



Thermoelectric coupling analysis of high-voltage breakdown industrial frequency pyrolysis in Fuyu oil shale

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ABSTRACT

A high voltage can achieve the electrical breakdown of an oil shale, and a heating channel is formed inside the oil shale. Subsequently, the industrial electrical frequency is used to heat the oil shale with the produced plasma and the inner surface of the conductive carbonization channel, which then causes the oil shale to crack. A three-dimensional coupling model of an oil shale is established by the finite element analysis software, and the temperature field distribution of a high-voltage breakdown of an oil shale is obtained by numerical calculations. The reliability of the numerical simulation is verified by laboratory tests. When the voltage is 1000 V, the breakdown current in the oil shale is 22 A. After heating for 6 min, the heating channel temperature of the oil shale reaches 643 °C. Within a 25-mm heating channel length, the temperature reaches 347 °C, which meets the demand of oil shale pyrolysis. Combined with the numerical simulations and experimental results, the high-voltage industrial-frequency pyrolysis oil shale has high heating efficiency and high energy utilization efficiency. Thermoelectric coupling analysis is an effective way to study the high-voltage-breakdown industrial-frequency pyrolysis of oil shale.

1. Introduction

Energy is the lifeblood of the national economy in recent years, and all countries worldwide are facing severe problems in traditional energy supplies. The shortages of fossil fuels, coal, oil, and natural gas directly lead to the development and utilization of unconventional energy sources, such as oil shale [1]. The oil shale resources in Northeast China are rich in reserves, but they have the characteristics of thin reservoir, low grade, and deep burial. Oil shale ground retorting causes serious pollution to the environment, and in-situ pyrolysis is confronted with the problems of slow heating rate and low energy utilization efficiency [2–4]. The high-voltage industrial-frequency in-situ pyrolysis of oil shale technology, means the breakdown of oil shale to form a heating channel; subsequently, the process of heating the oil shale through the inner surface of the heating channel carbonization is used to generate oil and gas [5]. Moreover, in-situ pyrolysis causes less pollution to the environment. In this process, the oil shale rises rapidly and has high energy efficiency, but the heat and mass transfer are very complex, primarily involving the interaction of the electric field, temperature field, flow field, and stress field. The input of the electric field energy plays a decisive role in heat conduction, while the distribution of the oil

shale temperature field influences the dielectric constant and resistivity of oil shale.

In the past, research on the heat and mass transfer of oil shale was primarily based on the steady-state heat transfer model. Yue Ma et al. established a one-dimensional steady heat transfer model, simulated the heat conduction of the Longkou oil shale, and obtained an analytical expression based on mathematical deduction. They found that the coefficient of thermal conductivity is a polynomial function of temperature [6]. Fan Zhang et al. found the first-order model of the heat transfer simulation that shows the heat transfer process between the porosity and rock matrix, and found that if the block size and the heating rate are not too large, the first-order approximation of heat transfer can be used without significant loss of accuracy [7]. V. F. Simonov et al. established a mathematical model, assumed that the mixing of shale and the heat transfer agent particles are instantaneous and uniform, and found that most particles have no temperature gradient inside [8]. Liangzhi Xia established a two-stage drying model, performed a heat and mass transfer simulation of the Liushuhe oil shale in a fluidized bed dryer, and found that the gas temperature and flow velocity are important parameters of the whole drying process. The effects of particle size in the drying process are more obvious than that

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of the constant drying period [9]. Gennady, Gerasimova et al. established a mathematical model from using the Galoter technology to heat the oil shale, indicating that for a single-particle oil shale in the heat and mass transfer process, two reactions occurred to reduce oil shale production [10]. Sun Z developed the thermoelectric coupling analysis model for the heat balance of a magnesium electrolytic cell and the temperature distribution; with the change in current intensity, the corresponding depth of the electrolyte must be maintained to maintain the heat balance [11]. Nicolas Piatkowski and others formulated the energy conservation equation of the non-steady constant, established the model for the instantaneous reduction region, and used the finite volume method to simulate the radiative heat transfer and the electrical reaction dynamics coupling solution, and showed that the heat transfer process of synthesis gas solar reactor is the rate control mechanism [12]. Berna Hascakir et al. studied the influence of microwave radiation heat transfer on oil yield. They showed that oil shale recovery is not only related to pyrolysis temperature, but also to the temperature holding time. However, the expression of heat transfer is too few [13]. The heat and mass transfer of oil shale with a single physical field has been simulated; although the simulation results will not be significantly different, the theoretical calculation and modelling methods are neither accurate nor rigorous enough.

The oil shale is anisotropic, and the distribution of kerogen in an oil shale is irregular; therefore, the distribution of energy in the heat and mass transfer process is not uniform. In the heating process, many physical fields interact with each other. Therefore, this paper uses the finite element analysis software to establish a three-dimensional (3D) model and analyses the heat transfer progress of a high-voltage industrial-frequency oil shale pyrolysis by means of thermoelectric coupling, and then verify the reliability of the thermoelectric coupling analysis by an indoor experiment.

