GEOTHERMAL WELL DESIGN HANDBOOK

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I. INTRODUCTION

This handbook provides a simplified process for the user, at a desk and using a handheld calculator, to estimate the performance of geothermal wells which are produced by natural, flashing flows. To accomplish this, the user must indicate the well diameter and depth, and the reservoir conditions. The process presented here then enables the user to determine the total pressure drop in a flowing well, and therefore to find the fluid pressure, temperature and steam quality at the wellhead. By applying the handbook process to several input data sets, the user can compile sufficient information to determine the interdependence of input and output parameters. For example, a graph of flowrate as a function of wellhead pressure may be constructed, or the effect of diameter changes on pressure at the wellhead might be examined.

To make the process of the handbook possible, several simplifying assumptions were made:

- adiabatic wellbore flow (no heat transfer through the well casing)
- no dissolved solids in the geothermal fluid
- no dissolved gases in the geothermal fluid
- single phase flow in the wellbore at producing zone.

These assumptions allow the elimination of several additional variables from the problem formulation. This simplified formulation lends itself well to the treatment given in the handbook.

There are 5 (five) input parameters to be specified by the user:

- Wellbore diameter
- Depth of well to the top of the producing zone

- Temperature of the fluid at the top of the producing zone
- Total mass flowrate of fluid in the well
- Pressure in the wellbore at the top of the producing zone.

The input pressure in the wellbore is a function of the total mass flowrate, as explained in Chapter II.

The process used to find wellhead fluid conditions for a given set of input parameters is divided into three major segments:

- Calculation of single-phase pressure drop in the wellbore, performed on a hand-held calculator,
- Determination of two-phase pressure drop from graphs supplied in Chapter IV,
- Evaluation of fluid conditions at the wellhead, using physical properties found in Chapter IV graphs.

A detailed explanation of the handbook process outlined above is presented in Chapter II. A sample calculation that uses the step by step approach of the Well Design Data Sheet comprises Chapter III.

Outputs from the process noted above are the conditions of the geothermal fluid at the wellhead and consist of the following:

- Fluid pressure
- Fluid temperature
- Steam Quality, or percent by weight of steam in the flowing fluid.

It is expected that the output described above will be used most often in making economic analyses to determine the feasibility of geothermal energy projects. Such analyses may include the number, size and relative costs of several combinations of wellbore diameter and flowrate, or determination of necessary input values to supply sufficiently high wellhead temperatures and pressures to a specific conversion process. Chapter II explores these possible uses of the handbook results further.

II. DISCUSSION OF THE HANDBOOK PROCESS

The process used in this handbook to find the pressure drop in a geothermal well in two-phase flow is shown in schematic form in Fig. 1 and explained in this chapter. Assumptions have been made to permit the process to be presented in handbook form; these are also explained. Comments on use of the results of the process are given.

ASSUMPTIONS

Several assumptions were made to simplify the fluid mechanics of the well flow pressure drop calculation. These are as follows:

- Adiabatic wellbore flow (no heat transfer through the well casing)
- No dissolved solids in the geothermal fluid
- No dissolved gases in the geothermal fluid
- Single phase flow in the wellbore at the producing zone.

The thermodynamics of the phase change from liquid water to steam in the flowing fluid are simplified by the first assumption. The pure water assumptions eliminate chemical interaction considerations from the pressure drop computation; dissolved constituents can also serve to change the point where two-phase flows begin. Additional information on the steam quality of the reservoir fluid is needed to perform the handbook process if there is flashing in the reservoir. This information is difficult to estimate, and virtually impossible to measure. The occurrence of phase change in the reservoir is not common. Without these assumptions, the dimension of the pressure drop calculation becomes unmanageable in a handbook format.

INPUT PARAMETERS

There are 5 (five) input parameters that must be specified by the

FIGURE 1. Design Handbook Utilization Sequence.

user. They are:

- Wellbore diameter - inside diameter of the well casing, given in inches;
- Depth of well to the top of the producing zone, given in feet;
- Total mass flowrate of fluid in the well in pounds per hour;
- Temperature of the fluid at the top of the producing zone, under flow conditions given in degrees Fahrenheit. Since a temperature gradient may exist within the producing zone, the value of the bulk fluid temperature at the top of the producing zone may change when shifting from shut-in to flow conditions. A simple approach to the determination of a reasonable value is to assume a uniform contribution throughout the producing zone and therefore to average the expected shut-in temperatures at the top and bottom of the producing zone. If a detailed temperature survey of the producing zone is available, a more accurate temperature can be determined. This input temperature will be referred to as "production temperature" in the text;
- Pressure in the wellbore at the top of the producing zone, under flow conditions, measured in pounds per square inch, absolute. It is important to note that the specified pressure will vary as a function of flowrate because of pressure drop in the formation. This input pressure will be referred to as "production pressure" in the text.

Several of the user inputs defined above are parameterized in a discrete range to limit the number of two-phase flow wellhead pressure curves that are presented. If it is at all possible for the user to choose his input wellbore diameter, mass flowrate and production temperature from the values listed in Table 1, page 6, the process of finding the corresponding wellhead conditions is simplified considerably. The need for interpolation, and therefore the evaluation of multiple input data sets for a single solution, is then eliminated. An example of a problem requiring interpolation is presented in Chapter III.

It is possible to use this handbook to evaluate wellhead pressure,

TABLE 1

Values of Input Parameters Used in Construction
of Two-Phase Wellhead Pressure Graphs

Production Temperature: 300°F, 350°F, 400°F, 450°F
500°F, 550°F, 600°F, 650°F

Mass Flowrate: 200,000 lbs/hr
300,000 lbs/hr
400,000 lbs/hr
500,000 lbs/hr
600,000 lbs/hr
800,000 lbs/hr
1,000,000 lbs/hr
1,200,000 lbs/hr

Wellbore Diameter:

6 inches Outside Diameter = 5.524 inches Inside Diameter
7 5/8 inches OD = 7.125 inches ID
8 5/8 inches OD = 8.097 inches ID
9 5/8 inches OD = 9.063 inches ID
10 3/4 inches OD = 10.192 inches ID
11 3/4 inches OD = 11.15 inches ID
13 3/8 inches OD = 12.715 inches ID
16 inches OD = 15.375 inches ID

temperature and steam quality for wells with changes in diameter. This is done by thinking of such a well as a series of constant (though different) diameter wells stacked upon each other. The fluid conditions calculated for the top of one constant diameter segment then become the input conditions for the next higher segment in the stack. This technique is explained in Chapter III.

