Quick Tools for Geothermal Development Planning

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Keywords: Geothermal, development, software, heat source, decline, economic.

ABSTRACT

In many cases, a quick method of assessing geothermal field development is needed. This is simply because the business environment is rapidly and constantly changing, and quick rearrangements of development plans are often required. Generally, this type of work starts with assessing the capacity of the geothermal field. This is done on the basis of a volumetric heat storage calculation. Once the potential is known, the decision of development capacity can be made more easily. However, prior to the decision, the nature of the hydrothermal system in question has to be understood (e.g. liquid, two-phase, or vapor dominated). This is needed to know the amount of liquid and vapor being extracted, separated, and re-injected into the reservoir. The number of the production and re-injection wells can then be derived. Later, the decline behavior of the reservoir throughout the entire lifetime of the project must be modeled. The model depicts the long term make-up wells scenario (e.g. what year, and how many). Finally, the project design can be optimized to yield the best economic values. Using the programs provided, this assessment of development can be completed in a manner of minutes.

1. INTRODUCTION

The tools for geothermal planning are:

1. VolumetricHeatStored.exe,
2. SingleFlashOutput.exe,
3. PowerOutput.exe,
4. DeclineModel.exe, and
5. EconExerciser.exe.

These copyright protected programs are also displayed in Figure 1 and require connection to the Pertamina Geothermal Network for operation. Copies are available through the author, and these programs only occupy 3.5 MB. All programs are written and compiled by the author using Borland Delphi 2005. The program was purchased in one package with the Borland Interbase when the IRIS was updated in 2005. All icons use the new Pertamina logo.

The correct operation of these programs requires:

1. General knowledge about hydrothermal system
2. A bit of mathematical background
3. Knowledge on thermodynamic properties of water (liquid and vapor)
4. The philosophy of economic assessment (e.g. IRR, NPV, WACC)
5. Up-to-date market prices of all resources/materials in the project.

Detailed technical calculations are not discussed in this paper, since the tools can be operated simply by clicking-and-deciding. Therefore, every single figure should have a meaning to the user. The following references are suggested for complete documentation:

1. Geothermal Diploma Course Lecture Notes in Auckland, New Zealand,
2. Thermodynamics Properties of Water and Steam, by Mayhew & Rogers, and
3. Pertamina Standard Management/ Economic Courses.

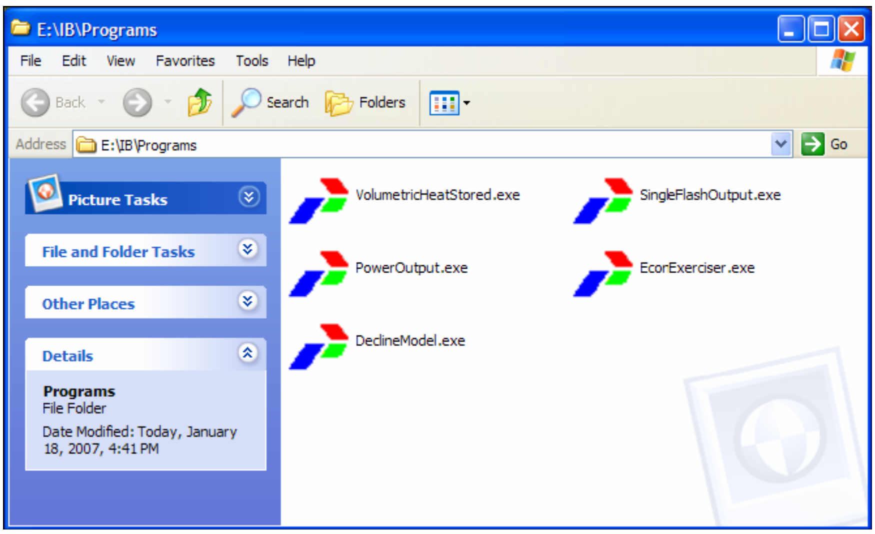
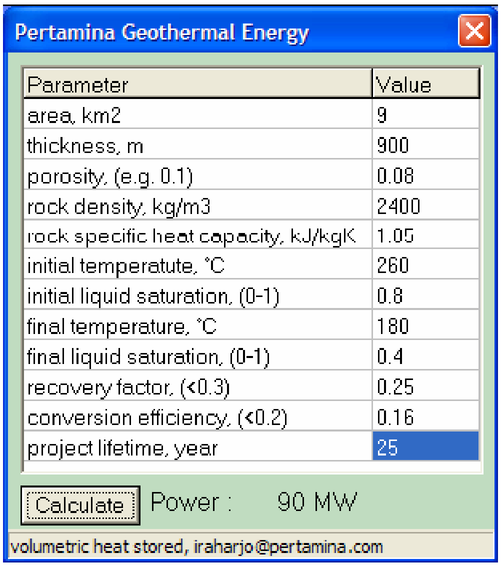


