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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Society of Petroleum Engineers Annual Technical Conference and Exhibitions (Account No. 20-5704-039)

DATE AND PLACE: October 3-6, 1993, Houston, TX

AUTHOR: Sitakanta Mohanty

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PERSONS PRESENT:

Attendance at the Society of Petroleum Engineers (SPE) Annual Technical Conference and Exhibitions was 9,193 persons from over 500 companies and universities.

BACKGROUND AND PURPOSE OF THE TRIP:

The purpose of this trip was to participate in the 68th Annual Technical Conference and Exhibitions organized by the Society of Petroleum Engineers (SPE). The purpose of this year's Annual Conference was to disseminate the latest technology available to the worldwide petroleum industry. More than 325 technical papers in 59 sessions covered a range of topics on upstream petroleum technology. Additionally, nearly 444 companies from 7 countries displayed their latest equipment and services. This conference and exhibitions is the largest technical conference organized by the Society of Petroleum Engineers every year, and is considered as one of the best technology transfer events each year, in terms of structured programs and informal opportunities to discuss, examine, and share ideas and experiences with other researchers. There were many general interest sessions devoted to the multidisciplinary approach to problem solving. The proceedings of this meeting can be obtained from the author.

Oil and gas industries expend significant efforts into understanding the physics of single and multiphase flow and transport in both unfractured and fractured reservoirs. Both experimental and theoretical studies are actively pursued by these industries. Due to the similarity between flow of air-water and oil-water or gas-oil systems in porous media, the technologies developed in these industries are directly relevant to studying fluid flow at Yucca Mountain. The author of this report attended this conference to learn about advances in experimental techniques for studying heat and fluid flow through fractured media that may be useful to the DECOVALEX and/or Repository Design, Construction, and Operations project.

SUMMARY OF PERTINENT POINTS:

Among the technical sessions, there was continued emphasis on reservoir/aquifer characterization, multiphase flow, and enhanced formation evaluation as evidenced by the number of sessions devoted to these areas and the attendance in them. The presentations also indicated an increasing thrust towards quantitative integration of geological, geophysical, and engineering data to make meaningful predictions of reservoir/aquifer geometry and properties. Established areas such as drilling, well testing, and reservoir simulation were also well represented. Attachment 1 shows a list of selected topics which may be of interest at CNWRA. The following is a summary of the pertinent talks organized by theme, not by session.

Petrophysics

Luffel et al. developed three laboratory methods to measure matrix gas permeability (K_m) of shale (K_m=0.2 to 19x10^{-8} md) cores and drill cuttings at native water saturation: (i) pulse pressure testing of the core plugs with helium, (ii) pulse pressure testing of the drill cuttings with helium; and (iii) degassability of the of core plugs with helium and methane. Most of the core plugs tested showed multiple microfractures that remained open at reservoir stress, and these dominate conventional flow tests. The degassability process is important to understand since it mimics the dual processes of desorption and gas transport that occur in the reservoir. No recommendation was provided for how to correct for the coring induced microfractures.

Christoffersen et al. presented a relatively simple and fast method to determine high-pressure drainage capillary-pressure curves with accurate and reproducible results. The method is based on a modified desaturation method using thin membranes instead of porous plates. The results were compared with mercury injection and centrifuge data at room temperature. The capillary pressure did not vary linearly, as expected based on the Young-Laplace equation. This has been explained as a possibility of phase redistribution resulting in film-like flow at reduced IFTs (Cahn transition).

Renaud et al. presented the use of Environmental Scanning Electro Microscope (ESEM), a new technique they have used in their laboratory to visualize rock samples in their natural state in presence of fluid distribution, and during microdynamic experiments in presence of gas/liquid and liquid/liquid systems. They presented test results of condensation/imbibition tests on shaly samples. The direct visualization of contact angle and imbibition effectiveness in an air/brine system showed a clear affinity of clays for brine and imbibition process mainly controlled by shape factor. Step-by-step visualization of fluid distribution illustrated displacement mechanism at the microscale. It has also been shown that ESEM is an accurate technique to visualize thin films.

