THERMAL STRESS ANALYSIS FOR EXHAUST HEAT EXCHANGER

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ABSTRACT

Thermal stress induced in an object or structural member by restraint against movement is required to accommodate temperature changes. In this paper, the thermal stress and deformation of the exhaust heat exchanger on board a ship is analysed. The flow and temperature distributions of exhaust heat exchanger are conducted in ANSYS Static Structural by the coupled analysis of fluid and solid zones. According to the numerical analysis it is found that the thermal stress is increasing non-linearly with the increase of inlet sea water temperature. By increasing inlet sea water temperature will increase thermal stress. The result indicates that the maximum stress is equal to 479 MPa which is exceed the yield stress. Therefore, current heat exchanger being used is insufficient in design. By varying the different sea water inlet temperature and sea water inlet pressure at allowable limit still shows that maximum Von Misses Stress for current design is exceeding yield stress. The new design is proposed by increasing of thickness plate from 2mm to 3mm and proven to produce maximum Von Misses Stress below the yield stress which is equal to 245MPa. Percentage area for total thermal stress is also much lower compare to current design.

ABSTRAK

Tegasan haba ke atas sesuatu objek atau bahagian struktur yang disebabkan oleh sekatan terhadap pergerakan diperlukan untuk menampung perubahan suhu. Dalam kajian ini, tekanan haba dan perubahan bentuk ke atas penukar haba ekzos kapal telah dianalisa. Pengagihan suhu dan aliran penyejuk pada penukar haba ekzos dianalisis menggunakan ANSYS Static Structural dengan menggabungkan kedua-dua analisis ke atas zon cecair dan zon struktur. Menurut analisis berangka didapati bahawa tekanan haba semakin meningkat secara tidak linear dengan peningkatan suhu kemasukan air laut. Dengan meningkatkan suhu kemasukan air laut akan meningkatkan tegasan haba. Keputusan telah menunjukkan bahawa tegasan haba maksimum adalah sama dengan 479 MPa yang melebihi tegasan alah material yang digunakan. Justeru, penukar haba yang digunakan ketika ini didapati tidak memenuhi keperluan pengoperasian dalam aspek reka bentuk. Dengan mengubah pelbagai parameter suhu masuk air laut dan tekanan masuk air laut pada julat yang dibenarkan didapati maksimum Von Misses Stress masih melebihi melebihi tegasan alah material tersebut. Oleh itu, reka bentuk baru telah dicadangkan dengan meningkatkan ketebalan plat dari 2mm kepada 3mm dan terbukti menghasilkan maksimum Von Misses Stress 245 MPa iaitu dibawah tegasan alah material. Peratusan kawasan bagi keseluruhan tegasan haba juga jauh lebih rendah berbanding dengan reka bentuk sekarang.

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LIST OF SYMBOLS

σ	-	Von Misses Stress
$\varepsilon_x, \varepsilon_y, \varepsilon_z$	-	Normal Strain
μ	-	Poisson’s Ratio
τ_i	-	Sheer Stress
α	-	Thermal expansion coefficient
Q	-	Heat transfer rate,
E	-	Young’s modulus
x, y, z	-	Coordinate directions
d_i	-	Inner diameter of inner tube
d_o	-	Outer diameter of inner tube
D_i	-	Inner diameter of outer tube
D_o	-	Outer diameter of outer tube
ρ	-	Density

CHAPTER 1

INTRODUCTION

Sea water cooling system are widely used for exhaust gas before being discharged to the exterior by Royal Malaysian Navy. An example ship that use kind of system are corvette, mine counter measure vessel, new generation petrol vessel and frigate. Currently corvette ship use butterfly valve provided with sea water cooling jacket to refrigerate the engine gas.

Particulate emission from diesel engines is receiving a great deal of attention due to its probable carcinogenic property. In the exhaust pipe of a diesel engine, the change of the exhaust gas temperature can result in nucleation and condensation of volatile materials and coagulation of particulates.

During startup phase the propulsion engine exhaust is carried away through the above sea level outlet by positioning the on line butterfly valve open (300 in dia), while the butterfly valve (600 in dia), mounted on the underwater projecting duct, is in close position. This valve position also occurs when the ship moves on reverse gear or, anyhow, during manouvering or moving forward slowly.

When the engines develop full power and during the normal navigation the butterfly valve (600 in dia) on the below sea level outlet remains open and the butterfly valve on the above sea level outlet is held closed.