Figure 1: Five Basic programs for planning geothermal field development.

2. HOW BIG IS THE POTENTIAL

A method called volumetric heat storage calculation has been utilized in the geothermal industry for a long time. The method basically involves heat transfer from the source to the sink. A fraction of the heat flow is then used to calculate the work, while the rest is dumped into the heat sink. The method is automated in the program named VolumetricHeatStored.exe. Simply double-clicking its icon will cause the window shown in Figure 2 to appear. It contains the parameters and their respective values.



Parameter	Value
area, km2	9
thickness, m	900
porosity, (e.g. 0.1)	0.08
rock density, kg/m3	2400
rock specific heat capacity, kJ/kgK	1.05
initial temperatute, °C	260
initial liquid saturation, (0-1)	0.8
final temperature, °C	180
final liquid saturation, (0-1)	0.4
recovery factor, (<0.3)	0.25
conversion efficiency, (<0.2)	0.16
project lifetime, year	25

Figure 2: Volumetric Heat Stored Calculation Window showing the parameters and their respective values.

The first parameter, area, is the most crucial to the volumetric heat stored calculation. A good understanding of geophysics is needed to outline the size of the anomaly. In most cases, the anomaly is based on the low resistivity structure of the prospect. The low value is caused by clay alteration blanketing the prospect. It should be noted that the process is not reversible, and an extinct system may mislead interpretation. Reservoir thickness is somewhat arguable, as some users simply use a thickness of 1 km, while others use a thickness of 20-40 ohm.m layer for the first guess. Down-hole temperature profiles can also be used as guidance when available. The combination of geophysical structure and down-hole temperature knowledge naturally yields the best guess. Finding the porosity in the reservoir is always a problem in volcanic environments, especially when dealing with fracture-connected porosity. The best way to obtain this parameter is from laboratory measurement. This approach is carried out by comparing the matrix and the wet density.

Finding the value of the next parameter, density, should be guided by a geologist or geophysicist. A first guess is obtained by looking at the geological map, visiting the field, and considering what the most possible rock in the reservoir is. Are they andesites, pyroclastic rocks, or sedimentary rocks? The geophysicist then compares the Bouguer anomaly map at various densities. This work often leads to a better guess for rock density. The value of rock's specific heat is very tricky to measure. Many authors have published values, and they can simply be quoted. If the rock is solid (e.g lavas or silisified rock) a value of 1.0-1.1 kJ/kgK is appropriate. On the other hand, when the rock is fragmented (e.g. pyroclastics or sedimentary rocks), a value of 0.9-1.0 kJ/kgK is a good choice. The next parameters are reservoir temperature and initial steam fraction in the reservoir. The values can be obtained by a geochemist using appropriate aqueous geothermometry or down-hole measurement when available. The common geothermometry techniques are SiO2, Na-K, and/or Na-K-Ca depending on geological conditions. The method in the largest flow should always be applied, and preferably when sinter silica is also found. Special care must be taken when the content of Mg is high. More complicated methods, such as gas geothermometry, can also be used.

