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Modeling and simulation of an acoustic well stimulation method

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HIGHLIGHTS

- A model for the simulation of an acoustic well stimulation (AWS) method is presented.
- A DtN-map is introduced for the accurate numerical simulation of the AWS method.
- The performance of the AWS method is investigated for a wide range of frequencies.

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ABSTRACT

This paper presents a mathematical model and a numerical procedure to simulate an acoustic well stimulation (AWS) method for enhancing the permeability of the rock formation surrounding oil and gas wells. The AWS method considered herein aims to exploit the well-known permeability-enhancing effect of mechanical vibrations in acoustically porous materials, by transmitting time-harmonic sound waves from a sound source device—placed inside the well—to the well perforations made into the formation. The efficiency of the AWS is assessed by quantifying the amount of acoustic energy transmitted from the source device to the rock formation in terms of the emission frequency and the well configuration. A simple methodology to find *optimal emission frequencies* for a given well configuration is presented. The proposed model is based on the Helmholtz equation, a sound-hard boundary condition at the casing, and an impedance boundary condition that effectively accounts for the porous solid–fluid interaction at the interface between the rock formation and the well perforations. Exact non-reflecting boundary conditions derived from Dirichlet-to-Neumann maps are utilized to truncate the circular cylindrical waveguides considered in the model. The resulting boundary value problem is then numerically solved by means of the finite element method. A variety of numerical examples are presented in order to demonstrate the effectiveness of the proposed procedure for finding optimal emission frequencies.

1. Introduction

The decrease of oil and gas recovery from a reservoir is clearly an important problem that affects the energy industry. One of the main causes of such problem is the local reduction of the reservoir permeability around producing wells due to

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the deposition of scales, precipitants and mud penetration during exploitation which, over time, give rise to an impermeable barrier to fluid flow [1]. Well stimulation methods play a prominent role in the exploitation of these essential natural resources as they are intended to increase the permeability of the reservoir, allowing the trapped fluid to flow toward the borehole and thus enhancing the productivity of the well. Various well stimulation methods are used in practice to cope with local deposits, including solvent and acid injection, treatment by mechanical scrapers and high pressure fracturing. Each one of these conventional methods have significant drawbacks and undesirable effects. Some of them, for instance, are expensive and produce damage to the well structure, while others are highly polluting, leading to harmful ecological effects associated with the contamination of underground water resources [1,2]. The demonstrated effectiveness of mechanical vibrations on enhancing fluid flow through porous media [2–4], on the other hand, has led to the development of the so-called *acoustic well stimulation* (AWS) methods, which nowadays have broad acceptance by the hydrocarbon industry mainly due to the fact that they partially overcome the aforementioned issues.

This paper considers an AWS method based on the transmission of acoustic waves, emitted by a transducer submerged into the well, to the rock formation surrounding the well. The transducer is designed to trigger one of the physical processes known to enhance the permeability of the porous medium. Among such physical processes, we mention the reduction of the fluid viscosity by agitation and heating, stimulation of elastic waves on the well walls (to reduce the adherence forces in the layer between oil and rock formation), excitation of natural frequencies associated with the vibration of the fluid inside the porous medium, and the formation and collapse of cavitation bubbles near clogged pores of the rock formation (see [3] for a review). A variety of transducer designs have been proposed over the last three decades, which consider operation frequency and intensity ranges selected to target one (or several) of the aforementioned physical processes [5–8].

This paper presents a mathematical model and a numerical procedure that allows us to find optimal emission frequencies for which the amount of energy transmitted from the transducer into the rock formation is maximized. The proposed methodology can potentially improve the performance of the whole class AWS methods considered, as the aforementioned physical processes take place within the porous medium. In detail, we develop a mathematical model based on the Helmholtz equation and an impedance boundary condition [9] that effectively accounts for the porous solid–fluid interaction at the interface between the rock formation and the well perforations [10]. Exact non-reflecting boundary conditions derived from Dirichlet-to-Neumann (DtN) maps are utilized to truncate the circular cylindrical waveguides considered in the model [11–13]. The resulting boundary value problem is numerically solved by means of the finite element (FE) method [14–16]. Optimal emission frequencies are then found by scanning the quotient of the emitted energy to the transmitted energy—toward the region of interest—over a range of frequencies. As expected, the optimal emission frequencies correspond to field distributions for which resonances occur inside the perforations.

The outline of this paper is as follows: The mathematical model is presented in Section 2. The DtN-FE method is then described and validated in Section 3. Section 4 provides numerical results for realistic well configurations. Section 5, finally, gives the concluding remarks of the present work.

2. Mathematical model

2.1. Geometry

A perforated well is created through two successive processes called drilling and completion. The former begins by drilling a borehole in the ground, which is covered by metal pipes that are attached to its walls by a layer of cement (cf. Fig. 1). This part of the process, commonly referred to as casing, aims to stabilize the borehole structure. Once the well is cased, the

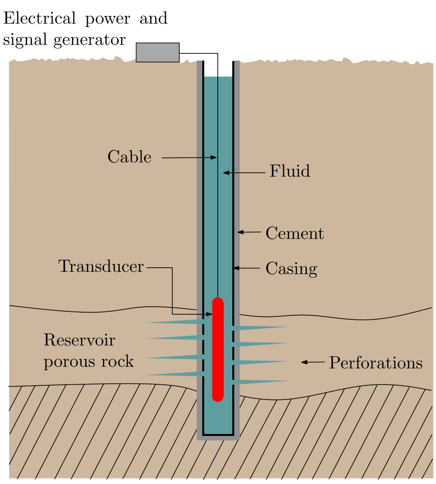

Fig. 1. Diagram of the operation of an AWS method in a perforated (completed) well.