ADVANCED CAE APPLICATIONS FOR LNG PLANT DESIGN

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ABSTRACT

Demand for LNG is strongly supported by not only emerging economies but also by countries all over the world considering eco-friendly energy source. With the mission of “Energy and Environment in Harmony”, Chiyoda Corporation has designed and constructed a number of liquefied natural gas plants (LNG plants) over 35 years and recently successfully completed world’s largest 7.8mtpy LNG trains in Qatar. In these LNG plant projects, scaling-up and optimization capabilities were the keys to success from technological and economical view point therefore more rigorous approaches were required for its design. Chiyoda group has introduced advanced Computer Aided Engineering (CAE) in early 90’s and utilized CAE for detailed LNG plant designs as rigorous and also reliable approach. In this paper, CAE applications in LNG plant design will be briefly reviewed and as a typical contribution of CAE to LNG plant design, Hot Air Recirculation (HAR) study will be presented. The production capacity of LNG plant is highly linked with “Hot Air” surrounding multiple LNG trains, which is mainly exhausted from air cooled heat exchangers (ACHEs), because the temperature of induced air affects available power of gas turbines used as mechanical drivers and also refrigerant condensing temperature at the refrigerant condensers. In HAR study, a multidiscipline group studies LNG plant layout by using well validated Computational Fluid Dynamics (CFD) technique incorporating site-specific meteorological and geographical data. In addition to accumulated design knowledge through a number of previous projects, CAE utilization can provide practical design and achieve competitive LNG plant as well as reliable plant performance.

1. INTRODUCTION

In design work for LNG plant, a huge number of information is generated and the management of the information becomes quite important. Efficient management of the information over design phases can realize well-organized design approach and leads not only proper performance or safety of plant and also competitive capital investment for complex LNG plant. In this situation, advanced Computer Aided Engineering (CAE) technologies have been introduced in early 90’s and utilized for detailed LNG plant designs in Chiyoda. For recent large LNG plant design, it is also observed that some conventional technologies cannot be easily extended and multiple areas of technologies including scaling-up/optimization capability are required to achieve design goals. With recent enhanced computing capabilities, CAE technologies are also taking important roles in such large LNG plant design as multi-physics platform and visualization tool to share actually design specific and required information among engineers working in multidiscipline group, which is an essential style for recent large and complex LNG plant design, “Design by Analysis”.

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Following are main CAE tools used for LNG plant design;

Process simulator
Steady-state process simulation which calculates heat and material balance of whole the plant and LNG plant design is based on the results of the process simulator.

Dynamic simulation
Basically steady-state process simulation does not take into account dynamic characteristics of rotating equipment such as compressors in LNG plant; however the dynamic characteristics of those equipments can be critical elements in recent LNG plant, especially for process upset conditions and process startups and shutdowns. Dynamics simulation is utilized to review and verify a plant behavior incorporating its dynamic characteristic and essentially required to improve plant performance and keep safety and reliability of plant operations.

Computational Fluid Dynamics (CFD)
Fluid motion in multi-dimensional domain is numerically analyzed incorporating thermal effect. Flow inside pipe, reactors and etc. is evaluated to check or optimize equipment design. Reacting flow problems also can be reasonably treated. Recent development of computing capabilities enhances its utilization for large scale outdoor environment problems such as hot air recirculation (HAR) study for air cooled heat exchanges (ACHEs), consequence study for hazardous material leakage/ dispersion, fire and explosion.

Structural Analysis
Structure's deformations, internal forces, stresses are evaluated incorporating its detail shape and load acting on it. Finite Element Method (FEM) and etc. is applied. Fluid-Structure Interaction (FSI) and Flow Induced Vibration (FIV) problem are also treated as a part of Structural Analysis.

In the following section, applications of those CAE technologies in LNG plant design will be briefly reviewed.

2. ADVANCED CAE APPLICATIONS IN LNG PLANT DESIGN

Dynamic Simulation for Compressor Circuit and Fuel System
Figure 1a shows typical configuration of mixed refrigerant (MR) compressor circuit. Dynamic simulation around compressors is conducted to ensure proper systems and operations to prevent any damages of compressor because its damage can lead extensive loss of profits during the downtime. Figure 1b shows a typical simulation result for driver trip scenario. Adequacy of an anti-surge system and sizing of hot/cold bypass valves are studied to prevent surging.