Putz et al. presented the use of a gamma ray attenuation measurement device that allows measurements of saturations along a 1 m long core to 450 bar and 170 °C. This was accomplished by using an americium 241 source and a detector that can be translated and rotated very precisely along and around the core. The precision of the measurements was not always found to be satisfactory due to very small contrasts in absorption coefficients between phases present in the porous medium and statistical errors. They recommended that one should use a more active source to enhance precision with this kind of setup.

Howard and Spinler presented their work on the measurements of wettability and fluid saturations using nuclear magnetic resonance (NMR) technique. They claimed the method to be rapid and accurate in the determination of fluid saturations and the estimate of wettability was qualitative. Relaxation-time populations generated by a non-linear optimization technique distinguished between the water and the oleic phases in pore at various water-saturation states. Shifts of these relaxation time populations were interpreted as indicators of pore wall wettability. Shifts in the short relaxation time component as a function of water saturation reflect differences in wettability and electrical resistivity saturation exponent.

McDougall and Sorbie presented their work on the combined effect of capillary and viscous forces on the two phase flow in finely laminated porous media. The paper presents a pore-scale analysis of unsteady-state imbibition and drainage processes, which attempts to elucidate the interaction between capillary and viscous force in finely laminated porous media. Results demonstrate how small scale lamination can greatly affect the large-scale dynamics of water injection, especially where the principal flow direction is across the lamina orientation and matrix wettability.

Tjolsen et al. used four depositional environments while numerically studying under the given injection and production scheme, and found that the introduction of stochastic relative permeability curves had no significant effect on the mean production performance, compared with constant relative permeabilities throughout the reservoir. They considered distribution of permeability varying in two to three orders of magnitude. Based on simple linearization scheme, it is possible to calculate an approximate correlation between absolute permeability and the front velocity. Extreme values of this correlation combined with strong anisotropy in the reservoir affect the time to water break-through while strong negative correlation delays the breakthrough, when compared to the constant relative permeability situation.

Kalaydjian et al. presented their results on three-phase flow in water-wet porous media. They performed steady-state measurements of gas and oil relative permeabilities for two water-wet media under positive and negative spreading conditions. The spreading power is defined as a balance of interfacial tension between various interfaces. In drainage, gas relative permeability, due to a gas blocking, seems to be lower for positive spreading power, which is due to a loss in hydraulic continuity. Steady-state curves, especially for negative spreading power are higher than unsteady-state curves due to different hydraulic continuity.

Knutson et al. presented a paper entitled "Characterization of Low-Permeability Media using Outcrop Measurements." They presented results from their studies of a complex fractured system in a formation with low matrix permeability. Outcrop and well measurements and observations were used as the basis for this study. Fracture permeability was measured by using a field scale permeameter. These measurements on highly fractured basalts were performed to use more realistic data in the simulation as well as to verify the data from small scale laboratory data. The results thus obtained were reported to have narrowed the range of uncertainty for modeling fluid flow and contaminant transport in a highly fractured basalt formation.

Integrated Geostatistics

Kara et al. presented some results on the study of outcrops and subsurface cores to test the aptness of outcrop characteristics to subsurface reservoirs and to determine whether sedimentologically defined geologic units are useful in modeling flow units. The approach used characterization using geostatistical analysis methods. They concluded that the average and maximum errors in the arithmetic mean are functions of the number of data and heterogeneity while standard deviation errors are only function of number of data. They established a linear relationship between average error and the inverse of the square root of the number of data and a quadratic relationship with maximum error. This is true for both arithmetic mean and standard deviation error. Error in arithmetic mean is related to error in coefficient of variations. The variogram for subsurface and outcrop data consistently indicated hole effect when unit boundaries are crossed.

