WELLBORE THERMAL SIMULATION MODEL (GTEMP1)

THEORY AND USER'S MANUAL

DEA 67
PHASE II

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Wellbore Thermal Simulation Model (GTEMP1)

Theory and User's Manual

DEA-67, Phase II

Project to Develop and Evaluate
Coiled-Tubing and Slim-Hole Technology

By

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1. Introduction

This wellbore thermal model, GTEMP1, has been jointly developed by Maurer Engineering Inc. and the Department of Modern Mechanics of the University of Science and Technology of China (USTC) as part of the DEA-67 project. This program, written in Visual Basic, is designed for use with IBM compatible computers with Microsoft Windows 3.0 or later version.

GTEMP1 is a downhole thermal simulation model developed for improving the prediction of high downhole temperatures. The program models natural and forced convection and conduction within the wellbore and heat conduction within the surrounding rock formation. A variety of well operations can be modeled including injection, production, forward and reverse circulation with liquid, gas, or two-phase steam. The windows-style program graphically displays the output data.

1.1 MODEL DESCRIPTION

The key features of GTEMP1 are listed below.

1.1.1 General Features

1. Microsoft Windows environment
2. Supports English, metric, and customized unit systems
3. Supports both color and monochrome monitors
4. Handles boreholes of any inclination from vertical to horizontal
5. Handles up to 20 flow periods of operation
6. Results, data, and graphs can be output to screen, printer, and disk files
7. Graphically shows temperatures (and pressures) in tubing, annulus, and other selected locations
8. Calculates temperature gradients in multilayer rock formations
9. Handles mixing and cooling in the surface circulation system

1.1.2 Calculation Features

1. Fully-transient heat conduction
   a. wellbore flowing stream
   b. rock formation
2. Wellbore fluid flow options
   a. injection and production

b. forward and reverse circulation

c. inlet temperature, flow rate, and fluid property change

d. multiple fluids in wellbore

e. two-phase steam injection and production

3. Well completion options

a. casing size, weight, and setting depth

b. variable tubing area

c. length of cement columns

d. annulus packer fluids

The Output Window is a compilation of "child" windows of text reports and graphs as explained in Section 6.1.3.

1.2 DISCLAIMER

No warranty or representation is expressed or implied, with respect to these programs or documentation, including their quality, performance, merchantability, or fitness for a particular purpose.

1.3 COPYRIGHT

Participants in DEA-67 can provide data output from this copyrighted program to third parties and can duplicate the program and manual for their in-house use, but cannot give copies of the program or manual to third parties.

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2. Theory

2.1 GENERAL

2.1.1 Nomenclature

A	=	cross sectional area of tubing or azimuth of well lateral
A_a	=	cross sectional area of annulus
B	=	buoyancy
C_D	=	drag coefficient
C_p	=	specific heat capacity
D	=	hydraulic diameter of the duct
E	=	energy
F	=	drag
Fr	=	Froude number
f	=	friction factor
G	=	mass flux density
Gr	=	Grashof number
g	=	acceleration of gravity
H	=	enthalpy
h	=	specific enthalpy or conversion coefficient
I	=	inclination of well lateral
I	=	radial level index
j	=	axial level index
k	=	thermal conductivity
$(L)_B$	=	bubble flow/slug flow boundary number
$(L)_M$	=	transition flow/mist flow boundary number
$(L)_S$	=	slug flow/transition flow boundary number
M	=	consistency index of power-law fluid
m	=	exponent of power-law fluid or mass flow rate
Nu	=	Nusselt number
p	=	pressure
Pr	=	Prandtl number

Q	=	volume flow rate
q	=	heat flow rate
R	=	universal gas constant
Re	=	Reynolds number
r	=	radial coordinate or relative coefficient
T	=	temperature
t	=	time
U	=	thermal conductance
V	=	volume
v	=	velocity
W	=	gravity
Z	=	compressibility factor
z	=	axial coordinate
β	=	volumetric coefficient of thermal expansion
γ	=	slug flow liquid distribution coefficient, or ratio of specific heat, or strain rate for non-Newtonian fluid
δ	=	measure of roughness
θ	=	duct inclination from vertical
K	=	thermal diffusivity
μ	=	viscosity
μ_{eff}	=	effective viscosity
μ_p	=	plastic viscosity for Bingham fluid
v	=	kinematic viscosity
ρ	=	density
σ	=	surface tension between water and steam
τ	=	frictional gradient term; shear stress
τ_o	=	yield point for Bingham fluid
Φ	=	void fraction of the gas

Subscripts

g	=	gas
I	=	inner; grid number along radial direction
j	=	grid number along axial direction
o	=	outer

s   =   solid

t   =   total

w   =   water

1   =   inlet condition

2   =   exit condition

2.1.2 Wellbore Description

Figure 2-1 shows a well completion for an injection or production well; Figure 2-2 shows a well completion for a circulation well. In these figures, the tube in the center is the tubing or drill pipe; the casings outward in order are: production casing, intermediate casing, surface casing, conductor pipe, and finally borehole. Outside the borehole is rock formation.
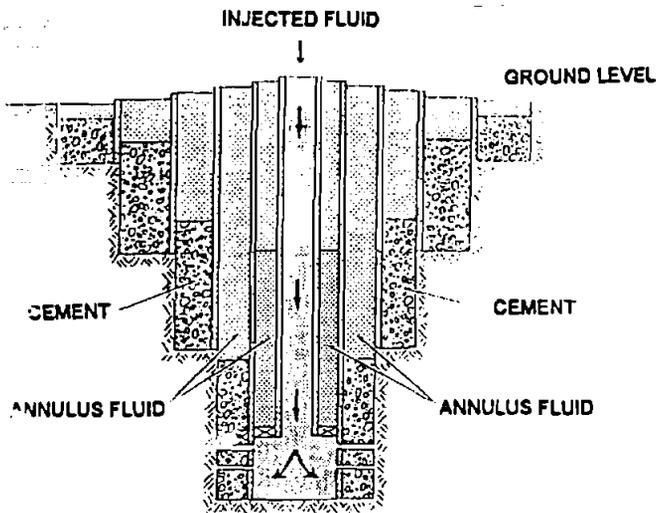
Figure 2-1. Wellbore Completion Model for Production and Injection
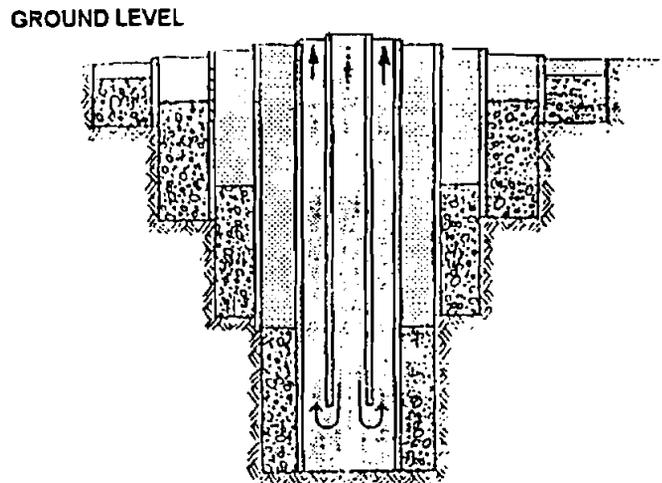
Figure 2-2. Wellbore Completion Model for Circulation

2-3

2.1.3 Numerical Grid

The model's grid system is illustrated in Figures 2-3 and 2-4. Three temperatures are computed in the wellbore at each depth (Figure 2-3). Radial boundaries of mathematical cells are located at the well centerline, at the outside surface of the tubing or drill pipe, and at the first casing string (production casing). The location of the outer boundary of the third cell is the radial position outside of the wellbore/rock interface. The distance from the borehole wall to the outer boundary is equal to the distance from the outside of the first casing string to the borehole wall, i.e., the centerline of the third cell is located at the well and rock interface (the radial location of the third temperature node). The first node is for fluid in the tubing or drill pipe, which represents the flowing production, injection or circulating fluid temperature, or simply a temperature near the center of the well during shut-in. The second node is for fluid in the annulus, which represents the annular fluid temperature during circulation.

The heat conducted along the well axis in the wellbore is ignored. Axial step length is selected to be 200 ft, or specified by the user, and radial step length is generally a few inches to a few feet. Axial temperature gradients are much less than radial temperature gradients for most applications. Fluid and rock cells are selected for computing the node temperatures as shown in Figures 2-3 and 2-4.

For thermal modeling of horizontal wells and deviated holes, it is reasonable to assume that the trajectory of a wellbore is on a plane. It is only necessary to compute the temperature on a plane that is perpendicular to the trajectory plane.
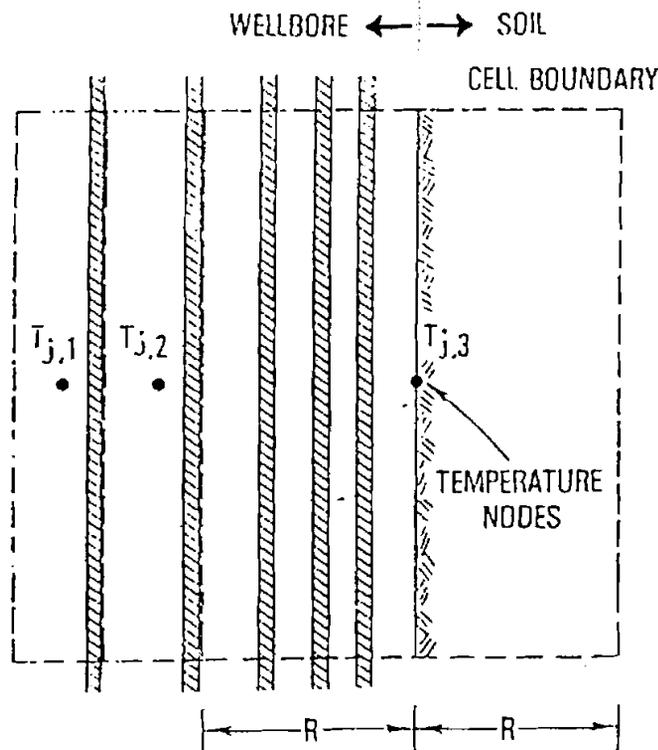
Figure 2-3. Mathematical Cells in Wellbore
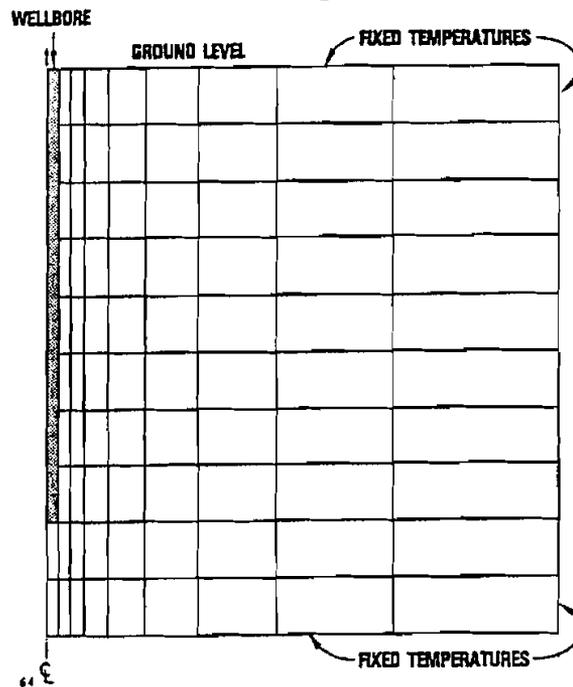
Figure 2-4. Mathematical Grid for Formation

2.1.4 Solids Properties

Material properties of solids in and around a well must be determined to properly model heat flow. Solids that must be modeled are cement, rock, and steel. Because thermal properties may not be significantly different between two types of the same material, GTEMP1 presently uses only one set of properties each for cement and steel.

Thermal properties required are density, specific heat capacity, and thermal conductivity.

All solids properties are treated as constants. Table 2-1 lists the properties initially assigned to each solid. The user may change the values for rock and steel in the input data windows, if necessary.

TABLE 2-1. Thermal Properties of Solids

Material	Density (LBM/FT³)	Specific Heat Capacity (BTU/LBM-°F)	Thermal Conductivity (BTU/HR-FT-°F)
Cement	104	0.20	0.60
Rock	140	0.30	0.92
Steel	490	0.11	26.1

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2.1.5 Operational Options

There are seven operational options available in the model that are listed below:

1. Liquid Forward Circulation:

   Predicts temperatures for forward circulation with liquid. Fluid enters the well at the surface, travels down the tubing, and returns up the annulus to the surface.

2. Liquid Reverse Circulation:

   Predicts temperatures for reverse circulation with liquid. Fluid enters the well at the surface, travels down the annulus, and returns up the tubing to the surface.

3. Liquid Injection:

   Predicts temperatures for fluid injection. Fluid enters the well at the surface, travels down the tubing, and flows into the rock formation with no flow in the annulus.

4. Liquid Production:

   Predicts temperatures for fluid production. Fluid enters the well at the bottom and travels up the tubing to the surface with no flow in the annulus.

5. Gas Forward Circulation:

   Predicts temperatures and pressures for forward circulation with gas. Gas enters the well at the surface, travels down the tubing, and returns up the annulus.

6. Steam Injection:

   Predicts temperatures and pressures for two-phase steam injection. Steam enters the well at the surface, travels down the tubing, and flows into the rock formation with no flow in the annulus.

7. Steam Production:

   Predicts temperatures and pressures for two-phase steam production. Steam enters the well at the bottom and travels up the tubing to the surface with no flow in the annulus.

2.2 LIQUID INJECTION, PRODUCTION, AND CIRCULATION

2.2.1 Fluid Properties

Material properties of the fluids in a well strongly influence the heat transfer between the well and rock. Fluid properties that must be defined in thermal simulation include density, viscosity, specific heat capacity, and thermal conductivity.

Fluid viscosity strongly affects convection heat transfer. The power-law and Bingham fluid models are used to compute viscosity for non-Newtonian fluids present in most wells.

Rheologic properties of high-solids muds and weighted muds (specific gravity greater than 1.5) are approximately those of a Bingham fluid. Properties of low-solids muds and diluted muds are similar to those of a power-law fluid. Effective viscosity is defined as the ratio of the shear stress to the shear strain rate, γ,

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$$\mu_{eff} = M\gamma^{m-1} \qquad \text{(Power-law fluid)} \qquad (2\text{-}1)$$

$$\mu_{eff} = \mu_p + \tau_o/\gamma \qquad \text{(Bingham fluid)} \qquad (2\text{-}2)$$

where M is the consistency index, m is the exponent, μ_p is the plastic viscosity (or coefficient of rigidity), and τ_o is the yield point. Shear strain rate (γ) can be calculated from the fluid properties, fluid volume flow rate, and well geometry.

If viscometer readings R_{600}, R_{300}, R_{200}, and R_{100} are the only data available, the effective viscosity may be calculated from these readings.

Temperature is an important variable for determining fluid viscosity. All fluid properties are assumed in the model to be measured at 70°F. The impact of temperature changes on viscosity is automatically updated during calculation.

Specific heat capacity is used to determine sensible heat and energy accumulation in a fluid. The value of specific heat capacity for a particular fluid is related to the solids fraction in the fluid. It is assumed that all fluids are derived by adding solids to water. Solids fraction is computed as follows:

$$SF = 0.00508(\rho - 8.33), \qquad \text{(for } 8.33 < \rho < 10.3\text{)}$$

$$(2\text{-}3)$$

$$SF = 0.0317(\rho - 10.3), \qquad \text{(for } \rho > 10.3\text{)}$$

where ρ is the fluid density in lbm/gal. Having determined the solids fraction, specific heat is computed:

$$c = 1.0 - 0.777SF \qquad (2\text{-}4)$$

where c is in BTU/lbm-°F.

Thermal conductivity controls the conduction of heat in the radial direction through the fluid. Like heat capacity, it is computed from the solids fraction as defined in Eq. 2-3.

$$K = 0.399 + 9.60SF \qquad (2\text{-}5)$$

where K is in BTU/hr-ft-°F.

2.2.2 Coupling Rock and Well

A thermal conductance must be formulated to describe the transfer of heat between the wellbore and rock. When heat flows between the rock and well, it must pass through various combinations of steel, cement, fluid, and rock. Conductance is computed from the well geometry and the properties of these materials. Heat passes from temperature nodes j,2 to j,3 through a composite

radial system of various materials (Figure 2-3). The rate of heat flow through such a system may be written as

$$q = U\Delta z \Delta T \qquad (2\text{-}6)$$

where the thermal conductance U is

$$U = 2\pi \left[\frac{1}{hr_1} + \frac{\ln(r_2/r_1)}{k_1} + \frac{\ln(r_3/r_2)}{k_2} + \cdots \right]^{-1} \qquad (2\text{-}7)$$

This particular formulation is for fluid flowing inside a pipe with convection coefficient h and thermal conductivities, k_1, k_2, etc. k_1 may be the conductivity of steel, k_2 may relate to the natural convection occurring in the fluid in one of the annular regions, and h is the convection coefficient discussed in the next section.

2.2.3 Convection Coefficient

Convection in wellbore fluids can significantly influence the rate of heat transfer from a well to the surrounding rock formation. When fluid flows past a solid wall surface, heat transfer between fluid and solid surfaces is called convection heat transfer. The rate of heat transfer through a solid surface is

$$q = h\Delta T \qquad (2\text{-}8)$$

where ΔT is the temperature difference between the fluid and solid. The convection coefficient may be computed from

$$h = Nu\frac{K}{D} \qquad (2\text{-}9)$$

where D is the pipe diameter, K is the thermal conductivity of the fluid, and Nu is the Nusselt number. The Nusselt number is a measure of the heat flow rate at the fluid/solid interface, which is related to the Reynolds (Re) and Prandtl (Pr) numbers (Gebhardt, 1961)

$$Nu = 0.023\,Re^{0.80}Pr^{0.35} \qquad (0.6 < Pr < 100)$$

$$Nu = \frac{(f/8)\,RePr}{1.2 + 11.8(Pr - 1)Pr^{-0.33}(f/8)^{1/2}} \qquad (Pr > 100) \qquad (2\text{-}10)$$

where f is the nondimensional friction factor. This friction factor is related to the Reynolds number.

$$f = \frac{64}{Re} \qquad (Re < 2000)$$

$$f = \frac{64 + 0.007735(Re - 2000)}{2000} \qquad (2000 < Re < 4000)$$

$$f = \frac{0.316}{Re^{0.25}} \qquad (4000 < Re < 350000)$$

$$f = 0.013 \qquad (Re > 350000)$$

(2-11)

The rate of heat transferred across the annular region is increased by natural convection, which can be expressed in terms of an effective thermal conductivity, K_{eff}. The effective thermal conductivity may be calculated from

$$K_{eff} = 0.049 \, (GrPr)^{0.333} \, Pr^{0.074} \qquad (2-12)$$

where the Grashoff number, Gr, is defined by

$$Gr = \frac{(R_0 - R_i)^3 \rho^2 \beta g \Delta T}{\mu^2} \qquad (2-13)$$

where β is the volumetric coefficient of thermal expansion, ΔT is the temperature difference across annulus, and g is the acceleration of gravity.

2.2.4 Energy Balance in a Fluid Cell

Energy in a fluid cell must obey the first law of thermodynamics, that is, energy must balance. This law leads to an equation of the form

$$T_{j,\,i}^{n+1} = A_{j,\,i} \, T_{j-1,\,i}^{n+1} + B_{j,\,i} T_{j+1,\,i}^{n+1} + C_{j,\,i} T_{j,\,i-1}^{n+1} + D_{j,\,i} T_{j,\,i+1}^{n+1} +$$

$$E_{j,\,i} \left(T_{j,\,i}^{n} + T_{j-1,\,i}^{n} \right) + F_{j,\,i} T_{j-1,\,i-1}^{n+1} + G_{j,\,i} T_{j-1,\,i+1}^{n+1}$$

(2-14)

This equation can be written for every position of j,i in the wellbore to yield a system of simultaneous linear algebraic equations. The unknowns are the temperatures at each node at time step n+1 for a total of $3N_z$ equations and unknowns, where N_z is the number of nodes in the vertical direction.

2.2.5 Energy Balance in a Rock Cell

Energy balance is also required for each cell containing rock. This requirement is met by:

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$$T_{j,i}^{n+1} = A_{j,i} T_{j-1,i}^{n+1} + B_{j,i} T_{j+1,i}^{n+1} + C_{j,i} T_{j,i-1}^{n+1} + D_{j,i} T_{j,i+1}^{n+1} + E_{j,i} T_{j,i}^{n} \qquad (2\text{-}15)$$

Equation 2-15 may be applied to all nodes in the formation to produce a system of $(N_r\text{-}3) \times N_z$ simultaneous algebraic equations, where N_r is the number of nodes in the radial direction. An equal number of unknowns exist for temperatures at the nodes.

2.2.6 Solution Scheme

As described in previous sections, Eqs. 2-14 or 2-15 may be applied to every temperature node to form a system of simultaneous linear algebraic equations. These equations can be solved for finding the new temperature at each new time step, $n+1$.

A Gauss-Seidel iteration is employed to solve the equations to determine the new temperatures. Equations 2-14 and 2-15 are iteratively applied until two successive calculations of each temperature are sufficiently close.

2.3 GAS CIRCULATION

The method for computing temperatures in the rock formation with gas circulation is the same as that discussed in the previous section for fluid circulation. The fluid properties of gas are used in these calculations, including density, specific heat capacity, and convection coefficient. Equations 2-14 and 2-15 are still valid for gas circulation.

2.3.1 Flow Variables

The flow of gas is described by three conservation laws of fluid mechanics: balance of mass, momentum, and energy.

Figure 2-5 illustrates the flow of gas in a constant area duct with cross-sectional area A and length Δz.
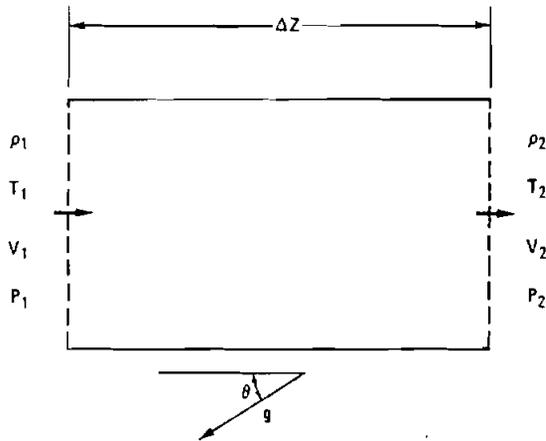
Figure 2-5. Constant Area Flow Cell

The mass flux density G is defined by

$$G = \rho v \qquad (2\text{-}16)$$

It is easy to prove that G is constant for constant-area ducts due to the balance of mass.

Balance of momentum is expressed in the following form:

$$P_2 - P_1 + G(v_2 - v_1) + F + W = 0 \qquad (2\text{-}17)$$

$$F = \frac{1}{2}\frac{f}{D}\int_{z_1}^{z_2} GvdZ$$

$$W = \int_{z_1}^{z_2} \rho g\cos\theta dZ$$

where

D is the hydraulic diameter, and f is the Darcy friction factor.

An additional relation needed to solve Eq. 2-17 is the equation of state for an ideal gas

$$P = \rho RT \qquad (2\text{-}18)$$

where R is the ideal gas constant. If the temperature is known, Eq. 2-17 is reduced to a nonlinear integral equation for the velocity. When velocity has been determined, the remaining flow variables can be determined.

