Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

COMPUTATIONAL SYSTEM TO ESTIMATE FORMATION PERMEABILITIES BY SUPERPOSITION OF THE WELL INFLOW CURVE WITH GEOTHERMAL INFLOW TYPE CURVE

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Key Words: geothermal reservoirs, inflow type curves, formation permeabilities, computation system, inflow reference curves, wells output curves.

ABSTRACT

Formation permeabilities are usually determined from pressure transient tests or laboratory measurements on drill cores. The use of geothermal inflow type-curves may be a viable alternative to estimate this reservoir parameter. The inflow type-curves relate produced mass flowrate to flowing pressure in the feed zone of the well. By superposition of the inflow curve of a geothermal well with geothermal inflow type curves it is possible to estimate the absolute formation permeability at the feed-zone of the well. The permeability value implicit in the type-curve of the best match is then the permeability value sought. This methodology does not require field measurement of the inflow curve of the well. Use of two geothermal inflow performance dimensionless reference curves, one for mass productivity and another for thermal productivity, allows calculation of the well complete inflow curve, when combined with reservoir static pressure P_0 and a single measurement of mass flowrate, flowing pressure and specific enthalpy $(W,P,h)_0$ at the well feed-zone or at the wellhead. In order to do this, a computation system was developed which is described in this work. The system makes it possible to overlap the geothermal well inflow curve on to different geothermal inflow type-curves and then to select the best possible match. Type-curves covering the temperature range from 200 to 350°C in 25°C increments and Corey and linear relative permeabilities were considered. The system also allows estimation of the output curves associated to the well inflow curve by considering each calculated point of the well inflow curve as the input of a geothermal well flow simulator. The computation system shows instantaneously the estimated mass output curve (mass deliverability curve) for the well under analysis and the corresponding thermal power and specific enthalpy output curves. When it is required to validate the proposed methodology for a particular well, the $(W,P,h)_0$ data may be from a previous discharge test and then the system will display the estimated output curves comparing them with all the field data of the corresponding discharge test. This system can be considered as a complementary tool to the laboratory measurement of permeability and to the transient pressure tests as well as to well analysis.

1. INTRODUCTION

In previous works Geothermal Inflow Performance Relationships (GIPR curves or geothermal inflow type curves) have been numerically obtained for a wide range of formation properties by considering two phase feeds in the well (Moya, 1994; Moya et al., 1999). Each type-curve shows a particular behaviour which depends on these properties. In a preliminary analysis of wells of Los Azufres, México, geothermal field, Moya et al. (1999) demonstrated that by superposition of the geothermal well inflow curve with these inflow type-curves, it is possible to estimate the absolute formation permeability at the feed-zone of the geothermal well. The permeability value implicit in the type-curve of the best match is the permeability value sought. The knowledge of $(W,P,h)_0$ and P_0, allows the calculation of the well inflow curve (Iglesias and Moya, 1998), from two geothermal inflow performance dimensionless reference curves previously obtained by Moya (1994), Moya et al., (1995). The well inflow curve so calculated also allows estimation of the corresponding well output curve (Moya et al., 1998).

To obtain type curves a numerical simulator of geothermal reservoirs was used (Moya and Iglesias, 1995) which includes a state equation for the binary system H_2O-CO_2 valid up to 350°C and 500 bar (Moya and Iglesias, 1992). This simulator is a modified version of the TOUGH simulator (Pruess, 1987). Absolute permeabilities of 10 and 100 mD (base cases) and Corey and linear relative permeabilities, were considered. Initial temperatures varied from 200 to 350°C while initial CO_2 content was assumed to be 0.5% by mass. Moya (1994) and Moya et al. (1999) showed that the shape of the type-curves essentially depends on the temperature at the well feedzone, whereas the range of mass flows of each type-curve is directly proportional to the value of absolute permeability of the rock formation and to the functionality of relative permeability of each phase. The porosity, density, thermal conductivity and specific heat do not affect type-curves enough to affect the permeability diagnostic.

