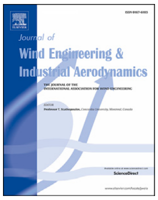
Journal of Wind Engineering & Industrial Aerodynamics 172 (2018) 409–422

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia



Numerical and wind tunnel investigation of Hot Air Recirculation across Liquefied Natural Gas Air Cooled Heat Exchangers

Saud Ghani *, Seifelislam Mahmoud Ahmad Gamaledin, Foteini Bakochristou, Esmail El-Bialy [1], Mohamed Mostafa Mohamed, Rodina Mohamed El Hassan Elsawi

Qatar University, Mechanical and Industrial Engineering, Doha, Qatar

ARTICLE INFO

Keywords:
Air Cooled Heat Exchangers (ACHE)
Hot Air Recirculation (HAR)
Liquefied Natural Gas (LNG) plants
Computational Fluid Dynamics (CFD)
Wind tunnel testing

ABSTRACT

Air Cooled Heat Exchangers (ACHE)s are used for heat rejection in Liquefied Natural Gas (LNG) plants. Their thermal performance decreases under elevated ambient temperatures and windy conditions as exhaust air recirculates back into the ACHE units causing Hot Air Recirculation (HAR). This paper investigates the effect of various incident wind speed and directions on HAR. Understanding HAR helps to avoid undesirable work conditions. Three dimensional Computational Fluid Dynamics (CFD) studies were utilized to simulate the airflow around a full scale LNG plant. The simulations clearly captured HAR between parallel ACHE banks (Cross-HAR) and within a single ACHE unit (Self-HAR). Wind tunnel smoke visualization was used to qualitatively assess the CFD model. The impact of removing downstream ACHE protection screens on the HAR was computationally investigated showing an exhaust air temperature reduction of 5 °C. Different HAR mitigation methods were proposed using different configurations of side winglets. Horizontal winglets were shown to be more effective than vertical winglets as they decreased intake and exhaust air temperatures by about 5 °C and 8 °C respectively and increased exhaust air velocity by 1.2 m/s. This work provides a thorough understanding of HAR around ACHEs and proposes mitigation methods to reduce its effects on plant production.

1. Introduction

Usage of Air Cooled Heat Exchangers (ACHE)s in Liquefied Natural Gas (LNG) plants is increasing due to the low cost and availability of air. They are the most commonly used type of heat exchangers throughout different refining and gas processing plants (Fahmy and Nabih, 2016; Meyer, 2004). For minor heat load applications, such as lubrication oil coolers, a single ACHE unit can provide the required cooling load. For higher cooling load applications, such as air cooled condensers of LNG plants, ACHE units are configured in banks operated by large number of vertical axial flow fans. Utilizing air as a cooling medium is economically advantageous in areas where the available water requires extensive treatment to prevent fouling or when high investment is required to expand an existing plant's cooling water supply (Hall, 2012). In comparison to water-cooled power plants, air-cooled condensers provide a higher plant-level efficiency of 5–10% (Bustamante et al., 2016). Utilization of ACHEs reduces the plant industrial water consumption, promotes environmental conservation and increases the plant modularity and capacity (Kuntysh et al., 1997). Compared to water based cooling, ACHEs offer economic benefits when optimizing the process heat-transfer (Fahmy and Nabih, 2016). Stringent environmental regulations governing water use and discharge of effluent streams tend to favor air cooling. The current design practices favor air cooling when minimum process temperatures are above 65 °C. Water cooling is considered to be more suitable for process temperatures below 50 °C (IPS-E-PR-785, 2012; KLM Technology Group, 2011). Hall (2012) discussed different selection guidelines and installation recommendations of different heat exchangers. Selection of appropriate equipment and configuration meeting the plant's capacity goals is an effective strategy to develop a successful LNG plant (Mokhatab et al., 2013). The plant implementation technology depends on different criteria such as economic, environmental, financial, license or technical factors (Castillo and Dorao, 2012). LNG plants have largely been outlined along the train concept (Kirillov, 2010). Due to cost saving benefits of scale economics, LNG train sizes have been increasing (Habibullah et al., 2009). ACHEs banks should be located so that the hot air exhaust doesn't pose a hazard

---

* Corresponding author.

