MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

22nd Annual International Symposium
October 22-24, 2019 | College Station, Texas

Refrigerated tanks base plate-heating hazards – A case study of Ethylene tanks

Mahmoud Mohamad Hassan[2], Mahesh Murthy*[2], Pulak Pal[4], Gys Van Zyl[1],
Integrity Engineering Solutions[1], SABIC[2], Global EHSS, SADAF[4]
*Presenter E-mail: murthym@sabic.com

Abstract

Cryogenic storage tanks are commonly used for the storage of refrigerated liquids at sub-zero temperatures. Such tanks are often of double-wall construction with thermal insulating material in the annular space between the two tanks. These tanks commonly employ foundation heating (electrical or steam) to prevent freezing of the soil beneath the tank and the associated risk of frost heave. Frost heave occurs when water beneath the tank freezes and unevenly expands leading to structural damage. A case study presented in this paper is for a storage tank where liquid ethylene is contained at -104°C , in which the foundation heating system conduits were found to be severely corroded. This resulted in Class 1, Division 2 violation of Hazardous Area Classification Code of the company's engineering standards and also potential for frost upheave and structural damage of ethylene tank.

Thermal finite element analysis was used to estimate the temperature distribution beneath the tank and the potential for frost heave. In the analysis, the effect of parameters like soil conductivity, soil temperature, environmental temperature and insulation conductivity on soil temperature was evaluated. Sensitivity analysis was used to determine the critical parameters and field temperature measurements were used to quantify these parameters through best fit with analysis results.. Ground water table heights were measured at wells in the area and local historical data. Detailed analysis indicated that the heat transfer from ethylene tank to the soil did not result in sub-zero temperatures beneath the tank and would not cause frost heave. As a result, the foundation heating was discontinued utilizing Management of Change processes. In addition to compliance with Hazardous Area Classification, substantial heating costs were also saved as an outcome of this study. Details are reported in this paper.

Keywords: Process Safety Management, Cryogenic, Hazard, Hazardous Area Classification, Frost heave and Ethylene

Background:

During routine preventive maintenance inspection, conduits carrying electrical cables were found severely corroded underneath the ethylene tank. The conduits contain electrical heating elements that are used to maintain the foundation temperature above 0°C. This is required to prevent freezing of the ground water which would result in frost heave due to uneven expansion of the soil. The damaged conduits also posed a hazardous area classification breach of Class I, Division II, as per the company's engineering standards [1] .

The storage tanks contain liquid ethylene at -104^{o}C), much lower than the ambient temperature for Saudi Arabian soil conditions [2] . Given the hazards of frost upheave and hazardous area classification breaches, there were two options available. Option 1 was to empty the ethylene tanks, repair the defects and put it back to service. Option 2 was to undertake a detailed engineering study to determine soil temperatures beneath the tanks and evaluate the actual need for foundation heating.

Option 1 was found to be extremely expensive considering extensive periods of shutdown. Option 2 was chosen and the results of the Finite Element Analysis (FEA) is presented in detail in this paper.

Study methodology:

Soil temperature distribution by thermal FEA

Heating elements are provided in the soil beneath the cryogenic ethylene storage tanks, with the objective of preventing damage to the tank due to frost heave. A large number of the heating elements and conduits had been damaged, and effective repair was extremely difficult to implement. Furthermore, considering typical high environmental temperatures in middle-eastern region, the likelihood of frost heave should be significantly less than in cooler climates [3] . Finite element thermal analysis was performed in order to evaluate the possibility of sub-zero temperatures beneath the tank (and specifically beneath the concrete ring-wall)

A schematic outline of Ammonia tank is given is Figure 1.