In order to facilitate the permeability diagnosis through the methodology described in Moya et al. (1999), a computation system was developed which allows making this diagnosis in an automated way from only $(W,P,h)_0$ and P_0 furnished by the user. The user can overlap the well calculated inflow curve on different geothermal inflow type-curves and then select the best possible match. The system instantaneously estimates type-curves for other permeability values different to 10 or 100 mD (base cases) through a scale factor which the user may choose freely, in accordance with Darcy's law, when the other parameters are fixed.

The system also shows the estimated mass output curve for the well under analysis and the corresponding output curves of thermal power and specific enthalpy. On each curve, the respective maximum values are indicated as well as the initial data $(W,P,h)_0$ and the reservoir static pressure P_0. When it is required to validate the methodology for a particular well, the

$(W,P,h)_0$ data may be from a previous discharge test and then the computerized system will display the estimated output curves comparing them with all the field data of the corresponding discharge test. The system operates under Windows 3.1 environment and later versions

2. GENERAL DESCRIPTION OF THE SYSTEM

The system basically contains a pair of dimensionless reference curves of geothermel inflow behaviour, one for mass productivity and another one for thermal productivity (Moya, 1994; Iglesias and Moya, 1998), and 28 cases of geothermal inflow type-curves which involve different reservoir thermophysical properties in the temperature range from 200 to 350° (Moya et al., 1999). The system allows capturing and storing information provided by the user, running a geothermal wellbore simulator, presenting different graphic screens and printing graphs, tables and reports.

The geothermal wellbore simulator incorporated into the system is the Vsteam simulator (Intercomp, 1981). This simulator involves the conventional correlations and maps for the calculation of two phase pressure drops with changes of flow regime. The system executes the well simulator in order to calculate the datum $(W,P,h)_0$ at bottomhole when the user provides the datum at wellhead. The datum $(W,P,h)_0$ at bottomhole together with P_o allows the system to calculate the complete inflow curve of the well using the correlations of the dimensionless reference curves. The system once again activates the simulator for the calculation of the well output curve associated with the inflow curve previously calculated. If the value $(W,P,h)_0$ corresponds to a wellhead datum of a previous discharge test, the system calculates the well output curve in the way already described, comparing it to the complete data of the discharge test, for validation of the methodology for this particular well.

If the user requires a permeability diagnosis without estimation of output curves and when the datum $(W,P,h)_0$ is not at bottomhole , then the system will not activate the wellbore simulator. However, some geothermal fields have available numerous records of well discharge tests at different stages of their productive life and whose sequential analysis could provide very relevant information on their potential. The system would facilitate this type of analysis, in addition to promptly providing an estimation of the distribution of permeabilities all over the field, as a support in taking decisions on exploring and exploiting of the field and, as a complementary tool to the measurements of permeability in the laboratory and to the field pressure tests. When the user requires this kind of study from discharge test data, then the system will activate the wellbore simulator through the system's "Input" .

Upon activating the "input" (Fig. 1) with the geometric and simulation characteristics of the well and with the complete data of discharge test, the system immediately shows the adjustment of these field data. The menú "Discharge test data" allows selecting the initial datum $(W,P,h)_0$ from which inflow and output curves may be estimated. When selecting the wellhead datum the user must establish the value P_0 and the increase of mass flow required for the calculation of the curves. At this point the system displays the estimated mass output curve compared to the complete field data of the discharge test (figure 2). The corresponding output curves of thermal power and of specific enthalpy are displayed when in the "Curves" menu the pertinent selection is made (figure 3). In each of these curves the maximum values corresponding as well as the initial datum $(W,P,h)_0$ and that of P_0 considered are indicated, showing themselves compared to the corresponding field data. A typical output is shown in figure 4.

In order to describe most of the options offered by the system a complete analysis of a well discharge test will be considered. The output curves will be estimated for each of the values $(W,P,h)_0$ of the discharge test (sensibility analysis to the wellhead datum). The graphic outlets of the system will show these curves compared with each other as well as with the field data of the complete discharge test. Likewise the graphic outputs of the sensitivity analysis of these curves to the value of reservoir static pressure in a range of ± 4bar around the value P_o is shown. Finally, the permeability parameter obtained for each of the values $(W,P,h)_0$ of the discharge test in the same range of P_o ± 4 bar will be shown.

