GeoSteam.Net: Steam Transport Simulator for Geothermal Pipeline Network

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ABSTRACT

In the project CEMIE-Geo, the development of a steam transport simulator, GeoSteamNet for the geothermal pipeline network in the Web platform using the Angular framework is in progress. The URL of the website is http://www.INEELGeoSteam.Net/GeoSim. It uses the web service, http://www.INEELGeoSteam.Net/INEELGeoSteamNet.asmx, developed for the calculation of steam transport in components like pipeline and elbow of the pipeline-network of a geothermal plant. The steam-transportation algorithm is based on the conservation of mass, linear momentum, and total (mechanical plus thermal) energy. Similarly, a demo program is written on the Windows platform to resolve the well-known problem of three reservoirs (i.e. three pipes connecting two production wells and a power plant).

1. INTRODUCTION

In geothermal systems, the primary resource for generating electrical energy is steam, which moves the turbines. Most geothermal fields produce a mixture of liquid (water) and vapor (steam). The steam is separated in a separator at the wellhead. The separated steam is transported to the turbine through a steam-pipeline network, consisted of pipes, manifolds, valves, expansion, reduction, etc. The steam (fluid) flow in the geothermal pipeline networks is more complex than that in any other type of system, since the pressure, temperature and flow-rate of fluid in geothermal wells are controlled by nature. Additionally, the large distance between the wells and their topographic settings in a geothermal flied also complicate the steam flow in the pipeline networks. The conditions of the well opening (i.e. the pressure and flow-rate control at the wellhead) produce the incrustation (mainly the deposition of silica and calcite) in both geothermal reservoir and pipeline network. Similarly, instability in the form of pressure fluctuations has been observed in the geothermal pipeline network (even sometimes in the wells) if the well openings are not synchronized. Thus, the knowledge of numerical simulation of steam flow in a pipeline network of geothermal system is vital for the rationalization and optimization of steam, used in the transformation of thermal energy into electrical energy.

Enormous efforts have been made to understand the mechanisms of vapor transport in the pipeline networks of several geothermal fields around the world (Garcia et al., 2009). Consequently, it has resulted in the development of several computer programs: VapStat-1 (Marconcini and Neri, 1979), FLUDOF (Sanchez et al, 1987), Sims.Net (TS & E, 2005), etc. There are many recent studies on the fluid and heat flow in pipeline networks: prediction of pressure, temperature and velocity distribution of two phase flow in petroleum wells (Cazarez-Candia and Váquez-Cruz, 2005), and fluid flow characteristics with uncertainty in a geothermal well (García-Valladares, 2007).

All programs were written to solve a specific problem and do not yield satisfactory results when used for different production conditions even in the same field. Garcia et al. (2009) simulated the effect of superficial field topography on the steam transport in the pipeline network of Los Azufres geothermal field with using the commercial software packages Pipephase and Sims.Net. They found that the transport of geothermal fluids from the wellhead to the power plant through very long and complex pipeline networks directly affects the amount of electricity generated per unit of fluid produced. A group of NASA (National Aeronautics and Space Administration) developed a computer program, "Generalized Fluid System Simulation Program (GFSSP)" to calculate the pressure and flow distribution in complex networks of fluids (Majumdar, 1999). In this work the algorithm of GFSSP is modified for unidirectional steady state steam flow in the geothermal power plant. The numerical solution approach for the equations of conservation of mass, linear momentum and energy is adapted from Patankar (1980) and Majumdar (1999). Verma and Arellano (2010) wrote a computer program, PipeCalc in Visual Basic 6.0 for the steam flow in a pipeline using the modified algorithm of GFSSP.

The paper presents the development of web service, http://www.INEELGeoSteam.Net/INEELGeoSteamNet.asmx for steam transport in components, pipeline and elbow. Similarly, a website, http://www.INEELGeoSteam.Net/GeoSim for steam transport simulator in a geothermal pipeline network is development in Angular. The stream-transportation algorithm is based on the conservation of mass, linear momentum, and total (mechanical plus thermal) energy. Additionally, a demo program is written in Windows platform to resolve the three reservoirs problem (i.e. a three pipes network connecting two production wells and a power plant).