PROCESS TO FIND THE TOTAL PRESSURE DROP

The sequence of calculations used in this handbook is a common one: given the fluid conditions at the top of the producing zone, the pressure drop in the fluid as it rises up the wellbore is computed. The well pressure drop calculation is divided into two parts: single phase and two-phase. The single phase pressure drop is the sum of two components: elevation pressure drop and pipe friction pressure drop. The two-phase pressure drop has three components: an elevation pressure drop, pipe friction pressure drop, and an acceleration pressure drop due to the density change that is part of the phase change process. The pressure of the wellhead is then the difference of the production pressure minus the sum of the single phase and two-phase pressure drops. The sequence used here permits calculations to be made by the user without any iteration steps on his part.

In summary, the handbook sequence is used as follows:

- choose values for input parameters, based on user's knowledge of the reservoir and conversion process or end use of resource;
- evaluate fluid properties from Chapter IV graphs;
- compute single phase pressure drop and location of flash horizon (point of transition of two-phase flow);
- find wellhead pressure from two-phase pressure graphs of Chapter IV;

- find wellhead temperature from saturation conditions graph;
compute wellhead Quality.

Single Phase Pressure Drop

To begin the single phase pressure drop sequence, a check should be made to assure that the well is indeed in single phase flow at the top of the producing zone. The saturation pressure for the production temperature is found on the graph of saturation temperature-pressure relationships, located in Chapter IV. This pressure is then compared to the production pressure; if the production pressure is larger, the well is in single phase flow at the top of the producing zone, and the handbook sequence can then be followed.

The first component of the single phase pressure drop is the elevation pressure drop term. It is a function of the production temperature and is read off the Properties Graph in Chapter IV.

Several constants are required to compute the friction pressure drop, the second component of the single phase pressure drop. The friction factor is the only constant found in the pressure drop formula, but it is a function of the Reynolds number of the wellbore flow. Reynolds number is a dimensionless parameter computed from velocity and physical properties of the flowing fluid. To compute the Reynolds number, it is necessary to find the density and viscosity of the fluid, both of which are functions of temperature. These values are obtained from Chapter IV Properties Graphs.

The friction factor, f , is a function of Reynolds number, and to a lesser extent, a function of pipe diameter. The Properties Graph that shows the Reynolds Number, vs. friction factor curves indicates minimum, maximum and average values of f with respect to pipe diameter. The average

value can be used with reasonable accuracy since the friction pressure drop term contributes only 1% to 5% of the single phase pressure drop. However, f values may be estimated from the graph for those who desire to be as precise as possible.

The single phase pressure drop is determined on a per foot of wellbore length basis. The total available single phase pressure drop is then found by subtracting the saturation pressure (found in the initial step to determine if single phase flow exists in the wellbore) from the production pressure. This saturation pressure is a function of the production temperature, and if the pressure in the wellbore drops below this value, boiling must start.

Since the available total pressure drop for single phase flow is known and the pressure drop per foot of wellbore in single phase flow has been calculated, a simple division of the first by the second will equal the length of wellbore in single phase flow. Thus we now know how far from the top of the producing zone boiling begins. The depth to the producing zone is an input parameter, so a subtraction will yield the length of wellbore in two-phase flow. This value is the input needed to find the pressure drop in the two-phase flow zone.

Two-Phase Pressure Drop

The calculation for pressure drop in the two-phase flow zone is complicated; it requires correlations to compute the elevation pressure drop term and friction pressure drop term. These correlations are functions of the physical properties and relative volumes of the steam and liquid water constituents of the fluid. An iterative procedure is necessary to complete the calculation; it is most easily done by a digital computer

program.

There are many correlation coefficients for two-phase flow that exist in the technical literature. After consideration of several of the more prominent, those chosen for this edition of the design handbook are Hughmark for elevation pressure drop and Dukler, Case II, for two-phase friction pressure drop.

A decision was made to run a representative set of input conditions through the computer program and then present the output in graphic form. This method has two advantages: a large volume of data can be presented on a minimum amount of paper, and similar data sets with only one parameter change can be presented on the same graph for comparison purposes.

The graphs included in the handbook each consist of eight (8) curves on a single set of axes. The curves represent the results for inputs of a specified diameter, two (2) mass flowrates and four (4) temperatures. The mass flowrate, temperature and diameter have each been parameterized as 8 discrete values. Thus a total of 64 two-phase wellhead pressure graphs have been generated. The axes chosen as being the most convenient to use the data were Length of Two-Phase Zone as the abscissa and Wellhead Pressure as the ordinate. Wellhead pressure was chosen because it is one of the output parameters of the handbook sequence; length of two-phase zone can be easily calculated once the single phase pressure drop is computed, and provides a most logical independent variable, since the pressure drop is a direct function of length of the flow path.

OUTPUT

There is an index at the start of Chapter IV to allow fast and easy location of the two-phase Wellhead Pressure graphs, based on the input parameters used in the single phase calculation. Once the proper graph is located, the user finds the length of two-phase zone (computed

as the result of the single phase pressure drop) on the abscissa, follows that value vertically to its intersection with the proper curve, and reads the corresponding Wellhead Pressure off the ordinate.

Once the wellhead pressure is found from the above-described graphs, the wellhead temperature is fixed due to the saturated condition of the flow. The wellhead temperature is found from the graph of saturation pressure-temperature relationships in Chapter IV. Quality of the geothermal fluid, expressed as a percent by weight of the total flow, is easily computed using conservation of energy and enthalpies of the fluid at the flash horizon and at the wellhead.

ANALYSIS

The analysis of the output of this handbook is dependent on the use to be made of the geothermal fluid after extraction. A general methodology will be presented here. Since in most cases, some knowledge of the reservoir is available, the depth to the producing zone and the production temperature can be fixed. By varying well diameter and mass flowrate inputs, a parametric set of wellhead temperatures, pressures and qualities can be calculated. An estimate of the number and size of wells needed to operate the users' intended process can now be made. With this information, cost comparisons can be calculated for the several cases of diameter and flowrate inputs used. If reservoir characteristics are not well defined, additional cases with changes in depth and temperature can be computed. Economic optimization can be conducted by adding costs for the process itself as a function of fluid pressure and temperature at the wellhead to the well costs as computed above.

