



HEAT TRANSFER WITH CATALYTIC HEATERS

TECHNICAL BULLETIN TB-2010 1 OF 2

prepared by:

Enviro Vault

#105 - 7370 Sierra Morena Blvd. S.W.

Calgary, Alberta

T3H 4H9

Gareth Evans, Project Engineer E.I.T.

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1.0 Introduction

TECHNICAL BULLETIN TB-2010 1 OF 2 HEAT TRANSFER WITH CATALYTIC HEATERS

Enviro Vault® developed the patented concept of installing an “Internal Chamber” inside of an oilfield tank to house valves, heaters, level controls, and provide spill containment. Resources of both the Canada Industrial Research Assistance Program (NRC-IRAP) and the Alberta Innovates - Technology Futures (AITF, formally the Alberta Research Council) are being utilized for a research and development project. For years, Enviro Vault® has been able to offer freeze protection in tanks by installing a catalytic heater. Now, the aim is to expand that application and use catalytic heaters installed in an Enviro Vault® (vault) to elevate and maintain fluid temperature. Energy requirements, fuel efficiencies, and air emissions are being analyzed while comparing against a conventional fire tube application. A heater sizing calculator is in development to analyze heating requirements for a variety of tank sizes and applications. Initial calculations show positive indicators that confirm Enviro Vault’s recommendations for freeze protection. An 18” x 24” catalytic heater inside an Enviro Vault® is capable of providing freeze protection for tank fluids and valves in an insulated 400 bbl tank. The next step is acquiring test data through an independent third party (AITF) for verification. Results will be used to size multiple catalytic heaters for the ThermoVault™. Enviro Vault’s vision in bringing the

ThermoVault™ to market includes;

- *increased operational safety*
- *an alternative to firetubes and expensive regulation compliant fuel gas trains*
- *heat for light oil applications which, when using a firetube, is against regulations in some areas*
- *potential carbon tax savings to producers*

Analysis of a Typical Hot Oil Tank

Tank and fluid properties include:

Size	400 bbl
Material	Steel
Dimensions	12’ diameter and 20’ height
Shell, Roof & Floor	3/16” shell and roof with ¼” floor A36
Insulation	1.5 inch thick layer of spray foam U factor of 0.1 BTU/hr/°F/ft ²
Flow rate	50 bbl/day, 90% water, 10% oil (API 45°)

2.0 Energy Balance HEAT TRANSFER WITH CATALYTIC HEATERS

The following assumes that heat is supplied by the thermal energy of methane. Fuel energy will be required to heat incoming fluid up to tank temperature, balancing cooling losses from the tank to the atmosphere and compensate for inefficiencies in transfer of heat from the heater to the tank fluid. Newton's Law of Cooling governs the loss of heat to the atmosphere by convective heat transfer from tank surfaces. Heat losses due to inefficient heat transfer can be calculated and/or determined by measuring energy contained in the exhaust gas of the heater.

The heat duty is expressed in the following equation:

$$\text{Eqn. 1: } m_{\text{CH}_4} \times (\Delta H)_{\text{rxn}} = m_f \times C_{p_f} (T_{\text{out}} - T_{\text{in}}) + q_{\text{loss}} + q_{\text{bloss}}$$

where: m_{CH_4} = mass rate of methane, lb/hr

$(\Delta H)_{\text{rxn}}$ = delta heat of reaction, BTU/lb

m_f = mass rate of tank fluid, lb/hr

C_{p_f} = specific heat capacity of tank fluid, BTU/ lb/°F

$(T_{\text{out}} - T_{\text{in}})$ = temperature difference, °F

q_{loss} = heat losses, BTU/hr

q_{bloss} = heat losses in burner exhaust, BTU/hr

3.0 Heat Transfer Analysis

Heat is transferred from the catalytic heater to the process fluid through a combination of radiation, convection and conduction. Tank heat losses to the atmosphere will also be examined.