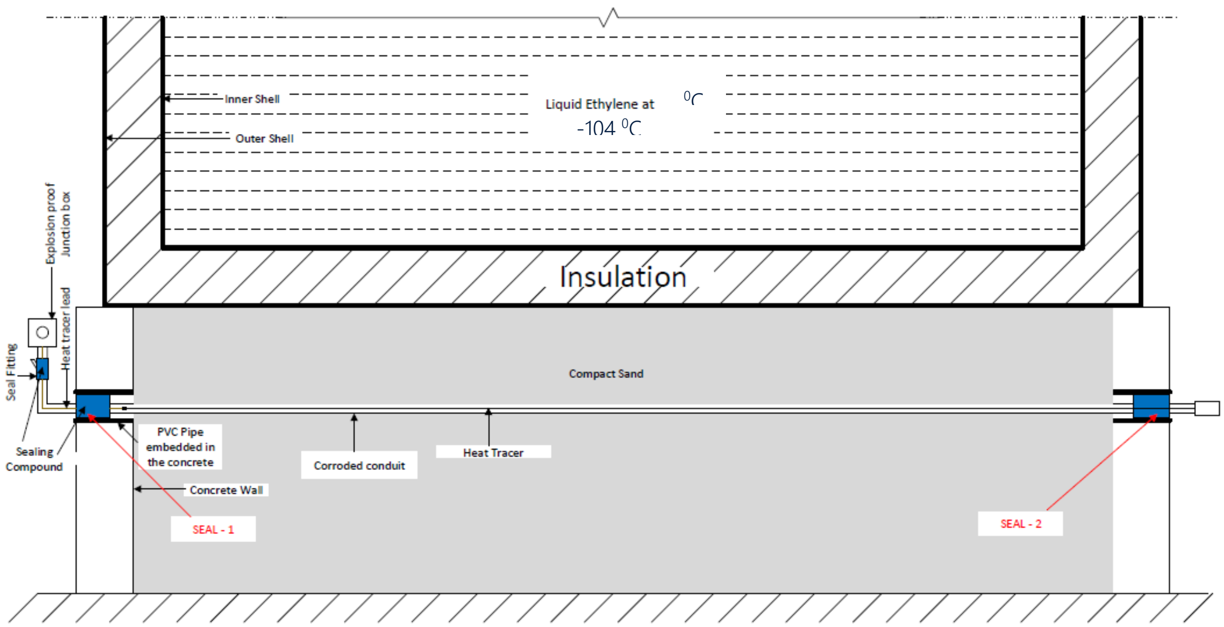

Figure 1 – Schetatic outline of Ethylene tank

An axisymmetric finite element model of the lower parts of the tank was created. Primary components as illustrated in Figure 2 below:

- Carbon steel shell and floor (inner and outer)
- Concrete ringwall and layer on outer tank bottom plate
- Dry sand (below inner tank bottom plate)
- Foam glass insulation between inner and outer tank bottoms
- Perlite insulation (between inner and outer tank shells)
- Saturated sand (soil beneath tank)

