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EVALUATION OF CFD SIMULATION ON PRESSURE DROP IN 3D PRINTED PARTS

Wallen F. Souza[1], Mateus M. Chalub[2]
Maria A. F. Veloso[1], Yasmin Carvalho[2], Andre A. C. Santos[2]

[1] Departamento de Engenharia Nuclear – Escola de Engenharia
Universidade Federal de Minas Gerais
Av. Antônio Carlos 6627
31270-901 Belo Horizonte, MG.
[2] Centro de Desenvolvimento da Tecnologia Nuclear,
Comissão Nacional de Energia Nuclear,
Av. Pres. Antônio Carlos, 6627
30270-901 Belo Horizonte, MG.
[1]wallenfds@yahoo.com.br

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ABSTRACT

With the advance of 3D printing, recent studies have shown many works in different areas using 3D printing. Among the various 3D printing processes, the Fused Deposition Modeling (FDM) process stands out. It is a widely used 3D printing technology that uses thermoplastics to print parts. The process involves melting a thermoplastic filament and depositing it layer by layer to create a 3D object. The roughness of the printed object is dependent on the layer height, which is adjustable in most FDM systems. The geometric precision of the printed object is dependent on the nozzle and build platform temperature, build speed, layer height, and cooling fan speed, which are all adjustable in most FDM systems. Many works in the nuclear field of verification and validation use the FDM process to produce prototypes in the thermo hydraulic area. The geometric precision affects pressure drop. This work seeks to utilize the experimental data from W.F. de Souza *et al*. and conduct additional experiments to assess with a CFD roughness model for 3D printing parts. Three equations were applied to the sand grain model, and the resulting simulations were compared to the experimental data. This study confirms that for these scenarios, it was not possible to accurately simulate pressure drop.

1. INTRODUCTION

Many studies have focused on pressure drop in nuclear reactors as it is associated with reactor efficiency. One of the primary characteristics of pressure drop in turbulent flows is roughness [1]. To assess and predict pressure in nuclear projects, researchers have been using CFD as a tool. For this purpose, it is essential to conduct tests on prototypes to validate the created models[2]. Prototypes printed using the FDM 3D printing process exhibit high roughness values [3][4]. In CFD, the model used to simulate roughness is the so-called equivalent Sand Grain roughness height [5][6]. The imperfections generated on the surface, which are responsible for altering the boundary layer and influencing the heat and momentum transfer of the components, are approximated by a model of semi-spheres. This effect has been studied by several researchers[3][7]. The high roughness of printed parts can cause a considerable pressure drop from parts produced compared with traditional manufacturing such as machining, even with a short relative length of the printed part compared to the length of the hydraulic system [8].

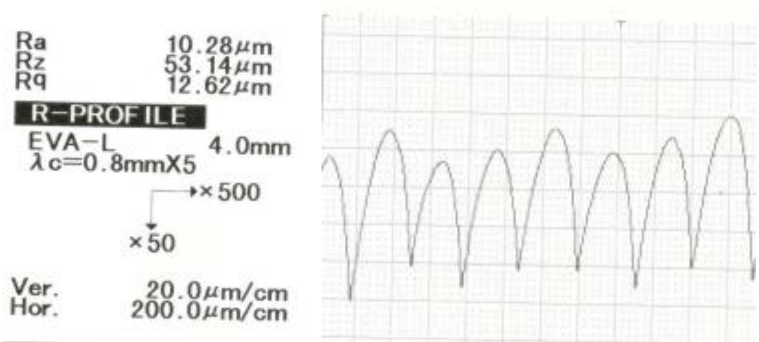

Fig. 1. Profile of the roughness of the printed perforated plate

Fig. 1 show the profile of surface and roughness value of the perforated plate with 0.15 mm layer height (h_{layer}). The objective of this work is to show the difference between the results of the applications Sand Grain roughness height model [5] and compared to the experimental results of the pressure drop on printed perforated plates, apply another roughness model, and propose a new one to approximate the simulated pressure drop values with the experimental test values.

