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WAVELET DECOMPOSITION APPLICATIONS FROM PRESSURE SIGNALS FOR TURBULENCE ANALYSIS

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Abstract. *The study and modeling of turbulence have been discussed for many decades, and as a result of these studies there are currently applied two great approaches to Computational Fluid Dynamics (CFD) simulations, being RANS (Reynolds Average Navier Stokes) and LES (Large Eddy Simulation) modeling are more used. Five numerical meshes of a device emulating a biphasic heat exchanger were constructed and RANS approach was used with the Transition SST turbulence model. The time of the simulation was 100 s and the system input pressure data were processed by wavelet technique (in 11 frequency bands) and by Fourier transform. The results show that the profile for the sparse mesh is closer to the expected behavior for RANS approach, while for the refined mesh it is closer to the expected behavior for LES approach.*

Keywords: *Turbulence models, numerical mesh, wavelet decomposition, RANS, LES*

1. INTRODUCTION

Studies of turbulence modeling have occupied great space mainly in the areas of engineering (Neto et al. (1993)). Initially, for CFD (Computational Fluid Dynamics) simulations, RANS (Reynolds Average Navier Stokes) simulations, for this modeling class the properties are transported as averages in time, so a field of a property is by definition a mean property in a range of time. For many years this type of approach has been widely used to solve scientific and industrial problems. However other approaches have been presented with a focus on filling some gaps presented by this approach. LES (Large Eddy Simulation) approach has the proposal of capturing large scales and modeling small scales, requiring more refined mesh and also a smaller increase in time, then can capture more temporal disturbances, reflecting in larger oscillations such as velocity and pressure field.

This paper aims to question the threshold between these approaches showing that the same model (RANS) can capture more or less information by changing only the temporal and spatial filters, given by the numerical mesh and the time step in the simulation strategies.

The work presented by Roache (1994) shows that the adherence between the simulated data tends to be uniform, going to an asymptote of information, that is, with the increase of the numerical mesh refining the solution tends to a single result. On the other hand, in the present study it was observed that when there is a change in numerical mesh and time interval, the compressible biphasic flow (water / air) produces pressure oscillations at different scales.

This paper shows a qualitative observation of pressure signal behavior at different levels. Through wavelet decomposition, pressure signals were separated into specific frequency bands, with the objective of evaluating the

magnitude of the signals in different frequency bands for the 5 meshes. The modeling used, the wavelet filter, the study geometry and the pressure profiles resulting from the simulation are presented in this paper. These profiles were separated and the power spectral densities of each of the different pressure ranges presented.

2. MATERIALS AND METHODS

The influence of the numerical mesh on the pressure signal results at the entrance of a pseudo double pass heat exchanger was studied. A simplified geometry of a heat exchanger used by Venturi et al. (2017) was used considering a 20 mm slice of the central part. This part does not include deflectors or tubes, as the interest of the study is the phenomenon of liquid transport by gas from the lower compartment to the top and then out of the equipment.

2.1 Numerical simulation

The geometry used comprises the three-dimensional air inlet tubing and a double-shell shell-tube heat exchanger slice. The thin section numerical meshes were made with a transverse direction volume and lateral symmetry condition. In this system a pressure signal was obtained at the water and air supply inlet, as shown in Figure 1

