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空冷式 LNG プラントにおける Hot Air Recirculation (HAR)

Hot Air Recirculation Phenomenon in an Air Cooled LNG Plant

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Abstract:

With the push towards air cooled systems in modern liquefied natural gas (LNG) plants, the need for better methods for analyzing the dispersion of hot air exiting the air-cooled heat exchangers (ACHE) is becoming increasingly important. One focus for improving the LNG plant production rates is the control of hot air recirculation (HAR) around the ACHE units and gas turbines. Current computational fluid dynamics (CFD) methods for modeling HAR in LNG plants do not sufficiently consider the site weather conditions for the input parameter, resulting in a decreased accuracy of the CFD models. This paper highlights the need for CFD models to include detailed long term weather data in order to accurately simulate the HAR phenomenon. CFD results have shown close agreement with actual temperature data taken around ACHE and gas turbine air intake locations.

1. Introduction

One of the main contributors to the production capacity being constrained for LNG plants is the rise in the local air temperature caused by rejected heat from the large banks of air-cooled heat exchangers (ACHE). ACHEs are large fans sitting atop the main pipe racks that are used to cool the process fluids for the LNG plant. A rise in the intake air temperature caused by hot air recirculation (HAR), the phenomenon in which the hot air from the ACHEs flows back into the ACHE intake or the intake of other equipment such as the gas turbines, is a critical issue that the plant owner/operator faces. The performance of the ACHEs and gas turbines can be significantly influenced by the temperature of the intake air into the ACHEs and turbine drivers. A 1°C temperature rise can end up costing the plant owner millions of dollars per month, which is why HAR has been a major concern for owners in recent years.

The ACHE intake air temperature is strongly influenced by the weather conditions at the site such as wind direction and wind speed. The following are the two modes of HAR, which are heavily dependent on the weather conditions at the site (as shown in see **Fig.1**).

- Recirculation of hot air from the exhaust of an adjacent train when the wind blows perpendicular to the LNG trains
- Recirculation of hot air within the same train, or self-recirculation

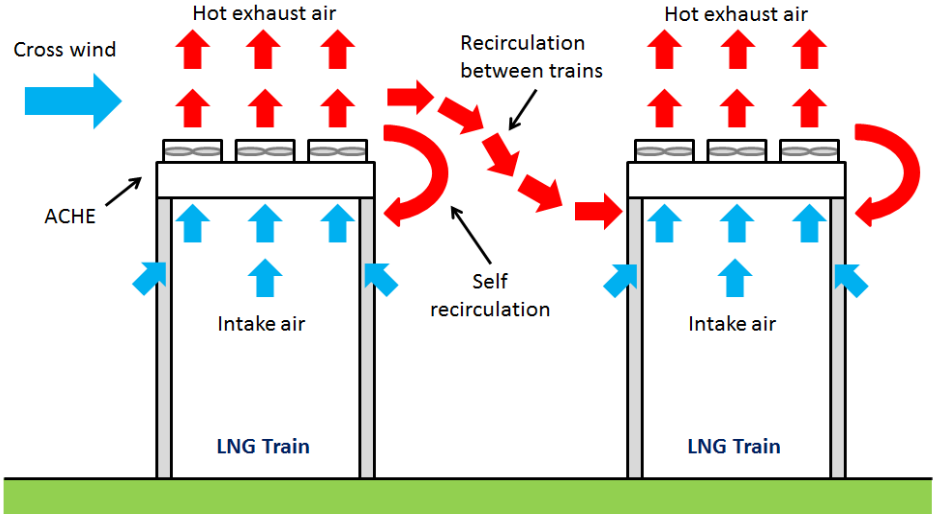

Fig.1 Two modes of HAR.

Malaysia LNG (MLNG) Tiga shown in **Fig.2** is an air-cooled, gas turbine driven LNG plant which consists of two LNG trains (Train 7 and 8). The plant utilizes Propane Pre-cooled Mixed Refrigerant (C3-MR) by Air Products and Chemicals Inc. (APCI) with expanders for the liquefaction process. As an air-cooled LNG plant, the performance of the ACHEs is critical in ensuring sustainable LNG plant production.

HAR impacts the performance of the ACHEs and the gas turbine drivers of the refrigeration compressors for MLNG Tiga. The performance of the propane condenser, which accounts for nearly half of the ACHEs for MLNG Tiga, is especially sensitive to the intake air temperature. The ability of the LNG plant to produce LNG is determined by the performance of the ACHEs such as the propane condenser as well as the gas turbines.

