

A Numerical Simulation of LNG Low Temperature Pipe Pre-Cooling Process

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Abstract. LNG Low Temperature pipe pre-cooling is difficult point of completion and commissioning of LNG project, under the flow rate of 0.2m/s,0.5m/s and 1m/s, FLUENT software is used to conduct simulation of BOG gas pre-cooling technology for 63010mm Low Temperature pipe to obtain temperature change regularity of pipe during BOG pre-cooling process and real-time display of temperature of Low Temperature pipe during pre-cooling process and to formulate pre-cooling plan of Low Temperature pipe.

Preface

After the constructions of LNG cryogenic pipelines are finished, the LNG pipelines should be processed by precooling. Because LNG is a liquefied natural gas (LNG), the operating temperature is -163 degrees. Direct input without precooling will not only cause shrinkage deformation, but also cause bending deformation and thermal stress damage, which is due to the top and bottom surface temperature difference of the low temperature pipes because cooling is too fast .

Precooling is the key work to ensure that the LNG project could be put into trial operation successfully. First of all, the cold BOG gas circulate in the pipeline, cooling must be carried out slowly, the pipeline temperature reach to 95~-118, then LNG can be directly delivered. Through the precooling, LNG pipeline temperature drops from room temperature to low degree of working state, which ensures the operation of LNG cryogenic pipelines.

Low Temperature Pipeline Structure

Take the domestic LNG pipeline as an example, diameter of cut off part for horizontal straight pipe is 63010mm and its length is 5m, this cut off part is the object of study. Pipeline structures are simplified to consist of the steel pipe and cold insulation layer, the BOG are selected as precooling gas, 20mm thick 0Cr18Ni9 are selected as steel pipe, and insulation layer of pipeline is composed of two layers, inner layer is composed of polyisocyanurate foam, which is 100mm thick, outer layer is composed of foam glass, which is 50mm thick, physical parameters are listed in Table 1.

Tab.1 Physical parameters of pipeline structure

Parameters	Density (kg/m ³)	Specific heat(kJ/kgK)	Kinematic viscosity (m ² /s)	Thermal conductivity W/(mK)
BOG	0.717	2223	1.43710 ⁻⁵	0.03
0Cr18Ni9	7860	460	/	11.8
Polyisocyan u-rate Foam	80	358.7	/	0.019
Foam glass	16	880	/	0.06

Model Building

When the BOG gas are injected into pipe, through heat transfer with the pipe wall surface, the BOG gas temperature increases, so the pipeline precooling could be realized. When pipeline is precooled to a certain temperature, cold amount is transferred to the inner insulation layer. Since then, through heat conduction between internal and external insulation layer and heat convection transfer of external insulation layer and the atmosphere environment, the external insulation layer temperature of pipeline gradually reduced. The actual precooling process of the low temperature pipe is more complex. Therefore, for the convenience of the study, the model needs to be simplified:

(1) Neglecting the axial heat conduction of the pipe wall, only considering the radial heat conduction;

(2) Neglecting the thermal contact resistance between the outer wall of the pipe and the cooling layer;

(3) Thermal conductivity and other physical properties of heat pipe wall and cold insulation materials will not change with temperature.

On the basis of the above simplified assumptions, the model satisfies the continuity equations, momentum equations and energy equations, the formulations are shown in equation (1) ~ (5), and the heat conduction differential equation of the insulation layer is shown in equation (6):

$$\frac{\partial \rho}{\partial \tau} + \nabla \cdot (\rho \vec{U}) = 0 \quad (1)$$

$$\frac{\partial(\rho u)}{\partial \tau} + \text{div}(\rho u \vec{U}) = \text{div}(\mu \text{grad} u) + S_u - \frac{\partial p}{\partial x} \quad (2)$$

$$\frac{\partial(\rho v)}{\partial \tau} + \text{div}(\rho v \vec{U}) = \text{div}(\mu \text{grad} v) + S_v - \frac{\partial p}{\partial y} \quad (3)$$

$$\frac{\partial(\rho \omega)}{\partial \tau} + \text{div}(\rho \omega \vec{U}) = \text{div}(\mu \text{grad} \omega) + S_w - \frac{\partial p}{\partial z} \quad (4)$$

$$\frac{\partial(\rho c_p T)}{\partial \tau} + \text{div}(\rho c_p \vec{U} T) = \text{div}(\lambda \text{grad} T) + S_T \quad (5)$$