Determining whether a system is liquid or vapor dominated must be performed by a geochemist. If a reservoir is interpreted to have 80 % liquid, then simply input 0.8 for the initial liquid saturation. 180°C is commonly used for the final temperature or cut-off temperature. The value, which corresponds to 10 bara, is used in electricity generation applications, not for direct geothermal usage. After a long time of exploitation, the reservoir will "dry out." The final liquid saturation is a figure representing the "dry out conditions." At the first stage, an assumption must be made on the basis of the exploitation method (e.g. aggressive or conservative).

The next parameter is recovery factor, with reasonable values ranging from 0.25 to 0.3. However, the Wairakei system is reported to have a recovery factor of almost one, since the hydrothermal system is well understood. The last parameter, conversion efficiency, is somewhat related to Carnot efficiency, where in some geothermal applications, the temperature of the heat source can vary from 240-300°C, and heat sink is about 50°C. Geothermal equipment has considerably low efficiencies, so values ranging from 0.16 to 0.18 are good choices. After all the parameters are input, clicking the calculate button will give the volumetric heat stored result. For the sake of the accuracy of the method, the value is rounded to ten. Using the parameters listed in the Figure 2, the potential is calculated to be about 90 MW. For this example, this field is considered to be developed in a project scheme with a total capacity of 55 MW.

3. HOW MUCH STEAM IS NEEDED TO GENERATE ONE MW OF ELECTRICITY

For many years people have been using 8 ton/hour of steam to produce one MW of electricity. In many cases, this is true. However, to obtain a proper value, one should use the the PowerOutput program. After clicking the corresponding icon shown in Figure 1, the window shown in Figure 3 will appear.

In this example, the turbine inlet is 8 bara, while the condenser pressure is 0.2 bara. In addition, for every MW of capacity, a fraction of the steam is lost in the turbine axis and another fraction is used for gas removal, totaling about 0.3 ton/hour. Thus, a gross flowrate of 7.7 ton/hour of steam generates 1.06 MW. The isentropic line AB is theoretically a straight line. This in not the case in the real world, where the point B always shifts to the left, as represented by the turbine-generator efficiency. In the condenser/ cooling tower, roughly 20-40% of the remaining steam is condensed into a slightly acidic liquid. For a single 55 MW turbine, one re-injection well for condensate is needed. People often utilize a non-productive exploration well for this purpose, which saves money. Thus, to produce 55MW of electricity, a steam rate of 440 ton/hour is required. When a 10% excess is taken into account, the total figure is 484 ton/hour.

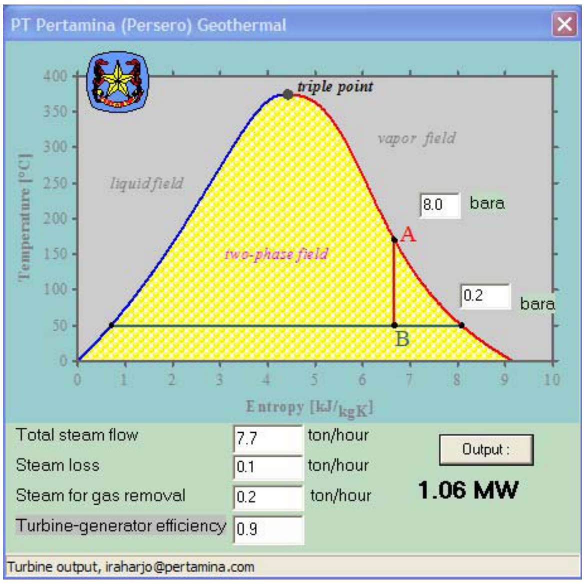


Figure 3: Temperature-entropy (T-s) diagram showing the isentropic process of steam at 8 bara expanding and condensing to 0.2 bara.