Bashore et al. presented a paper entitled "The Importance of the Geologic Model for Reservoir Characterization using Geostatistical Techniques and Impact on Subsequent Fluid Flow." The authors argue that the choice of geologic framework for guiding geostatistical estimations will have significant effect on the characteristics of the reservoir models generated. However, the effect of predictions of fluid flow behavior may not necessarily be as significant and is controlled by at least two factors such as, flow parameters and spatial continuity. Breakthrough time may not necessarily indicate difference in flow behavior. The choice of the spatial continuity model may have a larger effect than the choice of correlation strategy. The incorporation of secondary data sets, such as seismic inversions, can provide information on small scale variations in interwell heterogeneity, which may have a profound effect on

fluid flow estimates and estimate uncertainty. The soft data will be ignored or misapplied by the geostatistical algorithms if the data sets are not properly correlated.

Rossini et al. presented the use of a two stage geostatistical approach to coherently distribute the reservoir heterogeneity over the field. Here the assumption is that the reservoir heterogeneity is related to the presence of facies, with very different petrophysical properties and porosity-permeability relationships. When a production history exists, the generation of "n" equiprobable porosity and permeability images provides the opportunity of minimizing the adjustment to the static model during the history match phase. The match of the production history was the discriminating criterion for the selection of the reservoir image.

Munthe et al. presented a method to incorporate subseismic faults in a reservoir description. The program is based on a stochastic model in which the faults are modeled as fault planes and displacement of adjacent rock. The generated set of fault is applied to a reservoir description (permeability field). The fault plane may act as a barrier to flow.

Tyler et al. discussed a case study where they obtained good outflow forecasts when working with a small subset (14) of geostatistical reservoir descriptions realizations and history matching these to get a range of anticipated total outflow. The "pairing down" to 14 realizations was done using geological facies distribution criteria. Guerillot et al. discussed the importance of incorporating uncertainties in reservoir/aquifer boundary limits (obtained from seismic depth images) into volumetric studies. They presented a study showing how these uncertainties can affect well test responses.

Sagar and Kelkar discussed a new method to incorporate effective permeability calculated from well test data into geostatistical reservoir descriptions. Experiments on a synthetic permeability field showed poor pressure response matches when the well data constraint is not included in the simulations. Incorporation of dynamic information (from well tests, tracers, etc.) into geostatistical reservoir descriptions is being increasingly attempted but is very time intensive with current methods like simulated annealing. Panda and Lake, and Ouenes et al. discussed results of parallelizing the annealing algorithm and reported 3-10 fold speedups over conventional annealing. Sultan et al. presented an automatic history matching method; the production profile is matched by using annealing to generate the "right" permeability field. These techniques are still in the academic realm with trials on 'toy' cases [5 wells, two-dimensional (2D) reservoir, etc.] and will be a while before they become suitable for field size studies.

Scale-Up Methods

Duquerroix et al. proposed algebraic formulas combining arithmetic and harmonic averaging (extension of Cardwell and Parson's results), which are derived from perturbation techniques while accounting for anisotropy. These formulaes are valid in 2D and three-dimensional (3D) problems. Formulas work well for large permeability contrast and anisotropic ratios either for simple log-normal or geostatistically generated media. In the first application, the numerical calculations were carried out for the upscaling of isolated cells. In the other case, well test simulations were performed either with the original fine grid or further coarse grid. The originality of this work is to combine both stochastic and algebraic approach to upscale equivalent permeabilities. However, these formulae are not valid in the extreme conditions of percolation. The form of the formula displays extreme rigorous bounds and so the global uncertainties is known.

Lemouzy et al. presented a scale-up method to compute relative permeability and capillary pressure for grid block scale under the assumption of capillary force dominated flow. The authors have recommended to apply this method for reservoirs/aquifers with low gravity segregation, with rocks exhibiting medium to low permeability and high capillary forces, and moderate injection rates. The authors have claimed that their work shows that the relative permeability is no longer a scalar, but rather a tensor at large scale. This behavior comes from the distribution of heterogeneities that causes different horizontal and vertical flows. The authors have indicated that this pseudoization method in three dimension could be extended to the physical hypotheses such as gravity segregation and capillary equilibrium with gravity effects.

Li and Lake discussed a general method to scale flow through 2D anisotropic heterogeneous permeable media for a two phase flow. The results indicated the interplay of local heterogeneity (the variance at a lower cutoff in a power-law variogram), global heterogeneity (the variance at an upper cutoff), and regional heterogeneity (the power-law upper cutoff and exponent).

