, and cumulative oil cut.

The Hall plot technique[4,5] was also implemented and integrated in the dynamic surveillance tool for analyzing injection wells with the assumption of a series of steady-state injection conditions. A Hall plot, as shown in **Fig. 8**, is a plot that displays the cumulative water injection on the x-axis and the Hall coefficient on the y-axis. The Hall coefficient is a running sum of the injection pressures for a water injection well. This technique was deployed and used in waterflood studies resulting in better reservoir understanding, and improved efficiency in monitoring and control of injection performance, and management of waterflood project.

Production Data Monitoring Tools

Automated real-time or near real-time production data plays an important role for monitoring day-to-day reservoir performance and field operational activities. Through the integrated dynamic surveillance tool, we developed views to provide automated real-time access to the daily gas production data, and to the central production-data-acquisition systems of oil and gas fields at Saudi Aramco. A brief description of these tools follows.

Daily Gas Production Data

Having access to gas production data on daily basis is critical for monitoring the performance of gas wells. We automated the updating of the daily gas production data, making it available online to the gas reservoir management and gas production engineering through an integrated dynamic surveillance tool. The engineers now have access to all historical gas production data up to present for all gas wells, which is crucial to the efficient management of gas fields. It provides reservoir and production engineers an online access to gas production data on daily basis, enabling close monitoring of production performance of gas wells, predicting instantaneous gas production rates, detecting production problems, and tracking the compliance of the well production to the reservoir management guidelines. **Figure 9** shows a comparison of the past and current workflow processes of the daily gas production data.

Real Time Data Coupling to PI and SCADA Systems

Among the solutions provided in this tool, include a system for real time data retrieval, visualization, and analysis of reservoir production performance. This achieved by linking the integrated dynamic surveillance tool with Plant Information (PI) and Supervisory Control and Data Acquisition (SCADA) systems. **Figure 10** shows the integrated workflow process of real-time data coupling to the PI and SCADA systems. With this tool, data such as daily fluid rates, condensate rates, wellhead pressures and temperatures can be provided in real-time at the engineer's desktop. These real-time data are critical for the day-to-day monitoring of wells performance, troubleshooting, and optimization, leading to improved efficiency of field management practices.

Rock and Fluid Data Analysis Systems

Hydrocarbon phase-behavior data and petrophysical core samples data are among the most important information required by research scientists, reservoir engineers, and geoscientists for reservoir characterization and description. The following section presents two systems that were developed aiming at analyzing the hydrocarbon phase behavior and petrophysical data through an integrated dynamic surveillance tool.

Hydrocarbon Phase Behavior Analysis System

This system was developed using the integrated dynamic surveillance tool as a front-end, enabling the R&D scientists to retrieve, report, visualize, map, and analyze pressure-volume-temperature (PVT) properties data with ease. It provides the user with an online access to several PVT properties data of black oil and gas condensate fluids. Among the black oil data are the PVT sample, hydrocarbon analysis, differential liberation process, thermal expansion, compressibility, bubblepoint, and volume-density-viscosity data. The gas condensate data include depletion process analysis, retrograde condensation, fluid composition, dewpoint, and pressure-volume relations. The system can also be utilized by reservoir simulation engineers in building and preparing the PVT input data for the simulation models, and by reservoir management engineers in conducting PVT-dependent field studies. The system has resulted in significant savings of time and effort of R&D scientists and engineers in conducting quality control, experimental optimization, and research field studies.

Petrophysical Data Analysis Tool

Customized templates were also developed to help research scientists retrieve petrophysical data from the corporate database and display them for analysis and interpretation. These petrophysical data include core porosity, permeability, fluid saturation, hydraulic flow unit, reservoir quality index (RQI), normalized porosity index (NPI), and flow zonation indicator (FZI). Petrophysical data are extensively used in interpretation, calculation, and completion of other technical and research studies to support the development of oil and gas reservoirs.

The main advantages of linking the petrophysical data to the integrated surveillance tool through the corporate database are:

- Reducing the time required for retrieving core plug data and allowing the engineer and scientist to use additional derived functions to manipulate data or adding more properties to core plugs, and
- Integration with complementary well data, such as production and well test data, that may be used for better interpretation and correlation of reservoir parameters.

