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CFD modelling of a water-jet reflector cleaning process

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An in-depth analysis of water-jet cleaning process for concentrated solar thermal (CST) systems by fluid dynamics simulations has been undertaken. Water-jet shear pressure (a proxy for surface cleaning efficiency) as a function of parameters such as nozzle diameter, jet impingement angle, standoff distance, water velocity and nozzle pressure has been modelled with ANSYS CFX software.

Introduction

In the last three decades, a number of studies on cleaning aspects and techniques such as spray technology, abrasive water-jetting (AWJ), air-jet impingement on flat smooth and rough surfaces have been conducted in addition to related research in similar sectors such as droplet impact dynamics, soil erosion and soiling mitigation.

According to findings carried out mostly from 1978 to 2011, several scientists focused on jet impingement topic and connected cleaning aspects, carrying out experimental tests. The majority of that research, except most recent studies, lack a mathematical model. Therefore an understanding of the effect of modelled parameters in the cleaning process was incomplete and limited by the outputs that were accessible to those early stage experiments. [1, 2].

Methodology

Initial geometries, nozzles, flat target surface and volume of control were created in SolidWorks 2013, a parametric three-dimensional modelling platform which is effective for modifying complex parametric geometries. Nozzles chosen for this study are full cone types, with a section of 30x20mm and 2mm diameter. In the array setup, the distance between nozzles is fixed at 60mm to minimise interaction between adjacent flows. The modelled geometries were imported into ANSYS Workbench v.15 and processed with CFX package.

A computational domain was created around each nozzles geometry and the target flat surface. The size of the domain (600 x 300 mm) was chosen to ensure all surface impingement characteristics were captured. Regarding the mesh phase, tetrahedral elements were applied throughout the entire domain followed by a manual refinement on grid resolution with minimum size of 0.001 mm, maximum size of 5 mm and maximum facet size of 3mm. For the various simulations carried out, tetrahedral elements vary from approximately 1,190,000 to 1,468,000 because of standoff distances changes. The mesh resolution created on the target surface is characterized by more than 4000 elements per meter, sufficient to provide a mesh independent result for the shear stress generated.

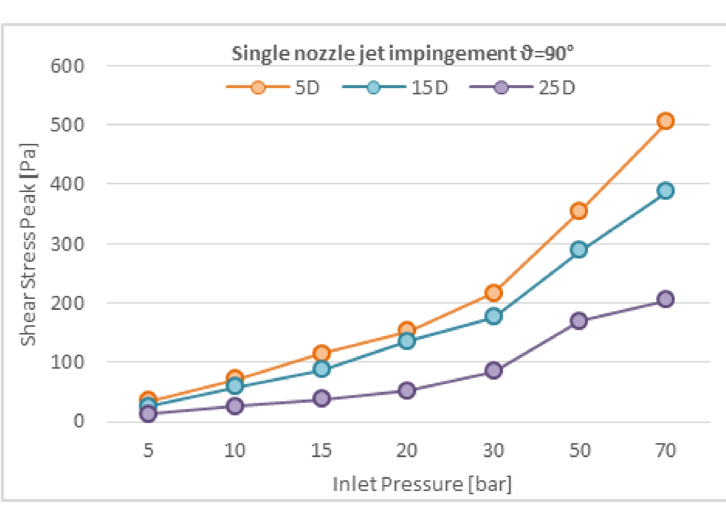

Figure 1a: Water-jet shear stress with ϑ= 90° and at three standoff distances for single nozzle.

