Computational analysis of heat transfer in three types of motorcycle exhaust materials

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Abstract. The finite element method is one method used in the structural and nonstructural analysis. This paper aims to the simulated of the finite element method on nonstructural problems namely heat transfer. The media used has been a motorcycle exhaust system modeled with COMSOL Multiphysics 5.4 software by combining annealed stainless steel 405 with 35% chrome stainless steel, Beta-21S Titanium, and Carbon II type as a large tube on the exhaust model. The results of computing simulation obtained are that the lowest heat transfer value in Carbon II material type with a heat transfer rate of 325 K.

1. Introduction
The heat transfer is one of the phenomenon in this world that have researched in mathematics physics and engineering problem, there are many studies about heat transfer in process of material especially exhaust system in motorcycle. As we known exhaust system is one part of motorcycle that specific transfer as exhaust gas that has the function os removing gas produced from engine combustion. There are three ways process of heat transfer that can occur, namely heat transfer by conduction, convection, and radiation.

Heat transfer is one of an interesting problem in engineering world studies. So, simulations of heat transfer are needed so that the properties and characteristics of the heat transfer rate can be known. In this study, the phenomenon of heat transfer will be solved numerically. There are three methods in determining numerical solutions that can be used, namely the finite element method, finite difference method, and finite volume method. The author, in this case, uses a method that is the finite element method. Furthermore, the solution obtained will be simulated computationally using COMSOL Multiphysics 5.4 software based on the finite element method to determine the rate of heat transfer. [1].

2. Research methods
In this research, the finite element method is computed using COMSOL Multiphysics 5.4[2,3]. Before determining the analysis in the program, it is necessary to make the model of the motorcycle exhaust system. After the simulation, the results obtained are only limited by analyzing the heat transfer rate according to three different material oh exhaust model.
2.1. Exhaust system model
Before the simulation run, the measurement of the component in the exhaust model must be determined. In conducting research on heat transfer it is necessary to first review the variables or factors that influence heat flow in a volume control or in this case motorcycle exhaust. Determination of the model and its constituent components is the most important thing in heat transfer analysis. Furthermore, the geometry model that has been formed will be discerned into simple elements. In this research, the mesh is used so much that a special program is needed in counting and discretizing objects[4].

In this study, Illustration of manual completion of heat transfer by conduction and convection using the finite element method. Due to a large number of elements making it very inefficient to calculate the characteristics of each element manually, the heat transfer problem in the exhaust will be simulated with COMSOL Multiphysics 5.4 software.[5] COMSOL Multiphysics is a finite element-based software that can simulate a variety of mathematical-physics problems both structural and non-structural analysis. The COMSOL Multiphysics program was once used with the title of the research being the validation as simulation software for heat transfer calculation in buildings: Building simulation software validation. COMSOL Multiphysics COMSOL Multiphysics 5.4 is the latest software output that has been refined from the previous version which is integrated with MATLAB and Microsoft Office Excel so that it allows users to connect the use of COMSOL Multiphysics 5.4 with MATLAB and Microsoft Office Excel.[2,6]

2.2. Finite Element Method
Finite Element Method is a numerical procedure to obtain a solution of differential equations, which can be ordinary differential equations or partial differential equation in technical problems or physical problems every day[7]. Types of problems in finite element method that can be solved are divided into two groups, namely the structural analysis problem group and the nonstructural problem group:
1. Structural problem, such as:
   1. Strain and stress analysis
   2. Buckling Analysis
   3. Vibration Analysis
2. The nonstructural problem, such as:
   1. Mass transfer and heat transfer
   2. Fluids mechanic
   3. Electricity potential distribution

The essence of the Finite Element Method is the division of complex elements into simpler elements or what is called a mesh. Meshing is the process of division of elements on objects, the type of mesh is divided into two, rectangular mesh and triangular mesh. The structure of the mesh is divided into two namely regular and irregular mesh. An organized mesh has an arrangement that has a pattern whereas an irregular mesh has no pattern.

