WELLTEST SPECIALISTS

*i*REPORT

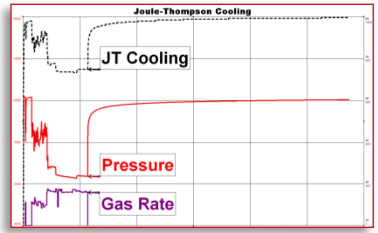
Welltest 105: **Thermal Data**

Welltesting & Thermal Data

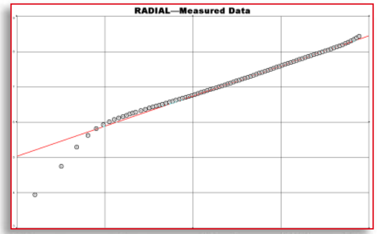
Responsibility Chain Management	Petroleum Reservoir and Production Engineering teams initiate hydrocarbon welltests. Well testing is about measuring and recording flow rate and pressure/temperature data. Thermal data provide vital diagnostics. Responsibility chain management of data requires an integrated team: from wellsite acquisition or collection; to field-office processing, data validation, and technical reporting; to engineering analysis (PTA, AOF, IPR) and legal submissions (AER, SEC). Corporate directors, managers, and stakeholders depend on reliable, traceable, advice from testing wells.
Welltesting Team	Talented and experienced wellsite equipment operators are always appreciated for safe running, installation, and recovery of scientific instruments. Knowledgeable and particular field-office technicians are valued for accurate, timely technical reporting. Engineers need to know what standards to expect, and to do whatever data processing might be required to achieve professional acceptance.
Wireline Team	Slickline operators, equipment, tools, and instruments are intrinsic to petroleum welltesting. Subsurface pressure recorders include sensor temperature data. Stand-alone 'wet' temperature recorders are occasionally a useful addition for flowing gradients and production optimization.
Engineering Team	Engineering is quirky: words are different, acronyms are strange, expectations are high, accuracy and precision are standard protocols. All staff in the responsibility chain need an awareness of equipment, tools, and operations. Practical knowledge about quality control, data validation, and technical reporting ensures consistent, reliable deliverables. Literacy with oil patch nomenclature (words, acronyms, subscripts, superscripts) is requisite for effective communication and comprehension.
Bridging Technical Gaps	Welltest Specialists technical training material has been written to bridge technical gaps and help new staff get up to speed with welltest engineering workflow and workspace.
Thermal Data	This *i*REPORT will focus on observations and diagnostics related to temperature data included with recorded subsurface pressure data.

Welltest 105: Thermal Data

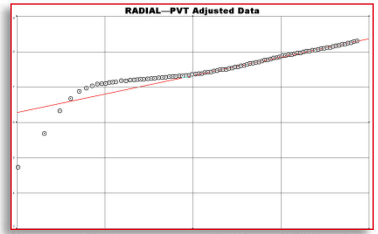
Joule-Thompson Cooling Effects



Joule-Thompson (JT) Cooling



Measured: s = –1, k = 14 mD



Corrected: s = +1, k = 24 mD

Western Canadian Sedimentary Basin welltests are often conducted in gas bearing formations. At the sandface, during production, Joule-Thompson (JT) cooling is the thermal effect most often observed. This phenomena is the result of gas expansion on exiting narrow perforations. Reservoir pressure and temperature conditions factor in. Pressure Transient Analysis (PTA) software uses pseudo-pressures vs. pseudo-times for compressibility corrections in gas because 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).

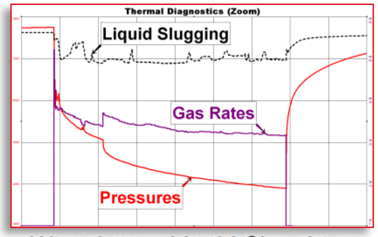
As we can see from the real gas law, changes in temperature (ΔT) also alter the pressure/ volume balance (pv), thus affecting pseudo-pressure and pseudo-time calculation algorithms. Pseudo-variables are used to correct data for the fact that analytical equations (i.e. Darcy's law) assume *constant* conditions. This is analogous to conversion of gas flow rates to standard conditions or correcting gasoline (petrol) volumes at the pump to a standard ambient temperature.

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 sensor or element temperature (strain, quartz). 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!*

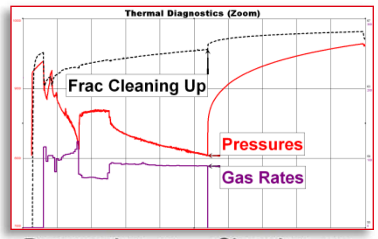
Unfortunately analytical software *does not use thermal data* as provided by electronic gauges to calculate pseudo-pressure and pseudo-time variables. Only one input temperature is employed for all running calculations (middle plot). Using the associated temperature for every calculation resulted in the bottom plot. 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 a *very nearby boundary* that cannot be accounted for by geology. It could be thermal effects!