3. SYSTEM OPTIONS

The options of the system (Fig. 5) on a first approach are three: "Output Curves", "Inflow Curves" and "Permeability diagnostic". The first two also allow the options of "Sensitivity to the Wellhead Datum" and "Sensitivity to the Static Pressure". The permeability option internally handles both sensitivity analyses.

3.1 Output Curves

This option is used for carrying out the well analysis at the wellhead. By default the output curve displayed on screen is that of mass productivity. If the user wishes to display associated output curves of thermal power and of specific enthalpy it is necessary to resort to the menu "curves". In every case the system shows the estimated output curves compared to the corresponding field data (Fig. 4). Likewise, by means of the menu "curves" the inflow curve associated with the mass productivity output curve may also be displayed, independently of the option "permeability diagnostic" in the menu "options". On the other hand, once the option "output curves" has been activated, the user can carry out the sensitivity analysis of these curves, regarding the wellhead datum or the static pressure, selecting the corresponding option in the same menu "options".

3.2 Sensitivity to the wellhead datum

Selecting wellhead data $(W,P,h)_0$ of the discharge test under study, the system will show sequentially and simultaneously all the estimated curves compared to the complete field data of the discharge test. This allows a quick analysis of the sensitivity of the methodology to the wellhead datum $(W,P,h)_0$. An example is given in figure 6. This kind of analysis implies keeping P_o constant. Deviation percentages of each estimated curve in relation to field data are shown by the system in the form of tables, datum per datum and as a global average for each curve. For this, the option "Table of values” in the menu “curves” must be selected.

3.3 Sensitivity to static pressure.

The user will also be able to carry out sensitivity analysis of estimated output curves to the value P_o keeping $(W,P,h)_0$ constant, see figure 7. The frame “Apply static pressure” allows changing the value P_o. As in the previous case, by selecting “Table of values” it will be possible to analyse deviation percentages of estimated curves in relation to field data to each P_0.

3.4 Inflow Curves

The same types of analysis carried out with the option “Output Curves” may be carried out with the option “Inflow Curves”, with the difference that the system will show the estimated inflow curves without comparing them to the field data since these data correspond to the wellhead. For the overlap of each estimated inflow curve with the geothermal inflow type-curves, the user must activate the option “Permeability Diagnostic”.

3.5 Permeability Diagnostic

For each estimated output curve of the well there is a corresponding inflow curve in such way that to infer the value of permeability of rock formation at the feedzone of the well (inflow zone), the system allows the user to overlap the inflow curve of the well with different geothermal inflow type-curves and then select the best possible overlap. The implicit permeability value in the type-curve of the best overlap corresponds to the permeability value sought.

The system includes 4 type-curve cases for each of the 7 temperatures considered in the range from 200 to 350°C in 25°C increments, corresponding to different values of the combination of parameters [absolute permeability - relative permeability] that are: [10mD-Corey], [10mD-Lineal], [100mD-Corey] and [100mD-Lineal]. This makes a total of 28 type-curve cases each one of them involving 6 curves corresponding to 5, 10, 15, 20, 25 and 35% of accumulated produced fluid. The system allows one to instantly obtain type-curves for other values of absolute permeability different to 10 and 100 mD, through a scale factor which the user may freely establish in accordance to Darcy’s law.

Figure 8 shows the window of the option “Permeability Diagnostic” where the user can carry out the overlaps of the well inflow curve with the different cases of geothermal inflow type-curves. In the left lower frame of this window, the user can instantly observe the overlaps, selecting type-curves from the central frame. For the quick selection of the type-curves more representative of each well, the user may take as reference the fluid temperature at bottomhole conditions indicated in the right lower frame (T_{wf}) as well as the maximum values W_{max}, Pow_{max}, h_{max} of the well inflow curves of mass productivity, thermal power and of specific enthalpy, respectively. In the narrow frame placed above the window, the user may select the datum $(W,P,h)_0$ of the discharge test, below provide the value $P_{o,}$ and then establish the scale factor (“Factor”) to obtain type-curves different from 10 and 100 mD. In figure 5 it can be observed that the well inflow curve overlaps well with a type-curve where bottomhole temperature is 275°C and relative permeability of the two phase flow is the Corey type. The scale factor is 0.63 applied to type-curves of 100 mD. Therefore, the permeability for the well considered is 63 mD. All the permeability values inferred by the system are referred to a value of the reservoir thickness of 100 m.