Assuming a linear velocity and employing the method of residuals, Eq. 2-17 can be solved approximately for the exit velocity v_2:

2-11   ©1997 Maurer Engineering Inc.

where

$$v_2 = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$$

(2-19)

where

$$a = G - \frac{1}{2v_1}\left[\rho_1 g\cos\theta - \frac{Gf}{2D}v_1\right]\Delta z$$

$$b = -p_1 - Gv_1 + \frac{1}{2}\left[3\rho_1 g\cos\theta + \frac{Gf}{2D}v_1\right]\Delta z$$

(2-20)

$$c = GRT_2$$

Equation 2-19 does not have a real solution for negative values of the determinant b^2-4ac. The physical sense of a negative determinant is that the flow has choked, i.e., there is not enough pressure to support the assumed mass flow rate. Either the inlet pressure needs to be increased or the flow rate decreased until the determinant is positive.

2.3.2 Air and Nitrogen Properties

In GTEMP1, air and nitrogen are modeled as ideal gases. The properties are listed in Table 2-2.

TABLE 2-2. Gas Properties

	GAS CONSTANT (J/KG-°K)	SPECIFIC HEAT CAPACITY (J/KG-°K)	RATIO OF SPECIFIC HEAT
AIR	287.06	1004.0	1.40
NITROGEN	296.80	1038.3	1.40

The thermal conductivity is defined by the following relationship

$$k = C_p\mu/Pr$$

(2-21)

where C_p is the specific heat capacity, and the Prandtl number Pr is

$$Pr = \frac{4\gamma}{9\gamma - 5}$$

(2-22)

where γ is the ratio of specific heat for both air and nitrogen.

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Viscosities are determined by the following correlation (Zucrow and Hoffmure, 1976)

$$\mu = T^{\frac{1}{2}} \left[A_0 + \frac{A_1}{T} + \frac{A_2}{T^2} + \frac{A_3}{T^3} + \frac{A_4}{T^4} \right]^{-1} \qquad (2\text{-}23)$$

where the coefficients are listed in Table 2-3.

TABLE 2-3. Coefficient A_i

	A_0	$A_1 \times 10^{-2}$	$A_2 \times 10^{-4}$	$A_3 \times 10^{-6}$	$A_4 \times 10^{-8}$
Air	0.552795	2.810892	-13.50843	39.353086	-41.419387
Nitrogen	0.579561	2.847486	-13.23249	37.106107	-37.549675

2.4 TWO-PHASE STEAM PRODUCTION AND INJECTION

2.4.1 Flow Patterns

Vertical two-phase steam flow is categorized by the regimes of flow geometry and velocity. There are four generally accepted categories of two-phase steam flow: bubble, slug, transition, and annular-mist (Figure 2-6).

1. Bubble Flow

   The pipe is almost completely filled with liquid; the gas volume is small. Gas is distributed as small, randomly-sized bubbles that rise at velocities dependent on their size. The gas phase has little effect on the frictional pressure drop caused by the liquid velocity.

2. Slug Flow

   Gas bubbles coalesce to form larger, cap-shaped bubbles nearly spanning the pipe. Bubble velocity is greater than liquid velocity. Both gas and liquid phases have a significant effect on pressure drop.

3. Transition Flow

   A transition from continuous liquid phase to continuous gas phase occurs. Although liquid effects are important, the gas phase dominates behavior.

4. Annular-Mist Flow

   The gas phase is completely dominant and the liquid phase is carried as droplets.

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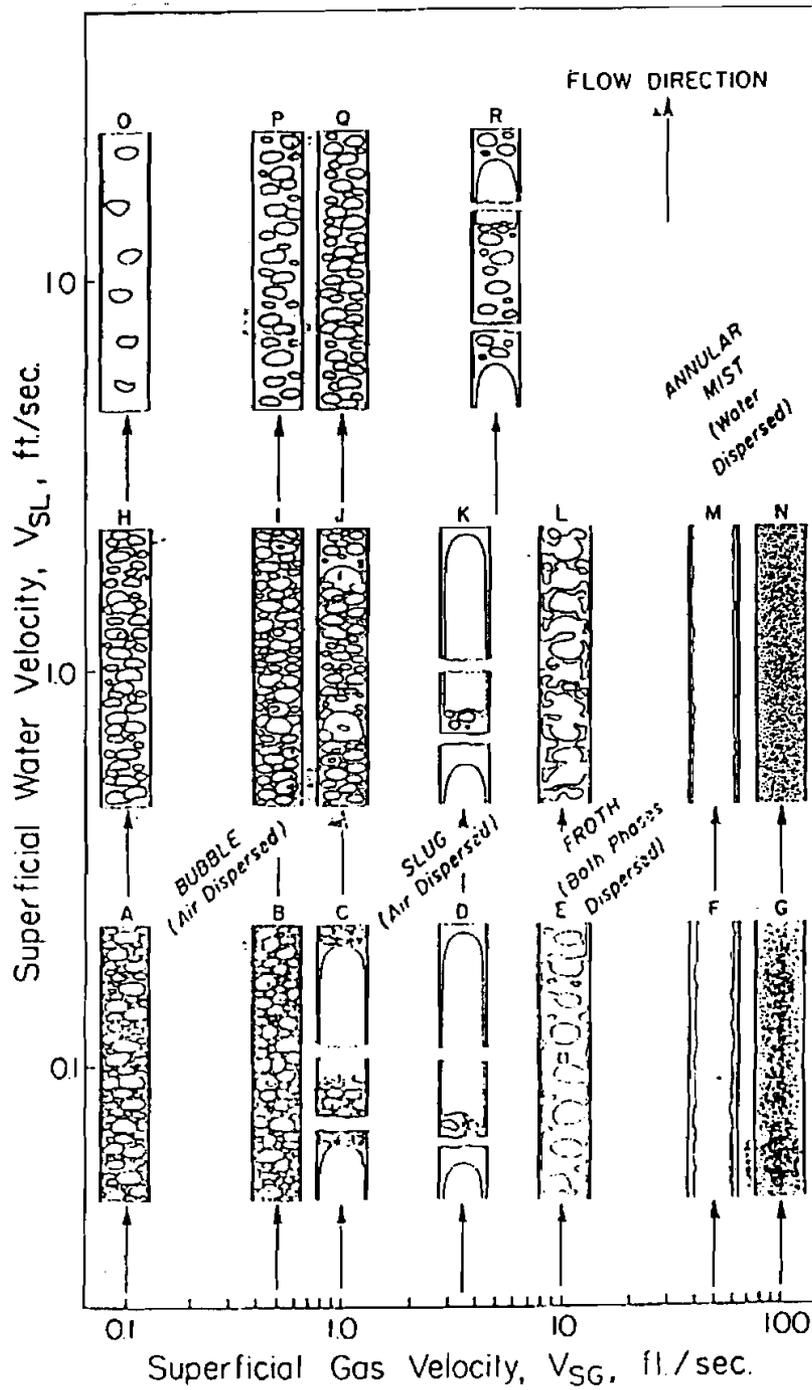
Figure 2-6. Vertical Flow Patterns of Two-Phase Steam (Govier et al., 1961)

Modeling temperature in a two-phase steam flow is performed as follows. For inlet conditions to a flow element, the flow regime is identified. Appropriate correlations are then used to determine frictional and gravitational pressure drops across the element. Exit pressure is determined and saturated temperature is then determined from thermodynamic correlations. The energy equation is then solved to determine the phase change in the flow element. For single component calculations, pressure and temperature are independent variables, and momentum and energy equations are solved simultaneously, as in previous sections.

2.4.2 Determination of Flow Regime

Flow regime limits are defined by the following dimensionless numbers:

$$(L)_B = 1.071 - 0.2218v_{ns}^2/D \qquad \left[(L)_B \geq 0.13\right]$$

$$(L)_S = 50 + 36v_{gD}v_{sw}/v_{sg} \tag{2-24}$$

$$(L)_M = 75 + 84\left(v_{gD}v_{sw}v_{sg}\right)^{0.75}$$

where

v_g = Q_g/A_g = gas average velocity

v_w = Q_w/A_w = liquid average velocity

v_{sg} = Q_g/A = superficial gas velocity

v_{sw} = Q_w/A = superficial liquid velocity

v_{ns} = $v_{sg} + v_{sw}$ = average velocity of two-phase mixture

v_b = bubble rising velocity

v_{gD} = $v_{sg}(\rho_w/g\sigma)^{0.25}$ = gas velocity number

A = cross-section area

A_g = area fraction of gas

A_w = area fraction of water

Q_g = gas volume flow rate

Q_w = water volume flow rate

ρ_w = density of water

σ = surface tension

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Limits for various flow regimes are defined in the following way:

Bubble flow: $\qquad v_{sg}/v_{ns} < (L)_B$

Slug flow: $\qquad v_{sg}/v_{ns} < (L)_B$

$\qquad\qquad\qquad v_{sD} < (L)_S$ (2-25)

Transition flow: $\quad (L)_M > v_{sD} > (L)_S$

Mist flow: $\qquad v_{sD} > (L)_M$

2.4.3 Pressure Drop Correlations for Two-Phase Flow

The basic equation used to predict pressure drop is the conservation of momentum for the mixture of two-phase steam:

$$\Delta p + G_g \Delta v_g + G_w \Delta v_w + W + F = 0 \qquad (2-26)$$

where

$$W = \int_{z_1}^{z_2} \rho_t g \cos\theta \, d$$

$$F = \int_{z_1}^{z_2} \tau_f \, dz$$

$$G_g = Q_g \rho_g / A$$

$$G_w = Q_w \rho_w / A$$

$\rho_t \quad = \quad$ density of the mixture

$\tau_f \quad = \quad$ frictional pressure drop of the mixture

The terms ρ_t and τ_f are defined by correlations for each flow regime (Orkiszowski, 1968).

2.4.4 Phase Changes

Balance of energy provides the equation for determining phase changes. The energy equation for a two-phase mixture of gas and water has the following form:

$$\Delta\left[\left(h_w + \frac{v_w^2}{2}\right)G_w + \left(h_g + \frac{v_g^2}{2}\right)G_g\right] + g\cos\theta G\Delta z - \int_{z_1}^{z_2}\frac{q}{A}dz = 0 \qquad (2-27)$$

where h is the specific enthalpy, q is the heat flux per unit length of pipe, and Δ denotes the change in properties from inlet to exit of a flow element.

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2.4.5 Temperature in the Wellbore

The thermodynamic region where liquid water and vapor coexist is called the two-phase region, and states of liquid and vapor are called saturated-liquid and saturated-vapor states. Gibb's law of equilibrium requires that pressure and temperature cannot be independent variables in the two-phase region. The saturated temperature T_s is given by the following equation:

$$T_s = T_c / [1.73010 - \sum_{i=1}^{6} B_i (lnp/lnp_c)^{i-1}] \qquad (2\text{-}28)$$

where

$B_1 = -0.45800227;$ $B_2 = 1.0158658;$ $B_3 = 0.53542626$

$B_4 = 0.07074624;$ $B_5 = -0.26191199;$ $B_6 = 0.10003160$

the critical temperature $T_c = 647.19$ °K; and the critical pressure $p_c = 220.88$ bars.

2.5 SURFACE MUD TANK

The circulated fluid returns to the surface mud tank and will be mixed with the fluid in the tank. The temperature of this mixed fluid may be calculated by considering the balance of energy as follows:

$$\overline{T} = \frac{T_0 (V - Qdt) \rho C_p + (Q \rho C_p + Q_2 \rho_2 C_{p_2}) dt\, T_{out}}{V \rho C_p + Q_2 \rho_2 C_{p_2} dt} \qquad (2\text{-}29)$$

where

$\overline{T}$	=	mixed fluid temperature
T_0	=	fluid temperature in the tank
Q	=	fluid volume flow rate
Q_2	=	volume flow rate of secondary flow (influx)
ρ	=	circulation fluid density
ρ_2	=	secondary fluid density
C_p	=	circulation fluid specific heat capacity
C_{p_2}	=	secondary fluid specific heat capacity
dt	=	circulation time increment
T_{out}	=	exit temperature of fluid
V	=	surface tank fluid volume

Note that the fluid temperature in the tank is different from the environmental temperature, and that heat transfer will occur between the tank and its environment. The final fluid temperature (T) of the mixed fluid in the tank may be approximately predicted by the following equation (Sucec, 1985).

$$T = T_f + (\overline{T} - T_f)\,e^{-\phi dt} \tag{2-30}$$

where

T_f = environmental temperature

ϕ = $\dfrac{\alpha A_s}{\rho C_p V}$

α = comprehensive heat transfer coefficient

A_s = fluid surface area of the tank.

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3. Input Data Files

There are five data files associated with the input for GTEMP1: well data file (WDI), survey data file (SDI), tubular data file (TDI), parameter data file (PDI), and project file with the extension name (.GTE) containing the paths and filenames of all four files.

3.1   WELL DATA FILE — WDI

The WDI file stores the well name and identification and is for reference only. The user can run the program without the WDI file. The extension for the WDI file is ".WDI."

3.2   SURVEY DATA FILE — SDI

The survey data file consists of a sequence of measured depths, each with an associated inclination angle and azimuth angle. These values can be input into the program individually or imported from a WELPATH5 (DEA-44 program) generated survey. The extension for the SDI file is ".SDI." The SDI file must be in ASCII format, and the structural format of the file is:

```
Number
Inclination Unit Indicator
Azimuth Unit Indicator
MD₁, Inclination₁, Azimuth₁
MD₂, Inclination₂, Azimuth₂          n Stations
                                     or Survey
                                     Data points
MDₙ, Inclinationₙ, Azimuthₙ
```
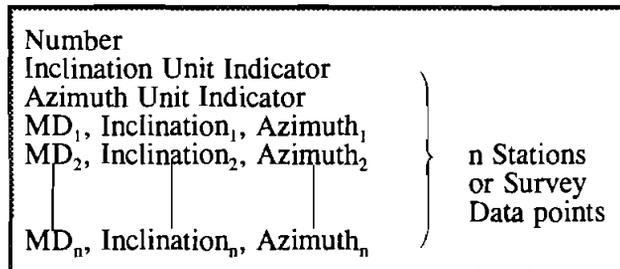
Number is the number of measuring stations.
Inclinhation Unit Indicator is either D or M:

> "D" signifies that inclination readings were entered in decimal degrees. Example: 29.50.

> "M" signifies that inclination readings were entered in degrees and minutes. Example: 29:30.

Azimuth Unit Indicator is either A or O:

> "A" signifies that the azimuth readings were entered in angular format. Example: 150.

> "O" signifies that the azimuth readings were entered in oil-field format. Example: S30E.

The measured depth in the first survey station must be 0; therefore, the data file must start at the surface.

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Data in the SDI files are stored on disk in the angular and decimal degree format. Inclination and azimuth angle unit indicators instruct the program to display or accept the data in a certain format.

A maximum of 400 survey stations can be accommodated by the program.

3.3 TUBULAR DATA FILE — TDI

Table 3-1 displays required tubular data for GTEMP1.

TABLE 3-1. Tubular Data Table (Required)

TUBING DATA	ID OD BOTTOM OF TUBING INTERVAL LENGTH OF CEMENT OUTSIDE TUBING
CASING DATA	ID OD CASING SETTING DEPTH LENGTH OF CEMENT OUTSIDE CASING
GEOTHERMAL TEMPERATURE DATA	UNDISTURBED SURFACE TEMPERATURE UNDISTURBED BOTTOM-HOLE TEMPERATURE
WELLBORE GEOMETRY DATA	MEASURED DEPTH HOLE MAXIMUM DIAMETER

Table 3-2 displays additional tubular data that have been given default values.

TABLE 3-2. Tubular Data Table (Default)

TUBING/CASING THERMAL PROPERTIES	DESCRIPTION THERMAL CONDUCTIVITY SPECIFIC HEAT CAPACITY DENSITY
ROCK FORMATION THERMAL PROPERTIES	DESCRIPTION THERMAL CONDUCTIVITY SPECIFIC HEAT CAPACITY DENSITY VERTICAL DEPTH
GRID	RADIAL GRID NUMBER MAXIMUM RADIAL DISTANCE VERTICAL GRID SIZE

In most cases, default values can be used in the calculation. These values may be modified, if necessary.

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3.4 PARAMETER DATA FILE — PDI

The parameter data file serves two major functions: 1) describes the flowing stream in the wellbore, and 2) specifies the time interval when flowing stream data are to be used. As many as twenty operation schedule changes can be stacked to describe the flowing history of a well. The parameter data are summarized in Table 3-3.

TABLE 3-3. Parameter Data Table

OPERATION SCHEDULE	SECONDARY FLOW IDENTIFICATION (Y/N) FLUID IDENTIFICATION NUMBER (OR GAS TYPE) FLUID INLET TEMPERATURE FLUID VOLUME FLOW RATE FLOW PERIOD END
SECONDARY FLOW	FLUID IDENTIFICATION NUMBER INLET TEMPERATURE VOLUME FLOW RATE
GAS PROPERTIES	STANDPIPE PRESSURE
INITIAL FLUID	FLUID IDENTIFICATION NUMBER IN TUBING & ANNULUS PACKER FLUID IDENTIFICATION NUMBER
STEAM PROPERTIES	STEAM IDENTIFICATION NUMBER (0/1) STEAM QUALITY (0) OR INLET PRESSURE (1)
FLUID PROPERTIES OR	FLUID IDENTIFICATION NUMBER DENSITY PLASTIC VISCOSITY (BINGHAM FLUID) YIELD POINT (BINGHAM FLUID) CONSISTENCY COEFFICIENT (POWER-LAW FLUID) EXPONENT OF POWER LAW (POWER-LAW FLUID)
VISCOMETER READING	FLUID IDENTIFICATION NUMBER DENSITY VISCOMETER READING AT R = 600 REV/MIN VISCOMETER READING AT R = 300 REV/MIN VISCOMETER READING AT R = 200 REV/MIN VISCOMETER READING AT R = 100 REV/MIN
SURFACE TANK	TANK MUD VOLUME FLUID SURFACE AREA ENVIRONMENTAL TEMPERATURE SURFACE COEFFICIENT OF HEAT TRANSFER CONTROL PARAMETER (0-INLET/1-ANNULUS/2-MIXED)

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3.5 PROJECT FILE — GTE

The project file documents the set of files and settings used for a specific case. The project file contains the path and filenames of well, survey, tubular, and parameter data. It also contains the operational option selections.

Files that make up a project do not have to be in one directory of the hard drive, because the project file documents the file locations. In addition, a single file, such as the survey data file, can be part of more than one project.

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4. Program Installation

4.1 BEFORE INSTALLING

4.1.1 Check the Hardware and System Requirements

GTEMP1 is written in Visual Basic®. It runs in either the standard or enhanced mode of Microsoft Windows 3.0 or higher. The basic requirements are:

- Any IBM-compatible machine built on the 80286 processor or higher

- Hard disk

- Mouse

- CGA, EGA, VGA, 8514, Hercules, or compatible display (EGA or higher resolution is recommended)

- MS-DOS version 3.1 or higher

- Windows version 3.0 or higher in standard or enhanced mode

A 486 (or higher) IBM compatible PC and Windows 3.1 (or higher) are highly recommended for fast performance.

For assistance with the installation or use of GTEMP1 contact:

Xichang Zhang/Gefei Liu/Lee Chu/Russell W. Hall, Jr.
MAURER ENGINEERING INC.
2916 West T.C. Jester Boulevard
Houston, Texas 77018-7098 U.S.A.
Telephone: 713/683-8227   Fax: 713/683-6418
Internet: http://www.maureng.com
E-Mail: mei@maureng.com

4.1.2 Check the Program Disk

The program disk received is one 3½-in. 1.44 MB disk. The disk contains sixty-eight files. These are executable files, example data files of GTEMP1 and other library files used by the application.

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THREED.VBX	MDICHILD.VBX	SETGTE.EXE	GTEMP1.EX_	SETUP.LST
VBRUN300.DLL	CMDIALOG.VBX	GRAPH.VBX	GSW.EXE	GSWDLL.DLL
VER.DL_	GRID.VBX	COMMDLG.DLL	SETUP.EXE	SETUPKIT.DLL
WTTEST1.GTE	WTTEST1.WDI	SPIN.VBX	WTTEST1.GT1	WTTEST1.GP1
WTTEST2.GTE	WTTEST2.WDI	WTTEST1.SDI	WTTEST2.GT1	WTTEST2.GP1
WTTEST3.GTE	WTTEST3.WDI	WTTEST2.SDI	WTTEST3.GT1	WTTEST3.GP1
WTTEST4.GTE	WTTEST4.WDI	WTTEST3.SDI	WTTEST4.GT1	WTTEST4.GP1
WTTEST5.GTE	WTTEST5.WDI	WTTEST4.SDI	WTTEST5.GT1	WTTEST5.GP1
WTTEST6.GTE	WTTEST6.WDI	WTTEST5.SDI	WTTEST6.GT1	WTTEST6.GP1
WTTEST7.GTE	WTTEST7.WDI	WTTEST6.SDI	WTTEST7.GT1	WTTEST7.GP1
WTTEST8.GTE	WTTEST8.WDI	WTTEST7.SDI	WTTEST8.GT1	WTTEST8.GP1
WTTEST9.GTE	WTTEST9.WDI	WTTEST8.SDI	WTTEST9.GT1	WTTEST9.GP1
WTTEST10.GTE	WTTEST10.WDI	WTTEST9.SDI	WTTEST10.GT1	WTTEST10.GP1
ROCK.DBS	TUBING.DBS	WTTEST10.SDI		

To avoid conflict with other library versions, we recommend that all .VBX and .DLL files be installed in the same sub-directory as the GTEMP1 executable (GTEMP1.EXE) and example data files. All these procedures are accomplished by a simple set-up command explained in Section 4.2.

To run, the user must install all the files into the appropriate directory on the hard disk. Please see Section 4.2 to set up GTEMP1.

4.1.3 Backup Disks

It is advisable to make several backup copies of the program disk and place them in different storage locations. This minimizes the probability of all disks developing operational problems at the same time.

The user can use the COPY and DISKCOPY command in DOS, or the "Copy Disk..." command in the Disk menu in the File Manager in Windows.

4.2 INSTALLING GTEMP1

4.2.1 Automatic Installation

The following procedures install GTEMP1 from the floppy drive onto working sub-directories of the hard disk (i.e., copy from A: drive onto C: drive sub-directory GTEMP1).

