APPLICATION REMIT

PermMapper Testing Solutions

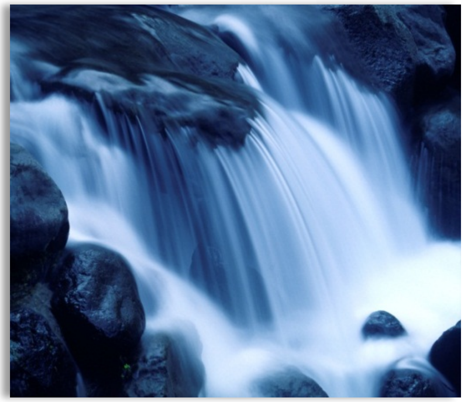
DETERMINING COAL SEAM BULK PERMEABILITY

Challenges

Coal as a fossil fuel plays an important role as the primary source of energy for the generation of electricity worldwide. However, it also serves as both a source rock and reservoir for natural gas, which is adsorbed on to the internal structure of the coal. Coal seams also tend to be water saturated, which exerts sufficient pressure to trap the gas. However, breakup of the coal through mining causes the gas to be released, with emissions rising with increasing gate-road lengths, wider longwall faces, thick seam mining and higher gas content coal. The higher gas emissions impose a greater burden on ventilation systems, with gas drainage techniques therefore employed to comply with prescribed minimum ventilation air (MVA) gas concentration limits and outburst threshold limits. Drainage typically involves the drilling of surface wells and in-seam boreholes strategically positioned across the lease away from the mine shafts.

Quantifying potential gas emission rates involves developing an in-depth understanding of the amount of gas stored in the coal seam(s), the amount of pressure drawdown required to desorb the gas and coal seam deliverability, which is a measure of gas and water production potential. This is influenced by mechanical and chemical coal seam and fluid properties, which is captured in the definition of fluid phase mobility, a term which incorporates permeability. Quantifying permeability of the coal is thus a crucial goal.

Permeability is essentially a measure of the resistance to flow in a porous media, and, in accordance with Darcy's Law, is the constant of proportionality linking pressure drop in the direction of flow to flow rate, under steady state



FEATURES, ADVANTAGES & BENEFITS

- Accurate determination of coal seam bulk permeability by inducing and monitoring reservoir pressure transients.
- Pressure transient analyses techniques enables computation of additional coal seam parameters, augmenting reservoir characterisation, thereby boosting understanding of coal seam behaviour.

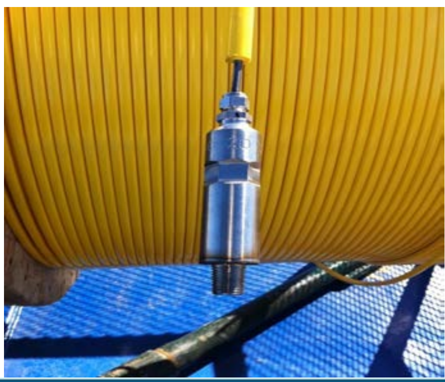
FEATURES, ADVANTAGES & BENEFITS Continued

- Various alternative systems are available to cater for wide range of test types, and that can be configured to suit field, well and reservoir conditions.
- Complemented by a Reservoir Engineering Support function to aid test type selection and test design.
- Expert PTA can also be provided, including diagnosis and reservoir modelling.
- All systems permit isolated testing of multiple zones to be conducted in a single trip.
- Availability of real-time pressure data enables test design to be modified to account for reservoir uncertainties.
- Ability to conduct real-time pressure transient analyses affords Petroleum Engineers a means to optimise durations of flowing and shut-in periods, and also guide decisions on whether to instead abort tests.
- Measured formation pressure data can be relayed real-time to remote client offices, allowing off-site Petroleum Engineers to monitor and direct well test operations if required.
- Access to real-time bottom hole pressure data can also aid in diagnosing optimal fluid cushion levels needed at start of each test.

incompressible flowing conditions. It is thus not a parameter than can be directly observed or measured, only inferred from the ratio of other physical parameters. Furthermore, reservoir permeability can vary in direction (anisotropy) and with location (heterogeneity), and change over time with changes in effective earth stresses. Mapping these variations across the coal seams requires extensive individual permeability tests, supported by studies in reservoir Petrology, Geology and surface lineaments to identify trends linking permeability with other pertinent reservoir characteristics.