3.1 Radiation

Heat transfer through radiation is dependent on surface temperatures, emissivity and geometry in this application. Two infinite sized plates radiating to each other is selected for modelling because the catalytic heater is mounted within a few inches of the vault wall ($L/d > 20$). The heat flux equation is as follows:

$$\text{Eqn. 2: } q = \sigma \times (T_1^4 - T_2^4) / (1/\epsilon_1 + 1/\epsilon_2 - 1) \quad \text{where: } q = \text{heat flux per unit area, BTU/hr/ft}^2$$

σ = Stefan-Boltzman const, BTU/hr/ft²/R⁴

T_1 = hot surface absolute temperature, R

T_2 = cold surface absolute temperature, R

ϵ_1 = emissivity of hot surface, no units

ϵ_2 = emissivity of cold surface, no units

$$\sigma = 0.1714 \times 10^{-8} \text{ BTU/hr/ft}^2/\text{R}^4$$

$$T_1 = 1210 \text{ R (750 }^\circ\text{F, heater manufacturer recommended)}$$

$$T_2 = 535 \text{ R (75 }^\circ\text{F, tank temperature)}$$

$$\epsilon_1 = 0.88 \text{ (heater manufacture recommended)}$$

$$\epsilon_2 = 0.96 \text{ (based on rusted steel value of 0.94)}$$

3.0 Heat Transfer Analysis

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Using Eqn. 2, radiative heat transfer from a catalytic heater to the tank is estimated at 3,000 BTU/hr/ft². The heater manufacturer claims that their heaters are valued at 5,000 BTU/hr/ft². Enviro Vault[®] will be testing the heaters to verify the actual heat transfer.

Maximum radiative heat transfer can be achieved by operating the heater as hot as possible. Enviro Vault[®] must note that 800 °F is the limit for the Class 1, Div 1 explosion proof rating on the catalyst pad. The vault should also be painted flat black to maximize radiative transfer. Figures 1 and 2 demonstrate a strong relation of the rate of heat transfer to the catalytic heater surface temperature and emissivity. Figure 3 shows that radiative heat transfer is a weak function of tank metal temperature below 150 °F. Radiative heat flux declines with tank metal temperatures above this value.