2. STEAM TRANSPORT ALGORITHM

Verma (2012) presented the algorithm for steam transport in a geothermal pipeline, which considers the conservation of mass and momentum (Newton's second law) and the first and second laws of thermodynamics (Smith and Van Ness, 1975; Majumdar, 1999). The second law of thermodynamics defines the direction of a spontaneous process. In the pipeline network of geothermal power plant, the steam flows from high to low pressure and heat flows from high to low temperature. Thus the second law of thermodynamics is indirectly validated and will not be considered here. The steam transport can be dealt quite accurately with considering certain geometrical simplification like unidirectional steady state steam flow (Verma and Arellano, 2010).
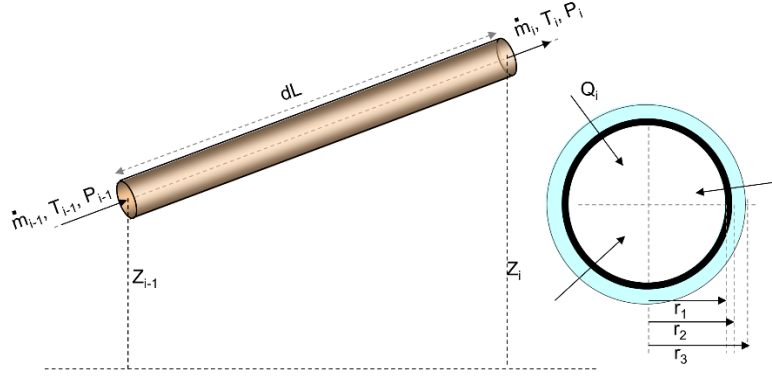
Figure 1: Schematic diagram of ith control volume element of a pipeline. T, P, Z and $\dot{m}$ represent temperature, pressure, elevation and mass flow rate at the node i-1 and i, respectively. The cross-sectional view of the element shows the positive heat flux Q_i. r_1, r_2 and r_3 are radii of inner and outer part of the pipeline, and outer part of the insulation over it, respectively.

2.1 Continuity Equation

For steady state flow the continuity equation (conservation of mass) in three dimensions is

$$\nabla \cdot (\rho \vec{u}) = 0 \tag{1}$$

where ρ is density and $\vec{u}$ is velocity. Figure 1 shows a schematic diagram of ith control volume element between nodes i-1 and i. The finite difference discretization of continuity equation in one dimension along the pipeline is expressed as

$$\rho_i u_i = \rho_{i-1} u_{i-1} \tag{2}$$

The subscripts i and i-1 represent the values at the respectively node and i=1, 2, …, n (no. of segment).

2.2 Conservation of Energy

The equation of the conservation of energy is expressed as

$$\Delta \left(H + \frac{u^2}{2} + gZ \right) = Q - W_s \tag{3}$$

where Q is the amount of heat per unit mass given to the control volume element from surroundings. W_s is shaft work per unit mass which is zero here. H is enthalpy per unit mass, Z is the elevation from the reference datum line, and g is the acceleration due to gravity. Figure 1 also presents a cross-sectional view of pipeline. The rate of heat-transfer to the control volume element from the surroundings (Rajput, 1999) is given by

$$H_T = - \frac{2\pi \, dL \, (T_{in} - T_{out})}{\left[\frac{1}{h_{in} r_1} + \frac{\ln\left(r_2/r_1\right)}{k_A} + \frac{\ln\left(r_3/r_2\right)}{k_B} + \frac{1}{h_{out} r_3} \right]} \tag{4}$$

where r_1, r_2, and r_3 are radii as shown in Figure 1. k_A and k_B are thermal conductivities of pipeline and insulation over it, respectively. h_{in} is the convective heat transfer coefficient between steam and inner part of the pipeline. Similarly, h_{out} is the convective heat transfer coefficient between outer part of insulation and surrounding air. T_{in} and T_{out} are the temperature of inner steam and outer air, respectively.

For steady state flow the heat transferred to the control volume element from the surrounding will be transferred to the inflowing fluid. Thus the heat added (given) to per unit mass of inflowing fluid is

