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HEAT TRANSFER IMPAIRMENT IN FUEL ASSEMBLIES OF ADVANCED GAS-COOLED REACTORS

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Abstract. Heat transfer impairment is investigated in fuel assemblies of an Advanced Gas-cooled Reactor, comparing the flow and temperature for a situation without carbon deposition (clean fuel pins) with a situation with carbon growth changing the surface of the fuel pins.

1 INTRODUCTION

The objective of this work is to simulate the wall-resolving Reynolds Average Navier-Stokes (RANS) equations for the 3-D flow inside a fuel assembly of an Advanced Gas-cooled reactor (AGR) including the effect of a carbon layer that grows on the steel surface of the pin during production. The pin geometry includes small ribs in a multi-start helical arrangement that is designed to increase heat transfer area and turbulent mixing, allowing the gas to take more power out of the nuclear fuel. The off-designed conditions due to the long operational time of the reactors make it necessary to use computational modelling to better assess ageing effects. One such effect is heat transfer impairment due to the carbon layer. This is a problem in which the resolution of the near wall layer is of high importance as it is responsible for reproducing the correct anisotropy introduced by the curvature in the near wall region. In this study, a very fine 3-D model of a section of the fuel assembly is used to evaluate the effect of the carbon layer on fuel pin temperatures, which can reach the structural limit due to the insulating effect.

2 BACKGROUND

Most of the nuclear reactors in the UK are Advanced Gas-cooled Reactors, where the main coolant is CO_2. In the reactor, a fuel element contains 36 fuel pins that hold the fuel pellets. The 36 fuel pins are contained within a cylindrical graphite sleeve. The fuel pins have helical ribs in order to increase the rate of heat transfer from the pins and to improve gas mixing. After years of operation, the CO_2 reacts with the steel on the fuel pin and carbon deposits form at the surface of the pins (see Fig. 1). This is detrimental to the performance of the fuel pin in two ways, by adding an insulating layer and by changing the shape of the ribs. The net effect is to impair the heat transfer from the fuel pellets to the coolant gas, leading to an increase in the temperature of the steel can, which could lead to weakening of the material.

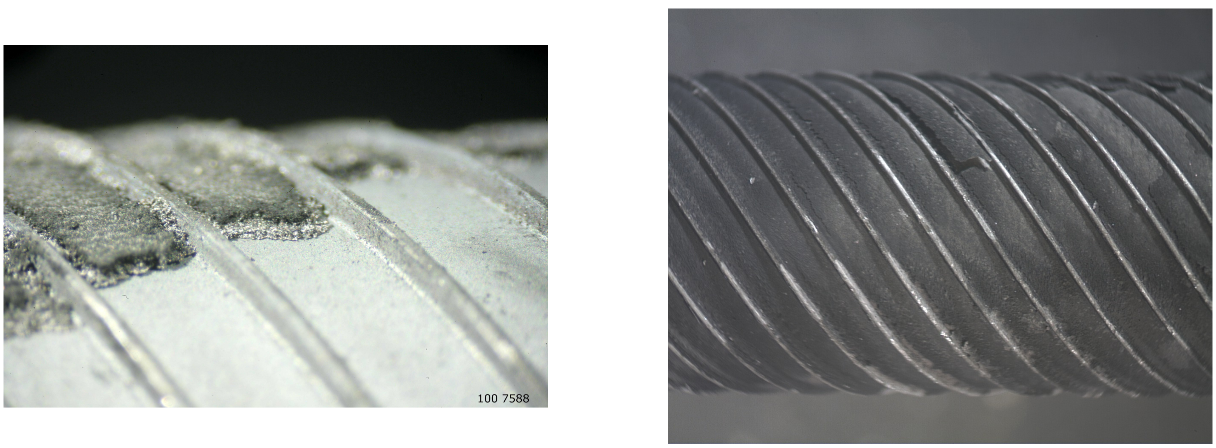

Figure 1: Examples of CO_2 presence on and between riblets.

3 METHODOLOGY

The aim of this work is to simulate the flow in a cross-section of the fuel assembly (120° wedge with 12 pins) to obtain correlations that allow a direct comparison from experiments on a single pin to the cluster, and to investigate the heat transfer impairment for 2 configurations, the former with clean surface and the latter with a surface covered by carbon. Due to the size of the ribs ($\sim$ 0.5 mm), the size of the fuel element ($\sim$ 180 mm in diameter and $\sim$ 1 m in length) and the high Reynolds numbers of the flow ($\sim 10^6$) large meshes are required to capture the turbulence and heat transfer effects. The numerical setup needs to be fine enough to be able to represent accurately the effects of the carbon layer that grows on the fuel pins. The main effect on the flow is due to the change in shape of the rib profile, which has a direct impact on the recirculation zone and therefore on friction and heat transfer coefficients. These are challenging 3-D flows in which a good prediction of the near-wall layer is necessary. A full Reynolds stress model [1] is needed in order to capture the curvature effects due to the helical arrangement of the ribs. The model also involves conjugate heat transfer to take into account the insulating effect of the carbon layer on the steel surface. The solver used is the open source software Code_Saturne [2]. It has been used before to perform an over 1 B cell mesh simulation of a section of the fuel assembly [3] and the results obtained during this previous work show that the near-wall resolution needs to be increased to obtain accurate results for the heat transfer impairment.

4 FIRST RESULTS

Some first results in the case of no deposit are shown on a coarse mesh (see Fig. 2). Results will be presented using finer meshes (∼80 million cells, running on 6,144 cores of a Cray X30), showing the velocity and temperature fields. The effect of carbon deposition will be modelled based on Post-Irradiation Examinations of the fuel pins where a representative thickness and profile can be derived. The model will include the solid carbon layer and the steel can to be able to determine the effect of the insulating layer on the steel temperature. This will be done using the internal coupling feature of Code_Saturne for computing conjugate heat transfer.

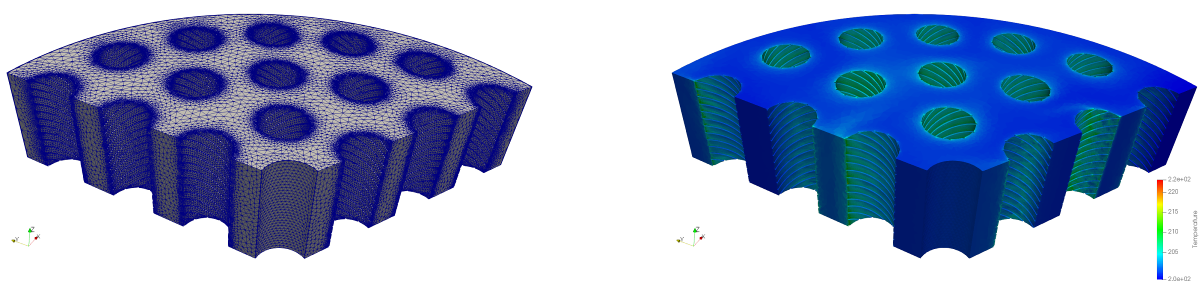

Figure 2: Examples of CO_2 presence on and between riblets.

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