Figure 9 shows the best overlaps of inflow curves obtained from the different initial values $(W,P,h)_0$ of the discharge test. As can be observed, the permeability diagnostic is not very sensitive to the datum $(W,P,h)_0$ considered, which shows the applicability of the methodology, at least, for this particular well. As expected, the permeability diagnostic is indeed sensitive to the value of P_0 (figure 10).

Finally, the overlap of the well inflow curve on the linear relative permeability type-curves allows estimation of a possible minimum permeability value. An example is shown in the figure 11.

4. CONCLUSIONS

The computing system allows one to estimate quickly and reliably both output and inflow curves of geothermal wells as well as formation permeabilities, from only $(W,P,h)_0$ and P_0 furnished by the user. When the user requires to prove the applicability of the system for a particular well, the $(W,P,h)_0$ datum may be from a previous discharge test and then the system will display the estimated output curves comparing them with all the field data of the corresponding discharge test. Accordingly, the system facilitates the analysis of large amounts of existing information concerning wells productivity behaviour. Likewise it makes it easy to obtain, in a very short time, an estimate of the complete distribution of permeabilities in a geothermal field, as a reference point to the laboratory measurements and transient pressure tests.

5. REFERENCES

Iglesias E.R., Moya S.L. (1998). Applicability of geothermal inflow performance curves to CO_2-bearing reservoirs, Geothermics, Vol. 27, No. 3, pp. 305-313.

Intercomp (1981). Vertical steam-water flow in wells with heat transfer-VSTEAM, User's Manual. Resource Development and Engineering, Inc., Houston, Texas, U.S.A.

Moya S.L., Iglesias E.R. (1992). Solubilidad del bióxido de carbono en agua en condiciones geotérmicas, Geofisica Internacional, Vol. 31, No. 3, pp. 305-313.

Moya S.L. (1994). Efectos del bióxido de carbono sobre el transporte de masa y energía en yacimientos geotérmicos, Ph.D. Thesis, UNAM, 204 pp.

Moya S.L. , Iglesias E.R. (1995). Numerical simulation of carbon dioxide effects in geothermal reservoirs, Proceedings of the TOUGH Workshop ' 95, LBL-37200, pp. 119-130.

Moya S.L., Iglesias E.R., Aragón A. (1995). Curvas de referencia adimensionales para estimar productividades de masa y energía de yacimientos geotérmicos con/sin bióxido de carbono, Geotermia, Revista Mexicana de Geoenergía, Vol. 11, No. 3, pp. 167-179.

Moya S.L., Aragón A., Iglesias E., Santoyo E. (1998). Prediction of mass deliverability from a single wellhead measurement and geothermal inflow performance reference curves, Geothermics, Vol. 27, No. 3, pp. 317-329.

Moya S.L., Uribe D., Aragón A., García A. (1999). Estimation of formation permeability at the feedzone of geothermal wells employing inflow type-curves, Geothermics, In review.

Pruess K., 1987. TOUGH Users's Guide; Report LBL-20700, Lawrence Berkeley Laboratory, 78 pp.