Figures 11 to 13, show examples of analysis plots of petrophysical data used by R&D scientists in conducting research studies. The hydraulic unit is a statistical representation of the reservoir zonation and reservoir quality. The functions of the RQI and NPI are to quantify the flow character of the reservoir and provide an association between petrophysical properties and the micro and macro level properties of the tested core samples. The FZI is commonly used in conjunction with cluster analysis or probability plots to differentiate between the flow zones.[6]

Well Test Knowledge Management System

A knowledge management system was developed to provide well test analysis information in one environment. **Figure 14** shows a schematic diagram of the well-test-knowledge management system. The system is designed to display pressure derivative signatures as thumb nails at the well locations on a base map of any chosen field. A mouse-click on each thumbnail enlarges it for detailed viewing and interpretation. The system also allows the engineer to launch the well test analysis application directly, for further analysis and interpretation of any well test. This will help reduce the time it takes to analyze a well test, by looking for patterns in interpretation and comparing analysis results from nearby wells.

Conclusions

In this paper, we have presented several software tools aimed at automating the daily workflow processes of reservoir and production engineers, as well as research scientists. These automated tools proved to increase user productivity, reduce time and effort, optimize operational activities, enhance reservoir analysis, increase collaborative efforts between reservoir and production engineers, and minimize human errors, leading to improved efficiency of field management practices. The integrated solutions are also dynamic, fully automated, and capable of providing true performance monitoring, with reliable real-time production and injection data validation. Through these integrated dynamic tools, engineers can efficiently manage oil and gas fields throughout the E&P lifecycle, make better and quicker decisions based on up-to-date production data, manage more wells in less time, and detect production problems early in the well's life.

Nomenclature

h	=	formation thickness, ft
k	=	permeability, md
q	=	oil rate, Bbl/d
Δp	=	pressure drop, psi
r_e	=	outer reservoir radius, ft
r_w	=	wellbore radius, ft
s	=	skin, dimensionless

Acknowledgement

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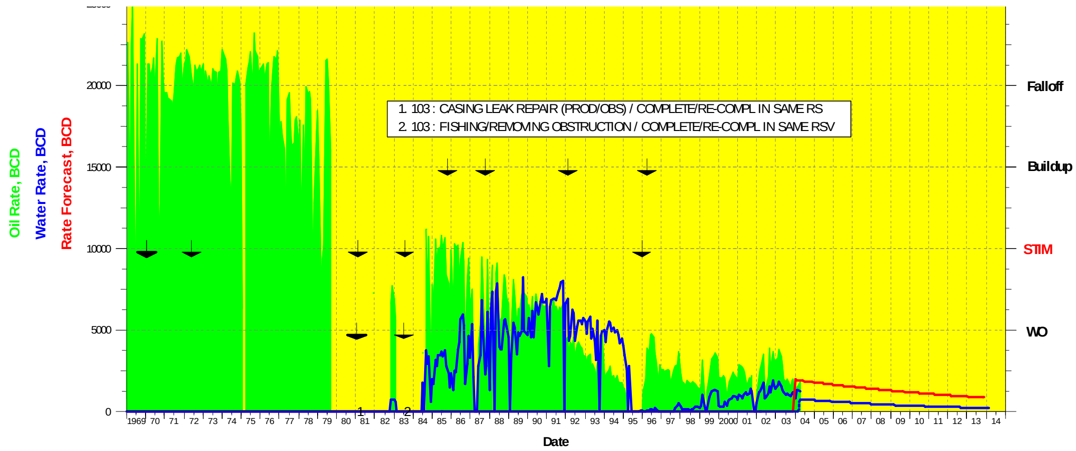

Fig. 1- Remedial well analysis tool showing production history and forecast using decline curve analysis.