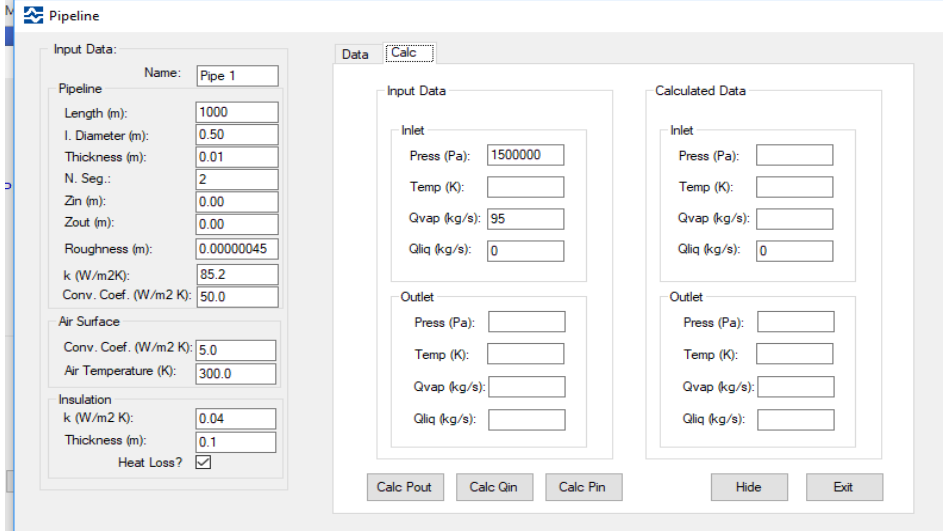$$Q = \frac{H_T}{\dot{m}} \times \left(1 + \frac{dL}{2u} \right) \tag{5}$$

The multiplying factor $\left(1 + \frac{dL}{2u} \right)$ is the time required to pass the fluid through the control volume element. Thus the discretization of energy equation is

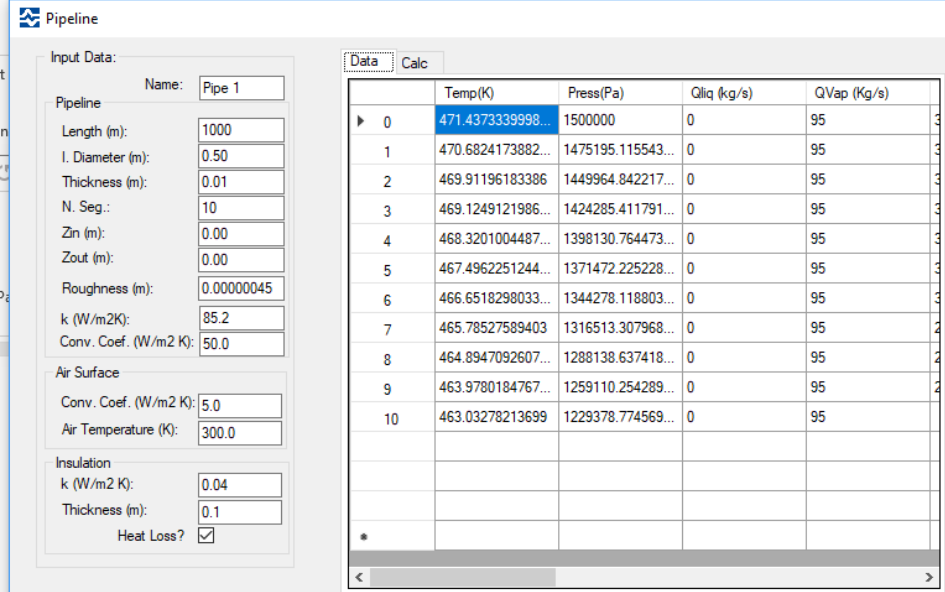$$H_i - H_{i-1} + \frac{u_i^2 - u_{i-1}^2}{2} + g(Z_i - Z_{i-1}) = Q_i \tag{6}$$

where Q_i is the amount of heat per unit mass given to i^{th} control volume element.

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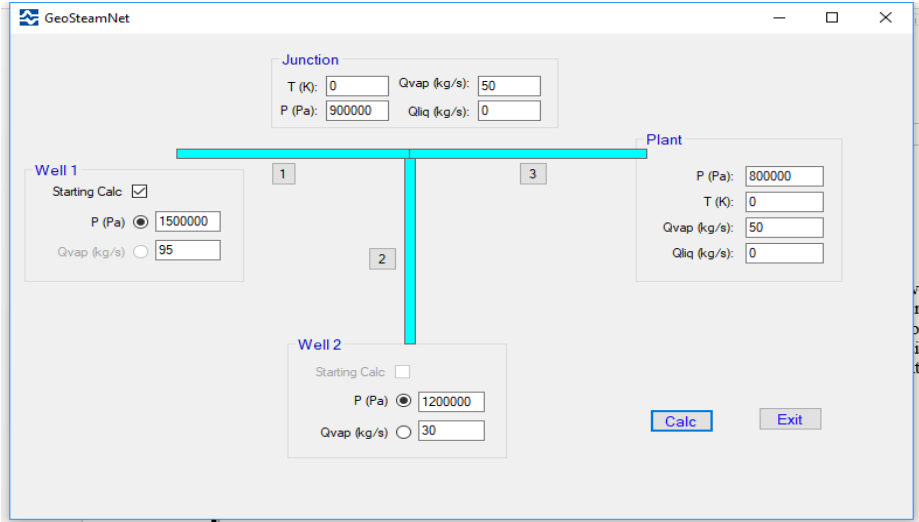
(a)

(b)

(c)

Figure 2: The interfaces of the demonstration program: (a) main form, (b) individual pipeline form for input parameters, and (c) the calculated results for individual pipeline.