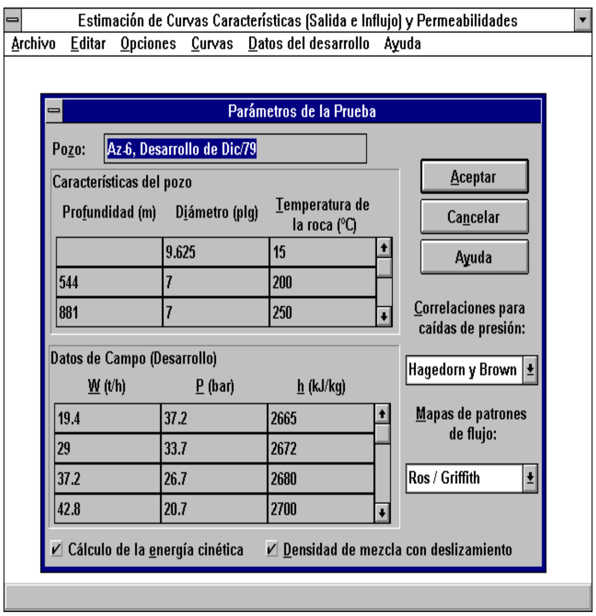

Figure 1. Input of the System to activate well simulator

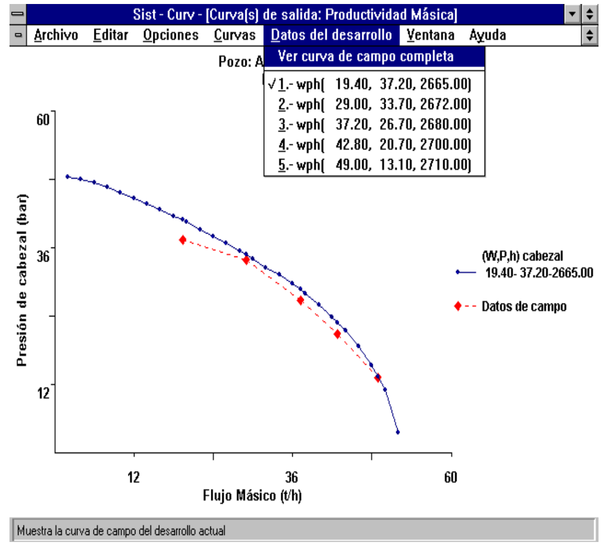

Figure 2. Field Data Menu.

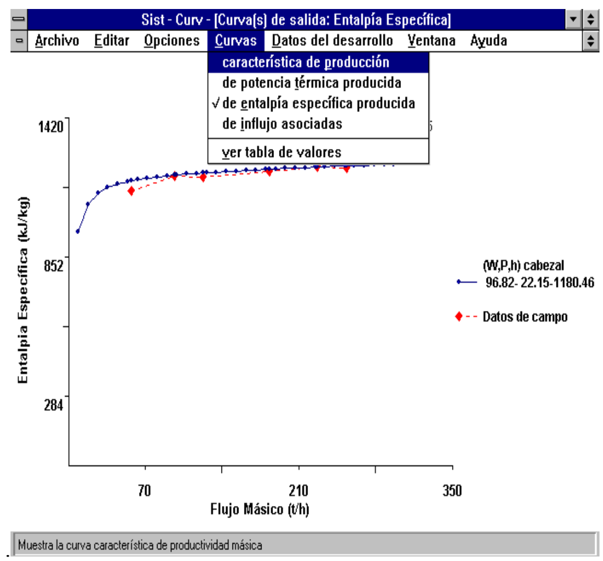

Figure 3. Curves Menu..

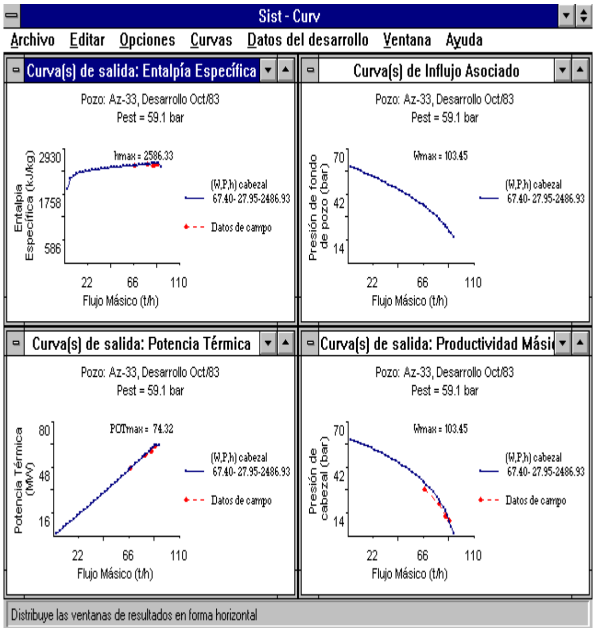

Figure 4. Typical System Output.

