MxL

INDUCTION HEATING SYSTEM

Production
Enhancement
Projection
Software

Relax

PEPS is not a drink with something missing

PEPS is not a little white energy pill

PEPS is not for sale or lease

PEPS quantifies MxL heater results

WHY

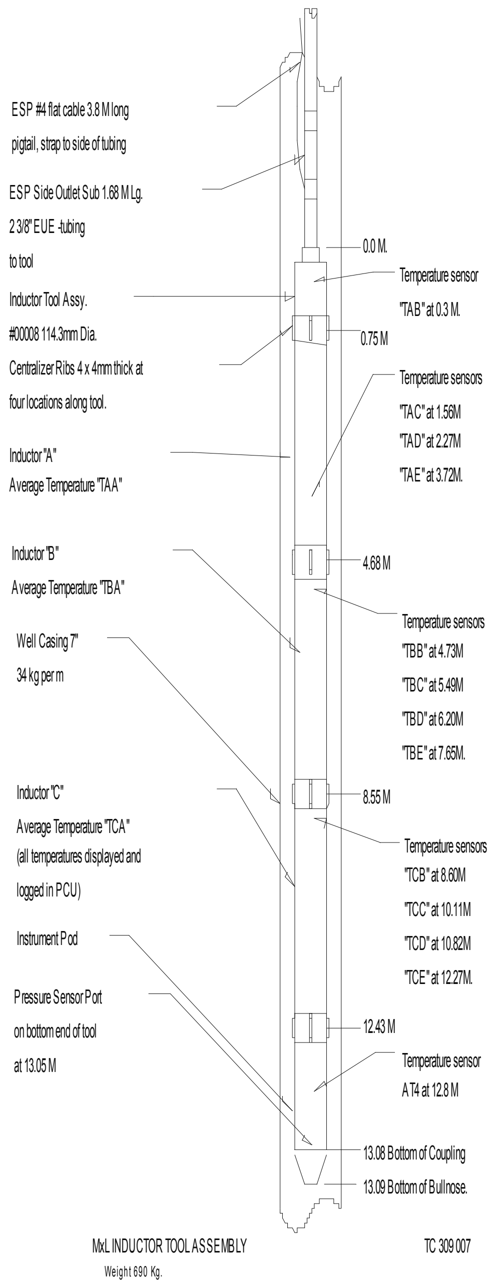
Production Enhancement Projection Software (PEPS) was developed to enable Madis to select the size and power rating of the MxL system

PEPS has been updated, through the years, to incorporate operating observations

We now use it to assist with management of our Induction Heating Systems in order to interpret production response as well as evaluate system potential for candidate wells

We also use it to explain MxL system operation

MxL



The MxL system Inductor Tool Assembly (ITA) is placed inside the casing at the reservoir.

Electromagnetic energy from the inductors passes through the annulus fluid to heat the casing and near wellbore directly to improve oil mobility.

A series of temperature sensors within the assembly measure the tool skin temperature.

