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Effect of Guide Fin Structures and Boundary Parameters on Thermal Performances of Heat Exchanger for Waste Heat Recovery Thermoelectric Generator

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가이드 핀 구조와 경계 파라미터가 폐열 회수용 열전발전 열교환기의 열적 성능에 미치는 영향

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Abstract The present study examined the effects of various guide fin structures and boundary parameters on the thermal performance of heat exchangers used in heat recovery thermoelectric generators. The heat transfer rate and pressure drop of the heat exchangers without fins, with circular fins, with triangular fins, and with combined circular and triangular fins were simulated numerically using ANSYS 19.1 commercial code to confirm the effect of the guide fin structures. The heat transfer rate of the heat exchanger with combined fins was 27.0%, 5.2%, and 1.5% higher than those without fins, with circular fins, and with triangular fins, respectively. The pressure drop characteristic of the heat exchanger with the combined fins was 28.3% higher than that without fins but 9.2% and 10.5% lower than those with circular fins and with triangular fins, respectively. The heat exchanger with combined fins as the optimal model showed the highest heat transfer rate of 5664.9 W and pressure drop of 1454.02 Pa for highest hot gas temperature, maximum flow rates of hot gas and coolant, and lowest coolant temperature.

요 약 본 연구는 다양한 가이드 핀 구조와 경계 파라미터가 폐열 회수 열전발전용 열교환기의 열적 성능에 미치는 영향에 대하여 다룬다. 가이드 핀 구조의 영향을 확인하기 위하여 ANSYS 19.1 소프트웨어를 사용하여 핀이 없는 유형, 삼각형 핀, 원형 핀, 원형 핀과 삼각 핀 조합 열교환기의 열전달율 및 압력 강하 특성을 수치해석 하였다. 원형 핀과 삼각 핀 조합 열교환기는 핀이 없는 열교환기, 원형 핀 또는 삼각 핀이 있는 원형 핀 또는 삼각 핀 열교환기와 비교하여 각각 27.0%, 5.2% 및 1.5% 높은 열전달율을 나타내었다. 그리고 복합 핀 열교환기의 압력강하는 핀이 없는 열교환기와 비교하여 28.3% 높았지만, 복합 핀 열교환기와 비교하여 9.2% 및 10.5% 낮은 압력강하 특성을 나타내었다. 최적모델로서 복합 핀 열교환기는 최대 고온 가스 및 냉각수 질량 유량, 최고 고온 가스 온도 그리고 최저 냉각수 온도 조건에서 최대 열전달율 5664.9 W 및 최대 압력강하 1454.02 Pa을 나타내었다.

Keywords : Guide Fins, Heat Exchanger, Heat Transfer Rate, Pressure Drop, Thermal Performance, Thermoelectric Generator

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1. Introduction

In the recent times, to reduce the exhaust emission and to utilize the waste exhaust heat, research is trending towards the applicability and efficiency improvement of thermoelectric generators[1]. The thermoelectric generators convert the waste heat into electricity but the conversion efficiency is low[2]. Kunal et al. have proposed coupled numerical approach to suggest the optimum internal fin structure for hot exchanger based on thermal, electrical and structure performances[3]. The numerical and artificial intelligence approaches are developed to predict the thermal performances of thermoelectric generator systems[4]. The two stage, segmented and linear thermoelectric generators show better thermal and electrical performances compare with conventional thermoelectric generators[5,6]. The main objective of the present study is to suggest the optimum model of heat exchanger with guide fin structure based on thermal performances. The effect of various boundary parameters such as, hot gas and coolant mass flow rates and temperatures are investigated on the thermal performances of the optimum model.

2. Numerical method

Computational domain is shown in Fig. 1. It consisted of main heat exchanger with diffuser section at inlet and outlet, two coolant channels on the opposite side of heat exchanger and over the frame. Frame was provided with 10 equal passages within the heat exchanger to pass the hot gas. Inlet diffuser passage was provided with four different models of heat exchangers, model A (without fins), model B (circular fins), model C (triangular fins) and model D (combined circular and triangular fins), which are shown in Figs. 2 (a), (b), (c) and (d), respectively. Numerical analysis was conducted using boundary conditions which is shown in Table 1. Mesh domain is shown in Fig. 3. Tetrahedron mesh elements with 1,199,958 elements and 797,986 nodes were generated in ANSYS meshing with the combined fins for the numerical analysis.