Characteristic Data:

Max exhaust pressure	- 2.5 bar
Max operational exhaust temperature	- 700^{o}C
Operating sea water pressure	- 1.5 bar
Plate Thickness	- 2mm
Material	- Stainless Steel

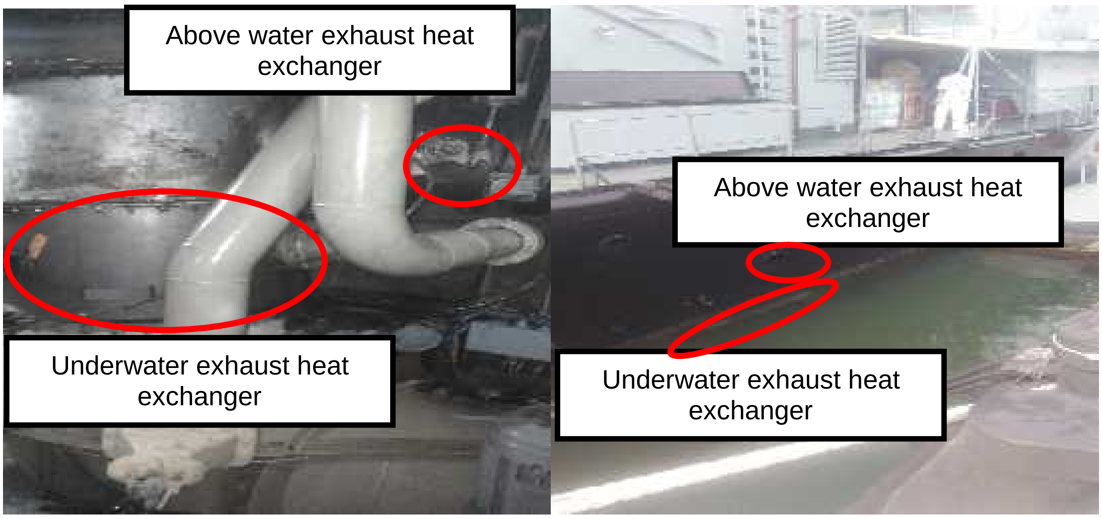

Figure 1.1: Location of Above Water Exhaust Heat Exchanger and Below Water Exhaust Heat Exchanger.

The engine gas (flue gas) is refrigerated before being discharged to the exterior, the two flue outlets provided, one above and one below the sea level respectively, are provided with sea water cooling jacket as Figure 1.1.

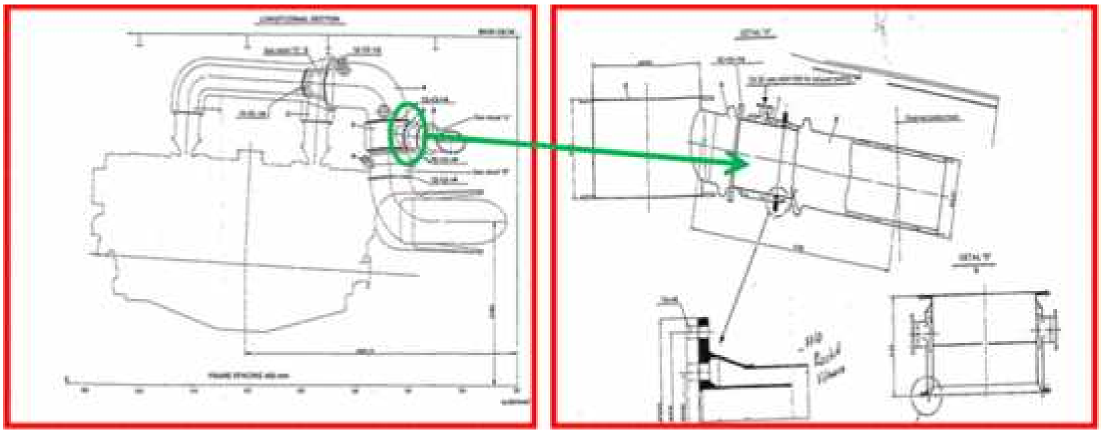

Figure 1.2: Layout Arrangement of Exhaust Cooling Valve

The effect of this refrigeration causes remarkable decrease in the exhaust gas volume that makes its mixing sea water much easier; such a mixing also facilitated by the shape of the flue outlet which directs the flue gas as much parallel as possible to the flow line along the ship's immersed hull as shown in Figure 1.2. The longitudinal axis of the exhaust duct end is not normal to the ship side; it is instead bent astern.