4. HOW MUCH LIQUID WILL BE PRODUCED

Once the steam rate for such development is understood, the total flow rate from the reservoir should be calculated. This gives an idea of how much fluid is involved and how to manage it. This calculation is based on the fluid flash mechanism with respect to mass and energy conservation, (e.g. isenthalpic process). This calculation is automated in the SingleFlashOutput.exe, as shown in Figure 4. The program requires only four inputs: reservoir temperature, reservoir dryness, cut-off temperature, and amount of steam required. For the sake of curiosity, the thermodynamic properties of water in these conditions are also shown. The generated diagram can also be used as a stand-alone steam table.

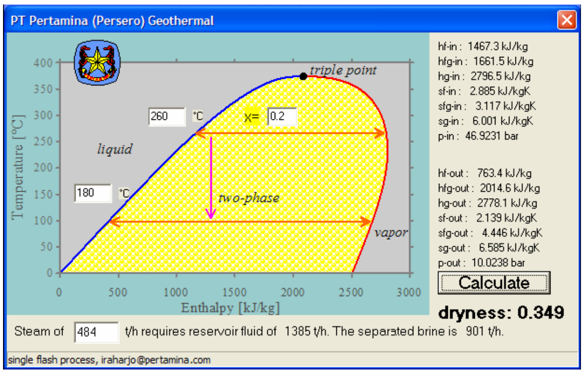


Figure 4: Temperature-enthalpy (T-h) diagram showing a single flash process from the reservoir to the surface production facility.

For the purpose of exercise in this paper, we have stated that the 260°C reservoir contains 20% steam, (i.e. dryness of 0.2). The figure is simply input in the respective box. The other inputs are the cut-off temperature of 180°C and the steam flow rate of 484 ton/hour. After clicking the calculate button, the total flowrate of extracted fluids is displayed, 1385 ton/hour in this case. The flow rate of the separated brine is also shown (901 ton/hour). For the purpose of this exercise, the capacity of a re-injection well is assumed as 300 ton/hour. Thus, three re-injection wells are needed. The number of production wells is discussed in the following chapter.

5. HOW IS THE RESERVOIR DECLINE

The long term prediction of the reservoir output is modeled to yield the forecasted make-up wells. The decline behavior itself is a tricky calculation. It is controlled by two parameters: the decline rate and the exploitation scheme. The decline rate is the difference between two successive annual production rates. The exploitation scheme is represented by a value ranging from zero (aggressive) to one (conservative exploitation). The program called DeclineModel.exe automates this problem. The program used to model the decline is shown in Figure 5.

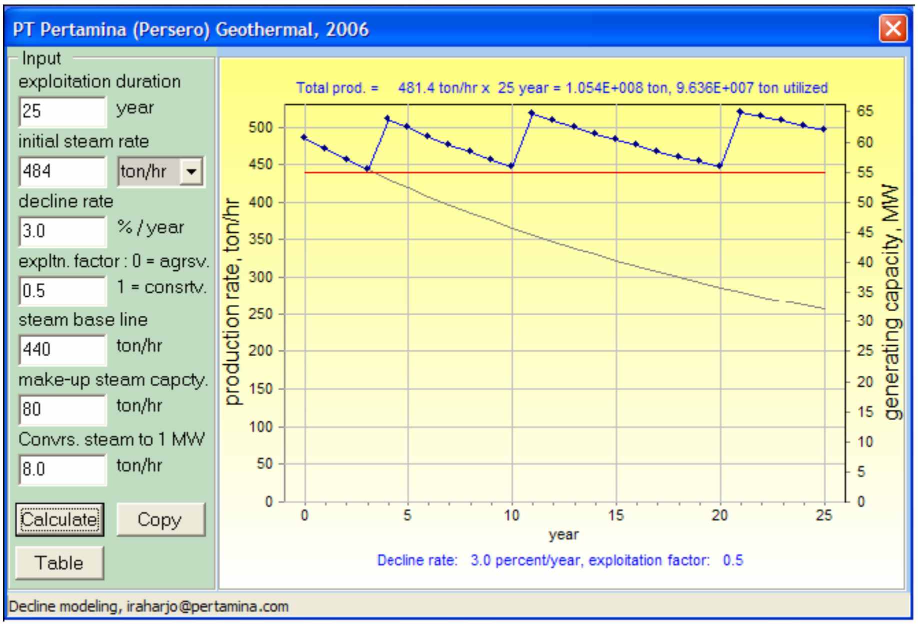


Figure 5: The long term decline model showing the respective years of the make up wells.