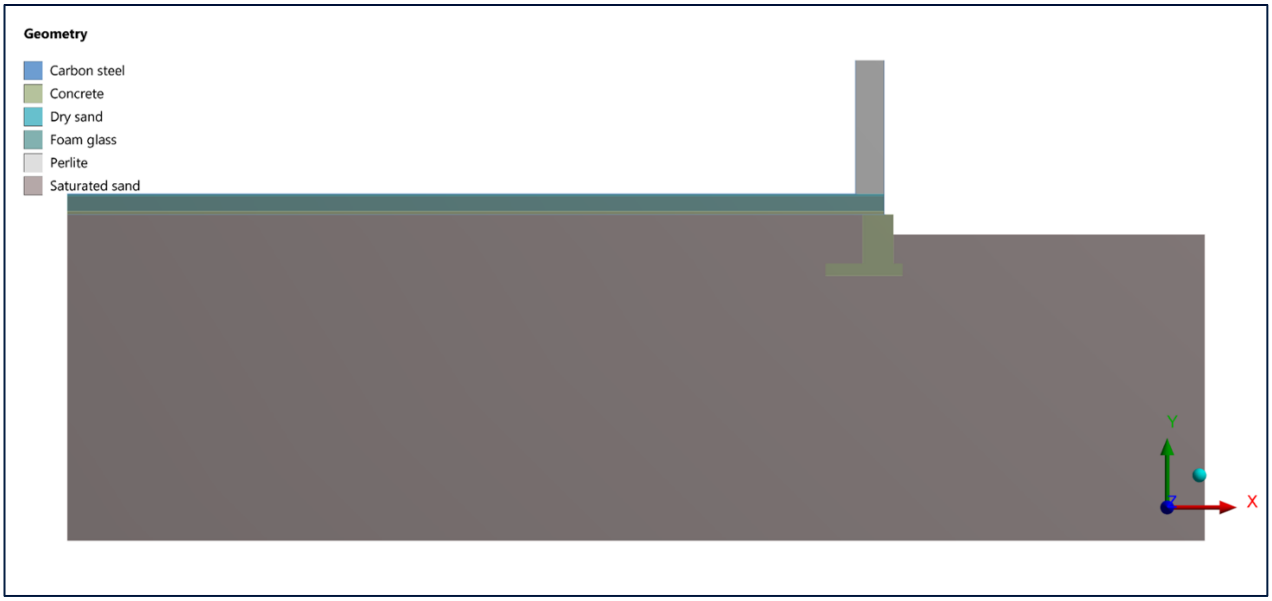

Figure 2 - Geometry and primary components of finite element model of tank bottom parts

The finite element mesh consisted of quadrilateral elements and is illustrated in Figure 3.

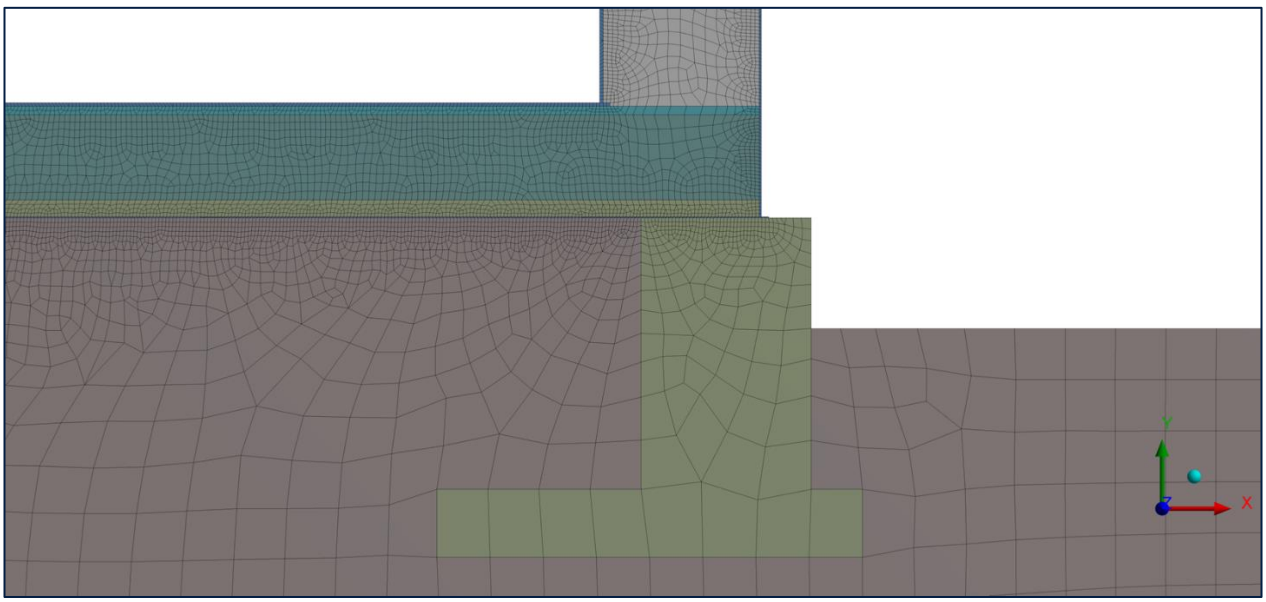

Figure 3:Finite element mesh

Boundary conditions used in the analysis are:

- Temperature inside inner tank (-104°C)
- Convective heat loss to ambient (10 W/m^2°C, ambient temperatures were varied)
- Soil temperature remote from tank (29°C, based on measurements)

