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GeoSteamNet: 1. THERMODYNAMIC DATA FOR STEAM FLOW IN A PIPELINE NETWORK OF GEOTHERMAL SYSTEM

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ABSTRACT

Recent trend for programming thermodynamic data in a computer code is through ActiveX components; however, the iteration process in them makes the execution very slow. This intricacy is resolved with creating an ActiveX control *StmTblGrd* for the thermodynamic properties of water. First a grid (matrix) for a specified range of temperature (say 400 to 600 K with 40 segments) and pressure (say 100000 to 20000000 Pa with 40 segments) is created. Using the ActiveX component *SteamTables* the values of selected properties of water for each element (nodal point) of the 41x41 matrix are computed. The grid can be saved in a file for its reuse. A linear interpolation within an individual phase, vapor or liquid is implemented to calculate the properties at a given value of temperature and pressure.

In an Excel worksheet the enthalpy of one thousand random datasets for temperature and pressure is calculated using the ActiveX control *StmTblGrd* and component *SteamTables*. The uncertainty in the enthalpy calculated with *StmTblGrd* is within ±0.03%. The calculations were performed on a personal computer, which has a processor "Pentium(R) 4 CPU 3.2 GHz, RAM 1.0 GB" and Windows XP. The total execution time for the calculation with *StmTblGrd* is 0.3 s, while it is 60.0 s for *SteamTables*. The accuracy can be further improved by refining the grid.

INTRODUCTION

Recently, the Comisión Federal de Electricidad (CFE) has initiated a project to rationalize and optimize the use of steam for the generation of electrical energy at the Los Azufres geothermal system, Mexico (Ruíz et al., 2010). The project contemplates: a) the development of a numerical hydraulic model of the Los Azufres steam pipeline network (Garcia et al., 2009) and b) the installation of telemetric system to monitoring the characteristics of production wells. To comply above goal the Instituto de Investigaciones Electricas (IIE) has commenced a project, "GeoSteamNet: A computer package to simulate the steam flow in a pipeline network of a geothermal system". The first part of this project was to compile the thermodynamic data required for the simulation task.

Recent trend in the numerical simulation of complex systems is to implement ActiveX components for the thermodynamic properties of substance (span, 2002). Accordingly, Verma (2003, 2009) developed ActiveX components *SteamTables* and *SteamTablesIIE* the thermodynamic properties of water, based on the IAPWS-95 (International Association for the Properties of Water and Steam) formulation. In the numerical simulation of a system like steam flow in a pipeline network of geothermal system, the values of independent variables (temperature and pressure) change from point to point. The spatial grid of a geothermal pipeline network may consist of thousands of nodal points. The iteration process in the algorithm of pipeline network will demand to the computation of the thermodynamic properties of water several times, which makes the computation very slow.

This article presents the development of an ActiveX control, *StmTblGrd* to tabulate the thermodynamic properties of water in a specific range of temperature and pressure. The data can be stored in a file for future calculations. An interpolation method is developed to calculate the liquid and vapor properties at a given temperature and pressure.

PROGRAM DESCRIPTION

Verma (2003, 2009) explained the basic aspects associated with the programming of an ActiveX component and its use in MS-Excel. The programming and use of an ActiveX control is similar to that of ActiveX component except the control has a graphic user interface (GUI). An ActiveX control is a server application that exposes its functionality through properties, methods and events. When we create an ActiveX control, we create a project file *SteamTablesGrid.vbp* and control class file *StmTblGrd.ctl.* Visual basic uses the files to create the actual control file *SteamTablesGrid.ocx* which has the ActiveX control *StmTblGrd.* Here we discuss the installation and functionality of *StmTblGrd*.

The file *SteamTablesGrid.ocx* must be registered with the REGSVR32 utility in the Windows environment (Verma, 2003). Once an *.ocx* is registered, it may be accessed in a computer program in any language that supports Object Link Embedding (OLE) in the Windows environment. Similarly, we must register the *MyLibComp.dll*. The library *MyLibComp* contains an improved version of ActiveX component *SteamTables* (Verma, 2003) and *MoodyChart* for calculating the frictional coefficient for fluid flow in a pipeline (Verma, 2008). The *StmTblGrd* control uses internally *SteamTables*. If we install the demonstration program (*DemoStmTblGrd)* presented later, all the files will be registered automatically.