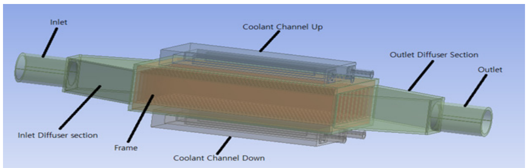
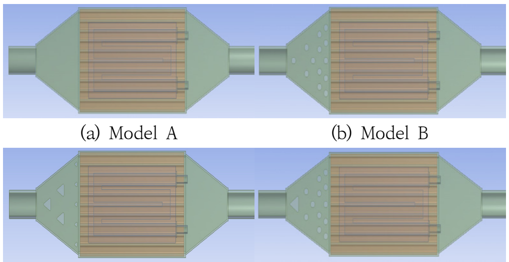


Fig. 1. Computational domain



(a) Model A (b) Model B

(c) Model C (d) Model D

Fig. 2. Model with various geometrical configurations

Table 1. Boundary conditions used in numerical modeling

Parameter	Specification
Hot gas	Hot air
Coolant	Water
Material	Aluminum
Inlet hot gas temperature (°C)	400, 450, 500, 550, 600
Inlet coolant temperature (°C)	20, 30, 40
Inlet hot gas mass flow rate (kg/s)	0.01, 0.015, 0.02, 0.025, 0.03
Inlet coolant mass flow rate (kg/s)	0.01, 0.02, 0.03, 0.04, 0.05
Turbulence model	k-ε

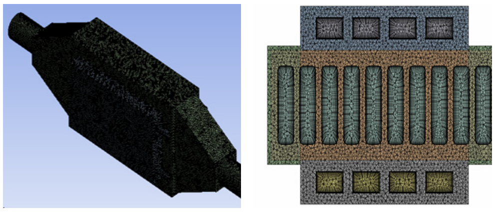


Fig. 3. Mesh domain

3. Results

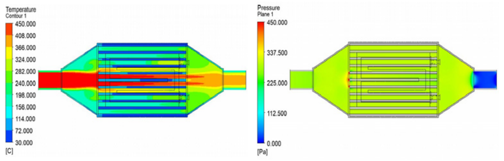
3.1 Effect of different guide fin structures

The heat transfer rate and pressure drop of heat exchanger with and without guide fins in the inlet diffuser were calculated using Eqs. (1) and (2) and compared to investigate the effect of guide fins[7,8].

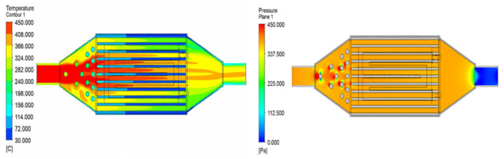
$$Q = \dot{m} C_p (T_i - T_o) \quad (1)$$

$$\Delta P = (P_i - P_o) \quad (2)$$

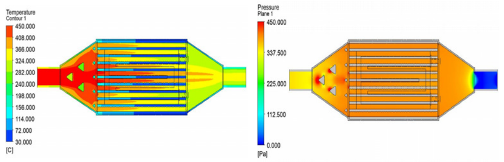
$\dot{m}$ is mass flow rate, C_p is specific heat, T_i and T_o are inlet and outlet temperatures and P_i and P_o are inlet and outlet pressures.