1. Start Windows by typing "WIN" <ENTER> at the DOS prompt.

2. Insert the disk.

3. In the File Manager of Windows, choose Run from the File menu. Type a:setup and press <Enter>.

4. Follow the on-screen instructions.

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After successful set up of GTEMP1, there is a "DEA Application Group" that contains GTEMP1 application icon, as shown in Figure 4-1.
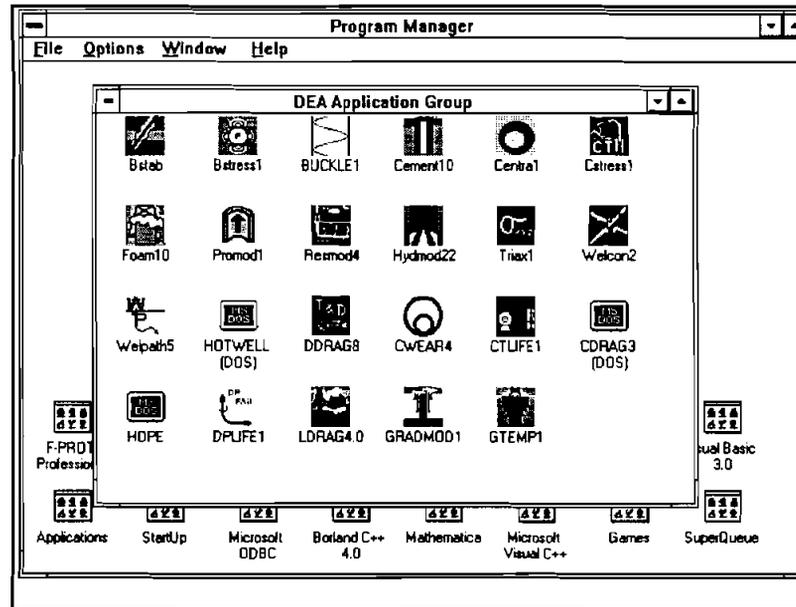
Figure 4-1. "DEA Application Group" Window Created by Setup

4.2.2 Manual Installation

Follow these steps to manually install the program should automatic installation fail:

1. Create a sub-directory on drive C: C:\GTEMP1

2. Copy all files on the disk into C:\GTEMP1

3. The file extension with the third character underscored is the compressed file. To expand these files, the user can type the following commands in the DOS environment.

        EXPAND   VER.DL_   VER.DLL

        EXPAND   GTEMP1.EX_   GTEMP1.EXE

4. Type: CD.. <Enter> then key in "WIN" <Enter> to start Windows 3.0 or a later version.

5. Select "New..." from File under "Program Manager" Window. In the "New Program Object" dialog box that follows, select the Program Group option, then click on the <OK> button.

6. In the "Program Group Properties" dialog box, key in "DEA Application Group" after label "Description," and key in "DEAMEI" after "Group File," then click on <OK> button. A Group Window with the caption "DEA Application Group" appears.

7. Select "New..." from File under "Program Manager" Window. In the "New Program Object" dialog box that follows, select the Program Item option, then click on the <OK> button.

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8. In the "Program Item Properties" dialog box, key in "GTEMP1" after label "Description." Key in "C:\GTEMP1\GTEMP1.EXE" after label "Command Line." Click on the <OK> button. The GTEMP1 icon appears inside the "DEA Application Group" Window.

4.3 STARTING GTEMP1

4.3.1 Starting GTEMP1 from Group Window

To run GTEMP1 from the Group Window, simply double-click the GTEMP1 icon, or when the icon is focused, press <ENTER>.

4.3.2 Using Command-Line Option from Windows

In the Program Manager, choose Run from the File menu. Then type C:\GTEMP1\GTEMP1.EXE <ENTER> as shown in Figure 4-2.
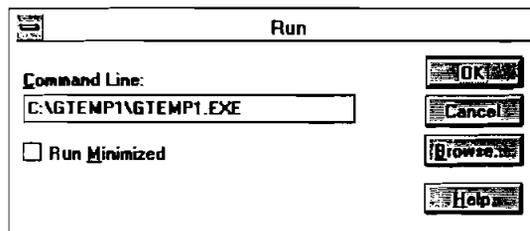
Figure 4-2.   Using Command Line to Start GTEMP1

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5. Windows Environment

GTEMP1 runs in the Windows environment. For comprehensive information about Windows, see *Concise Guide to Microsoft Windows 3.1* by Kris Jamsa (Microsoft Press, 1992) or other books on Microsoft Windows. This section presents only a brief description of the Windows environment.

5.1 TYPICAL WINDOWS

Consider the parts of a typical window. Figure 5-1 shows the Program Manager Window with various components.
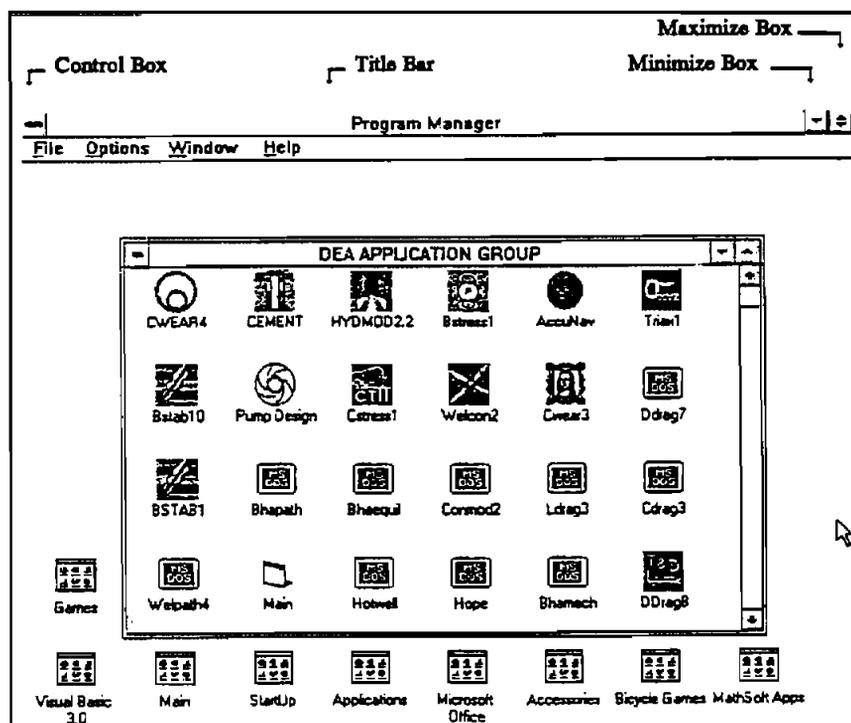
Figure 5-1. Program Manager Window

1. **Title Bar**

   The title bar serves two functions: to display the name of the current window and to indicate which window is active. The active window is the one in which the title bar is in color. (On monochrome monitors, the difference is shown by the intensity of the title bar). The user can make a window active by clicking anywhere within its border.

2. **Control Boxes**

   At the left of the title bar is the control box. It has two functions: 1) it displays the CONTROL menu, which enables the user to control the window size using the keyboard and 2) double-clicking the control box ends the current program.

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During execution of GTEMP1, the control boxes are not needed. The program runs according to its own flow chart.

3. **Minimize and Maximize Boxes**

At the right of the title bar are the MINIMIZE and MAXIMIZE boxes. The box with the up arrow is the MAXIMIZE box. The box with the down arrow is the MINIMIZE box. If a window has been maximized, the MAXIMIZE box changes to a RESTORE box with both up and down arrows, as shown in Figure 5-1.

- Clicking on the MINIMIZE box reduces the window to an icon. The window's name in the title bar appears below the icon. To restore a window from an icon, double-click on the icon.

- Clicking on the MAXIMIZE box enlarges the window to fill the total working area.

- Clicking on the RESTORE box, sizes the window so that it fills only a portion of the total working area, which is determined by how the user manually sizes the window.

The user should avoid clicking these boxes while running GTEMP1 unless necessary.

4. **Icons**

Windows makes use of icons extensively. Icons are small graphic symbols that represent specific applications. Icons are identified by their appearance, as well as an accompanying label. Usually, the user can start an application by double-clicking its icon.

5.2 DIALOG BOXES

In the dialog box of a normal window, the user will find one or more of the following elements.

1. **Text Box**

TEXT boxes display information that the user enters. Sometimes there is text already typed in for the user. The arrow keys can be used to edit the existing text. Figure 5-2 shows a typical text box.

<u>C</u>ommand Line:

| C:\GTEMP1\GTEMP1.EXE |
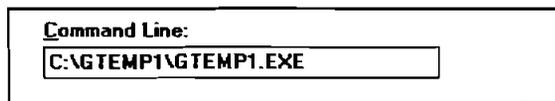
Figure 5-2. Text Box

2. **Option Button**

An OPTION button is an exclusive setting. Selecting an option immediately causes all other buttons in the group to be cleared. Figure 5-3 is a typical option box.

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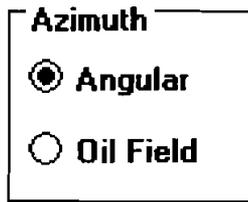
Figure 5-3.
Option Buttons

3. Command Button

A COMMAND button performs a task when the user chooses it, either by clicking the button or pressing a key. The most common command buttons are the **OK** and **Cancel** buttons found in almost every dialog box. In most cases, there is a button with a thick border—the default button, which is executed if your press <ENTER>. Figure 5-4 shows a typical command button.

Figure 5-4. Command Button

4. List Boxes

A LIST box gives the user a list of options or items from which to choose. If the LIST box is too small to show all possible options, a SCROLL box appears on the right side of the box. From the LIST box, the user can make a selection by clicking on it, or from the keyboard, by highlighting the desired item with the arrow keys, and then pressing <ENTER>. Figure 5-5 is a typical list box.

exam-1.wt1
exam-10.wt1
exam-2.wt1
exam-3.wt1
exam-4.wt1
exam-5.wt1
exam-6.wt1
exam-7.wt1
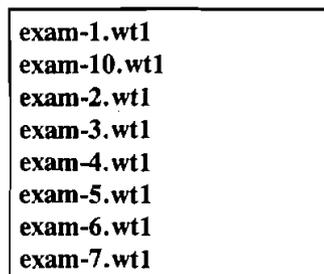
Figure 5-5. List Box

5. Drop-Down List Boxes

A DROP-DOWN LIST box is indicated by a small arrow in a box to the right of the option. The current setting is shown to the left of the arrow. When the user clicks on the small arrow, the box expands to list all selections. A typical drop-down list box is shown in Figure 5-6.

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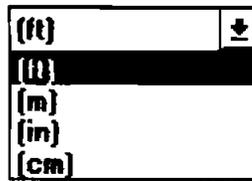
Figure 5-6.
Drop-Down List Box

6. **Scroll Bars**

SCROLL BARS are graphical tools for quickly navigating through a long list of items. There are two types of scroll bars: HORIZONTAL and VERTICAL SCROLL BARS.

The small box inside the bar is called the SCROLL BOX. The two arrows at the end of the scroll bar are scroll buttons (Figure 5-7). Clicking the scroll buttons or moving the SCROLL BOX changes the portion of information being viewed.
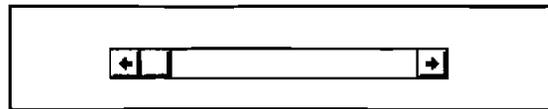
Figure 5-7. Scroll Bar

7. **Grid**

GRIDS display a series of rows and columns (Figure 5-8). In case of a long list of items, or a large amount of information, scroll bars attach to the grid providing easy navigation.

I.D. (in)	O.D. (in)	Casing Set Depth (ft)
8.68	9.63	5000
12.35	13.38	3000
19.12	20	1000
29	30	100

Figure 5-8. Grid

In the data input window, grids are used to assist with data entry. Some columns of the grid only allow numeric input. Typing an alphabetical character is not allowed by the program. The user can edit an entry by typing desired characters or pressing the <BACKSPACE> key to delete. In many grids, just like a spreadsheet, the user can insert or delete rows.

Note: In the Output Window, grids are for presentation only. They do not allow editing.

The grid supports word-wrapped text presentations, resizeable columns and rows, etc. Even though the user can manually change column widths or row heights of a cell, it is not recommended because all grids in GTEMP1 are carefully designed to fit the length of the appropriate data string.

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6. Basic Operation of GTEMP1

GTEMP1 operates in a Windows environment. Windows graphics user interface (GUI) and point-and-click environment give the power and flexibility needed in this application. In this chapter, basic operation and functions of GTEMP1 are described.

6.1 WINDOWS IN GTEMP1

There are three principal types of windows in GTEMP1: Introductory, Input, and Output Windows. The flow diagram of GTEMP1 Windows is shown in Figure 6-1.
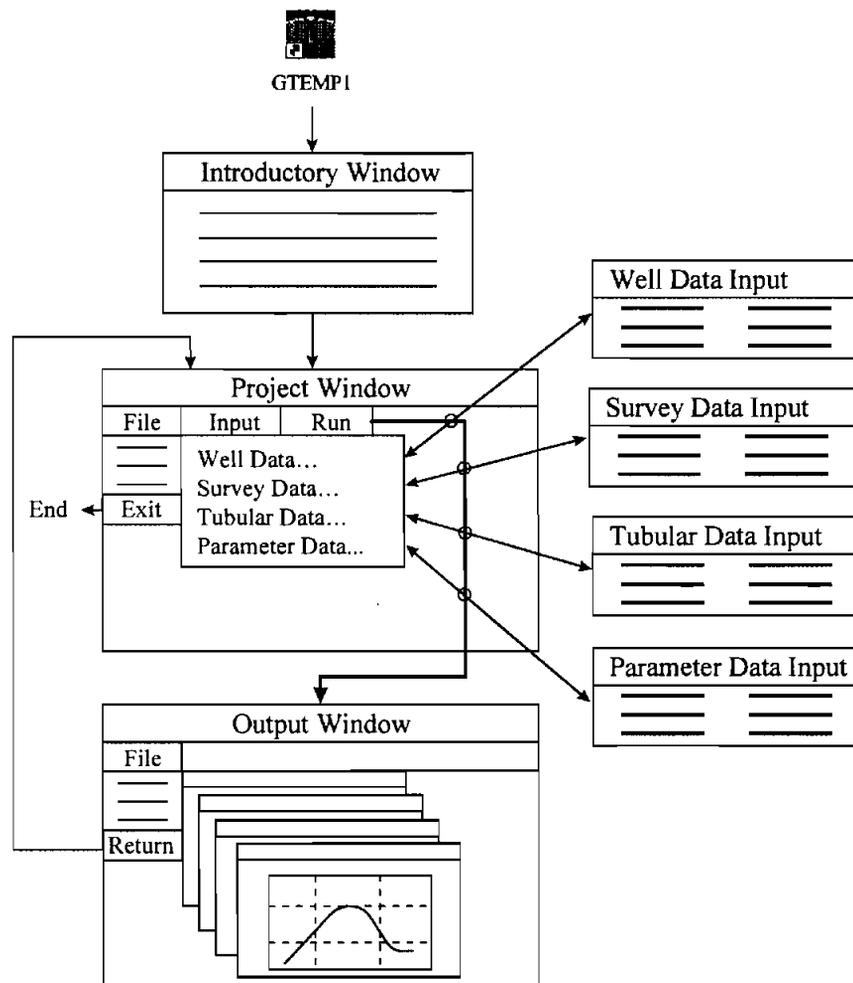
Figure 6-1. Flow Diagram of GTEMP1

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6.1.1 Introductory Window

Figure 6-2 shows the Introductory Window containing basic information on the program and the disclaimer.


```
┌─────────────────────────────────────────────────────────────┐
│ ┌──┐                    Maurer Engineering Inc.              │
│ ├──┘                                                         │
│                                                              │
│            Wellbore Thermal Simulation Model (GTEMP 1.0)     │
│                                                              │
│                           DEA-67                             │
│          Project to Develop and Evaluate Coiled-Tubing and   │
│                      Slim-Hole Technology                    │
│                              By                              │
│                    Maurer Engineering Inc.                   │
│   ─────────────────────────────────────────────────────     │
│                                                              │
│   This copyrighted 1996 confidential report and computer program are for the sole │
│   use of Participants on  the Drilling Engineering Association DEA-67 project and  │
│   their affiliates, and are not to be disclosed  to other parties.  Data output from  the │
│   program can be disclosed to third parties.  Participants and their affiliates are free │
│   to make copies of this report and program for their in-house use only.          │
│                                                              │
│   Maurer Engineering Inc. makes  no warranty or  representation,  either expressed │
│   or implied,  with respect to the program or documentation, including  their quality, │
│   performance, merchantability, or fitness for a particular purpose.               │
│                                                              │
│   ┌────────────────────────────────────────────────────┐    │
│   │ International keyboard users should read Appendix A of User's Manual │  │
│   └────────────────────────────────────────────────────┘    │
│                                                              │
│              ┌──────────┐       ┌──────────┐                 │
│              │    OK    │       │   Exit   │                 │
│              └──────────┘       └──────────┘                 │
└─────────────────────────────────────────────────────────────┘
```

Figure 6-2. Introductory Window

There are two command buttons, "OK" and "Exit." Clicking "Exit" terminates the program. The "OK" button is the default command that means the user can press the button by pressing <ENTER> or clicking on the button. This invokes and displays the Project Window.

6.1.2 Input Window

The Input Window consists of five windows for input data of different categories. They are: Project, Well Data Input, Survey Data Input, Tubular Data Input, and Parameter Data Input Windows.

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6.1.2.1   Project Window

Figure 6-3 shows the Project Window of GTEMP1.
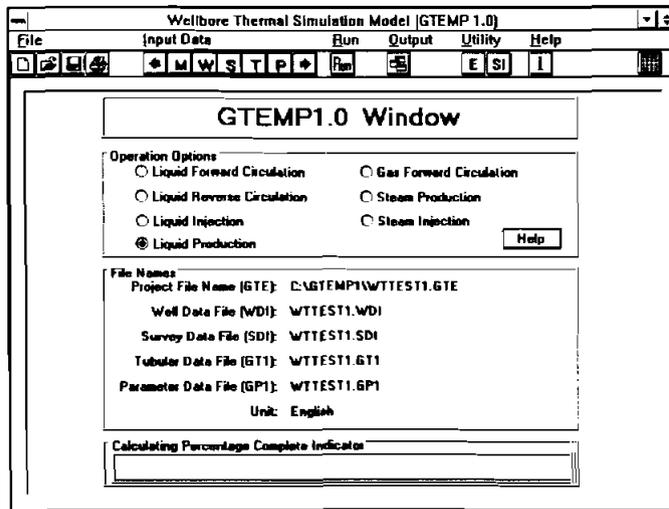
Figure 6-3. Project Window

The Project Window consists of four segments:

1. Operational options available.

2. Path and name of each data input file.

3. System of units currently in use.

4. Calculating progress indicator.

The project file for GTEMP1 has the extension "GTE."

6.1.2.2   Well Data Input

Figure 6-4 shows a typical Well Data Input Window.
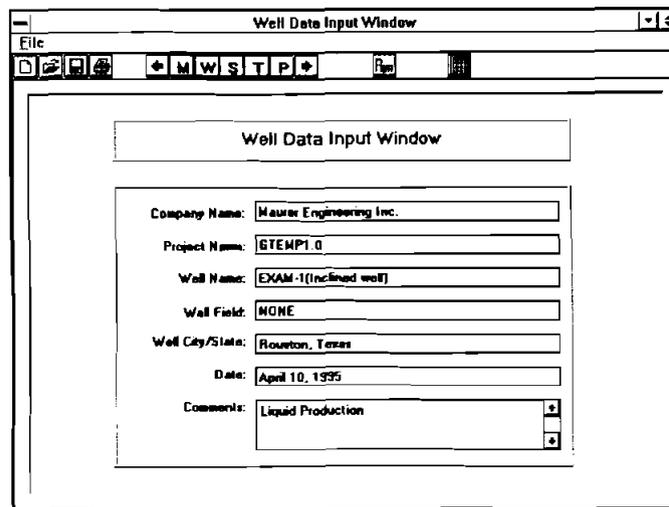
Figure 6-4. Well Data Input Window

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The user is asked to input a series of strings representing the company name, project name, well location, date, and comments. These are optional and need not be completed. They are not used in calculations or in file name specifications.

Well data files for GTEMP1 have the extension "WDI."

6.1.2.3   Survey Data Input

Figure 6-5 shows a typical Survey Data Input Window.

Figure 6-5. Survey Data Input Window

The user can input up to 400 survey data points. Measured depth, inclination and azimuth angles each have two unit options independent of the selected application system of units.

When the cursor is in the text box, press the ← or → key to move the cursor inside the box to edit. Pressing the ↑ or ↓ key moves the cursor to the box above or below. If the user wants to move the cursor to the right or left box, hold down the Ctrl key and press → or ←. Of course, the user can use the mouse or press the tab key to locate the cursor.

SDI files used in GTEMP1 are compatible with any SDI files for other DEA software applications developed by Maurer Engineering Inc.

The survey data file for GTEMP1 has the extension "SDI."

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6.1.2.4 Tubular Data Input

Figure 6-6 shows a typical Tubular Data Input Window.

Figure 6-6. Tubular Data Input Window

Note that tubing input is from the surface to the bottom of the hole, and casing input is from the smallest to the largest casing (from inside to outside). Initial depth of the well must be shorter than or equal to the total measured depth in the survey data file. Wellbore diameter must be greater than the largest casing OD.

The user can change the units for data input by using the [Unit Change] command button after clicking the corresponding grid (see Section 6.3.7 for details). The [Help] button in the geothermal temperature grid provides basic information on geothermal temperatures and their gradients in several regions (Figure 6-7).
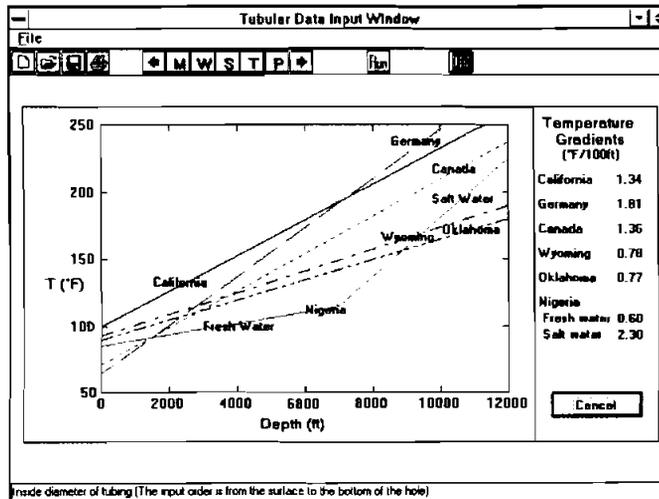
Figure 6-7. Geothermal Temperatures and Gradients

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The user can use the [Default Parameter] command button to change the default parameters if any modification is desired. Figure 6-8 shows the Default Tubular Data Window.
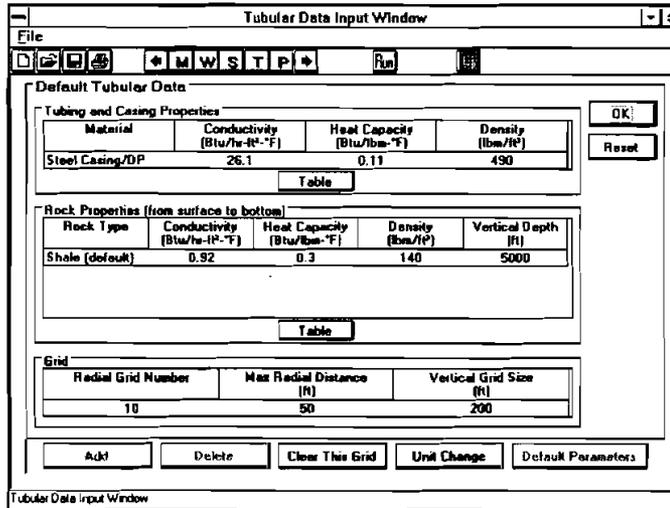
Figure 6-8. Default Tubular Data Window

The user can modify the thermal properties of tubing and casing, as well as rock. The user can also specify the grid used in the calculation. To assist the user in the selection of thermal properties, GTEMP1 has two database tables of commonly encountered materials (Figures 6-9 and 6-10). The user can edit these tables by using the "Add" and "Delete" command buttons, or copy the desired material parameters to the Default Tubular Data Window by selecting the material and clicking the [Copy to TDI...] command button. The [Reset] command button is used to set these parameters back to the default values. Note that the user must modify the rock properties for a multi-layer rock formation.
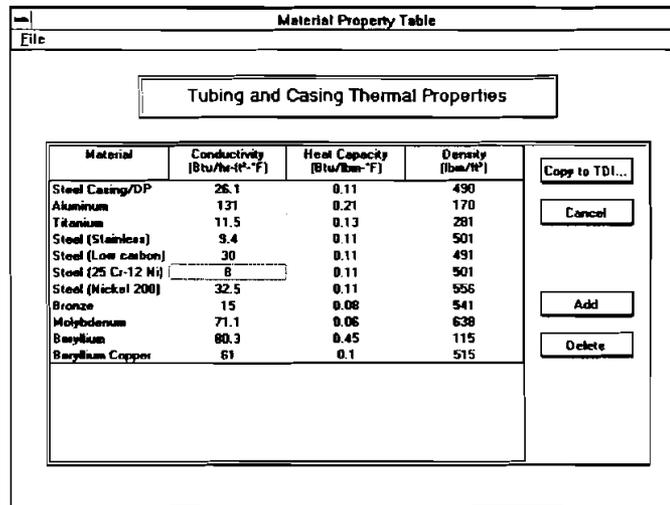
Figure 6-9. Tubing and Casing Thermal Properties Table

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Figure 6-10. Rock Thermal Properties

The tubular data file for GTEMP1 has the extension "GT1."

