Steam Coil Air Heater (SCAH) Modelling as Porous Medium to Analyze Flow Characteristic and Reduce Self Energy Usage in Gresik Unit 1 Steam Power Plant

Eko Ariyanto, Wawan Aries Widodo

Abstract— **This study deals with flow and heat transfer characteristic in a Heat Exchanger if its tube modules completely or partially dismantled. The heat exchanger is a Steam Coil Air Heater (SCAH) Installed in Gresik unit 1 Steam Turbine Power Plant. Nowadays, the power plant operates mostly utilized natural gas as a fuel. When it utilized natural gas SCAH are not give benefit and only give flow resistance for combustion air flow. This study uses numerical simulation model with commercial Computational Fluid Dynamic (CFD) software. The simulation on the 3D model with a steady state flow condition. The model use energy model, Heat Exchanger Model, realizable k-Epsilon for viscous turbulence model and SCAH model as Porous Medium (PM). Modeling SCAH as a PM will avoid time-consuming mesh generation and simulations with high CPU usage. Fives scenarios of tube module dismantling simulated in 100% load. This study result both quantitative and qualitative data correspond with flow and heat transfer characteristic. The model with original scenarios gives good result in terms of pressure and outlet temperature with commissioning data. The contour data results show there are several secondary flows due to enlargement of flow area. Numerical results of variation S1,S2,S3,S4 are indicated decreasing total pressure drop about 32.27%, 51.29%, 47.04%, 65.25% respectively. And temperature rise for each scenario will decrease to 29.29% (S1), 46.51% (S2) , 47.92% (S3), 68.28% (S4) respectively, except for S5 have no pressure drop and temperature rise since all modules are dismantled.**

Keywords—porous medium (PM), steam coil air heater (SCAH), numerical simulation, power plant.

I. INTRODUCTION

A power plant is converting prime energy from fuel to use electricity for the people. There are many kinds of power plant such as steam power plant, combine cycle power plant, hydropower plant, diesel engine, and a few renewable energy power plants.

Gresik unit 1 steam turbine power plant is one of the power plants that supply Java Bali Grid. It was built in 1980 with residual oil fuel. In 2003 it was modified to burn both residual oil and natural gas. Nowadays, it burns mostly natural gases due to economic and availability issues. Some issue arises since it modified from residual oil to dual fuel (residual oil and natural gases). SCAH that designed to prevent sulfur condensation on main air heater flue gas side was not needed anymore. The other issue is that natural gases will have higher Air to Fuel Ratio (AFR) than residual oil. To dismantle the tube module of SCAH partially or completely will reduce flow resistance and increase combustion air supply. For the same airflow, it will reduce Forced Draft Fan (FDF) power to supply combustion air. Reducing FDF power means reduce self-energy usage and increase energy transferred to the grid.

SCAH as a heat exchanger modeled as Porous Medium (PM). This approach will avoid time-consuming meshing process and high CPU usage for simulation. Each tube module in SCAH will be modeled as PM instead of drawing it one by one. With this way, to modeling real and complex geometry of SCAH is avoided.

There are several papers studied modeling Heat Exchanger using Commercial Computational Fluid Dynamic (CFD) software. Commercial CFD software used to study many types of heat exchanger with various issues such as flow maldistribution, fouling, pressure drop, and thermal Analysis [1]. Modeling heat exchanger as PM in CFD simulation widely used for many purposes. Although several commercial CFD software provides a specific tool for modeling Heat Exchanger, data availability such as dimensions and arrangement are not exhaustive enough to set up a real look like a model. PM Modelling will simplify the methodology to modeling heat exchanger in a Commercial CFD software. Musto et al. [2] studied this simplified methodology to model heat exchanger in Commercial CFD software of an oil cooler for aerospace application. This study concludes that PM Model is particularly suitable to model heat exchanger when heat exchanger performance data in terms of heat rejection and pressure drop versus mass flow rate are available. PM approach also used to study a hydrodynamic characteristic of a complex geometry heat exchanger. Wang et al. [3] conducted a numerical investigation of a hydrodynamic characteristic for Plate-Fin Heat Exchanger (PFHE). This study showed that PM modeling give hydrodynamic characteristic results closed to experimental results.

This study would simulate airflow in SCAH if its tube module dismantled partially or completely. It uses the PM approach in commercial CFD software to analyze flow and heat characteristic inside SCAH with various tube module scenarios. Such scenarios aimed to reduce self-energy usage and increase combustion air for the boiler. Four partially and one completely dismantled tube module scenarios were modeled as PM with commercial CFD software. The model with original scenarios gave good result in terms of pressure and outlet temperature with commissioning data of the SCAH. The contour data results show that there are several secondary flows due to enlargement of flow passage area.