Formation Evaluation Techniques

There were two papers which discussed permeability and porosity estimation from well logs. Oraby and Wolcott discussed a lithology independent porosity model using just thermal and epithermal neutron porosity. They report significant reduction in log acquisition costs with this approach. Amaefule et al. presented a new method, using core/log data, to zonate the reservoir/aquifer into flow units and also to predict permeability in uncored intervals.

Simulation

Makurat of Norwegian Geotechnical Institute presented a paper entitled "Discrete Element Simulation of faulted Reservoir behavior." Makurat et al. used a distinct element code with respect to its mechanistic behavior during fluid pressure drawdown at a well. Special emphasis was given to the effects of compartment pressure reduction on the activation of existing faults, the change of fault sealing properties due to fracturing of the intact rock mass and the determination of the behavior of the existing faults during fluid pressure drawdown with respect to shear displacement and changes in the fault/fracture conductivities. The simulation showed that several segments of the existing faults in the vicinity of the drawdown region could be activated. Some faults with shear stresses below peak showed large shear displacements and were therefore considered activated. Shear fracturing of the intact rock was found to be possible in several zones around the drawdown region.

Buchsteiner et al. (with N.R. Warpinski of SNL) studied the reduction in fluid flow into a well due to the stress-induced permeability reduction in fissured reservoirs. They employed a model relating effective stress and permeability/permeability anisotropy.

Chaouche et al. investigated effects of capillary heterogeneity induced by variation of permeability in the direction of displacement in heterogeneous porous media. Experiments and pore network simulations were used to study displacement in a heterogeneous porous medium involving changes in the direction of displacement and to test the validity of macroscopic, continuum models. It was found that the heterogeneity affects the saturation profile significantly at lower rates. For drainage, a good agreement was found between continuum model predictions, experimental results, and the pore network numerical models, on which they concluded that the capillary heterogeneity effects act much like a body force (gravity). The results were interpreted using invasion percolation concepts. For secondary imbibition, a poorer agreement exists between continuum model and experimental results at low capillary numbers

which requires the use of pore network simulator involving film flow. But numerical simulations were conducted using 2D geometry only.

Shinta et al. presented a paper on tracer transport in characterization of dual-porosity reservoirs. They presented a single porosity model for the tracer response analysis in fractured reservoirs. This technique is useful in characterizing fractures in terms of flow anisotropy and quantifying fractures properties such as porosity and permeability. Due to the good resolution of the tracer response, the analysis can determine the orientation and conductivity of the high permeability fractured systems in the reservoir. Five-point and nine-point finite difference, two-dimension, two phase model has been used. Options have been included to eliminate or minimize grid orientation effect in the fractured and unfractured reservoirs. The nine-point options appropriately account for the permeability tensor and flow channeling.

Killough presented a critical analysis of the state of the art of reservoir simulation using parallel computing. Many researchers are lured by the scalability of the distributed memory parallel computing with hundreds or even thousands of inexpensive, but powerful, RISC bases processors for conducting large scale simulations. His presentation addressed several hurdles to be overcome for the flow simulation purposes: load balancing, data structures, and linear equation solutions. He showed that reservoir simulation is scalable. He also addressed the bottlenecks in the development of full scale parallel flow simulation model.

IMPRESSIONS/CONCLUSIONS:

This conference presented an excellent opportunity for the participants to become cognizant with the technical progress accomplished in the areas of laboratory and field experiment techniques, for two- and three-phase flow in porous media, modeling to understand physics of multiphase flow through porous media, and integrated reservoir/aquifer descriptions. The major part of the conference focused on the accurate description of the reservoir/aquifer based on the available information, such as, well test data, lithology, geophysical data, and tracer test data. This conference was extremely informative and useful in the sense that it gave an opportunity to identify the active areas of research in the oil industry which are pertinent to studying fluid flow and transport at Yucca Mountain. This conference also offered the author an excellent opportunity to discuss with experts the issues relating to flow through fractured media.

PROBLEMS ENCOUNTERED:

None.

PENDING ACTIONS:

None.

