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Adiabatic Heat

On occasion, customers will experience a little known phenomenon called adiabatic heating that can cause damage to a wireline when equalizing pressure between the well and lubricator. This condition usually occurs when a main valve is opened to a pressurized wellbore very quickly allowing the air in the lubricator's riser to compress rapidly and heat up to the point of melting the wireline inside (see Fig. 1). While this issue is easily avoidable by following best practice procedures, the concept can be difficult to understand and often requires a deeper explanation of which this memo will attempt to provide.

FIG. 1

The problem is to calculate what happens when a "frac" valve is opened very quickly to allow fluid at high pressure to enter a section of riser pipe that is filled with air at atmospheric pressure.

The formula for the rise in temperature of air, when it is compressed so rapidly that there is not time for any significant amount of heat to be lost is:

$$T2 = T1 \left(\frac{P2}{P1} \right)^{\frac{(k-1)}{k}}$$

This is called an adiabatic compression. In practice you could never compress the air fast enough to keep from some heat being lost but this calculation sets an upper limit.

T1 = Temperature of air trapped in the riser, (75+235) = 310R (Rankin)
T2 = Temperature of air in the riser after an adiabatic compression, Degrees R (Rankin)
P1 = Absolute pressure of air before compression = 15 psi
P2 = Absolute pressure of air after compression = 3,500 psi
k = Ratio of specific heats for air changing state at constant pressure divided by the specific heat for air changing state at constant volume = 1.4

Using the values above the calculated temperature of the air after an adiabatic compression would be:

$$T2 = 310 \left(\frac{3500}{15} \right)^{\frac{(1.4-1)}{1.4}}$$

T2 = 1470R, (1470R-235 =1235F).

- **T2 = 1200F the temperature, in degrees F, of the air after compression from 15 psia to 3500 psia without any loss of heat.**

Consider a 26 foot riser with an ID of 5”. In the riser is a 24 foot tool that is 3.125” in diameter. The volume, Vr, filled with air at 15 psia is:

$$Vr = \pi (Dr)^2 \; Lr - \pi (Dt)^2 \; Lt$$

Dr = 5 inches
Lr = 26 X 12 = 312 inches
Dt = 3.125 inches
Lt = 24 X 12 = 288 inches

Vr = 16,000 Cubic inches, (9.25 lbs.)

The volume after adiabatic compression, Vrc is:

$$Vrc = Vr \left(\frac{T1}{T2} \right)^{\frac{1}{k-1}}$$

Vrc = 500 Cubic inches.

The length of the column of compressed air in the riser, Lrc, is:

$$Lrc = \frac{Vrc}{\pi (Dr)^2}$$

Lrc = 6 inches

The amount of heat generated in this compression can be calculated:
Wa = Weight of air in riser = 9.25 lbs
cp = specific heat for air = 0.24
Q=Heat Generated = Wa(cp)(T2 – T1) = (9.25)(0.24)(1235 – 75) = 2575 BTU

If the tool is near the bottom of the riser, then there is about 2 feet of cable in the riser and it will be the 6 inches of cable that is exposed to the highest temperatures of the compressed air. Temperatures of 1200 F can quickly damage the cable and can even affect the metallurgy of the armor wire. With about 2500 BTU available from the compressed gas applied to this short section of cable, irreversible damage to the cable end can be expected.

Here are some things to keep in mind:

- The **maximum temperature** the air will reach is determined **only** by the pressure change, i.e. going from atmospheric, 15 psi to 2500 or 3500 psi.
- The **amount** of heat available at this high temperature, to damage the cable, increases directly with the height of the air column and the square of the diameter of the casing.
- Keep in mind that the theoretical calculated maximum temperature is based on the condition that the pressure change is so rapid that there is not enough time for the air to escape through the packer and flow tubes or for heat to be conducted away by the casing.
- In the real world, some air will escape and some heat will be conducted away but if the valve is opened fast enough, you can reach temperatures high enough to melt cable insulation and affect the armor metal properties.

If these high temperatures seem unreal, go put your hand on the head of an ordinary air compressor. Even a 150 psi compressor gets quite hot, so when you are dealing with a compression to 3500 psi you can expect much higher temperatures.

The solution to avoid these high temperatures is to flood the air space in the riser with water before opening the valve or crack the valve very slowly to allow the heat to be dissipated.