

CORRELATION OF FLOWMETER VELOCITY WITH FLUID PHASE USING THE FLOWING SURVEY DATA OF WELL SK-2D

Christine Sy Hingoyon

PNOC-Energy Development Corporation, Makati, Philippines

Abstract

With the aim of further evaluating the many benefits that the electronic Temperature-Pressure-Spinner (TPS) logging tool can provide, this paper attempts to correlate the spinner responses fluid velocity) recorded with the phase of the fluid during a TPS survey of a discharging well. TPS data of well SK-2D in the Mindanao Geothermal Project, Philippines was used in this study.

Wellbore simulation was performed in SK-2D to determine the fluid phase while discharging at different well openings. The wellbore simulator used can only handle single feed zone which is located at the bottom of the wellbore. Since SK-2D is a multi-feed well, a simulation procedure is proposed that accounts for the different production zones observed using the single feed wellbore simulator. With this method, a good match of the flowing temperature and pressure data, the mass flow and enthalpy data was obtained. The simulation results (i.e. dryness, velocity, enthalpy, and density) were then correlated with the recorded spinner responses. Finally, a procedure for correlating the spinner responses with the fluid phase is suggested.

1. Introduction

When a geothermal well is discharged, the fluid inside the wellbore column is of varying phases. By using the downhole temperature and pressure data generated by the mechanical Kuster gauges, it is possible to recognize whether a certain region of the wellbore is two phase or not, but the approximate dryness value cannot be determined. A lot of important wellbore information could be gathered if the dryness value of the fluid of a discharging well could be measured, such as the real density of the fluid, real enthalpy values, and a more accurate interpretation of the different feed zones.

Electronic Temperature-Pressure-Spinner (TPS) measuring instruments have been recently used in geothermal production logging to improve data acquisition and interpretation. This instrument is an improvement on the Kuster temperature and pressure gauges because it can transmit downhole information to the surface while the survey is ongoing, and it also has a spinner response which allows downhole velocity measurements. The spinner is rotated by the moving fluid. The number of revolutions per second (*rps*) of the spinner can be recorded at the surface and this value can then be related to the velocity of the moving fluid. The spinner response depends on the fluid flow properties however, and if the fluid is two-phase, on the dryness fraction and flow regime.

It is the goal of this report to study the different parameters (i.e. fluid properties) that can affect the spinner rotation of the TPS instrument. It is also desired to develop an estimation of the dryness of the fluid in any part of the wellbore column of a flowing well based on the corresponding *rps* values that are recorded during a flowing TPS survey. Flowing TPS data of production well SK-2D in Mindanao 1 Geothermal Production Field was used in deriving the correlation.

The technique used in this study was to determine the dryness fraction of the fluid in the wellbore column using wellbore simulation. The flowing survey data of well SK-2D at different well openings have been simulated. The resulting dryness values from these simulations were then used to calculate the fluid properties. The spinner response (*rps* values) were then plotted against the calculated fluid

properties to analyze how each of the parameters could affect the spinner rotation. Finally, a procedure and an equation have been developed that directly associate the spinner rotation/rps to the fluid dryness fraction.

2. SK-2D Flowing TPS Surveys

SK-2D is a production well in Mindanao 1 Geothermal Power Project, Philippines. It is a deviated well with an azimuth of 224.18° and a total depth of 1500.2 m vertical and 1837.6 m measured¹. It was completed on May 13, 1993. The well encountered four faults, but only two occur below the production casing shoe. In addition to these faults; lithologic contacts between basaltic and andesitic units contribute some permeability to the well (Panem and Zaide, 1993).

The well has an injectivity index value of 21.3 L/s-MPa based on the completion test. The permeable zones were surmised to be at 691–713 m, 730–739 m, 956–965 m, 1050–1073 m, 1450–1500 m, 1600–1650m, and 1700 m to bottom. The first four zones are in the cased-off section of the well, and were determined during drilling when circulation losses were encountered at these depths. There was no circulation experienced from 1752.1 to 1826.2m.

The cased-off portion was later perforated and acidized to access the two phase zone detected and the mud damaged permeable zones were acidized to improve its productivity. While on discharge, a series of TPS surveys was carried out. It was found out from the plots of the downhole data that only the two permeable zones at the perforated section 691–713 m, and 730–739 m were producing two-phase fluids. The plots of the TPS survey results at different wellhead pressures (WHP) are shown in Figures 1 to 3 and the bore output during its discharge test is given in Table 1 below.