Figure 1 shows the *StmTblGrd* control on a form. There are two options to create the steam tables grid: a) read data from a file and b) create a grid for a specified range of temperature and pressure. In order to create a data grid we provide the values of temperature and pressure ranges with the number of segments for each range. For example, the control in Figure 1 shows the temperature range as 400 to 600 K with 40 segments and pressure range as 100000 to 20000000 Pa with 40 segments. The segments define the nodal points of the grid. In this case the matrix is 41x41 dimensions. We used the MKS units for all the parameters.

The list box in the "Input Data" frame contains the properties of water to be calculated. The property "0. State" is always selected. We can select up to five other properties from the list and press the button "Calculate". The number is limited to five in order to utilize the computer memory efficiently. In most of the problems we need less than five properties of water. For example, the steam flow in a pipeline is dealt with density, enthalpy and viscosity. If we need more than five water properties, we can create two instances of the control. The figure also shows the calculated values in a Tabs control. For example, the selected properties are "2. Density", "5. H", "8. S", "9. Cp" and "19. Vis". The values of these properties along the saturation curve are calculated on the tab "Saturation". The property "State" defines the compressed liquid region with value 15 and the superheated steam region with value 14. If a grid point is on the saturation curve, it leaves blank and uses the values from the saturation properties.

Additionally, the created grid can be stored in a file with the button "Save in File" and read it back from the file with the button "Read File". The control is initialized with a file StmTblGrd.dat. If we load first time the control, there is no initialization file. However, we may create a grid and save it as default file with the button "Save as Default". It saves the data in the file *StmTblGrd.dat*, which resides in the folder *C:\WINDOWS\SYSTEM32.* The advantage of this option is that if we will use a certain grid for long time, we can save as default. The control will load it automatically when we initiate the program.

In the object-oriented programming language, a property is a special sort of class member. A property can be read-only, write-only, or read-write. The properties of an ActiveX control which can be modified by the user (i.e. Property Let code) are considered as write only and serve as input parameters. Similarly, the read only properties (i.e. Property Get code) serve as output parameters and the user cannot change them. The value of read and write properties (i.e. Property Let and Property Get Codes) can be modified as well as obtained their values after calculations by the user. Table 1 describes the properties of *StmTblGrd* control.

Calculation Algorithm

Figure 2 shows the schematic diagram of steam tables grid. The grid is divided in two parts: compressed liquid region and superheated steam region by the separation boundary (i.e. the saturation curve and critical isochors). If the values of temperature and pressure of a point are such that it falls within a cell which has all four nodes in the compressed liquid like point 1 or in the superheated steam region like point 2, the properties of the point are calculated with interpolating the values of the nodal points. In the case of point 3 a temporary cell is created using the liquid saturation values of the properties and then the properties of point 3 are interpolated. The properties of point 4 are calculated from the points a, b and c as shown in the figure. Thus the calculation algorithm is based on a linear interpolation method in the individual phase, liquid or vapor.

Verma (2009) presented the existence of another liquid phase (named as Liquid 1) below 277.15 K; however, the present algorithm is based on the linear interpolation. Therefore, we should develop the grid above this temperature.