2. Indoor test

2.1. Test principle

As shown in Fig. 1, the wiring diagram of the high-voltage-breakdown industrial-frequency oil shale pyrolysis is shown. Under high-voltage electricity, a small arc is first formed at the end of the electrode. The oil shale at the end of the electrode is ionized and rapidly expands and decomposes, resulting in the phase transition of the crystal. The breakdown channel enters the oil shale from the end of the electrode, and the extension velocity of the breakdown channel in the oil shale is greater than the electrode discharge rate along the surface. In addition, owing to the breakdown process, the energy is very high [15–17]. Kerogen in oil shale decomposes rapidly, producing a large amount of oil and gas. Carbon residue is generated on the surface of the breakdown channel. The resistance of the carbon residue is low, and the conductivity is better than that of the conventional oil shale; therefore, the speed of breakdown will be greatly improved. When the internal breakdown process of oil shale is completed, the heating channel with high carbon content will be formed on the wall of the breakdown channel. Owing to the industrial frequency, the oil shale now corresponds to a conductor, and an enormous energy breaks down the kerogen in the oil shale surrounding the heating channel. The oil and gas produced are expelled along the pores inside the oil shale. The reason is that part of the kerogen in the oil shale is within a confined space and with the temperature increasing, which cause kerogen pyrolysis, then, the heat release and phase change [2,4,22], yet the oil and gas cannot be discharged; therefore, the closed-space pressure increases rapidly until it reaches the ultimate stress of the oil shale. In confined space damages, and even cracks, the channel is heated to extend the temperature of oil shale, which increases the thermal expansion coefficient. With more cracks, a better electrical conductivity is achieved, and the whole pyrolysis of oil shale is realized.

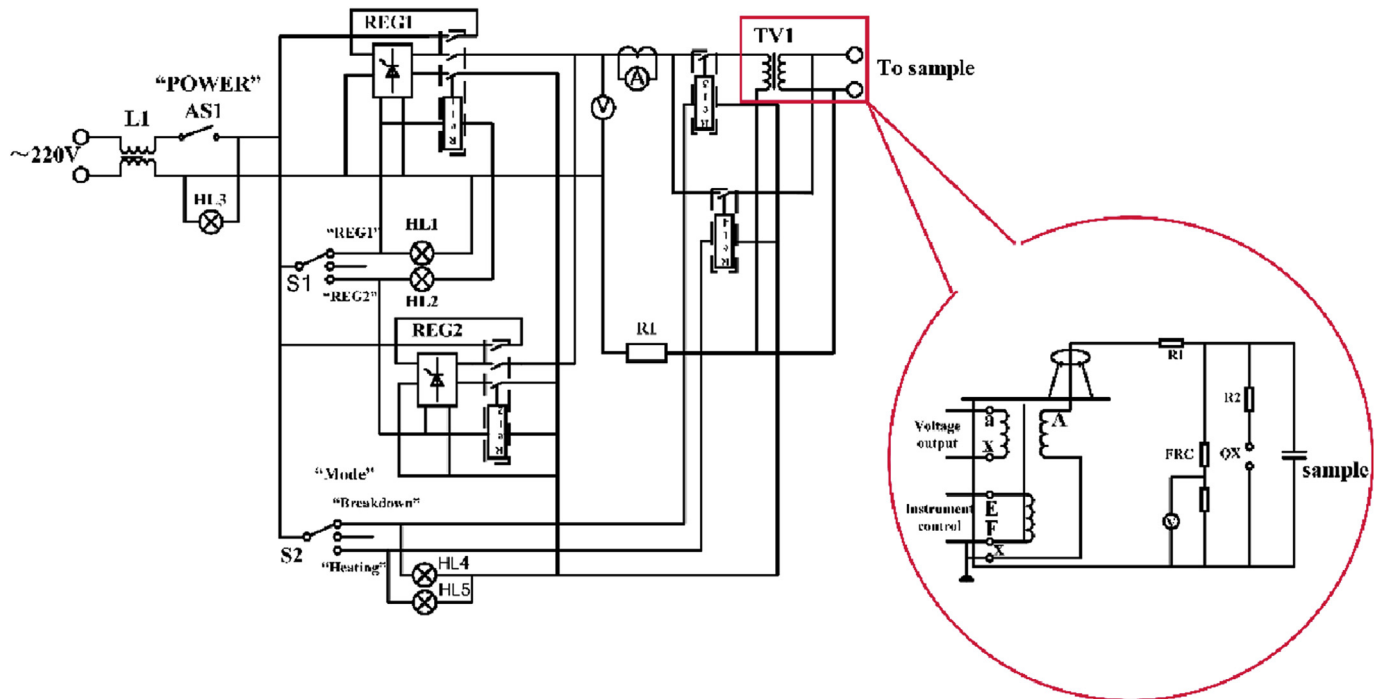


Fig. 1. Schematic diagram of high-voltage-breakdown industrial-frequency electrical pyrolysis L1- Self-induction coil; Power AS1- Master switch; REG1- Current regulator; REG2- Voltage regulator; HL- power light; RL- Relay; R1, R2- Current limiting resistor; FRC- resistance-capacitance voltage divider; QX- discharging ball gap.

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