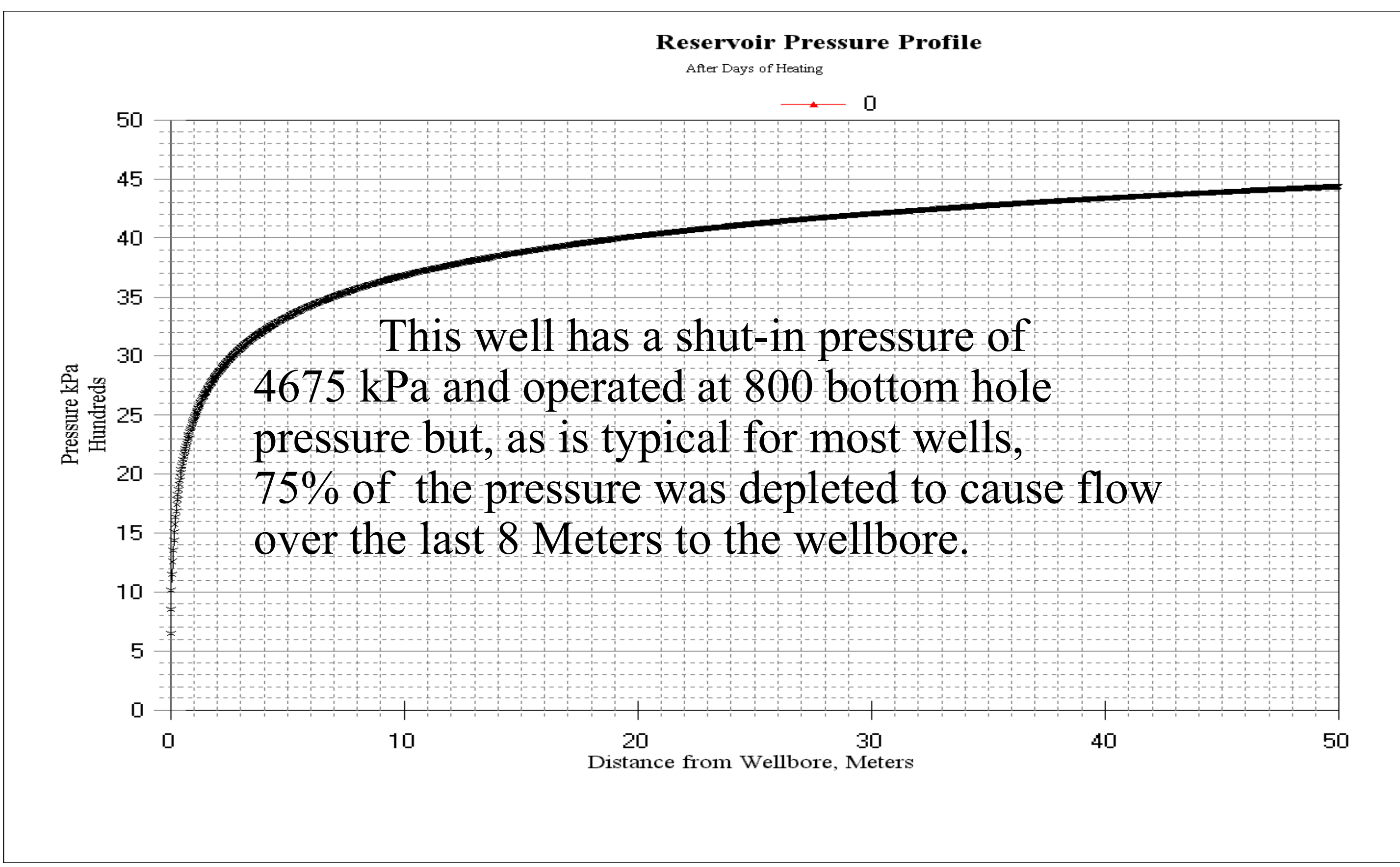
The annulus fluid temperatures, transmitted up to a Power Conditioning Unit (PCU), are used to control power delivered thus providing closed loop temperature control.

A pressure sensor located in the instrument pod, at the bottom of the tool, provides real time Bottom Hole pressure

OBSERVATIONS

Temperature sensors across the reservoir have provided data that indicates heat transfer into a producing reservoir is up to five times greater than for static conditions

Combine that information with the research of AOSTRA, Guzman-Andrade, and others, and we can examine the pressure profile in a reservoir. The PEPS generated profile makes it apparent that a viscosity change will be most effective near the wellbore

