MINISTERUL EDUCAȚIEI ȘI CERCETĂRII
UNIVERSITATEA PETROL-GAZE DIN PLOIEȘTI
B-dul. Bucureşti nr. 39, 100680 Ploieşti - România
www.upg-ploiesti.ro
Telefon +40 244 573 171 Fax +40 244 575 847

INSTITUȚIA ORGANIZATOARE DE STUDII UNIVERSITARE DE DOCTORAT
UNIVERSITATEA PETROL-GAZE DIN PLOIEȘTI
DOMENIUL FUNDAMENTAL – ȘTIINȚE INGINEREȘTI
DOMENIUL DE DOCTORAT – MINE, PETROL ȘI GAZE

TEZĂ DE DOCTORAT

CONTRIBUȚII PRIVIND REACTIVAREA SONDELOR DE GAZE NATURALE DIN ZĂCĂMINTE DEPLETATE

CONTRIBUTIONS REGARDING THE REACTIVATION OF NATURAL GAS WELLS FROM DEPLETED RESERVOIRS

AUTOR,
Stoica I. Ioan Alexandru

CONDUCĂTOR ȘTIINȚIFIC:
Prof. univ. dr. ing. Lazăr AVRAM

PLOIEȘTI, 2026

ABSTRACT

Este de-acum bine cunoscut faptul că România dispune de un potențial geologic considerabil în domeniul gazelor naturale, cu o tradiție îndelungată în explorarea și exploatarea acestor resurse. Bazinul Transilvaniei, în mod particular, conține numeroase zăcăminte de gaze libere, situate în structuri geologice complexe, care necesită metode avansate de analiză, simulare și optimizare a extracției. În condițiile în care, o mare parte a acestor zăcăminte este depletată, creșterea factorului final de recuperare devine un obiectiv strategic pentru industria de profil.

În plus, contextul actual marcat de provocările climatice, reglementările de mediu tot mai stricte și presiunea tranziției energetice impune o reevaluare a modului în care aceste resurse pot fi valorificate în mod sustenabil.

Lucrarea de față își propune să analizeze în profunzime caracteristicile geologice, petrofizice și tehnologice ale zăcămintelor de gaze naturale din Bazinul Transilvaniei, cu accent pe strategiile moderne de extracție și simulare numerică, în vederea optimizării procesului de exploatare. De asemenea, sunt abordate implicațiile economice și perspectivele de valorificare a zăcămintelor depletate, fie prin reactivare, fie prin conversia acestora în depozite subterane de înmagazinare în concordanță cu cerințele unei piețe energetice aflate într-un proces accelerat de transformare.

Mai mult dificultățile tehnologice întâlnite în exploatarea zăcămintelor de gaze naturale aflate la stadiul de maturitate sunt diferite, complexe și reclamă tratarea în mod diferenţiat a celor trei componente fundamentale: zăcământ, sonde, infrastructură de suprafaţă. Intervenția într-una dintre ele sau intervenția concomitentă în cele trei componente este dictată de o rațiune bazată pe tandemul tehnico-economic.

Lucrarea este structurată pe cinci capitole propriu-zise, iar tematicile selectate pentru cercetare își au esența în constatările, observațiile sau fenomenele întâlnite de autor în procesul de exploatare a sondelor de gaze naturale din Bazinul Transilvaniei, ca urmare a implicării directe în procesele de lucru, ca și în elaborarea unor planuri de dezvoltare a unor zăcăminte comerciale.

Tendințele actuale de exploatare a zăcămintelor depletate de gaze naturale sunt prezentate în capitolul 1, în contextul aplicării conceptului de *reabilitare*. Am plecat de la premisa că pentru suplimentarea cantității de gaze necesare, există câteva metode generale: mărirea factorului de recuperare al zăcământului; identificare unor noi acumulări de gaze în cadrul obiectivelor de exploatare; identificare unor noi acumulări de gaze între obiectivele de exploatare; identificarea unor noi acumulări de gaze în afara obiectivelor de exploatare, prin posibilitatea continuității lor în afara perimetrelor de exploatare. Aceste metode au la bază rezultatele investigărilor geofizice moderne, reanalizarea datelor existente și reconstrucția

