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极限重力下冲压发动机再生冷却中燃油流动及传热特性研究

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摘　要　为了了解重力水平对超燃冲压发动机再生冷却中航空燃油流动及传热特性的影响，本文采用有限容积法对不同重力水平下水平圆管内 RP-3 航空煤油的流动和传热进行三维数值模拟。水平圆管内径为 1.8 mm，壁厚为 0.2 mm，长为 300 mm，管内工质为 RP-3 航空煤油，管壁受到 q=400 kW/m^2 的均匀热流密度加热。研究结果表明，根据重力水平的不同可将二次流流型沿管长的变化归纳为 3 种流型演变规律。0g 时截面流型由入口段的汇流发展为源流，最终再次变为汇流；当重力水平增加至 0.1g 时，在管道轴线上方出现涡状流动，涡胞中心沿管长方向逐渐向下移动，最终流型转变为汇流；当重力水平增加至 0.3g 时，涡状流动涡胞中心位于管道轴线下方，沿着管长方向快速上移至轴线上方，最终发展至管道轴线下方。随着重力水平的增大，水平圆管轴线上方流体的湍动能逐渐增大，而轴线下方流体的湍动能却逐渐减小。流体湍动能受浮升力效应诱导二次流影响呈非对称分布。重力水平的增大能强化下管壁附近的对流换热，而抑制上管壁附近的对流换热，在上壁面出现了传热恶化现象。管壁平均对流换热系数会随重力水平的增大而增大。

关键词　极限重力；再生冷却；超临界压力；航空煤油；流动传热
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Study on the Flow and Heat Transfer Characteristics of Fuel in Regenerative Cooling System of Scramjet Engine under Extreme Gravity

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Abstract　In order to study the effects of gravity level on the flow and heat transfer characteristics of aviation kerosene in the regenerative cooling system of scramjet engine, the finite volume method was used to study the flow and heat transfer of RP-3 aviation kerosene in horizontal tube at different gravity levels. The horizontal tube has an inner diameter of 1.8 mm, a wall thickness of 0.2 mm, a length of 300 mm. The working medium is RP-3 aviation kerosene. The tube wall is heated by a uniform heat flux of 400 kW/m^2. Results show that the variation of the secondary flow pattern along the tube can be summarized into three kinds of evolution laws according to gravity levels. At 0g, the flow pattern on the cross-section develops from the confluence flow to the source flow, and finally becomes the confluence flow again. When the gravity level increases to 0.1g, there is a vortex above the pipe axis. The center of the vortex gradually moves downward. The confluence flow is observed finally. Once the gravity level rises to 0.3g, the center of the vortex is located below the pipe axis. The center of the vortex moves up and down around the pipe axis. With the increase of gravity level, the turbulent kinetic energy of the fluid above the axis of the tube increases, while the turbulent kinetic energy of the fluid below the axis decreases. The asymmetric distribution of turbulent kinetic energy is affected by the secondary flow induced by buoyancy effect. The increase of gravity level strengthens the convective heat transfer at the lower wall, while it weakens the

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