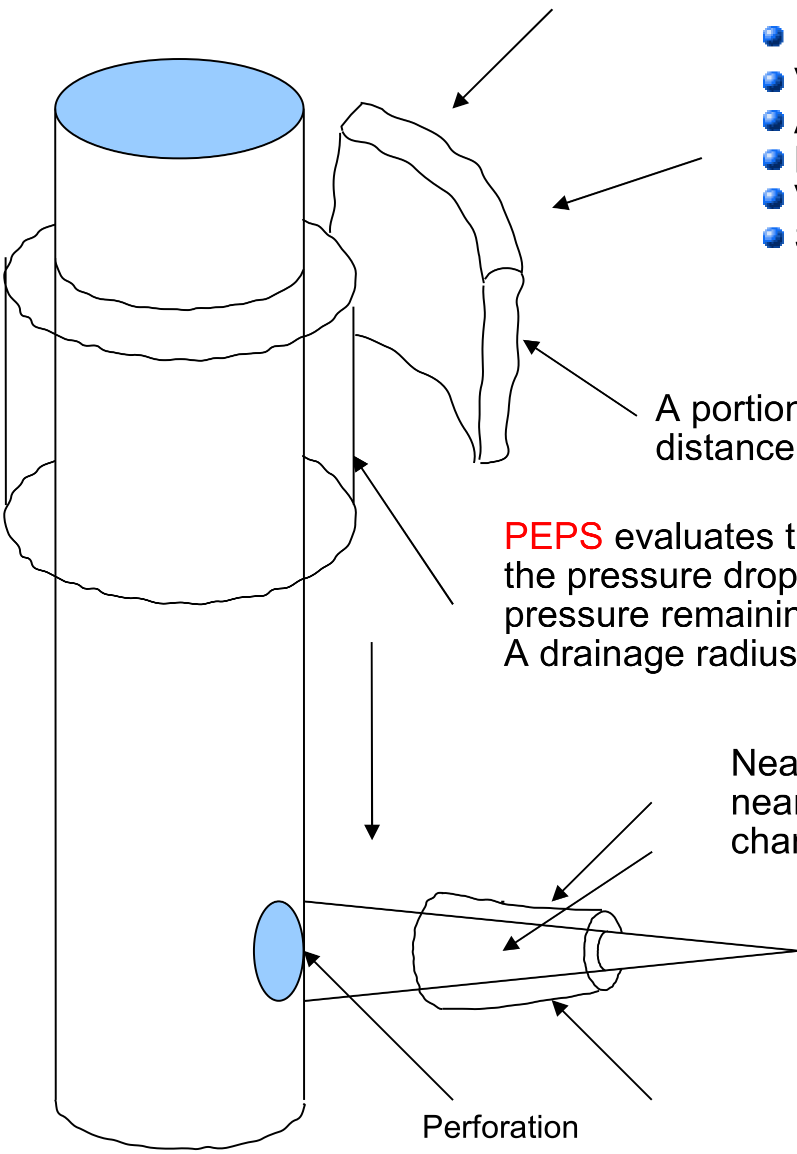


Any flow enhancement made in the near wellbore will cause a substantial improvement in production

RESERVOIR PRESSURE GRADIENT

The pressure profile is dependent upon

- Permeability of reservoir
- Viscosity of fluid
- Area through which fluid is flowing
- Live oil dead oil pressure characteristics
- Volume of fluid flowing
- Shut-in reservoir pressure and drawdown



A portion of a “hollow cylindrical shell” at a distance from the wellbore is shown

PEPS evaluates the flow through each shell to calculate the pressure drop across the shell then determines the pressure remaining as the wellbore is approached.
A drainage radius of 75 Meters is usually considered

Near the wellbore the fluid flow must turn nearly 90 degrees to reach a perforation channel

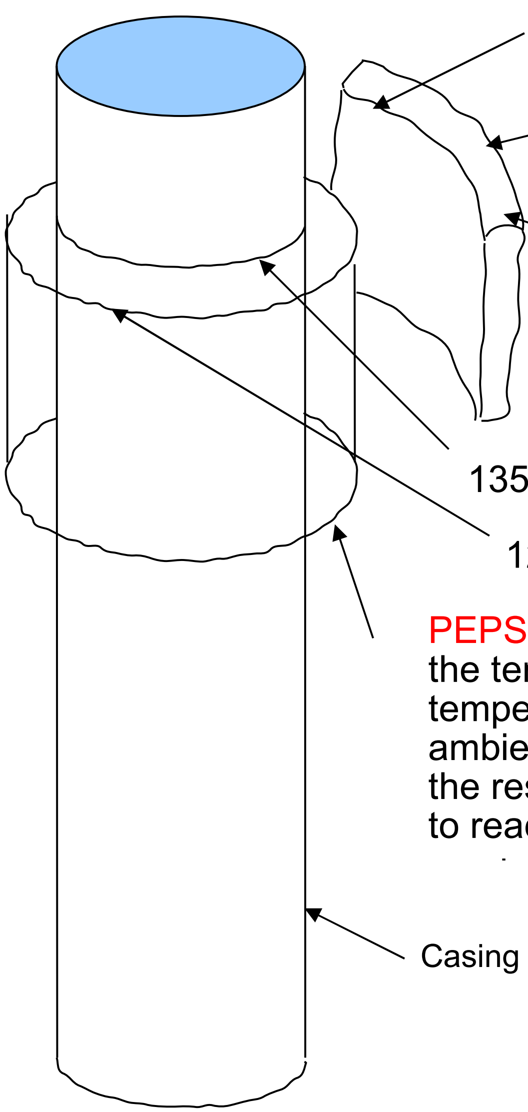
The fluid only enters the annulus through a slot or perforation and that constricting geometry and tortuous path results in favourable benefits from a temperature increase in the near wellbore region. The heating part of the PEPS program plots the temperature with respect to distance from the wellbore.

The client's well and production information is screened carefully, as is the measured reservoir temperature, to check for a match between unheated production and PEPS results. Once the proper adjustments have been determined, to create a match, all factors except viscosity and production rate remain unchanged. The effect of viscosity change due to heating is then assessed and PEPS generates a pressure profile with respect to distance from the wellbore. By increasing the time that heat has been applied or by changing the heating rate (KW) we are able to evaluate incremental production increases in response to energy added to the reservoir

RESERVOIR TEMPERATURE GRADIENT

The temperature profile is dependent upon

- **Thermal conductivity of reservoir**
- **Net heat flow into reservoir**
- **Heat extracted by produced fluid**
- **Area through which heat is flowing**
- **Heat accumulated in the reservoir**
- **Power from Induction Heater**



A portion of a “shell” at a distance from the wellbore is shown

PEPS evaluates the heat transfer through each shell to calculate the temperature drop across the shell and then generates several temperature profiles. The terminus of each profile is the reservoir ambient temperature. PEPS calculates the net heat stored in the reservoir and how many days of heating would be required to reach that condition. (typical temperatures are shown)

If the fluid flow vector was on a radial line, directly toward the casing, there would be very little heat transfer into the reservoir. Fortunately the fluid must go around grains of rock that form the permeable strata so that part of the time it is at an angle to the radial line and fluid flow at an angle to the radial enhances the transfer of heat from grain to grain. At a distance from the wellbore the average deviation angle of fluid flow is 45 degrees but near the perforations the deviation angle approaches 90 degrees which increases the transfer rate by a factor of two to three times.