6.1.2.5 Parameter Data Input

Figure 6-11 shows a typical Parameter Data Input Window.

Figure 6-11. Parameter Data Input Window

The user can change the input units by using the [Unit Change] command button after clicking the corresponding grid. Note that fluid viscosity must be the value at 70°F.

The parameter data file for GTEMP1 has the extension "GP1."

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6.1.3 Output Window

After all data are input, click the Start command from the Run menu in the Project Window to begin calculating. The calculating percentage complete indicator at the bottom of the screen shows the percentage of calculation completed.

When the calculation is complete, the program unloads the Project Window and shows the Output Window with four "child" windows arranged in a tiled format. "Child" windows are employed to display text reports and graphs of output. A "child" window is a window confined to its "parent" window — the Output Window. "Child" windows can be displayed independently by selecting the corresponding menu item in the windows menu of the Output Window. The user can manipulate them as normal windows — move, resize, close, etc. The arrangement commands in the windows menu (Cascade, Tile, Arrange Icons) have the same functions as those in the Program Manager of Windows.

Figure 6-12 shows the Output Window with the four "child" windows tiled inside.
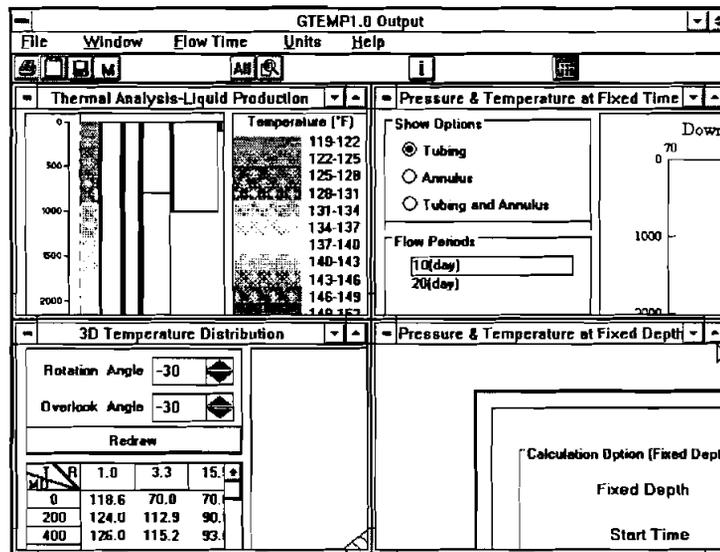
Figure 6-12. Output "Child" Windows

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6.1.3.1   Thermal Analysis

Figure 6-13 shows a typical Thermal Analysis Window.
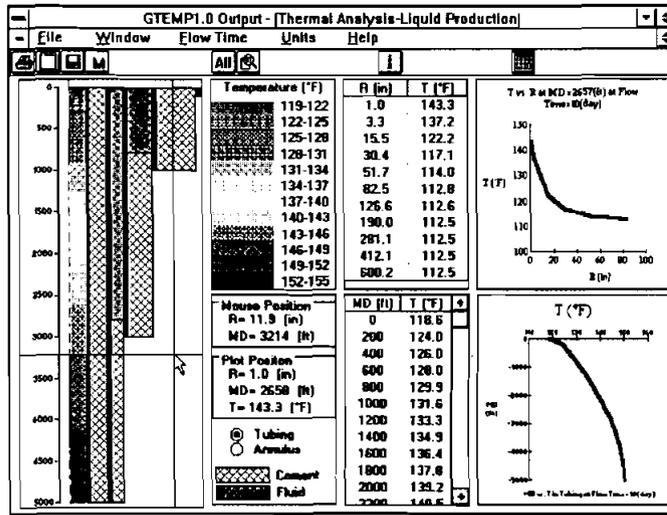
Figure 6-13. Thermal Analysis Window

The graph in the left portion of the window shows the wellbore configuration. This figure also shows temperature distribution, with different colors in the tubing for production and injection or in both the tubing and annulus for circulation. By positioning the mouse at an interesting point on the wellbore configuration graph and clicking it, the user can obtain temperature distributions in both the radial and axial directions, as indicated by the intersecting lines. The user may also select the tubing or annulus option buttons if temperature distributions in the tubing or annulus are desired. These temperature distributions are printed in two grids and plotted in two graphs in this window. The user can enlarge or reduce any of these graphs by double-clicking them. Figures 6-14, 6-15, and 6-16 show these enlarged graphs.
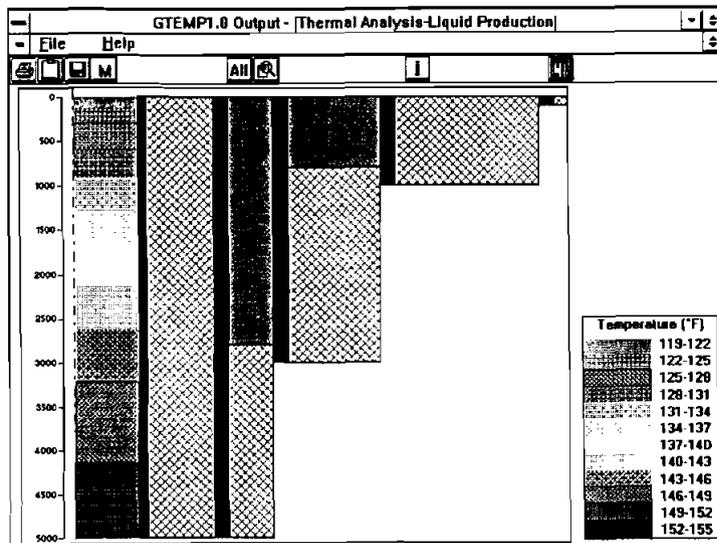
Figure 6-14. Wellbore Configuration

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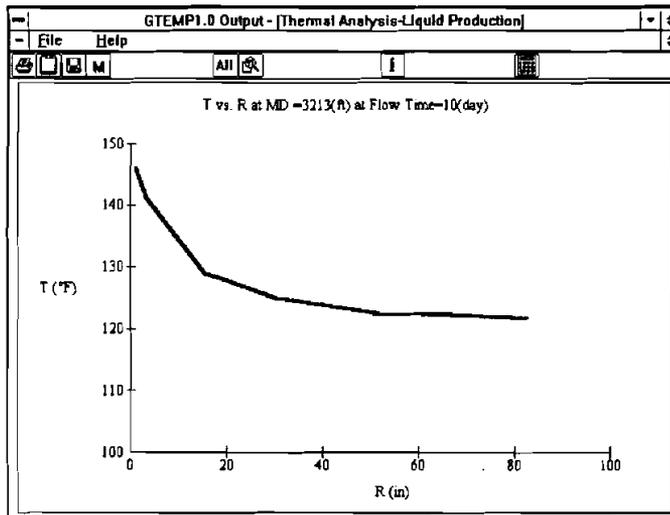
Figure 6-15. Temperature   Distribution   in   Radial
Direction
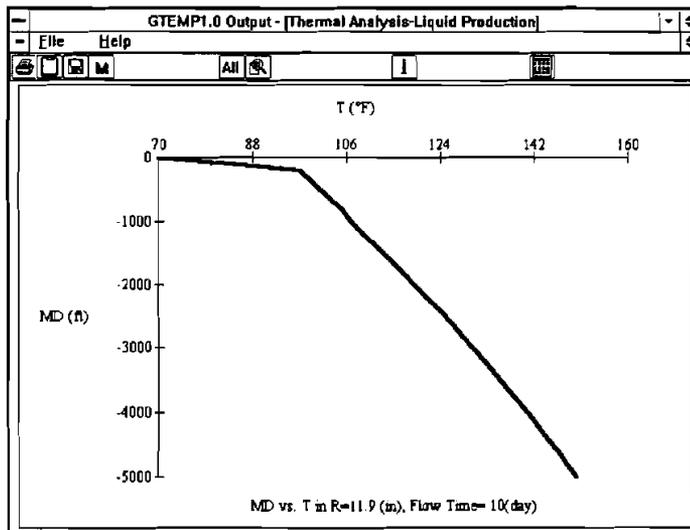
Figure 6-16. Temperature Distribution in Axial Direction

To print out the grids or graphs, refer to Section 6.2.2.

6.1.3.2   Three-Dimensional Temperature Distribution

Figure 6-17 shows a typical Three-Dimensional Temperature Distribution Window.

6-10   ©1997 Maurer Engineering Inc.

GTEMP1.0 Output - [3D Temperature Distribution]

File   Window   Flow Time   Units   Help

Rotation Angle -30
Overlook Angle -30
Redraw

MD\R	1.0	3.3	15.
0	118.6	70.0	70.
200	124.0	112.9	90.
400	126.0	115.2	93.
600	128.0	117.4	96.
800	129.9	119.7	99.
1000	131.6	122.5	100.
1200	133.3	124.5	103.
1400	134.9	126.4	105.
1600	136.4	128.3	108.
1800	137.8	130.1	111.
2000	139.2	131.8	113.
2200	140.5	133.5	116.
2400	141.8	135.2	119.
2600	142.9	136.7	121.
2800	144.0	138.3	124.

R [in]; MD [ft]; T [°F]

3D Temperature Distribution at Flow Time 10(day)

Figure 6-17.   Three-Dimensional Temperature Distribution Window

In the right portion of the window is a three-dimensional view of temperature distribution.   In the left portion of the window is the temperature distribution grid displaying temperatures at different radii and measured depths.   By changing rotation and overview angles using the scroll bars or typing in the text box and clicking the [Redraw] command button, the user can view the three-dimensional temperature distribution from different angles.   By double-clicking grid or graph, the user can enlarge or reduce those portions of the screen.

Figures 6-18 and 6-19 show the enlarged grid and graph.

GTEMP1.0 Output - [3D Temperature Distribution]

File   Help

MD\R	1.0	3.3	15.5	30.4	51.7	82.5	126.6	190.0	281.1	412.1	600.2
0	118.6	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
200	124.0	112.9	90.8	81.4	75.9	73.7	73.2	73.2	73.2	73.2	73.2
400	126.0	115.2	93.6	84.5	79.0	76.9	76.4	76.4	76.4	76.4	76.4
600	128.0	117.4	96.4	87.5	82.2	80.1	79.6	79.6	79.6	79.6	79.6
800	129.9	119.7	99.0	90.4	85.3	83.2	82.8	82.8	82.8	82.8	82.8
1000	131.6	122.5	100.5	92.8	88.2	86.4	86.0	86.0	86.0	86.0	86.0
1200	133.3	124.5	103.2	95.7	91.3	89.6	89.2	89.2	89.2	89.2	89.2
1400	134.9	126.4	105.9	98.7	94.5	92.8	92.4	92.4	92.4	92.4	92.4
1600	136.4	128.3	108.5	101.7	97.6	96.0	95.6	95.6	95.6	95.6	95.6
1800	137.8	130.1	111.2	104.6	100.7	99.1	98.8	98.8	98.8	98.8	98.8
2000	139.2	131.8	113.8	107.5	103.8	102.3	102.0	102.0	102.0	102.0	102.0
2200	140.5	133.5	116.4	110.5	106.9	105.5	105.2	105.2	105.2	105.2	105.2
2400	141.8	135.2	119.0	113.4	110.0	108.7	108.4	108.4	108.4	108.4	108.4
2600	142.9	136.7	121.6	116.3	113.1	111.9	111.6	111.6	111.6	111.6	111.6
2800	144.0	138.3	124.0	119.1	116.2	115.1	114.8	114.8	114.8	114.8	114.8
3000	145.0	139.9	126.3	121.9	119.3	118.2	118.0	118.0	118.0	118.0	118.0
3200	145.9	141.2	128.8	124.8	122.4	121.4	121.2	121.2	121.2	121.2	121.2
3400	146.7	142.5	131.2	127.6	125.5	124.6	124.4	124.4	124.4	124.4	124.4
3600	147.5	143.7	133.7	130.5	128.6	127.8	127.6	127.6	127.6	127.6	127.6
3800	148.1	144.8	136.1	133.3	131.6	130.9	130.8	130.8	130.8	130.8	130.8
4000	148.7	145.9	138.5	136.1	134.7	134.1	134.0	134.0	134.0	134.0	134.0
4200	149.2	146.9	140.9	138.9	137.8	137.3	137.2	137.2	137.2	137.2	137.2

R [in]; MD [ft]; T [°F]

Figure 6-18.   Three-Dimensional Temperature Distribution Table

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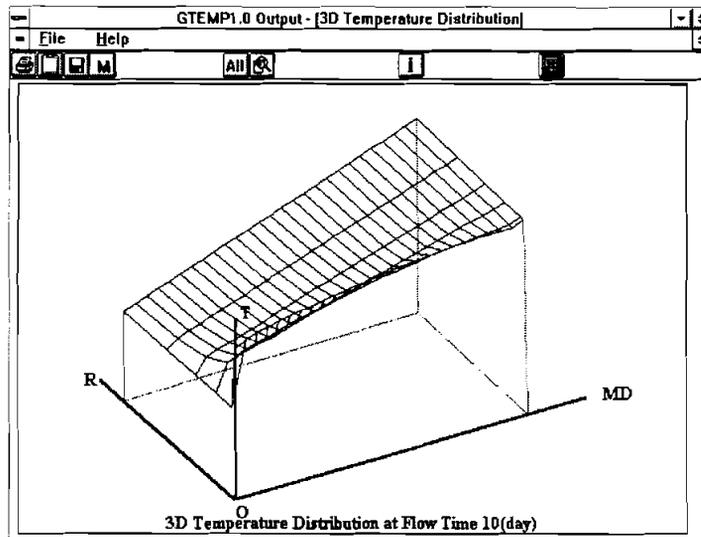
Figure 6-19. Three-Dimensional Temperature Distribution Graph

6.1.3.3 Temperature and Pressure in Tubing and Annulus

Figure 6-20 shows a typical Temperature and Pressure in Tubing and Annulus Window. Note, for operations with gas and steam, both temperature and pressure are plotted. For operations with liquid, only temperature is plotted.
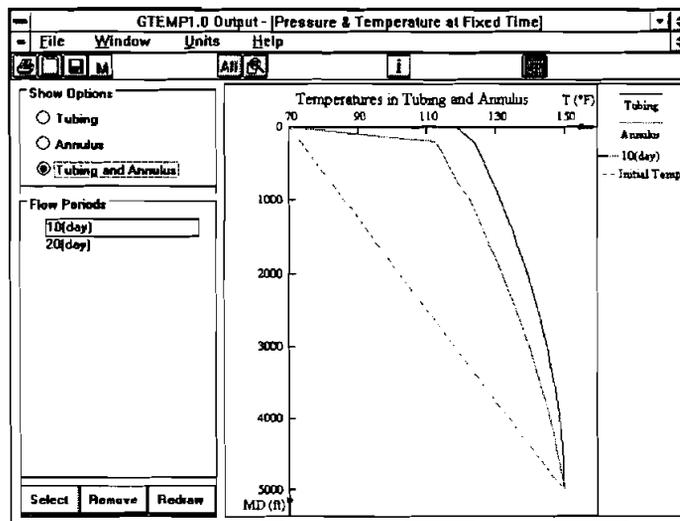
Figure 6-20. Temperature and Pressure in Tubing and Annulus Window

In the right portion of the window is the temperature distribution graph (and pressure distribution graph, if gas or steam is used in the operation). To show temperature distributions in the tubing, annulus, or tubing and annulus together with the undisturbed geothermal temperature distribution, the user can select one of the following options:

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1. Tubing

2. Annulus

3. Tubing and Annulus

There are three command buttons in this window:

1. "Select" — selects a flow period by clicking the desired flow period and the [Select] command button

2. "Remove" — removes a flow period by clicking the desired flow period and the [Remove] command button

3. "Redraw" — updates the graph in the right portion of the window after the "Select" or "Remove" command has been executed

The user can select and plot one or more flow periods listed in the "Flow Period" frame. The user can enlarge or reduce the graph by double-clicking it. Figure 6-21 shows the enlarged graph.
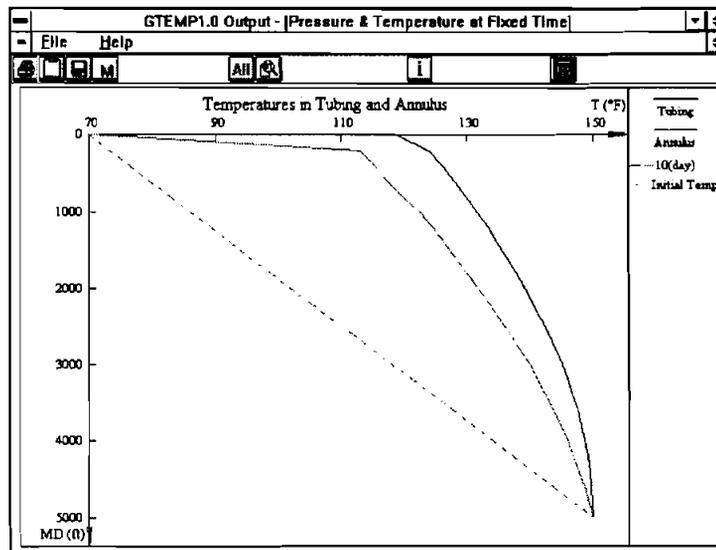
Figure 6-21. Temperature in Tubing and Annulus

6.1.3.4 Temperature and Pressure in Tubing

Figure 6-22 shows a typical Temperature and Pressure in Tubing Window-1.

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GTEMP1.0 Output - [Pressure & Temperature at Fixed Depth]

File   Window   Help

Calculation Option (Fixed Depth and Time Period)

Fixed Depth: [10000] (ft)   OK

Start Time: [0] (day)   Cancel

End Time: [10] (day)

Calculating Percentage Complete Indicator
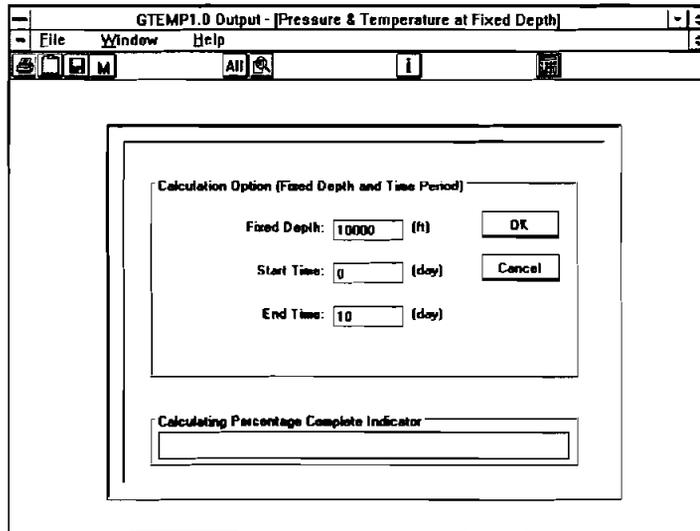
Figure 6-22.   Temperature and Pressure in Tubing Window-1

Note that for operations with gas and steam, both temperature and pressure in the tubing are output; for operations with liquid only, temperature in the tubing is output.

The user can specify the position in the tubing and time period by typing these numbers in the "Fixed Depth," "Start Time," and "End Time" text boxes. When finished, click the [OK] command button to calculate temperature and pressure profiles and display the results in the Temperature and Pressure in Tubing Window-2 (Figure 6-23).

GTEMP1.0 Output - [Pressure & Temperature at Fixed Depth]

File   Window   Units   Help

t (hour)	T (°F)
0.24	86.0
0.54	89.6
0.92	93.1
1.38	96.6
1.97	100.0
2.70	103.4
3.62	106.8
4.76	110.3
6.19	113.7
7.98	117.0
10.22	120.2
13.01	123.0
16.50	125.2
20.87	127.0
26.32	128.2
33.15	129.0
41.67	129.4
52.33	129.7
65.65	130.0
82.31	130.2
103.12	130.4
129.14	130.7
161.67	130.9
202.33	131.2

Downhole Temperature vs. Time in the Tubing at 1000 (ft)

T (°F)

Time (hour)

Figure 6-23.   Temperature and Pressure in Tubing Window-2

In the left portion of the window is the grid showing the temperature at different times. In the right portion is a graph showing temperature versus time at a fixed depth in the tubing. The user can enlarge or reduce the graph by double-clicking it. Figure 6-24 shows the enlarged graph.
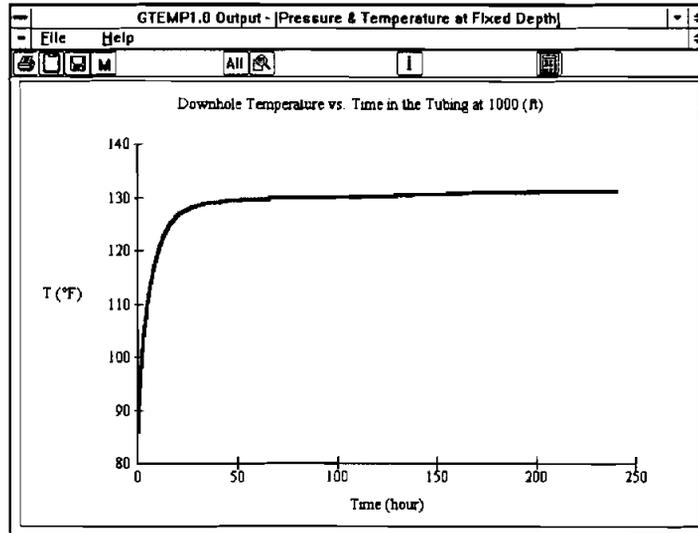
Figure 6-24. Temperature Versus Time in the Tubing

Note that the user may calculate and display the temperature and pressure profiles at other tubing positions or time periods by selecting "New Profiles..." from the File menu of this window.