modelelor de zăcământ. Pentru atingerea unui FFR cât mai mare, realizat cu costuri cât mai reduse, am propus diferite principii şi metode moderne, care, toate la un loc contribuie la o cunoaştere cât mai corectă a zăcămintelor unei structuri gazeifere. În principiu, e vorba de: folosirea principiilor moderne ale geologiei secvențiale prin identificarea ciclurilor de sedimentare; reinterpretarea proprietăților petrofizice pe baza investigărilor recente de gaură tubată/netubată; reinterpretarea modelului 3D, a contactelor de gaze/ apă, pe baza istoricului de producție; modelarea continuității zăcămintelor, forma, extinderea lor după identificarea faciesurilor depoziționale ale ciclurilor sedimentare; modelarea exploatării zăcământului pe baza istoricului de producție, a simulării curgerii și realizarea modelului dinamic 3D etc. Pentru a da consistență acestor aspecte, am prezentat cinci cazuri concrete din zăcăminte depletate, unde s-au aplicat cu succes metodele prezentate în această lucrare.

În capitolul 2 sunt abordate chestiuni legate de modelarea numerică a curgerii gazelor naturale în zăcămintele depletate. Mai exact spus, e vorba de utilizarea modelării numerice pentru identificarea posibilelor zone nedrenate sau slab drenate din zăcământ, a limitelor de drenaj dintre sondele adiacente, a extinderii conului depresionar din timpul producției, a interferențelor dintre sonde sau frontiere de curgere asimetrice etc. În acest sens, am avut în vedere câteva elemente de bază privitoare la calibrarea datelor din ecuație după istoricul de producție, compararea presiunii din grid cu curbele de refacere și calibrarea după istoricul de presiune. Pentru stabilirea bazelor teoretice ale modelării am trecut în revistă: aproximarea ecuației de difuzie prin metoda diferențelor finite; aplicarea seriei Taylor; stabilirea condițiilor inițiale şi a celor la limita de drenaj; soluționarea câmpului de presiune prin rezolvare matriceală; soluția triagonală. În continuare, pentru a construi ecuațiile cu diferențe finite pentru curgerea gazelor reale am apelat la metoda de aproximare a blocurilor de grid. Finalmente, printr-un extins studiu de caz, am determinat zonele de influență ale sondelor la un zăcământ depletat (un zăcământ din depozitele sarmațiene ale bazinului Transilvaniei), obținând astfel o suplimentare a contribuțiilor, acest capitol sensibil al modelării numerice a zăcămintelor depletate. Mai mult, prin modelul prezentat, aplicat la un zăcământ de gaze libere din bazinul Transilvaniei, am construit un cadru teoretic prin care se poate urmări comportamentul zăcământului depletat prin discretizarea zăcământului și setarea unor proprietăți discrete (în cazul de față presiunea de zăcământ). Iar prin extinderea modelării, ea poate servi la identificarea unor zone slab drenate care se pot valorifica în viitor, contribuind astfel la mărirea factorului de recuperare.

În capitolul 3, dedicat tehnicilor performante de redeschidere a zăcămintelor depletate de gaze naturale, am prezentat, într-un tot unitar, evoluția și evidențierea rolului investigărilor geofizice moderne, strategia valorificării zăcămintelor depletate, precum și tehnicile moderne de extracție folosite pentru a atinge scopul dorit – mărirea factorului final de exploatare, într-o activitate cu rentabilitate maximă. Desigur, seismica 4D este una dintre cele mai importante dezvoltări tehnologice din industria geofizică. La scurt timp după introducerea sa, a devenit un instrument extrem de eficient pentru a aborda multe dintre provocările asociate cu gestionarea zăcământului, cum ar fi cartografierea gazelor nedrenate sau ocolite în rezervoare complexe, incertitudinea evaluării rezervelor[1], amplasarea mai bună a sondelor de producție și injecție și proiectarea instalațiilor de dezvoltare, toate conducând la dezvoltarea optimizată a câmpului[2]. Mai departe, aplicarea unor metode noi de cercetare prin inventarierea zăcămintelor existente, în afara noilor informații ale cercetărilor seismice 2D, 3D și 4D, trebuie să aibă în vedere și actualizarea informațiilor privitoare la starea găurii de sondă, la porozitate, la saturație ș.a., prin noile și variatele metode de investigații geofizice: PNN, RST, PLT, CBL-VDL, MIT-MTT.