2. METHODOLOGY

1- The facilities used in this study are described in the work of Souza [8], The study utilized six Reynolds numbers, each associated with a distinct flow rate. Flow profile is fully developed and has 1200mm of downstream. The dimensions of the plate are detailed in Fig. 2.

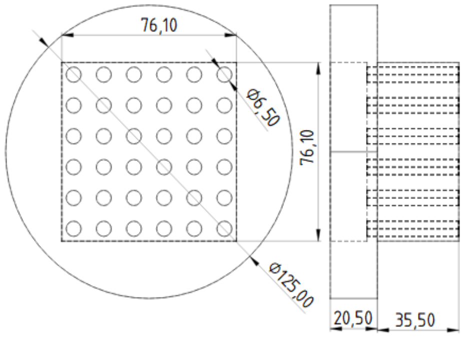

Fig. 2. Dimensions in millimeters of the perforated plates

The plates were subjected to experimental tests with a temperature of water 20±1ºC.

Tab. 1. Parameters of the experimental tests

V(m/s)	Flow rates(kg/s)	Reynolds
0.345485984	2.002014722	26311.62026
0.431371815	2.499707949	32846.40904
0.51815654	3.002637429	39405.9937
0.603711695	3.498459429	45843.74386
0.689503644	3.995603714	52379.27387
0.776794443	4.501437714	59022.09481

Tab. 1 contains the experimental data used in the simulations. Tab. 2 The table below presents the roughness values for four plates produced to evaluate pressure loss. One plate is made of acrylic and the other three are printed with different roughness values measured in average roughness Ra. In this work, the printed plates will be referred to as $h_{0.10}$; $h_{0.15}$ e $h_{0.25}$ considering the different layer heights of the printed parts and the reference acrylic plate as Ap. The table below presents the roughness values of the plates, printed and the reference acrylic plate:

Tab. 2. Roughness of the plates

	Acrylic plate (Ap)	**Printed plate h=0.10mm**	**Printed plate h=0.15mm**	**Printed plate h=0.25mm**
Roughness [µm]	1.47µm	5.94µm	8.55µm	14.64µm

The experimental pressure values will be compared to the simulated values in CFD. Three equations will be applied to the sand grain model in the software.

$$\varepsilon = 5.863\ Ra \tag{1}$$

$$\varepsilon = 6.2\ Ra \qquad (2)$$

Equation (1)is the equation proposed by T. Adams, where Ra represents the average surface roughness, and the constant value corresponds to the equivalent sand grain length. Equation (2)was proposed by Kochi, and the terms have the same meaning.[5][7]. In work's Barroso[9]. The application of T. Adams' sand grain model to the printed spacer grid has demonstrated that the predicted values are consistently lower than the corresponding experimental data. Consequently, we propose the introduction of an equation as a pedagogical tool to enhance the accuracy of the simulated pressure drop within the printed plates, aligning them more closely with the experimental findings.

$$\varepsilon = h_{layer} \qquad (3)$$

Equation (3) introduced in this paper, includes the layer height h_{cam}, measured in [mm], and accounts for the variation in roughness. This equation is based on the assumption that roughness is directly proportional to the layer height.

Software CFX of the Ansys 2022 was used to predict the pressure drop. Boundary conditions are the same experimental analyses conditions. Simulations were conducted for one hole model. Simulation of the Pressure drop at one hole of the Perforated plates with same features can be used for comparison with perforated plate with plus holes, since t/Do is the same. Thickness (t) and orifice diameter (Do). Turbulence model is Kε. Condition inflation was applied in the wall of the hole only. Function inflation is the refined prism mesh applied on unstructured mesh near the wall for capitation of the non-slip of the fluid.

Fig. 3 show refined of grid and the dimensions of 1/8 hole with 39mm of length and dimensions of test section with 260mm downstream and 32.5 upstream of the perforated plate.

