MODELLING AND SIMULATION OF MICROWAVE USING TWO DIMENSIONAL FDTD METHOD

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ABSTRACT

The heating of crude oil in Indonesia is done by fossil fuels, which has been known that fossil fuels are limited nonrenewable energy sources. One of alternative heating methods can be performed by using microwaves. A modelling study of the heating crude oil with a microwave sources fixed in the reservoir has been created. This study aims to simulate the microwave propagation and heat tansfer on the crude oil reservoir. The simulation of microwave propagation and heat transfer visualized by Visual Basic 6.0 with FDTD method (Finite Differrence Time Domain). The simulation results presented in the two-dimensional form. The heating of crude oil using a magnetron as the microwave generator with operating frequency of 2.45 GHz. The microwave guided by rectangular waveguide with TM_{11} mode. The reservoir with size 10 x 10 m^2 has the dielectric constant 4.09 and the dielectric loss 0.007 and the crude oil has the dielectric constant and dielectric loss 2.8 and 0.15, respectively. The simulation run by Gaussian pulse with the parameter variation of time and position coordinate. Based on the simulation results, the temperature distribution models are $T(t) = 0.2262e^{(0.0101t)}$.

Keywords : crude oil, propagation microwave, heat transfer, FDTD, time, simulation.

I. INTRODUCTION

For a developing country like Indonesia, fulfillment the needed energy still largely relies on crude oil as an energy source. Dependence on crude oil was giving a serious problem for global problem. The crude oil is a nonrenewable energy resource so that it is limited supply. Therefore, it takes a technological innovation to increase oil production.

The crude oil is a nonrenewable energy resource so that it is limited supply. Therefore, it takes a technological innovation to increase oil production. During this time a number of petroleum drilling industry is still using conventional methods. The conventional method is a method of heating oil by using fossil fuels, for example by steam injection method. Steam injection is the process of heating the crude oil with flowing steam into oil wells. The heating crude oil aims to reduce the oil viscosity grades so that it has high mobility and the more effective oil displacement. However, the disadvantage of the steam injection method is the heat loss in the transmission process and the cost of production wells is quite large because it uses fossil fuels so that it still are the less effective [6].

One alternative for heating crude oil is heating using microwave energy. Method of heating by microwaves is based on the antenna radiation is affected by the geological formation that is able to distribute the heat includes a large reservoir volume. The microwave utilizes the propagation of electromagnetic energy waves that it traverse the media in the process of heat distribution [3].

The method of heating crude oil with microwaves has several advantages including; an increase in the value of enhanced oil recovery [12], compactness of the equipment (including the off-shore), has high efficiency in the process of generating energy radiation, reducing heat loss when passing through overburden [3]. Other advantages of microwave heating method is rapid heat transfer process, volumetric, selective heating, the speed of switching "on" and "off", and pollution-free to the environment [5].

a model of heat transfer in the heating of crude oil on the reservoir will be needed to predict the application of microwaves in the heating of crude oil on an industrial scale drilling. Model heating by microwaves is based on the dielectric properties. A related study by using microwaves through the modeling of crystalline inorganic materials (KRS5), KRS6, Resinox 10 231, steatite 7292 and mica conducted Hill and Jenning [7]. Furthermore, the microwave energy source, Hill and Marchant do research on silica and mica material [8]

For fluid material, Cherbański and Rudniak [5] do the modeling microwave heating in water. However, with different materials Ratanadecho, et al [15] conducted a study of microwave heating numerically and experimentally in pure water and salt water. Furthermore, for similar material, Salvi et al [17] investigated the modeling of the heating of microwaves for a continuous flow of cases.

Especially for materials crude oil, associated research conducted Santos et al [18] with a microwave source that is placed in a cylindrical reservoir with heat distribution analysis using the moment method. Research related to the source of microwaves in a reservoir carried Abdurrahman and Merribout [1], only the form of the reservoir in the form of a box with a heat distribution analysis using COMSOL.

In this study, the researcher intends to study models of heat transfer to the material heating crude oil using microwave source that is placed at the bottom of the wellbore (the reservoir) so that microwave energy to achieve crude oil in the reservoir area more effectively. The heat distribution and microwave propagation using two-dimensional FDTD method. Thus, based on the description above, designed a study on the modeling of the heating of crude oil by using microwaves in the reservoir.