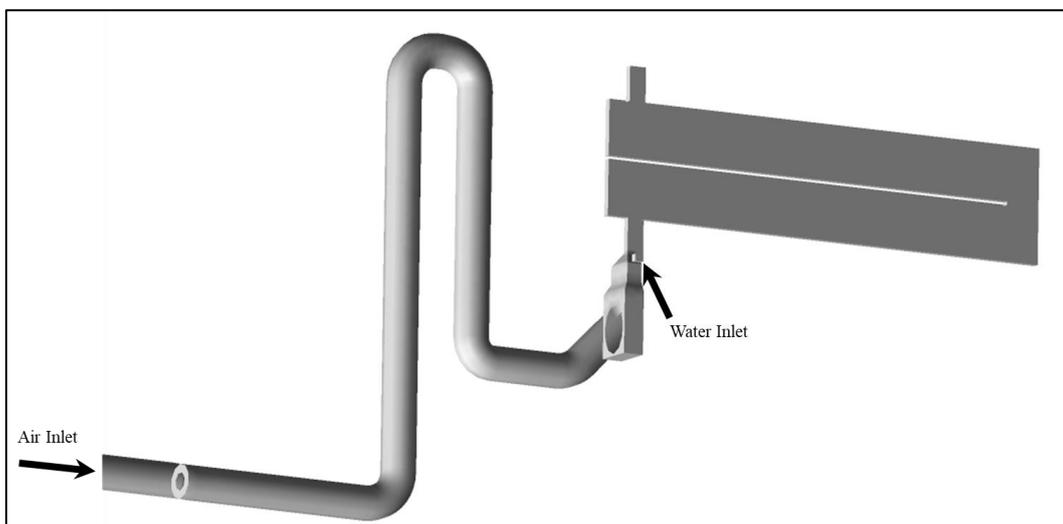


Figure 1. Geometry used for simulations

For the mathematical modeling the finite volume method was used in a three-dimensional Eulerian approach, calculating the conservation equations of mass, momentum and energy. The energy modeling is necessary because the air is modeled as ideal gas. Since the gas is modeled as ideal, the specific mass (ρ) is considered constant only for the liquid, while the dynamic viscosity (μ) is considered constant for both phases. For the turbulence modeling the Transition SST model was used. The SST transition model was chosen, this model was chosen because there are moments of high and others of low turbulence (Koerich; Rosa (2016)). This model was chosen because it presents a particularity of being able to better model the transition region between laminar and turbulent flow. For this equipment operates with periods of low and high speed alternately, due to the formation and liberation of the flows, in the form of gusts.

As shown by Venturi et al., (2015) the closure equation that need, volumetric fraction, (α) in each control volume, given by Equation 1, where v is the velocity.

The Transition SST model was chosen because it is able to better model the transition region between laminar and turbulent flow

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (v\alpha) = 0 \quad (1)$$

The VOF approach considers only one Eulerian field, the properties such as specific mass (ρ) and viscosity (μ) are weighted by the volumetric fraction, according to Equations 2 e pela 3, respectively

$$\rho = (1 - \alpha_2)\rho + \alpha_2\rho \quad (2)$$

$$\mu = (1 - \alpha_2)\mu + \alpha_2\mu \quad (3)$$

The SIMPLE algorithm was used for the coupling between pressure and velocity. For solution of the momentum. For solution of the momentum it was used Second order interpolation schemes. For solution of others conservatives properties it was used the first order interpolation schemes. The geometric reconstruction scheme was used for to represent the interface between fluids. It was used the time step adaptive with the courant number around 2,5 (defined by Equation 4, where v_x is the velocity in component x, Δ_t is the time step and Δ_x is the volume size in dimension x).

$$Co = \frac{v_x \Delta_t}{\Delta_x} \quad (4)$$

2.2 Wavelet

For the analysis of the pressure oscillation signals of the simulation was used the wavelet decomposition. This technique was developed in the 1980s (Burrus et al. (1998)) and it consists of the decomposition of a signal into several frequency classes. Through this technique it is possible to decompose and then recompose the signal (reconstitution of the original signal) or each of the decomposed levels. This recomposition is called the inverse of the wavelet transform.

For example, to reconstruct a transient pressure signal at a given time, simply add the value of the pressure signal at all levels (P_{wn}), thus recomposing the original signal as shown in Equation 5

$$P_t = \sum_1^n P_{wn}|_t \quad (5)$$

As an alternative treatment to each of the individual levels of the wavelet transform, it is possible to regroup some specific levels. Yang and Leu, (2008) did a work by applying Multi-Resolution Analysis (MRA) on the pressure oscillations of an "L-Valve". For pressure fluctuation analysis, the third-order Daubechies - wavelet (Dau-blet3) model was used.

According to Addison (2005), the Fourier transform is applied to the entire interval making a global average of oscillations, which may mask transient characteristics of transient phenomena. To get around this, the researcher suggests making a series of Fourier Transforms with shorter timeframes (Short Time Fourier Transform - STFT), to capture some local phenomenon. However, the use of the wavelet transform analyzes the whole spectrum and also local spectra (due to the analysis in different frequency bands), which allows the analysis of the behavior of the variable of interest over time.

