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A Coupled Thermal Model for Refrigeration Cycle and Cabin of the First Produced Vehicle Based on the National Vehicle Platform

M. H. Shojaeefard*, G. R. Molaeimanesh, A. Yarmohammadi, S. Changizian

Automotive Engineering School, Iran University of Science and Technology,Tehran, Iran

ABSTRACT: Nowadays, a lot of efforts have been spent to develop effective automotive air conditioning systems due to their critical role in passengers comfort. In this study, a transient numerical thermal model has been developed for the first produced vehicle based on the national vehicle platform. At first, each component of the refrigeration cycle is modeled. In the next step, thermal loads for the vehicle's cabin are calculated along with the solar load at every location of Iran and every hour of the day. The proposed model is used for thermal analysis of the heating, ventilation and air conditioning performance of the first produced vehicle based on the national platform. Also, for thermal analysis of the heat exchangers which are used in the model, *ε-NTU* method has been used. The proposed model can be an effective computer-aided engineering tool for analyzing the performance of automotive the heating, ventilation and air conditioning systems. Finally, the amount of 5.239 kW thermal load acting on the vehicle cabin is calculated. Also, results indicate that the proposed model can reduce the vehicle cabin temperature from 60 °C to 25 °C within 25 minutes.

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1- Introduction

Future of the earth is confronted with environmental concerns such as air pollution in cities, ozone layer depletion and global warming. A major part of these concerns stems in the nowadays transportation sector. Automotive Heating, Ventilation and Air Conditioning (HVAC) system has an effective role in vehicle emission due to its relatively large power consumption (i.e. large fuel consumption) and also the application of potentially harmful refrigerant. Therefore, enhancement of HVAC system performance can result in less fuel consumption and more compact refrigeration systems with less refrigerant charge. Besides, lowering energy consumption of HVAC system can be an effective path for mileage extending in the modern vehicles such as Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs) [1-3]. Since condenser is usually believed to be the component which has the largest departure from the ideal performance in a refrigeration cycle [4], we focus on the condenser optimization through an evolutionary algorithm to enhance the HVAC system performance in the current study. In the current study, on the way of enhancing condenser performance, a model based on *ε-NTU* method which distinguishes different single-phase and two-phase regions is proposed. After validation of the proposed model with the experimental data, the flat-tube louvered-fin condenser is optimized via multi-objective GA with the heat transfer rate and pressure drop as objective functions and the fin pitch and fin height as decision variables. The number of fins is fixed while the condenser size can be changed regarding packaging space. Such a constraint leads to almost constant condenser mass and hence the material cost will not change significantly after optimization.

2- Methodology

To develop the thermal model for the refrigeration cycle, all components are modeled individually and afterward these models are integrated into a single model via an iterative algorithm. The components of the refrigerant cycle are:

- Compressor model
- Condenser model
- Expansion valve model
- Evaporator model

After modeling each component of the refrigeration cycle, these models are integrated via the algorithm. In addition to geometric and operational parameters of components, two other parameters of compressor suction pressure ($P_{suc,comp}$) and compressor discharge pressures ($P_{dis,comp}$) are considered as input. The values of these two parameters are initially guessed and during iterations, the values are converged to the exact value. The degree of superheat in the suction side of the compressor and the degree of subcooling at the condenser outlet are restricted to prescribed values of $\Delta T_{SH,Set}$ and $\Delta T_{SC,Set}$, respectively. As the first stage, the compressor model is implemented. Then, considering thermal losses of the tube connecting compressor and condenser, the condenser model is implemented. The calculated degree of subcooled refrigerant at the condenser outlet ($\Delta T_{SC,Cal}$) is compared with the prescribed value ($\Delta T_{SC,Set}$) and the condenser inlet pressure (i.e. the compressor discharge pressure) is corrected until these two parameters agree. After this step, the losses due to the tube connecting condenser and expansion valve are taken into account and then by accepting the expansion

Corresponding author, E-mail: shojaeefard@iust.ac.ir

valve outlet pressure as the compressor suction pressure (i.e. neglecting the pressure drop through the evaporator and the tube connecting expansion valve and the evaporator) the flow rate through the expansion valve ($\dot{m}_{exp}$) will be calculated. This flow rate then is compared with the calculated flow rate from the compressor model ($\dot{m}_{comp}$) and their difference would be lessened by correcting the compressor suction pressure. Once $\dot{m}_{exp}$ converges to $\dot{m}_{comp}$, the evaporator model is implemented. After finishing the iterative loop, the refrigerant mass flow rate and the total heat transfer rate from the condenser, refrigeration capacity by the evaporator and consequently, the refrigeration cycle *COP* will be calculated. After developing the thermal model of the refrigerant cycle, thermal loads acted on the cabin has been modeled. The acted loads are listed below:

- Sun load
- Human load
- Ambient load
- Exhausted gas load
- Engine load
- Ventilation load
- Equipment mass load

In the following, the results of the simulation and optimization are analyzed.