Apoi, odată identificate zonele cu potențial din zăcământul depletat, ca și riscurile legate de valorificarea lor, se pune problema modalităților de realizare concrete: reveniri la teste vechi; adiționări în cadrul obiectivelor deschise; reperforări ale zonelor deschise; adâncirile sondelor existente în zonele depletate; gaură nouă de sondă din coloana existentă (“sidetrack”), forajul unei sonde noi pentru mărirea FFR a zăcământului (“infill drilling”) ș.a. Alegerea uneia sau a alteia dintre aceste modalități este legată de factori economici, de accesibilitatea pe teren, de gradul de conservare a găurilor de sonde existente, de geometria lor etc. Și nu în ultimul rând, în cadrul acestui capitol, am prezentat, într-o formă sintetică, tehnicile moderne pentru lucrările de redeschideri: soluții moderne de perforare a stratelor; lucrări de fisurare hidraulică; soluții de cimentare a găurilor noi pentru zonele depletate; soluții în cazul forajului sub presiune controlată (MPD); soluții la lucrările realizate la subechilibru.

În capitolul 4 am prezentat șase studii de caz semnificative pentru: reperforarea zăcământului (sonda 1); adiționare în cadrul zăcământului (sonda 2); retragere la zăcământul superior (sonda 3); mărirea gabaritului de exploatare al zăcământului (sonda 4); revenire la zăcământ testat la 45 MSMCD cu sonda respectivă (sonda 5); propunerea de adâncire la zăcământul inferior (sonda 6).

La fiecare dintre ele am prezentat premisele proiectării lucrării, operațiile efectuate și rezultatele obținute.

În ultimul capitol, al 5-lea, sunt sintetizate concluziile şi contribuţiile personale prezentate pe parcursul întregii lucrări.

[1] G.E. Archie, "The Electrical Resistivity Log as an Aid in determining some Reservoir Characteristics", AIME, Vol.146, p.54. (1942)

[2] Wheaton, R., 2016. Fundamentals of applied reservoir engineering. Cambridge, MA: Gulf Professional Publishing, an imprint of Elsevier

ABSTRACT

It is now well known that Romania has considerable geological potential in the field of natural gas, with a long-standing tradition in the exploration and exploitation of these resources. The Transylvanian Basin contains numerous free gas deposits located in complex geological structures, which require advanced methods of analysis, simulation, and optimization of extraction. Given that a large part of these deposits is depleted, increasing the final recovery factor becomes a strategic objective for the industry.

Moreover, the current context—marked by climate challenges, increasingly strict environmental regulations, and the pressure of the energy transition—requires a re-evaluation of how these resources can be sustainably utilized.

This paper aims to thoroughly analyse the geological, petrophysical, and technological characteristics of natural gas deposits in the Transylvanian Basin, with a focus on modern extraction strategies and numerical simulation to optimize the exploitation process. It also addresses the economic implications and prospects for valorising depleted deposits, either through reactivation or by converting them into underground storage facilities, in line with the requirements of an energy market undergoing rapid transformation.

Furthermore, the technological difficulties encountered in exploiting mature natural gas deposits are varied and complex, requiring differentiated treatment of the three fundamental components: the deposit, the wells, and the surface infrastructure. Intervention in one or all three components is dictated by a rationale based on the technical-economic tandem.

The paper is structured into five main chapters, and the research topics selected are rooted in the findings, observations, or phenomena encountered by the author during the exploitation of natural gas wells in the Transylvanian Basin, because of direct involvement in work processes and in the development of commercial deposit development plans.

Current trends in the exploitation of depleted natural gas deposits are presented in Chapter 1, in the context of applying the rehabilitation concept. The premise is that to supplement the required amount of gas, several general methods exist increasing the recovery factor of the deposit; identifying new gas accumulations within exploitation targets; identifying new gas accumulations between exploitation targets; identifying new gas accumulations outside exploitation targets, through the possibility of their continuity beyond the exploitation perimeters.

These methods are based on the results of modern geophysical investigations, reanalysis of existing data, and reconstruction of deposit models. To achieve a higher final recovery factor (FRF) at lower costs, various modern principles and methods have been proposed, all contributing to a more accurate understanding of the deposits within a gas-bearing structure. These include: using modern principles of sequence stratigraphy by identifying sedimentation cycles; reinterpretation of petrophysical properties based on recent cased/uncased hole investigations; reinterpretation of the 3D model and gas/water contacts based on production history; modelling the continuity, shape, and extent of deposits after identifying the depositional facies of sedimentary cycles; modelling deposit exploitation based on production history, flow simulation, and creating a dynamic 3D model, etc. To substantiate these aspects, five concrete cases from depleted deposits are presented, where the methods discussed in this paper were successfully applied.