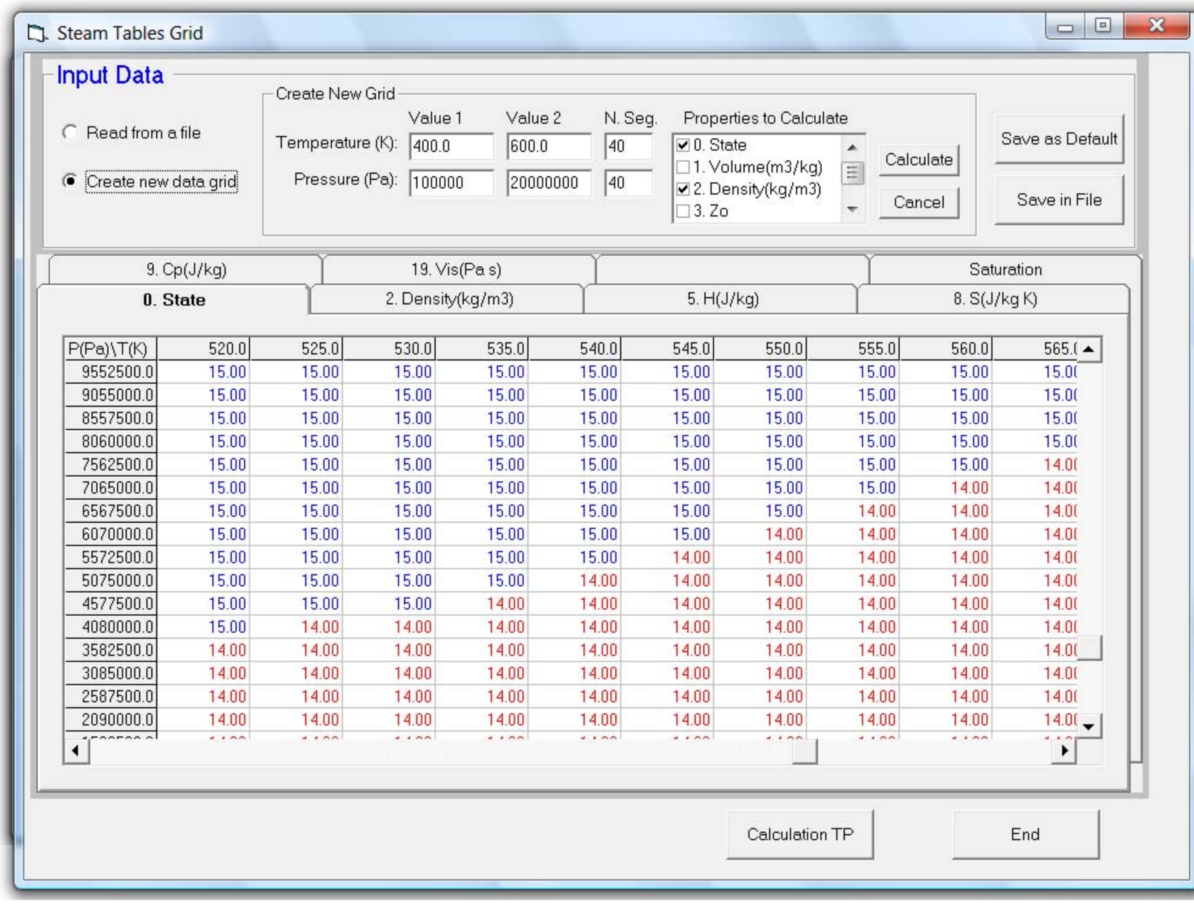

Figure. 1. First GUI from of the demonstration program DemoStmTblGrd. It has the ActiveX control StmTblGrd and two command buttons. The button "Calculation TP" shows the second form of the program.

Demonstration Program

The program package *DemoStmTblGrd* can be installed on a computer in the Windows environment with running setup program and following the instructions. The graphic user interface of the demonstration program is written in Visual Basic 6.0. The first from is shown in Figure 1. It has a *StmTblGrd* control and two command buttons. Once the grid has been generated or loaded from a file, we can calculated the properties of water at a given value of temperature and pressure by pressing button "Calculation TP". It displays a new form as shown in Figure 3.

To perform the calculation one has to provide the values of input parameters in the "input data" frame and press the button "Calculate" (Figure 3). The "Sep boundary" textbox can have value 1 for the calculation along the separation boundary (i.e. along saturation and critical isochors curve) or 0 for any values of temperature and pressure. The calculated values of all the selected properties are shown in the "Calculated Property" frame. The "Exit" button permits to go back the previous form (Figure 1).