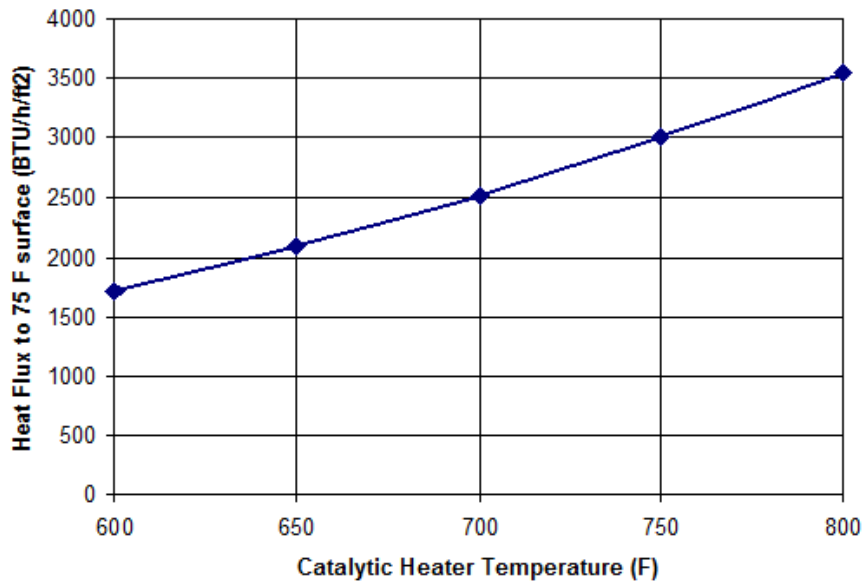


Figure 1: Effect of Catalyst Surface Temperature on Heat Transfer

3.0 Heat Transfer Analysis CONTINUED

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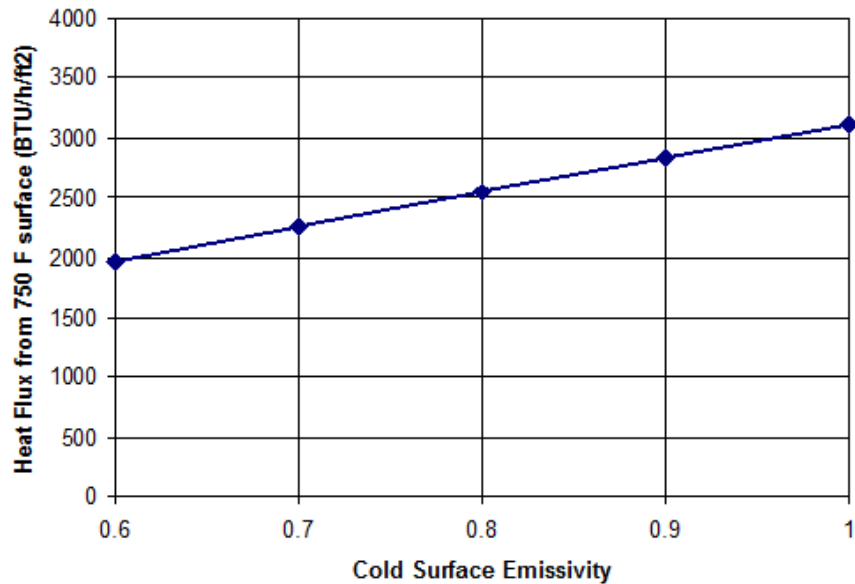


Figure 2: Effect of Tank Surface Emissivity on Heat Transfer

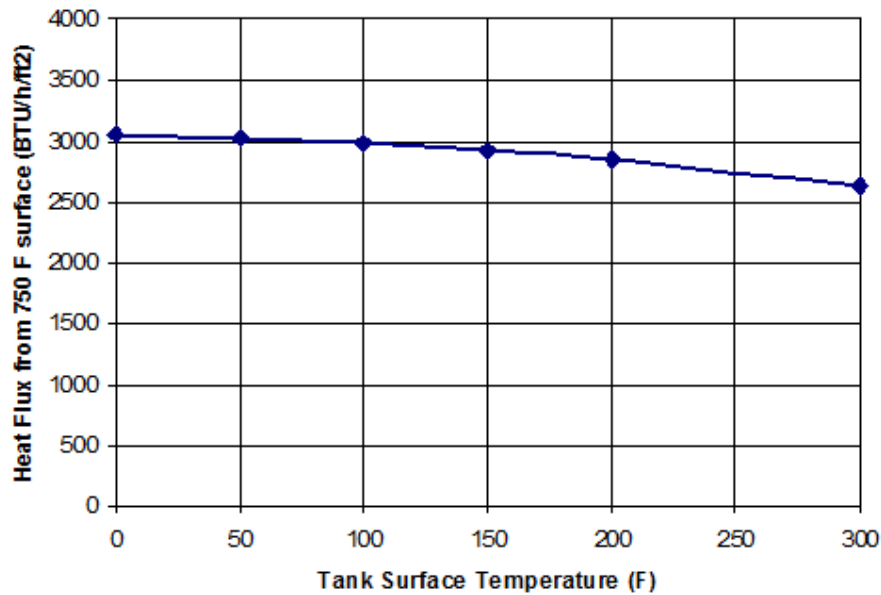


Figure 3: Effect of Tank Surface Temperature on Heat Transfer

(Chambers, Nikoo; 2010)

3.0 Heat Transfer Analysis

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3.2 Convection

Heat transfer through convection from a fluid to a solid surface depends on fluid speed and fluid properties. Approximate heat transfer coefficients depending on the type of flow are: 1-5 BTU/hr/°F/ft² for free convection with air, 2-100 BTU/hr/°F/ft² for forced convection with air, and 20-3000 BTU/hr/°F/ft² for forced convection with water. In addition to radiative heat transfer, some additional heat from hot combustion products will be transported by convection from the heater to the vault wall. Combustion product temperature and flow rate need to be estimated. At a 72% manufacturer heating efficiency with natural gas and assuming 10% excess air, the average combustion product temperature would be 475 °F. This was determined assuming good convective heat transfer with combustion products at a maximum 700 °F and leaving the vault environment at 250 °F. The combustion air requirements are 40 ft³/hr of air per ft² of heater surface area. Assuming an 18"x24" heater mounted vertically, the combustion air flow rate would be 120 ft³/hr.