Long term well operation can also be calculated, if the pressure of the reservoir can be predicted as a function of either time or

cumulative production. The method used here depends on production pressure and temperature, so that when standard reservoir engineering techniques are applied, sufficient information can be obtained so that calculation of wellhead pressures and temperatures for future operation is possible.

A final comment on the use of the output should be noted. Because of the simplifying assumptions made and the complex nature of two phase flow, the wellhead conditions determined via this handbook are approximations. This is why they are called estimates throughout the text. The output data have the most value when used to compare the relative merits of several proposed well configurations and the influence of individual parameters on well performance.

III. SAMPLES OF USE OF THE HANDBOOK PROCESS

The Well Design Data Sheet is introduced and its use explained in this chapter. By following the step by step instructions on the Well Design Data Sheet, the user can determine the wellhead fluid conditions for any set of input parameters that lie within the range of the parameterization noted in Chapter II. A blank Well Design Data Sheet (Fig. 2) to be reproduced and filled in by the user is provided. The first sample, using discrete values included in the input parameterization, is worked on a Well Design Data Sheet and accompanied by text explanation. A second sample where interpolation is necessary is also given. Also included is a detailed explanation of a method to use when a change in wellbore diameter is encountered after the onset of two-phase flow.

The fluid properties necessary to complete the single phase pressure drop calculations are presented in Chapter IV. These properties vary with temperature and are shown in graphic form. The graphs are marked to show their use in obtaining fluid properties for the sample calculation later in this chapter. Reference to the properties graphs at the noted steps in the sample should help the user in understanding their function.

Also contained in Chapter IV are the graphs of the two-phase flow pressure drop, presented as curves on Depth of Two-Phase Zone vs. Wellhead Pressure axes. These are the data necessary to compute the estimates of wellhead conditions using the methodology of this handbook. Calculations used to develop these curves were described earlier. It is expected that better correlations for the two-phase pressure drop calculation will be developed through laboratory and field experiments. Improved graphs in the above described format will be issued as replacements for the originals in this handbook, and more accurate estimates for the output parameters

Figure 2. Well Design Data Sheet

Parameter	Symbol	Units	Source	Value
Wellbore Diameter (casing inside dia.)	D	inches	input	
Depth to Top of Producing Zone	L	feet	input	
Mass Flow Rate	$\dot{M}$	lb/hr	input	
Production Temperature	T_{pr}	$^{\circ}F$	input	
Production Pressure	P_{pr}	psia	input	
Saturation Pressure at Production Temperature	$P_{sat}(T_{pr})$	psia	Graph P-4, pg. 35	
Single Phase Pressure Drop	P_{1p}	psi	$P_{1p} = P_{pr} - P_{sat}(T_{pr})$	
<p>IF $\Delta P_{1p} < 0$ Well is in two phase flow in producing zone</p> <p>STOP No further calculation can be made</p>				
Liquid Density	ρ	lb/ft ³	Graph P-1, p. 32, T_{pr}	
Elevation Unit Pressure Drop	$\left(\frac{\Delta P}{\Delta \ell}\right)_{elev}$	psi/ft	Graph P-1, p. 32, T_{pr}	
Absolute Viscosity	μ	centipoise	Graph P-2, p. 33, T_{pr}	
Reynolds Number	R_e	--	$R_e = (6.31607) \left(\frac{\dot{M}}{D\mu}\right)$	
Moody Friction Factor	f	--	Graph P-3, p. 34, R_e	
Single Phase Unit Pressure Drop	$\left(\frac{\Delta P}{\Delta \ell}\right)_{1p}$	psi/ft	(equation)	
Equation: $\left(\frac{\Delta P}{\Delta \ell}\right)_{1p} = \left(\frac{\Delta P}{\Delta \ell}\right)_{elev} \left[1 + (4.8377 \times 10^{-4}) \left(\frac{f \dot{M}^2}{\rho^2 D^5} \right) \right]$				

Figure 2. Well Design Data Sheet (continued)

Parameter	Symbol	Units	Source	Value
Length of Single Phase Zone	L_{1p}	ft	$L_{1p} = \Delta P_{1p} / \left(\frac{\Delta P}{\Delta \ell} \right)_{1p}$	
Length of Two Phase Zone	L_{2p}	ft	$L_{2p} = L - L_{1p}$	
IF $L_{2p} < 0$ Well is in single phase flow only Go to Option (A) below				
Wellhead Pressure *OUTPUT*	P_{wh}	psia	Two phase wellhead pressure graphs LA-1 through HD-8 (see index on pgs.30 & 31), L_{2p}	
Wellhead Temperature *OUTPUT*	T_{wh}	°F	Graph P-4, p. 35, P_{wh}	
Wellhead Liquid Enthalpy	h_{lwh}	BTU/lb	Graph P-5, p. 36, T_{wh}	
Liquid Enthalpy at Flash Horizon	h_{lfh}	BTU/lb	Graph P-5, p. 36, T_{pr}	
Phase Change Enthalpy at Wellhead Conditions	h_{lgwh}	BTU/lb	Graph P-6, p. 37, T_{wh}	
Steam Quality *OUTPUT*	Q	% by Weight	$\frac{h_{lfh} - h_{lwh}}{h_{lgwh}} \times 100$	
OPTION (A) Wellhead Temperature *OUTPUT*	T_{wh}	°F	$T_{wh} = T_{pr}$	
Wellhead Pressure *OUTPUT*	P_{wh}	psia	$P_{wh} = P_{pr} - \left[\left(\frac{\Delta P}{\Delta \ell} \right)_{1p} \cdot L \right]$	
Steam Quality = 0% for Single Phase Flow at Wellhead				

can then be determined.

SAMPLE WITH INPUT VALUES FROM THE DISCRETE PARAMETERIZATION

Use of the Well Design Data Sheet is demonstrated here for an input data set chosen from the discrete values used in the construction of the two-phase wellhead pressure curves. The filled-in Data Sheet for this sample is shown as Fig. 3. Please refer to it as you follow the text.

Let us assume we know that the top of the producing zone is 6000 ft. below the surface, and that the production temperature of the fluid as it starts up the wellbore will be 450°F. Further, a reservoir engineer has stated that at a flowrate of 500,000 lb/hr, the production pressure (in the wellbore at the top of the producing zone) will be about 2280 psia. There are plans to case the drilled well with 9 5/8" OD pipe which has an inside diameter of 9.063 inches. These values should be recorded, in the proper units, on the Sample Well Design Data Sheet, Fig. 3.