RECOMMENDATIONS:

None.

SIGNATURES:

Sitakanta Mohanty
Research Scientist

11/16/93
Date

ATTACHMENTS:

1. List of titles and authors of relevant papers.

CONCURRENCE SIGNATURES AND DATE:

A. Chowdhury, Manager
Repository Design, Construction, and Operations

11/19/93
Date

B. Sagar
Technical Director

11/23/93
Date

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ATTACHMENT 1

TITLES OF RELEVANT PAPERS PRESENTED AT THE SOCIETY OF PETROLEUM ENGINEERS

Annual Technical Conference & Exhibitions
October 3-6, 1993
Houston, TX

AUTHOR	TITLE
H. Buchsteiner, N.R. Warpinski, M.J. Economides	Stress induced permeability reduction in fissured reservoirs
M.N. Panda, L.W. Lake	Parallel simulated annealing for stochastic reservoir modeling
A. Quenes, N. Saad	A new fast parallel simulated annealing algorithm for reservoir characterization
T.A. Gray, C.Y. Chork, I.J. Taggart	Pitfalls in the fractal analysis of reservoir property data
C.Du, I. Ershaghi	A critical evaluation of short and long range correlation methods for heterogeneous rocks
L.J. Wietzerbin, J-L. Mallet	Parameterization of complex 3D heterogeneities: A new CAD approach
I. Ershaghi, M. Hassibi, X. Li	A robust neural network model for pattern recognition of pressure transient test data
G.A. Ulrich, W.W. Agnew, D.M. Proctor	Application of human health risk assessments in oil and gas production
E.R. Jefferys	Design applications of genetic algorithms
J-P.L. Duquerroix, P. Lemouzy, B. Noetinger, R.K. Romeu	Influence of the permeability anisotropy ratio on large-scale properties of heterogeneous reservoirs
J.H.M. Bonnie	Reconciliation of resistivity log readings in vertical and horizontal boreholes
O. Faivre	Fracture evaluation from quantitative azimuthal resistivities
J.O. Amaefule, M. Altunbay, D. Tiab,	Enhanced Reservoir description: Using core and

D.G. Kersey, D.K. Keelan	log data to identify hydraulic (flow) units and predict permeability in uncored intervals/wells
R.W. Paige, L.R. Murray, J.D.M. Roberts	Field application of hydraulic impedance testing for fracture measurement
K. Bhalla, B.H. Brady	Formation and fracture characterization by inversion of fracture treatment records
J. Bosio	The challenge of multidisciplinary teamwork
J. Caldwell	Some pitfalls to avoid to achieve multidisciplinary integration
T.S. Hickman	Professional development - how to become an indispensable team member
D.L. Luffel, C.W. Hopkins, P.D. Schettler, Jr.	Matrix permeability measurement of gas productive shales
J.E. Killough	Is parallel computing ready for reservoir simulation? A critical analysis of the state of the art.
A.A. Shinta	Tracer transport in characterization of dual-porosity reservoirs
J.C. Parker, K. Unlu, M.W. Kemblowski	A Monte Carlo model to assess effects of land disposed exploration and production waste on groundwater
P. MacDowell, P.R. Gray	NORM - projected financial and fiduciary impact on exploration and production operations
G.S. Feitosa, L. Chu, L.G. Thompson, A.C. Reynolds	Determination of reservoir permeability distributions from pressure buildup data
H. Fujii	Production system optimization using genetic algorithms
J.M. Hefner, R.S. Thompson	A comparison of probabilistic and deterministic reserve estimates: A case study
R.A. Edwards, T.A. Hewett	Applying financial portfolio theory to the analysis of producing properties
R.K. Sagar, B.G. Kelkar, L.G. Thompson	Reservoir description by integrating well test data and spatial statistics