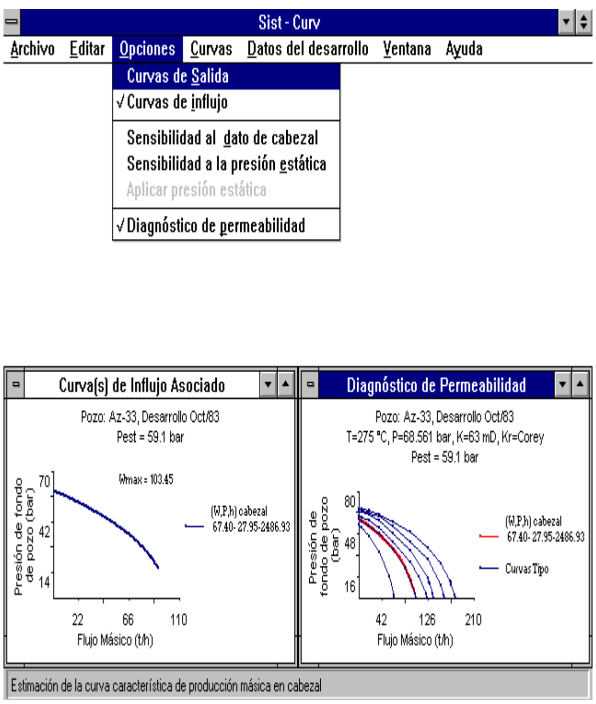

Figure 5. System Options. An overlap of the inflow curve of a geothermal well with geothermal inflow type curves is also shown.

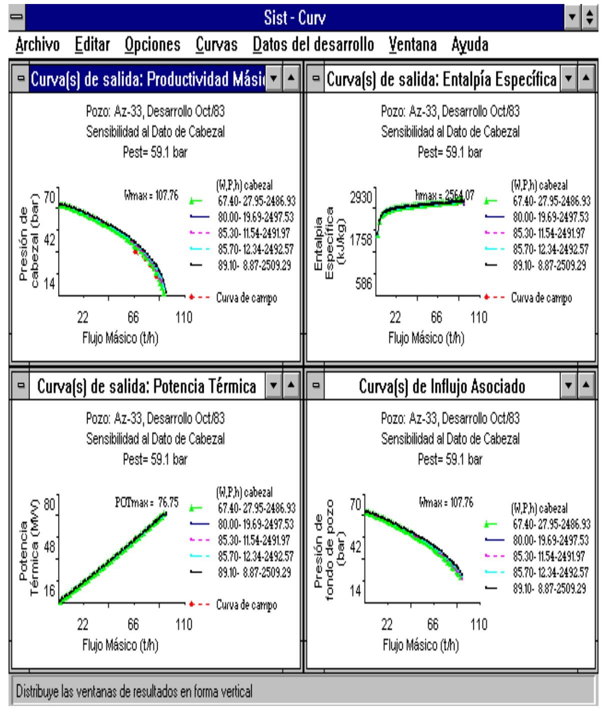

Figure 6. Option of Sensitivity to the wellhead datum of the estimated output curves of mass, specific enthalpy and thermal power as well as of he mass inflow curves.