Saturation pressure for the input production temperature is found on Properties Graph P-4, page 35. For the 450° used here, the saturation pressure is 423 psia. When the pressure of the fluid rising up the wellbore drops to this value, boiling will start to occur in the fluid. This is by definition the flashing horizon and the top of the single phase flow zone in the well. Thus the available single phase pressure drop is

$$\Delta P_{1p} = P_{pr} - P_{sat};$$

for the sample case, $\Delta P_{1p} = 2280 - 423 = 1857$ psi. If the saturation pressure is then more than the production pressure (i.e., $\Delta P_{1p} < 0$), then the producing zone is in two-phase flow and the handbook cannot be used to produce estimates of wellhead conditions.

Figure 3. Sample Case with Discrete Parameterized Input.

Well Design Data Sheet

Parameter	Symbol	Units	Source	Value
Wellbore Diameter (casing inside dia.)	D	Inches	input	9.063
Depth to Top of Producing Zone	L	feet	input	6000
Mass Flow Rate	$\dot{M}$	lb/hr	input	500,000
Production Temperature	T_{pr}	$^{\circ}\text{F}$	input	450 $^{\circ}$
Production Pressure	P_{pr}	psia	input	2280
Saturation Pressure at Production Temperature	$P_{sat}(T_{pr})$	psia	Graph P-4, pg. 35	423
Single Phase Pressure Drop	P_{1p}	psi	$P_{1p} = P_{pr} - P_{sat}(T_{pr})$	1857
IF $\Delta P_{1p} < 0$ STOP Well is in two phase flow in producing zone No further calculation can be made				CONTINUE
Liquid Density	ρ	lb/ft ³	Graph P-1, p. 32, T_{pr}	51.4
Elevation Unit Pressure Drop	$\left(\frac{\Delta P}{\Delta \ell}\right)_{\text{elev}}$	psi/ft	Graph P-1, p. 32, T_{pr}	0.357
Absolute Viscosity	μ	centipoise	Graph P-2, p. 33, T_{pr}	0.120
Reynolds Number	R_e	--	$R_e = (6.31607) \left(\frac{\dot{M}}{D\mu}\right)$	2.9×10^6
Moody Friction Factor	f	--	Graph P-3, p. 34, R_e	0.014
Single Phase Unit Pressure Drop	$\left(\frac{\Delta P}{\Delta \ell}\right)_{1p}$	psi/ft	(equation)	0.3607
Equation: $\left(\frac{\Delta P}{\Delta \ell}\right)_{1p} = \left(\frac{\Delta P}{\Delta \ell}\right)_{\text{elev}} \left[1 + (4.8377 \times 10^{-4}) \left(\frac{f \dot{M}^2}{\rho^2 D^5} \right) \right]$				

Figure 3 (Continued)

Well Design Data Sheet (continued)

Parameter	Symbol	Units	Source	Value
Length of Single Phase Zone	L_{1p}	ft	$L_{1p} = \Delta P_{1p} / \left(\left(\frac{\Delta P}{\Delta L} \right)_{1p} \right)$	5148
Length of Two Phase Zone	L_{2p}	ft	$L_{2p} = L - L_{1p}$	852
IF $L_{2p} < 0$ Well is in single phase flow only Go to Option (A) below				CONTINUE
Wellhead Pressure *OUTPUT*	P_{wh}	psia	Two phase wellhead pressure graphs LA-1 through HD-8 (see index on pgs.30 & 31), L_{2p}	269
Wellhead Temperature *OUTPUT*	T_{wh}	°F	Graph P-4, p. 35, P_{wh}	408
Wellhead Liquid Enthalpy	h_{lwh}	BTU/lb	Graph P-5, p. 36, T_{wh}	384
Liquid Enthalpy at Flash Horizon	h_{lfh}	BTU/lb	Graph P-5, p. 36, T_{pr}	431
Phase Change Enthalpy at Wellhead Conditions	h_{lgwh}	BTU/lb	Graph P-6, p. 37, T_{wh}	817
Steam Quality *OUTPUT*	Q	% by Weight	$\frac{h_{lfh} - h_{lwh}}{h_{lgwh}} \times 100$	5.8%
OPTION (A) Wellhead Temperature *OUTPUT*	T_{wh}	°F	$T_{wh} = T_{pr}$	
Wellhead Pressure *OUTPUT*	P_{wh}	psia	$P_{wh} = P_{pr} - \left[\left(\frac{\Delta P}{\Delta L} \right)_{1p} \cdot L \right]$	
Steam Quality = 0% for Single Phase Flow at Wellhead				

The first fluid properties needed in the single phase pressure drop calculation are the liquid density and the elevation unit pressure drop. These values, as found on curves on Properties Graph P-1, page 32, are $\rho = 51.4 \text{ lbs/ft}^3$ and $(\Delta P/\Delta L)_{\text{elev}} = .357 \text{ psi/ft.}$, and should be listed in the "Value" column of the sample Well Design Data Sheet, Fig. 3.

Absolute viscosity is next determined from Properties Graph P-2, page 33, to be 0.12 centipoises. This figure is entered and then plugged into the Reynolds number equation presented on the next line of the Data Sheet, along with the mass flow rate and wellbore diameter previously listed. The constant in the equation adjusts for units as given so that the product is dimensionless. The equation to be used is

$$R_e = 6.31607 \frac{\dot{M}}{D\mu}$$

The Reynolds number found ($R_e = 2.9 \times 10^6$) provides the necessary input to find the Moody friction factor from Properties Graph P-3, page 34. The Graph of friction factor vs. Reynolds Number shows a range of friction factors due to the different diameters considered, with an average value plotted in the center of the range. The value for this case was taken from the "average" curve. The Moody friction factor is found to be $f = 0.014$ and is noted on the sample Well Design Data Sheet.

All necessary information is now available to calculate the single phase unit pressure drop by using the following equation:

$$\left(\frac{\Delta P}{\Delta L}\right)_{1P} = \left(\frac{\Delta P}{\Delta L}\right)_{\text{elev}} \left[1 + (4.8377 \times 10^{-4}) \left(\frac{f \dot{M}^2}{\rho^2 D^5} \right) \right]$$

Symbols used in this equation are defined earlier and values are listed in Fig. 3. Use of a pocket calculator permits fast and accurate computation of the above parameter, whose value is .3607 psi/ft for our sample case.