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Figure 1. Steam coil air heater.

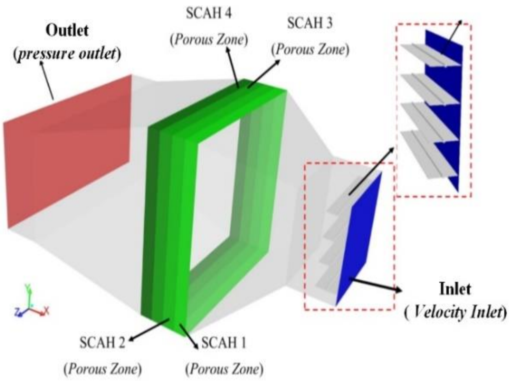

Figure 2. SCAH geometry model.

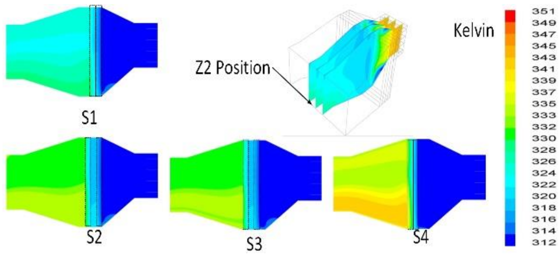

Figure 3. Side view temperature contour.

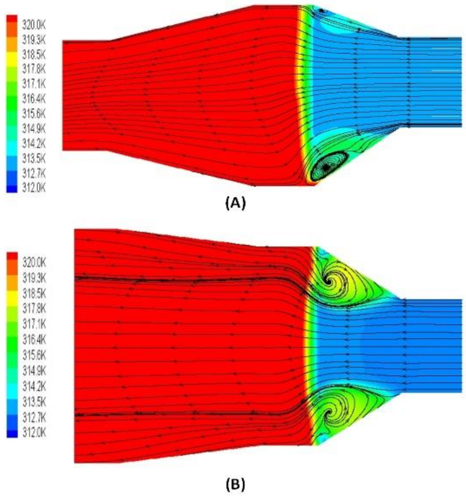

Figure 4. Stream trace and temperature contour.

II. METHOD

A. CFD Model and Simulation

The SCAH modeled in this study is illustrated in Figure 1. The incoming air supplied from FDF and the outlet goes to the central air heater. The duct mainly divided into three parts: inlet, SCAH, and outlet. The SCAH consist of four tube modules assembled independently of one another. SCAH module 1 (SCAH-1) and 2 (SCAH-2) consist of one row of 80 circular finned tubes for each. Whereas SCAH module 3 (SCAH-3) and 4 (SCAH-4) comprised of 2 rows 160 circular finned tubes in a staggered configuration. Figure 2 shows a 3D geometry model made in 3D based on real geometry with the horizontal flow direction on the x-axis. The model meshing is a hexahedral map meshing. The boundary condition for inlet flow defined as inlet velocity and outlet as outlet pressure. Inlet velocity data obtained from plant commissioning mass flow rate data.

The simulation use energy equation and heat exchanger macro. The heat exchanger macro is the ungrouped macro model with fixed heat rejection. Simple effectiveness method used for heat transfer model. The material in the model is air with constant properties assumption except for density, whereas air density modeled as an ideal gas. SCAH modeled as four PM block as it consists of four modules.

The simulation data compared with commissioning data for validation. It gave 0.54% error on outlet temperature and 0.01% on the inlet pressure. Grid independence test conduct on four grid sizes and result in small variation in pressure and temperature. Five SCAH module dismantling scenarios simulated with this model, they are S1 SCAH-1, and SCAH-2 assembled, S2 SCAH-1 and SCAH-3 assembled, S3 SCAH-2 and SCAH-4 assembled, S4 SCAH-3 and SCAH-4 assembled and S5 all module disassembled.

B. Heat Exchanger Modelling

SCAH modeled as PM model. Heat transfer process modeled in heat exchanger macro. Total heat rejection of the heat exchanger calculated from its commissioning data. Then, it divided proportionally with heat transfer area for each SCAH Module. Simple effectiveness heat transfer model needs to calculate heat exchanger effectiveness. It calculated with divided actual heat rejection with maximum possible heat transfer and resulted in 0.224.