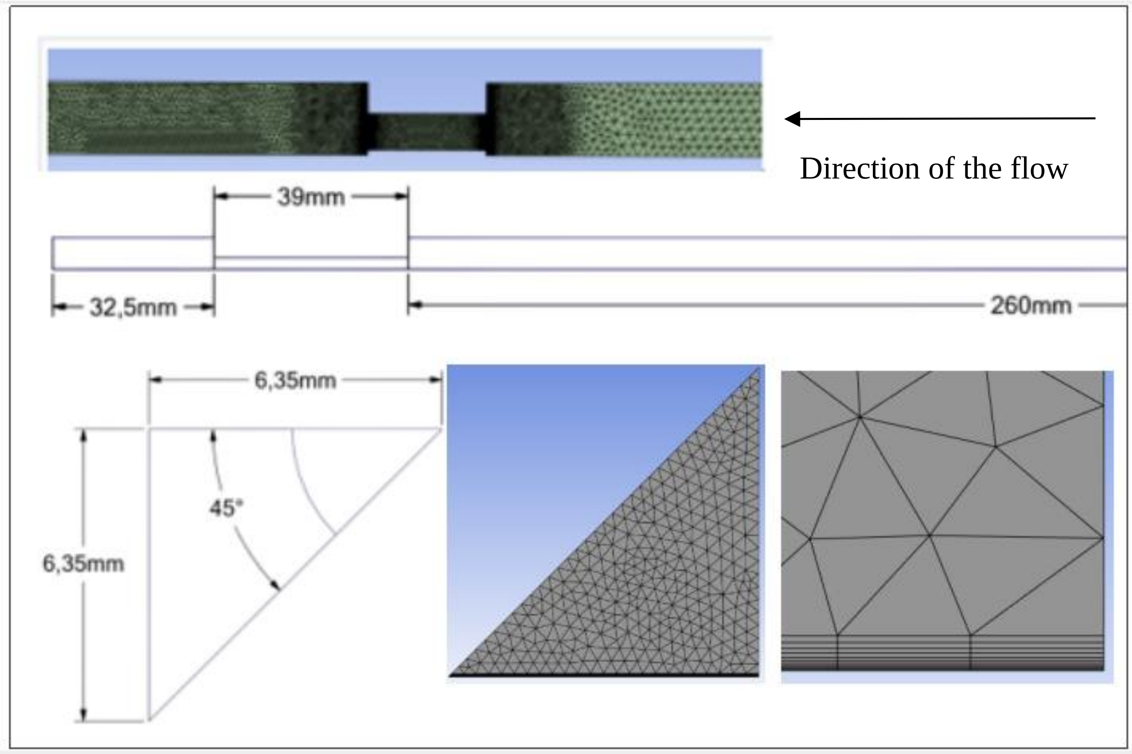

Fig. 3. Gride and simulated dimensions

3. RESULTS

Fig. 4 shows the comparison of the pressure drop in the acrylic plate. This plate was manufactured using a conventional machining process. The results show that the model applied according to equation (1) accurately predicts the experimental results.

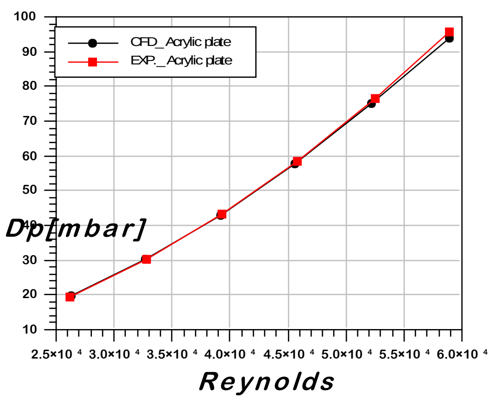

Fig. 4. Comparison of the Simulation CFD with experimental pressure drop. T.Adams model.

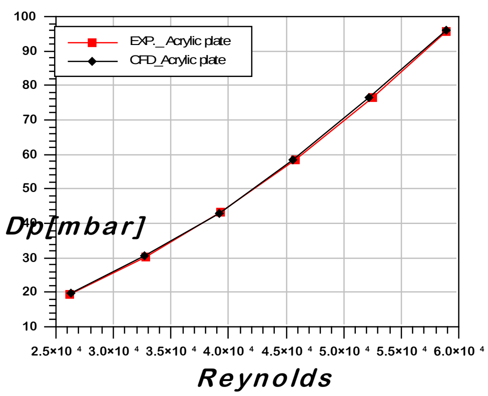

Fig. 5.Comparison of the Simulation CFD with experimental pressure drop Kochi model.