The length of the zone of single phase flow can now be computed using the following equation:

$$L_{1p} = \frac{\Delta P_{1p}}{\left(\frac{\Delta P}{\Delta L}\right)_{1p}}$$

Substituting values listed on Fig. 3 and performing the division, the length is found to be 5148 ft. Now the length of the two-phase flow zone can be computed, because the total well depth was an input parameter. This depth is also the location of the flash horizon and is given by

$$L_{2p} = L - L_{1p} = 6000 - 5148,$$

which is 852 ft. for the sample case.

When L_{1p} is greater than the total well depth, L , the flow over the entire well depth remains single phase. The wellhead temperature and pressure are then found using formulae presented in Option A on the Well Design Data Sheet. The temperature is unchanged due to the adiabatic wellbore assumption:

$$T_{\text{wellhead}} = T_{\text{production}}$$

The pressure drop is the product of the well depth and the single phase unit pressure drop; thus the wellhead pressure can be expressed as

$$P_{\text{wellhead}} = P_{\text{production}} - (L) \left(\frac{\Delta P}{\Delta L}\right)_{1p}$$

The above equations are valid only when L_{2p} is negative.

Once the length of the two-phase zone is known, the wellhead pressure can be found on one of the 64 graphs presenting output of the two-phase flow computer program. The Identification Key for these graphs is contained in Table 2. The Two-Phase Flow Wellhead Pressure Graph Index, pages 30-31, lists the locations by input parameter. For the sample case

Table 2
Two Phase Flow Wellhead Pressure
Graph Identification Key

<u>Production Temperature (T_{pr})</u>	<u>Designation</u>
300°, 350°F } 400°, 450°F }	L
500°, 550°F } 600°, 650°F }	H
<u>Mass Flowrate ($\dot{M}$)</u>	<u>Designation</u>
200,000 lb/hr } 300,000 lb/hr }	A
400,000 lb/hr } 500,000 lb/hr }	B
600,000 lb/hr } 800,000 lb/hr }	C
1,000,000 lb/hr } 1,200,000 lb/hr }	D
<u>Wellbore Casing Diameter (D)</u>	<u>Designation</u>
6" Outside Diameter (5.524" ID)	1
7 5/8 (7.125" ID)	2
8 5/8 (8.097" ID)	3
9 5/8 (9.063" ID)	4
10 3/4 (10.192" ID)	5
11 3/4 (11.15" ID)	6
13 3/8 (12.715" ID)	7
16 (15.375" ID)	8

Examples: For $\dot{M} = 600,000$ lb/hr, $T_{pr} = 400^\circ\text{F}$, $D = 10\ 3/4"$ OD,
curve is found on Graph LC-5;

For $\dot{M} = 300,000$ lb/hr, $T_{pr} = 550^\circ\text{F}$, $D = 7\ 5/8"$ OD,
curve is found on Graph HA-2.

conditions: $T = 450^{\circ}\text{F}$ yields "L" temperature designation; $M = 500,000$ lb/hr, "B" flowrate designation; and $D = 9\ 5/8"$ OD, "4" diameter designation. Thus, the Graph to be used in the sample case is LB-4. This Graph has eight curves, four temperatures at each of two flowrates. On the $T = 450^{\circ}\text{F}$, $M = 500,000$ lb/hr curve, a length of 852 ft. corresponds to a wellhead pressure of 269 psia. The value for wellhead pressure identified on this line of the Well Design Data Sheet is one of the three output parameters.

The second output parameter is the wellhead temperature, obtained from Properties Graph P-4 on page 35. Two-phase flow at the wellhead dictates that a saturation condition must exist, so that the temperature is fixed and known when the pressure is found. For the sample case, the wellhead temperature is 408°F .

Wellhead steam quality (Q) is a measure of the steam fraction of the wellhead fluid, by weight, expressed as a percent. This is the final output parameter of the handbook. It is calculated by assuming constant enthalpy in the wellbore, from the flash horizon to the wellhead. The fact that the fluid is 100% liquid at the flash horizon permits determination of enthalpy at that point. Since there is no loss of enthalpy, the fluid at the surface must have an equivalent value on a per pound basis. The two-phase flow pressure/length curves (Graphs LA-1 through HD-8) are used to find a wellhead pressure as detailed above. Now a liquid enthalpy (per pound) for wellhead conditions can be found from Properties Graph P-5, page 36, to be $h_{lwh} = 383.5$ BTU/lb. From this same source, Flash Horizon liquid enthalpy can be determined (using production temperature T_{pr}) to be $h_{lfh} = 431$ BTU/lb. Enthalpy for phase change (heat of vaporization)

is found from Properties Graph P-6 on page 37; using the wellhead temperature, this value is $h_{lgwh} = 714$ BTU/lb. The energy balance to determine steam quality is

$$Q = \frac{h_{lfh} - h_{lwh}}{h_{lgwh}} \times 100$$

substituting in the values obtained above quality is calculated to be

$Q = 5.8\%$ This completes the first sample calculation.

SAMPLE WITH INTERPOLATION

If the chosen values for either the production temperature, T_{pr} , or the total mass flowrate, $\dot{M}$, are not among those listed in the parameterization in Table 1, page 6, an interpolation technique must be used to find the process outputs of wellhead fluid conditions. It is assumed that enough standard pipe diameters are given to avoid the need to interpolate. The Interpolation Sample Well Design Data Sheet, Fig. 4, demonstrates how to handle such a case.

All input parameters remain the same as the previous sample, except that the production temperature, T_{pr} , has been raised to 470°F. The single phase pressure drop calculation is carried out similar to the first sample. However, note that since there has been a change in production temperature, the values of the fluid properties have also changed. Details of the calculation are not presented here, but may be followed on Fig. 4.

Once the length of the two-phase zone has been determined (as the final step of the single phase calculation), interpolation must begin. Linear interpolation is used because it is simple, and the technique is widely known. The input production temperature lies between the parameterized discrete values of 450°F and 500°F. So the proper Two-Phase Wellhead Pressure

Figure 4. Sample Case with Interpolation Well Design Data Sheet.