6.1.3.5   Geothermal Temperature

Figure 6-25 shows a typical Undisturbed Geothermal Temperature Window.
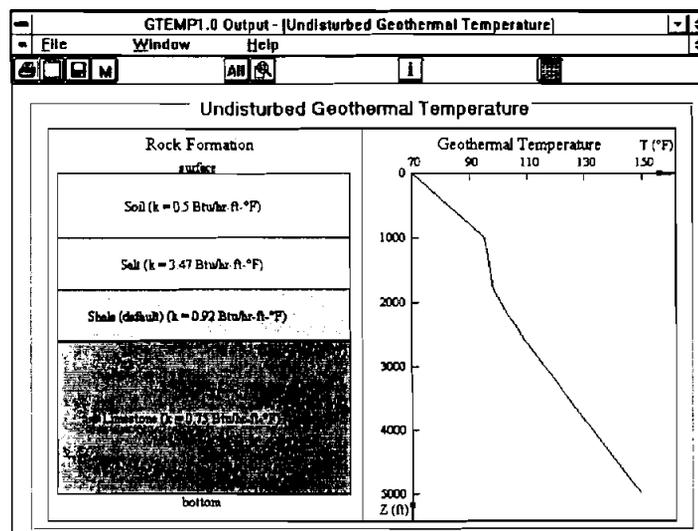
Figure 6-25. Undisturbed Geothermal Temperature Window

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This window will be displayed by selecting "Undisturbed Geothermal Temperature" from the Window menu. In the left portion of the window is a rock formation schematic showing the materials and their thermal conductivity. In the right portion is the undisturbed geothermal temperature profile.

6.2 GTEMP1 MENUS

The GTEMP1 menu system provides many convenient tools for running the application. As in other Windows applications, the user can pull down a menu by clicking the menu name with the mouse, or by pressing the ALT key on the keyboard and then striking the first letter or the underscored letter of the menu name. Once a menu is displayed, a command can be selected by clicking the command name with the mouse or by highlighting the command name and pressing <ENTER>.

6.2.1 Menus in the Input Windows

The Input Windows of GTEMP1 include five individual windows: one Project Window and four Data Input Windows. The menus in these windows are described in this section.

6.2.1.1 Project Window Menus

There are six menus in this window: 1) File, 2) Input, 3) Run, 4) Output, 5) Utility, and 6) Help (Figure 6-26).
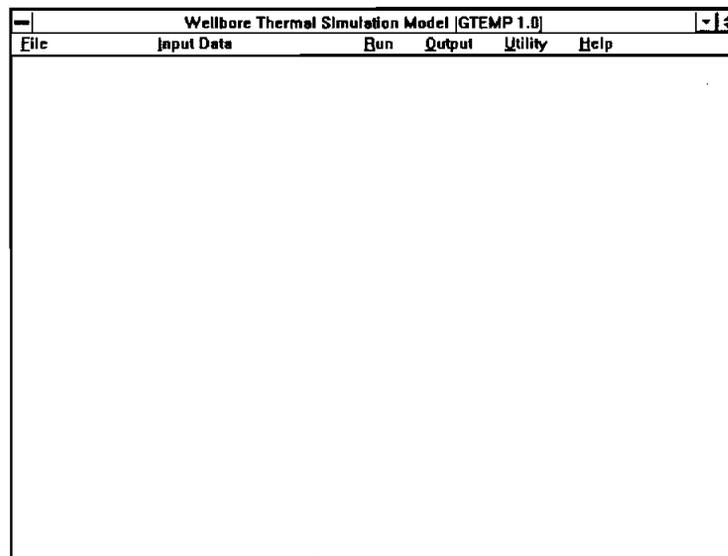
Figure 6-26. Project Window Menus

The File menu contains commands for creating, retrieving, saving, and printing project data (Figure 6-27).
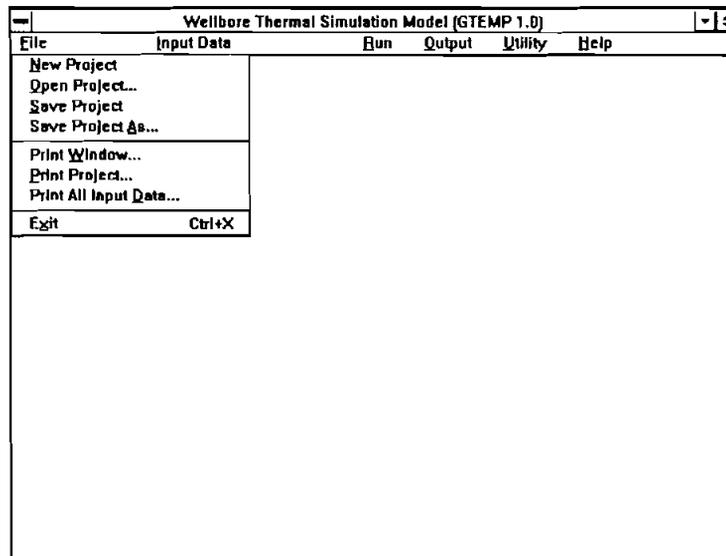
Figure 6-27. File Menu in the Project Window

Project files are used for quick future retrieval of a set of previously saved input data. The user can open an existing project file without opening each individual (WDI, SDI, TDI, PDI) file. The project file, which is a collection of the paths and filenames of all input data files, greatly simplifies data retrieval.

The eight menu items under the File menu are explained below:

1. "New Project" command clears all input data and sets all file names to null string with corresponding extension.

2. "Open Project..." command opens a dialog box that enables the user to explore the file system for input files with the extension "GTE." See Section 6.3.1 for a complete discussion.

3. "Save Project" command replaces the previous version of each of the input data files in the project with the one modified. Note that the project file (.GTE) does not contain any input data. It is simply a list of all the input data file names in the project. This list is updated every time the user saves the project.

4. "Save Project As..." command opens a dialog box. The user specifies the drive, directory, and the name of the project file. See Section 6.3.2 for details.

5. "Print Window..." command allows the user to print out the current window.

6. "Print Project..." command allows the user to print out the information related to the current project, such as path and filename of each individual data file.

7. "Print All Input Data..." command allows the user to print out all input data along with the project information.

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8. "Exit" command terminates GTEMP1. The program prompts the user to save the input files, if they have not been saved.

Files that make up a project do not have to be in one directory on your hard drive, since the project records the detailed path information about each input file. A single file, such as an SDI file, can be part of more than one project. However, if you rename or delete a file outside the GTEMP1 application, and then run GTEMP1 and try to open that file, GTEMP1 displays an error message to warn you that a file is missing.

The Input Data menu contains commands for opening and navigating through four individual Data Input Windows as displayed in Figure 6-28.
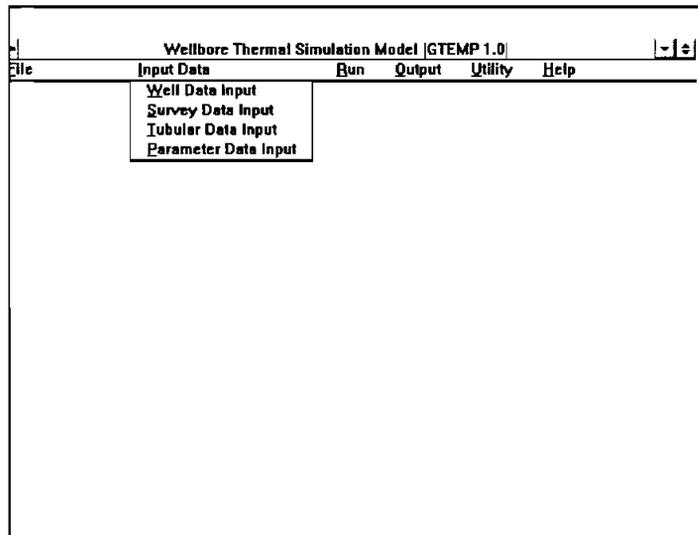
Figure 6-28. Input Data Menu in the Project Window

1. "Well Data Input" command opens the Well Data Input Window.

2. "Survey Data Input" command opens the Survey Data Input Window.

3. "Tubular Data Input" command opens the Tubular Data Input Window.

4. "Parameter Data Input" command opens the Parameter Data Input Window.

The Run menu (Figure 6-29) contains the command to start calculation. The "Start" command does just that. The program checks the validity of all data before calculation.

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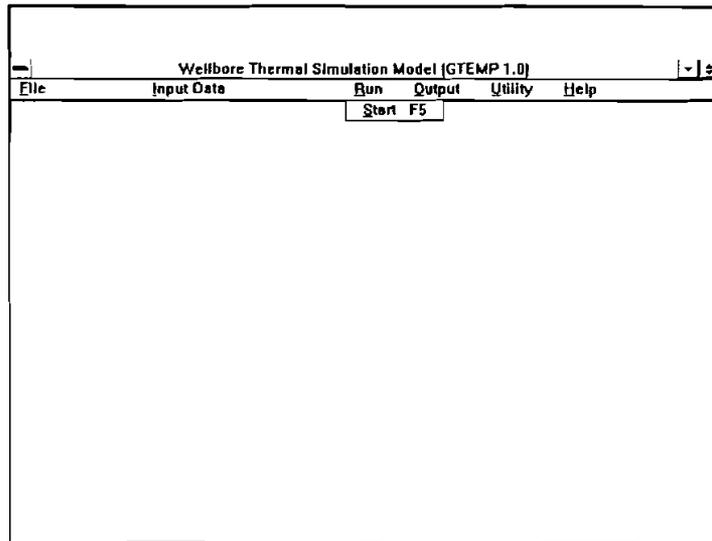
Figure 6-29. Run Menu in the Project Window

The Output menu (Figure 6-30) contains four menu items, which are described below:

1. "Results Display" command allows the user to go to the Output Window without calculating, if the calculation has been completed.

2. "New Results Display" command allows the user to display the Output Window without calculating, if the calculation has been completed and the input data have not been changed; or to display the Output Window after calculating, if the input data have been changed.

3. "Save Results As..." command allows the user to save the output results as a text file. The file extension name is ".OUT."
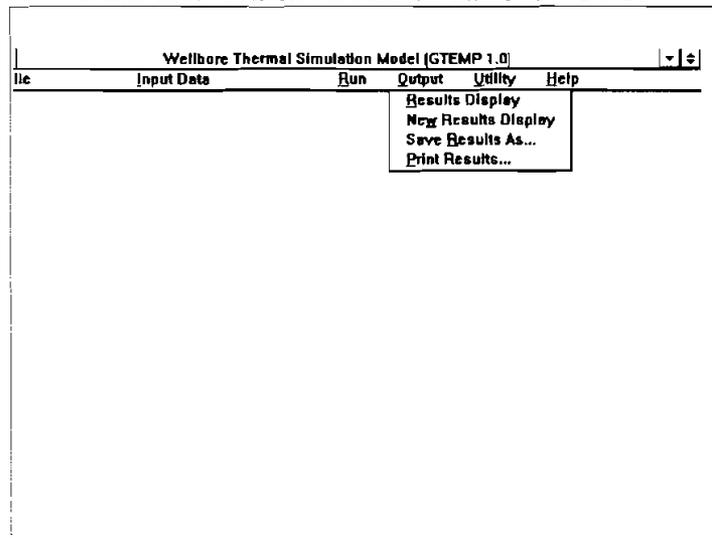
Figure 6-30. Output Menu in the Project Window

4. "Print Results..." command allows the user to print out the output results.

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The Utility menu contains commands that enable the user to select the system of units and unit conversion table, as shown in Figure 6-31.
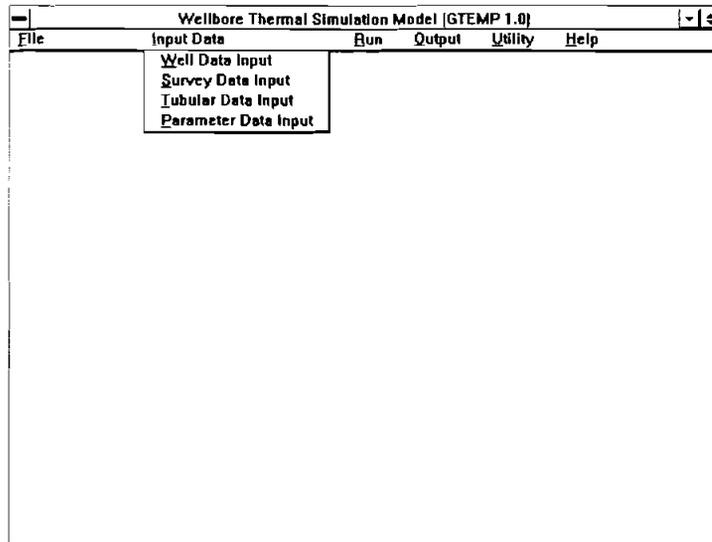
Figure 6-31. Utility Menu in the Project Window

1. "English" command selects the English system of units. A check mark appears to the left of "English." The default system of units is "English."

2. "SI (Metric)" command selects the Metric system of units. A check mark appears at the top left of "Metric." Once a system of units is selected, all input and output are expressed in the corresponding units. The selected system of units is also indicated in the Project Window, below the input data file names.

3. "Unit Conversion..." command provides the user with conversion information and tools for converting data from one system to another. See Section 6.3.6 for details.

The Help menu gives the user information about assistance, the operational options, and the computer system, as shown in Figure 6-32.

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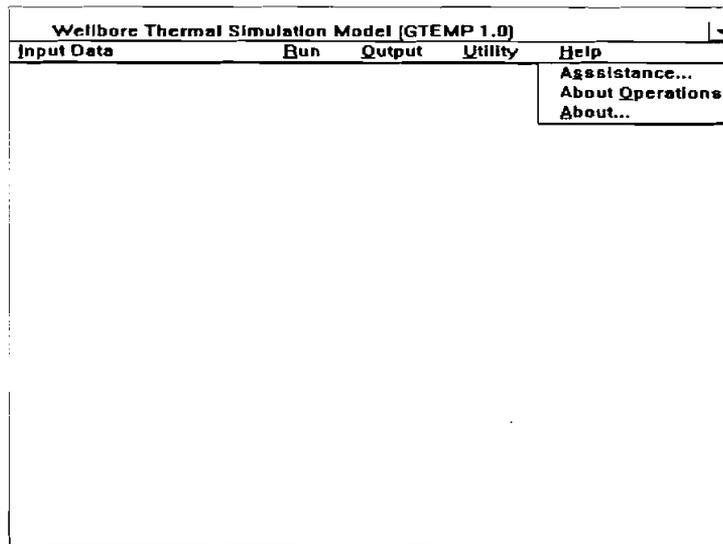
Figure 6-32. Help Menu in the Project Window

1. "Assistance..." command opens the "Assistance" dialog box that displays MEI's address, phone number, and other pertinent information. See Section 6.3.3 for details.

2. "About Operation..." command opens the "Operation Options" Window that gives the user information about the available operations. See Section 6.3.5 for details.

3. "About..." command opens the "About" dialog box that gives the user instant reference information about GTEMP1 and the current computer system information. See Section 6.3.4 for details.

6.2.1.2 Individual Data Input Window Menus

All Data Input Windows (WDI, SDI, TDI, PDI) have only one menu File. It contains commands for creating, retrieving, saving, and printing the corresponding data input file, as shown in Figure 6-33.
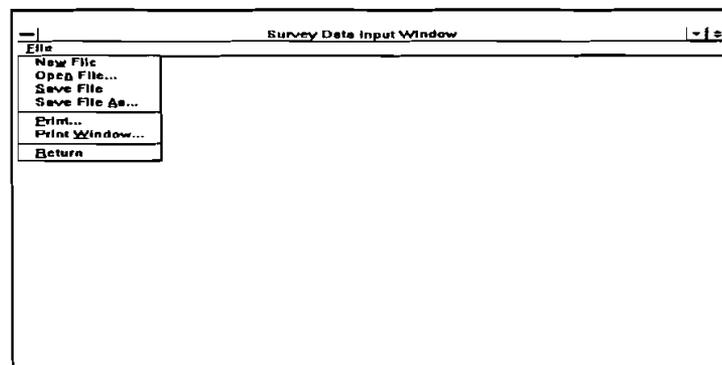
Figure 6-33. File Menu in the Individual Data Input Window

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1. "New File" command clears every entry box in the current data input window.

2. "Open File..." command opens the dialog box that enables the user to explore the file system for input files with the extension names, "WDI," "SDI," "GT1," or "GP1" depending on the current data input window.

3. "Save File" command replaces the previous version of the input data file.

4. "Save File As..." command enables the user to save a file under a new name specified, while also retaining the original file (Section 6.3.2). The new file is associated with the project file when you save the project.

5. "Print..." command allows the user to print out the input data of the current Input Window.

6. "Print Window..." command allows the user to print out the current window.

7. "Return" command closes the current data input window and return to the Project Window. GTEMP1 prompts the user to save the file if it has not been saved.

6.2.2 Menus in the Output Window

The Output Window has five menus: File, Window, Flow Time, Units, and Help (Figure 6-34).
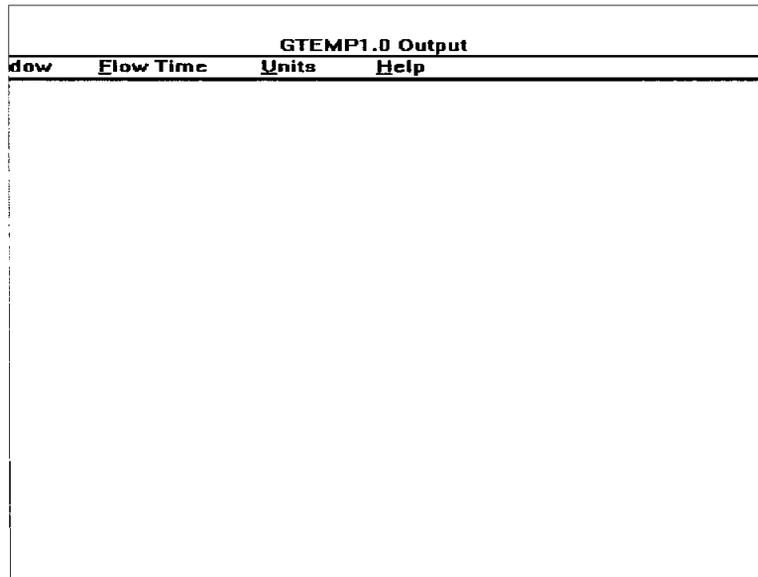
Figure 6-34. Menus in the Output Window

The File menu contains commands for printing text reports and graphs and controlling application flow (Figure 6-35).

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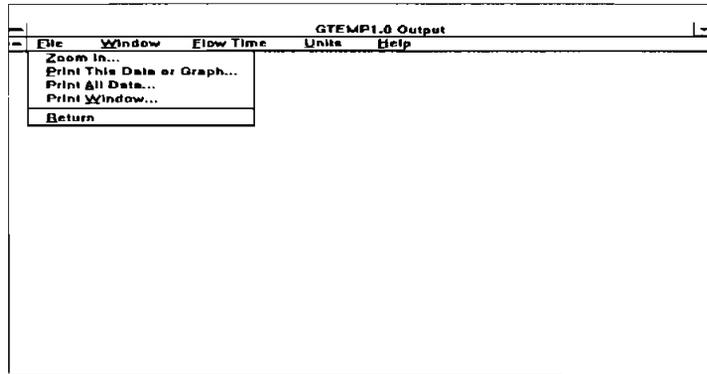
Figure 6-35. File Menu in the Output Window

1. "Zoom In..." command allows the user to enlarge the graphs in this window by selecting this command and clicking on any interesting graph.

2. "Print This Data or Graph..." command prints out the text report or graph in this window when the user selects this menu item and clicks the desired grid or graph.

3. "Print All Data..." command prints out all the text reports in this window.

4. "Print Window..." command allows the user to print out the current window.

5. "Return" command closes the Output Window and shows the Project Window.

The Window menu contains commands that allow the user to select, activate, stack and tile the "child" windows.

Figure 6-36 shows the pull-down Window menu.
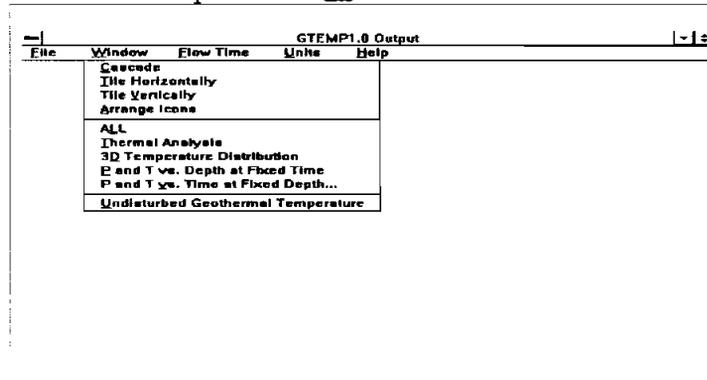
Figure 6-36. Window Menu in the Output Window

1. "Cascade" command stacks the windows as shown in Figure 6-37. The program adjusts the size of each open window to occupy the same amount of display space. The windows are then stacked starting from the upper left corner of the Output Window. Only their title bars are visible. To place a window in the foreground, click on the window's title bar with the mouse.

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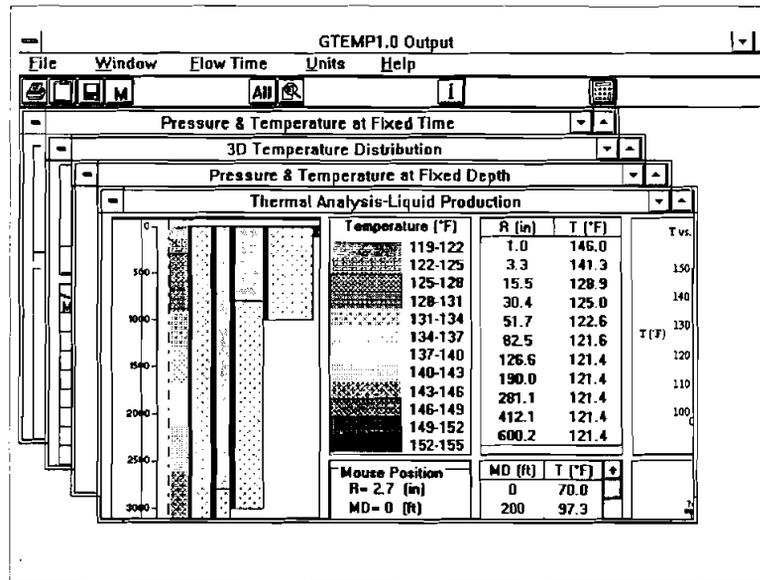
Figure 6-37. Cascaded Windows

2. "Tile Horizontally" command tiles all the opened "child" windows horizontally, as shown in Figure 6-38.
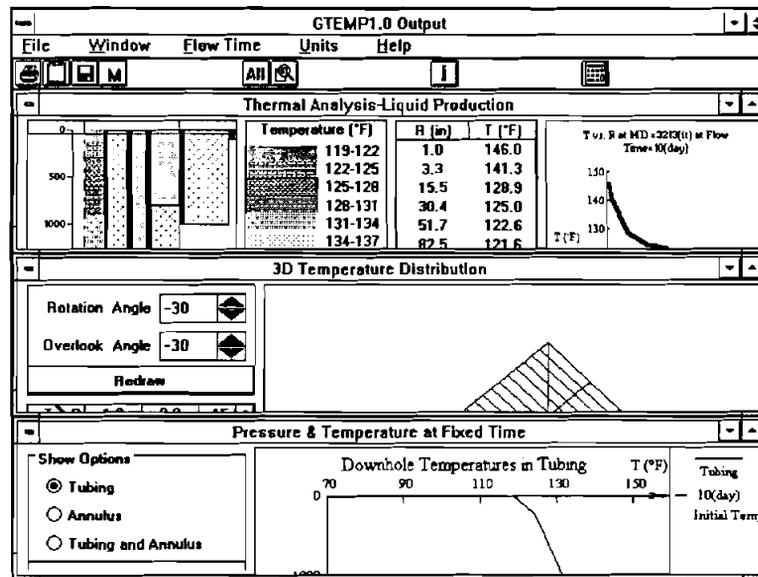
Figure 6-38. Horizontally Tiled Windows

3. "Tile Vertically" command arranges the open "child" windows vertically in the Output Window, as shown in Figure 6-39.