Eqn. 3: $Re = u \times d / v$ where: Re = Reynolds #

u = flow velocity, ft/s
 d = distance, ft
 v = kinematic viscosity, ft²/s

u = 0.86 ft/s
 d = 0.083 ft (1 inch heater distance mounting from vault)
 v = 4.43 x 10⁻⁴ ft²/s (at approximately 475 °F)

Using Eqn. 2, the Reynolds number was calculated to be 135 and found to be in the laminar flow regime (Re < 2300). For laminar flow between parallel plates, the Nusselt number is approximately 8.2 for constant wall flux conditions. The heat transfer coefficient for a Nusselt number of 8.2 will be about 1.1 BTU/hr/ft²/°F.

The applied Newton's Law of Cooling is as follows:

Eqn. 4: $q = h \times (T_g - T_w)$ where: q = heat flux per unit area, BTU/hr/ft²

h = convective heat transfer coefficient, BTU/hr/ft²/°F
 T_g = gas temperature, °F
 T_w = tank wall temperature, °F

h = 1.1 BTU/hr/ft²/°F
 T_g = 475 °F and T_w = 75 °F

Using Eqn. 4, a convective heat transfer from a catalytic heater to the tank will be about 440 BTU/hr/ft². This is approximately 7% of that by radiation in Eqn. 2.

(Chambers, Nikoo; 2010)

3.0 Heat Transfer Analysis

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3.3 Conduction

Heat is transferred through the vault metal wall by conduction. The conduction heat flux equation is as follows:

Eqn. 5: $q = k / l \times (T_h - T_c)$ where: q = heat flux per unit area, BTU/hr/ft²

k = thermal conductivity, BTU/hr/ft/°F

l = thickness of vault wall, ft

T_h = hot surface temperature, °F

T_c = cold surface temperature, °F

$q = 3,440$ BTU/hr/ft²

$k = 25$ BTU/hr/ft² (mild carbon steel)

$l = 0.0208$ ft (1/4" vault wall)

Rearranging Eqn. 5 yields a temperature difference ($T_h - T_c$) between the inner and outer wall of 2.9 °F. This demonstrates negligible resistance to heat transfer through conduction.

3.4 Free convection with vault wall and fluid

Heat will be transported from the vault wall to the tank liquids. Natural convection will occur since the contents are not actively stirred. Heat transfer is calculated using Eqn. 4 with a heat transfer coefficient calculated by the following:

Eqn. 6 $h = k / L \times (Nu_m)$

Eqn. 7 $Nu_m = 0.1 \times (Gr_L \times Pr)^{1/3}$

Eqn. 8 $Gr_L = g \times \beta \times (T_w - T_l) \times L^3 / \nu^2$

where: h = heat transfer coefficient, BTU/hr/ft²/°F

k = thermal conductivity of fluid, BTU/hr/ft/°F

L = vertical dimension of heated surface, ft

g = gravitational constant, ft lb/lb_f/hr²

β = coefficient of expansion, R⁻¹

T_w = hot surface temperature, °F

T_l = cold surface temperature, °F

ν = kinematic viscosity, ft²/hr

Nu_m = Nusselt number

Gr_L = Grashof number

Pr = Prandtl number

3.0 Heat Transfer Analysis CONTINUED

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The following is an example calculation with water as tank fluid assuming fluid properties for average temperature between the wall of 100 °F and bulk fluid of 75 °F.

$$k = 0.36 \text{ BTU/hr/ft}^2\text{/}^\circ\text{F}$$

$$\beta = 1 \times 10^{-4} \text{ R}^{-1}$$

$$v = 0.028 \text{ ft}^2\text{/hr}$$

$$\text{Pr} = 6$$

Using Eqn. 8 and assuming a heater height of 2 ft, the Grashof number is 1.06×10^{10} . The flow is turbulent free convection for $\text{Gr} > 10^9$.

Using Eqn. 7, the Nusselt number is 396.

Using Eqn. 6, the heat transfer coefficient is 71 BTU/hr/ft²/°F.

Rearranging Eqn. 4, the temperature difference is 48 °F (26.7 °C). A bulk water temperature of 75 °F (23.9 °C) yields an inner tank wall temperature of 123 °F (50.6 °C).

The following example calculation is with kerosene as the tank fluid. Heat transfer properties vary dramatically with temperature and boiling point distribution of oil. The initial calculation assumed fluid properties for average temperature between the wall of 100 °F and bulk fluid of 75 °F.

$$k = 0.1 \text{ BTU/hr/ft}^2\text{/}^\circ\text{F}$$

$$\beta = 3.9 \times 10^{-4} \text{ R}^{-1}$$

$$v = 0.15 \text{ ft}^2\text{/hr}$$

$$\text{Pr} = 35$$

Using Eqn. 8 and assuming a heater height of 2 ft, the Grashof number is 1.45×10^9 .