Well Design Data Sheet

Parameter	Symbol	Units	Source	Value
Wellbore Diameter (casing inside dia.)	D	Inches	input	9.063
Depth to Top of Producing Zone	L	feet	input	6000
Mass Flow Rate	$\dot{M}$	lb/hr	input	500,000
Production Temperature	T_{pr}	$^{\circ}\text{F}$	input	470 $^{\circ}$
Production Pressure	P_{pr}	psia	input	2280
Saturation Pressure at Production Temperature	$P_{sat}(T_{pr})$	psia	Graph P-4, pg. 35	515
Single Phase Pressure Drop	P_{1p}	psi	$P_{1p} = P_{pr} - P_{sat}(T_{pr})$	1765
IF $\Delta P_{1p} < 0$ STOP				Well is in two phase flow in producing zone No further calculation can be made CONTINUE
Liquid Density	ρ	lb/ft ³	Graph P-1, p. 32, T_{pr}	50.3
Elevation Unit Pressure Drop	$\left(\frac{\Delta P}{\Delta L}\right)_{\text{elev}}$	psi/ft	Graph P-1, p. 32, T_{pr}	0.351
Absolute Viscosity	μ	centipoise	Graph P-2, p. 33, T_{pr}	0.113
Reynolds Number	R_e	--	$R_e = (6.31607) \left(\frac{\dot{M}}{D\mu}\right)$	3.08×10^6
Moody Friction Factor	f	--	Graph P-3, p. 34, R_e	0.014
Single Phase Unit Pressure Drop	$\left(\frac{\Delta P}{\Delta L}\right)_{1p}$	psi/ft	(equation)	0.3548
Equation: $\left(\frac{\Delta P}{\Delta L}\right)_{1p} = \left(\frac{\Delta P}{\Delta L}\right)_{\text{elev}} \left[1 + (4.8377 \times 10^{-4}) \left(\frac{f \dot{M}^2}{\rho^2 D^5} \right) \right]$				

Figure 4 (Continued)

Well Design Data Sheet (continued)

Parameter	Symbol	Units	Source	Value
Length of Single Phase Zone	L_{1p}	ft	$L_{1p} = \Delta P_{1p} / \left(\left(\frac{\Delta P}{\Delta L} \right)_{1p} \right)$	4974
Length of Two Phase Zone	L_{2p}	ft	$L_{2p} = L - L_{1p}$	1026
IF $L_{2p} < 0$ Well is in single phase flow only Go to Option (A) below				CONTINUE
Wellhead Pressure *OUTPUT*	P_{wh}	psia	Two phase wellhead pressure graphs LA-1 through HD-8 (see index on pgs. 30 & 31), L_{2p}	<div>450°F 500°F</div> <div>252 psia 470 psia</div> <div>339</div>
Wellhead Temperature *OUTPUT*	T_{wh}	°F	Graph P-4, p. 35, P_{wh}	431
Wellhead Liquid Enthalpy	h_{lwh}	BTU/lb	Graph P-5, p. 36, T_{wh}	408
Liquid Enthalpy at Flash Horizon	h_{lfh}	BTU/lb	Graph P-5, p. 36, T_{pr}	452
Phase Change Enthalpy at Wellhead Conditions	h_{lgwh}	BTU/lb	Graph P-6, p. 37, T_{wh}	794
Steam Quality *OUTPUT*	Q	% by Weight	$\frac{h_{lfh} - h_{lwh}}{h_{lgwh}} \times 100$	5.54
OPTION (A) Wellhead Temperature *OUTPUT*	T_{wh}	°F	$T_{wh} = T_{pr}$	X
Wellhead Pressure *OUTPUT*	P_{wh}	psia	$P_{wh} = P_{pr} - \left[\left(\frac{\Delta P}{\Delta L} \right)_{1p} \cdot L \right]$	
Steam Quality = 0% for Single Phase Flow at Wellhead				

Graphs are checked and the following pressures found for a two-phase zone of 1026 feet:

$$450^{\circ}\text{F}: P_{wh} = 252 \text{ psia}$$

$$500^{\circ}\text{F}: P_{wh} = 470 \text{ psia.}$$

The interpolation multiplier is computed from the equation:

$$x = \frac{T_{pr} - T_{cooler}}{T_{hotter} - T_{cooler}} = \frac{470 - 450}{500 - 450} = 0.4$$

P_{wh} for the desired T_{pr} is found from an analogous equation:

$$x = \frac{P_{wh} - P_{450}}{P_{500} - P_{450}}$$

rearranging terms and substituting numbers:

$$P_{wh} = P_{450} + x(P_{500} - P_{450}) = 252 + 0.4(218) = 339 \text{ psia.}$$

Thus the interpolated wellhead pressure is 339 psia. The other wellhead parameters are calculated by following the remaining steps on the Well Design Data Sheet. An analogous calculation can be made for mass flow-rates that are not in the discrete parameterization data set.

If both the total mass flowrate and production temperature values to be used in the calculation are not in the discrete parameterization data set, proceed as follows:

- Compute the single phase pressure drop and find the length of the two-phase zone via the steps of the Well Design Data Sheet.
- Consider the discrete mass flowrate from the parameterization data set that is closest to, but less than, the actual value used in the problem. Obtain the Wellhead pressures using the Two-Phase Wellhead Pressure Graphs, from curves for the two temperatures from the discrete set that are closest to the input value, one greater than and one less than the actual input. Perform an interpolation following the above procedure to get a wellhead pressure that reflects the actual input production temperature, but is a function of the lower value discrete mass flowrate.
- Perform a similar interpolation to that outlined above at the mass flow rate closest to, but greater than the actual value from the problem.

- Perform a final interpolation using the actual input mass flowrate, and the two closest mass flowrates from the discrete set, with their corresponding wellhead pressure values. These are the values computed in the two previous steps. This final interpolation gives a wellhead pressure that has been corrected for both temperature and mass flowrates outside the input discrete parameterization.
- Using the wellhead pressure found in the last step, follow the Design Data Sheet sequence to obtain the other wellhead fluid conditions.

The user should be aware that linear interpolations are an approximation technique, and that the results that use interpolation will not be as accurate as those obtained directly from the discrete parameterization input. However, the simplifying assumptions made to permit the production of this handbook compromise the absolute accuracy of the results, so that the interpolation material can be used as an estimate with confidence.