Wellhead Pressure WHP, (Barg)	Massflow MF, (kg/s)	Enthalpy H (kJ/kg)
18.0	18.6	1292
12.0	44.0	1213
8.8	66.9	1149

Table 1: SK2D bore output summary from Molina et al. (1998)

Molina et al. (1998) calculated the individual contributions of the feed zones using the method discussed in the paper of Maceda et al. (1996). This involved the correlation of the well's spinner responses against the different cable (tool) velocities used. Since the method is more accurate for single phase flow, Molina et al. (1998) only used the method to directly calculate the contributions from the liquid phase feed zones. The contributions from the two-phase feeds were computed from the difference between the total massflow obtained from the bore output and the massflow obtained from the liquid feed zones.

3. Wellbore Simulation

Wellbore simulation is the calculation of pressure drop and pressure distribution in a geothermal well. The components of this pressure drop are gravitational, acceleration, frictional, and pressure loss due to changes in diameter. The calculation, which is in steps, could either be from top to bottom or vice versa depending on which data are known.

The simulator that was used in this study always assumes that the feed zone is at the bottom of the wellbore and that the well is made up of two different casing sizes. The input data that this program

¹ All the depths mentioned in this section are measured depths unless stated otherwise.

requires to be able to do its computation are the following: a). The total depth of the well in meters b). The depth where the production casing shoe is set c). The respective diameters of the two different casings d). The respective relative roughness of the two casings e). The pattern of the calculation, whether from bottom to top (i.e. flowing well) or vice versa f). The initial temperature and pressure values of the feed zone for liquid feeds; for two phase, the temperature and enthalpy are inputted instead g). Heatloss h). The pressure increment. This pressure increment is used for the calculation of the next depth /location. The change in depth/location (Δz) is calculated as:

$$\Delta z = \Delta P / [(dP/dz)_{gravity} + (dP/dz)_{acceleration} + (dP/dz)_{friction}] \quad (1)$$

where:
 ΔP = pressure increment
 (dP/dz) = pressure drop component either from gravity, acceleration or friction

The output that are generated by the program are the following a). The change in depth (Δz). b). The wellbore pressure and temperature c). Enthalpy d). Dryness e). Flow regime f). Momentum, friction, and gravity pressure drop components. All of these are reported with respect to the well depth. The summary of the input data is also given.

4. Simulation Methodology

The downhole temperature and pressure data as well as the bore output measurements (such as massflow, enthalpy, and wellhead pressure) will be simulated. This is done to be able to obtain the properties of the flowing fluid (particularly the dryness which is the main concern of this study). Production well SK-2D, as discussed in Section 2, is a multi-feed well. Since the simulator used can only consider a single feed zone at a time and always assumes that this zone is situated at the bottom, a method to overcome this limitation of the program has to be developed.

The different feed zones of well SK-2D that were enumerated in Section 2 (Table 2) were again considered here. Bearing in mind these depths, the flowing TPS profiles at the three different openings of the well (Figures 1 to 3) were observed. It can be seen from the three plots that consistent changes in temperature trends occur at the following depths: bottom-1600 m, 1600–1090 m, 1090-900 m and 900 in-wellhead.

A separate simulation run was done for each region enumerated above (for the three discharge wellhead pressures). The simulator can be used to simulate each region because the conditions of each satisfy the limitations of the software (which are : one feed zone and should be found at the bottom).

For the first region (bottom-1600m), the feed zone was assigned to be at the bottom. Then the simulated data from bottom to 1600 m (whole isothermal profile length) were kept. The massflow that was used here and the succeeding regions were the same massflows calculated by Molina et al. (1998). The diameter of the liner was assigned to be 0.2134 m (this value is 10% higher than the original liner value). This was intentionally done because, in reality, the fluid from the feed zone will flow interchangeably from the liner to the casing hole and vice versa. The value 0.2134 m is a safe assumption because it is still smaller than the diameter of the production casing (0.245 m). The relative roughness of the liner is assumed to be 0.007 m. This value was suggested by Hagdu et al. (1988), who made a study of the fluid flow in the liner of a geothermal well. Hagdu et al. (1988) concluded that the reasonable roughness height for a liner would be in the range of 0.001 m to 0.007 m. The temperature and pressure data of the bottom feed were based on the flowing survey data. Other input data that were used are the following:

$$\begin{aligned} \text{Production casing depth} &= 1217.16 \text{ m} \\ \text{Total depth} &= 1739 \text{ m} \\ \text{Casing roughness} &= 0.0000157 \text{ m} \end{aligned}$$

For the second region (1600-1090 m), the feed zone was taken to be at the bottom (1600 m). Because

of this, the simulation was started at 1550 m. This was done to also quantify the massflow produced from the previous feed zone. The simulation results that were only considered were from 1550m to 1100 m (whole isothermal profile length at this region). Input data are as follows:

Total depth = 1550m
Casing depth = 1217.46
Casing and liner diameter = 0.245 m and 0.2134 m respectively
Casing and liner roughness = 0.0000457 m and 0,007 m respectively
Massflow = massflows of regions 1 and 2
Temperature and pressure values are taken from flowing survey data

The third region (1090-900 m) assumes that the feed zone is at 1090m. Again, since the profile is almost isothermal and to quantify the previous feeds' massflows, the simulation was started at 1050 m. **Notice** that in this region, the production casing of the well was already the perforated part. So there is a need to increase the diameter of the perforated part (about 10% higher than the original casing diameter) as this also acts like a liner. Also, the roughness for this part is assumed as 0.007 m. Simulation results that were only considered were from 1050 m-800 m, this is the whole region before a new feed zone at the top occurs. The input data are as follows:

Total depth = 1050m
Casing depth = 691 m
Casing and liner diameters = 0.215 and 0.2691 m respectively
Casing and liner roughness = 0.0000457 and 0.007 respectively
Massflow = massflows of regions 1, 2, and 3
The temperature and pressure data are still from the flowing survey data.

The last region (900 m-top) is composed of two phase fluids. In the simulation, the feed zone is assumed to be at 750m. The simulation results that were considered were from 750 m to top. The input data are as follows:

Total depth = 750m
Casing depth = 691 m
Casing and liner diameter = 0.215, and 0.2691 m
Casing and liner roughness = 0.0000457. and 0.007 m
Massflow = massflows of regions 1, 2, 3, and 4

Table 2 summarizes the different contributions of each region.

REGIONS (DEPTH, M)	MASSFLOW (KG/S)		
	@ 8.8 BARG	@12.0 BARG	@18.0 BARG
1, (bottom-1600 m)	38.1	6.0	24.6
2, (1550-1100 m)	5.4 +38.1 = 43.5	2.1 +6 = 8.1	24.6 +3.6 = 28.2
3, (1050-800 m)	43.5 +17.4 = 60.9	8.1 + 2.9 = 11	28.2 + 12.3 = 40.5
4, (750 m-top)	6.0 + 60.9 = 66.9	11 + 7.6 = 18.6	40.5 + 3.5 = 44.0

Table 2: Summary of massflow contribution in each feed zone of SK 2D.

All the simulation results of the four regions, which were at different depths, were combined. The combination is plotted against the real flowing survey data and the bore output data to observe for the match.

5. Results and Discussion

Figures 4 to 6 show the simulated temperature and pressure values plotted side by side with the measured data taken from the flowing survey for all wellhead pressures. The plots show a very good match, especially for the temperature values. Among the three well openings, the 8.8 barg downhole data was the most difficult to match and the resulting simulation data has the most deviation from the measurements. This is even more evident in Figure 7 that shows the measured and simulated massflow and enthalpy plot versus wellhead pressure. But generally, a better match is obtained using the proposed method as compared to just assuming a single feed zone for the whole well.

The simulated fluid properties are also plotted versus depth and spinner responses and are shown in Figures 7 to 9. The results indicate that the simulated dryness values start to deviate from zero (liquid phase) at 900 in. This is consistent with earlier analysis that the flash point started at the same depth.

Table 3 is the tabulation of real and simulated enthalpy and wellhead pressure values for all the well's flow openings. The massflow is of course consistent with the real data because it is an input data.

Well Openings	Enthalpy (kJ/kg)		Wellhead Pressure (barg)	
	real	simulated	real	Simulated
8.8 barg	1149	1008	8.8	10.6
12.0 barg	1213	1213	12.0	12.9

Table 3: Measured and simulated wellhead pressure and enthalpy values

Equation for the Correlation of Spinner Rotation with Fluid Phase

From Newton's Laws of Motion which states that "when one object interacts with a second object, the force of the first object on the second is equal in magnitude but opposite in direction to the force of the second object on the first" we therefore have,

$$F_R = F_T \quad (2)$$

where:
 F_R = force brought about by the rotation of the spinner
 F_T = force that caused the spinner to rotate

Consider first F_R :

The spinner is assumed to be traveling in a uniform circular motion. Thus the corresponding force is given by

$$F_R = m \omega^2 r \quad (3)$$

where:
 m = mass of the spinner, kg
 ω = angular speed, 2π rad/s or rev/s
 r = distance between the two spinner ends, meter

Consider F_T :

From the description of the spinner flowmeter, it was said that it is the flow of fluid that makes the spinner rotate. Therefore this flowing fluid behaves like a force drag. Drag is the force on a body caused by the fluid which resists motion in the direction of the travel of the body (Robert Mott, 1972). This drag force is then expressed in the form,

$$\text{Drag} = F_T = C_D * 1/2 * \rho * A * V^2 \quad (4)$$

where:

C_D = drag coefficient which is dimensionless that primarily depends on the orientation of the spinner to the flowing **fluid**, and the physical shape of the spinner

ρ = density of the flowing fluid

A = characteristic area of the spinner

V = velocity of the flowing fluid. The relative velocity **is** considered here meaning, the summation of all the velocity.