The wavelet transform is similar to the Fourier transform, however it is more flexible in time, as the wavelet transform separates the signal into several frequency bands, while the Fourier transform averages the frequencies of the entire spectrum. of frequency.

The discrete wavelet transform (DWT) is the signal expansion, $x(t)$ with ($t = 1, \dots, N$), as the sum of the functions $\phi_{i,k}(t)$ e $\psi_{j,k}(t)$. They are produced by the expansion and translation of the parent wavelet pai orthogonal function ϕ (Equation 6) and the mother wavelet ψ function (Equation 7):

$$\phi_{j,k}(t) = 2^{-j/2} \phi\left(\frac{t - 2^j k}{2^j}\right); j, k, \in I \quad (6)$$

$$\psi_{j,k}(t) = 2^{-j/2} \psi\left(\frac{t - 2^j k}{2^j}\right); j, k, \in I \quad (7)$$

3. RESULTS ANALYSIS

For the study we used a pseudo heat exchanger (Figure 1), as presented by Dos Santos et al. (2017), which was based on a small scale heat exchanger adaptable for the treatment of hydrogen diesel oil in the HDT process presented by Venturi et al. (2017). The geometry does not contain tubes or deflectors, but represents the passage of the two-phase mixture, where the fluid mixture passes from the bottom to the top of the equipment (Figure 2).

In Figure 2 it is possible to observe the formation and movement of a slug flow in the lower part of the equipment, which causes pressure oscillations. Figure 3 (A-E) shows the pressure profiles for the 5 meshes studied, with the element size being 2.5 mm, 5.0 mm, 10.0 mm, 20.0 mm and 40 mm, respectively. This 100% increment between numerical meshes has been used to obtain a broad spectrum in the relationship between numerical mesh sizes.