The net heat flow rate to the reservoir, the reservoir fluid and rock characteristics and the length of time that heating has taken place are used in the PEPS program to determine the extent of heat penetration into the reservoir and a temperature profile with respect to distance from the wellbore. By entering a negative value for energy input we are able to arrive at suppressed bottom hole temperatures and use the resulting pressure profile to assist in determination of unheated production conditions.

MxL SYSTEM & POWER CONDITIONING UNIT (PCU)

The PCU automatically adjusts the power delivered to the inductors to hold a set downhole temperature regardless of oil flow or other variables.
Since heat flows from a hotter object to a cooler object the “shell” next to the casing is heated and then the next “shell” and so on.

EXAMPLE

If we apply heat at a rate of 1 KW per foot of reservoir for the first day we have generated 81,600BTU and if two barrels of oil are produced per foot of reservoir a simplified energy balance would be:

7” casing at 23#/ft and Specific heat of 0.18 = 4.14 BTU/^{0}F
2bbl 10 API oil 350# at Specific Heat of 0.45= 315 BTU/^{0}F

.

Temperature rise = BTU input divided by BTU/^{0}F of material

$$81{,}600/ (4.14 + 315) = 255^0\text{F}$$

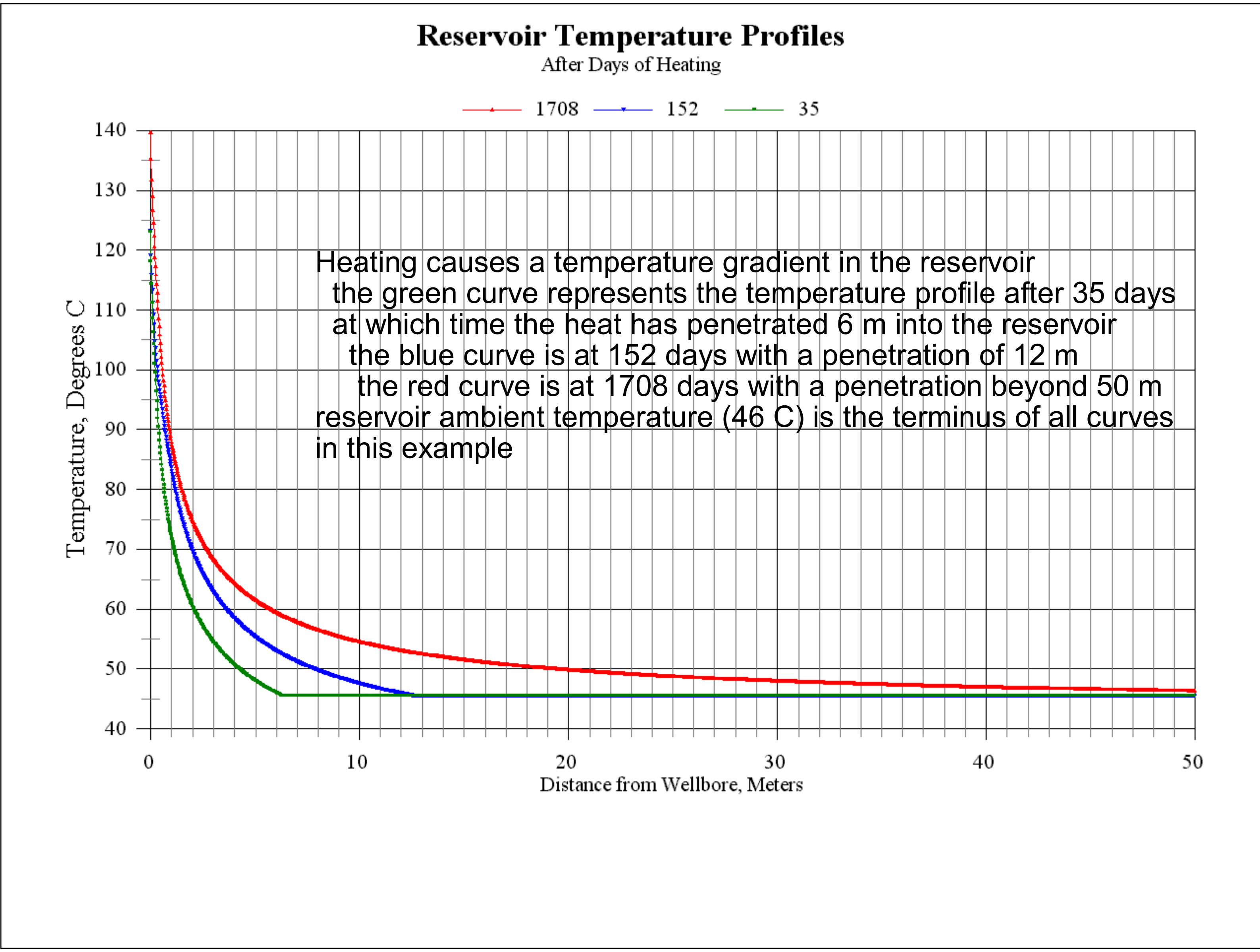
Since the casing is hotter than the reservoir some heat will transfer to the “shell” next to the casing which results in an actual temperature lower than given in the example but as the temperatures in the adjacent shell rises the heat transfer diminishes and the casing casing temperature rises until an equilibrium is reached.