In addition to the decline modeling, the steam baseline is also to be included. This value is shown as a red line, as shown in Figure 5. When the amount of available steam is close to this line, the production rate curve is shifted up following the total make-up capacity. As shown in Figure 5, the make up wells will be implemented 3, 10, and 20 years after the commissioning. Supposing the construction period is four years, the make up wells will be implemented in the years 7, 14, and 24. Since the steam capacity of each make-up well is assumed as 40 ton/hour, two wells are needed in the respective make up years. The Table button displays the tabulated values of the production. Once this chapter is done, the economic assessment of the project can begin.

6. ECONOMIC ASSESSMENT

In this chapter, the economic evaluation of such a geothermal project is discussed. There are no complicated calculations since all are performed by the program called EconExerciser.exe as shown by the Figure 6-a. The main concerns here are the management of financial resources and attaining the correct assumption. The program can be started by double clicking its icon, followed by the Edit button if a new project is about to be set up. These screens are shown in Figure 6-b.

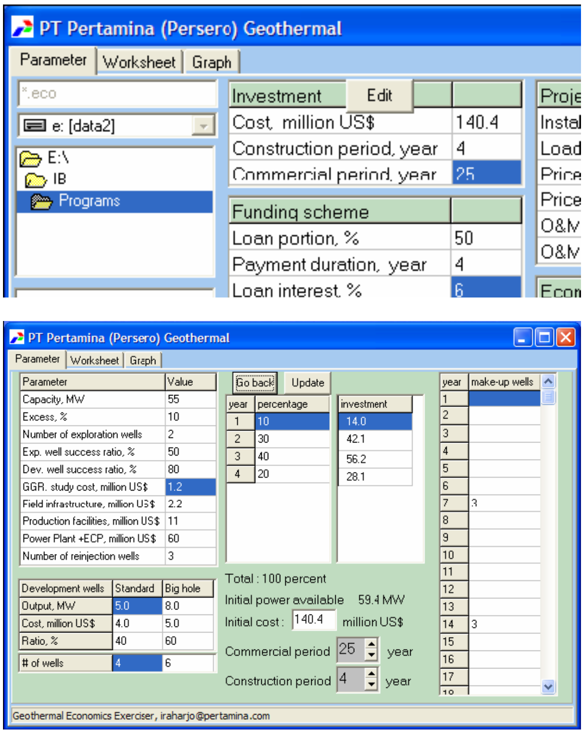


Figure 6: (a) The main window of EconExerciser.exe, and (b) the project definition tab. The tab is activated by clicking the Edit Button.

In this example, the 55 MW project requires two exploration wells, one of which is assumed to succeed while the other is assumed to fail (50% success). The assumed development well success ratio is higher at 80%. The expected well outputs are important parameters and have to be defined carefully. They determine the number of wells and the ratio between the number of standard and large holes. All other financial costs are also input to yield the total investment cost. The table at the center is the percentage distribution of the investment during the four construction years, while the table on the right is the forecast of the make-up wells. This is based on the decline model shown in chapter 5. Once all the figures have been added, the Update button is clicked to define the project scheme. The Go-back button is shown on the IRR simulation tab in Figure 7.