Fig. 5 Comparison of the CFD Simulation with experimental pressure drop uses the application of equation (2) and also perfectly predicts the pressure drop behavior.

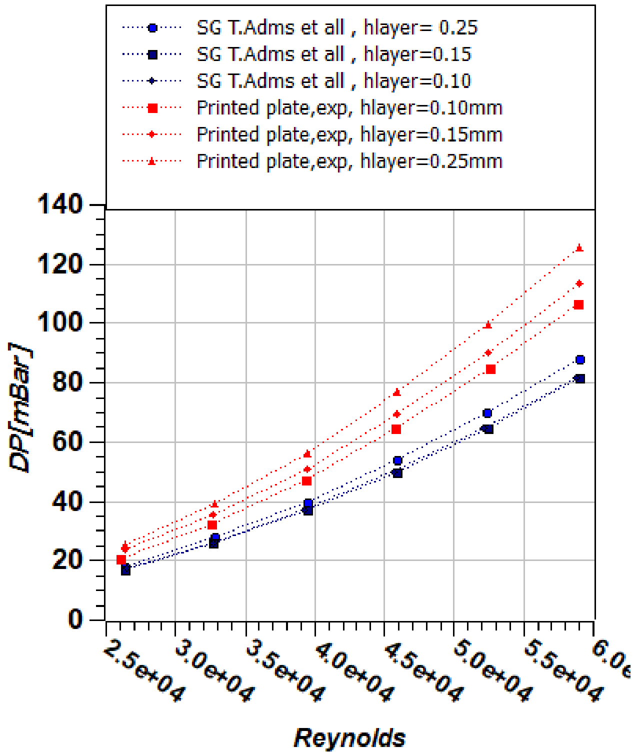

Fig. 6. Comparison of the pressure drop using equation model T.Adams and experimental results

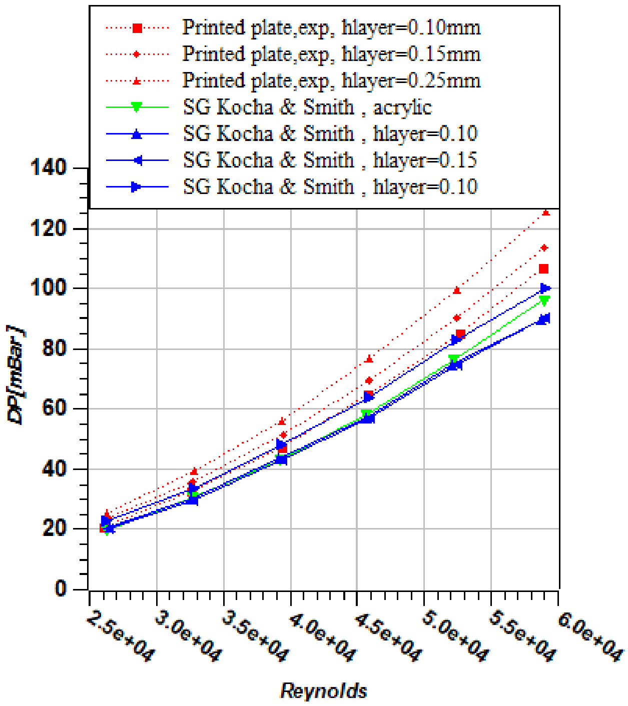

Fig. 7. Comparison of the pressure drop using equation model Koch & Smith and experimental results

A Fig. 6 presents a comparison of the simulated pressure drop for the printed plates with layer heights of $h_{0.10}$; $h_{0.15}$ e $h_{0.25}$, as obtained from CFD simulations. These results are compared with experimental data.

The discrepancies between the simulated and experimental pressure drop values are evident in Fig. 6.