= velocity of the fluid minus the cable velocity (velocity at which the TPS instrument **is** run-in)

= the cable velocity is subtracted from the fluid velocity (V_F) because not all of the spinner rotation is brought about by the fluid velocity but also by the cable velocity (V_C)

= the threshold velocity **is** not considered here, because it is such a small value and can be considered negligible

$$= V_F - V_C$$

Therefore Equation 2 becomes:

$$m \omega^2 r = C_D * 1/2 * \rho * A * (V_F - V_C)^2 \quad (5)$$

$$\omega^2 = (C_D * A / 2 * m * r) \rho (V_F - V_C)^2$$

$(C_D * A / 2 * m * r)$ can be considered as constant for a particular spinner, thus

$$\mathbf{J} = K * \rho (V_F - V_C)^2 \quad (6)$$

ω^2 is plotted against $[\rho (V_F - V_C)^2]$ on Figure 10 using the simulated data. The points were then fitted through the origin to generate an equation in the form of $Y = b X$. The value of b will also be the value of K . From Figure 10, K is consistently equal to 0.12 for both 12.0 and 18.0 barg wellhead pressures and is equal to 0.44 for the 8.8 barg. The discrepancy in the values of K obtained can be attributed to the different spinner pitch angle used during the flowing survey at near fullbore (8.8 barg) and the choked conditions (12.0 and 18.0 barg). Furthermore, it was proven in this study that indeed there is a correlation between the spinner rotation and the fluid dryness fraction because once the fluid density is **known**, the dryness fraction can also be known using

$$1/\rho_{TP} = [(1-x)/\rho_L] + [x/\rho_V] \quad (7)$$

where:

$$\rho_{TP} = \text{density of the two phase fluid}$$

$$\rho_L = \text{density of the liquid}$$

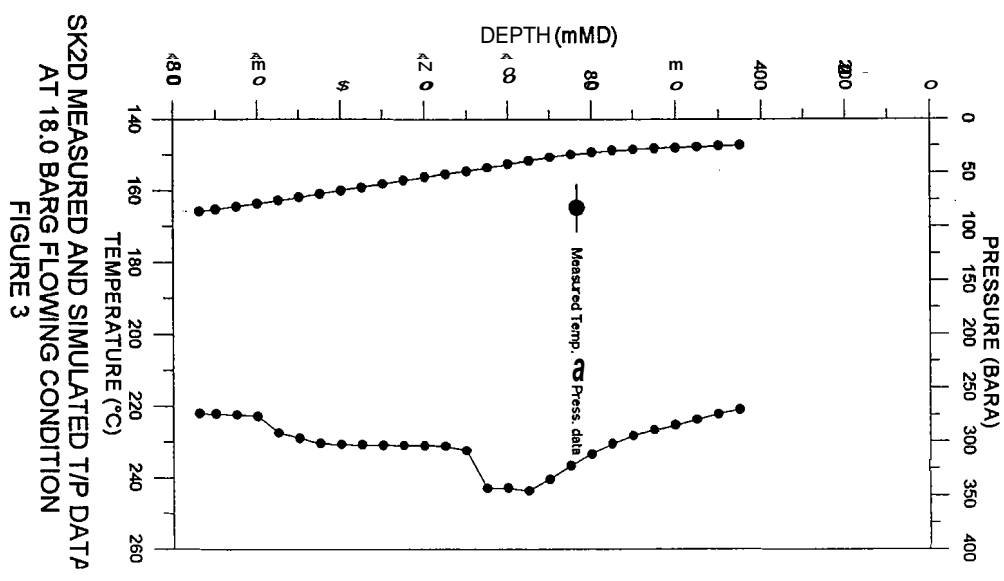
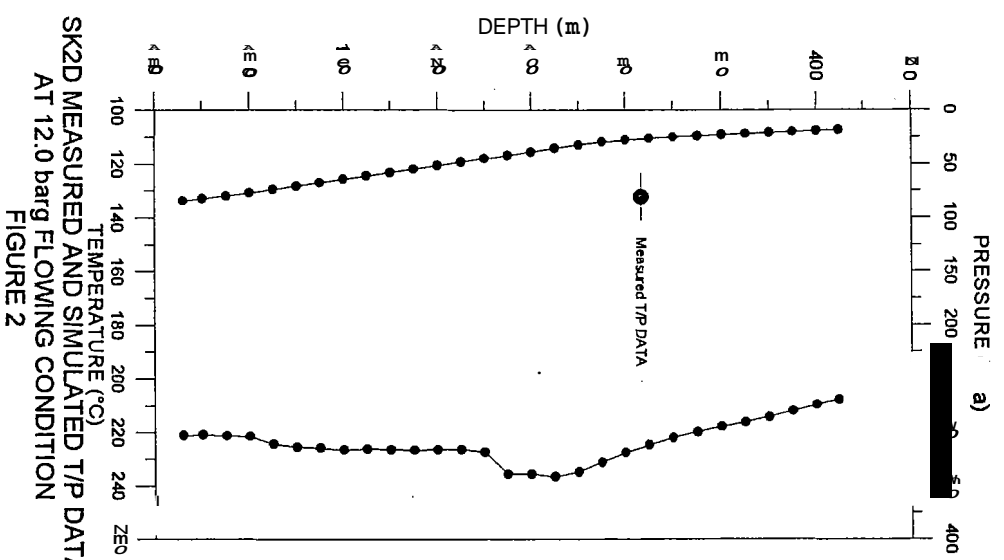
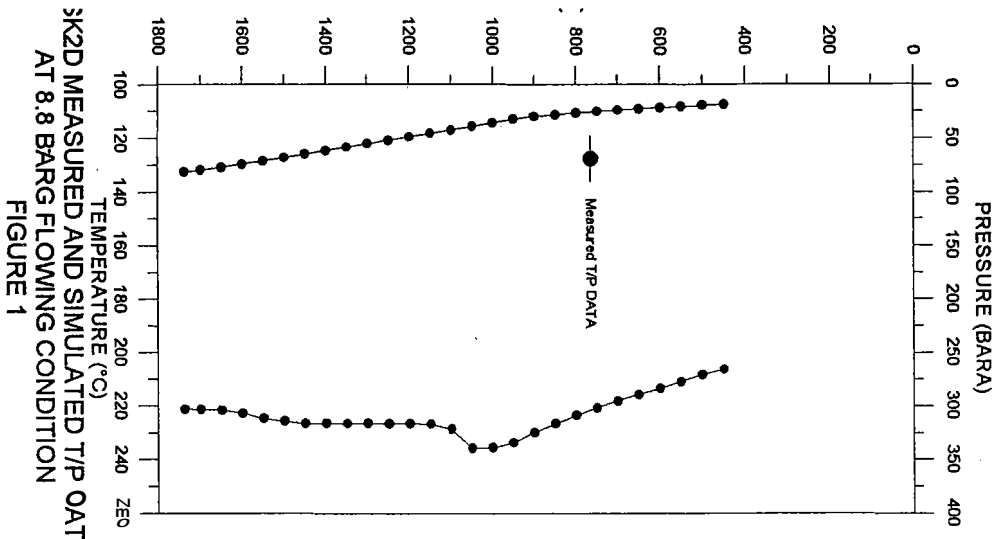
$$\rho_V = \text{density of the vapor}$$

6. Conclusions

- The plot of the different **flow** properties **with** respect to depth and spinner rotation for well SK-2D shows that dryness fraction and velocity are the main parameters that affect the spinner rotation. All other parameters are either just related to dryness or velocity values.
- It was proven by this study that spinner rotation for well SK-2D could be correlated **with** the fluid density and consequently, the dryness fraction. In particular the equation, $\omega^2 = K * \rho (V_F - V_C)^2$, can be used to calculate **the** two-phase density (therefore, also the dryness fraction) given the spinner rotation and the relative velocity. The value of K is determined empirically to be about 0.12 for **the** choked conditions and **0.44** for the near fullbore condition.
- In carrying out the work it was found that the limitations of the wellbore simulator that was used could be overcome by a simple method. **This** method is to separately simulate each feed zone and then combine them all together. The method gave a good match with the real temperature and pressure data and the bore output data.

