Insulated Tubing/Annulus Options

- Vacuum insulated tubing - distinct joints
- Vacuum insulated tubing - longer strings
- Tubing wrapped with insulation
- Expandable casing wrapped with insulation
- Stable foam filled annuli
- Nitrogen filled annuli (low & high press)
- Gelled diesel/water filled annuli

Heat Loss Methods

- Conduction is a major method of heat transfer in opaque solids such as pipes. If temperature at one end of a metal rod is raised, heat travels to the colder end.
- Convection is conduction between two objects that contact. Conduction between a solid surface and a moving liquid or gas is called convection. The motion of the fluid may be natural or forced. Reducing the motion, the heat capacity of the density of the fluid reduces the amount of heat transferred per unit of time.

Heat Loss Methods

- Radiation is different from both conduction and convection, because the substances exchanging heat need not be touching and can even be separated by a vacuum. The higher the temperature, the greater the amount of energy emitted. In addition to emitting, all substances are capable of absorbing heat. The absorbing, reflecting, and transmitting qualities of a substance depend upon the wavelength of the radiation and the conditions of the surfaces.

Convection

- The effects of convection heat transfer are minimized when there is little or no movement of a fluid in the annulus. Field analysis of gelled annular fluids has shown very good heat transfer reduction (50%) when the annular fluid movement is minimized. There are direct correlations between increasing fluid viscosity and reduction of heat loss.

Insulation Values
R/inch of thickness

N_2 with moisture and convection	0.001
Water (no convection - gelled)	0.13
Diesel, gelled	1.3
Nitrogen gas with no convection	2.3
Vermiculite	2.3
Cellulite	3.1 to 3.7
Glass Fiber	3.2 to 3.6
Rock Wool	3.5
Ceramic Beads	3
Polystyrene	3.6 to 5.0
Urethane Foam (rigid foam)	5.5 to 6.0
Vacuum Insulated Tubing	20 to 30+

Heat Conductance Values

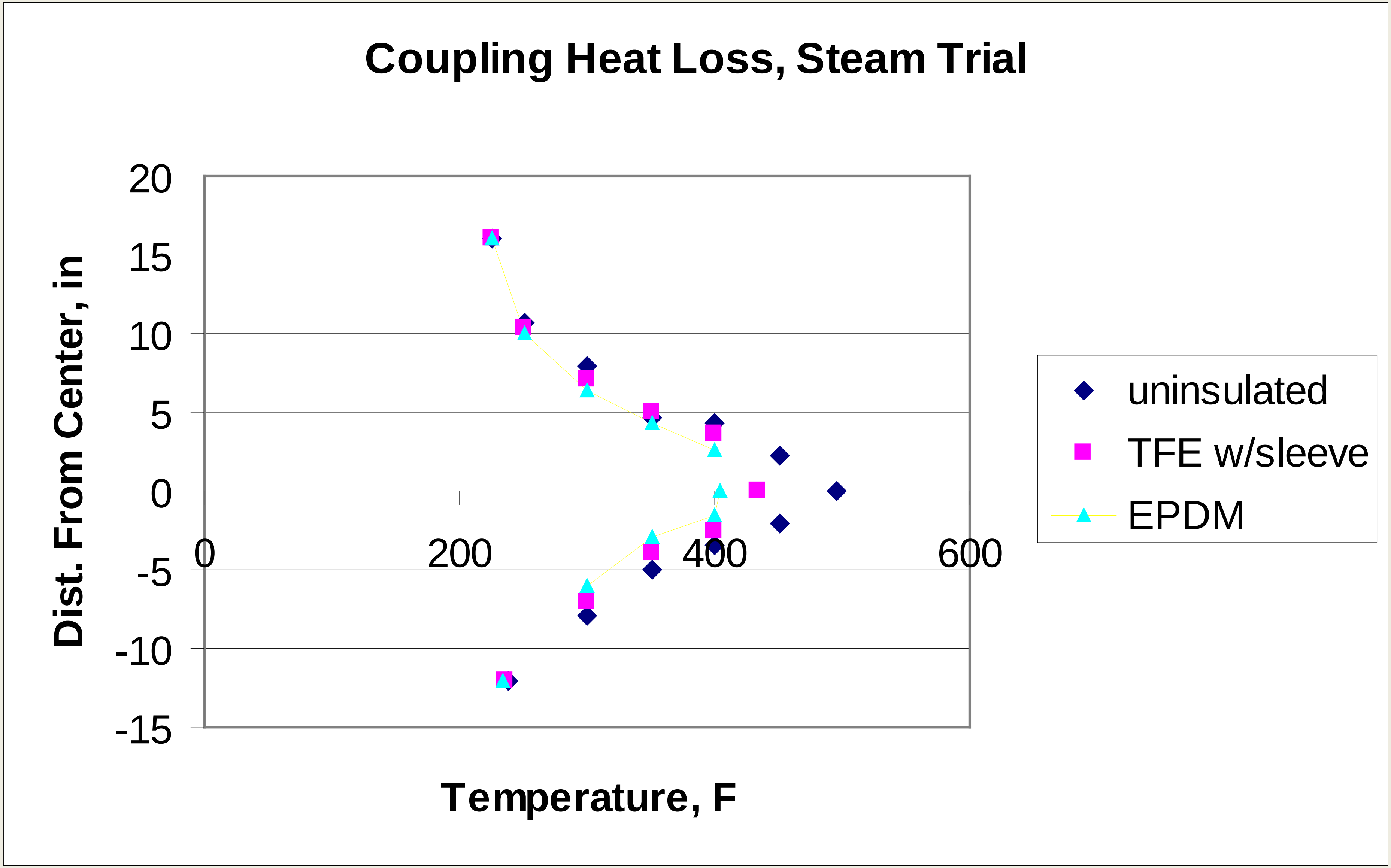
Water	0.385 BTU/(hr F ft)
Ceramic bead blanket	0.38
Calcium silicate liquid	0.268
Sodium Silicate liquid	0.176 - 0.187
Nitrogen gas	0.06 to 0.128
Ungelled Diesel	0.0827
Urethane foam	0.08
Gelled diesel	0.063
Gelled oil (N PAK from IMCO)	0.05
Vacuum Insulated tbg (best)	0.00438