Fig.2 MLNG Tiga Train 7 and Train 8.

An in-depth understanding of the relationship between the weather conditions and degree of HAR can considerably benefit the operation of an LNG plant. A better understanding of HAR can also provide clues to mitigating this issue.

This paper introduces a study which combines a thorough analysis of actual plant data collected at the MLNG Tiga plant with results from CFD analysis. Data from 152 temperature sensors installed near the air intakes of the ACHE units and wind data from two weather stations were used to verify the accuracy of the CFD simulation. CFD is shown to be an effective engineering tool in large-scale fluid flow applications. This paper also proves how effective this combined approach is in understanding the HAR phenomenon.

２． Owner/Operator Perspective on HAR

HAR in MLNG Tiga is normally observed during the day time around 10:00 to 16:00, and at night from 21:00 to 23:00. The impact of HAR on the plant production is significant since it largely occurs around the propane condenser, which has more than half of the total cooling duty provided by all the ACHEs in the liquefaction unit.

The HAR issue has been a major factor in a number of plant slowdowns and trips ever since the 2003 commissioning of MLNG Tiga. However, as the panel operators have become more experienced in handling the plant operation during HAR conditions, the number of plant trips due to HAR has dropped significantly. The last plant trip was recorded in 2007. Although plant trips due to HAR have been eliminated, plant slowdowns are still a concern in order to sustainably maximize the LNG capacity from MLNG Tiga. **Fig.3** below shows a typical plant slowdown cycle due to HAR for MLNG Tiga. See ref[1] for additional details of the plant operator’s experience in dealing with HAR.

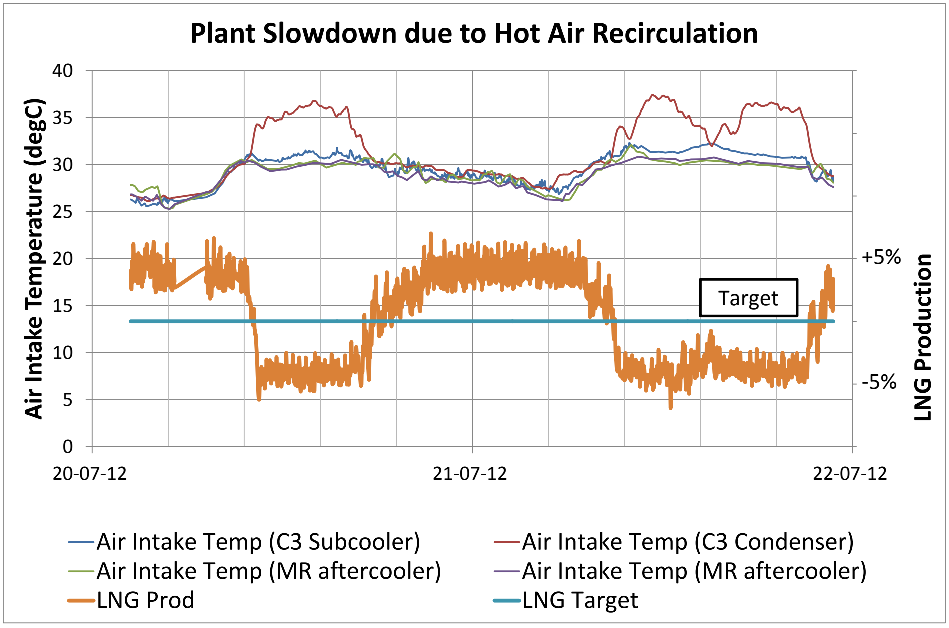

Fig.3 Plant slowdown due to HAR for MLNG Tiga.

A study conducted in 2012 showed that an increase of 1°C in the ACHE air intake temperatures can contribute to a significant LNG production loss per train.

3． Site Weather Analysis

A thorough assessment of the site weather conditions, particularly the wind direction and wind speed, is critical for an air-cooled LNG plant. Collecting accurate long term wind data is essential in understanding the relationship between the wind conditions and HAR. For this purpose, data from the plant was collected for nearly one year from April 2011 to January 2012 using two weather stations. The weather stations were installed near the MLNG Tiga area to measure wind direction, wind speed, and ambient temperature.

The wind data was divided into 16 wind directions and 6 wind speed ranges, with true north set at 0 degrees. Plant north is oriented 29.5 degrees in the counter clockwise direction of true north. All measured wind directions are based on the true direction. **Fig.4** below shows the frequency of occurrence (or wind rose) for each of the 16 wind directions measured at the two weather stations.