Microwaves are electromagnetic waves with a frequency range 1:12 - 40 GHz and a wavelength of about 1 mm to 1 m [9]. Microwaves generated electron resonance at high frequencies. In general, the device used as the source oscillation is a producer of microwave magnetron. A magnetron combine electric and magnetic fields are perpendicular to each other. The electric field is formed between the cathode and anode in the outside with a large difference in potential between the two, while the magnetic field generated from permanent magnets commonly located at the base of the magnetron. Electrons in this region move from the cathode in a spiral toward the outer portion of the anode. During the electrons emerging from the electron resonance container will release energy. This energy is produced through an antenna which is specially used in a cavity through a waveguide [13]

Basically, the microwave energy is derived from molecular interactions to electromagnetic fields is delivered directly into the material. This energy is a non-ionic radiation that causes the movement of molecules through ion migration and dipole rotation, but does not alter the molecular structure and range wavelength. Because microwave can penetrate the material and save energy, the heat generated covering the entire volume of material. In the heat transfer from the microwave does not rely on heat diffusion process with the surface of the material making it possible to happen quickly and are uniform heating of the material coating [14].

The microwave heating process successfully describes the phenomenon of heating on the layer of fluid that it is based on Maxwell equations.

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t} \tag{1}$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \varepsilon \frac{\partial \boldsymbol{E}}{\partial t} \tag{2}$$

$$\nabla . \boldsymbol{D} = \rho_v \tag{3}$$

$$\nabla . \boldsymbol{B} = 0 \tag{4}$$

Where : E is the electric field strength (V/m), D is the flux density of electric current (C/m^2), J is the electric current density (A/m^2), H is the magnetic field strength (A/m), B is the magnetic flux density (Wb/ m^2), ε is the electric permittivity, ρ_v is tightly charge.[11]

The heat flow equation at a fluid declared the temperature distributions per unit time as a result of heating by microwaves. The magnitude of the temperature distribution is stated as follows:

$$\frac{\partial T}{\partial t} + \vec{v}\nabla T = \frac{k}{\rho C_p}\nabla^2 T + \frac{Q}{\rho C_p} \tag{5}$$

Where , ρ is the density of the material (kg/m^3), C_p is the specific heat (J/kg.K), k is the heat conductivity (W/mk), T is temperature (K), v is the fluid velocity (m/s), Q is the volumetric heat as a result of the incident wave (W/m^3) [17].

The amount of heat resulting from exposure to microwave depends on the dielectric properties of the fluid and the electric field intensity is expressed by the following equation:

$$Q = 2\pi f \varepsilon_0 \varepsilon' |E|^2 \tag{6}$$

Where ε_0 is permittivity material in the air, ε' is the dielectric constant of the liquid, f is frequency, $|E|^2$ is the amplitude of the electric field [4].

The FDTD method (*Finite Diferrence Time Domain)* is finite difference method which is based on the Yee algorithm to analyze and simulate the electromagnetic waves [10]. The microwaves are part of the electromagnetic waves so that to analyze the propagation of micro wave in a dielectric medium is based on Maxwell's equations as follows:

$$\frac{\partial \widetilde{\boldsymbol{D}}}{\partial t} = \frac{1}{\sqrt{\varepsilon_0 . \mu_0}} \nabla x \boldsymbol{H} \tag{8}$$

$$\frac{\partial \boldsymbol{H}}{\partial t} = -\frac{1}{\sqrt{\varepsilon_0 . \mu_0}} \nabla x \boldsymbol{E} \tag{9}$$

When simulating electromagnetic waves in three dimensions it will be reviewed six different terrains such vectors: $\widetilde{\boldsymbol{E}}_x, \widetilde{\boldsymbol{E}}_y, \widetilde{\boldsymbol{E}}_z, \boldsymbol{H}_x, \boldsymbol{H}_y,$ and $\boldsymbol{H}_z$. However, if simulate electromagnetic waves in two dimensions then it will have been two groups of three vectors, namely:

(1) TM mode (*Tranverse Magnetic)* consists of : $\widetilde{\boldsymbol{E}}_z, \boldsymbol{H}_x, \boldsymbol{H}_y$
(2) TE mode (*Tranverse Electric)* consists of : $\widetilde{\boldsymbol{E}}_x, \widetilde{\boldsymbol{E}}_y, \boldsymbol{H}_z$

Based TM mode then the quation (2.67), (2.68) and (2.69) become :

$$\frac{\partial \widetilde{\boldsymbol{D}}}{\partial t} = \frac{1}{\sqrt{\varepsilon_0 . \mu_0}} \left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial x} \right) \tag{10}$$

$$\frac{\partial H_{\boldsymbol{x}}}{\partial t} = -\frac{1}{\sqrt{\varepsilon_0 . \mu_0}} \frac{\partial E_{\boldsymbol{z}}}{\partial y} \tag{11}$$

$$\frac{\partial H_{\boldsymbol{y}}}{\partial t} = -\frac{1}{\sqrt{\varepsilon_0 . \mu_0}} \frac{\partial E_{\boldsymbol{z}}}{\partial y} \tag{12}$$

The fourth equation above shows the distribution of electric field and magnetic field in space and time domain with waveguide mode TM. The wave field formed by the x-axis and y-axis so that the position coordinate electric field and magnetic field are expressed in the unit vector (i,j) [19].

II. RESEARCH METHODS

The orientation in this study is a simulation of heating crude oil with the use of microwaves in the reservoir. Reservoir is a place of crude oil that lies beneath the surface of the soil at a depth and a certain pressure. The reservoir is assumed shaped box. The reservoir characteristics and crude oil obtained from secondary data. Modeling the heating is done by using the finite difference method is based on space and time. This method is known as the finite difference time domain (FDTD). Therefore, the distribution of crude oil on the entire surface of the reservoir is assumed to be homogeneous, so that the results of the simulation are presented in the form of two-dimensional.

In this study, the type waveguides used are rectangular with a length of 10 m and a width of 10 m. Waveguides work on TM11 mode. Microwaves further transmitted along the z axis.

Materials used in the study is the crude oil that is assumed to be the initial condition of the physical parameter comprises of crude oil comprising: a viscosity of 3,9 cp, thermal conductivity at 0.38 $Wm^{-1}°C^{-1}$, mass types of 900 m^{-3}, and the specific heat of crude oil amounted to 2000 $W\ s\ kg^{-1}°C^{-1}$, a dielectric constant of 2.8 and dielectric loss 0.15. [2].

Microwaves are generated from a generator. The type of generator to arouse microwaves used is magnetron type MICRO Denshi UM-1500. Magnetron work at 2:45 GHz operating frequency with 1.5 kW maximum input power [15]. The selection of the type of generator is done on the grounds that the magnetron can work at high power so that it can be applied in the heating of crude oil on an industrial scale. The simulation of microwave propagation and heat transfer visualized by Visual Basic 6.0. Reservoir has a length dimension of size consisting of (a) by 10 m and width (b) by 10 m. Reservoir has a characteristic comprises a dielectric constant of 4.09; dielectric loss of 0.007.

The modeling method of heating crude oil using a microwave equation is based on a mathematical form. The heat transfer in heating crude oil based on the equation (5) follows :

$$\rho C_p\left(\frac{\partial T}{\partial t}+\vec{v}\nabla T\right)=k\nabla^2 T+Q$$

Where Q is obtained from the equation (6) :

$$Q=2\pi f\varepsilon_0\varepsilon''|E|^2$$

The form mathematical equation of heat transfer in the crude oil heating is a form of partial differential equations. The finite difference method is used to complete the partial differential equations from the heat transfer equation. Finite difference method is a numerical approach to model a problem that has the form of a mathematical form of partial differential equations.