Nitrogen gas difference is lab and field – convection is maximized in the field and minimized in the lab.

Conclusions (pt 1)

1. Vacuum insulated tubing (VIT) remains the best choice for reducing heat loss from producing fluids.
2. Heat loss from vacuum insulated tubing is most pronounced at the coupling. Coupling insulation methods are available but are less effective than the VIT body. Refluxing fluids and evaporating/condensing fluids on the outside of VIT are the main cause of heat loss.
3. Insulation wraps, regardless of type or design, are typically only fractionally as efficient as vacuum insulated tubing. The wrapped tubing insulation also has problems of scraping damage or fluid saturation damage to the wrap-on installation. Steel shells, coatings and hard foams have improved the durability.

Heat loss at a coupling on VIT . Heat measured on the outside of a insulated pipe with flowing steam on the inside.



Conclusions (pt 2)

4. Gelled annular liquids have the capacity to cut heat loss by 50% or more over ungelled liquids.
5. Nitrogen fill annuli are more effective in reducing heat transfer than liquid filled annuli, but suffer from convection which increases heat transfer.
6. Pressurized nitrogen and nitrogen foams have limited ability to reduce heat flow and are not comparable to vacuum insulated tubing.

Silicates, Foams, Nitrogen

- Other types of insulation in the annulus include nitrogen, silicate and foams. Each has potential for reduction of heat flow, but they do not compare to the heat flow reduction gained with vacuum insulated tubing.