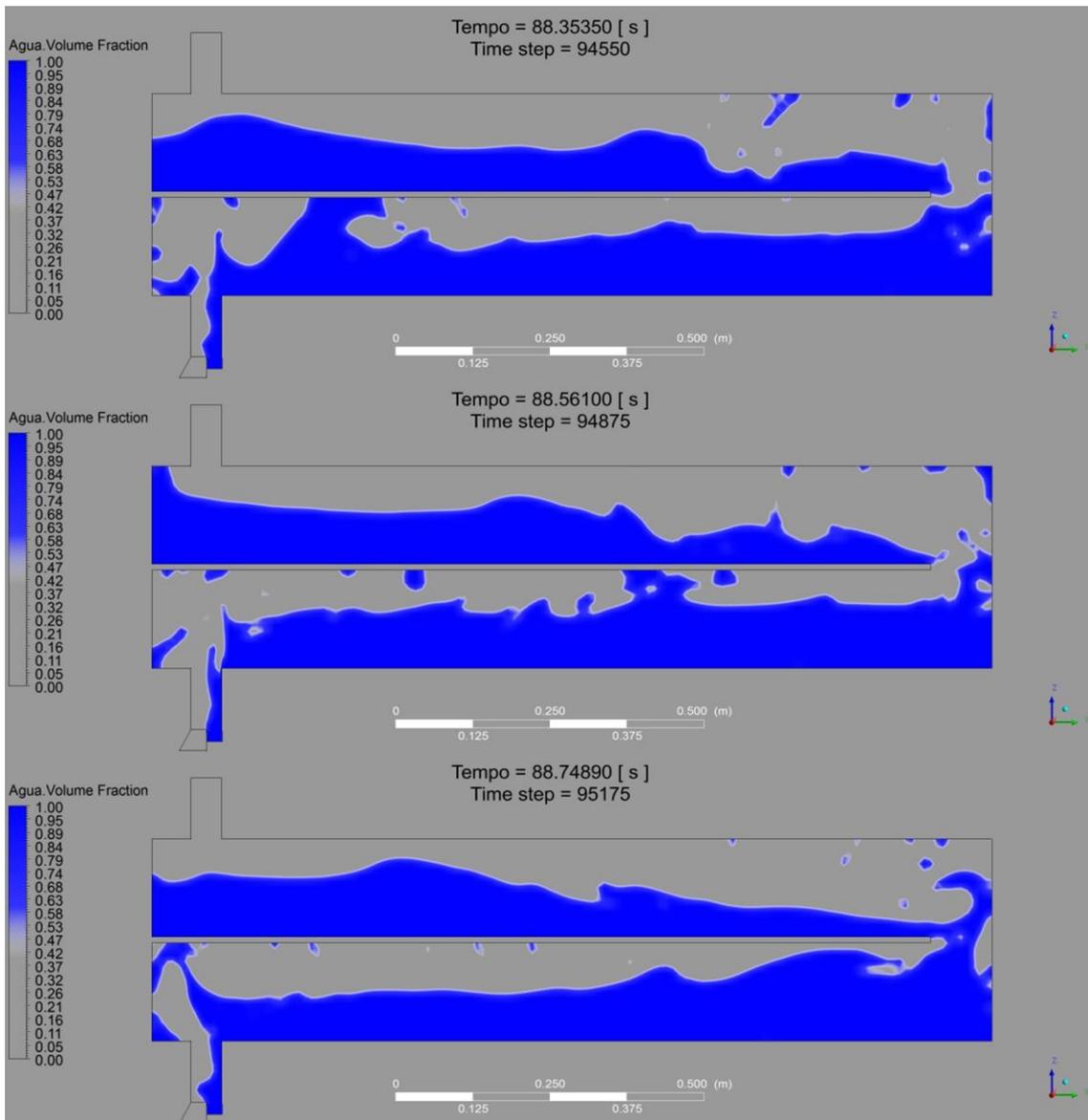


Figure 2. Movement of the slug flow in the equipment.

