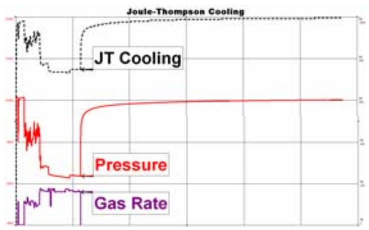
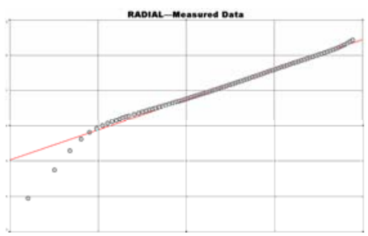
WELLTEST SPECIALISTS

*i*REPORT

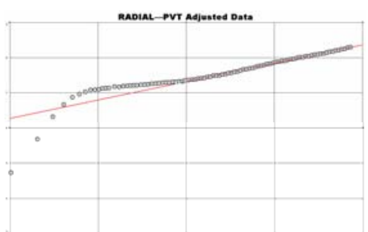
Information Report Thermal Data Valuable Diagnostic Tool for Welltest Interpretation and Analysis



Joule-Thompson (JT) Cooling



Measured: s = –1, k = 14 mD



Corrected: s = +1, k = 24 mD

Joule-Thompson Cooling Effects Alter Pressure Transient Analysis Results

In the Western Canada Sedimentary Basin most welltests are conducted in gas bearing formations. At the sandface, during production, Joule-Thompson (JT) cooling is the thermal effect most often observed. This phenomena is a result of gas expanding as it exits perforations and is a function of insitu reservoir pressure and temperature conditions. When we perform a gas well drawdown or buildup pressure transient analysis our computer software uses pseudo-pressures vs. pseudo-times. This is supposed to help account for the fact that viscosity (μ) and compressibility (Z) are *not* constant due to changing pressures (the drawdown required to flow a well). This is according to the real gas law (pv = nZRT).

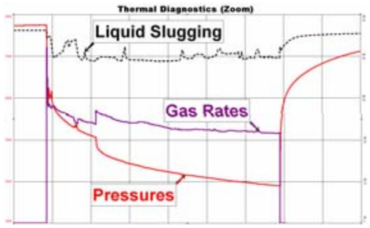
As we can see from the real gas law, changes in temperature (ΔT) also alter the pressure/ volume term, thus affecting pseudo-pressure and pseudo-time. Pseudo-variables are used to correct data for the fact that analytical equations (i.e. Darcy's law) assume *constant* conditions.

Electronic pressure gauges also measure temperature. A time/pressure/temperature data set should be provided. For purists, this is *not* a wet-gas temperature, it is the recorder housing temperature. There is a delayed response due to thermal conductivity or diffusivity of the housing itself. However, since these are the data we have available, we *should use them!* This would be analogous to converting gas flow rates to standard conditions or correcting gasoline volumes at the pump to a standard ambient temperature.

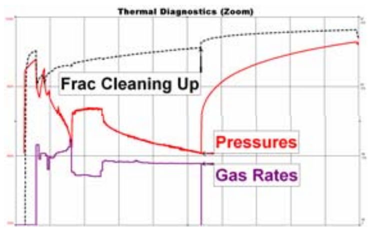
Unfortunately your software probably does *not* use the thermal data provided by electronic gauges to calculate pseudo-pressure and pseudo-time variables. As such, keep this in mind when quantitative results don't seem quite right. For instance, analytical software might indicate a false radial flow regime, negative skin or *very* nearby boundary that *can not be accounted for*. It could be thermals!

116, 4515 Bow Trail SW Calgary, AB T3C 2G3 Phone. 403–256–5767 Cell. 403–561–0409 e-Fax. 403–206–7161

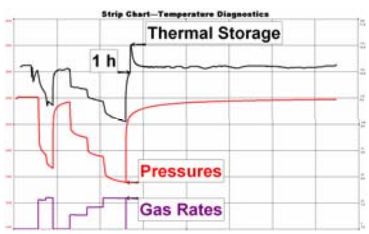
Thermal Data Trends Useful for Welltest Diagnostics



Warming = Liquid Slugging



Decreasing JT = Cleaning-up



Thermal Storage = Non-Radial

Downhole temperature data provide a useful diagnostic tool for understanding welltest behaviour. Often thermal data offer the only indication of welltest anomalies. Thermal data are also indicative of wellbore storage or afterflow effects and can help validate the start of radial flow conditions.

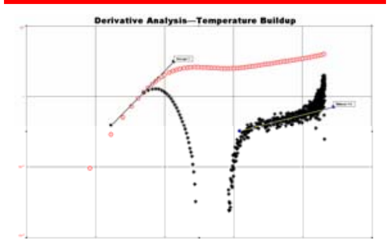
One common effect is warming spikes indicating liquid slugging, clean-up or influx. These effects may *not* be apparent from production data, if volumes are too-small-to-measure or from pressure data, if the magnitude of the anomaly is minor relative to the drawdown. Liquids have a much lower thermal diffusivity than gas so liquids stay warm longer as they are produced up-hole.

Another common effect is for the temperature data to exhibit an increasing trend (i.e. less JT cooling) while pressure data continue a decreasing trend (i.e. greater drawdown). This example indicates that the near wellbore region was continually cleaning-up throughout the post-frac welltest.

Diagnosing this situation would be important for qualifying the magnitude of the skin effect and fracture flow parameters at the end of the test (conductivity, skin-on-the-fracture-face), hence the effectiveness of an hydraulic fracture stimulation treatment and the long term transient deliverability forecast.