Chapter 2 addresses issues related to the numerical modelling of natural gas flow in depleted reservoirs. More specifically, it discusses the use of numerical modelling to identify potentially undrained or poorly drained zones within the reservoir, drainage boundaries

between adjacent wells, the extent of the depression cone during production, well interference, and asymmetric flow boundaries. To this end, several fundamental elements were considered, such as calibrating equation data based on production history, comparing grid pressure with recovery curves, and calibrating based on pressure history.

To establish the theoretical foundations of modelling, the following were reviewed: approximation of the diffusion equation using the finite difference method; application of the Taylor series; setting initial conditions and drainage boundary conditions; solving the pressure field through matrix resolution; and the tridiagonal solution. Subsequently, to construct finite difference equations for real gas flow, the grid block approximation method was used. Finally, through an extensive case study, the influence zones of wells in a depleted reservoir (from the Sarmatian deposits of the Transylvanian Basin) were determined, thereby contributing to this sensitive chapter on numerical modelling of depleted reservoirs. Moreover, through the presented model applied to a free gas reservoir in the Transylvanian Basin, a theoretical framework was built to monitor the behaviour of the depleted reservoir by discretizing it and setting discrete properties (in this case, reservoir pressure). By extending the modelling, it can serve to identify poorly drained zones that may be exploited in the future, thus contributing to increasing the recovery factor.

Chapter 3, dedicated to advanced techniques for reopening depleted natural gas reservoirs, presents a unified overview of the evolution and role of modern geophysical investigations, strategies for valorising depleted reservoirs, and modern extraction techniques used to achieve the desired goal—maximizing the final recovery factor in a highly profitable activity. Of course, 4D seismic is one of the most important technological developments in the geophysical industry. Shortly after its introduction, it became an extremely effective tool for addressing many challenges associated with reservoir management, such as mapping undrained or bypassed gas in complex reservoirs, uncertainty in reserve evaluation, better placement of production and injection wells, and development facility design—all leading to optimized field development.

Furthermore, the application of new research methods through inventorying existing reservoirs, beyond the new information from 2D, 3D, and 4D seismic surveys, must also consider updating data on wellbore condition, porosity, saturation, etc., using new and varied geophysical investigation methods: PNN, RST, PLT, CBL-VDL, MIT-MTT.

Once zones with potential in the depleted reservoir are identified, along with the risks associated with their exploitation, the question arises of how to proceed practically: revisiting old tests; additions within open targets; reperforation of open zones; deepening existing wells in depleted zones; side-tracking from existing casing; drilling new wells to increase the reservoir's recovery factor ("infill drilling"), etc. The choice among these methods depends on economic factors, field accessibility, the preservation state of existing wellbores, their geometry, and more.

Lastly, this chapter presents, in a synthetic form, modern techniques for reopening operations: advanced layer perforation solutions; hydraulic fracturing operations; cementing solutions for new wellbores in depleted zones; solutions for managed pressure drilling (MPD); and solutions for underbalanced operations.

Chapter 4 presents six significant case studies for:

- Reperforation of the reservoir (Well 1);
- Addition within the reservoir (Well 2);
- Withdrawal to the upper reservoir (Well 3);
- Expansion of the reservoir's exploitation capacity (Well 4);

- Return to a reservoir previously tested at 45 MSMCD with the respective well (Well 5);
- Proposal for deepening to the lower reservoir (Well 6).

For each case, the design premises, operations performed, and results obtained are presented.

Chapter 5, the final chapter, synthesizes the conclusions and personal contributions presented throughout the entire work.

Bibliografie

1. G.E. Archie, "The Electrical Resistivity Log as an Aid in determining some Reservoir Characteristics", AIME, Vol.146, p.54. (1942)
2. Wheaton, R., 2016. Fundamentals of applied reservoir engineering. Cambridge, MA: Gulf Professional Publishing, an imprint of Elsevier