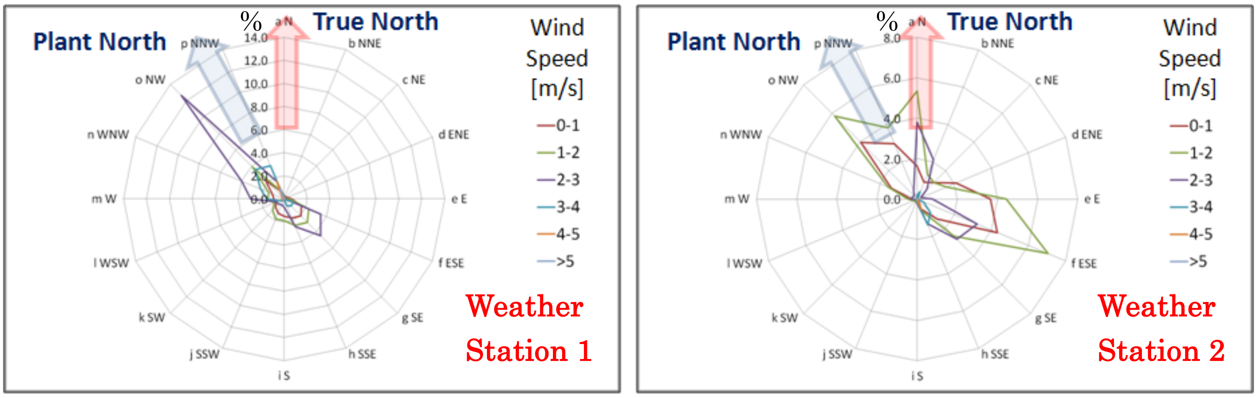

Fig.4 Wind rose for entire measurement period (April 2011 to January 2012).

Although differences exist for the two measurements due to their locations, the diurnal wind pattern appears to be similar. Winds near the seashore often exhibit a pattern of interchanging land and sea breeze throughout one day [2].

4． Influence of the Wind on ACHE Intake Temperatures

Temperature sensors installed for this HAR study were used along with permanent sensors to monitor ACHE and gas turbine air intake temperatures throughout the entire measurement period. A total of 152 temperature sensors were used to record temperatures at an interval of 10 minutes. The temperature sensors were evenly distributed throughout Train 7 and Train 8 so that an accurate temperature contour for the intake temperatures could be obtained. A detailed comparison with the CFD results can be made as a result of the large amount of temperature data collected. **Fig.5** shows the installation locations for each of the ACHE air intake sensors for Train 8 (identical locations for Train 7).

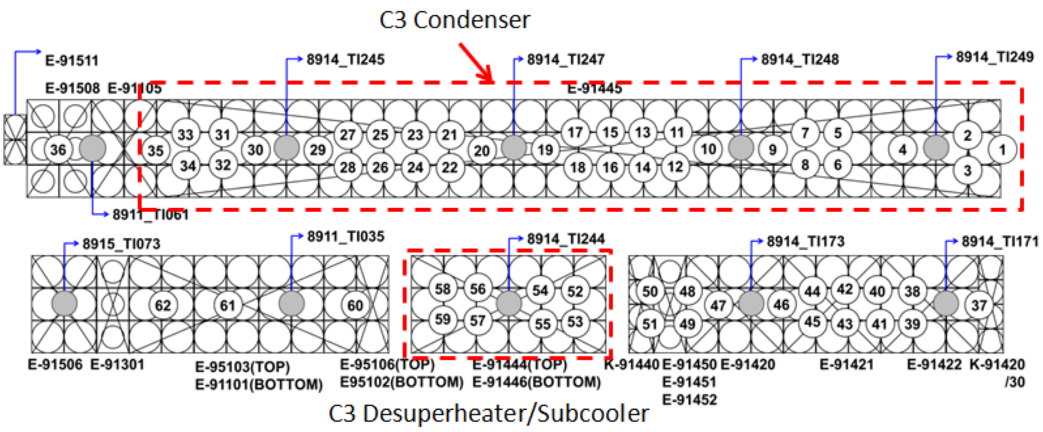

Fig.5 Installation locations for Train 8 ACHE temperature sensors (72 sensors/train).