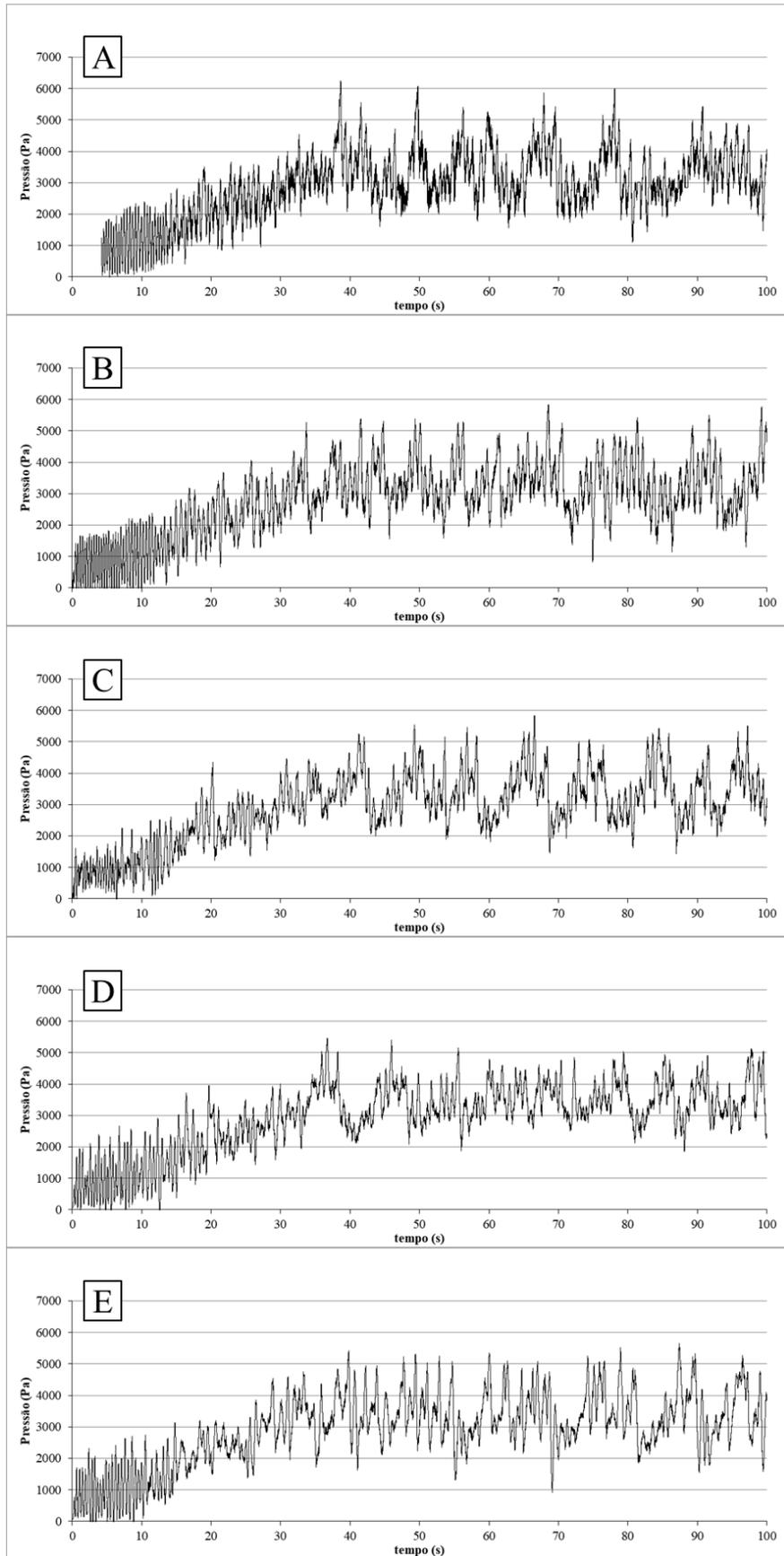


Figure 3. Pressure over time for the 5 mesh studied: A) 2.5 mm, B) 5 mm, C) 10 mm, D) 20 mm, E) 40 mm

Disregarding the initial part of the pressure signal, the energy density spectrum of these pressure data (Figure 4) shows that there is a strong agreement between the results of the different numerical meshes. The dominant oscillation frequency is exactly the same for 4 cases, only for the 20 mm mesh the results are slightly different. Since the amplitude of the pressure signals are also very similar, it can be noted that the results are very close globally.

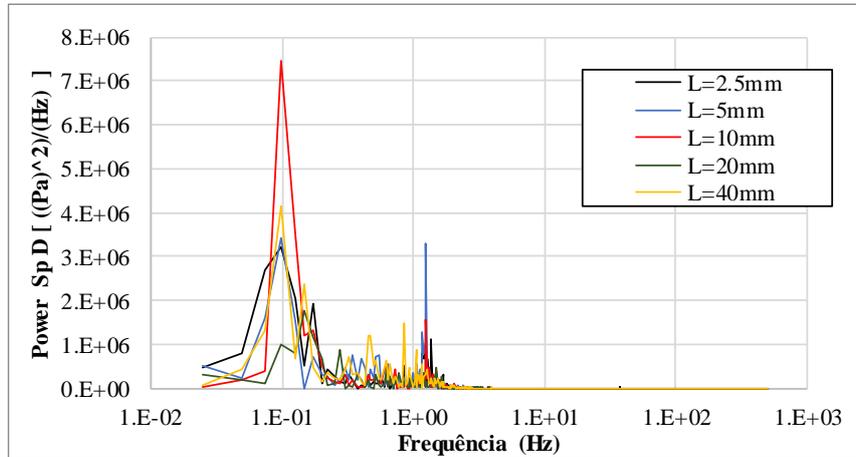


Figure 4. Fourier analysis

The pressure signals were separated into 11 different bands by wavelet decomposition (Wavelet Daubechies 3 (db3)), being parts of them (60 to 70s) shown in Figure 5, where it can be observed that for the small level signals, which are the For high frequency and low amplitude signals, there is a difference between the numerical meshes. However, for the higher levels, this difference is not so significant.