3. Davis J.C. (2002). Statistics and Data Analysis in Geology, third edition. USA: John Wiley & Sons, Inc: 461.
4. Cătuneanu, Octavian: *Sequence stratigraphy of clastic systems: concepts, merits, and pitfalls*, Journal of African Earth Sciences 35 (2002) 1–43
5. Plint, A.G. and Nummedal, D. (2000). The falling stage Systems Tract: recognition and importance in Sequencestratigraphic analysis. In: Hunt, D., Gawthorpe, R.L. (Eds.), Sedimentary Response to Forced Regression, 172. Geological Society London. Special Publication, pp.1–17
6. Nummedal, D. and Swift, D.J.P. (1987). Transgressive stratigraphy at sequence-bounding unconformities: some principles derived from Holocene and Cretaceous examples. In: Nummedal, D., Pilkey, O.H., Howard, J.D. (Eds.), Sea-level fluctuation and coastal evolution. Special Publication 41. Society of Economic Paleontologists and Mineralogists (SEPM), pp.241–260
7. Catuneanu, O., Bhattacharya, J. P., Blum, M. D., Dalrymple, R.W., Eriksson, P. G., Fielding, C. R., Fisher, W. L., Galloway, W. E., Gianolla, P., Gibling, M. R., Giles, K. A., Holbrook, J. M., Jordan, R., Kendall, C. G. St. C., Macurda, B., Martinsen, O. J., Miall, A. D., Nummedal, D., Posamentier, H.W., Pratt, B. R., Shanley, K.W., Steel, R. J., Strasser, A. and Tucker, M. E. (2010). Sequence stratigraphy: common ground after three decades of development. First Break, v.28, pp.21–34
8. Yang, Guofeng, Peng, Wenzheng, Ye, Hongfa, Wang, Zhengyan, Chen, Meng, and Xiangjun Liu. "Borehole Effect Correction in Pulsed Neutron-Neutron Logging for Formation Capture Cross-Section Determination." Paper presented at the SPWLA 65th Annual Logging Symposium, Rio de Janeiro, Brazil, May 2024. doi: https://doi.org/10.30632/SPWLA-2024-0103
9. Larry Jacobson; Venkataraman Jambunathan; Zhipeng Liu; Weijun Guo, Technical advances in pulsed-neutron interpretation for cased-hole logging: Physics, interpretation, and log examples, https://doi.org/10.1190/INT-2014-0174.1, January 2015
10. Tylor-Jones, T., Azevedo, L. (2022). The Seismic Method. In: A Practical Guide to Seismic Reservoir Characterization. Advances in Oil and Gas Exploration & Production. Springer, Cham, Switzerland AG 2023
11. Schreuder J.C. and Sharpe P.J. (1999). Drilling The Limit – A Key to Reduce Well Costs. SPE 57258, Asia Pacific Improved Oil Recovery Conference, Malaysia, October 1999.
12. Higgins, R. V., “Calculating oil recoveries for solution-gas drive reservoirs,” RI 5226, USBM, April 1956.
13. J.A. Kupeez, and L.S. Land, Progressive re-crystallization and stabilization of early stage dolomite: lower Ordovician Ellen burger group, West Test Taxes, International Association of sedimentologists, special publication, (1995).
14. Dahi Taleghani, A., Santos, L. (2023). Diagnostic Methods: Well Logging Methods. In: Wellbore Integrity. Springer, Cham. https://doi.org/10.1007/978-3-031-19024-7_6, 2023