As mentioned earlier, a major issue that the plant operator has experienced is the sudden rise in the Train 8 propane condenser air intake temperatures in the day time due to HAR. Although the night time effects of HAR on plant performance cannot be ignored, HAR has a much more detrimental impact during the day since temperatures are already elevated and close to the ACHE design limit. Based on the temperature data collected at the weather stations, the mean daily maximum ambient temperature was found to be approximately 30°C. Ambient temperatures generally reached a peak around 14:00. For this reason, this paper focused on the day time ACHE air intake temperatures.

Fig.6 shows the Train 8 average propane condenser temperature rise under various wind directions for steady wind conditions. Elevated ACHE air intake temperatures were clearly seen from the data for winds perpendicular to the trains (cross winds). The local temperature rise for several bays were much higher than the averages shown in **Fig.6**.

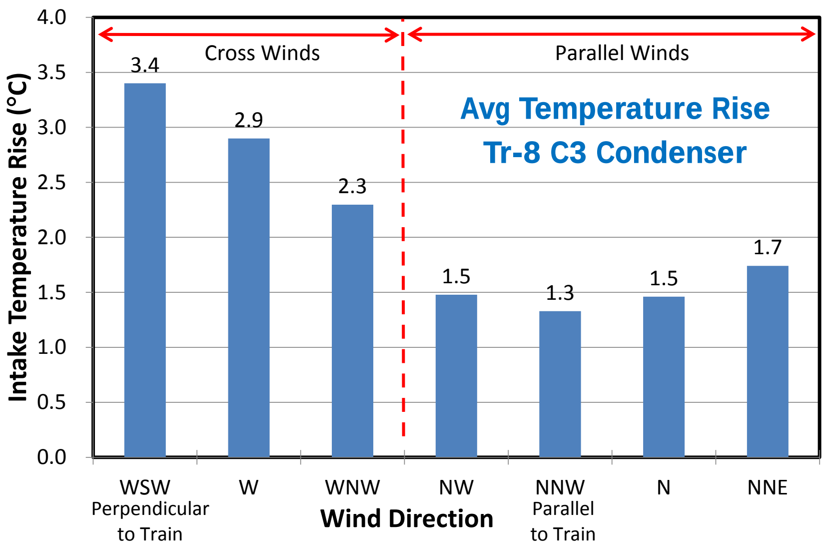

Fig.6 Train 8 propane condenser, average measured temperature rise (intake minus ambient) under day time wind directions.

5． Understanding the HAR Phenomenon using CFD

CFD is commonly used in order to understand the complex 3-dimensiontal nature of fluid flow for individual equipment within an LNG plant. With the growing availability of more powerful computers, CFD can now be used to evaluate the fluid flow at a larger scale as in the study presented in this paper. For this study, the flow characteristics of the hot air from the ACHE outlets were determined using CFD under different wind conditions.

The flow and temperature fields for the MLNG Tiga plant were simulated using the CFD software CFX 14.0 developed by ANSYS. The CFD model includes buildings, compressor enclosures, tanks, columns, vessels, drums, stacks, heat exchangers, and other equipment aside from the ACHEs and gas turbines that may significantly influence the air flow or temperature distribution within the plant. The CFD simulation model which was used in this study is shown in **Fig.7**. The effects of the atmosphere and turbulence were considered in properly simulating the wind for this analysis [3, 4].