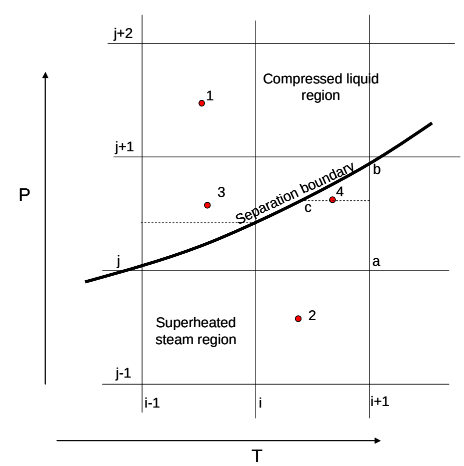

Figure. 2. A schematic diagram of steam tables grid. The separation boundary (i.e. saturation and critical isochors curve) divides the liquid and vapor phases. The indices i and j represent the nodal points for temperature and pressure, respectively. The interpolation algorithm for calculating the property values of points, 1 to 4 is explained in text.

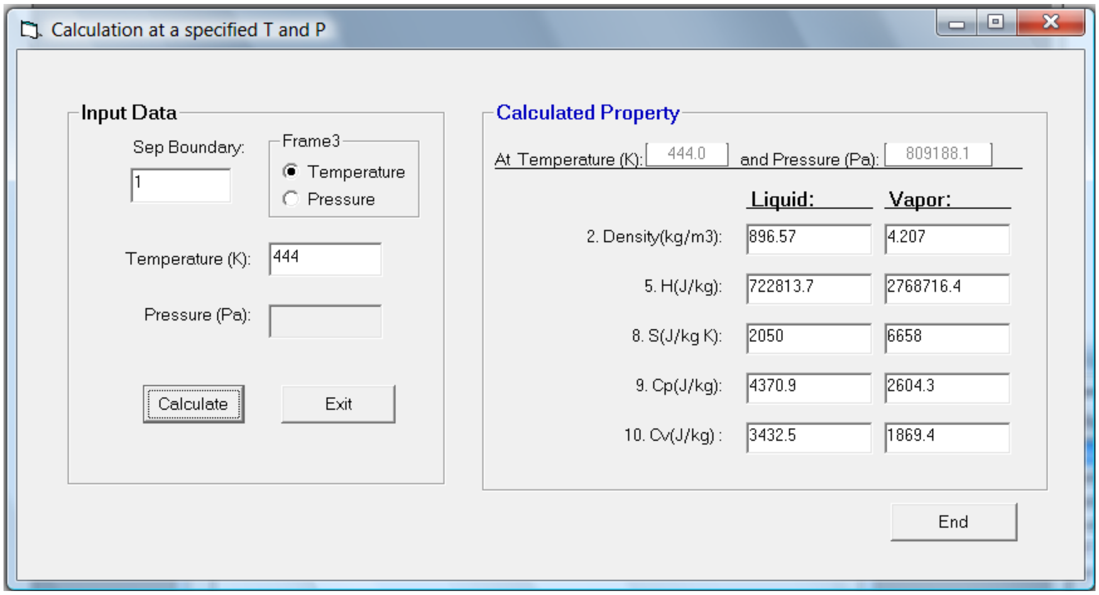

Figure. 3. Second GUI form of the demonstration program DemoStmTblGrd. The input parameters are provided by the user in the "Input" frame. On pressing the "Calculate" button it displays the calculated values of the selected properties in the "Calculated Property" frame.