7. References

- Atlas Wireline Services, (1982). Interpretative Methods for Production Well Logs 3rd edition.
- Beek, W.J** and Muttzall, M.K., (1975). Transport Phenomena.
- Hagdu, T. et al, (1988). Studies of the Flow in the Liner of a Geothermal Well. Geothermal Resources Council, Transactions, Vol. 12.
- Maceda, N.S. Gonzaga, L.D., Lacanilao, A.M., Noriega, M.T., Antonio, C.L. and Handy, L.E. (1997). Use of the Spinner Tool in Capacity Measurement of Geothermal Wells During Hot Injection. Proceedings, 22nd Workshop on Geothermal Reservoir Engineering Stanford University, Stanford California.
- Molina, P.O., Malate, R.C.M., Buning, B.B., Yglpaz, D.M. Austria, J.J.C. and Lacanilao, **AM** (1998). Productivity Analysis and Optimization of Well **SK2D** Mindanao 1 Geothermal Project, Philippines. Proceedings, 23rd Workshop on Geothermal Reservoir Engineering Stanford University, Stanford California
- Mott, R.L., (1972). Applied Fluid Mechanics.
- Panem, C. And Zaide, M.C., (1993). Geology of Well SK2D. PNOC-EDC internal report.
- Weidner, R.T. and Sells, R.L.(1974). Elementary Classical Physics 2nd edition.