15. Saini, P., Kumar, H. & Gaur, T. Cement bond evaluation using well logs: A case study in Raniganj Block Durgapur, West Bengal, India. J Petrol Explor Prod Technol 11, 1743–1749 (2021). https://doi.org/10.1007/s13202-021-01151-z, 2021
16. Ajgou, Nadir , Graba, Bachir , Sayah, Laid , Ismail, Moustafa , Yakupov, Alfir , Saada, Mahmoud , Rourke, Marvin , and Mongi Abdelmoula. "Effective Solutions To Well Integrity Management Using Multi Finger Caliper And Electromagnetic Tool." Paper presented at the SPE Gas & Oil Technology Showcase and Conference, Dubai, UAE, October 2019. doi: https://doi.org/10.2118/198570-MS, 2019
17. Baker Hughes. 2010. Baker Oil Tools: Coiled Tubing Solutions, Handbook.
18. Dornan, G., Autry, S., Fox, P., Krysinski, M., Nutter, G., and Cheblak, S. "Industry First; Rigless ESP Enables ellbore Access to Perform a Coiled-Tubing Clean Out.." Paper presented at the SPE International Heavy Oil Conference and Exhibition, Kuwait City, Kuwait, December 2018. doi: https://doi.org/10.2118/193652-MS
19. Allegretti, G., Lerose, M., Mangione, A., Di Vincenzo, S., Luppinan, S., Cervantes, J., Tarchi, M. L., Cerri, P., Abid, M. L., Boyce, R., Mahmoudi, H., Mebarki, S., and Nacer R. A. "A New Rigless Approach for Fishing a Stuck and arted Coiled Tubing in a Live Well." Paper presented at the ADIPEC, Abu Dhabi, UAE, October 2022. doi: https://doi.org/10.2118/211551-MS
20. Alshuhail, F., Alsaad, M., and Mahboob A. "Application of Biosteered Underbalanced Coiled Tubing Drilling in Optimizing Production." Paper presented at the International Petroleum Technology Conference, Bangkok, Thailand, March 2023. doi: https://doi.org/10.2523/IPTC-22931-EA
21. Huazheng, Shao, Ningjing, Jin, and Feng Li. "Case Study: High-Expansion Dissolvable Plug for Casing-Deformation Challenges in Plug-and-Perf Operations." *J Pet Technol* 77 (2025): 1–5. doi: https://doi.org/10.2118/0925-0007-JPT
22. Zhong Gongxiang (2014) “The Hydraulic Control System of Snubbing Unit Based on PLC”, Chinese Hydraulics & Pneumatics, 31(2), pp.117-120.
23. Grant J. Duncan (2008) “Avoid downhole Explosions, Buckled Pipe and Parted Tubing During Snubbing Operations”, Proc. Conf. on. SPE’s Annual Technical Conference and Exhibition, pp.1-12
24. Cappuccio, Pasquale , Imbò, Pasquale , and Simone Gorini. "Telemetry Managed Well Head Compressor: A Real Case Application." Paper presented at the Abu Dhabi International Petroleum Exhibition & Conference, Abu Dhabi, UAE, November 2018. doi: https://doi.org/10.2118/192689-MS, 2018
25. Mian, Mohammed A., "Petroleum Engineering Handbook for Practicing Engineer", Tulsa, Oklahoma, 1991.
26. L.P. Dake: *Fundamentals of reservoir engineering*, SHELL International Petroleum Maatschappij, Haga, 1978, p.256
27. John Lee, Robert A. Wattenbarger: *Gas Reservoir Engineering*, SPE Houston, Texas, 1999-2004, pag 259

28. John Lee, Robert A. Wattenbarger: *Gas Reservoir Engineering*, SPE Houston, Texas, 1999-2004, pag 261
29. M. R. J. Wyllie, A. R. Gregory, and G. H. Gardner, An experimental non-stainless movement (Residual Oil Saturation ROS) at wells Rt-5, and Rt-7, while the minimum values (ROS) and increasingly so values (MOS) at the well Rt-4.
30. John Lee, Robert A. Wattenbarger: *Gas Reservoir Engineering*, SPE Houston, Texas, 1999-2004, pag 264
31. Freundl, C., Rüde, U. (2011). Gauss-Seidel Iterative Method for the Computation of Physical Problems. In: Vöcking, B., *et al.* Algorithms Unplugged. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-15328-0_30, Springer, Berlin, Heidelberg
32. Nascimento, A., Maul, A. & Lupinacci, W.M. A novel approach to advancing the application of genetic algorithms in sequential seismic inversion. *Comput Geosci* 29, 42 (2025). https://doi.org/10.1007/s10596-025-10381-7, 2025
33. John Lee, Robert A. Wattenbarger: *Gas Reservoir Engineering*, SPE Houston, Texas, 1999-2004, pag 264
34. Toutounian, F. The stable A^TA-orthogonal *s*-step Orthomin(k) algorithm with the CADNA library. *Numerical Algorithms* 17, 105–119 (1998). https://doi.org/10.1023/A:1012013911053
35. Archer, J.S., Wall, C.G. (1986). Radial Flow Analysis of Well Performance. In: Petroleum Engineering. Springer, Dordrecht. https://doi.org/10.1007/978-94-010-9601-0_9
36. Fasshauer, G.E. Solving differential equations with radial basis functions: multilevel methods and smoothing. *Advances in Computational Mathematics* 11, 139–159 (1999). https://doi.org/10.1023/A:1018919824891, 1999
37. Shchipanov, A., Kollbotn, L. & Namazova, G. PTA-metrics for time-lapse analysis of well performance. *J Petrol Explor Prod Technol* 13, 1591–1609 (2023). https://doi.org/10.1007/s13202-023-01631-4, 2023
38. Pan, Y., Yan, ZG., Peiró, J. et al. Development of a Balanced Adaptive Time-Stepping Strategy Based on an Implicit JFNK-DG Compressible Flow Solver. Commun. Appl. Math. Comput. 4, 728–757 (2022). https://doi.org/10.1007/s42967-021-00138-1, 2021
39. Oertel, H. (2010). Fundamental Equations of Fluid Mechanics. In: Oertel, H. (eds) Prandtl-Essentials of Fluid Mechanics. Applied Mathematical Sciences, vol 158. Springer, New York, NY. https://doi.org/10.1007/978-1-4419-1564-1_5, 2009
40. Li, L., Abushaikha, A. A fully implicit parallel framework for complex reservoir simulation with mimetic finite difference discretization and operator-based linearization. Comput Geosci 26, 915–931 (2022). https://doi.org/10.1007/s10596-021-10096-5
41. Hafsi, Z., Ayed, L., Mishra, M., Elaoud, S. (2023). Analysis of Buckley-Leverett Problem for Water Flooding in Oil Reservoir Rock: Analytical and Numerical Modeling. In: Walha, L., *et al.* Design and Modeling of Mechanical Systems - V. CMSM 2021.