Research demonstrates that skin is a function of temperature. Significant JT cooling would be a function of a dramatic pressure drop across the perforations, thus indicating near wellbore damage. Negligible JT cooling would be associated with more optimal conditions. This observation has been used to qualify the nature of the near wellbore condition when pressure data have proven inconclusive for various reasons.

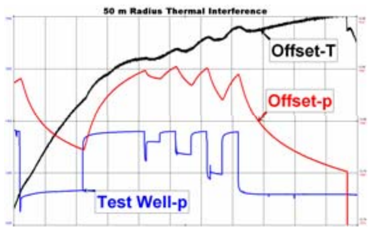
Thermal Derivative Analysis Indicative of Lithology Characterization



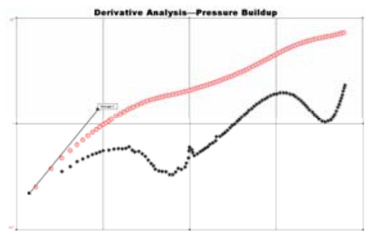
One overlooked characteristic of thermal welltest data is the interpretation of lithology changes. The temperature buildup, as temperatures return to insitu conditions, is a function of lithology conductivity, which differs for gas filled pores vs. liquid filled or for sandstone vs. shale. One diagnostic approach is to examine a *temperature* derivative plot.

The example illustrates a steadily increasing slope commonly associated with heterogeneous lithology.

Thermal Interference Demonstrated Beyond 50 m Radius



JT Cooling @ Pore Throat



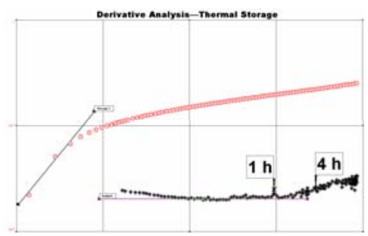
Complex Derivative Behaviour

A common assumption is that temperature changes around a wellbore do not penetrate deep into the formation during a test. Considering only thermal diffusivity and conductivity of the system (steel pipe, cement, reservoir rock), this assumption is reasonable.

However, Joule-Thompson (JT) cooling, a gas expansion phenomena, occurs *at the pore throat*, wherever that may be in the reservoir. The magnitude of the pressure drop that is required to cause JT cooling would be a function of permeability. The example is from a high permeability system and demonstrates pressure and *temperature interference* in an observation wellbore 50 m away from the production wellbore.

Such extensive alteration of reservoir temperatures suggests that a considerably long time might be required for the formation to return to insitu thermal equilibrium. Temperature recoveries lasting in excess of 1000 h been observed from the data provided by electronic pressure gauges. Moreover, such non-isothermal conditions might have implications on quantitative modeling results such as skin, permeability and transient gas deliverability forecasts, as all equations *assume* isothermal conditions. It *may not be possible* to quantify the effect of non-isothermal conditions on analytical results.

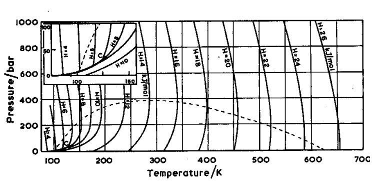
Thermal Data Helpful for Identifying Valid Radial Flow Conditions



Thermal Storage–Derivative

Welltest temperature data can be reflective of wellbore storage or afterflow effects and can help identify valid radial flow conditions. This example is the pressure derivative response for the thermal storage example presented above. Note what appears to be very early radial flow followed by a transmissivity (kh/μ) change only one hour after shut-in. Thermal diagnostics suggests that the pressure derivative behaviour during the initial 4 h of shut-in was likely affected by thermal storage effects (warming combined with gas compression). Hence, only pressure data *beyond 4 h* would be considered indicative of true reservoir characteristics and validity of the coincidental 'radial flow' would be questionable.

Wet Gas Temperature Sensors



Wet gas temperature sensors (as in production logging) could easily be added to modern electronic pressure recorder designs. As the use of temperature data increases for welltest diagnostics, limitations of using recorder *housing* temperatures will quickly become apparent. As recorder carrier (housing) designs differ between manufacturers, so does heat capacity and thermal conductivity and, hence, apparent thermal behaviour, such as JT effects, the phenomena illustrated by these N_2 p/T inversion curves.

Upgrading Analytical Software

PTTA—Pressure-Temperature Transient Analysis

Finally, Welltest Specialists Inc. believes welltest analysis software should be upgraded to utilize the available temperature data for calculation of pseudo-pressure and pseudo-time variables. This should not pose a significant problem to programming code. Since thermal data are already there (essentially free for the taking), they might as well be used to better our interpretative insight and quantitative results.

☑ Thermal Data Qualification

Qualify Your Application

This information report on thermal data is provided as a means of disseminating thoughts, information, knowledge and experience. The very nature of well testing is interpretative, as much art as science, such that there are no definitive answers. The magnitude of impact on quantitative results must also be qualified. Open discussion of the topics presented herein are encouraged.

ⓘ Selected Reference

Information Source

Contents of this information report were derived from the technical paper CIM 2000–31 *"Field Data Demonstrate Thermal Effects Important in Gas Well Pressure Buildup Tests"* by Robert V. Hawkes, CET, Ze Su, PhD and David Leech, BTech.

david@welltestspecialists.com

David Leech, BTech, Welltest Specialists Inc. 403–256–5767