The heat conduction differential equation satisfying the insulation layer is:

$$\frac{\partial(\rho h)}{\partial \tau} + \nabla(\rho h) = \nabla(K_{\text{eff}} \nabla T) + S_h \quad (6)$$

Numerical Simulation Results and Analysis

Inject the 153K BOG gas into pipeline which is 5 meters long at flow rate of 0.2 m/s, precooling the pipeline. Time step is set to 60s, save a set of data every 10 minutes, the total calculation time is 12h, at initial time pipeline and ambient temperature is set to 303k. Fig. 1 shows contours of temperature when pipe is precooled for 10min.

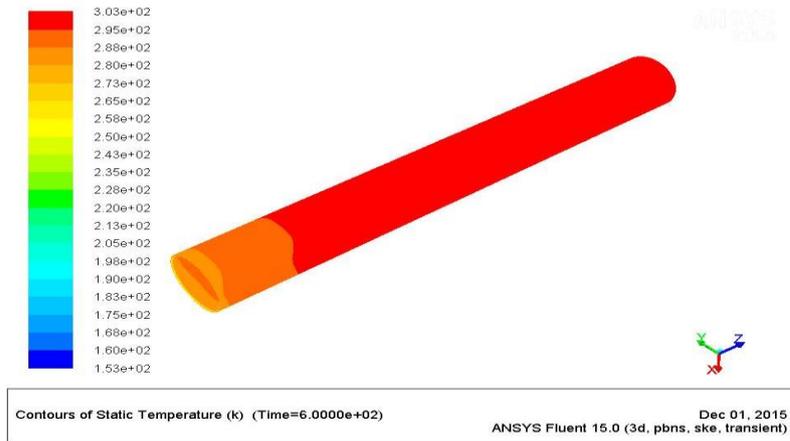


Fig.1 Temperature distribution of BOG pipeline for 10min precooling

When the BOG gas flow into the pipe at 0.2m/s, 0.5m/s and 1m/s respectively, the temperature drop of these three conditions for 12h precooling is simulated, and the temperature drop curve of the pipeline wall is obtained, as shown in Fig.2.

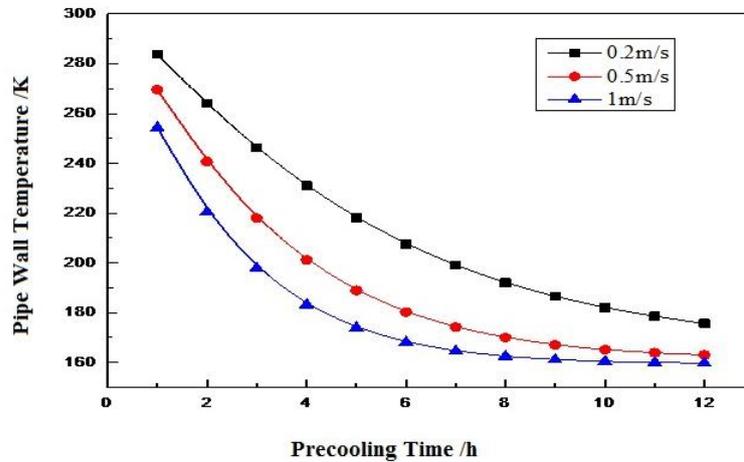
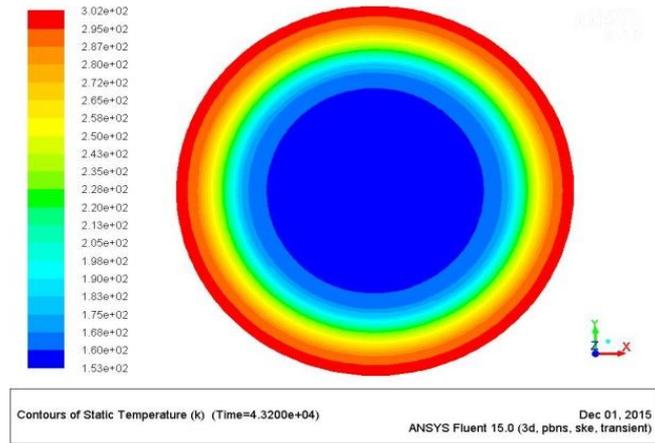