stages of the finite element method, such as:
   a. Selection of element types and discretization,
   b. Selection of the transfer function,
   c. Look for the relationship between the elements,
   d. Calculates the stiffness matrix of the elements created,
   e. Determining the element each other and then solve the numerical solution,
   f. Simulation

2.3. The Galerkin Method in the Finite Element Method
Galerkin method is one method that is often used in calculating ballast residuals. In determining the solution approach in the form of differential equations, it is necessary to determine the characteristics of the basic functions consisting of a linear combination of an independent function (basic functions).
Basic function:
\[ \bar{u} = \sum_{i=1}^{n} a_i G_i, \text{where } i = 1, 2, 3, 4, \ldots, n \]  

(1)

This method is a method that calculates and determines the ballast function for each element for each a, so the general equation of the Galerkin method is:
\[ W_i = \frac{\partial \bar{u}}{\partial a_i} = G_i, \quad i = 1, 2, 3, \ldots, n \]  

(2)

\[ \text{ atau } \int_x G_i E \, dx = 0, \quad i = 1, 2, 3, \ldots, n \]  

(3)

Heat flux in convection:
\[ Q_h = h \, (T - T_\infty) \]  

(4)

Fourier conduction:
\[ q_{x+dx} = -K_{xx} \frac{dT}{dx} \bigg|_{x+dx} \]  

(5)

General equation in energy conservation:
\[ Q_x A \, dt + Q A \, dx \, dt = C(\rho A \, dx)dT + Q_{x+dx} A \, dT + Q_h P \, dx \, dt \]  

(6)

the result of equation (4) through equation (5) will be substituted into equation (6) and then divided by \( A \, dx \, dt \), the result obtained is the conduction heat transfer equation together with convection heat transfer as follows:
\[ \frac{\partial}{\partial x} \left[ K_{xx} \frac{\partial T}{\partial x} \right] + Q = \rho C \frac{\partial T}{\partial x} + \frac{h P}{A} (T - T_\infty) \]  

(7)

3. Result and Discussion
The results of this study were simulated in the COMSOL Multiphysics 5.4 program which will be analyzed based on heat transfer on the surface of the exhaust model. Variation of three different material will be analyzed which combined material that given the low-temperature distribution. The material will be a combination of stainless steel 405 annealed to stainless stell 35% steel, titanium beta-21S, and C (diamond) type II and will be combined each other material. The program will runs in 10 s with the inlet temperature 373 K and inlet of model in 300 K and the heat capacity is similar each other 2.500 W/m²K in the flue gases. In the general problem heat of the material will be distributed at higher temperature to lowest temperature. The model of COMSOL Multiphysics 5.4 will be shown in Figure 1, Figure 2, and Figure 3.
Based on the computing of the COMSOL Multiphysics 5.4 combination of stainless steel 405 annealed with C (diamond) type II the heat distribution is A is 334 K, B is 332 K, C is 331 K, and 325 K in part of D and the chart distribution will be shown beside of the model.

Based on computing of the COMSOL Multiphysics 5.4 combination of stainless steel 405 annealed with Titanium beta-21S the heat distribution is A is 336 K, B is 335 K, C is 333 K, and D is 332 K and the chart distribution will be shown beside of the model.
And the last is a combination of stainless steel 405 annealed with Stainless steel chrome 35% steel the heat distribution is A is 334 K, B is 333 K, C is 332 K, and D is 330 K and the chart distribution will be shown beside of the model.

From the computation results on the exhaust model with three different materials combined with 405 annealed stainless steel namely C (diamond) type II, Titanium beta-21S, and 35% stainless steel chrome obtained C (diamond) type II. It can be seen in section A of 334 K, B of 332 K, C of 331 K, and D of 325 K. The analysis of heat transfer is focused on section D where the other two materials have a greater temperature distribution.

4. Conclusion

Based on the research that has been done the optimize combination material of exhaust system is combine of stainless steel 405 annealed with C (diamond) type II because based on the computing of program the heat distribution in part of D is 325 K. This value can be determined because of the heat conduction is lowest each other, it makes the heat distribution in part of D will be cooled in else material.

5. References

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