E-mail addresses: s.ghani@qu.edu.qa (S. Ghani), seif.mahmoud@qu.edu.qa (S.M.A. Gamaledin), f.bakochristou@qu.edu.qa (F. Bakochristou), bialy@qu.edu.qa (E. El-Bialy), mm099282@student.qu.edu.qa (M.M. Mohamed), rodinaelsawi@qu.edu.qa (R.M.E.H. Elsawi).

[1] Dr. Esmail El-Bialy is on leave from Cairo university, Giza, Egypt.

https://doi.org/10.1016/j.jweia.2017.11.026
Received 1 March 2017; Received in revised form 26 November 2017; Accepted 26 November 2017

or an inconvenience to personnel or adversely affecting the operation of adjacent equipment (Kolmetz and Widiawati, 2015). Furthermore, one of the most important aspects of ACHE design is to determine the flow resistance characteristics by analyzing the flow losses through the system (Duvenhage, 1996). Kuntysh et al. (1997) highlighted the high energy consumption of ACHEs. Furthermore, ACHEs often operate off-design because of the process increased demand, bundles replacement, or the improper positioning of units within the plant (Bouhairie, 2015). ACHEs are categorized into forced draft and induced draft (Hall, 2012; Kröger, 2004). For both types, air acts as a cooling medium and the either forced or induced through the Heat Exchanger (HE) bundle by a fan. In today's industry, forced draft ACHEs are more common. The advantages of using forced draft ACHEs are the decreased power consumption, ease of maintainability and low temperature fan exposure (Serth and Lestina, 2014). Forced daft ACHEs are more prone to HAR due to the slow exhaust air velocity (Bouhairie, 2015; Hall, 2012; Kolmetz and Widiawati, 2015). Induced ACHEs are less sensitive to changes in weather conditions since the airflow distribution is more uniform and the relatively high escape velocity (Kröger, 2004).

Since the ACHEs are open to the atmosphere, their thermal performance is affected by wind, rain, hail, and solar radiation (Branan, 2002; Maulbetsch and DiFilippo, 2010; van Rooyen & Kröger, 2007). Duvenhage and Kröger (1996) identified plume recirculation and performance reduction as the two major adverse effects of incident wind on ACHEs operation. In addition, Hotchkiss et al. (2006) concluded that Cross-flow wind adversely affects the ACHE fans total pressure rise and static efficiency.

There are two types of HAR, namely, Cross-HAR and Self-HAR. Cross-HAR normally occurs between parallel ACHEs banks. The exhaust of the first ACHE bank is recirculated towards the inlet of the parallel second ACHE bank. Self-HAR occurs within a single HAR where hot exhaust air is recirculated back to the inlet of the same unit.