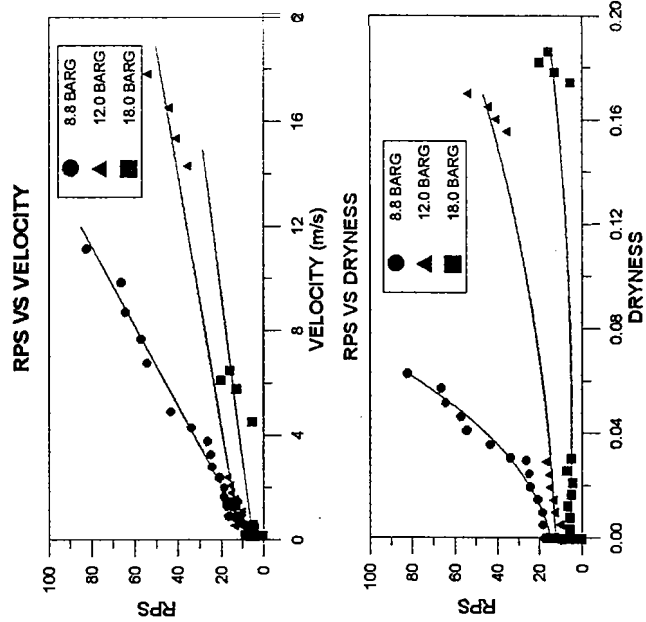
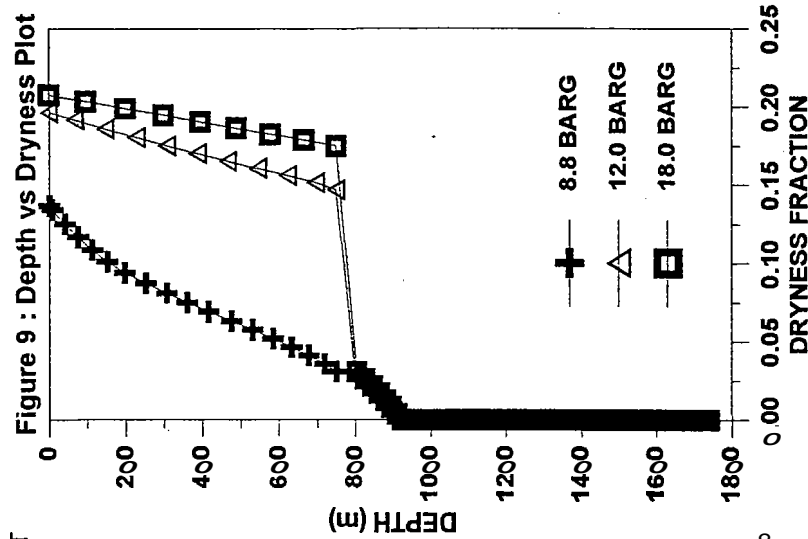
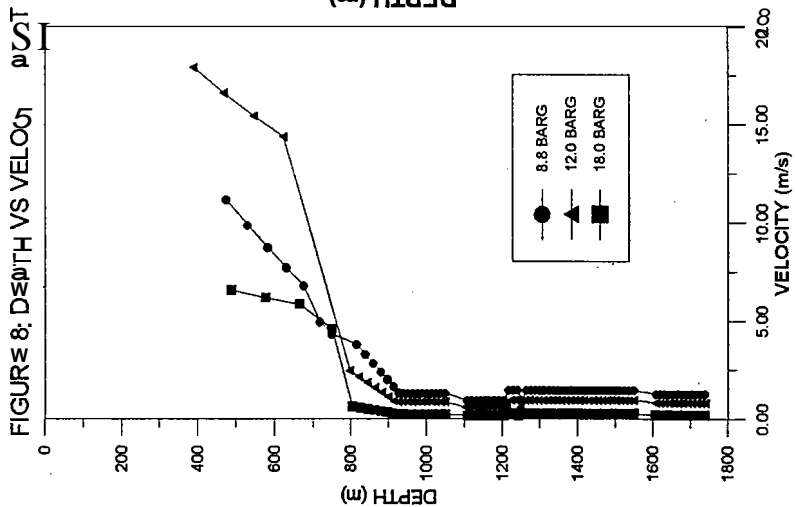
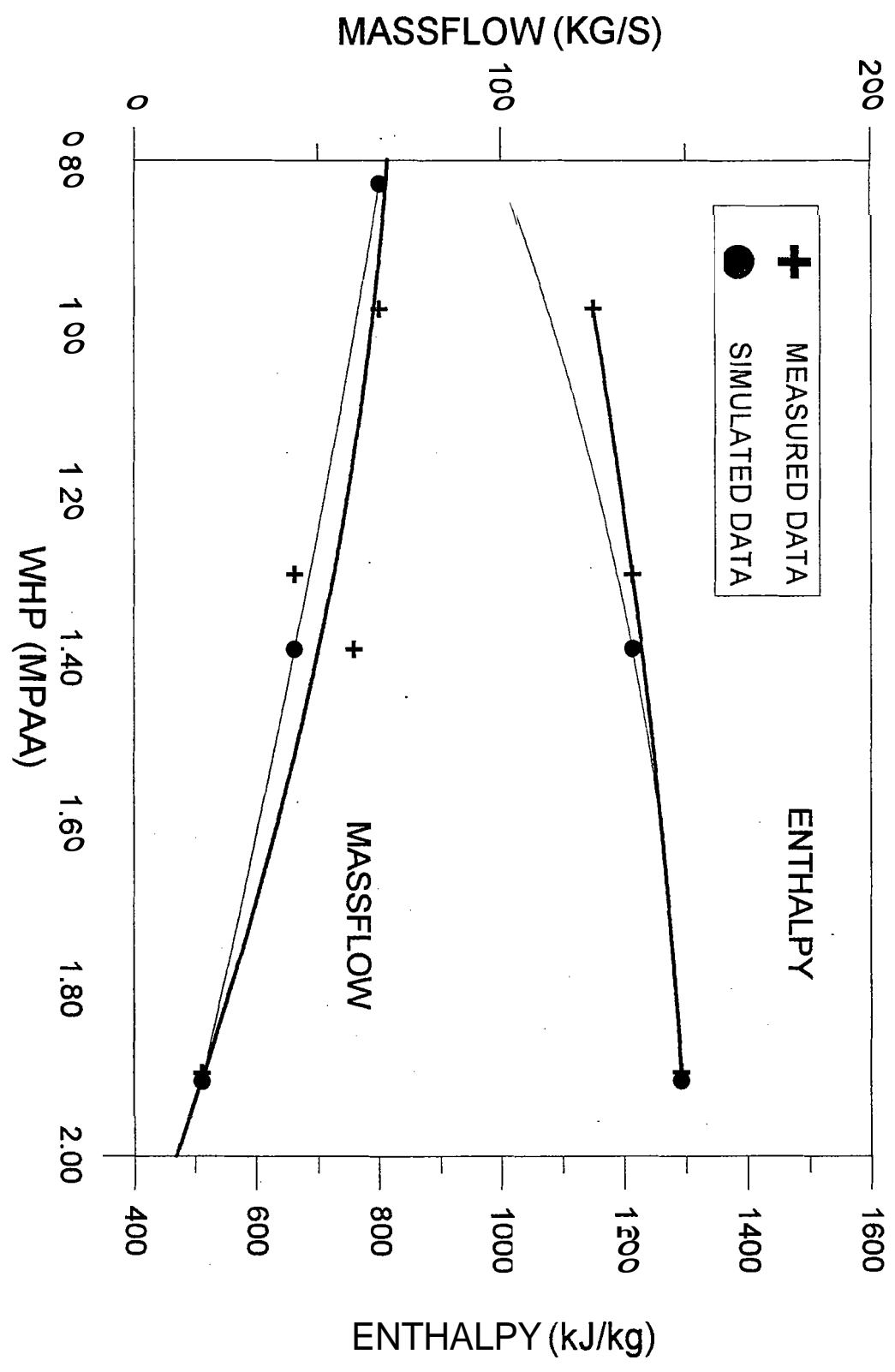
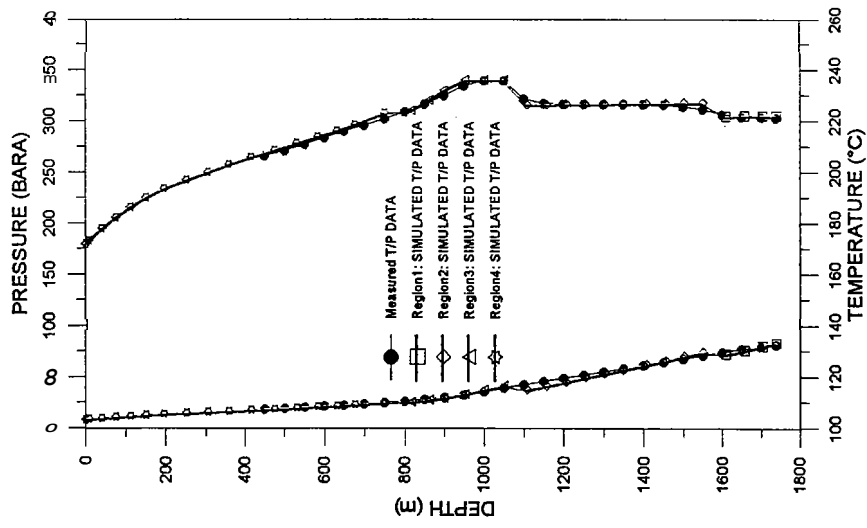
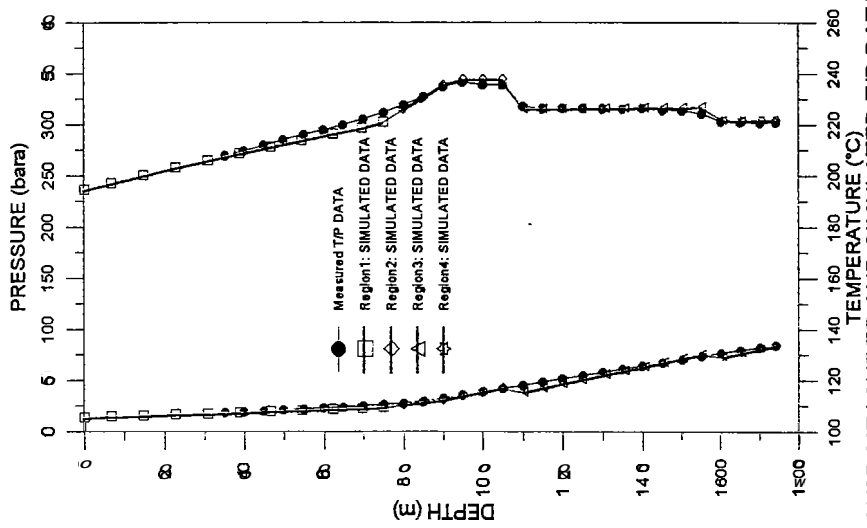