D.R. Guerillot, W.B. Beydoun	Reservoir boundary identification from seismic imaging for well test analysis
S. Aprilian, D. Abdassah, L. Mucharam, R. Sumantri	Application of fractal reservoir model for interference test analysis in Kamojang Geothermal Field, Indonesia
D. Li, L.W. Lake	Scaling fluid flow through heterogeneous permeable media
G.J.J. Williams, S.J. Kimminau	Reconciling waterflood residual oil saturations from laboratory and field studies
S.K. Peterson, J.A. Murtha, F.F. Schneider	Risk analysis and Monte Carlo simulation applied to the generation of drilling AFE estimates
K.L. Sublette, D.E. Morse, K.T. Raterman	A field demonstration of sour produced water remediation
J.E. Ryer-Powder, S.R. Custance, M.J. Sullivan	Determination of reference doses for mineral spirits, crude oil, diesel fuel number 2, and lubricating oil
J. Qiu, H. Toral	Three-phrase flow rate measurement by pressure transducers
S. Ding	A semianalytical method for estimating capillary pressure and permeability
C. Satik	A study of vapor-liquid flow in porous media
J.T. Ming Wang	The use of permeability tensors in modelling heterogeneous and fractured flow media
C.B. Tjolsen, E. Damsleth, T. Bu	Stochastic relative permeability usually have negligible effects on reservoir performance
W.M. Bashore, U.G. Araktingi, M. Levy, W.J. Schweller	The importance of the geological model for reservoir characterization using geostatistical techniques and the impact on subsequent fluid flow
M. Chaouche, N. Rakotomalala, D. Salin, B. Xu, Y.C. Yortsos	Capillary effects in heterogeneous porous media: Experiments, ore network simulations, and continuum modeling

P.M. Lemouzy, R.K. Romeu, I.F. Morelon	A new scaling-up method to compute relative permeability and capillary pressure for simulation of heterogeneous reservoirs
J. Kamath, R.E. Boyer	Critical gas saturation and supersaturation in low-permeability rocks
A.H. Makurat, M. Gutierrez, B. Knapstad, J.H. Johnsen, A. Koestler	Discrete element simulation of faulted reservoir behavior
C.F. Knutson, D.O. Cox, K.J. Dooley, J.B. Sisson	Characterization of low-permeability media using outcrop measurements
B. Kara, E. Kasap, R.W. Tillman	Quantitative description of muddy sandstone: Geostatistical parameters, automated facies generation,a nd measurement methodologies
M.A. Miller, H. Yang, J.T. Holder, M.J. Jonus, K.E. Gray, R.S. Fisher	Petrophysical properties of ferron sandstone during two-phase flow: Implications for heterogeneity in tertiary deltaic reservoirs
S. Ucan, F. Civan, R.D. Evans	Simulated annealing for relative permeability and capillary pressure from unsteady state non-Darcy displacement
F.J-M. Kalaydjian, J-C. Moulu, O. Vizika, P.K. Munkerud	Three-phase flow in water-wet porous media: Determination of gas/oil relative permeabilities under various spreading conditions
M.A.V. Vejar, D. Tiab	Generation and characterization of pseudo-wells for interwell reservoir description using fractal geometry and geostatistics
Z. Chen, J.V. McLemore, J.P. Heller	The miniporopermeameter for simultaneous measurement of permeability and porosity
K.J. Tyler, T. Svanes, S. Omdal	Faster history matching and uncertainty in predicted production profiles with stochastic modeling
J.J. Howard, E.A. Spinler	Nuclear magnetic resonance measurements of wettability and fluid saturations in chalk
R. Gauchet, P. Cheneviere, J.-P. Tricart	Visualization of rock samples in their natural state using environmental scanning electron microscope

A.G. Putz, Y.M. Morineau, R. Begani	Gamma ray absorption measurements: Laboratory experiements in bottomhole conditions
C. Rossini, F. Brega, L. Piro, M. Rovellini, G. Spotti	An application of combined geostatistical and dynamical simulations for developing a reservoir management strategy: A case history
D.L. Luffel, C.W. Kopkins, P.D. Schettler	Matrix permeability measurement of gas productive shales
S.R. McDougall, K.S. Sorbie	The combined effect of capillary and viscous forces on waterflood displacement efficiency in finely laminated porous media
K.R. Christoffersen, C.H. Whitson	Gas/oil capillary pressure of chalk at elevated pressures