The determination of modeling heating crude oil with the use of microwaves is done by stages as follows:

a. Determining micro wave equation which is based on Maxwell's equations.
b. Determining the value of a local electric field of translation of Maxwell's equations
c. Determine the equation of the local heat generation
$$Q=2\pi f\varepsilon_0\varepsilon'|E|^2$$
d. Determining the heat transfer model of heat transfer in accordance with the following equation:
$$\rho C_p\left(\frac{\partial T}{\partial t}+\vec{v}\nabla T\right)=k\nabla^2 T+Q$$
where the Q value obtained from the third stage. Coordinates used in the heat transfer equation is Cartesian. Heat transfer equation describes the temperature distribution as a function of position and time.
e. Changing the shape of the micro wave equation and heat transfer in a discrete form.
f. Visualizing micro wave propagation and heat transfer using Visual Basic 6.0
g. Doing variation time for propagation of microwave and heat transfer
h. Make a graph of the results and the time variation of the position coordinates to obtain the temperature distribution in the modeling of the heating of crude oil.

Manufacture of Simulation

The manufacture of simulation is a stage in the modeling of the heating of crude oil computationally. The simulation results in the form of micro-wave propagation and the propagation of heat in the form of a reservoir. The temperature distribution in the reservoir coordinate described in point (i, j). i and j are the unit vectors of Cartesian coordinates in the x and y. The temperature distribution of the position of the temperature in the time domain. The Stages of making a simulation for the propagation of microwaves and heat transfer illustrated in the following diagram:

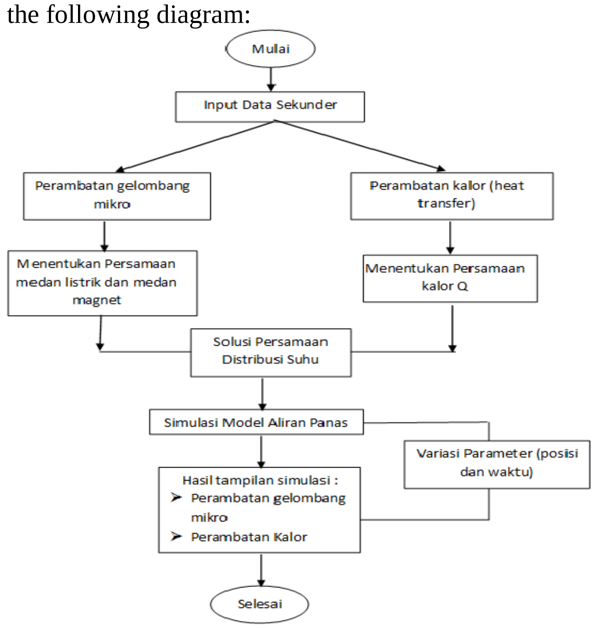

Figure 1. Flowchart of simulations.

III. RESULTS AND DISCUSSION

The time parameter in FDTD method known as "nstep" is the amount of time needed to perform the process on the system. The difference in appearance between the simulation results of heat propagation and microwave with choosing nstep 250 at the coordinate position (90.90), are shown in the following figure:

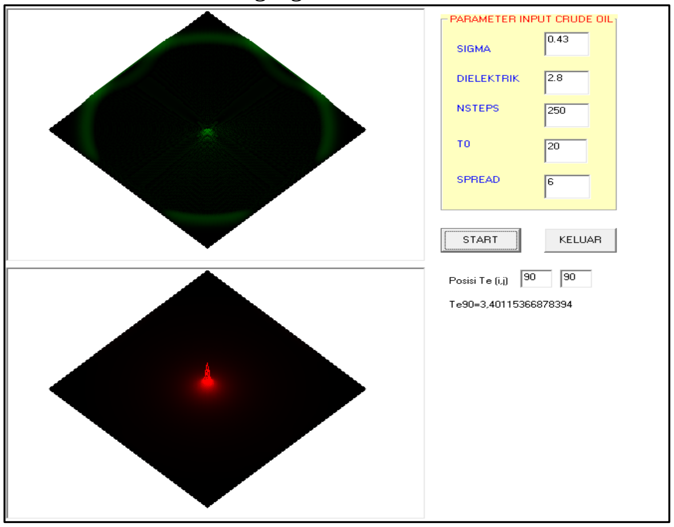

Figure 2. Simulation of propagation of microwave and heat

On propagation of microwaves with timing nstep 250 occurs reflection on the walls of the reservoir. The reservoir is assumed as a perfect reflector in this case. By using a gaussian pulse shape, then heat propagation occurs radially from the center of the microwave radiation. In this case, the propagation of microwaves have a radial shape. Basically when crude oil interacts with the microwaves, the microwave energy is absorbed by the crude oil. This energy causes rotation of dipoles crude oil. The rotation movement of the dipoles of crude oil following the oscillatory motion that generate friction between the dipoles. Friction of dipole-dipole oscillation motion is dependent on the frequency of microwaves coming. The higher the frequency of the microwaves, the greater the friction dipoles happened. As a result, more and more microwave energy is lost. The energy lost is certainly converted in the form of heat. Thus the temperature of crude oil after obtaining exposure to radiation from the microwave to be increased.