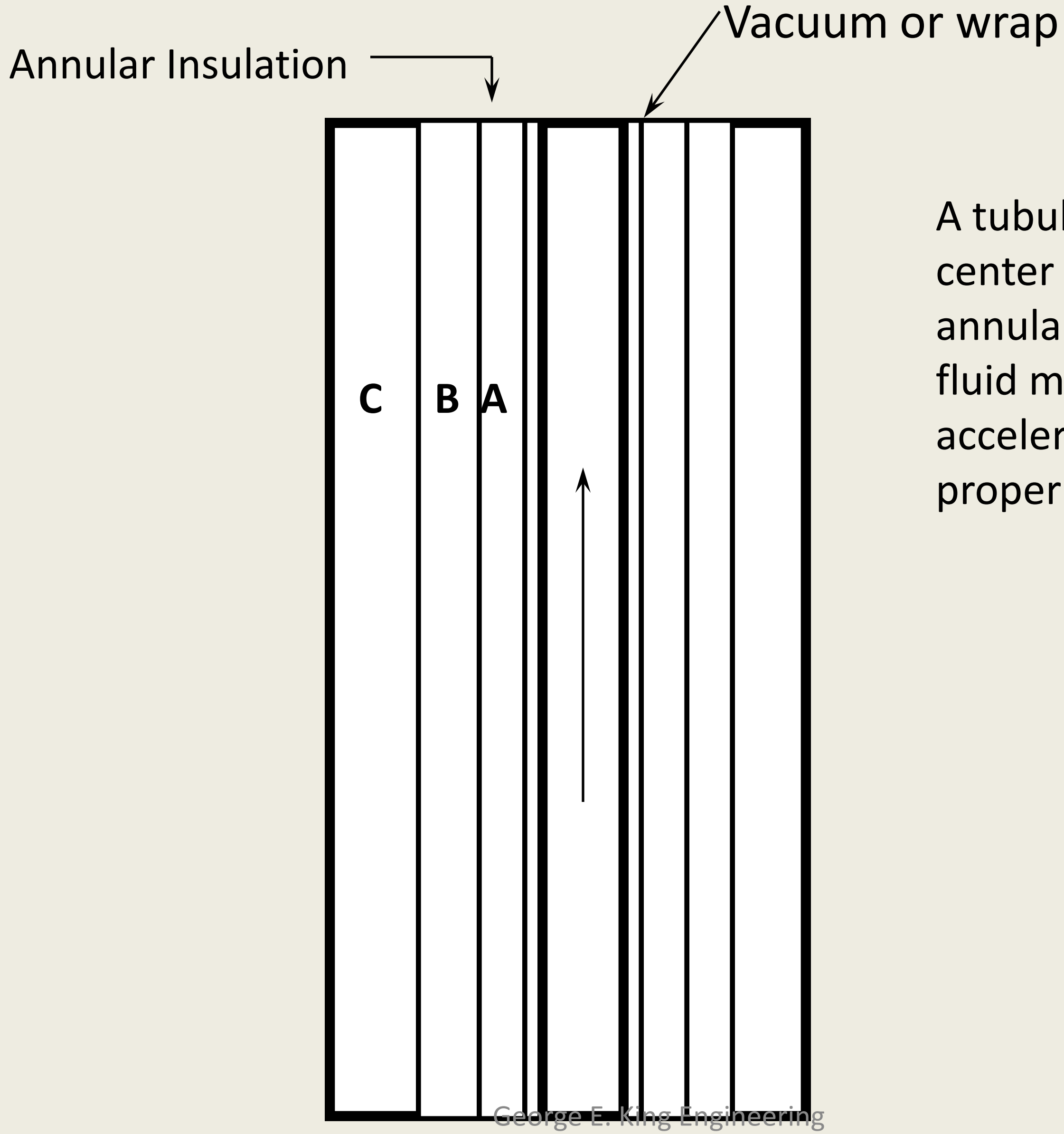
Nitrogen Insulation Problems

- a foam (75% gas,25% water) has 2.5 times less heat flow conductance than straight nitrogen gas. The difference is that the foam viscosity keeps fluids from mixing and transferring heat - convection. Most “liquid” foams (as opposed to rigid foams like styrafoam) , however, are not stable.
- Increasing pressure on the Nitrogen gas even slightly increases gas density and the heat transferred since there is more mass (more heat capacity) and almost no inhibition to mixing.

Nitrogen Insulation

- Heat transfer = Density $^{2/3}$
- Gas density varies markedly with pressure, where as viscosity is relatively unaffected by density.
  so: a 10 fold and a 100 fold increase in pressure would mean a 5 and 22 fold increase in heat transfer, respectively.

Heat Transfer - Insulation points



A tubular flow path in the center surrounded by annular spaces where fluid movement can accelerate heat loss unless properly insulated.

For radial heat flow by conduction through concentric tubulars, the transfer is:

$$q_k = 2\ pi\ k\ l\ \ dT / (\ln r_o / r_i)$$

where:

q_k = rate of heat flow by conduction, BTU/hr

pi = 3.14

k = thermal conductivity coefficient, BTU / (hr ^{o}F ft) across annuli

l = length of casing, inches

dT = differential temperature across annuli, ^{o}F

r_o = radius of tubing, inches

r_i = radius of casing, inches

The insulation provided by a wrap type material (Speed Tech Data construction application shown for example) is shown in the following table; the numbers are from construction material tests at ambient air around a pipe with 200°F contents and is specific for a 6" pipe. There are various suppliers of insulating wrap and no direct oilfield experience has been found at the time of this writing.

Conditions	Bare Pipe	1/8" wrap	¼" wrap
80°F ambient	461 Btu/hr-ft	253 Btu/hr-ft	165 Btu/hr-ft
45°F amb+15mph wind	1538 Btu/hr-ft	506 Btu/hr-ft	271 Btu/hr-ft

There is obviously some benefit from the wrap insulators, particularly when the area away from the coupling is considered. Combining an internal insulator and a wrap is clearly better than either process alone.