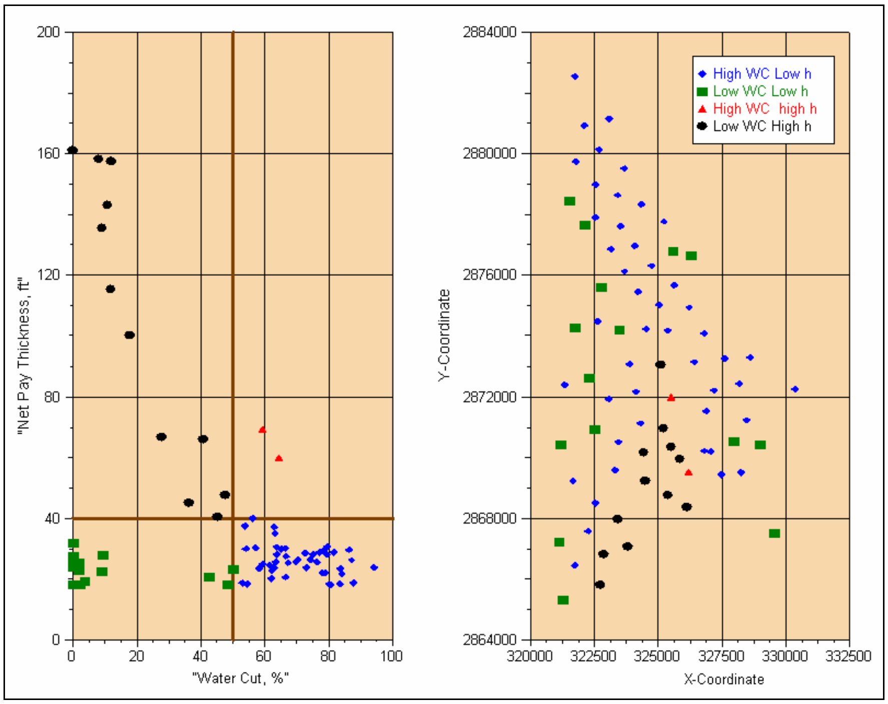

Fig. 2- Scatter plot of water cut and net pay thickness, with corresponding scatter plot of well locations.

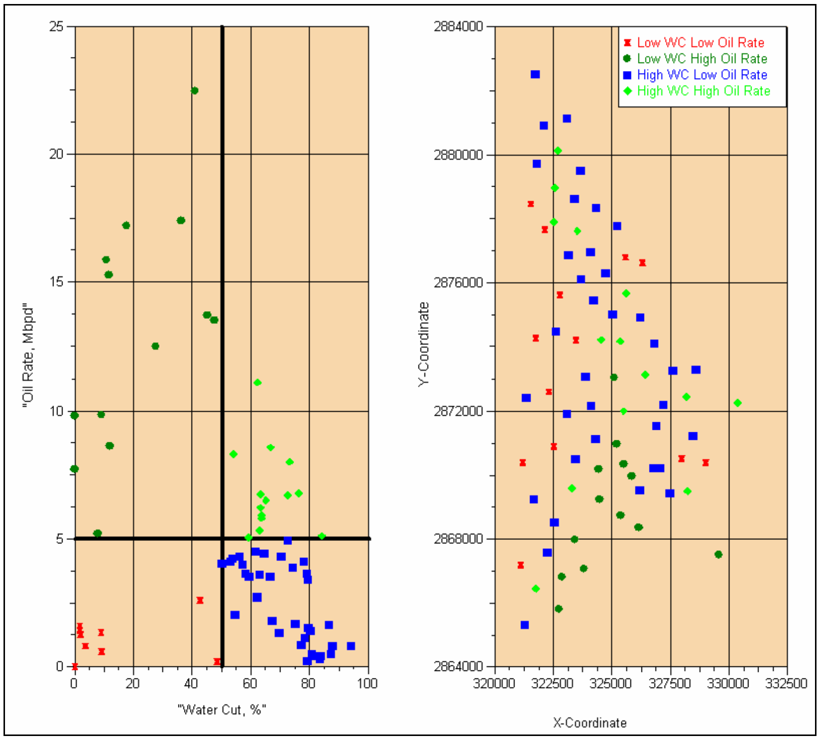

Fig. 3- Scatter plot of water cut and oil production rate, with corresponding scatter plot of well locations.