Each day of heating will result in a temperature rise within the reservoir as the heat conducts from the hot casing.

PEPS

The PEPS program calculates the net heat flow into the reservoir by subtracting the heat lost in the produced fluids from the heat generated by induction.
The net heat is then integrated over time to quantify the heat that has accumulated.
The program then uses the thermal properties of the strata and oil to calculate a temperature profile after a specified number of days of heating.
The amount of power applied, production rate, water-cut, reservoir dimensions, thermal transfer rates and rock characteristics are part of the calculations which the program applies to arrive at a projection.

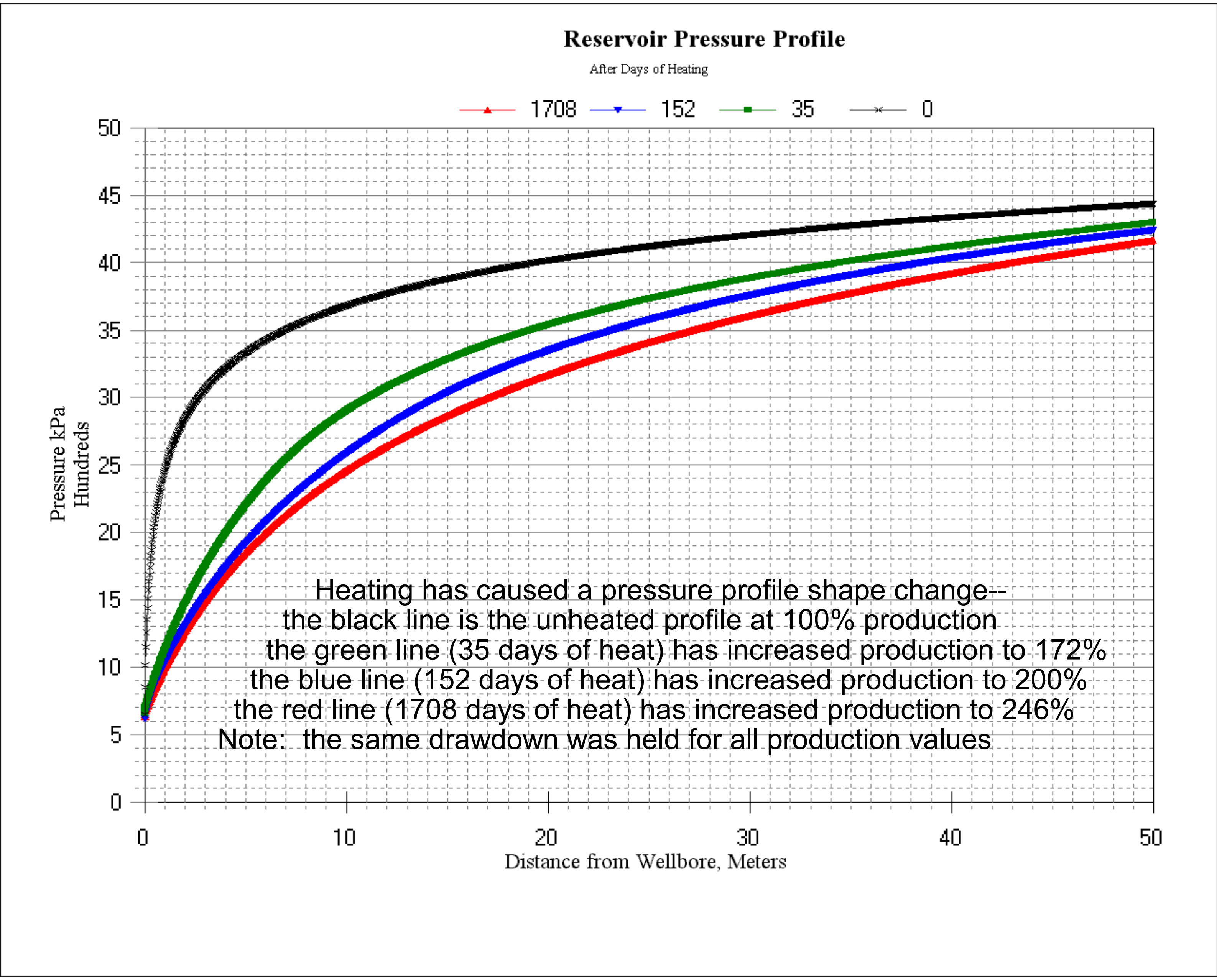
PEPS plots the temperature for each hollow cylindrical shell Vs the distance from the wellbore to generate a "Reservoir Temperature Profile"