This feature, while facilitating the engine exhaust when the ship is moving ahead will affect negatively the discharge of these combustion products when the ship moves on reverse. In this circumstance it is mandatory that the exhaust gas be routed through the pipe with outlet above sea level.

The material used to fabricate the butterfly exhaust valve is stainless steel, X8CrNil310-UNI 6900/71 (AISI 321). Parts are fabricated from sheets and assembled by longitudinal welding process. In the areas that are not refrigerated by sea water, the exhaust ducts and relative assembly flanges are fabricated.

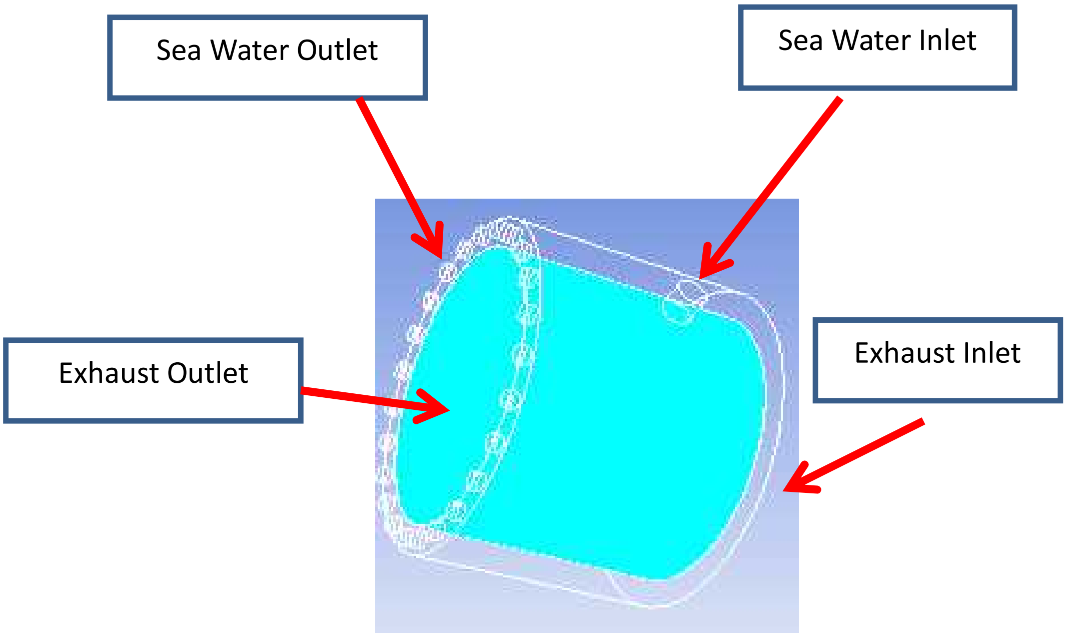

Figure 1.3: Functionality of Exhaust Cooling Valve

1.1 Research Background

Based on my research, it has been found that CFD has been employed for the following areas of study in various types of heat exchangers: fluid flow maldistribution, fouling, pressure drop and thermal analysis in the design and optimization phase. As presented by Muhammad Aslam Bhutta [1].

The quality of the solutions obtained from these simulations are largely within the acceptable range proving that CFD is an effective tool for predicting the behavior and performance of a wide variety of heat exchangers.

Analysis of flow is a major consideration of my topic. This is proven based on research by Jiang when they found Non-uniformity in fluid flow is one of the primary reasons resulting in a poor heat exchanger performance. This may be attributed to improper design of inlet/outlet port and header configuration, distributor construction and plate corrugations [2].

Heat distribution is affected to thermal stress. As found by Irfan and Chapman [3] where hot spots in the axial temperature gradient were a major source of thermal stress. All that research become my preference to solve my problem.

1.2 Research Objectives

Research objectives of this study are as follow:

a. To verify current design of exhaust heat exchanger in term of reliability and sufficiency.

b. To propose improvement of current design in order to reduce thermal stress and deformation.

1.3 Problem Statement

Always happen above water cooling exhaust become overheated during main engine is operated below 900rpm or engine rpm is not consistent. Engine room become very hot and temperature above 60^{o}C. As shown in Figure 1.4 temperature of exhaust cooling valve outer tube can reached about 153^{o}C during slow speed. Thus affected to personnel comfortability during working condition. Furthermore temperature rising had contributed to overall ship infrared signature.