Fig. 7 The application of equation (2) to simulate pressure drop yields results that exhibit a trend towards the experimental values. However, it is observed that the deviation increases for higher Reynolds numbers, exceeding 20%, while it decreases for lower Reynolds numbers.

A Tab. 3 show that as the print layer height increases, the percentage difference becomes even more pronounced.

Tab. 3- Percentual differences between CFD and experimental pressure drops

Exp.	Dif% ($h_{0.10}$)	Dif% ($h_{0.15}$)	Dif% ($h_{0.25}$)	Dif% (Ap)
CFD T.Adams	16%	22.0%	22.9%	0.67%
CFD Kochi	14.9%	20.5%	20.6%	0.20%

Experimental results indicate a significantly larger pressure drop for the printed plates compared to the acrylic plate.

Fig. 8 shows the result of applying the proposed equation (3). In the results obtained do not decrease the discrepancy between the CFD simulations and the experimental data.

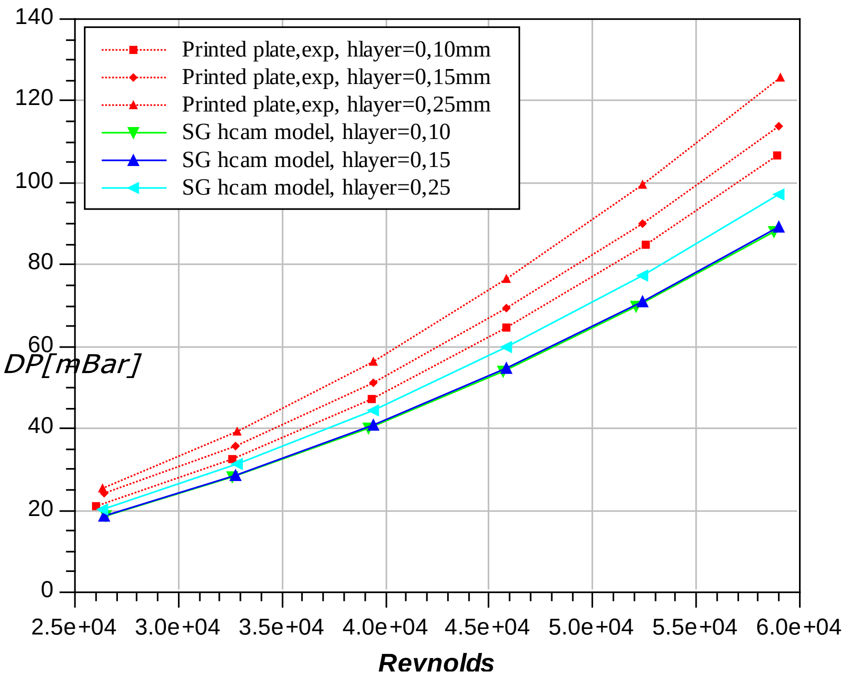

Fig. 8.Comparison of the pressure drop using equation model hcam and experimental results

4. CONCLUSION

CFD simulations were conducted using different values obtained from 3 different equations for simulations with the sand grain roughness approximation model. Results in figures 1 and 2 for the pressure loss applied to the acrylic plates show that the simulation results are consistent with the experimental results and can be used as a reference for simulations and experiments, as they present a standard of parameters that were used with the printed plates. The results of printed plates were compared to experimental data from perforated plates printed with varying roughness caused by different layer heights. It is observed that roughness significantly impacts the results of the printed parts. While for conventionally produced parts, the reference authors' models provide accurate results with differences less than 1%, the sand grain model is less sensitive to such large roughness variations as those found in printed parts. Kadivar previously noted that not all types of roughness are accurately simulated by the model. In this study, the uncertainties associated with the experimental data are approximately 3%. When considering the context of prototype construction for reactor thermal hydraulics, it is generally accepted that data uncertainties should not exceed 15%. This study confirms that for these scenarios, it was not possible to accurately simulate pressure drop. This indicates that for printed parts, further studies are required using a different model or formulation to ensure that the results align with the experimental data within the limiting range of the sand grain model equations.

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