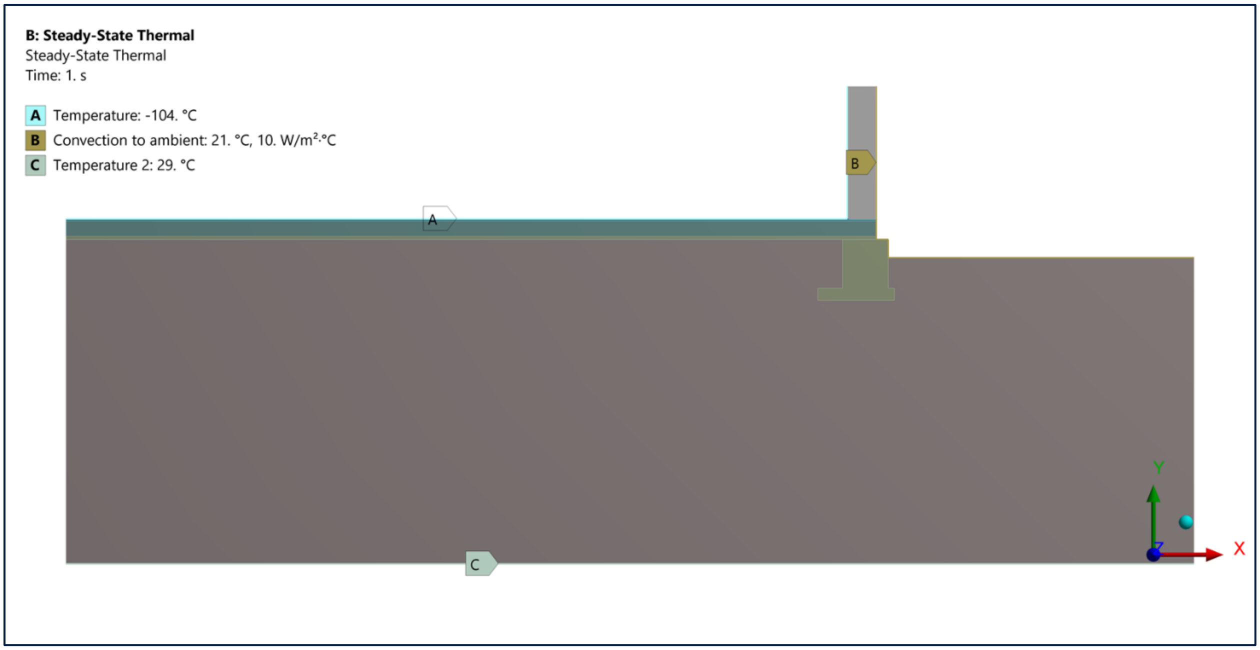

Figure 4: Boundary conditions used in thermal analysis

Parameters influencing heat transfer rates

Heat transfer rates are influenced by the following parameters;

- Soil temperature and
- Thermal conductivity

Soil temperature and thermal conductivity of the soil had high impact on the heat transfer rates . Thermal conductivity of foam glass and environmental temperature had a medium impact on the model. Thermal conductivity of concrete and saturated sand had a low impact on the heat transfer rates. The heat transfer analysis parameters are given in Table 1 below;

FEA Analysis parameters	Baseline	Range	
		Min	Max
Thermal conductivity, W/m.K			
Concrete	1	1	1.8
Dry sand	0.15	0.15	0.25

Saturated sand	3	2	5
Foamglass	0.05	0.048	0.056
Soil temperature, ºC	29	15	50
Environment temperature, ºC	21	0	50

Table 1 – Finite Element Analysis parameters

Parameters best fit

A number of model parameters in the finite element model influence the calculated temperature distribution:

- Thermal conductivity of:
  - Concrete
  - Dry sand
  - Saturated sand
  - Foam glass insulation
- Soil temperature
- Environment temperature

Data was not available to accurately quantify these parameters; therefore, a combination of temperature measurements and sensitivity analysis was used to estimate them. Figure 5 shows that the predicted depth of freeze beneath the tank is most sensitive to soil temperature and thermal conductivity.