Lecture Notes in Mechanical Engineering. Springer, Cham. https://doi.org/10.1007/978-3-031-14615-2_84, 2022

42. Liu, Q., Lv, B., Konietzky, H. *et al.* A Novel Method for Rock Permeability Determination Based on the Pressure Pulse Decay Method and Inverse Numerical Simulations. *Rock Mech Rock Eng* 57, 10229–10244 (2024). https://doi.org/10.1007/s00603-024-04095-y, 2024
43. John Lee, Robert A. Wattenbarger: *Gas Reservoir Engineering*, SPE Houston, Texas, 1999-2004, pag 258
44. John Lee, Robert A. Wattenbarger: *Gas Reservoir Engineering*, SPE Houston, Texas, 1999-2004, pag. 250
45. L.P. Dake: Fundamentals of reservoir engineering, SHELL International Petroleum Maatschappij, Haga, 1978, pag 274
46. Equation solver for 15 x 15 liniar equations system using the Gauss – Jordan elimination method, https://elsenaju.eu/Calculator/system-of-equations-Gauss-NxN.htm
47. N. Tsao, On the Equivalence of Gaussian Elimination and Gauss-Jordan Reduction in Solving Linear Equations. Cleveland: National Aeronautics and Space Administration, 1989.
48. D. Dasgupta, “In-Place Matrix Inversion by Modified Gauss-Jordan Algorithm,” Appl. Math., vol. 4, pp. 1392– 396, 2013.
49. L.P. Dake: *Fundamentals of reservoir engineering*, SHELL International Petroleum Maatschappij, Haga, 1978, pag 245-247
50. A. P. G. A., www.apga.org/apgamainsite/aboutus/facts/history-of-natural-gas
51. The history of the European oil and gas industry, www.doi.org/10.1144/SP465.23
52. Gazele naturale în România, www.wikipedia.org
53. Nanda, N.C. (2021). Evaluation of High-Resolution 3D and 4D Seismic Data. In: Seismic Data Interpretation and Evaluation for Hydrocarbon Exploration and Production. Advances in Oil and Gas Exploration & Production. Springer, Cham. https://doi.org/10.1007/978-3-030-75301-6_8, 2021
54. Nguyen, P.K.T., Nam, M.J. & Park, C. A review on time-lapse seismic data processing and interpretation. Geosci J 19, 375–392 (2015). https://doi.org/10.1007/s12303-014-0054-2, 2015
55. Newman, A.V.; Dixon, T.H.; Ofoegbu, G.; Dixon, J.E. Geodetic and seismic constraints on some seismogenic and non-seismogenic processes associated with the 2001 Bhuj earthquake. Bull. Seismol. Soc. Am. 2006, 96, 1910–1927.
56. Craft, B. C., and M. F. Hawkins, Applied Petroleum Reservoir Engineering, Prentice-Hall Inc., Englewood Cliffs, NJ, (1959), pp. 110-138.
57. Montgomry, D.C. and Runger G.C. (2003). Applied statistics and probability for Engineers, third edition. USA: John Wiley & Sons, Inc: 482.
58. Partha Pratim Mitra: Developments in Structural Geology and Tectonics, Vol. 6, 2023, pag. 285-326