Using Eqn. 7, the Nusselt number is 340.

Using Eqn. 6, the heat transfer coefficient is 17 BTU/hr/ft²/°F.

Rearranging Eqn. 4, the temperature difference is 202 °F (112.2 °C). A bulk water temperature of 75 °F (23.9 °C) yields an inner tank wall temperature of 277 °F (136.1 °C). This high wall temperature reduces the radiation heat flux from the heater down to 2,600 BTU/hr/ft² compared to 3,000 BTU/hr/ft². Therefore, if the tank fluid is predominantly oil, then the heat transfer from the catalytic heater would likely be reduced. This analysis provides support for testing with an oil-water mixture. This heat transfer analysis assumes heat transfer from the wall to the liquid by convection only. If metal temperatures are above the boiling point of water or components of the oil, heat transfer by boiling may also occur. Boiling heat transfer rates are significantly higher than natural convection rates and would dramatically lower the wall temperature.

(Chambers, Nikoo; 2010)

3.0 Heat Transfer Analysis

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3.5 Tank heat losses

Heat losses from the tank can be determined accurately using the insulation thickness, tank surface area and temperature difference. The following heat flux equation is:

Eqn. 9: $q_{\text{loss}} = U_T \times A \times (T_a - T_f)$ where:

- q_{loss} = heat loss, BTU/hr
- A = tank surface area, ft²
- T_a = ambient temperature, °F
- T_f = tank fluid temperature, °F
- U_T = total U-factor, BTU/hr/ft²/°F

Polyurethane spray foam insulation has an R-factor of 7 per inch. U-factor is the inverse of R-factor. The U-factor of air can be estimated using the wind velocity.

3.6 Heater Sizing – Freeze Protection Example

A heater sizing calculator is in development to calculate energy requirements with heating the fluid and heat loss from the tank with the catalyst. Input parameters are selected in Tables 1-3. This example has no in-flow of fluid to the 400 bbl tank.

Table 1 Tank specifications

Tank ID	12	ft
Wall Thickness	0.1875	in
Tank height	20	ft
Inlet temp	50	F
Outlet temp	50	F
Insulation thickness	1.5	in
Water cut	0.9	-

Table 2 Fluid properties

Water sp. heat	1	Btu/lb/R
Oil sp. Heat	0.479	Btu/lb/R
Water density	255.2	lb/bbl
Oil API	45	-
Oil density	204.6	lb/bbl

Table 3 Required information

Ambient Temp	-40	F
Wind velocity	20	mph
Fluid flow rate	50	bbl/d

Heat required to warm up fluid

	0	Btu/hr
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Heat loss from Tank with Catalyst

	7,998	Btu/hr
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Heater surface area required

	3	ft ²
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CO2 production

	3.65	tons/yr
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Note: theoretical catalyst heat flow of 3,000 BTU/hr/ft² (to be verified with testing this summer); natural gas CV of 23925 BTU/lb; polyurethane spray foam insulation.

Using the worst case scenario of the typical oil tank in Section 2.0 for freeze protection with -40 °F ambient and 20 mph wind, a heater surface area was calculated to be 3 ft². **This example sizes to an 18”x 24” heater.**

4.0 Conclusion

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Enviro Vault's mission is to be the standard in tank design. Enviro Vault® is an industry leader and works with all industry stakeholders to promote operational savings, enhanced safety, security and superior environmental stewardship. Innovation is pursued with a great interest in R&D. As stated on page one, Enviro Vault's vision in bringing the

ThermoVault™ to market includes the following;

- *increased operational safety*
- *an alternative to firetubes and expensive regulation compliant fuel gas trains*
- *heat for light oil applications which, when using a firetube, is against regulations in some areas*
- *potential carbon tax savings to producers*

Stay tuned for the results in the next technical bulletin when testing is complete.

5.0 References

*Chambers, Allan and Nikoo, Mehr. Analysis of Enviro Vault Tank Heaters, Milestone Report.
Alberta Innovates - Technology Futures, May 2010: Edmonton.*