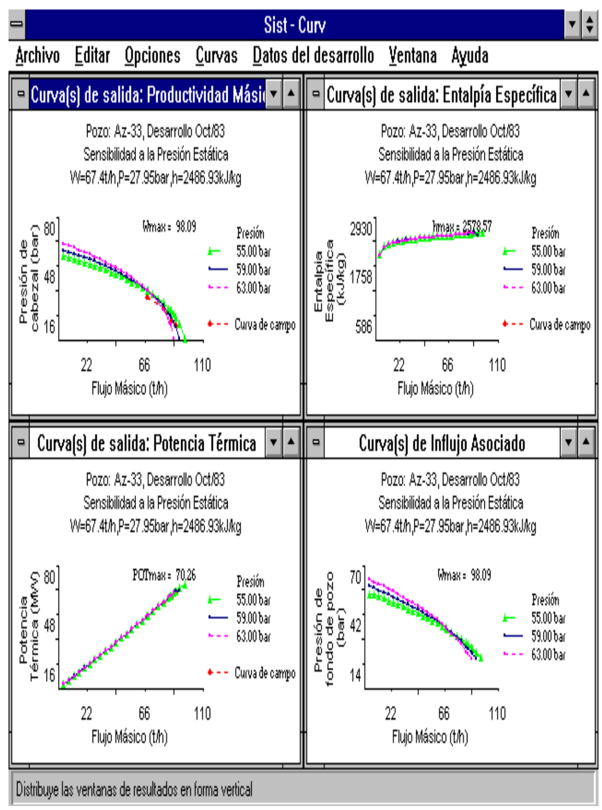

Figure 7. Option of Sensitivity to Static Pressure (P_0 = Pest) of the estimated output curves (mass, specific enthalpy and thermal power) as well as of estimated mass inflow curves.

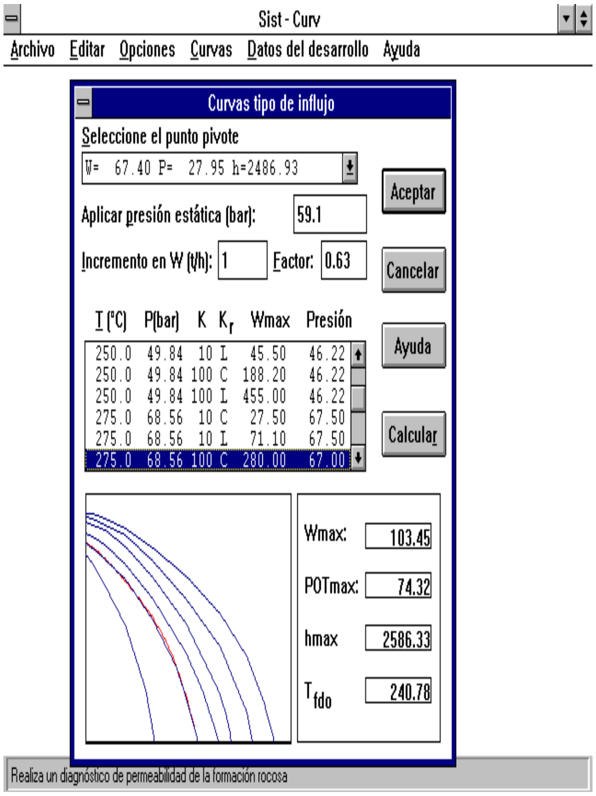

Figure 8. Window of the Option of Permeability Diagnostic where the user can carry out the overlaps of the well inflow curve with the different cases of inflow type curves.

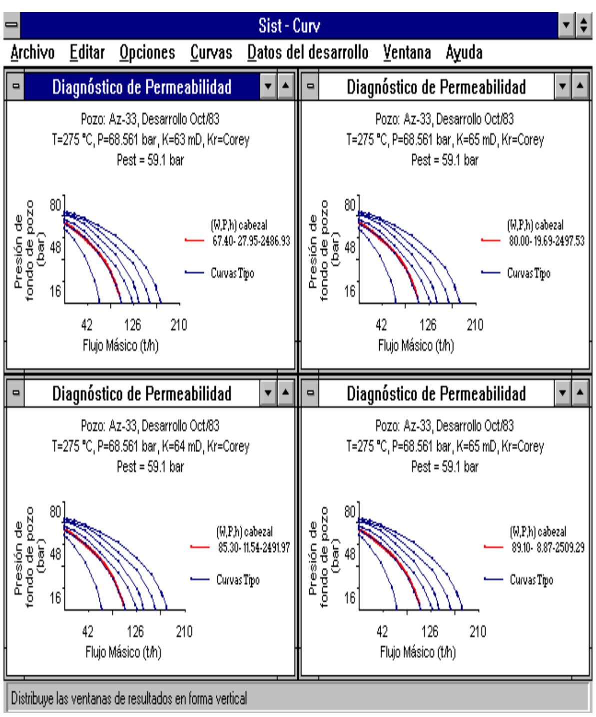

Figure 9. Permeability Diagnostic: Sensitivity to the wellhead datum $(W,P,h)_0$ [(W,P,h)cabezal] .