6-24   ©1997 Maurer Engineering Inc.
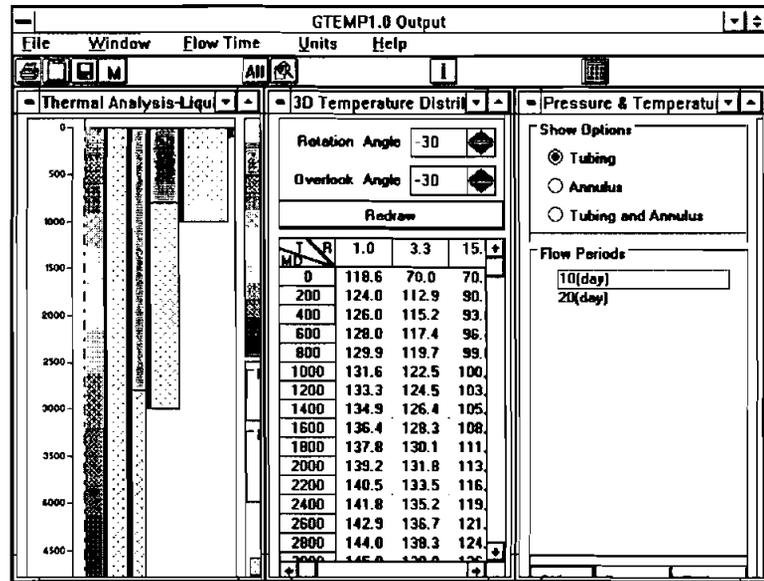
Figure 6-39. Vertically Tiled Windows

4.   "Arrange Icons" command restores the alignment of the window icons, as shown in Figure 6-40.
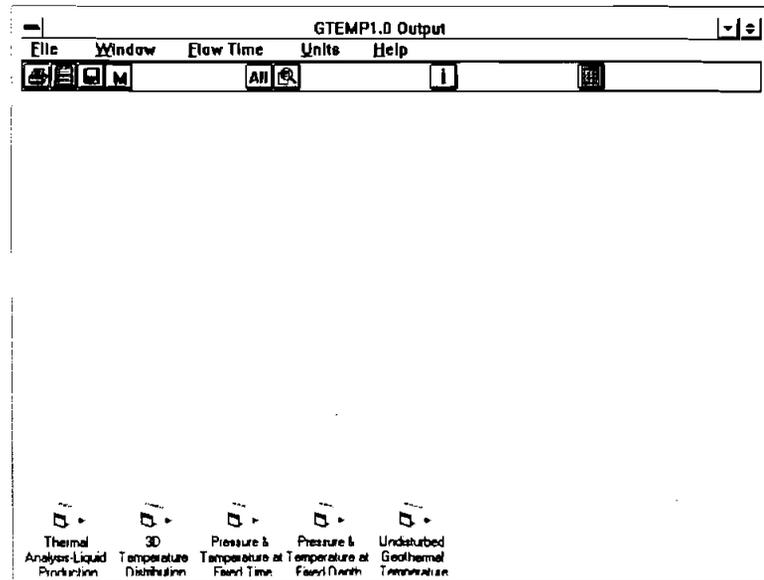
Figure 6-40. Arranged Window Icons

5.   "All" command displays the first four "child" windows of the output.

6.   "Thermal Analysis" command opens or activates the Thermal Analysis Window.

7.   "3D Temperature Distribution" command opens or activates the Three-Dimensional Temperature Distribution Window.

8.   "P and T vs. Depth at Fixed Time" command opens or activates the Temperature and Pressure in Tubing and Annulus Window.

9. "P and T vs. Time at Fixed Depth..." command opens or activates the Temperature and Pressure in Tubing Window.

10. "Undisturbed Geothermal Temperature" command opens or activates the Undisturbed Geothermal Temperature Window.

The user should always minimize or close "child" windows not presently needed to help maintain an orderly display.

The Flow Time menu lists all the flow periods available in the project. A check mark appears to the left of the currently selected flow period.

Figure 6-41 shows the Flow Time pull-down menu.
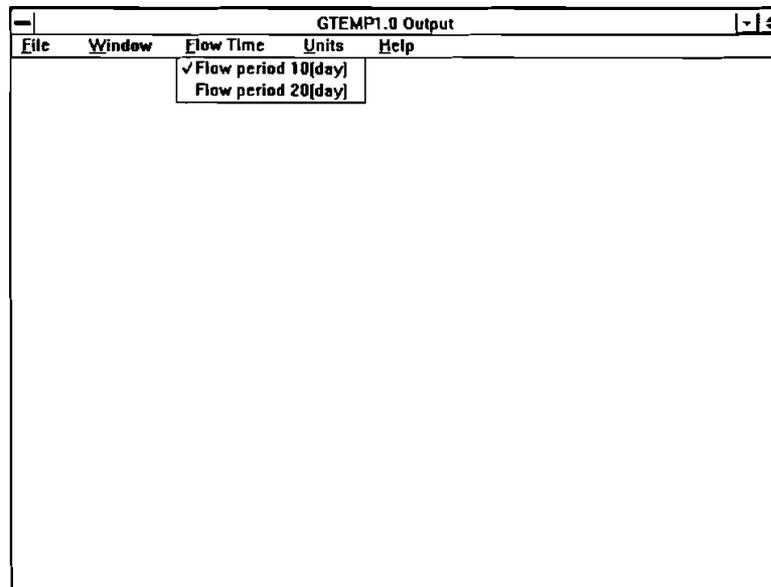
Figure 6-41. Flow Time Menu in the Output Window

The Units menu contains commands that enable the user to select the system of units and temperature unit, as shown in Figure 6-42.

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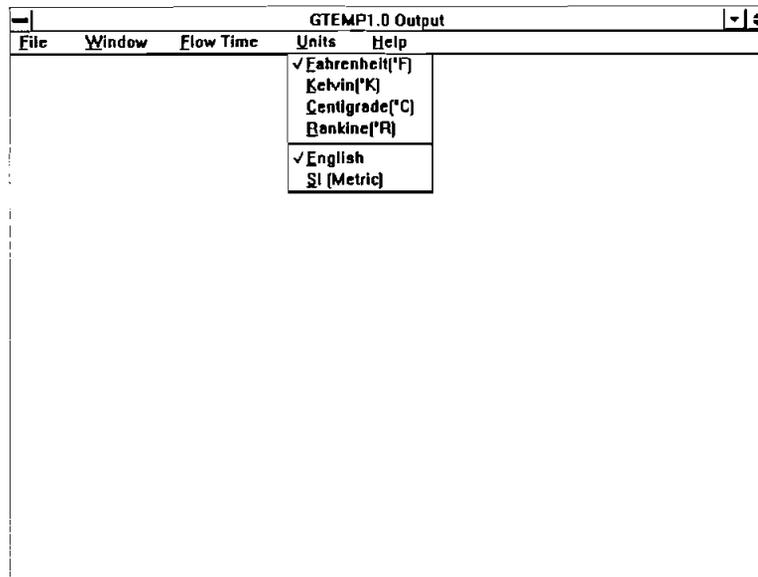
Figure 6-42. Units Menu in the Output Window

1. "Fahrenheit (°F)" command selects Fahrenheit as the temperature unit. A check mark appears to its left.

2. "Kelvin (°K)" command selects Kelvin as the temperature unit. A check mark appears to its left.

3. "Centigrade (°C)" command selects Centigrade as the temperature unit. A check mark appears to its left.

4. "Rankine (°R)" command selects Rankine as the temperature unit. A check mark appears to its left.

5. "English" command selects the English unit system. A check mark appears to its left.

6. "SI (Metric)" command selects the Metric unit system. A check mark appears to its left.

The Help menu in the Output Window is similar to that in the Project Window.

6.3 GTEMP1 DIALOG BOXES

There are eight types of dialog boxes in GTEMP1: Open File, Save File As, Assistance, About, About Operational Options, Unit Conversion and Calculator, Unit Change, and Graph Size.

6.3.1 "Open File..."

When the user selects the "Open Project..." command from the File menu of the Project Window, the following dialog box appears (Figure 6-43).

6-27 ©1997 Maurer Engineering Inc.

```
┌─────────────────────────────────────────────────────────────┐
│                                                             │
│  ┌───┐                                                      │
│  │ ⇒ │              Open GTE File                           │
│  └───┘                                                      │
│  File Name:              Directories:         ┌──────────┐  │
│  ┌──────────────┐        c:\gtemp1            │    OK    │  │
│  │ wltest1.gte  │                             └──────────┘  │
│  ┌──────────────┐ ┌┐    ┌──────────────┐ ┌┐  ┌──────────┐  │
│  │ wltest1.gte  │ │↑│   │ 🗁 c:\        │ │↑│ │  Cancel  │  │
│  │ wltest10.gte │ └┘    │ 🗀 gtemp1     │ └┘  └──────────┘  │
│  │ wltest2.gte  │       │              │                   │
│  │ wltest3.gte  │       │              │                   │
│  │ wltest4.gte  │       │              │                   │
│  │ wltest5.gte  │       │              │                   │
│  │ wltest6.gte  │ ┌┐    │              │ ┌┐                │
│  │ wltest7.gte  │ │↓│   │              │ │↓│                │
│  └──────────────┘ └┘    └──────────────┘ └┘                │
│  List Files of Type:     Drives:                           │
│  ┌──────────────┐ ┌┐    ┌──────────────┐ ┌┐               │
│  │Project Files(*.GTE)│↓│ │ 🖳 c: ms-dos_6 │↓│              │
│  └──────────────┘ └┘    └──────────────┘ └┘               │
│                                                             │
└─────────────────────────────────────────────────────────────┘
```
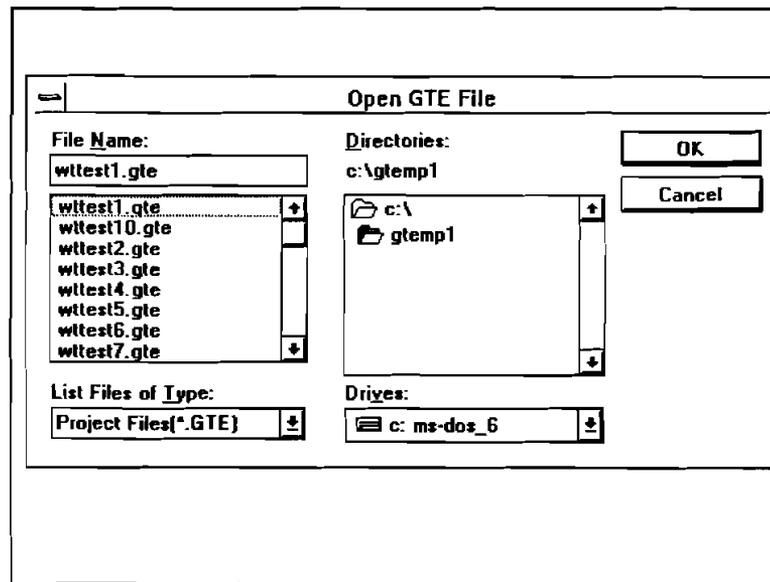
Figure 6-43. "Open GTE File" Dialog Box

This dialog box enables the user to search the file system for the desired files with the extension ".GTE."

The user can move between sections of the dialog box by simply clicking on the desired section. Alternatively, the user can press the <TAB> key on the keyboard until the focus moves to the desired section.

There are four list boxes: drive, directory, file, and type. They are located in one text box and two command buttons (OK and CANCEL). Their functions are described below.

1. The Drive List Box

In the lower right corner is the drop-down drive list box. In its normal state, it displays the current drive. When the user clicks the arrow at the right of the drive list box, it drops to list all valid drives. The user activates a new drive by single-clicking the one desired.

2. The Directory List Box

The directory list box displays the hierarchy of paths of the current drive. The current directory appears as a shaded open file folder; directions above it in the hierarchy appear as a nonshaded open file folder, and those immediately beneath the current directory are closed file folders. The user can change the directory by double-clicking the selected one. Note that in the directory list box, a single-click only selects (highlights) the item; a double-click is required for the command to be performed.

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3. The File List Box

The file list box displays the fields in the current directory. The file names shown are those specified by their extension name ".GTE." A single mouse click on an item makes it appear in the "File Name" text box. If the user chooses OK at this time, the data file is retrieved and all data related to the current calculation mode are displayed in appropriate entries. Double-clicking the selected file has the same effect as above.

When the user selects a new drive, the directory list box is updated, which then causes the file list box contents to be updated. When a new directory is selected, the file list box is updated, but the drive remains the same.

The path specification label always represents the current path information.

4. The Type List Box

This list box is set by the program. The user cannot change it. It specifies the type of files that are to be displayed in the file list box. In this "Open GTE File" dialog box, the type of file is "Project Files (*.GTE)."

5. "File Name" Text Box

When the user enters text in the "File Name" text box and then presses <ENTER>, this application should also do the following:

- If a drive letter is entered, the drive, directory, and file list boxes should be updated.

- If a directory path is entered (e.g., "\GTEMP1"), the directory list box and the file list box should be updated accordingly.

- If the name of an existing file (with the extension name "GTE") is entered, the dialog will be completed and the files will be retrieved.

6. Command Buttons

If the existing file name is shown in the text box, pressing OK completes the dialog and the data file is retrieved and displayed.

If the CANCEL button is pressed, the dialog is canceled and no information is made available to the application.

For example, select "C:" from the drive list box. In the directory list box, find "GTEMP1" under "C:\" and double-click it. Then the file list box should be updated and the file name "WTTEST1.GTE" appears in the file list box providing the user has set up GTEMP1 using the default sub-directory names. Double-click "WTTEST1.GTE" in the file list box to complete the input data file selection.

There are four additional open dialog boxes with different extension names. They are:

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1. "Open WDI File" for the Well Data Input Window.

2. "Open SDI File" for the Survey Data Input Window.

3. "Open GT1 File" for the Tubular Data Input Window.

4. "Open GP1 File" for the Parameter Data Input Window.

These dialog boxes are almost identical to the "Open GTE File" box in appearance; however, the filters in the type list box are different. Depending on the individual window, the filter in the type list box will be "WDI," "SDI," "GT1," or "GP1."

6.3.2 "Save File As..."

When the user selects the "Save Project As..." command from the File in the Project Window, the following dialog box appears (Figure 6-44).
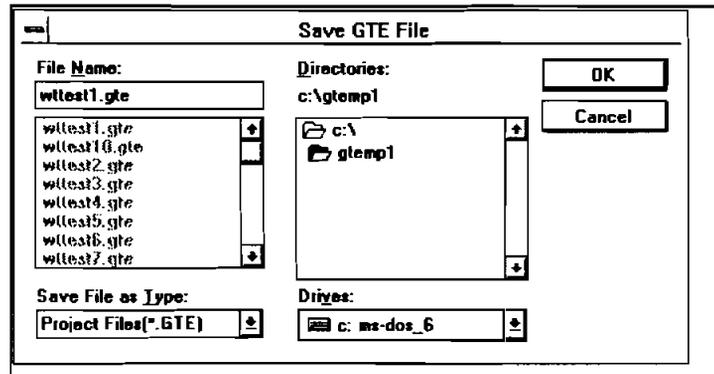
Figure 6-44. "Save Project As" Dialog Box

It looks similar to the "Open GTE File" dialog box; however, it allows the user to specify a file to save rather than open. Note that the filter in the type list box is "GTE."

There are five file save dialog boxes with different extension names. They are:

1. "Save WDI File" for the Well Data Input Window.

2. "Save SDI File" for the Survey Data Input Window.

3. "Save TDI File" for the Tubular Data Input Window.

4. "Save PDI File" for the Parameter Data Input Window.

5. "Save Result as" for the Project Window.

Depending on the individual window, the filter in the type list box will be "WDI," "SDI," "GT1," "GP1," or "OUT."

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6.3.3 "Assistance..."

When the user selects the "Assistance..." command from the Help menu in both the Project and Output Windows, the following dialog box appears (Figure 6-45).

```
┌──────────────────────────────────────┐
│ ▬|          Assistance                │
│                                        │
│  For assistance with the program, contact: │
│                                        │
│      Xichang Zhang    Gefei Liu        │
│        Lee Chu    Russell Hall         │
│                                        │
│       Maurer Engineering Inc.          │
│         2916 West T.C. Jester          │
│         Houston, Texas 77018           │
│              U.S.A.                    │
│                                        │
│       Tel:   (713) 683-8227            │
│       Fax:   (713) 683-6418            │
│       Telex: 216556                    │
│  Internet: http://www.maureng.com      │
│     E-Mail: mel@maureng.com            │
│                                        │
│            ┌──────┐                    │
│            │  OK  │                    │
│            └──────┘                    │
└──────────────────────────────────────┘
```

Figure 6-45. "Assistance" Dialog Box

6.3.4 "About..."

When the user selects the "About..." command from the Help menu in both the Project and Output Windows, the following dialog box appears (Figure 6-46).

```
┌────────────────────────────────────────────────────┐
│ ▬|              About GTEMP1                        │
│                                                     │
│  ▓▓▓  Wellbore Thermal Simulation Model (GTEMP 1.0) ┌────┐ │
│  ▓▓▓                                                │ OK │ │
│                        DEA-67                       └────┘ │
│        Project to Develop and Evaluate Coiled-Tubing and │
│                  Slim-Hole Technology               │
│                         By                          │
│               Maurer Engineering Inc.               │
│  ─────────────────────────────────────────────────  │
│                                                     │
│             CPU : Intel 80486                       │
│         Coprocessor : present                       │
│         Windows Mode : Enhanced Mode                │
│         Windows Version : 3.10                      │
│           Free Memory : 17289 KB                    │
│                                                     │
└────────────────────────────────────────────────────┘
```
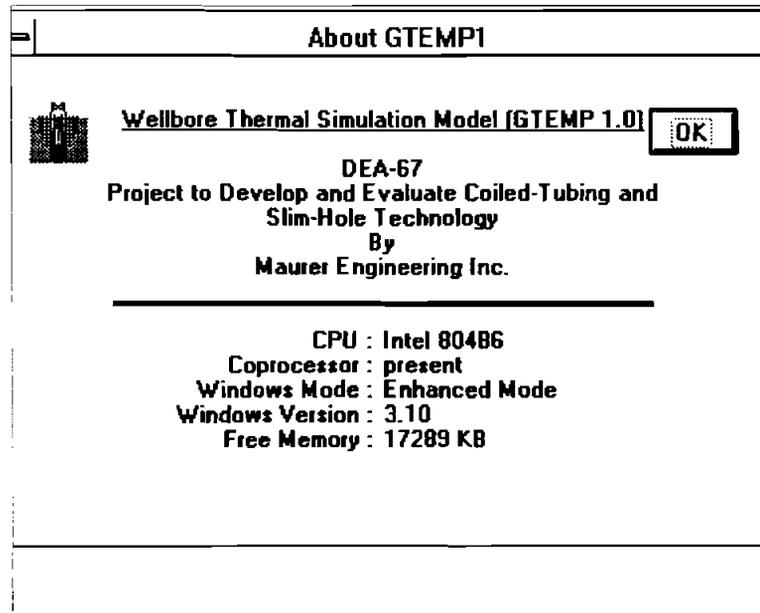
Figure 6-46. "About" GTEMP1 Dialog Box

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6.3.5 "About Operational Options..."

When the user selects the "About Operations..." command from the Help menu or clicks the [Help] command button in the Project Window, the following dialog box appears (Figure 6-47).
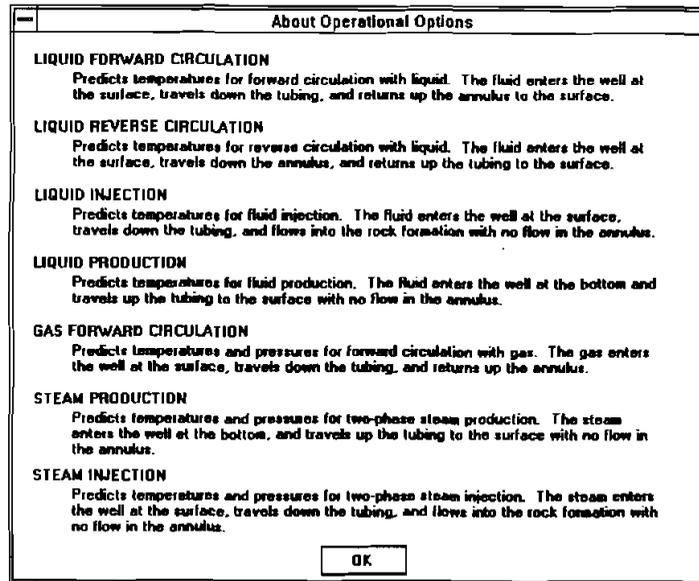
Figure 6-47. "About Operational Options"

6.3.6 Unit Conversion and Calculator

When the user selects the "Unit Conversion..." command from the Utility menu, the following dialog box appears (Figure 6-48).
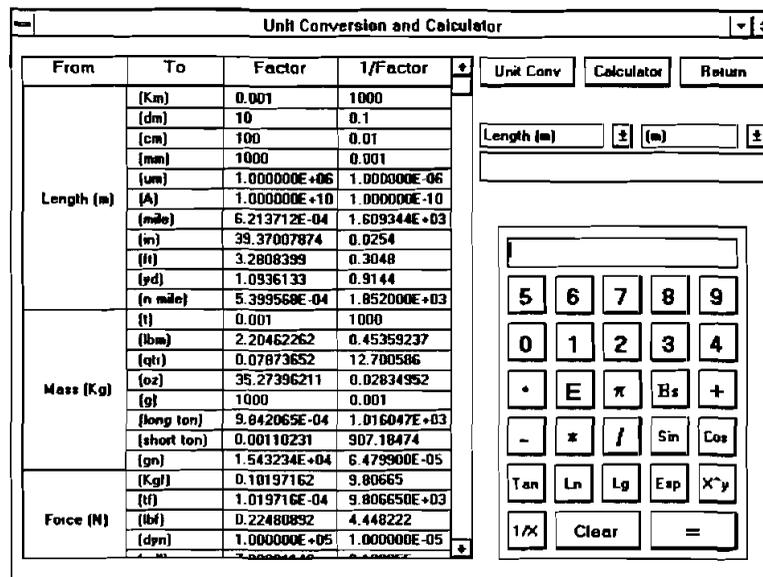
Figure 6-48. "Unit Conversion and Calculator"

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6.3.7 Unit Change

When the user clicks the [Unit Change] command button in both the Tubular Data Input and Parameter Data Input Windows, the following typical dialog box appears to allow the user to customize the units of a selected grid.
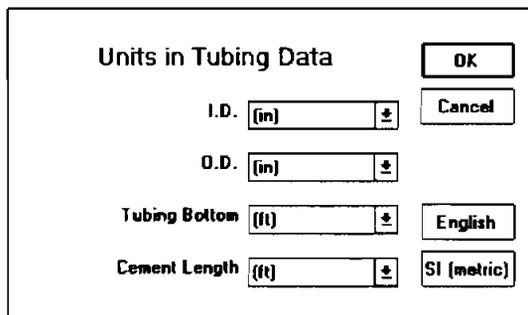
Figure 6-49. "Unit Change"

6.3.8 "Graph Size"

When the user selects the printing graph command in the Output Window, the following dialog box appears to allow the user to specify graph size.
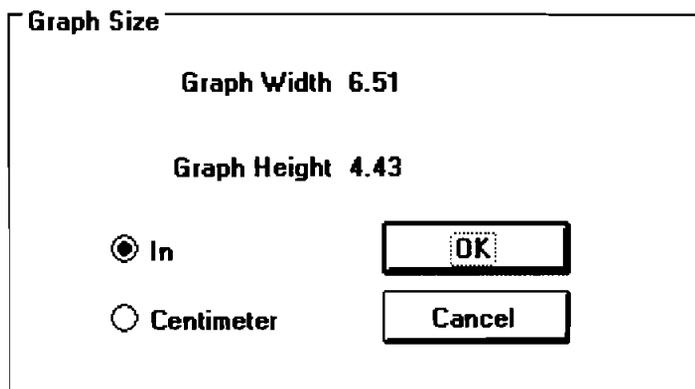
Figure 6-50. "Graph Size"

6.4 GTEMP1 ERROR HANDLING

When data in any Input Data Window, such as the Survey Data Input Window, are outside the appropriate range of values and the user attempts to close the window, the GTEMP1 error checking routine locates the error. The application then displays an error message explaining why the data are

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not acceptable. The user can ignore the error message and close the window, even though data in this window are in error. This enables the user to edit and view different Input Windows without having to have one completed before going to another.