FIGURE 7: SK2D MASSFLOW/ENTHALPY VS WHP

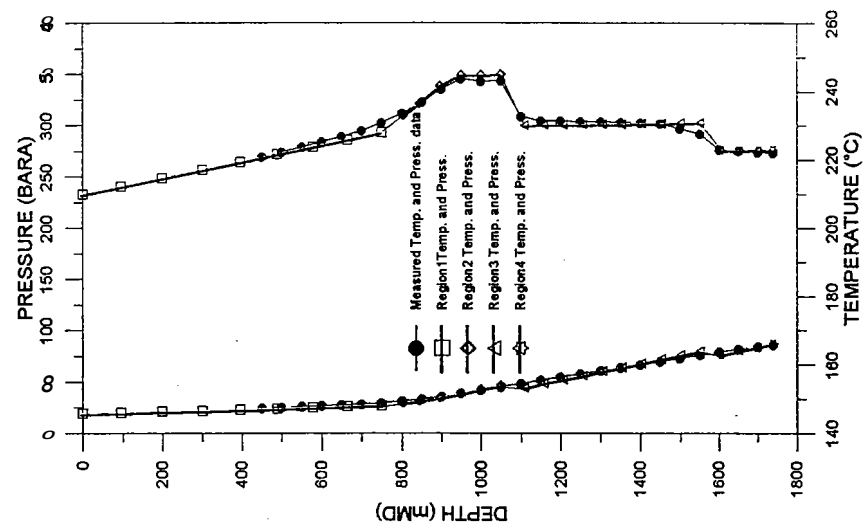




SK2D MEASURED AND SIMULATED T/P DATA
AT 8.8 BARG FLOWING CONDITION
FIGURE 4



SK2D MEASURED AND SIMULATED T/P DATA
AT 12.0 barg FLOWING CONDITION
FIGURE 5



SK2D MEASURED AND SIMULATED T/P DATA
AT 18.0 BARG FLOWING CONDITION
FIGURE 6

Figure 10: Determination of K