Welltest 105: Thermal Data

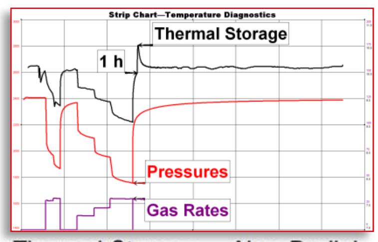
Thermal Data Diagnostics



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.

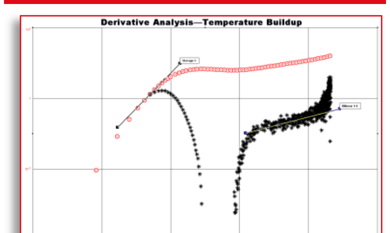
One common effect is **warming spikes** indicating liquid slugging, clean-up, or influx. These effects *may not be apparent* from production data, if volumes are too-small-to-measure, or from pressure data, if the magnitude of the anomaly is minor relative to the drawdown. Liquids have a much lower thermal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

Another common effect is temperature data exhibiting **decreasing JT effects** (i.e. progressively less JT cooling) while pressure data continue a decreasing trend (i.e. greater drawdown, which should increase JT effects). This example suggests 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): fixed only at the moment in time of shut-in. Analytical PTA equations do not account for changing skin, which is why pressure build-up or fall-off tests are better than drawdown tests. Effectiveness of hydraulic fracture stimulation treatments, and long-term transient deliverability **forecasts may be pessimistic** if the well continues cleaning up, i.e. flow capacity continues to improve, after the welltest.

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

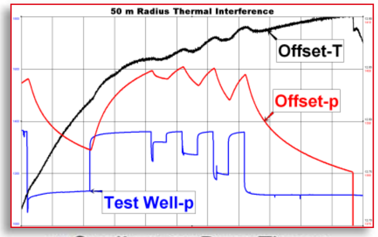


One overlooked characteristic of thermal welltest data is the interpretation of lithology changes. The temperature buildup, as temperatures return to insitu conditions, is a function of lithology conductivity, which differs for gas filled pores vs. liquid filled, or for sandstone vs. shale. One diagnostic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

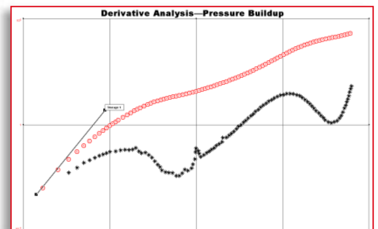
The example illustrates a steadily increasing slope commonly associated with heterogeneous lithology, corroborating with geology.

Welltest 105: Thermal Data

Thermal Interference



JT Cooling @ Pore Throat



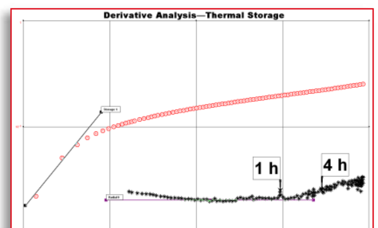
Complex Derivative Behaviour

A common reservoir engineering 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 producing 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 have been observed from data provided by electronic pressure recorders. Moreover, such non-isothermal conditions might have implications on quantitative modeling results such as skin, permeability, and transient gas deliverability forecasts, because *analytical equations assume isothermal conditions*. Numerical modelling is another issue.It may not be possible to quantify the effect that non-isothermal conditions have on analytical results.

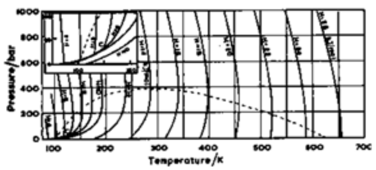
Valid Radial Flow



Thermal Storage–Derivative

Welltest temperature data can be reflective of wellbore storage or afterflow effects, and 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 boundary or transmissivity (kh/μ) change, only one hour after shut-in. Thermal diagnostics suggest 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. Validity of the coincidental ‘radial flow’ discounted.

Wet Gas Temperature Sensors



Limitations of using *recorder element temperatures* has been demonstrated. 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 is illustrated by these N_2 p/T inversion curves. Some welltesting objectives require running wet gas temperature gauges in tandem with pressure gauges. Wet gas (fluid) temperature sensors (as in production logging) could easily be added to modern electronic pressure recorder designs…

Call-to-Action

Pressure-Temperature Transient Analysis (PTTA)

Welltest Specialists believe that pressure transient analysis (PTA) software should be upgraded to utilize the readily 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 *i*REPORT 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 is encouraged.

Selected Reference

Information Source

Contents of this *i*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.

Contact

david@welltestspecialists.com

David Leech, BTech, PL(Eng), Welltest Specialists Inc. 403–256–5767, www.welltestspecialists.com