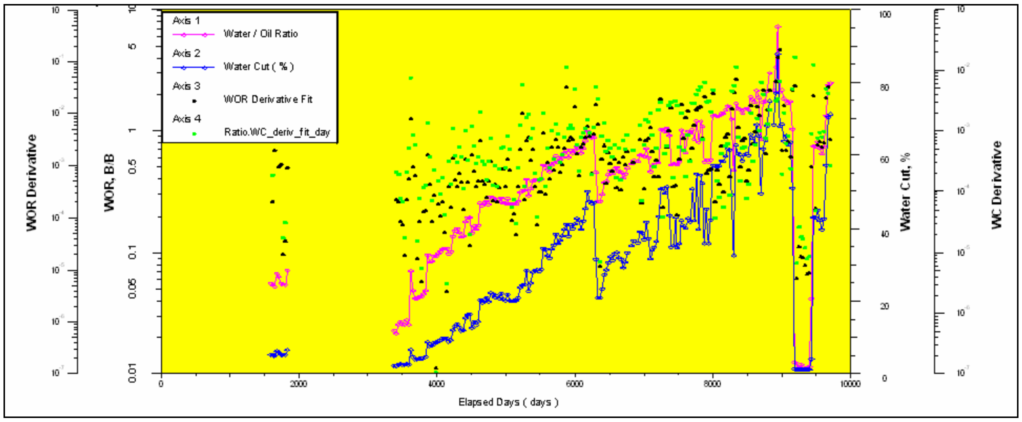

Fig. 4- Water diagnostic plots using water/oil ratio and water cut derivatives.

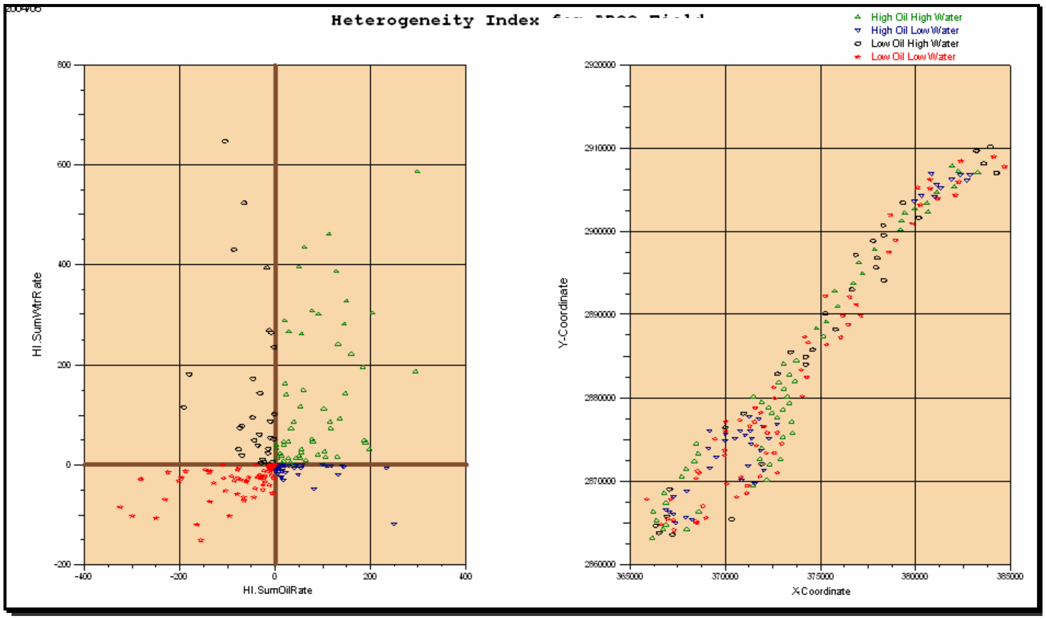

Fig. 5- Scatter plots of heterogeneity index and well locations.

