Oil & Gas Science and Technology – Rev. IFP Energies nouvelles **76**, E1 (2021)
© S. Sun et al., published by IFP Energies nouvelles, 2021
https://doi.org/10.2516/ogst/2021008

Available online at:
ogst.ifpenergiesnouvelles.fr

Advanced modeling and simulation of flow in subsurface reservoirs with fractures and wells for a sustainable industry
S. Sun, M.G. Edwards, F. Frank, J.F. Li, A. Salama, B. Yu

EDITORIAL

OPEN ACCESS

Editorial: Advanced modeling and simulation of flow in subsurface reservoirs with fractures and wells for a sustainable industry

Shuyu Sun[1,*], Michael Edwards[2], Florian Frank[3], Jingfa Li[4], Amgad Salama[5], and Bo Yu[6]

[1] Division of Physical Science and Engineering, King Abdullah University of Science and Technology, Mail box # 2077, Thuwal 23955-6900, Saudi Arabia
[2] Chair in Engineering, Swansea University, Singleton Park, Swansea, Wales SA2 8PP, UK
[3] Applied Mathematics (Modeling and Numerics), Friedrich-Alexander-University of Erlangen-Nürnberg, Cauerstraße 11, 91058 Erlangen, Germany
[4] School of Mechanical Engineering, Beijing Institute of Petrochemical Technology, Beijing 102617, China
[5] Faculty of Engineering, University of Regina, Regina, Saskatchewan, S4S 0A2, Canada
[6] School of Mechanical Engineering, Beijing Institute of Petrochemical Technology, Beijing 102617, China

Accepted: 22 February 2021

Flow in subsurface reservoirs is a crucial process in a wide range of applications at different time and space scales, such as petroleum exploration and recovery, groundwater contamination, subsurface carbon sequestration, and geothermal reservoir engineering. As an effective method, modeling and simulation of flow in subsurface reservoirs become essential components of many scientific and engineering applications in recent years. Significant advances have been made in this area, but accurate modeling and efficient, robust simulation still remain a challenging problem, especially for flow and transport in subsurface reservoirs with fractures and wells. To facilitate the exchange and dissemination of original research results and state-of-the-art reviews pertaining to flow in subsurface reservoirs with fractures and wells efficiently, we organized a special issue on "Advanced modeling and simulation of flow in subsurface reservoirs with fractures and wells for a sustainable industry" within Oil & Gas Science and Technology.

This special issue presents a total of 15 invited manuscripts contributed from influential worldwide universities, colleges, and industrial institutes. These manuscripts cover major topics relevant to the numerical modeling and algorithms for flow and transport in subsurface reservoirs, especially with fractures and wells for a sustainable industry; they not only present the ongoing research but also show general trends in the predictable future. These 15 articles can be classified into five groups and a brief summary of each group is given below.

Group A includes a number of new numerical methods in the acidizing process. Acidizing is an economical and effective practice used to remove the near wellbore damage that is performed by injecting acid into a formation through the wellbore, dissolving the rock, and improving its permeability. In this special issue, Liu *et al.* [1] developed a 3-D reactive flow model within a non-Darcy framework based on a two-scale continuum model. Five types of dissolution patterns, i.e., face dissolution, conical wormhole, wormhole, ramified wormhole, and uniform dissolution, were obtained as the injection velocity increases. It was found that there is no non-Darcy effect on the dissolution structure and breakthrough volume when the injection velocity is very low. However, more branches can be generated when the injection velocity is very high if the Forchheimer equation is adapted other than the Darcy equation. Wu *et al.* [2] generated a thermodynamically consistent Darcy–Brinkman–Forchheimer (DBF) framework, which modifies the momentum conservation equation so as to satisfy the Newton's second law. Based on the improved DBF framework, an energy balance equation was added to formulate a thermal DBF framework, which was validated by numerical tests and lab experiments. Parallelization to the underlying complex framework codes was realized and good scalability has been achieved.