CHANGE IN WELLBORE DIAMETER

Calculations for a "telescoping" well, one with changes in wellbore diameter, can be performed using the following sequence:

- Separate the total well depth (to the top of the producing zone) into Constant diameter segments: L_A , L_B , etc.
- Compute the pressure at the top of the bottom segment using the producing zone input parameters, following the sequence of the Well Design Data Sheet.
- Moving up from the producing zone, use the pressure, temperature, and flowrate values at the top of each segment as the input for the bottom of the succeeding segment.

There are two possible situations at the start of each new segment. The first is that the well is in single phase flow, in which case the Well Design Data Sheet sequence is used, with pressure and temperature inputs specified as those outputs of the previous segment. Secondly, if the flow is two-phase at the entrance to a new segment, the key to finding the conditions at the top of the subject segment is that the pressure at the

bottom of that segment is known.

In the second case, it is necessary to find an "equivalent length" of the two-phase flow zone for the new diameter of the segment. Take the known pressure from the top of the previous segment as the ordinate on the proper Two-Phase Wellhead Pressure Graph. Follow the constant pressure line to its intersection with the correct curve for the given conditions and proceed vertically down to the corresponding Depth of Two-Phase Zone. This value is the equivalent length, defined as the length of wellbore of the new diameter that would be required to generate a pressure drop to reach the known pressure, if the flash horizon was located in the segment under study. The length of the subject segment is then added to the "equivalent length", and a new Wellhead Pressure is found on the same graph. This new wellhead pressure in turn becomes the input pressure for the next segment.

The treatment presented here assumes no pressure drop across a diameter change.

IV. Properties Graphs and Two-Phase Flow Wellhead Pressure Graphs

Index

<u>Properties Graphs</u>	<u>Page</u>
Graph P-1 Liquid Density and Elevation Unit Pressure Drop at Saturation Conditions	32
Graph P-2 Absolute Viscosity at Saturation Conditions	33
Graph P-3 Moody Friction Factor as a Function of Reynolds Number	34
Graph P-4 Saturation Temperature-Pressure Relationships	35
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Graph P-6 Heat of Vaporization at Saturation Conditions	37

Two Phase Flow Wellhead Pressure Graphs

(See Next Two Pages)

Index to Two-Phase Flow Wellhead Pressure Graphs

Temperature	Flowrate	Diameter	Page
Low Temperature L { 300°F 350°F 400°F 450°F 500°F	A { 200,000 lb/hr 300,000 lb/hr	1 = 6" OD (5.524" ID)	38
		2 = 7 5/8" OD (7.125" ID)	39
		3 = 8 5/8" OD (8.097" ID)	40
		4 = 9 5/8" OD (9.063" ID)	41
		5 = 10 3/4" OD (10.192" ID)	42
		6 = 11 3/4" OD (11.15" ID)	43
		7 = 13 3/8" OD (12.715" ID)	44
		8 = 16" OD (15.375" ID)	45
	B { 400,000 lb/hr 500,000 lb/hr	1 = 6" OD (5.524" ID)	46
		2 = 7 5/8" OD (7.125" ID)	47
		3 = 8 5/8" OD (8.097" ID)	48
		4 = 9 5/8" OD (9.063" ID)	49
		5 = 10 3/4" OD (10.192" ID)	50
		6 = 11 3/4" OD (11.15" ID)	51
		7 = 13 3/8" OD (12.715" ID)	52
		8 = 16" OD (15.375" ID)	53
	C { 600,000 lb/hr 800,000 lb/hr	1 = 6" OD (5.524" ID)	54
		2 = 7 5/8" OD (7.125" ID)	55
		3 = 8 5/8" OD (8.097" ID)	56
		4 = 9 5/8" OD (9.063" ID)	57
		5 = 10 3/4" OD (10.192" ID)	58
		6 = 11 3/4" OD (11.15" ID)	59
		7 = 13 3/8" OD (12.715" ID)	60
		8 = 16" OD (15.375" ID)	61
	D { 1,000,000 lb/hr 1,200,000 lb/hr	1 = 6" OD (5.524" ID)	62
		2 = 7 5/8" OD (7.125" ID)	63
		3 = 8 5/8" OD (8.097" ID)	64
		4 = 9 5/8" OD (9.063" ID)	65
		5 = 10 3/4" OD (10.192" ID)	66
		6 = 11 3/4" OD (11.15" ID)	67
		7 = 13 3/8" OD (12.715" ID)	68
		8 = 16" OD (15.375" ID)	69

NOTE: To permit easier use of Two-Phase Wellhead Pressure Graphs during interpolation, the curves for 500°F appear on both the Lo- and High Temperature graphs.

Two-Phase Flow Wellhead Pressure Graphs (Continued)

Temperature	Flowrate	Diameter	Page
High Temperature	A { 200,000 lb/hr 300,000 lb/hr	1 = 6" OD (5.524" ID)	70
		2 = 7 5/8" OD (7.125" ID)	71
		3 = 8 5/8" OD (8.097" ID)	72
		4 = 9 5/8" OD (9.063" ID)	73
		5 = 10 3/4" OD (10.192" ID)	74
		6 = 11 3/4" OD (11.15" ID)	75
		7 = 13 3/8" OD (12.715" ID)	76
		8 = 16" OD (15.375" ID)	77
H { 500°F 550°F 600°F 650°F	B { 400,000 lb/hr 500,000 lb/hr	1 = 6" OD (5.524" ID)	78
		2 = 7 5/8" OD (7.125" ID)	79
		3 = 8 5/8" OD (8.097" ID)	80
		4 = 9 5/8" OD (9.063" ID)	81
		5 = 10 3/4" OD (10.192" ID)	82
		6 = 11 3/4" OD (11.15" ID)	83
		7 = 13 3/8" OD (12.715" ID)	84
		8 = 16" OD (15.375" ID)	85
High Temperature	C { 600,000 lb/hr 800,000 lb/hr	1 = 6" OD (5.524" ID)	86
		2 = 7 5/8" OD (7.125" ID)	87
		3 = 8 5/8" OD (8.097" ID)	88
		4 = 9 5/8" OD (9.063" ID)	89
		5 = 10 3/4" OD (10.192" ID)	90
		6 = 11 3/4" OD (11.15" ID)	91
		7 = 13 3/8" OD (12.715" ID)	92
		8 = 16" OD (15.375" ID)	93
High Temperature	D { 1,000,000 lb/hr 1,200,000 lb/hr	1 = 6" OD (5.524" ID)	94
		2 = 7 5/8" OD (7.125" ID)	95
		3 = 8 5/8" OD (8.097" ID)	96
		4 = 9 5/8" OD (9.063" ID)	97
		5 = 10 3/4" OD (10.192" ID)	98
		6 = 11 3/4" OD (11.15" ID)	99
		7 = 13 3/8" OD (12.715" ID)	100
		8 = 16" OD (15.375" ID)	101

