Proceedings of the 9th World Congress on Momentum, Heat and Mass Transfer (MHMT'23)
London, United kingdom – April 11 – 13, 2024
Paper No. ENFHT 295
DOI: 10.11159/enfht24.295

Thermal-Structural Co-Optimization of Passive Thermal Management System for Logging Tool

Jiale Peng, Chao Deng, Wei Lan, Xiaobing Luo
Huazhong University of Science and Technology
No. 1037, Luoyu Road, Wuhan, China
First. pengjiale@hust.edu.cn; Second. 515251657@qq.com
Third. 1529690965@qq.com; Corresponding. luoxb@hust.edu.cn

Extended Abstract

Logging tools play a crucial role in detecting underground oil and gas resources, operating in demanding high-temperature downhole environments. Previous studies have successfully employed several passive thermal management systems (PTMSs) to safeguard downhole electronics during operation[1-5]. This system comprises vacuum flasks, thermal insulators, phase change materials (PCMs), electronics, and skeletons. Among these components, a combination of vacuum flasks and insulators has been used to minimize heat transfer from high-temperature environments. PCMs positioned between the skeleton and insulators absorb heat generated by electronics, enabling the logging tool to operate safely for extended periods in high-temperature wells. Despite these advancements, the thermal performance in the PTMS can be further improved, with shorter system length to mitigate downhole operation risks. Consequently, there is a need to propose a PTMS that not only enhances heat transfer but also significantly reduces its overall length.

This paper introduces a PTMS designed for logging tools, aiming to enhance heat transfer and minimize length through thermal-structural co-optimization. The parametric geometry model of the logging tool was developed using Solidworks, and COMSOL was employed to simulate the thermal performance of the system. The Nelder-Mead algorithm was chosen for optimizing the logging tool, with the length of insulators and PCMs as the variables. The optimization objective was to minimize the overall length, with the constraint that the electronics' temperature should not exceed 125°C. Constraints were addressed using the external penalty function method, and a maximum of 200 optimization iterations was set. The external ambient temperature, total power consumption of the heat source, and operating time were 205°C, 25 W, and 9 hours, respectively. The optimal logging tool design was achieved through algorithmic iterations.

The initial total length of the logging tool was 4676 mm, with the initial maximum temperature of heat sources at 114.13°C. With increasing iterations, the overall length of the logging tool showed a downward trend, stabilizing after approximately 80 iterations. Simultaneously, the maximum temperature of heat sources fluctuated around the constraint temperature of 125°C. After 135 iterations, the optimized length reduced to 3778.8 mm, and the maximum temperature of heat sources reached 124.99°C. Additionally, the overall homogeneity of the logging tool improved. The optimization resulted in an increase in the latent heat utilization of PCM from 60.2% to 96.3%, demonstrating that the proposed structure can reduce length while enhancing heat transfer.

Thermal-structural co-optimization emerges as a crucial guideline for designing passive thermal management systems for logging tools, holding promising prospects in the petroleum industry.

References

[1] B. Shang, Y. Ma, R. Hu, C. Yuan, J. Hu, X. Luo, "Passive thermal management system for downhole electronics in harsh thermal environments," *Applied Thermal Engineering*, vol. 118, pp. 593-599, 2017.
[2] W. Lan, J. Zhang, J. Peng, Y. Ma, S. Zhou, X. Luo, "Distributed thermal management system for downhole electronics at high temperature," *Applied Thermal Engineering*, vol. 180, 115853, 2020.
[3] J. Peng, W. Lan, F. Wei, C. Deng, B. Xie and X. Luo, "A numerical model coupling multiple heat transfer modes to develop a passive thermal management system for logging tool," *Applied Thermal Engineering*, vol. 223, 120011, 2023.
[4] J. Peng, Y. Wang, S. Ding, C. Deng, F. Wei, X. Luo, "Rapid detection of the vacuum failure of logging tools based on the variation in equivalent thermal conductivity," *International Journal of Thermal Sciences*, vol. 188, 108245, 2023.

[5] J. Peng, C. Deng, F. Wei, S. Ding, R. Hu, X. Luo, “A hybrid thermal management system combining liquid cooling and phase change material for downhole electronics,” *Journal of Energy Storage*, vol. 72, 108610, 2023.