Pressure drop along the SCAH contributed by the vicious and inertial resistance. These factors reflected in the PM model by adding a source term (Si) in the momentum equation.

$$S_i = -\left(\frac{\mu}{\alpha}\vartheta_i + C_2\frac{1}{2}\rho|\vartheta|\vartheta_i\right) \quad (1)$$

The source term Viscous resistance dominant when fluid flow is low. When the velocity increases, the inertial resistance become dominant then Eq. 1 rewrite on one direction:

$$\Delta p = \frac{\rho v^2}{2}\ x\ C_2 x\ \Delta n_x \quad (2)$$

where C2 inertial resistance coefficient, v inlet velocity, and Δnx PM thickness.

C2 could be defined using the empirical equation. This study use pressure drop through a bank of tube equation:

$$\Delta p = Eu\frac{\rho v^2}{2}\mathrm{Z} \quad (3)$$

where u is inter tube velocity, Eu Euler number and z number of the row.

Comparing Eq. 2 and Eq. 3 (replace u with inlet velocity/v) result in C2 equation:

$$C_2 = \frac{\left(\frac{a}{a-1}\right)^2 x\ Eu\ x\ z}{\Delta n_x} \quad (4)$$

Eu defines from ref [4] equation since SCAH consist of

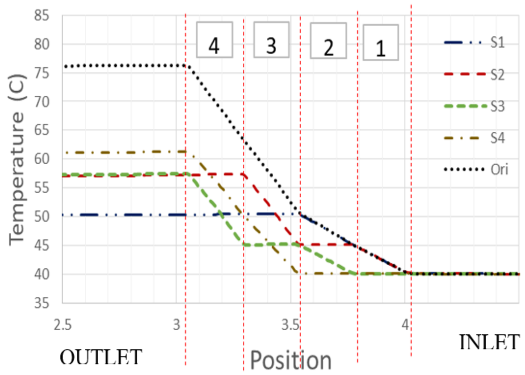

Figure 6. Temperature rise through SCAH1,2,3,4.

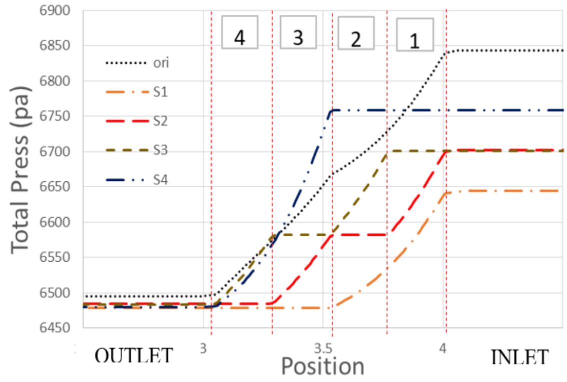

Figure 7. Pressure distribution through SCAH1,2,3,4.

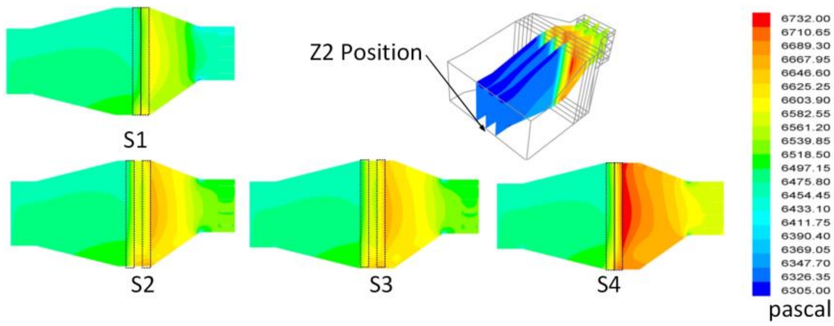

Figure 8. Pressure contour.

TABLE 1.
REDUCTION IN PRESSURE DROP, TEMPERATURE RISE, AND FDF POWER

	S1		S2		S3		S4	
Pressure drop (Pa)	197.8	67.7%	142.2	48.7%	154.6	53.0%	101.5	34.8%
Temp (C)	28.8	70.7%	21.8	53.5%	21.2	52.1%	12.9	31.7%
FDF Power (kW)	13.1	1.8%	9.4	1.3%	10.2	1.4%	6.7	0.9%

the finned tube in an inline and staggered configuration. Eq. 5 reflected the equation for inline configuration and Eq. 6 for staggered one.

$$Eu = 0.52 \left(\frac{d^*}{d_e}\right)^{0.3} \left(\frac{b-1}{a-1}\right)^{0.68} Re_{d^*}^{-0.08} C_z \quad (5)$$

$$Eu = 2\,\frac{\Delta p}{\rho z u^2} = 5.4 \left(\frac{d^*}{d_e}\right)^{0.3} Re_{d_e}^{-0.25}\, C_z \quad (6)$$

Based on Eq. 4, Eq. 5 and Eq. 6 result C2 value 15.2 for SCAH-1and 2, 35.9 for SCAH-3 and 4.