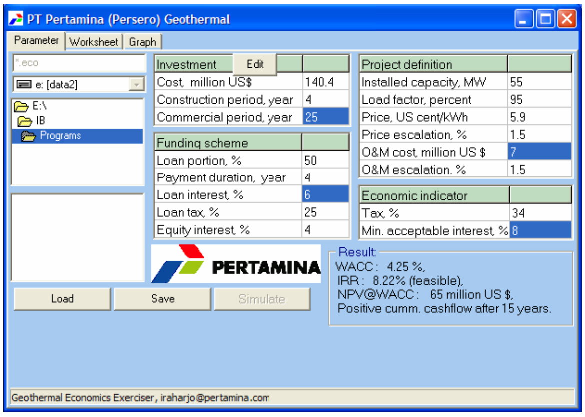


Figure 7: Selected economic parameters of the project.

As shown in the figure above, the total duration of the project is 29 years (four years of construction and 25 years of commercial operation). A total cost of 140.4 million US$ is estimated. It is assumed that 50 % of this is internally funded, and 50% externally financed. The loan payment duration is four years after commissioning, with 6% interest and 25% tax. It is surprising that such a project requires an electricity price of 5.9 US cent/kWh to obtain an internal rate of return greater than 8%. In many cases, the feasible IRR is dependent on the selling price, although other factors are also important. The program allows us to model the behavior of the selling price. This is carried out by clicking the Modeling Price button, and filling in the desired model. The Simulate button needs update to be clicked every time a value is altered anywhere in the program.

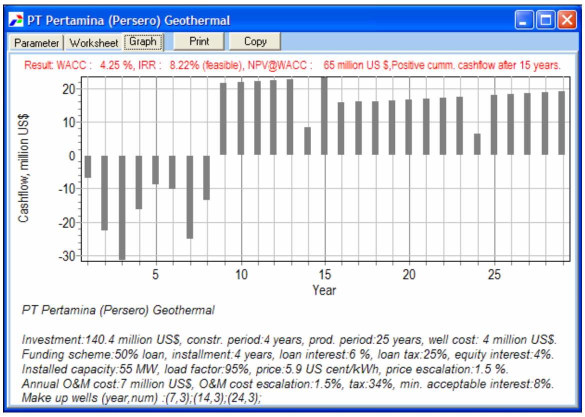


Figure 8: Cash-flow diagram of the project.

The program also shows the cash-flow forecast of the project, which is an important fact when analyzing the economic success of any major investment. As shown in Figure 8, cash-flow is negative within the first four years as a consequence of the development stages. Within the period of five to eight years, the cash-flow remains negative due to the payment obligation to the lenders and the initial make up well drillings. This payment includes the interest. Finally, the cash flow is positive for the rest of the project, indicating promising conditions. The low cash-flows in the years 14 and 24 are caused by the make up well drilling.

CONCLUSION

Five programs have been developed and tested to assist decision makers to yield a quick assessment of geothermal development. Users should perform exercises with the program until they feel comfortable with them. Like a fisherman having fishing tools, these programs are professional tools for the geothermal project managers. Alteration of important parameters for sensitivity analysis is highly recommended. Constructive comments are welcome.

ACKNOWLEDGEMENTS

The authors thank Imam B. Raharjo (Senior Geophysicist PT. Pertamina Geothermal Energy Indonesia) for the permission to let these programs be discussed and published in public.

REFERENCES

B.C Craft and M.F Hawkins.: *Applied Petroleum Reservoir Engineering*, Prentice Hall, 1991.

Grant, M.A., Donaldson, I.G. and Bixley, P.F.: *Geothermal Reservoir Engineering*, Academic Press, New York (1982).

Partowidagdo, Widjajono.: *Manajemen dan Ekonomi Minyak dan Gas Bumi*, Institut Teknologi Bandung (2002).

Saptadji, Nenny.: *Teknik Panasbumi*, Institut Teknologi Bandung (2001).

Scars, F. W. & Salinger, G. L.: *Thermodynamics Kinetic Theory & Statistical Thermodynamics*, Addison Wesley (1975).