To generate the profiles the program inputs (heating power and increased production) are increased to bring the casing temperature up to 120 to 130 Celsius with the same drawdown as existed in the unheated well

PEPS calculates the resulting pressure profiles on the fly making it easy to try a number of "what if" conditions

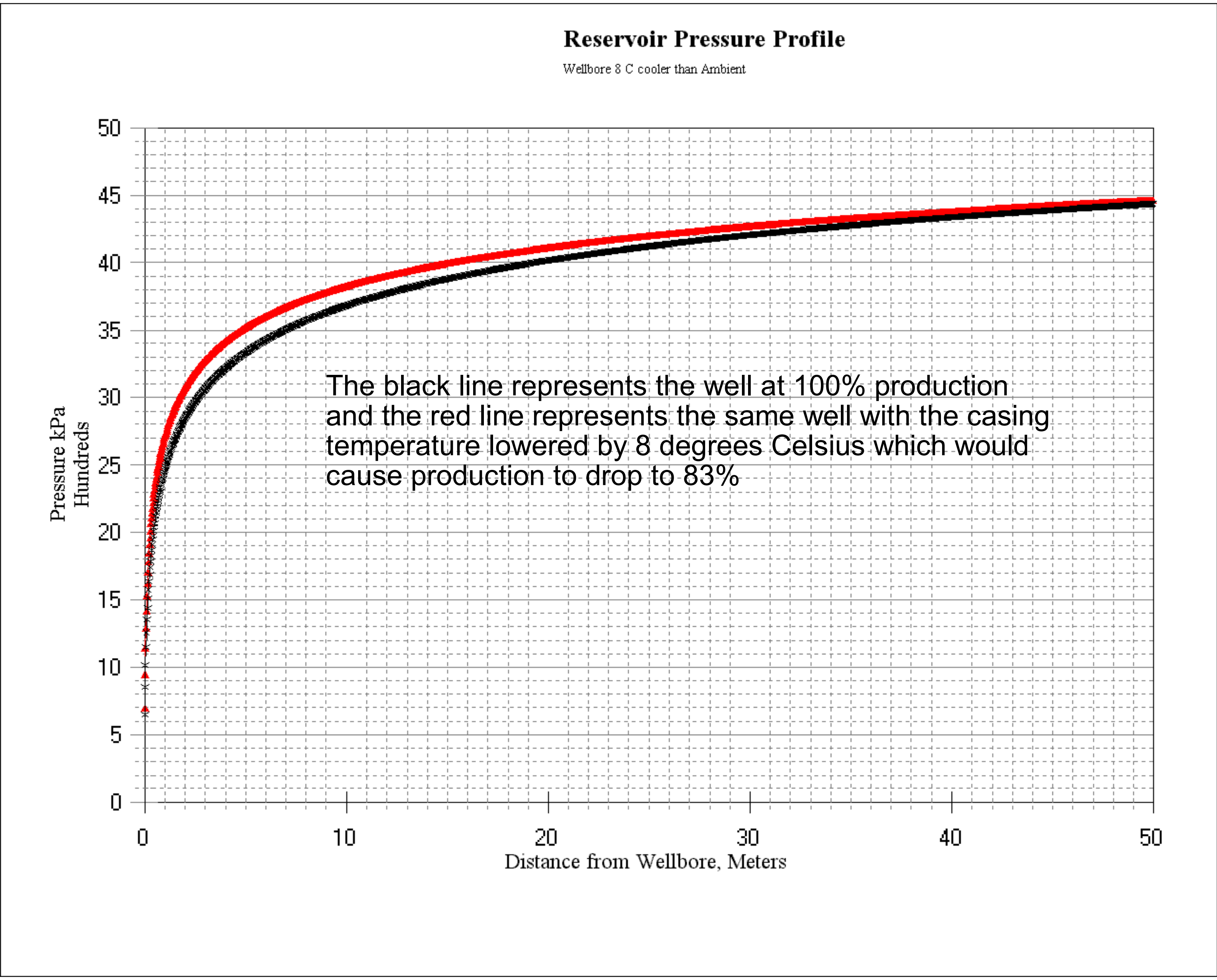
PEPS then generates pressure profiles for the heated reservoir at increased production with all other reservoir conditions unchanged