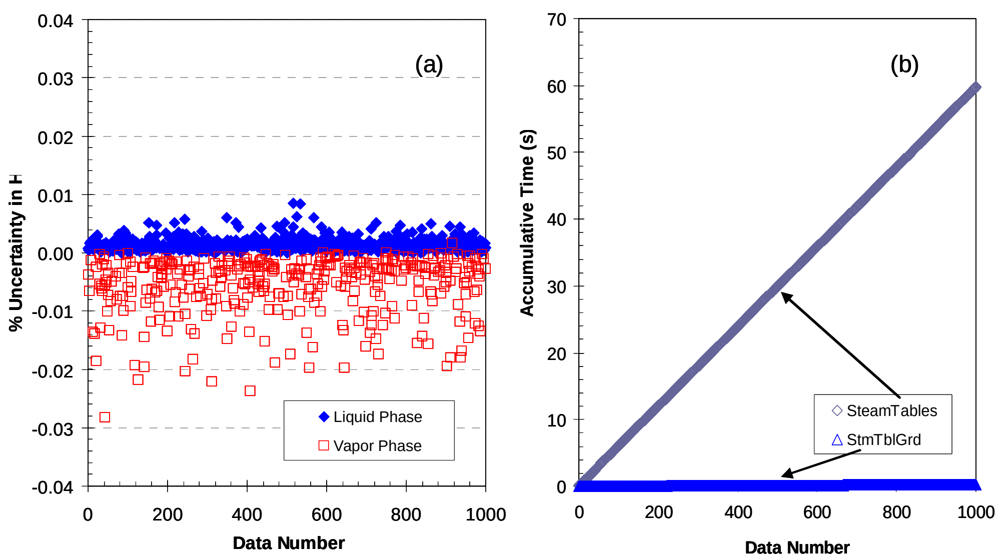

Figure. 4. a) A comparison of enthalpy values calculated using the grid control and SteamTables component for one thousand random values of temperature and pressure. The "% uncertainty in H" is defined as $\left[= \left\{\left(\left(H_{ctl} - H_{StmTbl}\right)/H_{StmTbl}\right) \times 100\right\}\right]$*, where* H_{StmTbl} *and* H_{ctl} *are the enthalpy values calculated from the ActiveX component SteamTables and control StmTblGrd, respectively. (b) A comparison of execution time for calculating the enthalpy of the T-P datasets (see Figure 4a) with the ActiveX control StmTblGrd and component SteamTables, respectively*

Using *StmTblGrd* in MS-Excel 2007

Verma (2003) described in details the procedure of writing a macro in the personal workbook of Excel, which permits to use the macro in any workbook. We can use the PropValue function to get the value of a water property in a cell of any worksheet. Figure 4(a) shows the percentage deviation in the enthalpy values of water for one thousand random values of temperature and pressure, calculated using *StmtblGrd* control and *SteamTables* component. First we created thousand values for each temperature and pressure using the Excel function "=RANDBETWEEN(lower, upper)", then we calculated the values of liquid and vapor enthalpy of water using the "*WtrStmTbls*" (Verma, 2003) and PropValue functions. It can be observed in Figure 4(a) that the uncertainty in the values is within ±0.03%. The liquid phase values have less deviation. The variation of vapor enthalpy near the separation boundary is almost exponential, so the linear interpolation makes some uncertainty. But the values are in good agreement for a numerical analysis of any practical system. If we need still better accuracy, we can create a finer grid. However, it will require more storage RAM memory. So, we can always adjust storage memory and accuracy according to our necessity.

Figure 4(b) shows the accumulative time for calculating the values of enthalpy for one thousand random datasets of T and P. The execution time for each run is calculated using the function "MicroTimer" (Microsoft, 2010). The listing of the function is included in the code available on the journal webpage. It can be observed that the total execution time for the calculation with *StmTblGrd* is 0.3 s, while it is 60.0 s for *SteamTables*. The calculations were performed on a personal computer, which has a processor "Pentium(R) 4 CPU 3.2 GHz, RAM 1.0 GB" and Windows XP. The execution time makes substantial difference when there is need to calculate the thermodynamic properties of water at several values of temperature and pressure like steam flow in a geothermal pipeline network. For example, if we have to calculate the properties for one million datasets of temperature and pressure, the execution for *StmTblGrd* will be 5 minutes, while it will be 16.7 hours for *SteamTables*.

CONCLUSIONS

The ActiveX control *StmTblGrd* is written in Visual Basic 6.0. The uncertainty in the enthalpy values form a 41x41 grid in the temperature range 400 to 600 K and pressure range 100000 to 2000000 Pa is only ±0.03%, while the calculation is 200-times faster than that of *steamTables* on a personal computer, which has a processor "Pentium(R) 4 CPU 3.2 GHz, RAM 1.0 GB" and Windows XP. The accuracy can be further improved by refining the grid. The generation and storage of data tables with a computer program avoids typographically mistakes. The use of in MS-Excel 2007 provides an accurate and efficient procedure in performing a wide range of calculations for complex systems which require the thermodynamic properties of water at various values of temperature and pressure

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