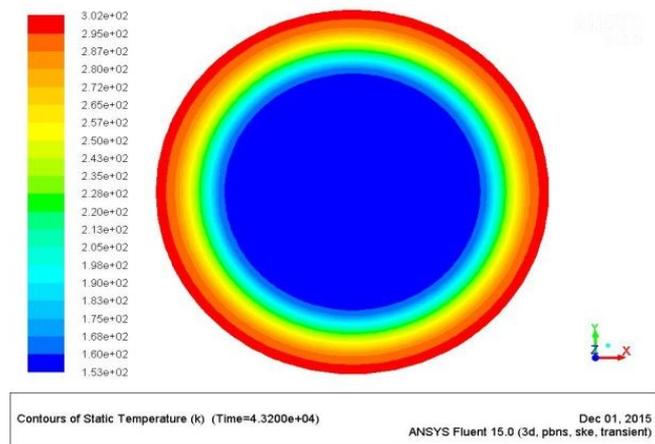
Fig.2 Curve of pipe wall temperature along with precooling time at different flow velocities

As can be seen from Fig. 2, the overall trend of three different flow rates of BOG pipeline precooling all change rapidly at first and then tends to be flat and has largest velocity of temperature drop within 1 hour precooling, temperature drop curve changes faster within the first 10 hours when the velocity is 0.2 m/s, 10 hours later the temperature drop curve will change slowly; temperature drop curve changes faster within the first 7 hours when the velocity is 0.5m/s, then the change tends to be slow; the temperature drop curve changes faster in the first 5 hours when the velocity is 1m/s, then the change tends to be slow. Mainly because of the low BOG temperature of inlet pipe section, the pipeline temperature differences are large, the convective thermal transfer coefficient is large, so the pipeline temperature drops faster. Therefore, it is necessary first to precooling at minimized velocity and increase velocity slowly.

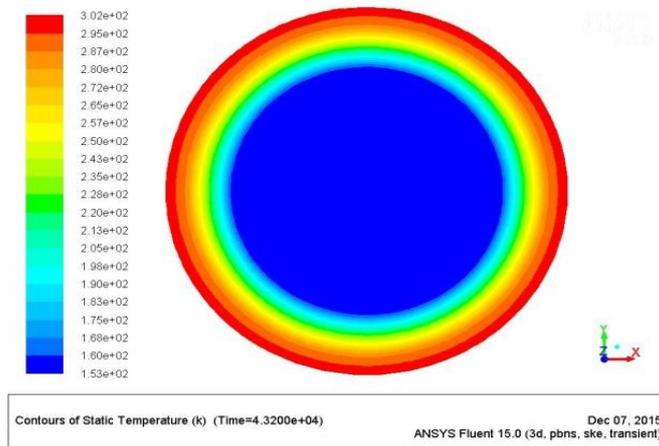
Because in pipe precooling process, the pipe wall temperature decreased gradually, and reaches a certain temperature, the cooling capacity are transfer to pipe inner insulation layer, internal insulation layers temperature is transferred to the outer thermal insulation layer through thermal conduction, this is also because convective thermal transfer between external thermal insulation layer and the atmosphere environment, so the thermal insulation layer temperature will have minor decreasing amplitude, Fig. 3 shows contours of cross-section temperatures under different flow rates for 12h precooling.



(a) is at flow rate of 0.2m/s



(b) is at flow rate of 0.5m/s



(c) is at flow rate of 1m/s

Fig.3 the cross-section temperatures under different flow rates for 12h precooling.

Conclusions

This paper use FLUENT software to simulate LNG pipeline precooling, calculate and analyze the pipe flow and pipeline temperature distribution of pipe, which is 610mm in diameter and 5 meters long, in precooling process. This paper then compares and analyzes the internal pipe wall temperature variation under different flow rates within 12h of precooling, calculate low temperature pipelines thermal stress and contraction displacement according to the temperature results data. Results show that the temperature drop curves of 0.2 m/s, 0.5m/s and 1m/s change faster at time of

10h, 7h and 5h respectively, which provide the references for the precooling of LNG low temperature pipeline.

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