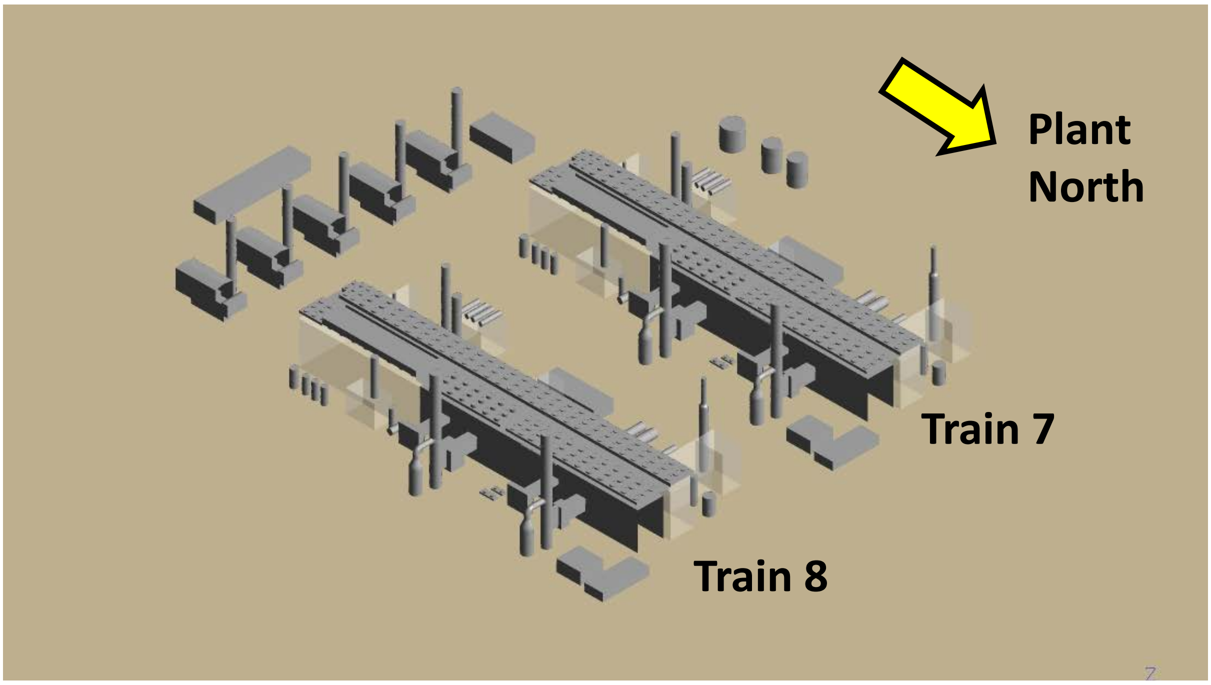

Fig.7 MLNG Tiga CFD model

5． 1 CFD Results for Cross Wind Case

The measured wind data shown in **Fig.4** was used as the basis for determining the conditions for the CFD simulation. In order to study the effects of a day time wind, a representative wind direction at an intermediate wind speed of 2 m/s was chosen for this study. HAR generally does not occur under calm winds. The WNW wind, which represents a relatively frequent cross wind direction, was chosen as the case to consider for this study. The results from the CFD analysis were used to understand the HAR phenomenon. Several outputs from the CFD analysis are shown in **Fig.8**.

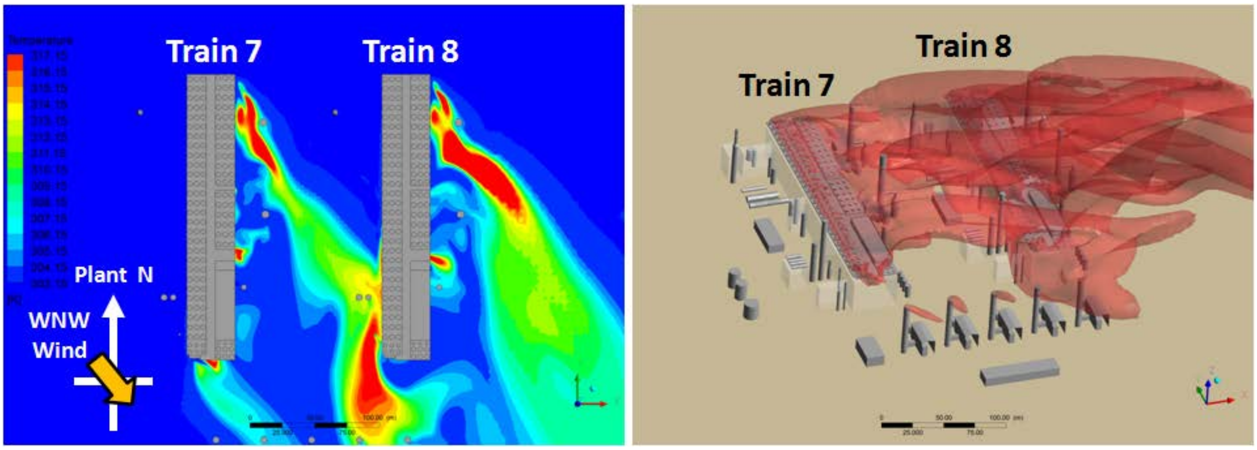

Fig.8　Temperature contour (left) and hot plume (right) for WNW wind.

Fig.8 shows a large volume of hot air from Train 7 flowing toward Train 8 for the WNW wind. This hot air reaches the Train 8 ACHEs and raises the air intake temperatures mainly on the west side of Train 8. Both self-recirculation and HAR from the upstream Train 7 is observed under this cross wind, leading to high Train 8 intake temperatures.