3- Results and Discussion

Based on solar thermal load calculations, the maximum amount of heat from the sun in the Iranian cities belongs to Ahvaz. This is happening on the 14th of July. As it can be seen in Fig. 1, the maximum value is about 1000 watts per square meter.

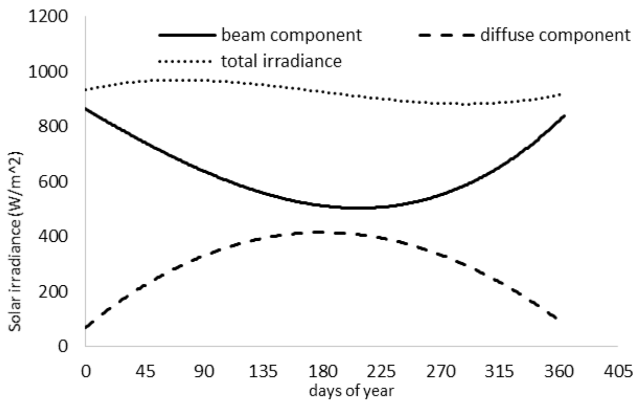

Fig. 1. The amount of radiation on different days in Ahwaz

In Fig. 2, the values of various parameters of solar radiation on the surface with a slope of 45 degrees, to all directions, at 14 pm on June 30 in Tehran is shown.

As shown in Fig. 3, exposure to the sun is the major cause of heat in the cabin and then heat transfer from the environment is the most important factor. Also, it is assumed that the vehicle can carry 5 passengers.

After a 1-hour operation of the air conditioning system, cabin temperature graph during the time, is same as Fig. 4.

4- Conclusions

In this paper, a numerical model of transient heat for the first produced vehicle based on the national vehicle platform developed and presented. As the first step, each component of the refrigeration cycle has been modeled and then these

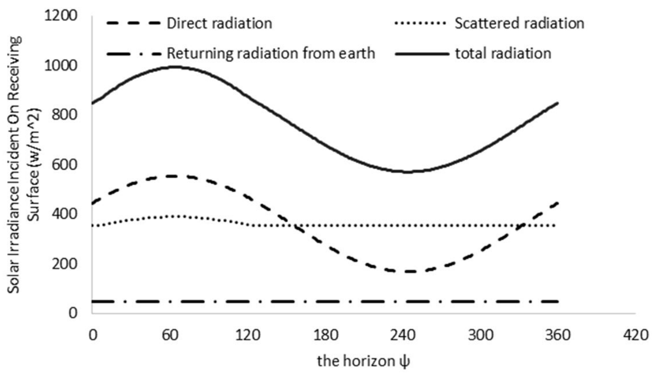

Fig. 2. The amount of radiation reaching the surface with a slope of 45 degrees in different geographical directions in Tehran

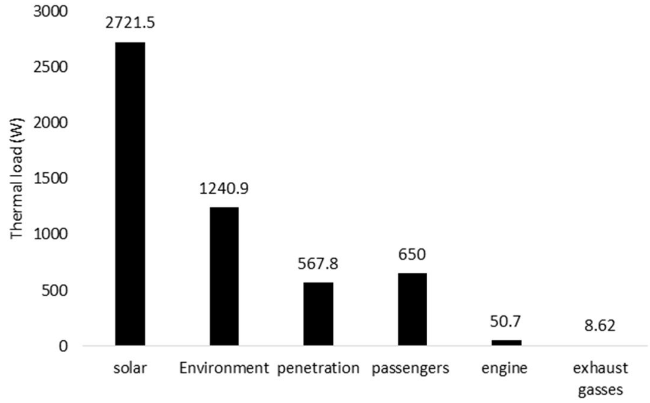

Fig. 3. Thermal loads entering the cabin

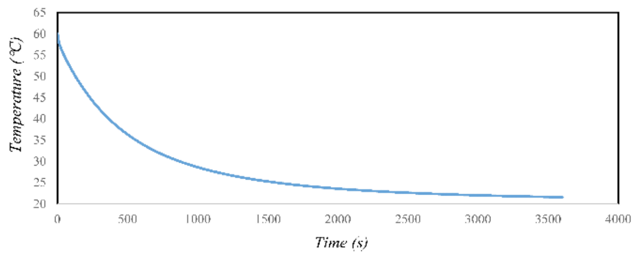

Fig. 4. Anticipated changes in cabin temperature

models have been integrated into an iterative loop. In this step, for modeling of the heat exchanger of the refrigerant cycle, *ε-NTU* method has been used. At the second step, seven different thermal loads acted to the cabin, are calculated. So, a database for calculating the thermal load of the sun at any location of Iran and every day of the year and for any position of the vehicle is provided. And as the final step, a coupled model based on the previous steps is presented for the first time. In this coupled model, four ordinary differential equation is solved by the Runge-Kutta method. Also, the accuracy of the coupled model with experimental results has been verified. At the end, for predicting the air cabin temperature of the first produced vehicle based on the national vehicle platform, this coupled model is used. The results indicate that after almost 25 minutes to start working air conditioning, cabin air temperature drops from 60 degrees Celsius to 25 degrees Celsius.

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