Group B deals with the numerical description of the geological features in fractured porous media. With the increased geological complexity of the fractured structure in the reservoirs along with the acidizing process, a proper description of the geological features in a digital manner is highly demanded. In this special issue, Mei *et al.* [3] applied the separation variable method and Bessel function

* Corresponding author: shuyu.sun@kaust.edu.sa

to solve the single-phase fractal pressure diffusion equation, and then the obtained analytical solution was used to deduce fractal shape factors in various dimensions. The proposed fractal shape factor was proven to be effective in the condition that the tortuosity fractal dimension of the matrix is roughly between 1 and 1.25. Léger and Clochard [4] presented a smooth surface interpolation method making it possible to take discontinuities (*e.g.* faults) into account that can be applied to any dataset defined on a regular mesh. By using a second-derivative multi-scale minimization based on a conjugate gradient method, the proposed approach was enabled to process millions of points in a few seconds on a single-unit workstation. The interpolated surface was continuous, as well as its first derivative, except on some lines that had been specified as discontinuities. Li *et al.* [5] compared the Extended Finite Element Method (XFEM) and the Extended Finite Volume Method (XFVM) in simulating the deformation of fractured porous media. It was found that the accuracy of the XFEM was slightly higher than that of the XFVM, but the latter was more efficient, which is useful in decision making regarding the choice of solving methods for the multi-field coupling problem in fractured porous media.

Group C focuses the modeling and simulation of flow, transport, and heat transfer in fractured porous media. The changing of saturation, velocity, stress, and temperature field in fractured porous media is directly relevant to reservoir recovery and production. In this special issue, El-Amin [6] developed analytical solutions for magnetic polymer transport in porous media, in which the magnetization was treated as a nonlinear function of the magnetic field strength and the effects of the magnetic/polymer/rock properties on the polymer concentration, pressure, and velocity were investigated. Gao *et al.* [7] proposed a new thermodynamically consistent energy-based model for two-phase flows in heterogeneous and fractured media, which was free of the gradient energy. A logarithmic energy potential was proposed as the free energy function to characterize the capillarity effect, and the discrete fracture model was incorporated to describe two-phase flows in fractured media. Wang *et al.* [8] generated a 3D Computational Fluid Dynamics-Discrete Element Method (CFD-DEM) coupling method to investigate the particle transport and deposition in rough fractures, in which the Gauss Model was applied to construct the rough surfaces. A comprehensive particle sedimentary analysis indicated that the deposition distance of particles was inversely proportional to the particle size and density ratio. Xu *et al.* [9] presented a multi-scale approach to study the effect of a pore size distribution on gas injectivity in intraformational water zones. The results indicated that the gas effective permeability increases in a less complex and more discrete pore network. El-Amin *et al.* [10] introduced a theoretical foundation of the stability analysis of the mixed finite element solution to the problem of shale-gas transport in fractured porous media with geomechanical effects, in which the differential system was solved by the Mixed Finite Element Method (MFEM).

Group D concerns flow and transport behaviors in wells. Wells, together with the inner pipelines, are the direct extension of subsurface reservoirs, as well as their connection with the other physical entities. Various operations on the many types of wells involved in petroleum engineering, including pressure/rate control and energy control on the injection wells, production wells and heaters, are the main approaches operated in real reservoir productions. In this special issue, Zhang *et al.* [11] discussed the effect of salinity on oil production, from both the viewpoints of low salinity water flooding techniques and an exploratory study on well inner surface scaling affected by fluid salinity. An advanced phase field model was developed incorporated with the scaling possibility test, and the results suggested the design of injection salinity considering scaling in the well pipelines. Bai [12] performed a critical review on the mechanisms of corrosion in pipelines, while the corrosion growth model and anti-corrosion techniques were presented to support the pipeline operation and integrity management for the wells. Liu *et al.* [13] formulated the numerical models for the common-used wells and related operations, including bottom hole pressure, water rate, oil rate, liquid rate, subcool, and steam control, and all these formulations were implemented in the in-house parallel thermal simulator. A semi-implicit multipurpose industrial reservoir simulator was proposed by Flauraud and Ding [14], to simulate wells equipped with intelligent completions taking into account the pressure drop and multiphase flow. Inflow Control Device (ICD) and Inflow Control Valve (ICV) were integrated in their simulator, and the semi-implicit coupling approach ensured the stability as well as efficiency.