5．2　CFD Results *vs.* Site Data

In order to assess the impact of HAR, the intake temperatures to the ACHEs and gas turbines were calculated using CFD. The temperature rise above the ambient temperature at the intake of each of the ACHE bays and gas turbines due to HAR were determined. These results were used to identify locations of ACHE air intake hot spots and compared with the site temperature data.

A comparison between the site data and CFD temperature rise results for a steady WNW wind are shown in **Fig.9**. The average temperature rise for each of the ACHE bays is provided in the figure. The gas turbine temperatures are also shown. The CFD results show a very close match with actual site data. Both the site data and CFD results show local hot spots toward the southern part of the propane condenser (E-91445), with a number of bays approximately 6 °C above the ambient temperature.

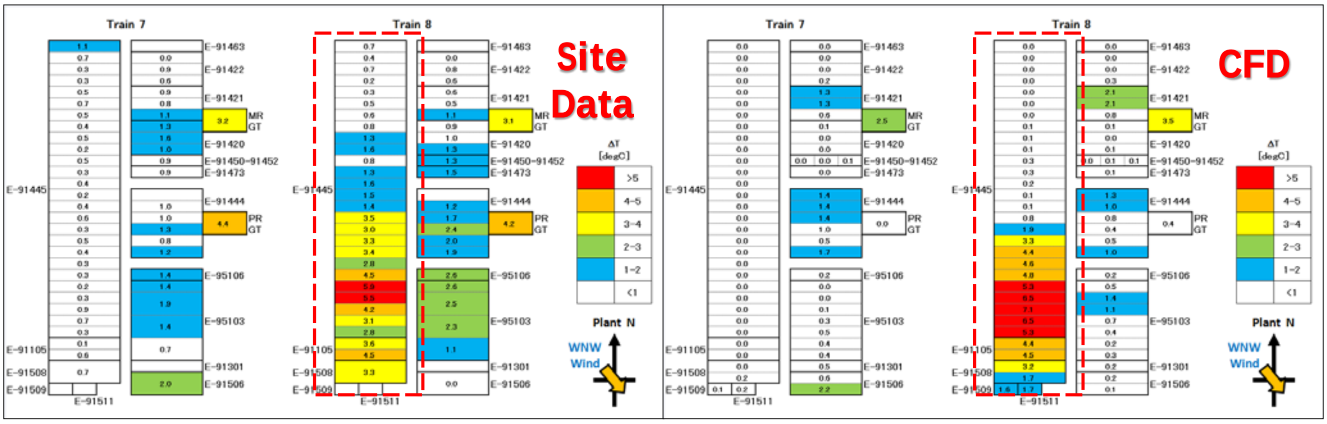

Fig.9　Temperature rise above ambient, site measured data *vs.* CFD (WNW wind).

The results have proven the effectiveness of CFD in understanding the HAR phenomenon at an actual plant. However, CFD alone cannot explain everything since there are limitations in simulating nature. Therefore, an extensive amount of site experience and data is crucial in assessing the CFD results and ultimately dealing with HAR.

6. Conclusion

An increase in the air intake temperatures of the ACHEs and gas turbines due to HAR can lead to a detrimental loss of production for an air-cooled LNG plant. As explained in this paper, HAR cannot be dealt with lightly, and understanding when and how it occurs is of utmost importance for any plant owner/operator in solving this issue.

The integration of actual data from the plant site and CFD analysis has proven to be effective in understanding the HAR phenomenon at MLNG Tiga. Since weather conditions such as the wind direction and wind speed strongly influence the degree of HAR observed, accurate long term wind measurements of must be taken. The weather data must be carefully evaluated first before using it as input to the CFD model to ensure the reliability of the CFD simulation. The CFD results were shown to match well with actual site ACHE data from MLNG Tiga.

The method presented in this paper in analyzing HAR was demonstrated to be effective for an existing LNG plant. However, constraints for a plant once it is constructed can significantly limit the mitigation measures that can be considered, which was the case for MLNG Tiga. By taking into account the impact of HAR early, a plethora of ideas based on experience can be proposed to optimize the plant for maximum LNG production.

JGC has been engaged in studies since 2008 to develop the CFD methods for analyzing the HAR phenomenon. These studies have led to major improvements in the accuracy of the CFD simulations. A large volume of measurements from other LNG plants have also been used to verify the accuracy of the CFD. Developments in the CFD methods are being applied on various LNG projects in the FEED and EPC phases, when the most optimal plot plan and equipment layout to reduce HAR need to be determined.

References

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