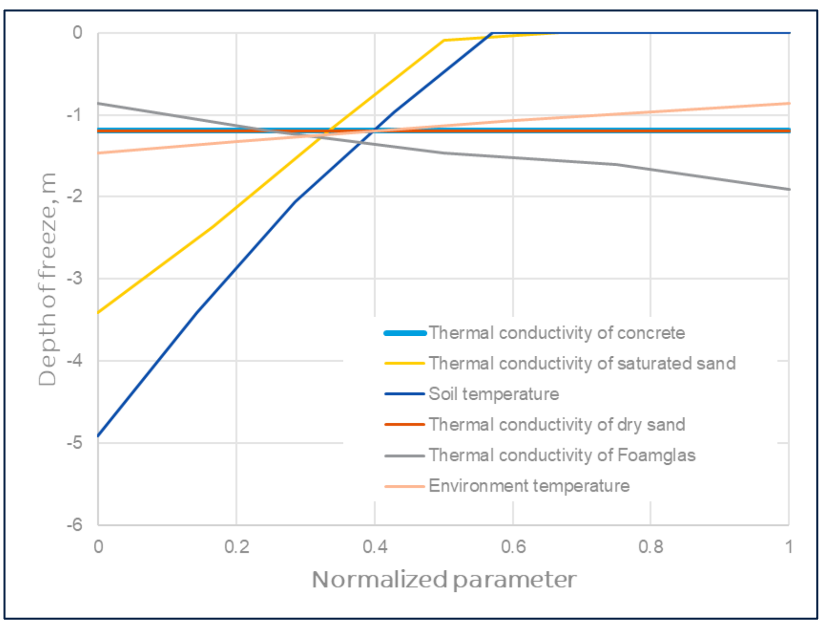

Figure 5 :Sensitivity of parameters to the prediction of depth of freeze beneath the tank

Temperatures measurements were performed on two tanks, after deactivating the heating elements. Thermal parameters in the FEA were adjusted until good correlation with measurements was achieved. Figure 6 illustrates the correlation between FEA results and temperature measurements for variations in the two most sensitive parameters.

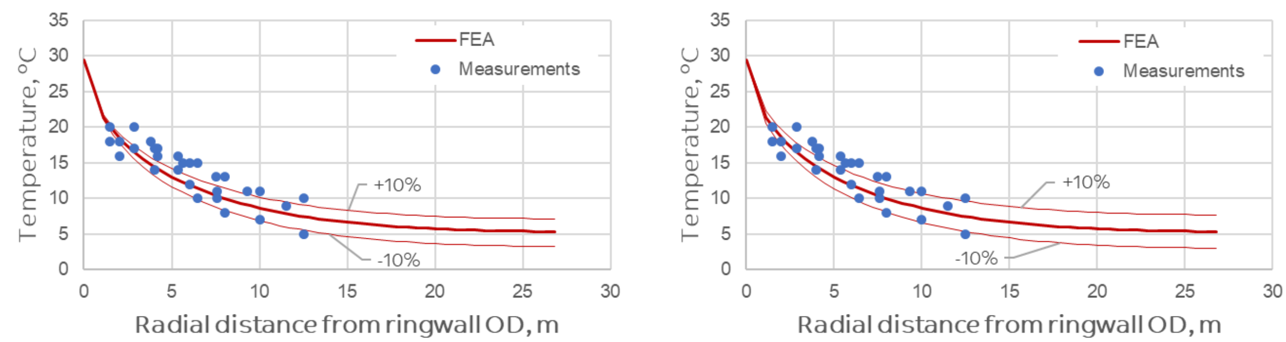

Figure 6: Illustrating soil conductivity and soil temperature parameters best fit with temperature measurements

Table 2 lists the values of all parameters used in the analysis that were determined by the sensitivity analysis and correlation with soil temperature measurements beneath the tanks.

Table 2: Best fit parameters

Thermal conductivity, W/m.K	
Concrete	1.8
Dry sand	0.15
Saturated sand	4.3
Foamglass	0.05
Soil temperature, °C	29
Environment temperature, ºC	Varies

Using the best-fit parameters, FEA was used to predict the soil temperature distribution beneath the tank in the event of a 0°C environmental temperature (50 year recurrence interval) and with deactivated foundation heating elements. The result provided in Figure 7 shows that no sub-zero temperature is predicted in the soil beneath the tank.