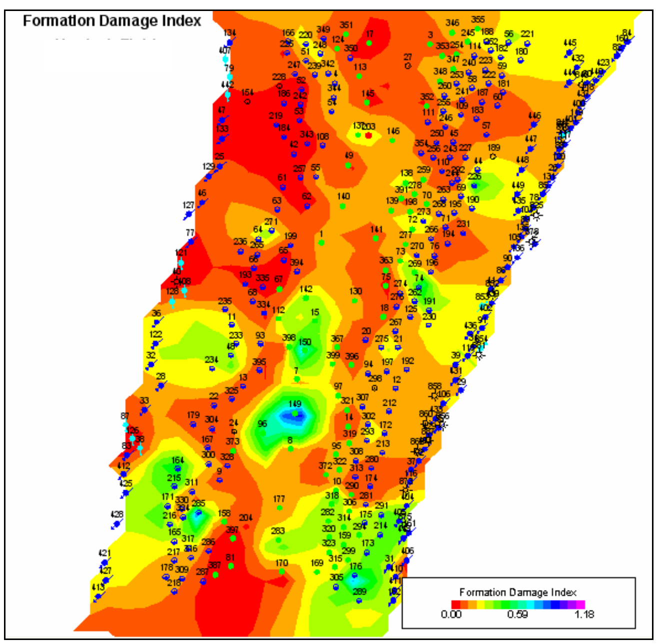

Fig. 6- A grid map of the formation damage index.

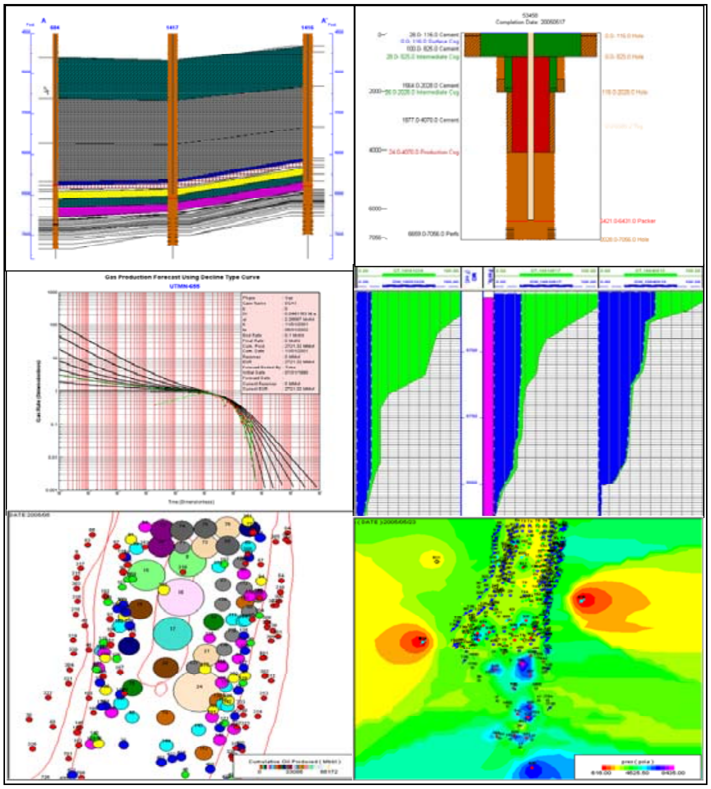

Fig. 7- Integrated reservoir analysis tool.

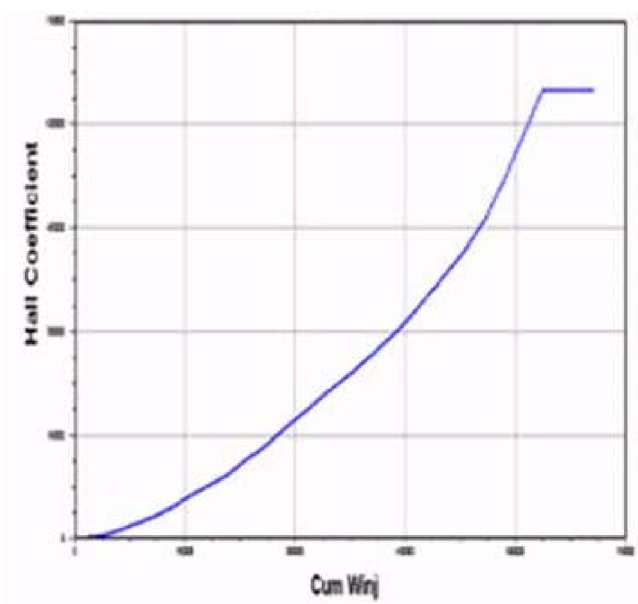

Fig. 8- A typical example of Hall plot.