Fuel gas system is another area where dynamic simulation is often used. Multiple fuel sources and users are incorporated and dynamic behavior of system is evaluated to maintain header pressures and fuel gas quality parameters such as Heating Value and Wobbe Index. Recently, a dynamic simulation for a system including equipment which is difficult to be expressed by conventional approach is modeled with CFD such as fuel mixing system as shown in Fig.2.
Figure 1a. Typical configuration of mixed refrigerant (MR) compressor circuit

Figure 1b. Typical dynamic simulation result for driver trip scenario of MR compressor circuit
Dynamic Simulation

Figure 2. A combined simulation of dynamic simulation and CFD for fuel mixing system

CFD Simulation for Consequence Analysis

Figure 3a shows CFD simulation results for flammable gas leakage scenarios. Two different gases such as methane and propane are studied which are commonly treated in LNG plant as refrigerant or product. As it can be seen in Fig.3a, flammable gas cloud size and located area are totally different even though the leakage and environment condition is completely identical. This kind of visualization can provide an insight to take effective measures for safety design development. Figure 3b shows an explosion simulation results for propane leakage case.

Health and Safety during fire or explosion hazardous can be considered especially for limited and congested space in an offshore facility such as FPSO. As shown in Figure 4, CFD simulation result and 3D plant model are utilized to represent a hazardous environment.

Methane leakage Propane leakage

Figure 3a. CFD simulation results for flammable gas leakage
3. HOT AIR RECIRCULATION STUDY

In this paper, as a typical contribution of CAE technology to LNG plant design, Hot Air Recirculation (HAR) study will be presented. The production capacity of LNG plant is highly linked with “Hot Air” surrounding multiple LNG trains, which is exhausted from ACHEs and Gas turbines, because temperature of induced air affects available power of gas turbines used as mechanical drivers and also refrigerant condensing temperature at ACHEs. As just described, HAR influences plant performance strongly and it can be optimized by plant layout and mechanical specification for ACHEs with consideration of competitive capital investment. From this view point, HAR study is basically conducted by a multidiscipline group in Chiyoda. Fig.5 shows typical work flow for HAR study.
Figure 5. Typical work flow for HAR study

Figure 6 shows a CFD model prepared to demonstrate hot air recirculation study for typical plant layout. The model geometry for two trains was built taking into account ACHEs, Gas turbine air intakes and exhaust stacks. The atmospheric conditions such as wind directions, wind velocity and ambient temperature are assumed. The sources of hot air are ACHEs and gas turbines.

Figure 6. CFD demonstration model for HAR study

Figure 7 shows a CFD simulation result. In this case, wind direction along ACHEs bank is assumed. Hot air exhausted from ACHEs and GT exhaust stacks generate large hot air plumes. Fig.8 shows visualized stream lines of air induced into ACHEs. At the upwind end of ACHEs bank, localized self-recirculation is taking place, however temperature rise of all ACHEs and GT air intake are small and remains lower than 0.5degC. Fig.9 shows a result of another case with wind direction crossing ACHEs bank. In this case, hot air exhausted at ACHEs in Train1 is induced by ACHEs in Train2 and localized self recirculation is also taking place almost all area inside Train1. As the result of the severe hot air recirculation, temperature rise of ACHEs are quite large and one reaches over 5.0degC, which is ten times larger than that for previous case.
These results suggest that HAR is quite sensitive to the plant layout. However, well validated CFD technology and accumulated design knowledge through a number of previous projects can provide optimized plant layout and several practical measures such as wind wall (shield) applications. In this demonstration case, the temperature rise at ACHEs can be reduced from over 5degC to 1degC with proper wind wall (shield) application.

Figure 7. Visualization of hot air around ACHEs by CFD simulation

Figure 8. Stream line induced into ACHEs for Case1; wind along ACHEs bank
4. WAY FORWARD

In this paper, advanced CAE applications in LNG plant design including HAR study were reviewed. For recent large LNG plant design, short delivery time and competitive capital investment are expected as well as proper performance and safety of plant. In this context, the role of advanced CAE technologies will be wider and enhanced. Integration of CAE technologies such as Fluid-Structure Interaction (FSI), 1-Dimensional and 3-Dimensional integration and multi-scale/multi-physics integration utilizing High Performance Computing (HPC) can be possible ways to reply those requirements.