Constraints

Geological setting, coal seam structure, tectonic activity, natural fracturing, reservoir composition and reservoir physical characteristics can vary widely, all of which can impact bulk permeability. In coal seams, permeability is impacted by frequency of the natural fractures, their interconnections, fissure aperture, direction of butt and face cleats, burial depths, matrix shrinkage upon desorption, post-fracture mineralization and in-situ stresses.



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Core Studies

It is possible to quantify permeability from tests on whole cores under precise controlled laboratory conditions. However, accuracy of such tests can be impacted by number of factors, including method used to capture the cores, extent of filtrate invasion, damage to cores during retrieval, poor core preservation at surface, improper re-stressing of cores in the laboratory, re-stress hysteresis of cores, and scaling effects (core diameter relative to primary, secondary and tertiary fracture network spacing). Furthermore, the high cost of coring and core laboratory studies imposes an economic limit on the number of such tests that can be performed, resulting in a discrete data set that is often too small to adequately capture field-wide variations and establish trends.

Wireline Logging

It is also possible to construct continuous profiles of permeability through the reservoir using wireline logs. Given it is not possible to measure permeability directly, complex multi-parameter correlations are used instead which equate permeability with other measured physical reservoir characteristics. The correlation coefficients are calibrated through comparison of computed permeability's with measured values obtained at discrete depths from core laboratory studies, which as mentioned previously, are in any case prone to sizeable errors. Measuring the parameters used by the correlations also involves running a combination wireline toolstring (typically gamma, Microlog, NMR, Bulk Density & Neutron Porosity), which again can be cost prohibitive. Furthermore, the values of permeability derived from these correlations are not deemed sufficiently accurate for certification of 2P reserves.

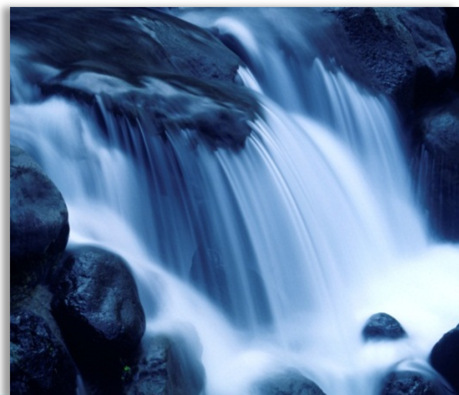
Solution

Well Testing using PermMapper

WellDog's PermMapper technology offering provides a means for determining bulk permeability from monitoring and analysis of pressure transients induced in the reservoir. Pressure transient analysis (PTA) techniques also yield values of average reservoir pressure, radius of investigation, total skin, conductivity and half-length of hydraulically induced fractures, depending on the type of test employed to induce the pressure transient.

In order to accommodate a wide range of reservoir conditions and test objectives, PermMapper systems can be configured to conduct variety of test types, including:

- Inflow Tests & Buildup Tests
- Slug Tests
- Injection Falloff Tests (IFT), including:
  - Tank Tests
  - Below Fracture Pressure Injection Fall-Off Tests (BFP-IFT)
  - Diagnostic Fracture Injection Test (DFIT