Based on the principle of microwave heating, the heat on the crude oil was resurrected after receiving microwave radiation. This causes propagation of microwaves in Figure 2 includes a reservoir area of the central region of radiation greater than the propagation of heat. Mathematically it is actualised in the form of heat equation.

$$Q = 2\pi f \varepsilon_0 \varepsilon'' |E|^2$$

Where E is the electric field generated from the micro-wave propagation simulation. Equation (6) shows that heat depends on the electric field of the microwave.

The FDTD method is a method that is based on the finite difference method in time domain so it is important to set time parameters The time is implicit in the FDTD method. The time variation used in the microwave propagation simulation and heat is from 100 up to n step step 800. By using the position coordinates (90.90) then each increase of 50 nstep the obtained value of crude oil of different temperatures. The simulation results of variation in the time parameter micro wave propagation and heat included in the following chart :

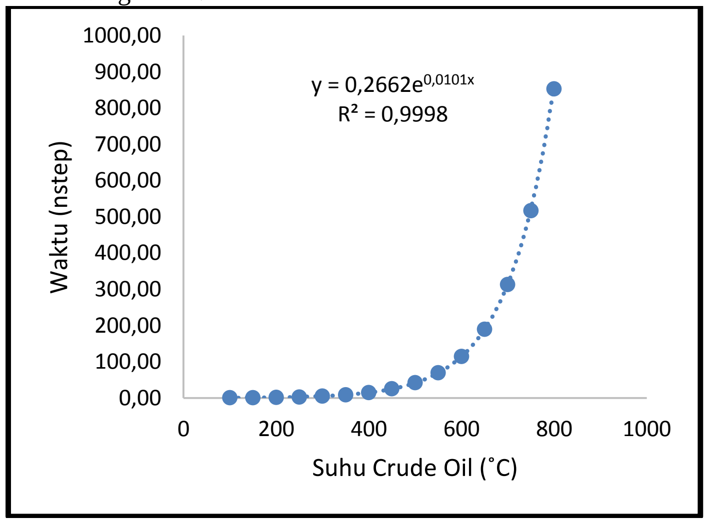

Figure 3. Effect of heating time to temperature crude oil

The forms of modeling the heating of crude oil from the graph shown in Figure 3. From the chart obtained by exponential-shaped line equation y = 0,2262 *exp* (0,0101x). This means that mathematically form of crude oil heating models using microwaves with the review time parameters are $T(t) = 0{,}2262\ e^{(0{,}0101t)}$.

The example of simulation results from micro wave propagation and heat transfer displayed on some nstep shown in the following figures consist of nstep 100, nstep 200, nstep 300.