GRAPH P-1 LIQUID DENSITY AND ELEVATION UNIT PRESSURE DROP AT SATURATION CONDITIONS

GRAPH P-2 ABSOLUTE VISCOSITY AT SATURATION CONDITIONS

GRAPH P-3 MOODY FRICTION FACTOR AS A FUNCTION OF REYNOLDS NUMBER

GRAPH P-4 SATURATION TEMPERATURE-PRESSURE RELATIONSHIPS

GRAPH P-5 LIQUID ENTHALPY AT SATURATION CONDITIONS

GRAPH P-6 HEAT OF VAPORIZATION AT SATURATION CONDITIONS

Legend

Diameter = 5.524 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$

GRAPH LAI : TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 7.125 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$

GRAPH LA-2: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 8.097 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$

GRAPH LA-3: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 9.063 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$

GRAPH LA-4: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 10.192 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$

GRAPH LA-5. TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 11.150 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$
 B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
 C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$
 D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
 E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$

F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
 G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
 H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$
 J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
 K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$

GRAPH LA-6: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 12.715 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$
 B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
 C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$
 D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
 E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$

F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$
 G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
 H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$
 J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
 K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$

GRAPH LA-7. TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 15.375 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$	F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$
B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$	G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$	H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$
D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$	J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$
E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$	K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$

Legend

Diameter = 5.524 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
 B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
 C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
 D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
 E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$

F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
 G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
 H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
 J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
 K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$

GRAPH LB-1: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 7.125 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$

GRAPH LB-2 TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 8.097 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$	G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$	J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$

GRAPH LB-3: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 9.063 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$	G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$	J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$

GRAPH LB-4: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 10.192 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 500,000$ lb/hr
 B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 400,000$ lb/hr
 C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 500,000$ lb/hr
 D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 400,000$ lb/hr
 E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 500,000$ lb/hr

F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 400,000$ lb/hr
 G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 500,000$ lb/hr
 H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 400,000$ lb/hr
 J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000$ lb/hr
 K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000$ lb/hr

GRAPH 9-5. TWO PHASE WELL HEAD PRESSURE CURVES

Legend

Diameter = 11.150 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$

GRAPH LB-6: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 12.175 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
 B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
 C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
 D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
 E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$

F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
 G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
 H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
 J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
 K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$

GRAPH LB-7: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 15.375 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$

GRAPH LB-8: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 5.524 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

GRAPH LC-1: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 7.125 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

GRAPH LC-2: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 8.097 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

GRAPH LC-3: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 9.063 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

GRAPH LC-4: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 10.192 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

GRAPH LC-5: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 11.150 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

GRAPH LC-6: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 12.715 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 800,000$ lb/hr
 B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 600,000$ lb/hr
 C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 800,000$ lb/hr
 D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 600,000$ lb/hr
 E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 800,000$ lb/hr

F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 600,000$ lb/hr
 G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 800,000$ lb/hr
 H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 600,000$ lb/hr
 J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000$ lb/hr
 K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000$ lb/hr

GRAPH LC-7: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 15.375 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$	J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$	K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

GRAPH LC-8 TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 5.524 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$
 B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$
 C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$
 D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$
 E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$

F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$
 G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$
 H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$
 J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$
 K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

Legend

Diameter = 7.125 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH LD-2: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 8.097 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH LD-3: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 9.063 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH LD-4: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 10.192 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH D-5 TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 11.150 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH LD-6: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 12.715 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$
 B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$
 C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$
 D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$
 E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$

F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$
 G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$
 H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$
 J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$
 K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH LD-7: TWO PHASE WELLHEAD PRESSURE CURVES

Legend

Diameter = 15.375 inches

A: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ F: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ B: $T_{pr} = 300^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ G: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ C: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ H: $T_{pr} = 450^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ D: $T_{pr} = 350^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ J: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 400^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ K: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH LD-8: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 5.524 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HA-1: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 7.125 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HA-2: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 8.097 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HA-3: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 9.063 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HA-4: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 10.192 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HA-5: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 11.150 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HA-6: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 12.715 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HA-7: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 15.375 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 300,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HA-8: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 5.524 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$

GRAPH HB-1: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 7.125 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HB-2: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 8.097 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$	F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$
D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$	H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HB-3: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 9.063 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HB-4: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 10.192 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HB-5: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 11.150 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HB-6: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 12.715 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$
B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$	F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$
C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$	G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$
D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$	H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HB-7: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 15.375 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 400,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 500,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HB-8 TWO PHASE WELL HEAD PRESSURE CURVES

LEGEND

Diameter = 5.524 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

GRAPH HC-1: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 7.125 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
 B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
 C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
 D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
 F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
 G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
 H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HC-2: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 8.097 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HC-3: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 9.063 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HC-4: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 10.192 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HC-5: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 11.150 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HC-6: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 12.715 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
 B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
 C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
 D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$

E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$
 F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$
 G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$
 H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HC-7: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 15.375 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 800,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 600,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$

GRAPH HC-8: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 5.524 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH HD-1 : TWO PHASE WELL HEAD PRESSURE CURVES

LEGEND

Diameter = 7.125 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH HD-2: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 8.097 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$

GRAPH HD-3: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 9.063 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HD-4: TWO PHASE WELL HEAD PRESSURE CURVES

LEGEND

Diameter = 10.192 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HD-5: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 11.150 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HD-6: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 12.715 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$	E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$
B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$	F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$
C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$	G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$
D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$	H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = \text{ ,000 lb/hr}$

GRAPH HD-7: TWO PHASE WELLHEAD PRESSURE CURVES

LEGEND

Diameter = 15.375 inches

A: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ E: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ B: $T_{pr} = 500^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ F: $T_{pr} = 600^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ C: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,200,000 \text{ lb/hr}$ G: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$ D: $T_{pr} = 550^{\circ}\text{F}$, $\dot{M} = 1,000,000 \text{ lb/hr}$ H: $T_{pr} = 650^{\circ}\text{F}$, $\dot{M} = ,000 \text{ lb/hr}$