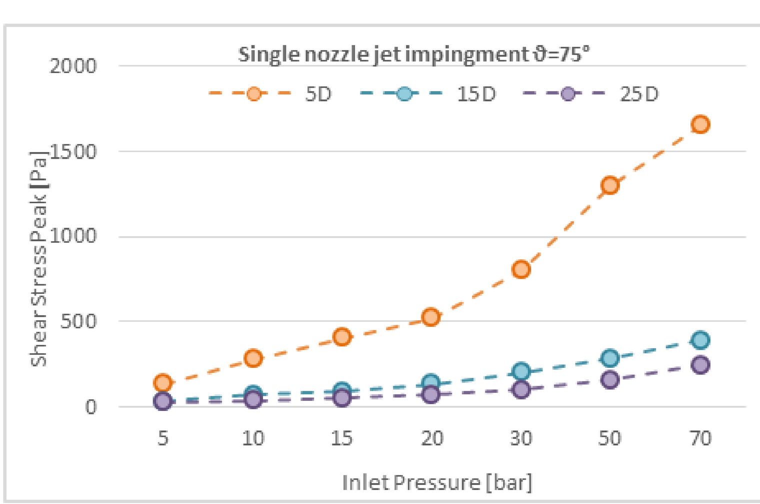

Figure 1b: Water-jet shear stress with ϑ= 75° for single nozzle .