2.3 Conservation of Linear Momentum

The conservation of linear momentum may be written as

$$V\,dP + u\,du + g\,dZ + dF = 0 \tag{7}$$

For both laminar and turbulent flow, the energy loss due to friction is expressed with the Darcy-Weisbach equation

$$dF = \frac{fu^2}{2D}dL \tag{8}$$

The Moody chart provides the value of friction coefficient f (Verma, 2008).

The discretization of momentum equation is

$$\left(\frac{\frac{1}{\rho_i} + \frac{1}{\rho_{i-1}}}{2}\right)(p_i - p_{i-1}) + \frac{u_i^2 - u_{i-1}^2}{2} + g(Z_i - Z_{i-1}) + \frac{fu_iu_{i-1}}{4r_1}dL = 0 \tag{9}$$

The idealizations imposed in the derivation of these equations are described by Smith and van Ness (1975). A comprehensive and systematic numerical solution approach is presented by Patankar (1980) and Majumdar (1999). The system of nonlinear equations is solved with Newton-Raphson method.

3. STEAM TRANSPORT SIUMLATOR WEBSITE

The URL of the steam transport simulator website is http://www.INEELGeoSteam.Net/GeoSim and it uses the web service, http://www.INEELGeoSteam.Net/ INEELGeoSteamNet.asmx. Presently, a branch, formed by pipeline and elbow of geothermal pipeline network can be simulated on the website. The user has to register to create his account, which is presently free of charge. To understand the functionality of GeoSteam.Net and compare the results with other simulators, we have created a window form application to resolve the well-known problem of three reservoirs (i.e. three pipes connecting two production wells and a power plant). The application can be downloaded from the website, http://www.INEELGeoSteam.Net/WtrStmTbl. Its use will be explained here.

3.1 DemoGeosteamNet

Run the setup for the installation of DemoGeosteamNet. Figure 2 shows the main interface forms of the demonstration program. Two geothermal wells are contacted to a power plant with tree pipelines. The input parameters of individual pipe can be changed on pressing the button 1 in Figure 2a. A well can be of two types: 1. Constant pressure and 2. Constant flowrate. The user has to select a well as the starting well, which has the highest pressure.

Figure 2b shows the form to input the characteristics of a pipeline. It is visualized on pressing the button 1 in Figure 2a. The input parameters are: for pipeline as length, inner diameter, thickness, thermal conductivity, and roughness, for insulation as thickness and thermal conductivity, and other parameters as convective heat transfer coefficient, air temperature and the number of segments in the pipeline to be considered during the simulations. Additionally, this interface permits to simulate the individual pipeline with giving the input and output parameters. For examples, we fill the inlet pressure and vapor flowrate, and press the button, Calc Pout; it calculates the following parameters at each node including the output node: temperature, pressure, liquid flowrate, vapor flowrate, heat loss due to conduction-convective-radiation, fractional energy loss (indirectly, the conversion of mechanical energy to thermal energy), total energy, thermal energy, kinetic energy and potential energy. Thus, the interface is very useful for a parametric study in a horizontal or vertical pipeline. Figure 2c shows the calculated results. For example, we can study the variation of inner diameter of pipeline to 1.0, 0.8., 0.6, 0.5, 0.4 and 0.3 m with keeping other parameters same.

Similarly, the demonstration program can be useful for comparing the results of other steam transport simulators.

4. CONCLUSIONS

The steam transport simulator for a geothermal pipeline network is under development in Angular for web platform. Presently, it simulates the steam transport in branch which is formed by pipelines and elbows, considering the conservation of mass, momentum and total energy. The mixing model of fluid at the junction node is also based on the conservation to total energy.

The algorithm of iteration during simulation of the steam transport in a pipeline network is precise, but it is presently slow. We are working on it. The empirical relations based on the correlation studies of experimental data in fluid mechanics demand the calibration of a numerical model for the real study system (e.g. the value of coefficient of convective heat transfer). Additionally, the present algorithm is constrained for the simulation of steam transport only due to the limitations of internal consistency in the thermodynamic properties of water. The energy balance at any point in the pipeline network validates the functionality of the present algorithm for steam transport in the geothermal pipeline networks.

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