Calculation can only be initiated from the Project Window. If any invalid data are found at this time, the application displays an error message stating in which Input Window the data are located and why the data are wrong. Figure 6-51 shows some of the error messages.
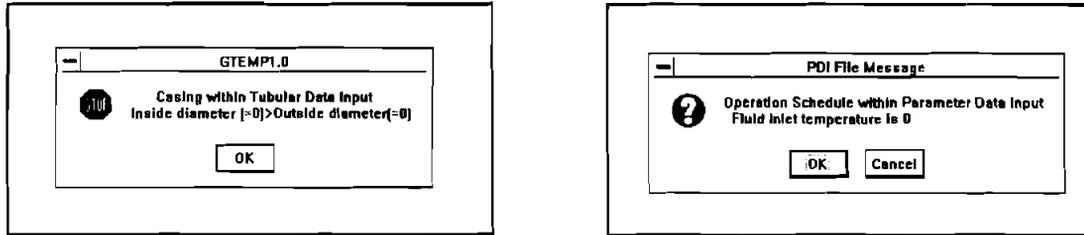
Figure 6-51. Error Messages of GTEMP1

When an error message appears, click <OK> or press <ENTER> to return to the Project Window or individual Input Window.

6.5 TOOL BAR

Tool bar buttons are command buttons at the top of each window which let the user access the menu command items quickly and easily. The functions of these command buttons on the tool bar are equivalent to those of some menu commands. Explanation of these commands and their relation to the menu commands are:

1. - Same as [New Project] or [New]

2. - Same as [Open Project...] or [Open File...]

3. - Same as [Save Project] or [Save]

4. - Same as [Print Project...] or [Print...]

5. - Go to previous Window

6. - Go to Main Window

7. - Go to WDI Window

8. - Go to SDI Window

9. - Go to TDI Window

10. - Go to PDI Window

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11. - Go to next Window

12. - Same as [Run]

13. - Same as [Output]

14. - Same as [About...]

15. - Same as [All]

16. - Enlarge active "child" window

The order of windows is: Main Window, WDI Window, SDI Window, TDI Window, PDI Window. The next window, when exiting the PDI Window, is the Main Window.

7. Example Run

7.1 OVERVIEW

This chapter presents a complete example run of GTEMP1. The input project file WTTEST1.GTE will be run to familiarize the user with program operation. The user should become familiar with:

- Menu operation
- Displaying and printing input data
- Displaying and printing output data

7.2 EXAMPLE CASE

Figures 7-1 to 7-5 present a print out of input data for this case. The data shown are from the supplied data files: "WTTEST1.GTE," "WTTEST1.WDI," "WTTEST1.SDI," "WTTEST1.GT1," and "WTTEST1.GP1."

```
===================================

     Wellbore Thermal Simulation Model

===================================


          [ Project Data Input ]

Project File Name: C:\GTEMP1\WTTEST1.GTE

     Flowing Model = Liquid Production

     WDI File Name:        WTTEST1.WDI
     SDI File Name:        WTTEST1.SDI
     TDI File Name:        WTTEST1.GT1
     PDI File Name:        WTTEST1.GP1

     Unit:                 English

=============== End of GTE file ===============
```

Figure 7-1. Project Data Input of the Example Case

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```
============================================

        Wellbore Thermal Simulation Model

============================================


              [ Well Data Input ]

         WDI File Name: WTTEST1.WDI

    Company Name          : Maurer Engineering Inc.
    Project Name          : GTEMP1.0
    Well Name             : EXAM-1(Inclined well)
    Well Field            : NONE
    Well City / State     : Houston, Texas
    Date                  : April 10, 1995
    Comments              : Liquid Production

=============== End of WDI file ===============
```

Figure 7-2. Well Data Input of the Example Case

```
============================================

        Wellbore Thermal Simulation Model

============================================


              [ Survey Data Input ]

         SDI File Name: WTTEST1.SDI

-------------------------------------------------------------
Station    Measured Depth         Inclination     Azimuth
              (ft)                  (Dec.)         (Dec.)
-------------------------------------------------------------

1             0.0                   0.0             0.0
2             5000.0                0.0             0.0


-------------------------------------------------------------

        =============== End of SDI file ===============
```

Figure 7-3. Survey Data Input of the Example Case

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```
        ================================================

                 Wellbore Thermal Simulation Model

        ================================================

                      [ Tubular Data Input ]

                  TDI File Name: WTTEST1.GT1

        --------------- Tubing and casing properties ---------------
        Material        Conductivity    Heat Capacity      Density
                        (Btu/hr-ft²-°F) (Btu/lbm-°F)       (lbm/ft³)
        Steel Casing/DP    26.10            0.11            490.00
        ------------------ Tubing configuration ------------------
          Tubing     ID        OD       Top      Bottom    Cement
           NO.       (in)      (in)     (ft)      (ft)      (ft)
            1        3.960     4.500      0        5000      5000

        ------------------ Casing configuration ------------------
          Casing     ID        OD       Depth         Cement Interval
           NO.       (in)      (in)     (ft)               (ft)
            1        8.680     9.630     5000              2200
            2       12.350    13.380     3000              2200
            3       19.120    20.000     1000              1000
            4       29.000    30.000      100               100

        --------------------- Well geometry ---------------------
                   Initial Depth      Bore Diameter
                       (ft)               (in)
                       5000              31.000

        --------------------- Rock properties ---------------------
                       (One-Layer Rock Formation)

        Material        Conductivity   Heat Capacity     Density       Vertical Depth
                        (Btu/hr-ft²-°F) (Btu/lbm-°F)     (lbm/ft³)          (ft)
        Shale (default)    0.92           0.30            140.00          5000.00

        ------------------ Geothermal temperatures ------------------
                   Surface Temperature        Bottom Temperature
                        (°F)                        (°F)
                       70.00                       150.00

        --------------------------- Grid ---------------------------
        Radial Grid Number   Max Radial Distance    Vertical Grid Size
                                    (ft)                   (ft)
              10                   50.00                 200.00

        ================ End of TDI file ================
```

Figure 7-4. Tubular Data Input of the Example Case

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```
|--------------------------------------------------------------------|
|            ====================================                    |
|                                                                    |
|              ·Wellbore Thermal Simulation Model                    |
|                                                                    |
|            ====================================                    |
|                                                                    |
|                   [ Parameter Data Input ]                         |
|                                                                    |
|                  PDI File Name: WTTEST1.GP1                         |
|                                                                    |
|-------------- Set Variables at Time = 0(DAY) --------------        |
|       Flowing Model = Liquid Production                            |
|       Fluid #1 Injection Into Tubing                               |
|       Fluid #1 In Well                                             |
|       Inlet Temperature = 150.0(°F)                                |
|       Flow Rate = 15.0(gal/min)                                    |
|       Time To Change Data = 10.0(day)                              |
|                                                                    |
|------------- Set Variables at Time = 10.0(DAY) -------------       |
|       Flowing Model = Liquid Production                            |
|       Fluid #1 Injection Into Tubing                               |
|       Fluid #1 In Well                                             |
|       Inlet Temperature = 150.0(°F)                                |
|       Flow Rate = 150.0(gal/min)                                   |
|       Time To Change Data = 20.0(day)                              |
|                                                                    |
|----------------- Wellbore fluid properties ----------------       |
|   Type      Density    P.V.      Y.P.          k           n      |
|   NO.      (lbm/gal)   (cp)    (lb/100ft²)  (lb-s^n/ft²)           |
|    1        10.00      15.00     5.00           X           X      |
|                                                                    |
|   NOTE:  P.V. = Plastic Viscosity                                 |
|          Y.P. = Yield Point (for Bingham Fluid)                   |
|          k    = Consistency Coefficenty                           |
|          n    = Exponent of Power Law (for Power Law Fluid)       |
|                                                                    |
|----------------- Wellbore Initial State -----------------         |
|          Fluid #1 In Tubing - Tubing Annulus                      |
|          Fluid #1 In Casing - Casing Annuli                       |
|                                                                    |
|                                                                    |
|         ================= End of PDI file =================        |
|--------------------------------------------------------------------|
```

Figure 7-5. Parameter Data Input of the Example Case

Use of these data generates the example results presented in this manual. The WTTEST1 data are for illustration only and should not be taken as preferred values.

Start GTEMP1 using the methods described in Section 4.3.

In the following sections, the procedures are explained step by step.

7.3 INPUT WINDOWS

Select "Open Project..." from the File menu in the Project Window. Retrieve the project file WTTEST1.GTE in C:\GTEMP1. After the user completes the dialog in the Project Window, other Data Input Windows can be displayed as shown in Figures 6-3, 6-4, 6-5, 6-6, and 6-11. Please refer to them.

7.4 OUTPUT WINDOW AND PRINT OUTS

Selecting "Start" from the Run menu in the Project Window launches calculation. The calculating percentage complete indicator shows the ongoing status of the calculation.

After calculation is complete, the Output Window and its "child" windows are shown in Section 6.1.3. The figures and text files displayed here are output through the printer through corresponding windows.

1. Thermal Analysis Report (Figure 7-6).

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```
------------R vs. T Data at Time=10(day), MD=0(ft)------------

                        R (in)          T (°F)
                        1.0             145.9
                        3.3             141.2
                        15.5            128.6
                        30.4            124.6
                        51.7            122.2
                        82.5            121.2
                        126.6           121.0
                        190.0           121.0
                        281.1           121.0
                        412.1           121.0
                        600.2           121.0

================ End of R vs. Temperature Data ================

----------MD vs. T in Tubing and Annulus at Time=10(day)---------

    Measured Depth (ft)     Tubing (T(°F))      Annulus (T(°F))
            0                   118.6               70.0
            200                 124.0               112.9
            400                 126.0               115.2
            600                 128.0               117.4
            800                 129.9               119.7
            1000                131.6               122.5
            1200                133.3               124.5
            1400                134.9               126.4
            1600                136.4               128.3
            1800                137.8               130.1
            2000                139.2               131.8
            2200                140.5               133.5
            2400                141.8               135.2
            2600                142.9               136.7
            2800                144.0               138.3
            3000                145.0               139.9
            3200                145.9               141.2
            3400                146.7               142.5
            3600                147.5               143.7
            3800                148.1               144.8
            4000                148.7               145.9
            4200                149.2               146.9
            4400                149.5               147.8
            4600                149.8               148.6
            4800                149.9               149.3
            5000                150.0               150.0
================ End of MD vs. Temperature Data ================
```

Figure 7-6. Thermal Analysis Report Print Out

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2. Wellbore Schematic (Figure 7-7).
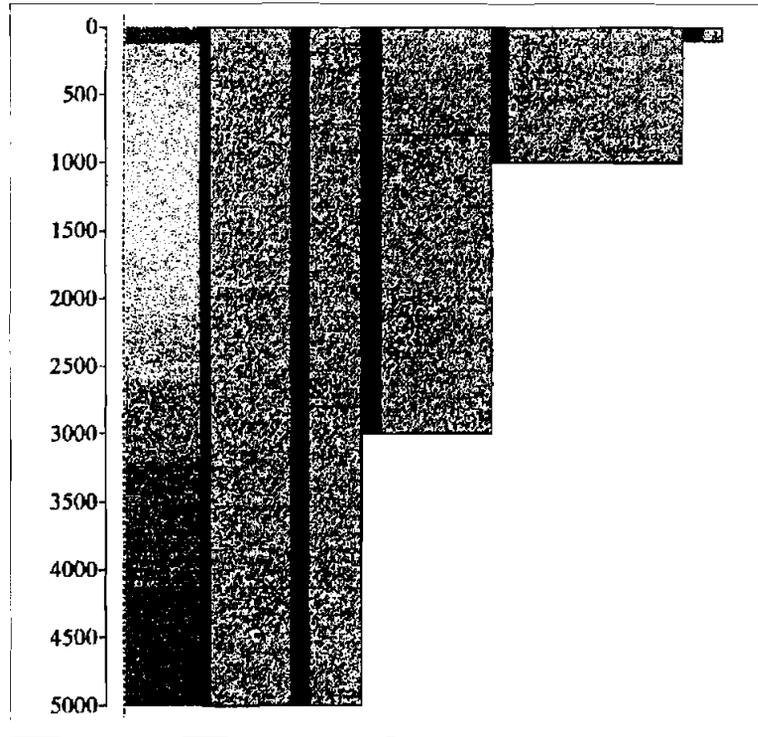

Figure 7-7. Wellbore Schematic Print Out
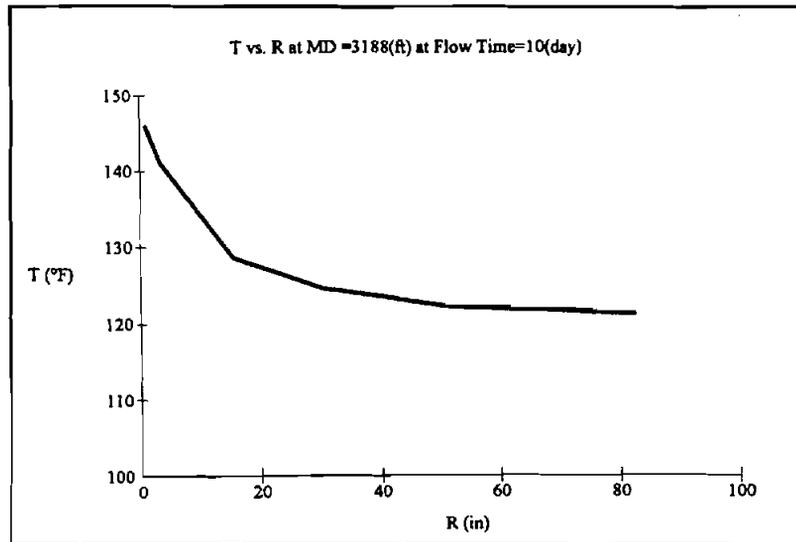
3. Radial Temperature Distribution (Figure 7-8).

Figure 7-8. Radial Temperature Distribution Print Out

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4. Vertical Temperature Distribution (Figure 7-9).
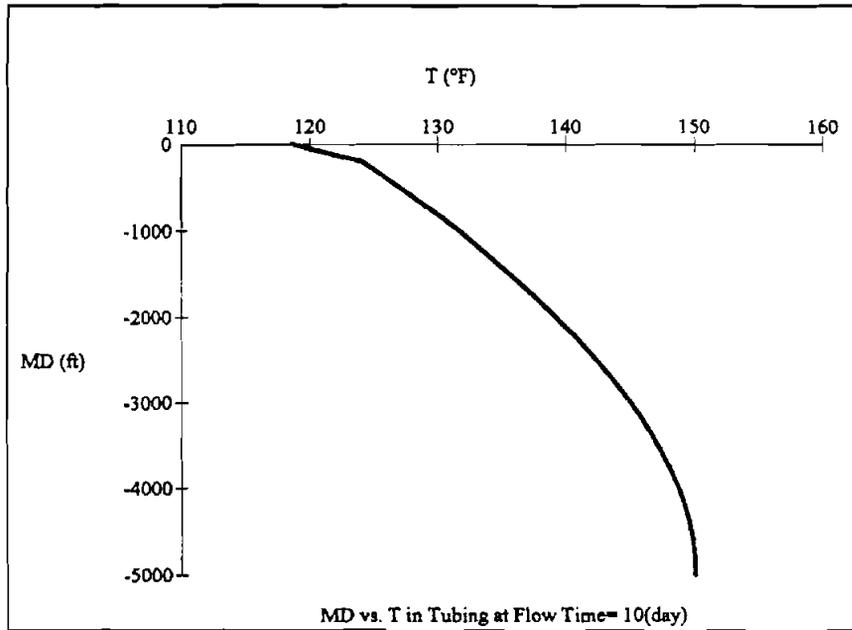
Figure 7-9. Vertical Temperature Distribution Print Out

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5. Three-Dimensional Temperature Report (Figure 7-10)

```
         ====================================================

         Wellbore Thermal Simulation Model Output Data

         ====================================================


         ---------------- Set Variables at Time = 0(DAY)----------------
              Flowing Model = Liquid Production
              Fluid #1 Injection Into Tubing
              Fluid #1 In Well
              Inlet Temperature = 150.0(°F)
              Flow Rate = 15.0(gal/min)
              Time To Change Data = 10.0(day)

         ------------------Temperature Distribution--------------------

Measured Depth                Radius
                  1.0      3.3      15.5     30.4     51.7     600.2

         0       118.6    70.0     70.0     70.0     70.0     70.0
         200     124.0    112.9    90.8     81.4     75.9     73.2
         400     126.0    115.2    93.6     84.5     79.0     76.4
         600     128.0    117.4    96.4     87.5     82.2     79.6
         800     129.9    119.7    99.0     90.4     85.3     82.8
         1000    131.6    122.5    100.5    92.8     88.2     86.0
         1200    133.3    124.5    103.2    95.7     91.3     89.2
         1400    134.9    126.4    105.9    98.7     94.5     92.4
         1600    136.4    128.3    108.5    101.7    97.6     95.6
         1800    137.8    130.1    111.2    104.6    100.7    98.8
         2000    139.2    131.8    113.8    107.5    103.8    102.0
         2200    140.5    133.5    116.4    110.5    106.9    105.2
         2400    141.8    135.2    119.0    113.4    110.0    108.4
         2600    142.9    136.7    121.6    116.3    113.1    111.6
         2800    144.0    138.3    124.0    119.1    116.2    114.8
         3000    145.0    139.9    126.3    121.9    119.3    118.0
         3200    145.9    141.2    128.8    124.8    122.4    121.2
         3400    146.7    142.5    131.2    127.6    125.5    124.4
         3600    147.5    143.7    133.7    130.5    128.6    127.6
         3800    148.1    144.8    136.1    133.3    131.6    130.8
         4000    148.7    145.9    138.5    136.1    134.7    134.0
         4200    149.2    146.9    140.9    138.9    137.8    137.2
         4400    149.5    147.8    143.2    141.7    140.8    140.4
         4600    149.8    148.6    145.5    144.5    143.9    143.6
         4800    149.9    149.3    147.8    147.3    147.0    146.8
         5000    150.0    150.0    150.0    150.0    150.0    150.0
         5200    153.2    153.2    153.2    153.2    153.2    153.2

         Note: Measured Depth in (ft); Radius in (in); Temperature in (°F)
         =================== End of 3D Temperature Data ===============
```

Figure 7-10. Three-Dimensional Temperature Report Print Out

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6. Three-Dimensional Temperature Distribution (Figure 7-11).

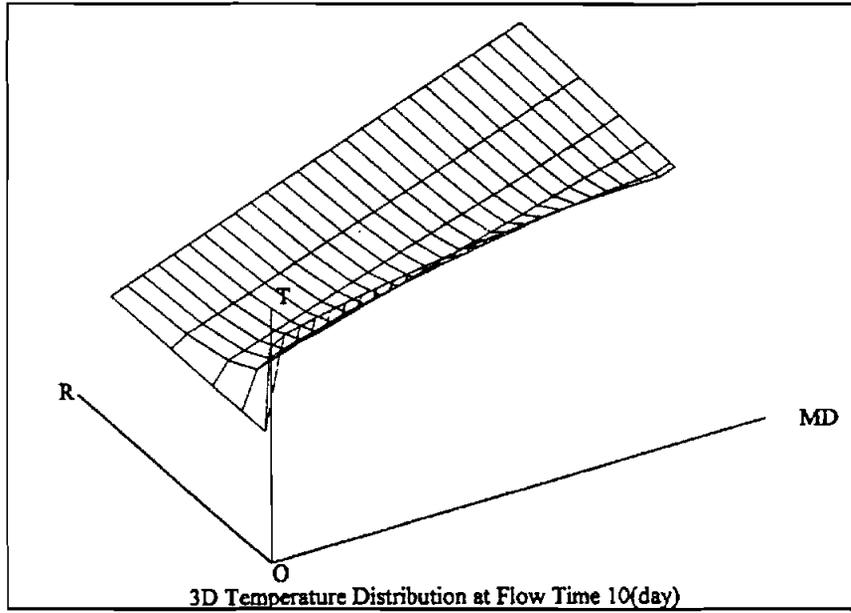3D Temperature Distribution at Flow Time 10(day)

Figure 7-11. Three-Dimensional Temperature Distribution Print Out

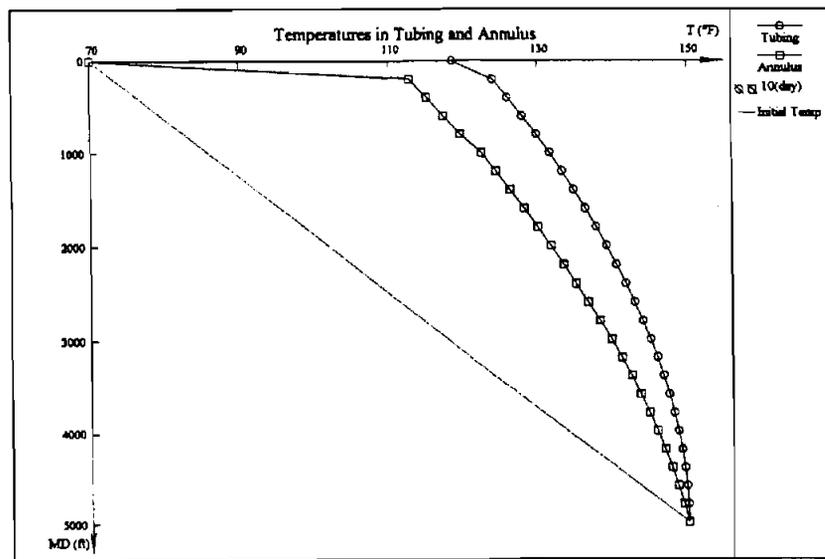7. Temperature in Tubing and Annulus (Figure 7-12).