59. Phung K.T. Nguyen et col.: A review on time-lapse seismic data processing and interpretation, ⓒ The Association of Korean Geoscience Societies and Springer 2015
60. Schlumberger, Log Interpretation Charts, 2015 Edition
61. RAS –Reservoir Analysis System, Prospecțiuni S.A. presentation
62. Temizel, C., Zhiyenkulov, M., Ussenova, K., and Tilek, K. (2018). “Optimization of well placement in waterfloods with optimal control theory under geological uncertainty,” in SPE Annual Technical Conference and Exhibition, Dallas, Texas, USA, September 2018 (OnePetro). doi:10.2118/191660-MS
63. Wang, C., Li, G., and Reynolds, A. C. (2007). Optimal well placement for production optimization Eastern Regional Meeting. Lexington, Kentucky, USA, October 2007: Society of Petroleum Engineers.
64. Pouladi, B., Karkevandi-Talkhooncheh, A., Sharifi, M., Gerami, S., Nourmohammad, A., and Vahidi, A. (2020). Enhancement of SPSA algorithm performance using reservoir quality maps: Application to coupled well placement and control optimization problems. J. Petroleum Sci. Eng. 189, 106984. doi: 10.1016/j.petrol.2020.106984
65. Li, L., Jafarpour, B., and Mohammad-Khaninezhad, M. R. (2013). A simultaneous perturbation stochastic approximation algorithm for coupled well placement and control optimization under geologic uncertainty. Comput. Geosci. 17, 167–188. doi:10.1007/s10596-012-9323-1
66. Julien Aubert, State and evolution of the geodynamo from numerical models reaching the physical conditions of Earth’s core, Geophysical Journal International, Volume 235, Issue 1, October 2023, Pages 468–487, https://doi.org/10.1093/gji/ggad229
67. D.J. Guillot, and E. Le Bastard, 2012, ―Learnings from Foamed Cement Job Simulations‖, paper OTC 23666, presented at Offshore Technology Conference 2012, Houston, April 30 – May 3, 2012.
68. Vela, Jose , Arias, Henry , Sanchez, Edwin , and Juan Ramon Garzon. "Foam Cement Proven as Effective Solution for Zonal Isolation in Difficult Wellbores: A Success Field Case in Colombian Mature Fields." Paper presented at the SPE Latin American and Caribbean Petroleum Engineering Conference, Virtual, July 2020. doi: https://doi.org/10.2118/199097-MS
69. Nelson, E.B, Guillot, D., Well Cementing, 2nd edition, Schlumberger, Sugar Land, 2006.
70. Kutchko, B, Crandall, et.al., ―A Look at Processes Impacting Foamed Cements’, SPE-180337-MS, 2016.
71. R.M. Ahmed, N.E. Takach, U.M. Khan, S. Taoutaou, S. James, A. Saasen and R. Godoy, 2009, Rheology of Foamed Cement‖ technical article published in Cement and Concrete Research Journal 39, pages 353 – 361, 2009 doi:10.1109/TVCG.2007.70405.
72. Ahmed Abdulhamid Mahmoud et col.: Foamed Cement Applications in Oil Industry Based on Field Experience: A Comprehensive Review, ACS Omega, 02.2024
73. Piot, Bernard, and Loizzo, Matteo, 1998, ―Reviving the Job Signature Concept for Better Quality Cement Jobs‖, paper IADC/SPE 39350, presented at IADC/SPE Drilling Conference, Dallas, March 3 – 6, 1998.

74. Davies, D.R., Hartog, J.J., and Cobbett, J.S.: ―Foamed Cement—A Cement with Many Applications,‖ paper SPE 9598 presented at the SPE Middle East Oil Technical Conference, Manama, Bahrain (March 9–12, 1981)
75. Cooley, C. H., Khonsari, M. M., & Lingwall, B. (2012). The development of open water lubricated polycrystalline diamond (PCD) thrust bearings for use in marine hydrokinetic (MHK) energy machines. https://doi.org/10.2172/1056274
76. Dowell –Schlumberger: Well Analysis Manual, 1997
77. Dowell –Schlumberger: Well Analysis Manual, 1997
78. Dowell –Schlumberger: Well Analysis Manual, 1997