1. For nstep = 100

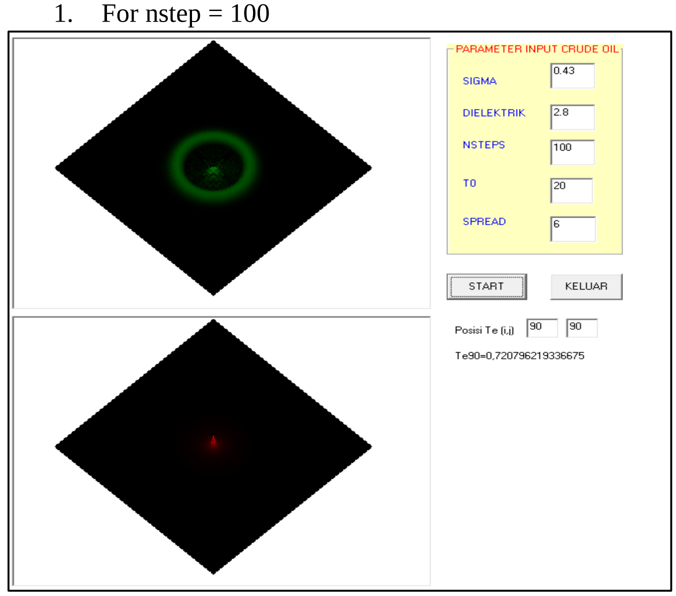

Figure 5. Simulation of microwave and heat with nstep = 100

2. For nstep = 200

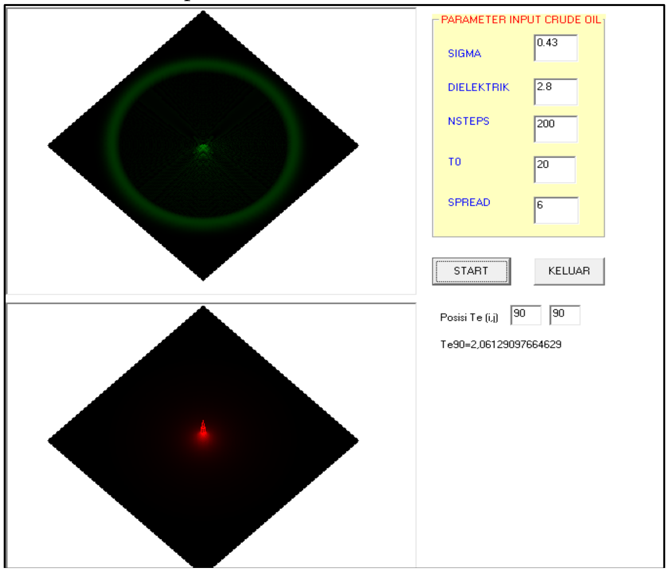

Figure 6 Simulation of microwave and heat with nstep = 200

3. For nstep = 300

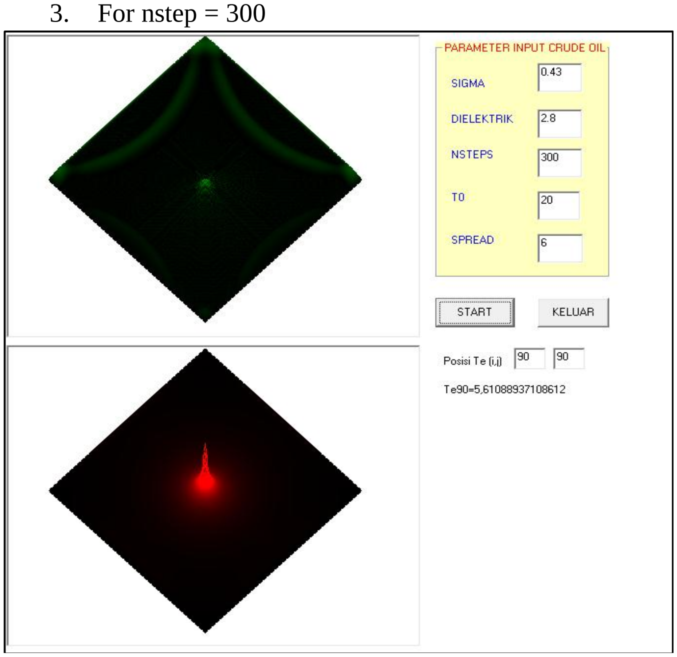

Figure 7. Simulation of microwave and heat with nstep = 300

Based on the results of the simulation images of microwave and heat from some nstep shows that the greater nstep, the wider the propagation of micro wave radially until it reaches the reservoir wall. Microwaves will be reflected after touching the reservoir wall. Furthermore, the reflection of microwaves back used to heat crude oil. As for the propagation of heat, the greater nstep the higher the peak point of view of heat in the form of a red color display increasingly clear. This indicates that the longer the crude oil is heated, the higher the temperature of the crude oil.

IV. CONCLUSION

The heat propagation modeling and propagation of microwaves on crude oil reservoir can be simulated computationally well using two-dimensional FDTD method. The simulation results of heat propagation and microwave showing the temperature distribution model with a mathematical form $T(t) = 0{,}2262\, e^{(0{,}0101t)}$.

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