Figure 1.4: Exhaust Heat Exchanger Temperature

The worst case scenario happen if ship constantly sailing 2 time a month sailing, the exhaust heat exchanger always crack at welded joint as shown in Figure 1.5. Frequent time average once in 3 month. The water discharge outboard also not consistent and intermittent especially if main engine rpm is increased and decreased frequently. Therefore, it is crucial to identify fluid flow maldistribution, fouling, pressure and thermal analysis in the design and optimization phase.

Figure 1.5: Area of Crack at Exhaust Heat Exchanger

1.4 Scope of research

Scopes of research are as follows:

a. Temperature distribution and pressure distribution of cooling water for various input temperature and pressure.

b. Thermal stress and deformation various input temperature and pressure.

c. Numerical method on simplify model and compare with current condition.

1.5 Theoretical Framework

The theoretical framework of this research is presented in **Figure 1.6**. The critical steps are during methodology process. Initial and boundary condition must be defined correctly.

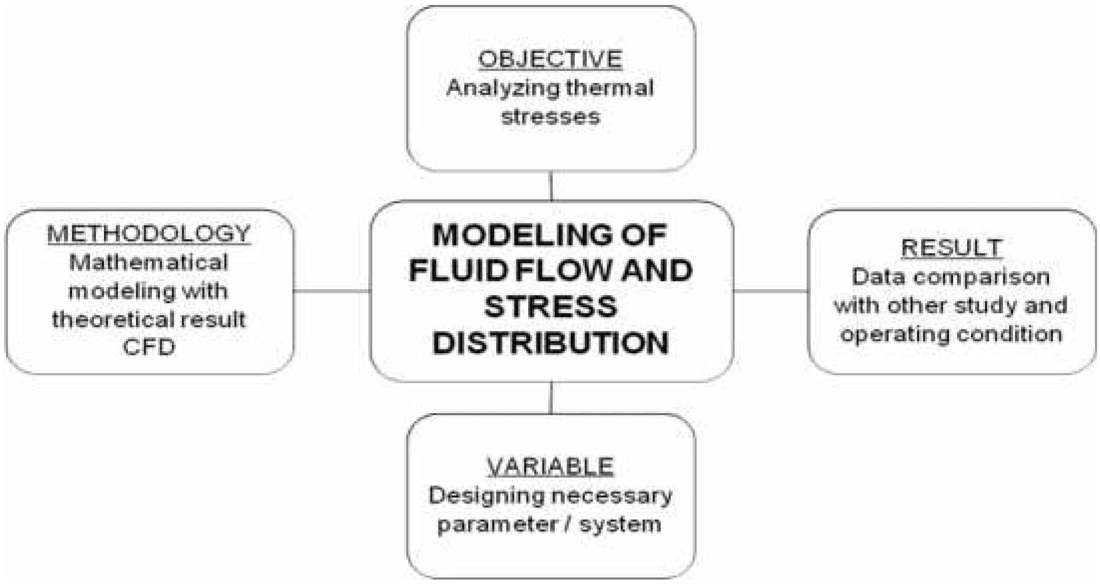

Figure 1.6: Theoretical Framework

1.6 Organization of Thesis

Chapter 1: Introduction

This chapter describes the research background of this. The objective of this project also been started in this chapter.

Chapter 2: Literature Review

In this chapter, the item that will be discussed is the related works and literature review that will supported this study.

Chapter 3: Methodology

The most significant chapter that is chapter 3 detailing on the research methodology variables and equations involved in the modelling and simulation part. Data collection method and the accuracy of the result are been listed in this chapter . It will also define the research variable and the data to be enquired.

Chapter 4: Result and Discussion

For this chapter, results and findings obtained from the FSI modelling are listed out and discussion is carried out for the result obtained. the reliability of the data obtained will also be discussed

Chapter 5: Conclusion and Recommendation

In this last chapter it is dedicated for conclusion of the study and recommendations on future improvements for different operating parameters needed in this study. This paper will have the reference list post.