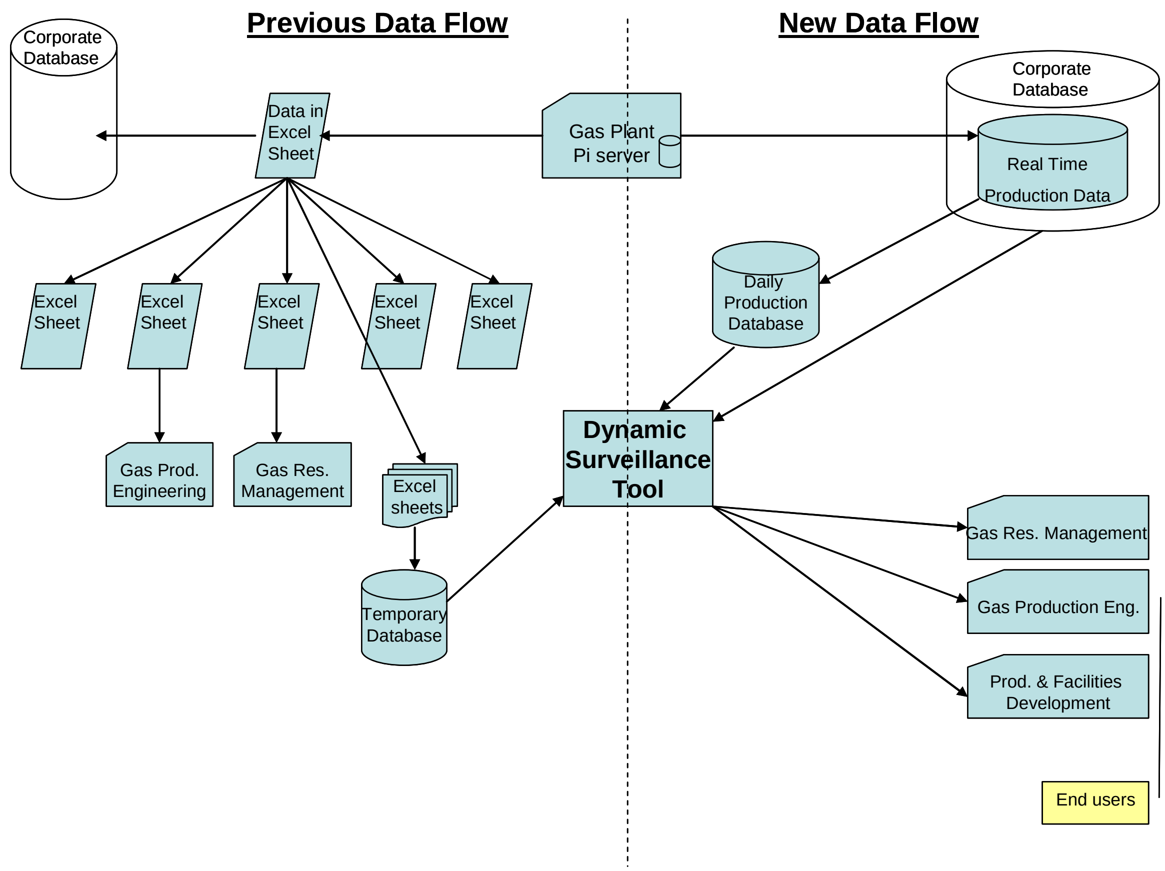

Fig. 9-Past and current workflow processes of daily gas production data.