PEPS plots the pressure for each hollow cylindrical shell, calculates how many days of heating are needed to reach the increased production, and generate a "Reservoir Pressure Profile"

During start-up of many systems we have observed that the bottom hole temperature (before heating commences) is about 8 Celsius lower than the reported or expected geothermal gradient temperature and……

PEPS is able to emulate the effect of gas expansion cooling by plotting the pressure profile for a decreased wellbore temperature

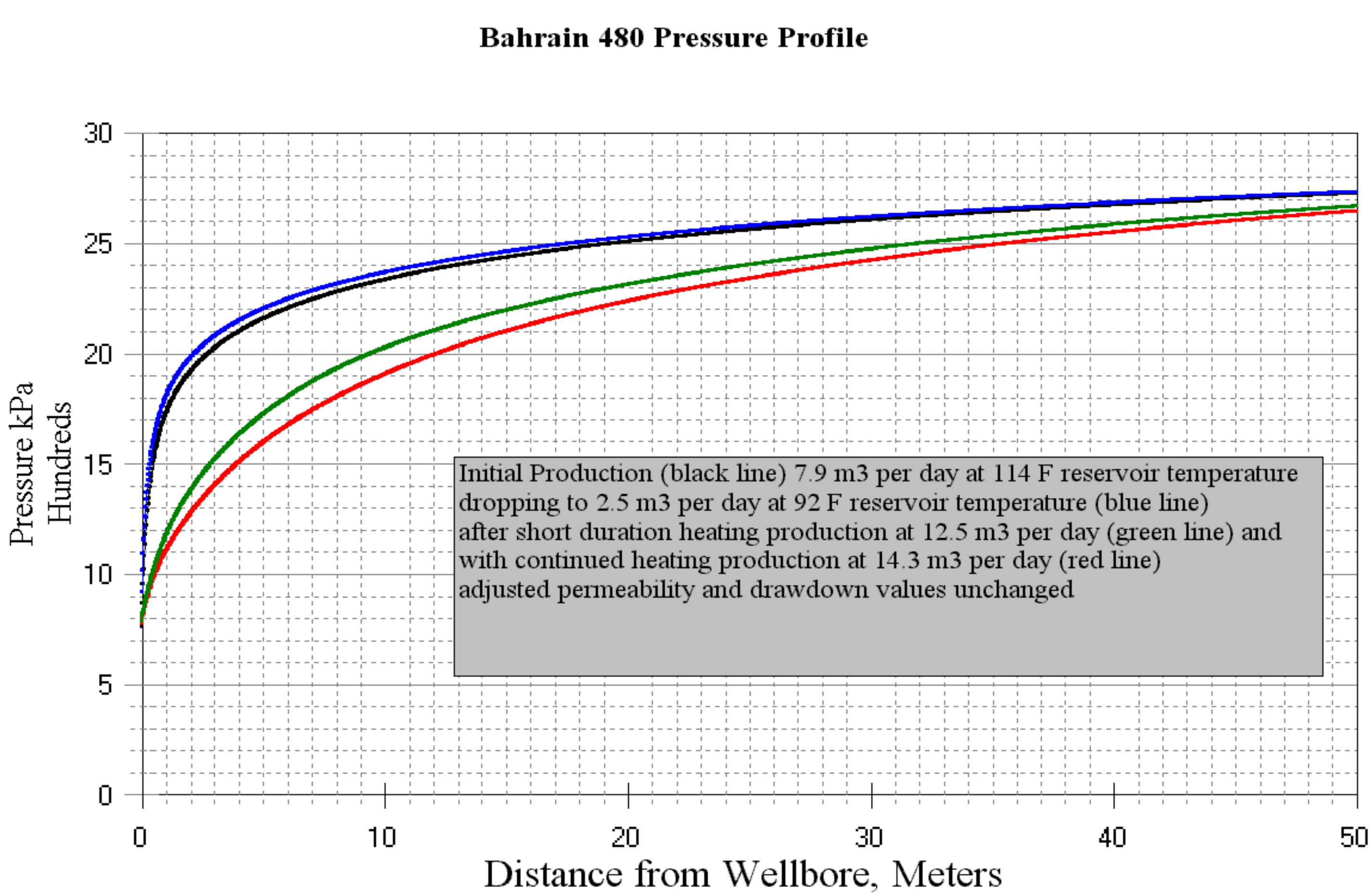


The exact nature of the lower temperature is not fully confirmed but gas expansion is suspected as a "lower than normal" bottom hole temperature has not been observed on wells without noticeable gas.

A good example of production cooling and the increase due to heating is given by the PEPS projection below and SPE paper SPE68220 on Bahrain well 480.

Well 480 had an IP of 8 m^3/d, and after two years on gas lift production declined to 2 m^3/d. It was then put on pump and after four years production was under 2 m^3/d.