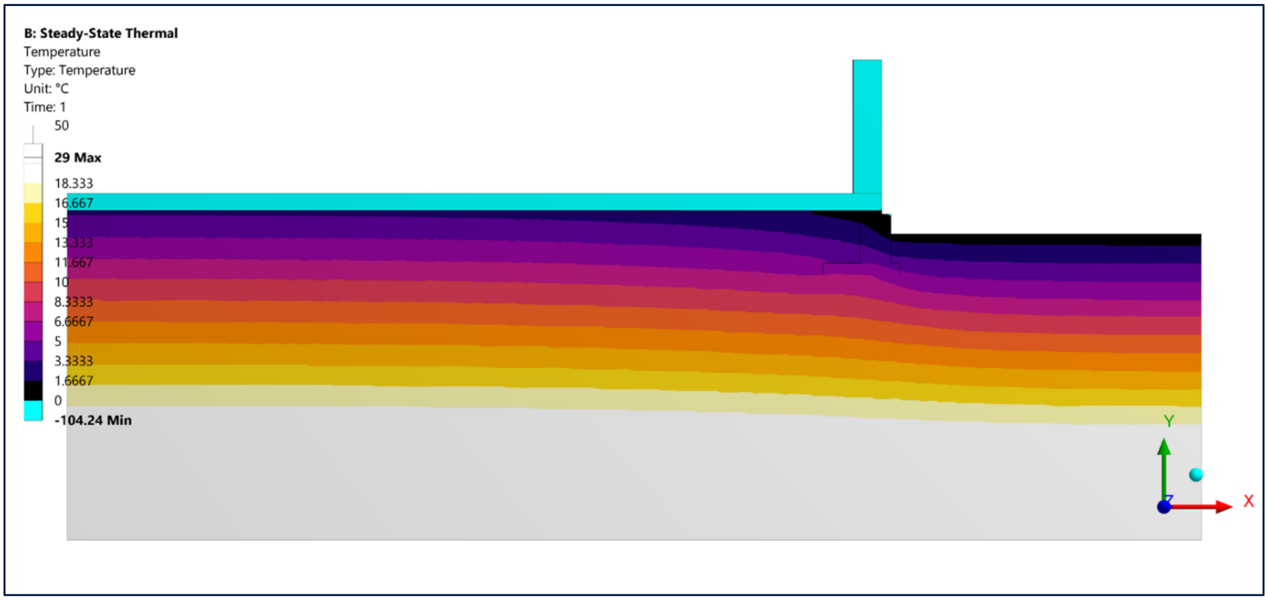

Figure 7: Temperature distribution with 0°C environmental temperature and best-fit parameters.

The study concluded that sub-zero temperatures are not expected beneath the tank under any realistic condition, and with this result as one of the considerations in a broader risk analysis, it was decided to disable the foundation heating on the two tanks.

Recommendations

- Turn off the base plate heater
- Approach of using FEA

Thermal finite element analysis was effectively used as a tool to obtain a more detailed understanding of the temperature distribution in the foundation of the storage tanks, which resulted in an informed decision to disable foundation heating, thereby eliminating a known safety hazard while reducing energy costs.

End notes

- Hazardous Area Classification hazard was eliminated due to de-activation of igition source. SABIC technical safety alert was also issued based on the case study [4]
- Frost heave was ruled out as credible scenario, given the context of Ethylene tanks.
- The FEA approach led to energy savings 122 kilo- watt, or an estimated equivalent of $ 40,000 for two ethylene tanks.
- Estimated indirect costs for repairing and restoring the foundation heaters were in the range of USD 70 million.
- 24 similar tanks were identified across SABIC that could be potentially be applied with similar approach. Estimated energy savings was in the range of 11085 Mega Watt Hour per annum.

References:

1. SABIC Engineering Standard   Hazardous Area Classification – S02-E05, Rev 0, June 2017
2. Typical ground water temperature in Saudi Arabia, accessed via http://webcache.googleusercontent.com/search?q=cache:ftp://ftp.ncdc.noaa.gov/pub/data/EngineeringWeatherData_CDROM/engwx/riyadh_sa.pdf, accessed via website https://www.ncdc.noaa.gov/; on 23 August 2019
3. Mansour Almazroui et.al. , 2013, Trends of temperature extreames in Saudi Arabia, International Journal of Climateology Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/joc.3722
4. Global EHSS Bulletin # 64, 15 May 2018, Issued by SABIC Internal Communications Department