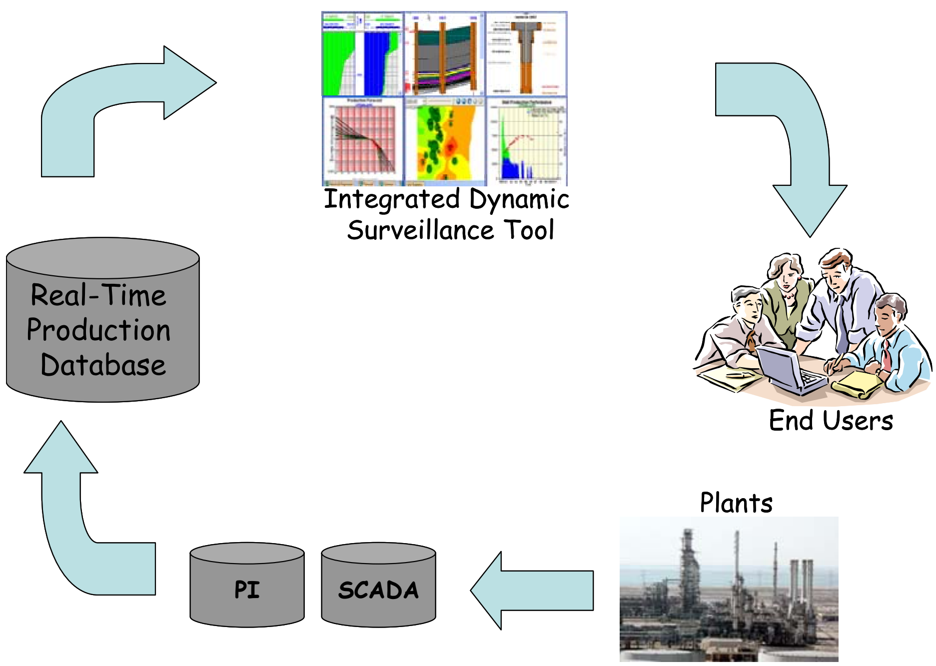

Fig. 10- Workflow of coupling integrated dynamic surveillance tool to Pi and SCADA systems.

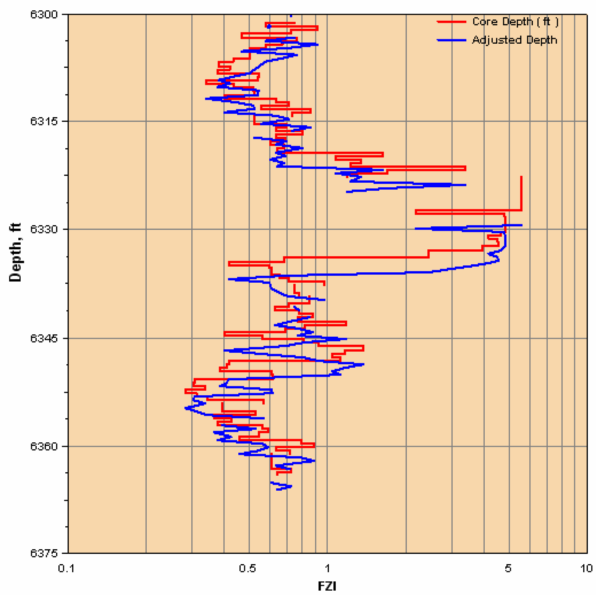

Fig. 11- Flow zone indicator (FZI) correlated with adjusted core and drilling depth.