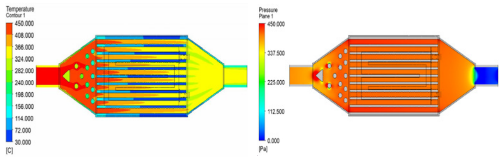
(a) Model A (without fins)



(b) Model B (circular fins)



(c) Model C (triangular fins)



(d) Model D (combined fins)

Fig. 4. Temperature (left) and Pressure (right) distribution

Fig. 4 shows temperature and pressure distributions for the models A, B, C and D. It was observed that, the addition of guide fins in inlet diffuser section gives more uniform distribution

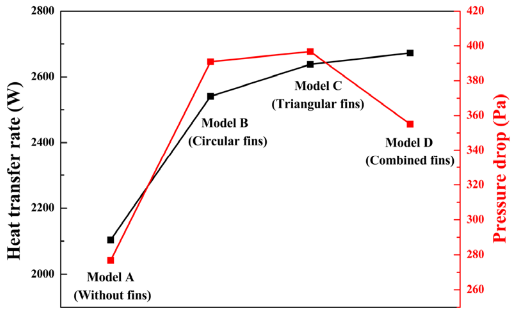


Fig. 5. Comparison of heat transfer rate and pressure drop for four models

of temperature and enhances the heat transfer rate. However, addition of guide fins in inlet diffuser section increased pressure drop due to turbulence (obstruction) for hot gas flow[9]. Fig. 5 shows the comparison of heat transfer rate and pressure drop for all four models. Model D showed heat transfer rate higher by 27.0%, 5.2% and 1.5% compared to models A, B and C, respectively. The pressure drop for model D was higher by 28.3% than model A but lower by 9.2% and 10.5% than models B and C, respectively. Hence, model D was accepted as optimal model to enhance the performance of heat exchanger because it provided uniform temperature distribution and higher heat transfer rate for hot gas. However, highest pressure drop for optimal model D was lower than models B and C.

3.2 Effect of boundary parameters

Open literature about the thermoelectric generator presents that the hot gas inlet temperature and hot gas inlet mass flow rate have more effect on the performance of heat exchanger for waste heat recovery thermoelectric generator compare with coolant inlet temperature and coolant inlet mass flow rate. Therefore, more attention was given while selecting the ranges of hot gas inlet temperature and hot gas inlet mass flow rate. The ranges of hot gas inlet temperature and hot gas inlet mass flow rate for the numerical analysis were selected based on experimental results presented by D. W. Lee[10]. Based on the experimental results of the literature, the hot gas inlet temperature and hot gas inlet mass flow rate ranges of the heat exchanger were selected as 400 °C to 600 °C and 0.01 kg/s to 0.03 kg/s, respectively for the present numerical study.

Fig. 6 shows the variation of heat transfer rate of the heat exchanger with the coolant inlet mass flow rate varied from 0.01 kg/s to 0.05 kg/s and the coolant inlet temperatures varied from 20 °C to 40 °C. Inlet mass flow rate and inlet temperature of hot gas were fixed to the values of 0.015 kg/s and 450 °C, respectively. For all coolant inlet temperatures, as the coolant inlet mass flow rate increased from 0.01 kg/s to 0.05 kg/s, the heat transfer rate from hot gas to coolant increased. This is due to increase in the heat capacity with rise in mass flow rate.

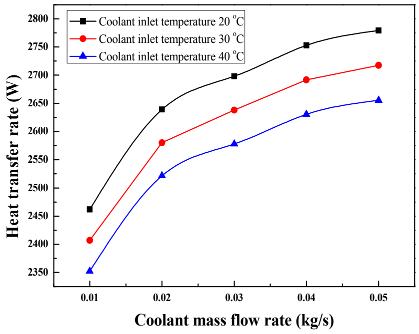


Fig. 6. Variation of heat transfer rate with respect to coolant inlet mass flow rate for various coolant inlet temperatures

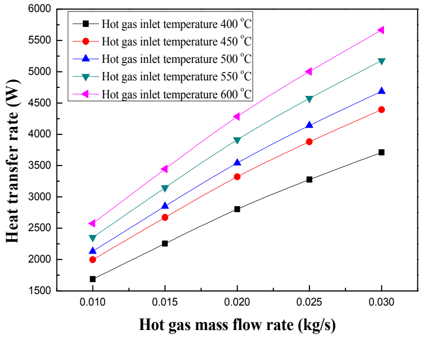


Fig. 7. Variation of heat transfer rate with respect to hot gas inlet mass flow rate for various hot gas inlet temperatures