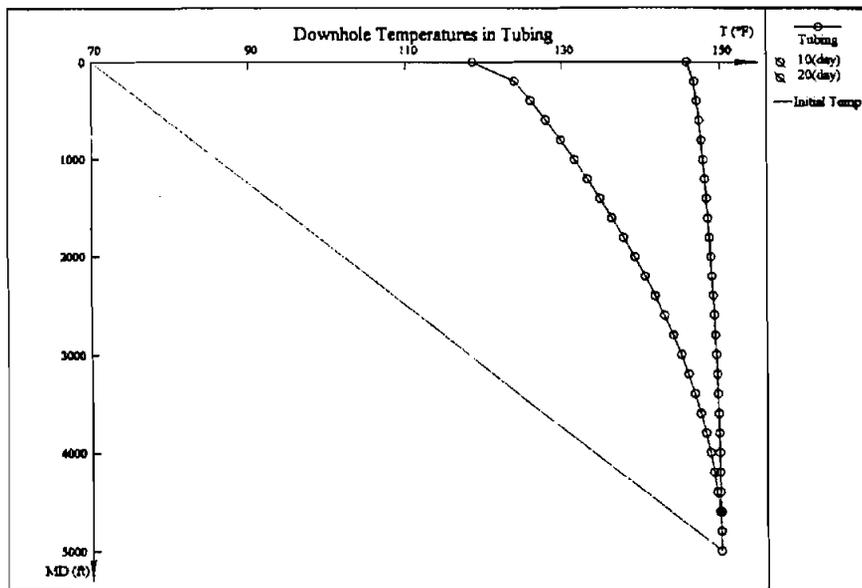Figure 7-12. Temperature in Tubing and Annulus Print Out

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8. Temperature in Tubing (Figure 7-13).

Figure 7-13. Temperature in Tubing Print Out

9. Temperature Versus Time in Tubing Report (Figure 7-14).

```
--------Temperature vs. Time in Tubing at MD=1000(ft)--------

          Time (hour)          Temperature (°F)
            0.240                  86.0
            0.540                  89.6
            0.915                  93.1
            1.384                  96.6
            1.970                 100.0
            2.702                 103.4
            3.618                 106.8
            4.762                 110.3
            6.193                 113.7
            7.981                 117.0
           10.216                 120.2
           13.010                 123.0
           16.502                 125.2
           20.868                 127.0
           26.325                 128.2
           33.146                 129.0
           41.673                 129.4
           52.331                 129.7
           65.653                 130.0
           82.307                 130.2
          103.123                 130.4
          129.144                 130.7
          161.670                 130.9
          202.328                 131.2
          240.000                 131.4
```

Figure 7-14. Temperature Versus Time in Tubing Report Print Out

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10. Temperature Versus Time in Tubing-I (Figure 7-15).
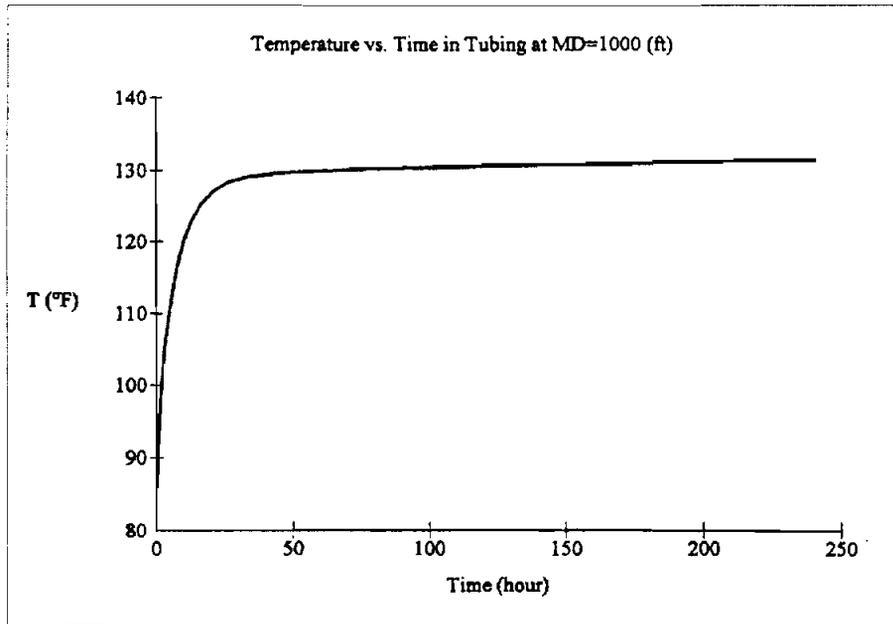
Figure 7-15. Temperature Versus Time in Tubing-I Print Out

11. Temperature Versus Time in Tubing-II (Figure 7-16).
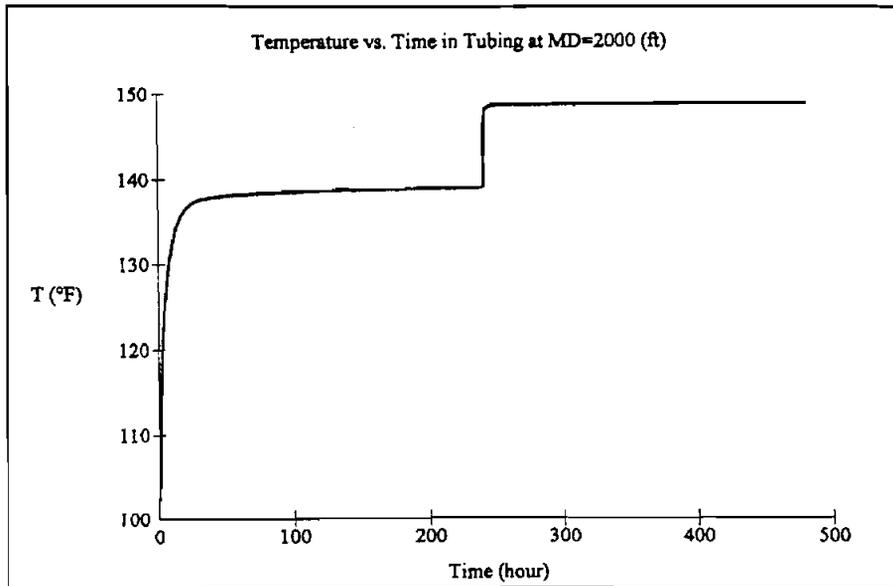
Figure 7-16. Temperature Versus Time in Tubing-II Print Out

12. Undisturbed Geothermal Temperature (Figure 7-17).
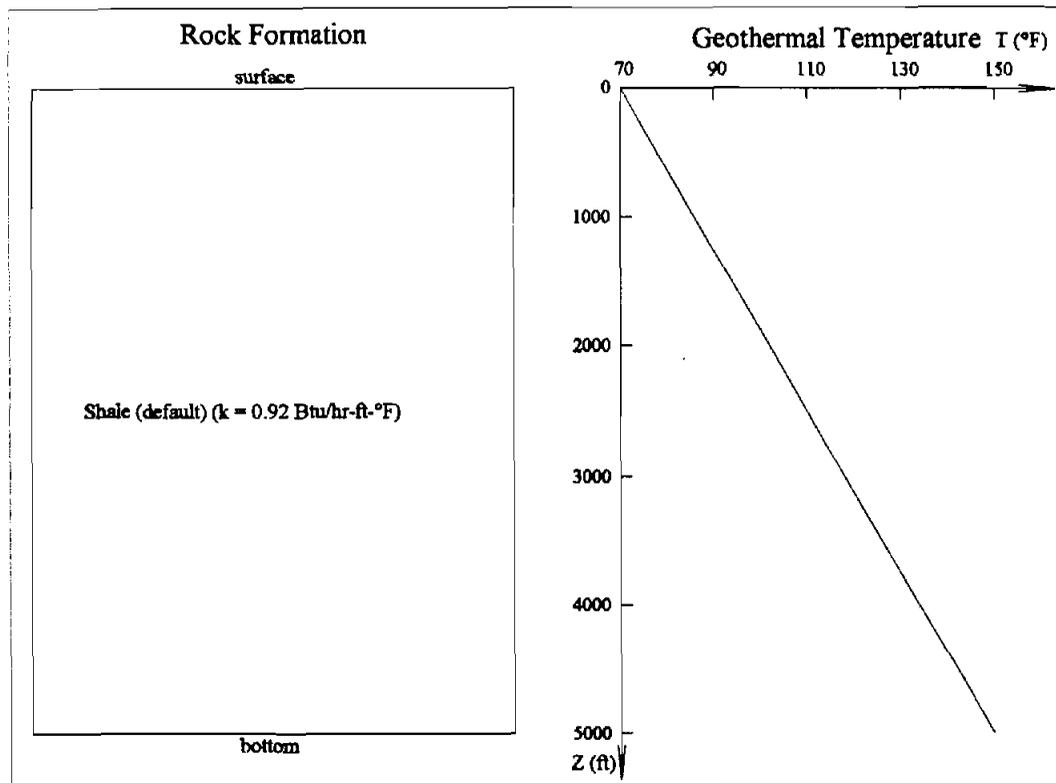
Figure 7-17. Undisturbed Geothermal Temperature Print Out

7.5 GTEMP1 QUICK START

Use the following procedure to get started in GTEMP1:

Install:

1. Start Windows (3.0 or a later version).

2. Insert the disk in drive A:.

3. In the File Manager, choose Run from the File menu.

4. Type A:\setup and press <ENTER>.

5. Follow on-screen instructions.

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Run:

1. Double-click the GTEMP1 icon in the "DEA Application Group" Window.

2. In the Project Window, choose "Open Project..." from the File menu.

3. From the "Open GTE File" dialog box, click drive C: in the drive list box, double-click the GTEMP1 sub-directory, click "WTTEST1.GTE" in the file list box, then click OK.

4. Click on menu items in the Input menu to view each of the data input windows (WDI, SDI, TDI, and PDI).

5. Click "Start" from the Run menu in the Project Window.

6. View the output "child" windows tiled in the Output Window.

7. To print out the text report or graph, activate the desired "child" window, select "Print..." from the File menu.

8. Choose "Return" from the File menu to return to the Project Window where the application can be terminated.

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9. Bug Report or Enhancement Suggestion Form

Name: _____   Company: _____

Address: _____   City: _____ State: _____

Phone No.: _____   Fax No.: _____ Date: _____

☐ Bug/Problem Report   ☐ Enhancement Suggestion

Program Name and Version Number: _____

Bug/Problem Description or Enhancement Suggestion: _____

_____

Regarding the Bug Report, please answer the following questions:

Computer System   Brand: _____

    Chip: ☐ 286   ☐ 386   ☐ 486   ☐ Pentium

    Type: ☐ Desktop ☐ Laptop ☐ Notebook ☐ Other

    RAM: _____MB   Speed: _____ MHZ

    Math-Coprocessor Present: ☐ Yes ☐ No ☐ Unknown

Printer Type: _____ (for printing error only)

Plotter: _____ (for plotting error only)

Within Network System: ☐ Yes ☐ No   Type: _____

Video Type: ☐ EGA ☐ VGA ☐ SVGA ☐ Mono ☐ LCD

Video Card Ram: _____ (video problem only)

Operating System

    MS-DOS Version No.: _____   MS-Windows Version No.:_____ (Windows Application)

    OS2 _____   MS-Windows NT Version No.: _____

    Other _____

Data/Parameters Causing Bug

    ☐ Will be mailed on diskette ☐ Will be faxed ☐ Attached ☐ None

Other Comments: _____

Please send or fax to:

> Lee Chu
> MAURER ENGINEERING INC.
> 2916 West T.C. Jester
> Houston, TX 77018-7098
> Ph: 713/683-8227 • Fax: 713/683-6418

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Appendix A

Appendix A
International Keyboard

All DEA computer programs developed at Maurer Engineering Inc. are written using the "U.S." Keyboard. Under this keyboard, the "1000 separator" is a comma, and the "decimal separator" is a period. Thus, the number **one thousand, two hundred and thirty-four and twenty-two/100** is written

<div align="center">1,234.22</div>

Numbers input into the programs are filed in this format.

Problems have occurred for some of our Participants who use the "International Keyboard," as is common in Europe and South America. Here, the same number would be written

<div align="center">1.234,22</div>

Here, the "1000 separator" is a period, and the decimal separator is a comma.

European and South American users find that their computers garble input data being loaded into our DEA programs.

This problem can be readily solved by changing the Windows "numbers format" from the International to the U.S. format. This is accomplished as follows:

1. From the DOS prompt, type

<div align="center">WIN <ENTER></div>

to open WINDOWS.

2. From the Menu bar, choose "Window" either by clicking on "Window" or keying in

<div align="center"><ALT> W</div>

This brings down the "Select Window" menu screen, as shown in Figure A-1.
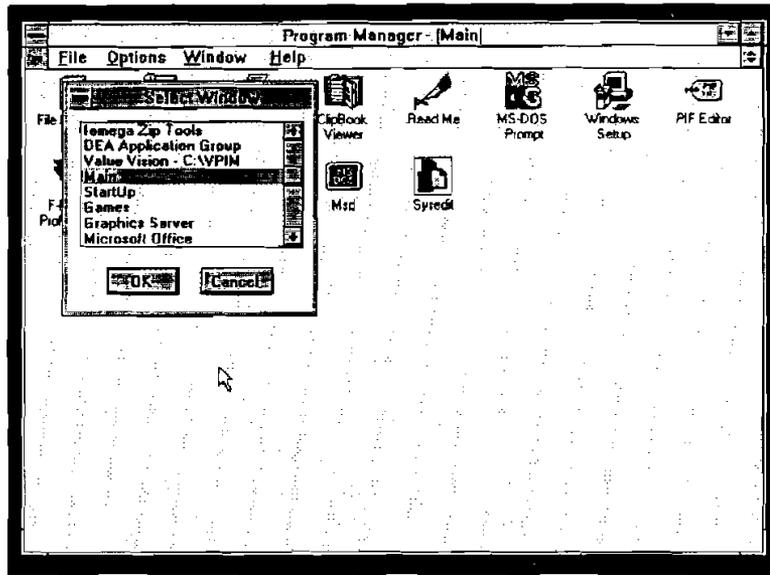
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Figure A-1. Windows Menu Bar

3. Select "Main" by clicking on "Main" and then clicking on the "OK" button. This brings down the "Main" menu screen, as shown in Figure A-2.
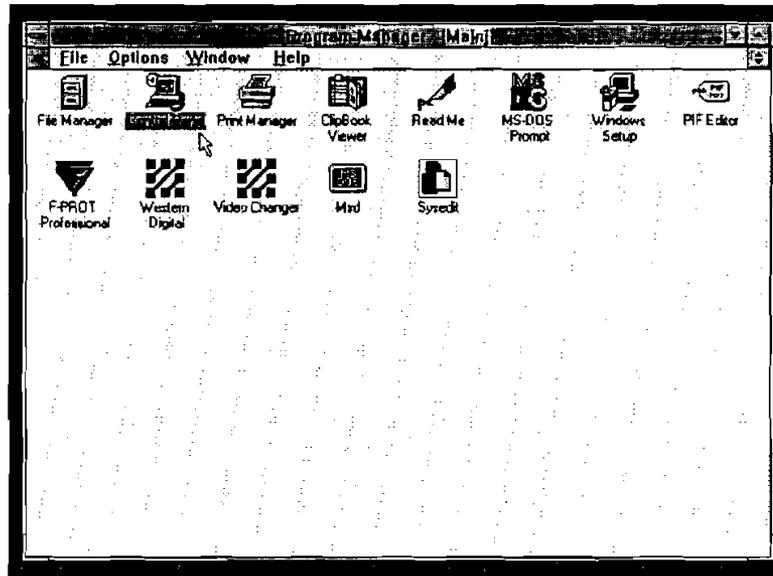

Figure A-2. Main Menu Screen

4. Select the "Control Panel" icon from the "Main" menu screen. This is done by pointing the mouse to this icon and double clicking. This brings up the "Control Panel" menu screen, as shown in Figure A-3.
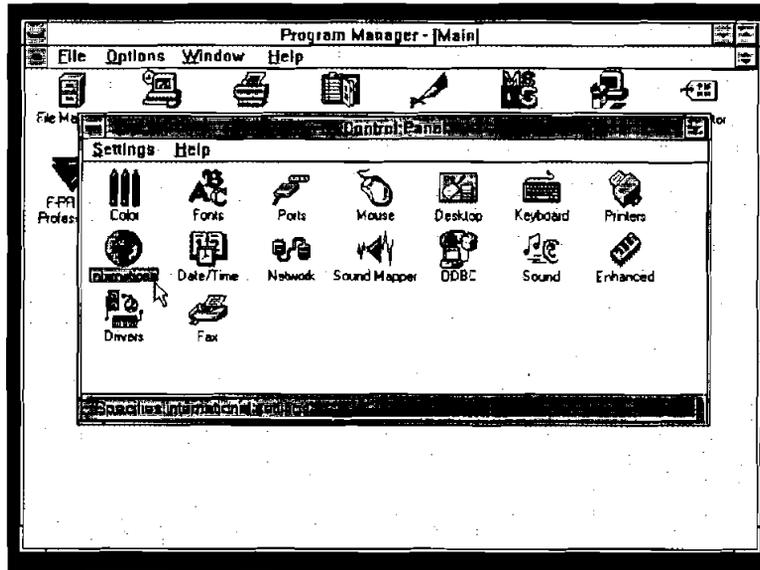
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Figure A-3. Control Panel Menu Screen

5. Select the "International" icon from this menu screen by pointing to it with the mouse and double clicking. This brings up the "International" Menu screen, as shown in Figure A-4.
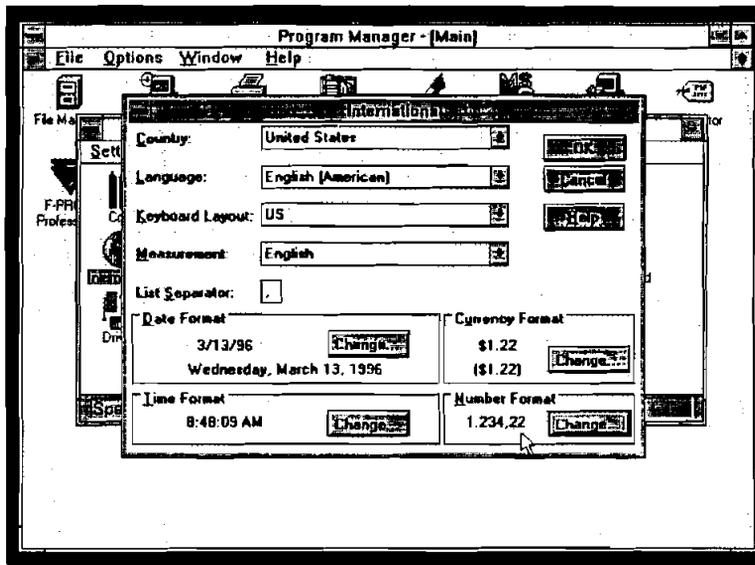

Figure A-4. International Menu Screen

6. In the lower right hand corner of the "International" menu screen is the "Number Format." If the number under the words "Number Format" is

1,234.22

The DEA programs will run. Click on the "Cancel" button in the upper right of this screen and back out to the "Windows"menu screen to run your program.

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If the number under the words "Number Format" is

1.234,22

it must be changed before a DEA program will run successfully.

7. To change "Number Format," click on the "Change" button in the "Number Format" box on the screen. This will bring up the "International – Number Format" screen. The "1000 Separator" box will be highlighted, as shown in Figure A-5. Key in

<DEL> ,

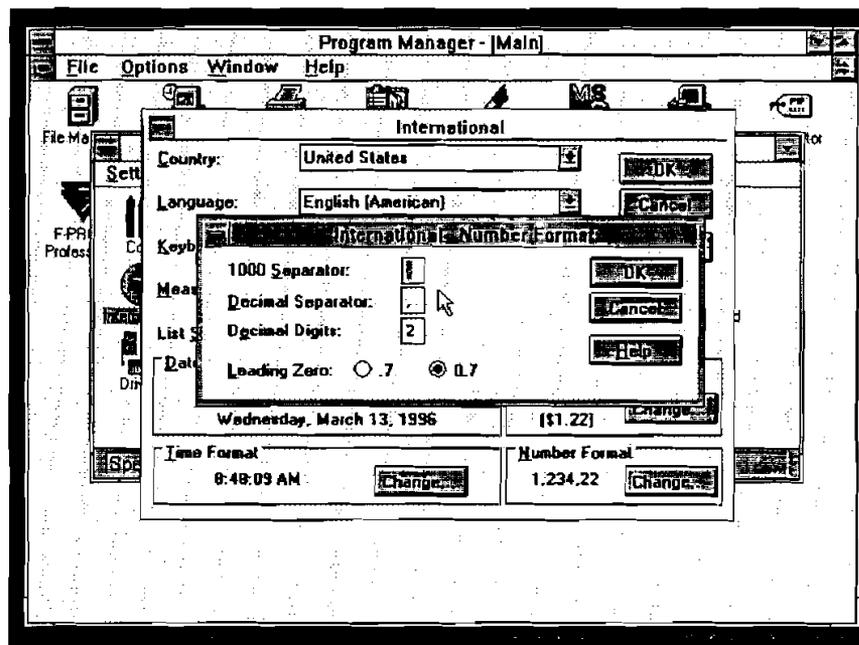This will erase the period from the "1000 separator" box and replace it with a comma.

Figure A-5. International — Number Format Screen

8. Either point the mouse to the box labeled "Decimal Separator" and click, or key in

<TAB>

This will highlight the "Decimal Separator" box.

9. Key in

<DEL> .

This will erase the comma from the box and replace it with a period.

10. Either key in

<ENTER>

or point the mouse to the "OK"button in the "International – Number Format" box and click. This will return you to the "International" menu screen, as shown in Figure A-6.
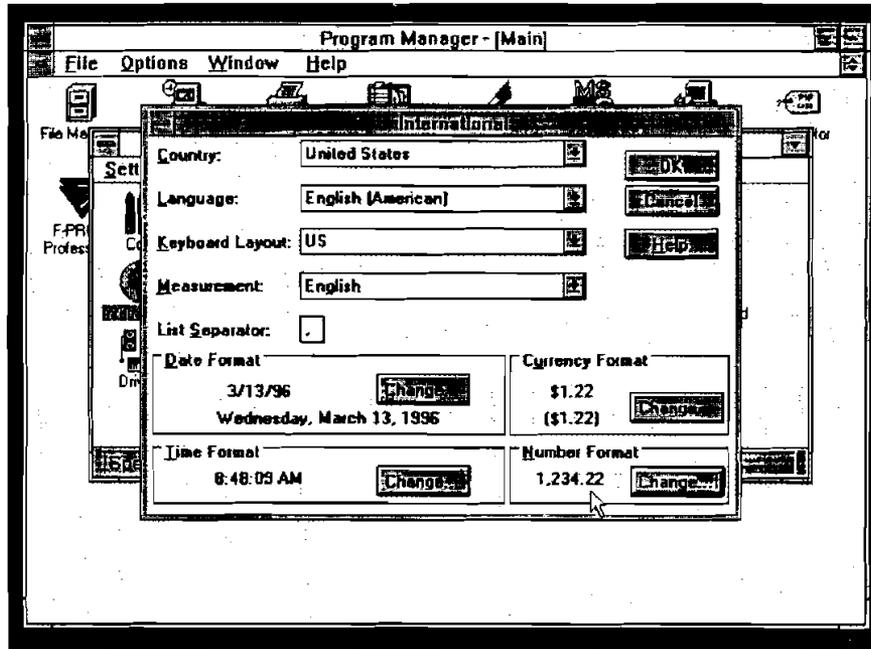

Figure A-6. International Menu Screen, with Correct Number Format

11. Click on the "OK" button to return to the "Main" menu screen.

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