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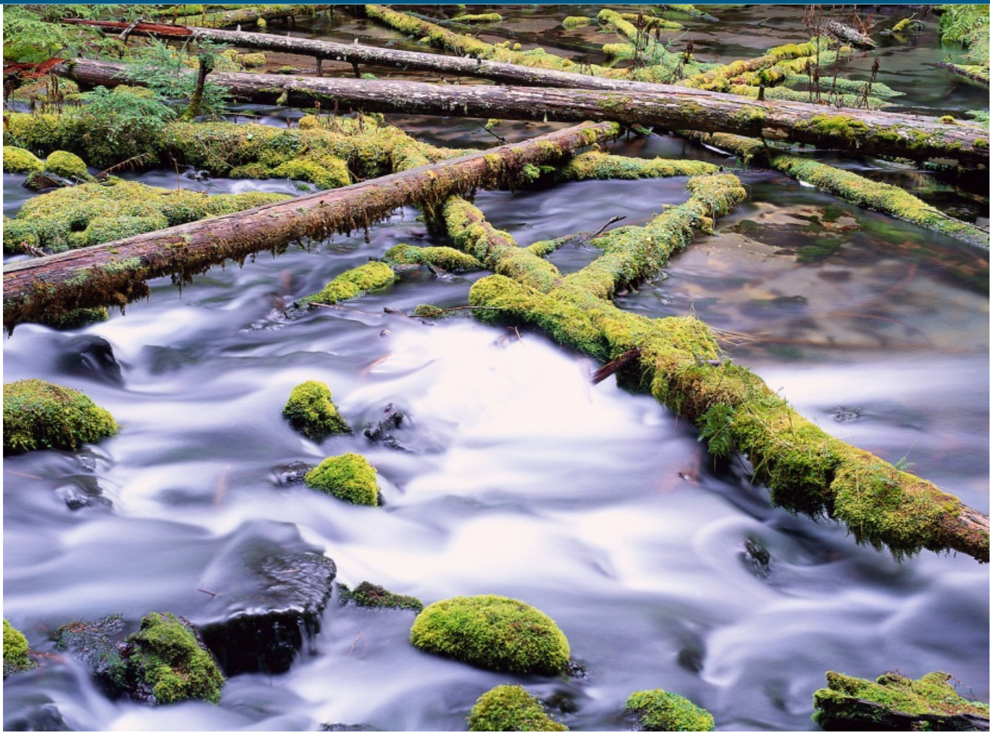

Reservoir Engineering Technical Support

Another important aspect of WellDog's PermSpotter service is provision of reservoir engineering technical support to help assist with test selection and design. Test selection methodology is driven by a decision tree that takes into consideration the well type, design, and status, as well as stimulation status, anticipated permeability, expected reservoir pressure, produced fluids from the target zone of interest, level of saturation and rig equipment.

Test design is driven by need to optimize quality of the pressure data acquired. This means performing tests, if possible, under single phase flowing conditions or, if multi-phase flowing conditions are unavoidable, minimizing saturation changes. It is also important to minimize changes in effective earth stresses, and prevent sudden pressure shocks to minimize completion skin effects. This needs to be counter-balanced against the desired radius of investigation.

Real-Time Data Acquisition

While technical due-diligence is crucial in shaping test selection and test design, uncertainties in reservoir characteristics may require changes to the test design during execution in order to optimize validity of pressure transient analyses. Access to real-time formation pressures during the flow and shut-in periods is therefore critical. WellDog's PermSpotter technology offering also includes provision of either wire-less or electric-line surface readout formation pressure monitoring systems.

The wire-less system relays pressure data to surface using a low frequency electromagnetic (E-M) signal propagated through the surrounding overburden to one or more receivers staked in the ground at surface, eliminating the need for complex inductive coupling systems or wet-mate connections and associated wireline equipment, thus saving costs and mitigating interruptions to rig operations. However, the use of a low frequency signal limits available bandwidth, constraining both data rate and pressure resolution.

For high permeability reservoirs, resulting in small and rapid pressure transients, pressure data can instead be acquired real-time using a pressure gauge deployed on conventional electric-line. Use of electric-line allows more resolute pressure data to be transmitted to surface at much higher data rates.

Pressure Transient Analysis

Real-time data from the surface readout pressure gauges is captured using ResPlot RTTM, which provides a means for viewing data as text, and also graphically as Cartesian plots. Basic real-time pressure transient analyses (PTA) can also be performed, comprising display of both semi-log (Horner) plots and log-log plots (c/w derivative). Data acquired by ResPlot RT can also be shared real-time with remote client offices via an Internet connection using Webex.