REFERENCES

1. Muhammad Mahmood Aslam Bhutta, Nasir Hayat1, Muhammad Hassan Bashir2, Ahmer Rais Khan, Kanwar Naveed Ahmad, CFD Applications In Various Heat Exchangers Design: A review, Sarfaraz Khan5, Department of Mechanical Engineering, University of Engineering & Technology, Lahore, Pakistan, 2011.
2. J.M. Gong, W.C. Jiang, Q.S. Fan, H. Chen, S.T. Tu, Finite Element Modelling Of Brazed Residual Stress And Its Influence Factor Analysis For Stainless Steel Plate Fin Structure, Journal of Materials Processing Technology 209 (2009) 1635 - 1643.
3. M. Irfan, W. Chapman, Thermal stresses in radiant tubes: a comparison between recuperative and regenerative systems, Applied Thermal Engineering 30 (2010) 196-200.
4. Muhammad Mahmood Aslam Bhutta, Nasir Hayat, Muhammad Hassan Bashir2, Ahmer Rais Khan, Kanwar Naveed Ahmad, CFD Applications In Various Heat Exchangers Design: A review, Sarfaraz Khan5, Department of Mechanical Engineering, University of Engineering & Technology, Lahore, Pakistan, 2011.
5. R.B. Fleming, The Effect Of Flow Distribution In Parallel Channels Of Counterflow Heat Exchangers, Adv. Cryog. Eng. 12 (1967) 352–357.
6. M. Tsuda, E. Takemura, T. Asada, N. Ohno, T. Igari, Homogenized elastic viscoplastic behavior of plate-fin structures at high temperatures: numerical analysis and macroscopic constitutive modeling, International Journal of Mechanical Sciences 52 (2010) 648e656.
7. F. Kawashima, T. Igari, Y. Miyoshi, Y. Kamito, M. Tanihira, High temperature strength and inelastic behavior of plate-fin structures for HTGR, Nuclear Engineering and Design 237 (2007)

8. M.G. Beiler, D.G. Kroger, Thermal performance reduction in air-cooled heat exchangers due to non-uniform flow and temperature distributions, Heat Transfer Eng. 17 (1996) 82–92.

9. C. Ranganayakulu, K.N. Seetharamu, K.V. Sreevatsan, The effects of inlet fluid flow nonuniformity on thermal performance and pressure drops in crossflow plate-fin compact heat exchangers, Int. J. Heat Mass Transfer 40 (1997) 2738.

10. C. Ranganayakulu, K.N. Seetharamu, The combined effects of wall longitudinal heat conduction, inlet fluid flow nonuniformity and temperature nonuniformity in compact tube-fin heat exchangers: a finite element method, Int. J. Heat Mass Transfer 42 (1999) 263–273.

11. E.Y. Ng, P.W. Johnson, S. Watkins, An analytical study on heat transfer performance of radiators with non-uniform airflow distribution, Proc. Inst. Mech. Eng. Part D: J. Automobile Eng. 219 (2005) 1451–1467.

12. S. Lalot, P. Florent, S.K. Lang, A.E. Bergles, Flow maldistribution in heat exchangers, Appl. Therm. Eng. 19 (1999) 847–863.

13. M.M.A. Bhutta, N. Hayat, M.H. Bashir, A.R. Khan, K.N. Ahmad, S. Khan, CFD applications in various heat exchangers design: a review, Appl. Therm. Eng. 32 (2012) 1–12.

14. Ting Ma, Yitung Chen, Stress analysis of internally finned bayonet tube in a high temperature heat exchanger, Applied Thermal Engineering 43 (2012) 101-108.

15. K.S. Syed, Z. Iqbal, M. Ishaq, Optimal configuration of finned annulus in a double pipe with fully developed laminar flow, Applied Thermal Engineering 31 (2011) 1435e1446.

16. W.C. Jiang, J.M. Gong, S.T. Tu, A study of the effect of filler metal thickness on tensile strength for a stainless steel plate-fin structure by experiment and finite element method, Materials and Design 31 (2010) 2387-2396.

17. K. Grijspeerdt, B. Hazarika, D. Vucinic, Application of computational fluid dynamics to model the hydrodynamics of plate heat exchangers for milk processing, J. Food Eng. 57 (2003) 237-242.

18. S. Jun, V.M. Puri, 3D milk fouling model of plate heat exchangers using computational fluid dynamics, Int. J. Dairy Tech. 84 (4) (2005).

19. M.V.D. Bonis, G. Ruocco, Conjugate fluid flow and kinetics modeling for heat exchanger fouling simulation, Int. J. Therm Sci. 48 (2009) 2006-2012.

20. R.K. Shah, D.P. Sekulic, Fundamentals of Heat Exchanger Design, first ed. Wiley, New York, 2003, 378-381.

21. G. Gan, S.B. Riffat, L. Shao, CFD modelling of pressure loss across tube bundles of a heat exchanger for closed-wet cooling towers, Int. J. Ambient Energy 21 (2000) 77-84.