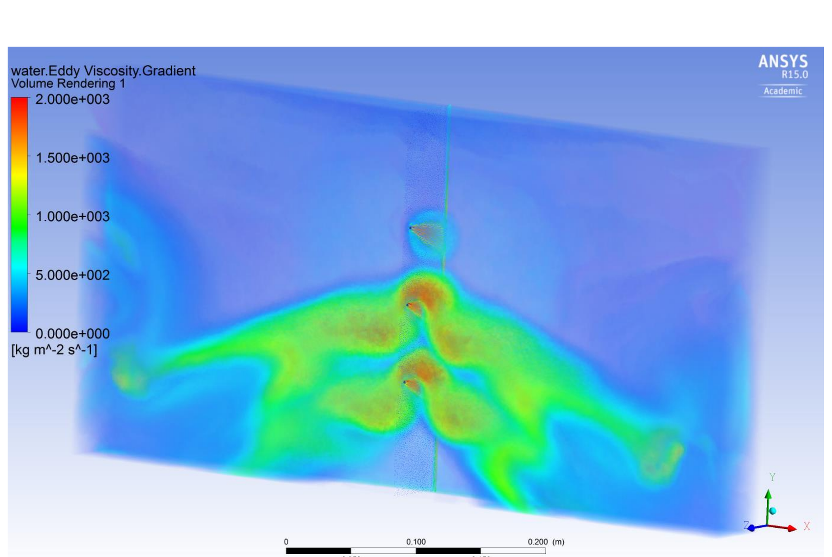

Figure 2: Presence of turbulent flow between adjacent jets

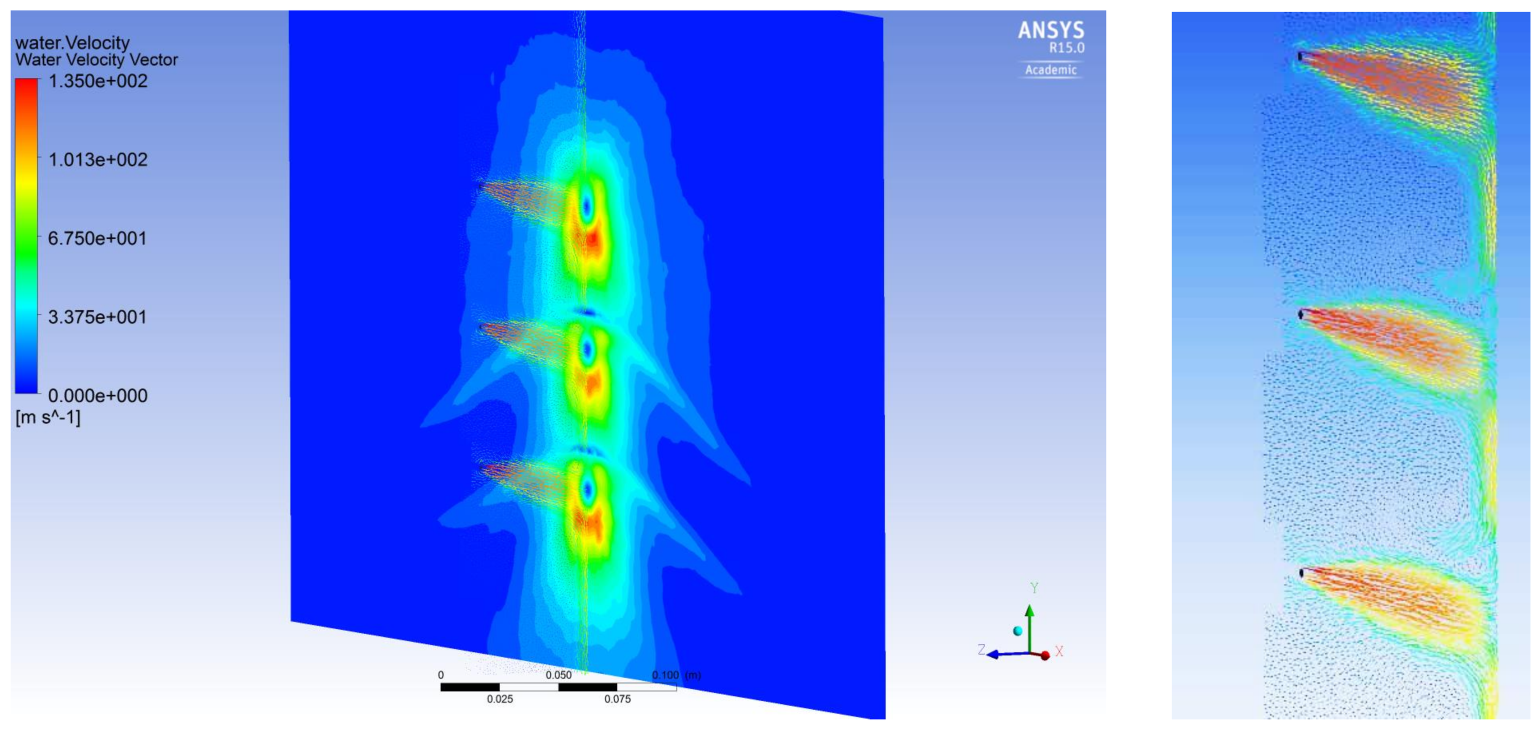

Figure 3: Three adjacent jets tilted 15° from the normal. The non-uniformity of shear flow could adversely affect cleaning

Results

In a single nozzle setup, results confirm an increase in shear pressure magnitude as a function of increasing inlet pressure. In figure 1a the water-jet behaviour at three different levels of standoff distances is shown. For low inlet pressures, there is not much difference in the shear force peak. More significant differences occur above a pressure of 20 Pa, especially between 5D and 25D standoff.

The average shear forces are increased by tilting the jet 15° from the normal (impingement angle ϑ=75°). The increase is most marked for the 5D standoff distance with modest enhancement of 3% and 10% for 15D and 25, respectively (Figure 1b).

With multiple jets significant turbulence develops in flows between adjacent jets. Visualisation of the volumetric contour of the water eddy viscosity gradient (Figure 2) illustrates the extent of the turbulent flow.

Figure 3 shows fluid flow in the impinging jets as well as the flow across the planar surface. The regions of high pressure are shown in red and the regions of low pressure are shown as blue. Arrows indicate direction of flow but not magnitude. It is clear that the turbulence is strongly influenced by the amount of spread of the jet prior to striking the planar surface. At closer standoff distance the jet impingement is more concentrated than for larger standoff, and interaction between jets more less significant.

The study on the optimal interaxial and standoff distances of the nozzle array needs further investigation as it has such a large influence upon turbulent flow. The mitigation of turbulence will be required in order to increase cleaning effectiveness.

Conclusions

In this paper a detailed study of water-jet impingement on a planar surface has been performed with single and multiple nozzle configurations. Three different standoff distances in conjunction with the variation of inlet pressure and angle of impingement have been considered in the CFD simulations by ANSYS v15 software.

Findings confirm a significant increase of shear stress as the standoff distance decreases. By varying the angle of impingement from ϑ= 90° to ϑ=75° for both configurations, an enhancement of shear forces occurs for all standoff distances but is more effective at 5D. Fluid flow and fluid shear may be significantly disrupted due to interaction between adjacent jets. Nozzle design and arrangement should minimise turbulent flow in order to maximise cleaning efficiency.

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