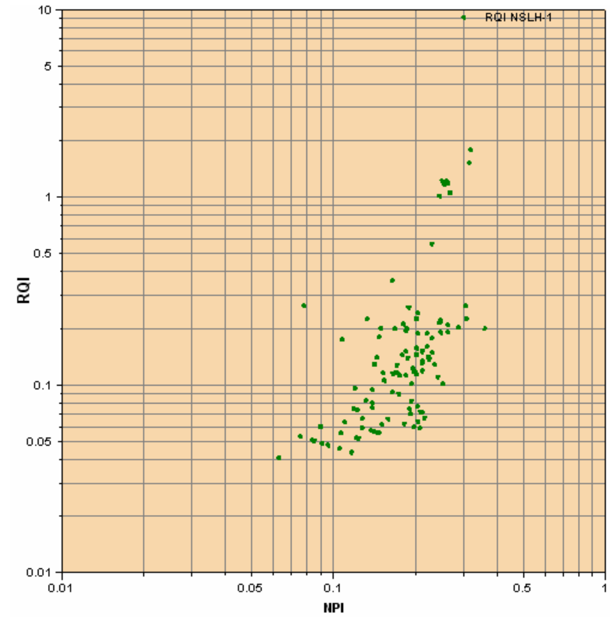

Fig. 12- Normalized porosity index (NPI) vs. reservoir quality index (RQI).

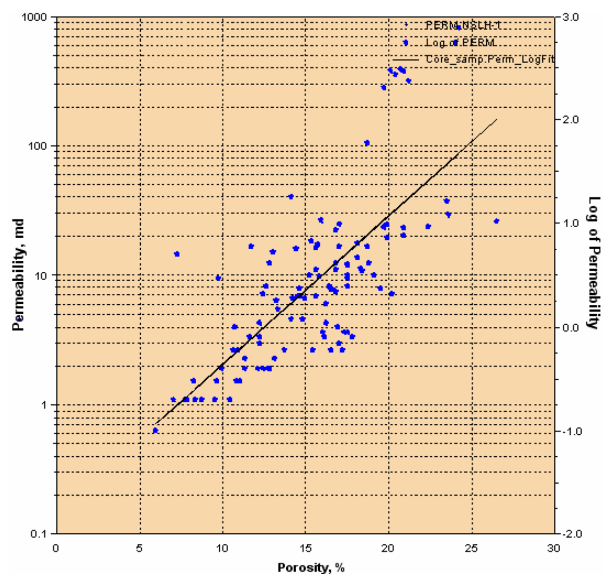

Fig. 13- Permeability-porosity transform.

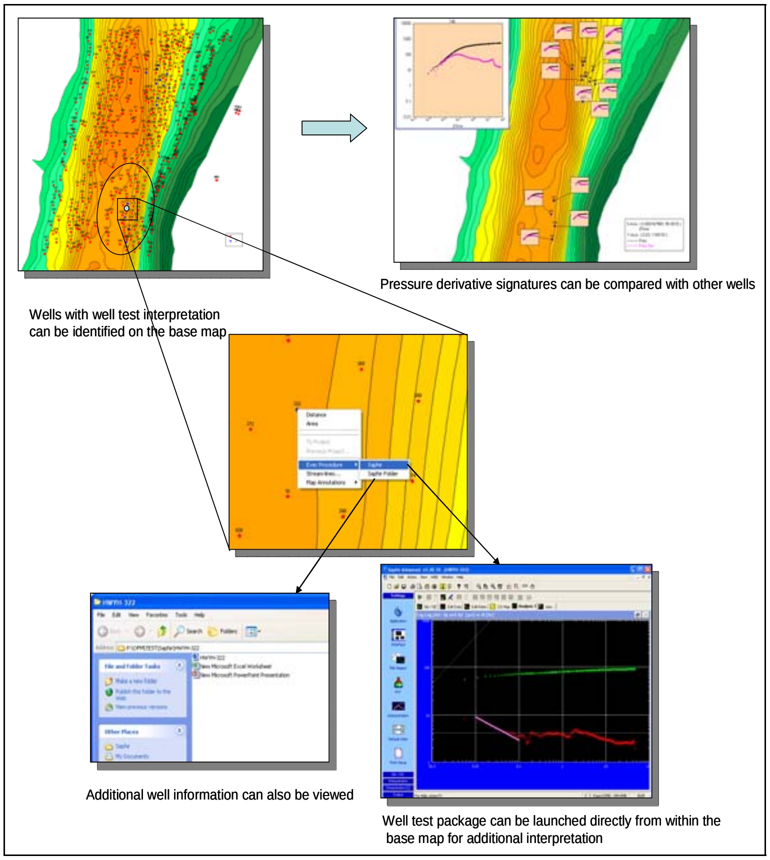

Fig. 14- Well tests knowledge management system.