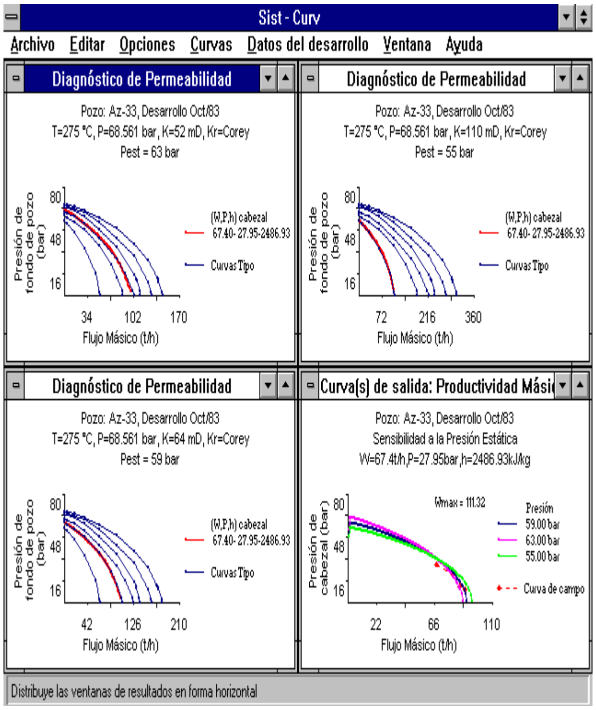

Figure 10. Permeability Diagnostic: Sensitivity to Static Pressure P_0 (Pest) .

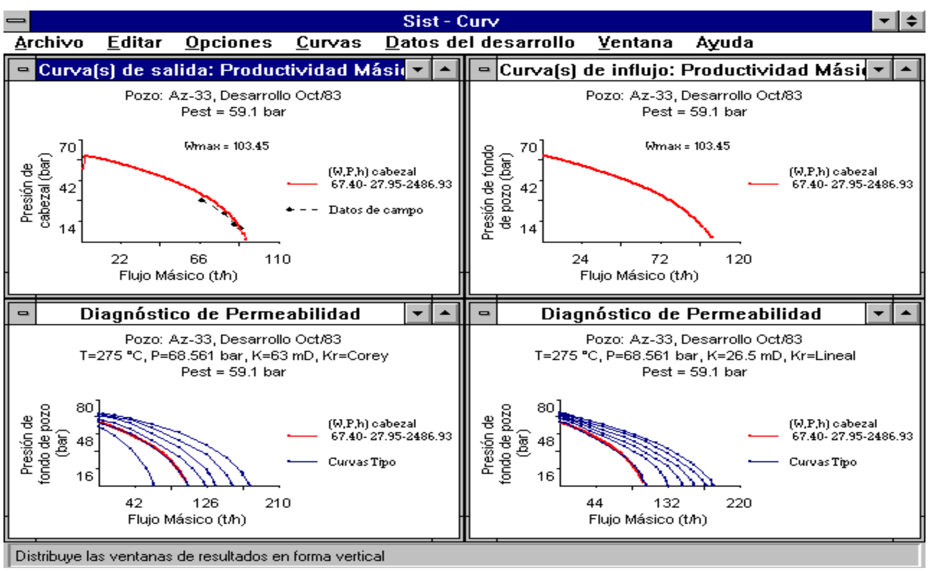

Figure 11. Permeability Diagnostic: Sensitivity to the Relative Permeability (Kr).