Group E demonstrates productivity analysis. The aim of modeling and simulation of flow in subsurface fractured reservoirs is to enhance the field production. In this special issue, Wang *et al.* [15] established a semi-analytical model for a horizontal well with multiple finite-conductivity reorientation fractures, combining the nodal analysis technique and fracture-wing method, to calculate its dimensionless productivity index and derivative for production evaluation. It was validated in their numerical simulation that the strong permeability anisotropy is a negative factor for well production and the productivity index gradually decreases with the increase of anisotropic factor, which meets the discussion in [9]. It was also pointed out that the well productivity index rises up with the increase of fracture number and fracture spacing, but the horizontal well has the optimal reorientation fracture number and fracture spacing to get the economical productivity.

We are glad to share above articles in our special issue with relevant communities of interest. Although this special issue cannot cover all topics in this area, we believe it will provide a valuable volume to readers on the advanced modeling and simulation of flow in subsurface fractured reservoirs. We sincerely hope the numerical models, algorithms, analytical methods, literature reviews, and all achievements presented in these papers will help to improve the fundamental understanding of the complex flow and transport behaviors involved in reservoir exploration and exploitation. Furthermore, we sincerely hope this special issue can provide a platform for bringing together investigators in this field to exchange the latest research ideas, and to promote further collaborations.

Acknowledgments. We would like to sincerely acknowledge all the authors for their inspiring contributions to this special issue. We would also like to thank the anonymous reviewers for their diligent, helpful and constructive comments that greatly contributed to improving the overall quality of the manuscripts. Finally, our thanks are extended to Oil & Gas Science and Technology for providing a wonderful opportunity to organize this special issue. The managing guest editor Shuyu Sun also expresses his sincere gratitude to the great support from the National Natural Science Foundation of China (51874262 and 51936001) and the Research Funding from King Abdullah University of Science and Technology (KAUST) through the grants BAS/1/1351-01, URF/1/3769-01, and REP/1/2879-01.

References

1 Liu P., Ren X., Kong L., Yao J. (2020) Three-dimensional simulation of acidizing process in carbonate rocks using the Darcy-Forchheimer framework, *Oil Gas Sci. Technol. - Rev. IFP Energies nouvelles* **75**, 48.

2 Wu Y., Kou J., Sun S., Wu Y.S. (2021) Thermodynamically consistent Darcy-Brinkman-Forchheimer framework in matrix acidization, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **76**, 8.

3 Mei L., Zhang H., Wang L., Zhang Q., Cai J. (2020) Fractal analysis of shape factor for matrix-fracture transfer function in fractured reservoirs, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 47.

4 Léger M., Clochard V. (2020) Fast interpolation method for surfaces with faults by multi-scale second-derivative optimization, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 62.

5 Li T., Han D., Yang F., Yu B., Sun D., Wei J. (2020) A comparative study on simulating flow-induced fracture deformation in subsurface media by means of extended FEM and FVM, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 41.

6 El-Amin M.F. (2020) Analytical solutions of polymer transport in porous media under magnetic effect, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 46.

7 Gao H., Kou J., Sun S., Wang X. (2020) Thermodynamically consistent modeling of two-phase incompressible flows in heterogeneous and fractured media, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 32.

8 Wang X., Yao J., Gong L., Sun H., Yang Y., Liu W., Li Y. (2020) Numerical study on particle transport and deposition in rough fractures, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 23.

9 Xu J., Chen Z., Li R. (2020) Impacts of pore size distribution on gas injection in intraformational water zones in oil sands reservoirs, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 75.

10 El-Amin M.F., Kou J., Sun S. (2020) Theoretical stability analysis of mixed finite element model of shale-gas flow with geomechanical effect, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 33.

11 Zhang T., Li Y., Li C., Sun S. (2020) Effect of salinity on oil production: review on low salinity waterflooding mechanisms and exploratory study on pipeline scaling, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 50.

12 Bai H. (2020) Mechanism analysis, anti-corrosion techniques and numerical modeling of corrosion in energy industry, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 42.

13 Liu H., Chen Z., Shen L., Guo X., Ji D. (2020) Well modelling methods in thermal reservoir simulation, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 63.

14 Flauraud E., Ding D.Y. (2020) A semi-implicit approach for the modeling of wells with inflow control completions, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 39.

15 Wang M., Fan Z., Zhao L., Xing G., Zhao W., Tan C. (2020) Productivity analysis for a horizontal well with multiple reorientation fractures in an anisotropic reservoir, *Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles* **75**, 80.