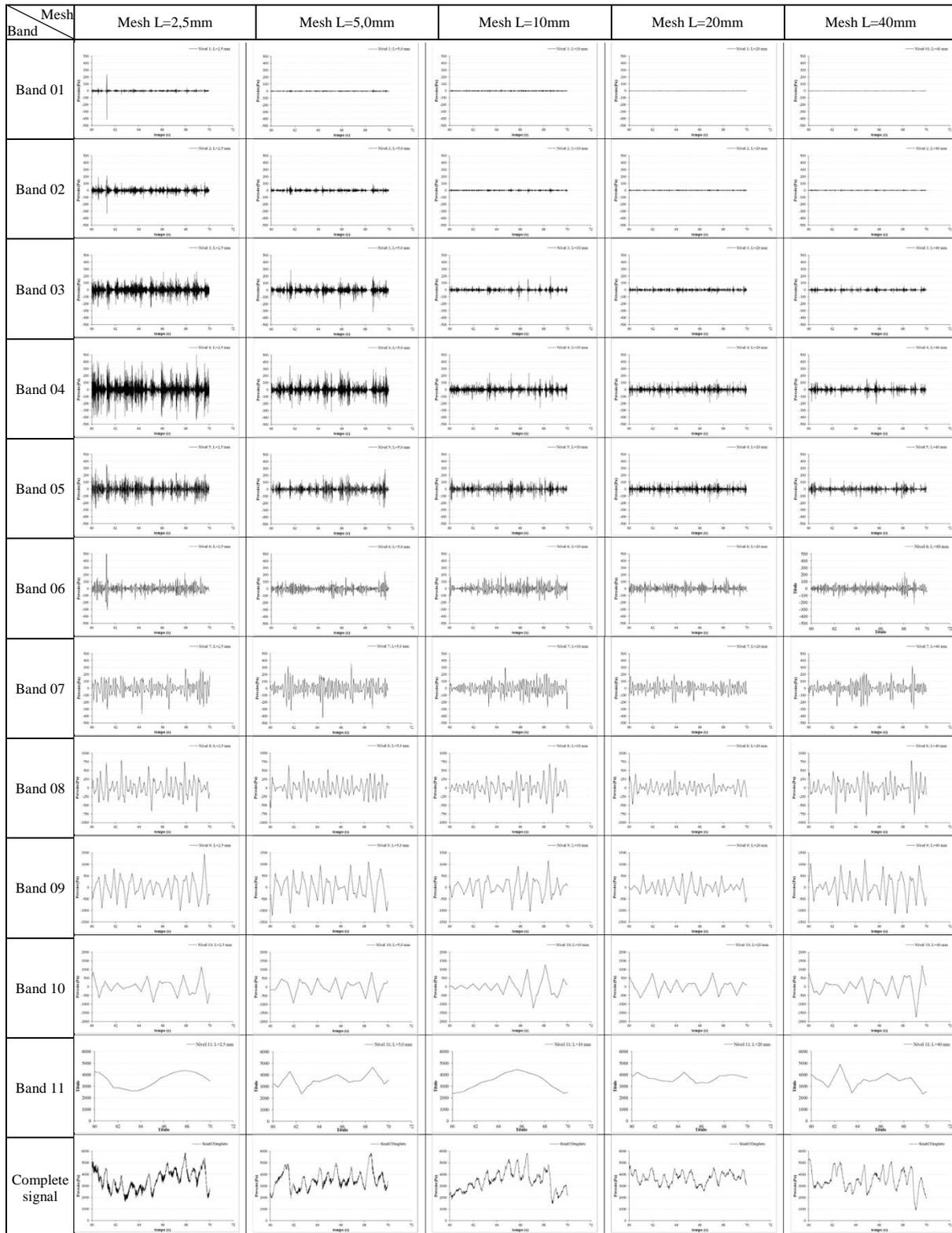


Figure 5. Pressure signal from 60 to 70s for 5 meshes in 11 different levels. (Dados em

The spectral power density analysis of these signals (Figure 6) shows that with increasing bands, the density peaks move toward the lowest frequency that is characteristic of frequency band decomposition, such as wavelet decomposition. This analysis confirms that in the larger bands the values are in the same order of magnitude, while in the smaller bands the differences between the meshes are more significant.