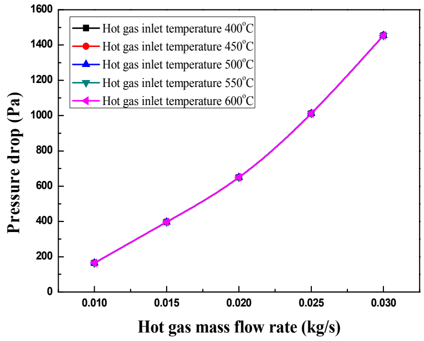


Fig. 8. Variation of pressure drop with respect to hot gas inlet mass flow rate for various hot gas inlet temperatures

Along with variation of inlet coolant mass flow rate from 0.01 kg/s to 0.05 kg/s, increase in the inlet coolant temperature from 20 °C to 40 °C resulted in reduction of heat transfer rate. Fluid at lower temperature has higher heat absorption capacity compared to fluid at higher temperature therefore, coolant at 20 °C absorbed more heat compared to coolant at 30 °C and 40 °C. Hence, it was concluded that, coolant with higher inlet mass flow rate and lower inlet temperature has better thermal performance. Considering gradual increase of the heat transfer rate at higher coolant mass flow rate, the coolant mass flow rate exceed of 0.05 kg/s are expected to show less effect on the heat transfer rate of the coolant channel. The pressure drop was 355 Pa for all the combination of coolant inlet temperatures and coolant inlet mass flow rates.

For the coolant inlet mass flow rate of 0.05 kg/s and coolant inlet temperature of 20 °C, variation of heat transfer rate with hot gas inlet mass flow rate of 0.01 kg/s to 0.03 kg/s and the hot gas inlet temperatures of 400 °C to 600 °C was simulated as shown in Fig. 7. Heat transfer rate increased with increase in the inlet mass flow rate and inlet temperature of hot gas. Hot gas at higher temperature transfers more amount of heat compared to fluid at lower temperature. Hot gas with higher mass flow rate has the ability to carry high heat capacity hence, it has more capacity to transfer heat to coolant. Therefore, combination of higher mass flow rate with higher temperature for hot gas gives more heat transfer rate. Fig. 8 shows the pressure drop variation with respect to hot gas inlet mass flow rate of 0.01 kg/s to 0.03 kg/s for all inlet temperatures of hot gas. This variation was simulated at coolant mass flow rate of 0.05 kg/s and coolant temperature of 20 °C. As mass flow rate increased from 0.01 kg/s to 0.03 kg/s, pressure drop also increased but it was same for each value of hot gas inlet temperature. Flow obstruction was more at higher mass flow rate hence, pressure drop was more at higher value of mass flow rate. Hot gas inlet temperature has no effect on pressure drop. From Figs. 7 and 8, it can be concluded that the optimal model D showed highest heat transfer rate of 5664.9 W and pressure drop of 1454.02 Pa for hot gas temperature of 600 °C, hot gas mass flow rate of 0.03 kg/s, coolant temperature of 20 °C and coolant mass flow rate of 0.05 kg/s.

4. Conclusion

The thermal performances of heat exchanger used for waste heat recovery thermoelectric generators were optimized based on heat transfer rate and pressure drop by considering four guide fin structures and various boundary parameters. Following points are concluded through the numerical investigation,

- Heat transfer rate of the heat exchanger with combined fins increased by 27%, 5.2% and 1.5% compared to heat exchangers without fins, with circular fins and with triangular fins, respectively.
- Pressure drop of the heat exchanger with combined fins was higher by 28.3% than that of the heat exchanger without fin, but was lower by 9.2% and 10.5% compared to heat exchangers with circular fins and with triangular fins, respectively.
- The heat exchanger with combined fins showed maximum heat transfer rate of 5664.9 W and maximum pressure drop of 1454.02 Pa at hot gas temperature of 600 °C, hot gas mass flow rate of 0.03 kg/s, coolant temperature of 20 °C and coolant mass flow rate of 0.05 kg/s. The heat transfer rate gradually increased with the increase of coolant mass flow rate and expected to be affected less beyond the coolant mass flow rate of 0.05 kg/s. The heat transfer rate linearly increased with the increase of hot gas temperature. Whereas the pressure drop was not affected by hot gas temperature at inlet of the heat exchanger.