III. RESULTS AND DISCUSSION

Figure 3 and Figure 6 show that the temperature rises when air flow through SCAH. It proves that PM successfully to represent SCAH as a heat exchanger. Uneven temperature distribution observed on temperature contour for S1, S2, S3, and S4 in Figure 3. Figure4 show area with the secondary flow has a higher temperature on the inlet side. The rising temperature on the secondary flow area in inlet makes uneven temperature outlet SCAH. Uneven temperature distribution at the outlet also contributed by uneven flow path length in SCAH. Longer flow path will result in a higher temperature. Fig 6 showed a temperature rise along with the flow for different scenarios. Each scenario showed that area, where SCAH module dismantled, have a low-temperature rise, it showed that the simulation successfully models SCAH module dismantling.

Secondary flow in the inlet showed in Figure 4 mainly caused by a sudden change in flow cross-sectional area. The long slope in the inlet duct to SCAH causes the most significant secondary flow occurs at the lower half of the SCAH inlet on side view (Figure 4A). Symmetrically change in a cross-sectional area creates symmetric secondary flow at the top view (Figure 4B).

Data comparison from all scenarios showed that SCAH tube bank could reduce secondary flow. Figure5 showed that in scenario 5 (S5) where all modules are dismantled, there is a high secondary flow on the lower half. It because no tube bank can improve the circulation in S5. If all tube will be dismantled to reduce self-energy usage, it is suggested to modify the duct or install some guide vane to reduce secondary flow.

Figure 7 showed a total pressure drop when air flow through SCAH tube banks for various scenarios. It showed that the PM model could reflect flow through tube banks in term of pressure drop. Figure 8 is a side view of static pressure distribution for all scenarios. Although they have different values, but all scenarios have the same flow pattern — static pressure changes with the flow cross-sectional area. Right before SCAH, the flow blocked by tube bank make its pressure increase indicated with red and yellow color, then it decreases gradually when pass-through tube bank. After leaving SCAH pressure and velocity change mainly because of flow cross-sectional area effect. Color change in pressure contour along the PM prove that PM model can reflect flow through tube bank.

All scenarios result in reducing in pressure drop compared to its original one (all SCAH module installed). The initial pressure drop and temperature rise with all module assembled are 292 pascals and 40.79 0C. And of courses temperature difference will decrease for each scenario. Pressure drop reductions mean to reduce in power needed by the fan to flow the air pass through SCAH. Pressure drop amount multiplies by its air debit (m3/s) will result in the amount of FDF power reduction. This will reduce self-energy usage in a power plant. Self-energy usage is electricity energy needed to run power plant auxiliary like a fan, pump, etc. The amount of pressure drop reduction, temperature rise reduction, and FDF power reduction are showed in table 1.

For S5, all modules are disassembled, means the pressure drop reduce to zero and equal to 19.28 kW of fan power reduction. Using Eq. 7, 75% fan efficiency and 96% motor efficiency, if all SCAH module disassembled for two steam turbines power plant units in Gresik (2 SCAH and 2 fans each unit) will reduce self-energy usage by 675,720 kWh/year. With Eq. 8 and emission factor table from ref [5] tier 1 approach, saving this number of energies will reduce greenhouse gas emission by 512,262 ton/year.

$$\Delta PES_{fdf} = FDF_{power}\ x\ t\ x\ \eta_{Fan}\ x\ \eta_{motor} \quad (7)$$

$$Emissions_{GHG,fuel} = Fuel\ Cons_{fuel} x Emisions\ Factor_{GHG,fuel} \quad (8)$$

Although several CFD software provides specific tools to simulate heat exchanger, it needs solid effort to draw and model it like a real geometry. PM approaches provide an alternative solution to model heat exchanger without time-consuming meshing process and high CPU usage simulation.

Pressure and temperature data show that the simulation result closed to SCAH's commissioning data. Pressure contour, velocity contour, and stream trace resulted from simulation give detail illustration of flow characteristic for each scenario. Temperature distribution shows the heat transfer characteristic of SCAH. The study proves that the PM model successfully illustrates heat exchanger in term of flow and heat transfer characteristic. Defining inertial resistance coefficient C2 with an empirical equation for PM give good result in pressure drop simulation. This method could be an alternative when heat exchanger performance data are not sufficient to define C2.

Dismantling all SCAH modules will reduce power plants self-energy usage and greenhouse gases emissions. But it suggested to modify the duct geometry or to install guide vane due to big secondary flow issue in S5.

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