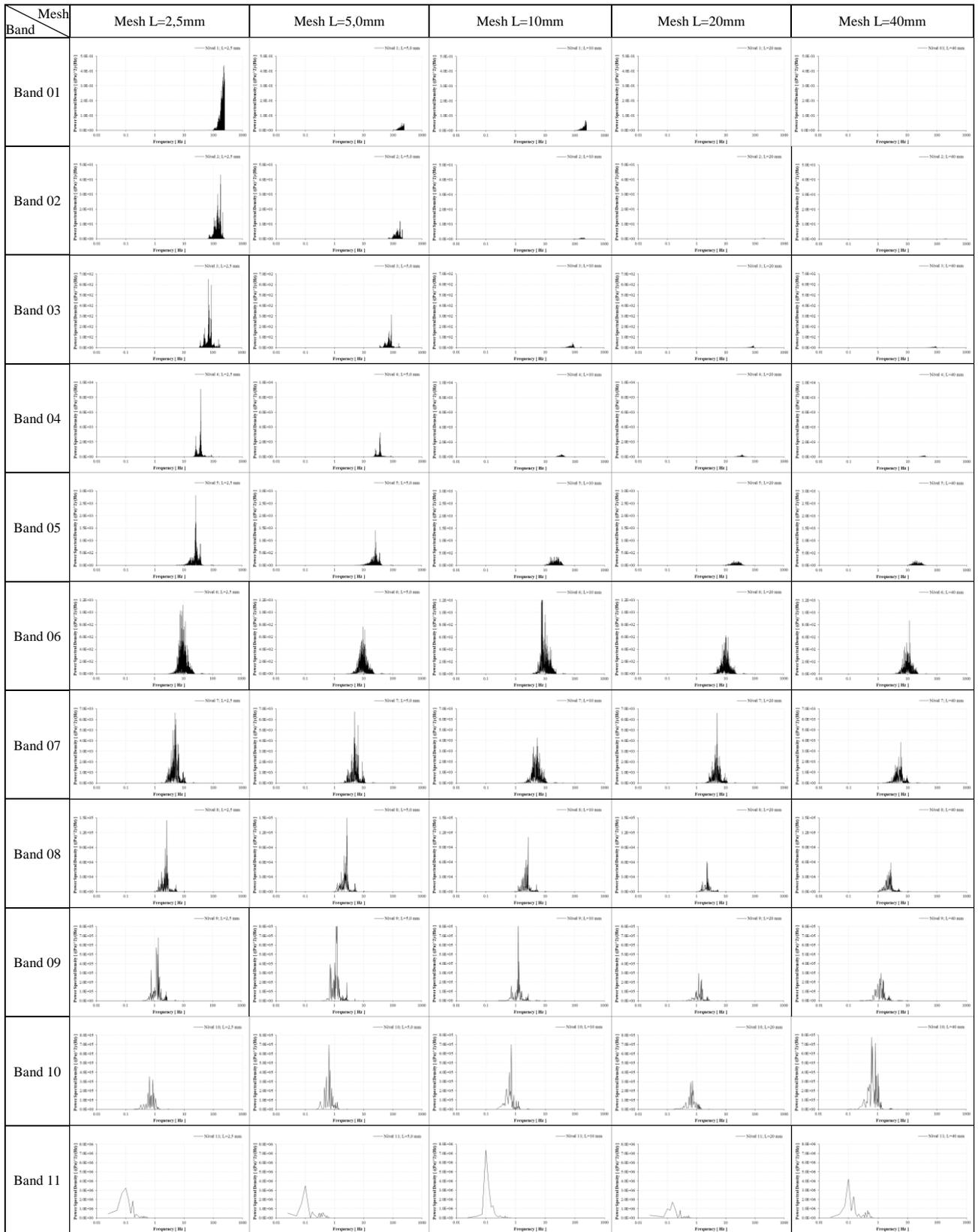


Figure 6. Power spectral density of pressure signal from 60 to 100 s for 5 meshes in 11 different levels

4. CONCLUSIONS

The data presented in this work show that for a high turbulence biphasic flow simulation using RANS approach, may or may not have similar results, depending on what one wishes to observe.

The results show that with RANS simulation with very small time step and very refined spatial discretization (mesh) it is possible to capture effects at very high frequencies, even at small amplitudes. In this situation it can be affirmed that the simulation with the refined mesh was able to capture oscillations from the flow scales that are not normally considered when performing a RANS simulation, but a LES turbulence model simulation.

On the other hand, for the simulation with the most sparse numerical mesh and suitable time step for such mesh, it is possible to capture only large scale oscillations. It is noteworthy that small scale oscillations are filtered by RANS modeling and disregarded for global flow.

5. ACKNOWLEDGEMENTS

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