References

[1] Y. Zhao, S. Wang, M. Ge, Z. Liang, Y. Liang, Y, Li, "Performance analysis of automobile exhaust thermoelectric generator system with media fluid", *Energy Conversion and Management*, Vol.171, pp.427-437, 2018
DOI: https://doi.org/10.1016/j.enconman.2018.06.006

[2] X. Liu, Y. D. Deng, K. Zhang, M. Xu, Y. Xu, C. Q. Su, "Experiments and simulations on heat exchangers in thermoelectric generator for automotive application", *Applied Thermal Engineering*, Vol.71, No.1, pp.364-370, 2014.
DOI: https://doi.org/10.1016/j.applthermaleng.2014.07.022

[3] K. S. Garud, J. H. Seo, M. S. Patil, Y. M. Bang, Y. D. Pyo, C. P. Cho, M. Y. Lee, "Thermal-electrical-structural performances of hot heat exchanger with different internal fins of thermoelectric generator for low power generation application", Journal of Thermal Analysis and Calorimetry, Online first(Accepted on 13 Mar. 2020), pp.1-33, 2020.
DOI: http://dx.doi.org/10.1007/s10973-020-09553-7

[4] K. S. Garud, J. H. Seo, C. P. Cho, M. Y. Lee, "Artificial Neural Network and Adaptive Neuro-Fuzzy Interface System Modelling to Predict Thermal Performances of Thermoelectric Generator for Waste Heat Recovery", *Symmetry*, Vol.12, No.2, 259, 2020.
DOI: http://dx.doi.org/10.3390/sym12020259

[5] M. Y. Lee, J. H. Seo, H. S. Lee, K. S. Garud, " Power Generation, Efficiency and Thermal Stress of Thermoelectric Module with Leg Geometry, Material,

Segmentation and Two-Stage Arrangement", *Symmetry*, Vol.12, No.5, 786, 2020.
DOI: http://dx.doi.org/10.3390/sym12050786

[6] X. Jia, Y. Gao, "Optimal design of a novel thermoelectric generator with linear-shaped structure under different operating temperature conditions", *Applied Thermal Engineering*, Vol.78, pp.533-542, 2015
DOI: https://doi.org/10.1016/j.applthermaleng.2014.12.011

[7] C. C. Weng, M. J. Huang, "A simulation study of automotive waste heat recovery using a thermoelectric power generator", *International journal of thermal sciences*, Vol.71, pp.302-309, 2013.
DOI: https://doi.org/10.1016/j.ijthermalsci.2013.04.008

[8] Y. Wang, S. Li, X. Xie, Y. Deng, X. Liu, C. Q. Su, "Performance evaluation of an automotive thermoelectric generator with inserted fins or dimpled-surface hot heat exchanger", *Applied Energy*, Vol.218, pp.391-401, 2018.
DOI: https://doi.org/10.1016/j.apenergy.2018.02.176

[9] S. Bai, H. Lu, T. Wu, X. Yin, X. Shi, L. Chen, "Numerical and experimental analysis for exhaust heat exchangers in automobile thermoelectric generators", *Case Studies in Thermal Engineering*, Vol.4, pp.99-112, 2014.
DOI: https://doi.org/10.1016/j.csite.2014.07.003

[10] D. W. Lee, "Experimental Study on Thermoelectric Generator Performance for Waste Heat Recovery in Vehicles", *Korean Journal of Air-Conditioning and Refrigeration Engineering*, Vol.26, No.6, pp.287-293, 2014.
DOI: http://dx.doi.org/10.6110/KJACR.2014.26.6.287

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