Two-Page Extended Abstracts of the Third Asian Conference on Thermal Sciences, 3rd ACTS
June 23-27, 2024, Shanghai, China

ACTS-O0073

Numerical research of the factors influencing the flow heat transfer and thermal oxidation coking process of aviation kerosene RP-3 under supercritical pressure in miniature serpentine tubes

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KEY WORDS: supercritical pressure, aviation kerosene RP-3, miniature tube, thermal oxidation coking, flow heat transfer

1. INTRODUCTION (Details for Submitting Paper)

New materials and cooling structures cannot be significantly improved against the background of increasingly severe thermal protection issues dealing with modern advanced aero-engines. In addition to assisting with fuel atomization and combustion, using aviation kerosene to cool the cooling air can resolve the cooling issue. Aviation kerosene undergoes thermal oxidation coking phenomenon after being heated to 150 °C[1], which can cause wall erosion, increased flow resistance, oil blockage, and increase heat transfer resistance. Therefore, coking is a significant issue that limits the application of air-oil heat exchangers for high-performance aero-engines that are used frequently and for extended periods of time. This paper constructs a model coupled with multiple fields of "fluid-solid-thermal-chemistry" in a straight tube. A 34-steps pseudo-detailed coking reaction kinetic model[2] is explored and verified, comprising 30 liquid phase oxidation reactions and 4 wall deposition reactions. The model's accuracy and applicability are confirmed when the computed results are compared with experimental coking data[2-3]. The deviation between the anticipated coking amount and experimental values is 10.2%. Furthermore, the thermal oxidation process of supercritical aviation kerosene RP-3 in a serpentine tube with an inner diameter of 1.8 mm is investigated using numerical simulation methods. The impact of various factors on the characteristics of thermal oxidation coking and flow heat transfer is investigated. The simulation results show that the thermal oxidation coking process of kerosene RP-3 is generally affected by temperature, and the elbow structure of the serpentine tube will cause local oscillation in the oxidation coking process. The location of the coking reaction will move towards the inlet when the inlet temperature and tube diameter rise and the mass flow rate falls within the laminar flow range; System pressure, elbow radius and count have little influence on the coking distribution. For the coking amount, an upsurge will result from an increase in tube diameter, system pressure, and mass flow rate within the laminar flow range; The coking amount is largely independent of the elbow radius and inlet temperature, and an increase in the elbow count will reduce it in the initial stage.

2. LENGTH AND LAYOUT

This article is approximately forty pages long, which has four sections and four sub-sections. The article layout is as follows:

I. Introduction Introduced the thermal oxidation process of aviation kerosene and its numerical simulation research.

II. Description and Validation of a Model for Aviation Kerosene Thermal Oxidation Coking Process

II-a RP-3 Aviation Kerosene Thermal Properties This sub-section introduces the physical properties data[4-7] of RP-3 aviation kerosene under supercritical conditions.

II-b Model Validation Through comparison with experiments, a pseudo-detailed oxidation coking reaction kinetics model suitable for aviation kerosene RP-3 was validated using CFD software in a straight tube, and the validation results were good.

III. Numerical Simulation of Aviation Kerosene Thermal Oxidation Coking Process in Serpentine Tubes

III-a Preprocessing of the Simulation This sub-section shows the results of structural mesh generation and independence verification for miniature serpentine tubes.

III-b Simulation Result This sub-section includes the basic case and the effects of factors (the inlet temperature, mass flow rate, system pressure, tube diameter, elbow radius and count) on the oxidation coking process.

IV. Conclusions

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3. FIGURES, EQUATIONS AND TABLES

3.1 Figures The following figure shows the secondary flow generated in the elbow, as well as the temperature and coking distribution along the serpentine tube. Through numerical simulation, this article studies the flow heat transfer and thermal oxidation coking process of aviation kerosene RP-3, and explores the effects of different factors.

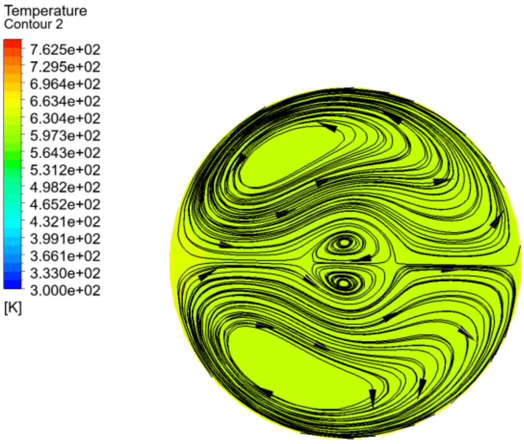

Fig. 1 Secondary flow generated at the cross-section of elbow

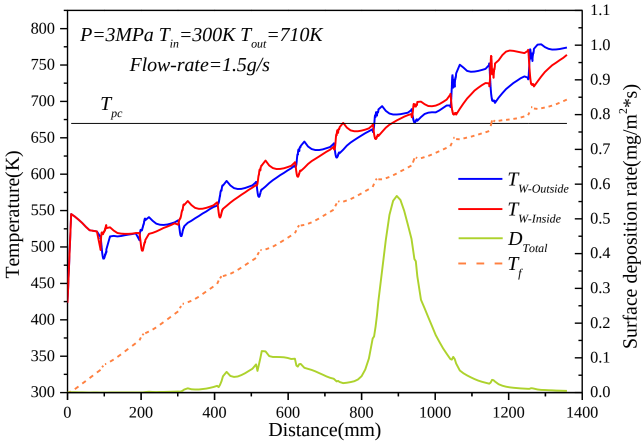

Fig. 2 Coking distribution and wall temperature distribution on two sides in serpentine tubes

4. CONCLUSIONS

(1) The simulation of the oxidation coking process in a serpentine tube shows that the oxidation coking process is mainly controlled by temperature. The erosion, mixing, and enhanced heat transfer caused by the elbow structure of the serpentine tube can have an impact on the oxidation process locally.

(2) The inlet temperature mainly affects the distribution of thermal oxidation coking reaction in the tube, with similar distribution curves and positions moving upstream; The total coking amount in the tube remains basically unchanged. The increase in mass flow rate within the laminar flow range will cause the coking distribution curve in the tube to shift downstream and increase the coking amount. The changes in system pressure mainly affect the physical properties of kerosene, leading to a slight increase in the peak coking rate and coking amount.

(3) The coking distribution curve will shift upstream and the coking amount will increase as a result of the drastic changes in the flow pattern and coking area brought about by the increased tube diameter. The influence of elbow radius on the thermal oxidation coking process of aviation kerosene RP-3 is negligible. However, in order to avoid occupying too much space, it is not recommended to choose a larger elbow radius. The change in the elbow count has little impact on the trend of coking distribution, and the coking amount will be reduced in the initial increase stage.

ACKNOWLEDGMENT

The authors appreciate the supports from the National Major Science and Technology Project of China (Nos. J2019-III-0021-0065 and J2019-III-0015-0059), and the Science Center for Gas Turbine Project (No. P2022-C-II-005-001).

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