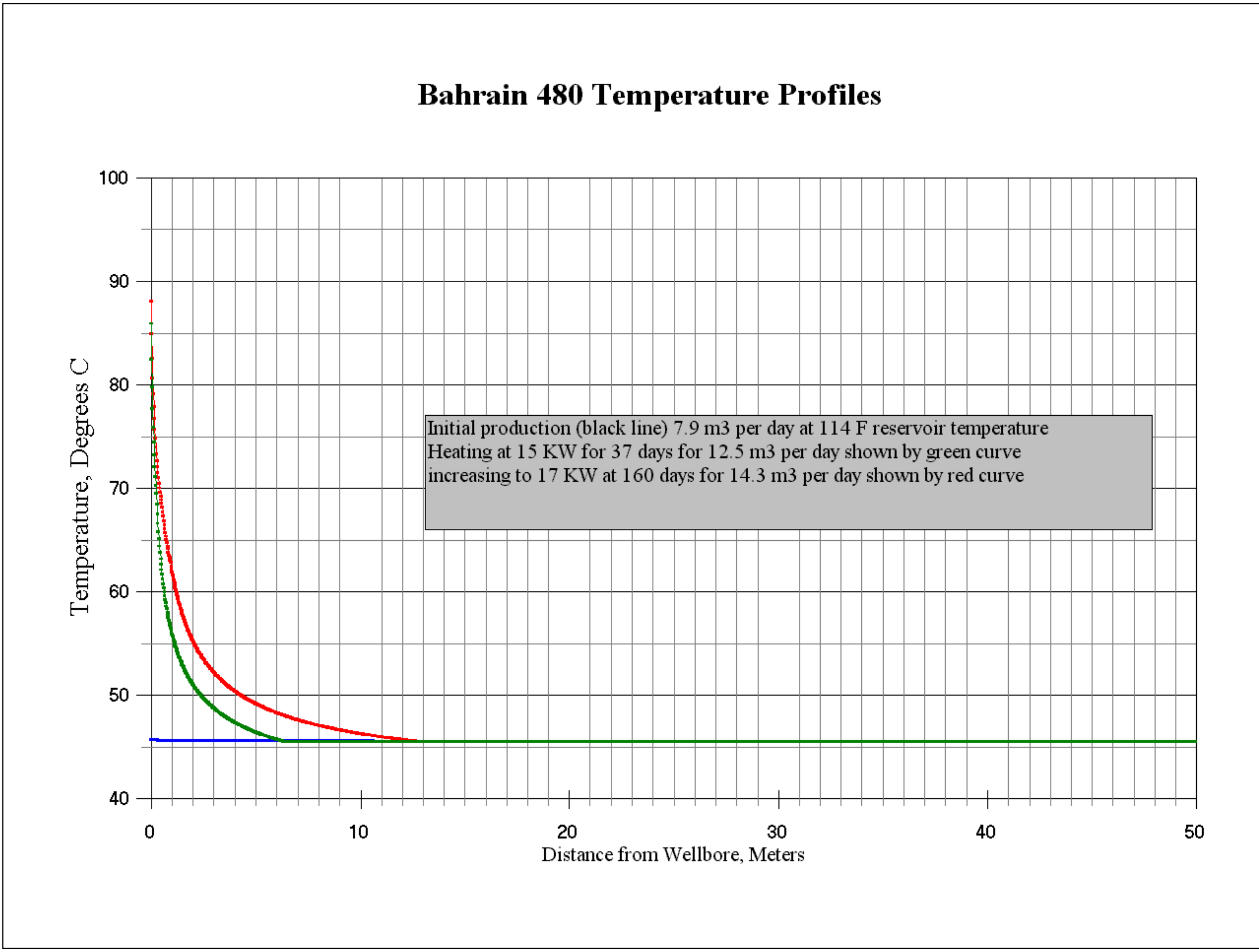
When the Induction Heater was installed it was noted that the bottom hole temperature had declined from 46 to 34 C. The black line is the IP profile and the blue line simulates the cooler reduced production profile. A few weeks of heating increased the production to 9.5 m^3/d peaking at 12.7 m^3/d.



The viscosity, reservoir pressure and dimensions were entered in the PEPS program and then the permeability was adjusted to match IP with initial 114 F bottom hole temperature. The observed temperature at the time of Heater installation was entered and it was found that the declined production matched reasonably well. The short term and medium term projections are about 10% higher than actual.

The actual power input commenced at 20 KW and as the reservoir temperature increased the power decreased to about the values projected by **PEPS.**

We noted that the power needed for 14.3 m3 per day production did not increase, as projected by **PEPS**, probably due to a drop from 60 to 30% in the water cut between the unheated and heated conditions.



Work is underway to account for change of state for wax melting and methane hydrate projections and to assess injection flow into the reservoir in conjunction with MxL Induction Heating.

We have over a year's worth of data from operation of a waxy well and shop tests for heat generation capabilities for air, gas or solvent injection.