Structures, wind and neighboring fans may result in a significant reduction in fans performance, or volumetric effectiveness, and increased fan blade vibration (Bredell et al., 2006). The volumetric effectiveness is an expression for the actual volume flowrate through the fan as a fraction of the ideal volume flowrate (Meyer, 2005). To ensure that ambient air is supplied to the ACHE units uninterrupted by upstream obstacles, it is preferred to raise ACHEs above the surrounding equipment (Walters, 2015). An ACHE unit must be designed at the maximum statistical summertime condition of the site. However, using the highest annual ambient air temperature to size the unit will develop an over-engineered and expensive design. During hot days, using low design air temperature leads to reduction of the plant production rates. ACHEs could be developed with a lenient design (non-critical duties), moderate design (normal duties) and very safe design (critical duties only) approach. The major difference between these three categories is the number of hours per year at which the design temperature would be exceeded (GBH interprises Ltd., 2012). A common practice is to use a design air temperature corresponding to 97%–98% of the total annual hourly temperature readings based on at least 5 consecutive years (IPS-E-PR-785, 2012; KLM Technology Group, 2011; Serth and Lestina, 2014). To ensure effective ACHEs performance and minimizing airside maldistribution, API (2013) recommends measures and guidelines including fan coverage, plenum depth, fan-cell partitions, inlet and exit velocities, and airside kinetic energy. Different techniques have been used to analyze HAR. Proposed mechanisms to control the airflow within the plant must be analyzed and simulated to avoid any adverse effects of the incident wind (Owen and Kröger, 2010; Yang et al., 2011). Gunter and Shipes (1971) performed actual field tests on both ACHE types to visualize Self-HAR. Gu et al. (2005); Wanli et al. (2014); White (2009) utilized wind tunnel testing to simulate HAR in Air Cooled Condensers (ACC)s. Liu et al. (2009) used CFD and wind tunnel tests to show that HAR varies with different incident wind directions in ACCs. Borghei and Haghighi (2011) analyzed wind effects on ACCss by utilizing 3D CFD modeling. They investigated HAR on a single ACC under the impact of different incident wind speeds and directions. The study concluded that the HAR severity is proportional to the incident wind speed. Furthermore, the peak value of Self-HAR was shown to be attributed to the perpendicular wind direction. Duvenhage and Kröger (1996) studied the impact of HAR on the performance of ACHEs. They stated that Self-HAR resulted in increased intake air effective temperature. Therefore, reducing the overall heat rejection rate of the ACHE unit. The air mass flowrate was shown to decrease throughout the system which reduced the fan performance due to the distortion of inlet airflow conditions. The authors found that the cross wind significantly reduced the air volume flowrate delivered by the up-wind fans, while winds along the longitudinal axis increased the HAR along the sides of the ACHE bank. He et al. (2014b) modeled a power plant equipped with ACCs to investigate mechanisms of air temperature rise at different wind conditions. The authors found that the diffusion of the exhaust air and HAR are significant in raising the air temperature at the fan inlets. Manish Baweja and Bartaria (2013) showed that the performance of ACHEs, and specially ACCs, is highly sensitive to airflow patterns and ambient conditions. Liu et al. (2009) claimed that HAR is more sensitive to the incident wind direction and wind speed. Hence, the authors suggested increasing the wind wall height and increasing the fans rotational speed to decrease HAR. He et al. (2014a,b) modeled a power plant to investigate the effect of blade angle installation of ACHEs axial fans. The authors found that changing of the blade installation angle for the windward fans alters the performance of the fan array as well as the heat transfer characteristics of the ACHEs. They also found that the adjustable blade fans are preferred to satisfy the off design working conditions. He et al. (2014a,b) modeled a power plant to investigate the influence of the fan rotating speed on the performance of the fan array as well as the entire air-cooled power plant. They found that the increase of the fan rotating speed of the windward fans would improve the performance of the fan array and the heat transfer characteristics of the ACC. A thorough understanding is required to control HAR. Hence, LNG industry tends to use rule of thumb developed over the years of operational experience to help mitigating HAR (Bouhairie, 2015). Although the degree of acceptability of ACHEs exhaust air temperature is subject to the owner's approval, there exist a general design limit for this temperature. Under normal conditions, the maximum ACHEs air outlet temperature should be 60 °C with fans in operation and 80 °C with free convection on the air side (IPS-E-PR-785, 2012; KLM Technology Group, 2011). Previously, several studies investigated HAR for single ACHE units. Nevertheless, this paper considered HAR occurrence in an operating full scale LNG plant. The effect of plant installations nearby the ACHE banks was highlighted and feasible HAR mitigation methods were proposed. Thermal imaging was used to capture the outer skin temperature of the full scale LNG plant equipment to provide the boundary conditions needed for the 3D CFD modeling. Moreover, scaled wind tunnel testing was performed to qualitatively assess the CFD modeling results.

2. Numerical CFD modeling

CFD modeling accounts for the actual physical geometry of the equipment and applies fundamental physics principles to evaluate different airflow characteristics such as velocity, temperature, and pressure. CFD modeling provides an effective means to evaluate the cause of the recirculation problems and offer solutions to improve performance (Rogers et al., 1999; Gosman, 1999). Bhutta et al. (2012) reviewed several CFD applications in various heat exchangers designs showing that CFD can be used effectively to obtain valuable results. He et al. (2013) utilized different wind speeds and ambient temperatures to numerically simulate airflow around ACC using User Defined Functions (UDF)s. The authors found that the wind speed influences the performance of air-cooled steam condensers due to the variation of pressure distribution around the Air Cooled Steam Condensers (ACSC) platform. While Borghei and Haghighi (2011) studied a single ACHE model, Farhana and Shaari (2013) utilized a full 3D CFD model of an actual LNG plant to investigate the effect of HAR on ACHEs exhaust air. The authors