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Parametric design and analysis of industrial dye mixing machines

Structural design analyses of industrial dye mixing machines, concerning mixing impeller geometries, mixing performances, and power requirements aren't generally of scientific quality. Our aim is to propose a practical method for minimizing execution time, using parametric design. In this study, Visual Basic API codes are developed in order to model the impellers in SolidWorks® software, and then flow analyses are conducted. Thus, velocity values and moment/torque values required for mixing operation are determined. This study is carried out for different shaft rotational speeds and different impeller diameters. Flow trajectories are obtained. After that, frequency analyses are conducted and natural frequency values are obtained. In the scope of this study, two different impeller types are investigated.

1. Introduction

Mixing can be explained as a preparation work of mixture that involves two or more mixing elements. Homogeneity of the mixture composition is very important because the grade of homogeneity determines the success of the mixture. Therefore, it is very important to choose the proper mixer equipment. The mixers differ from each other according to the following criteria: the type of current they create in the blended material, shaft's velocity, and viscosity of the mixture. The energy obtained from the motor must be transferred effectively to the product.

The most important part of the mixing equipment is the impeller, for this reason, most of the study is concentrated on the impeller zone and there are quite a

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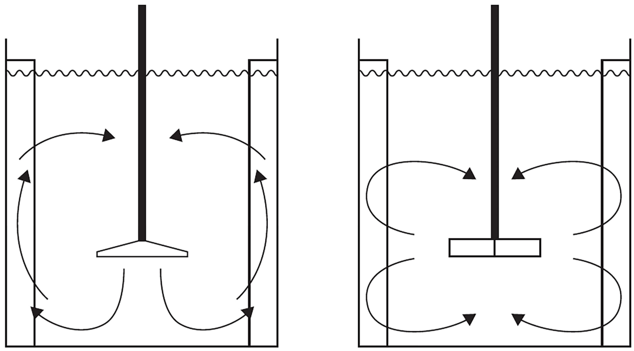
number of impeller types. By knowing the physical properties and the requirements of the process, the most efficient impeller can be selected. Turbine impellers are characterized based on flow patterns, as axial flow and radial flow ones [1].

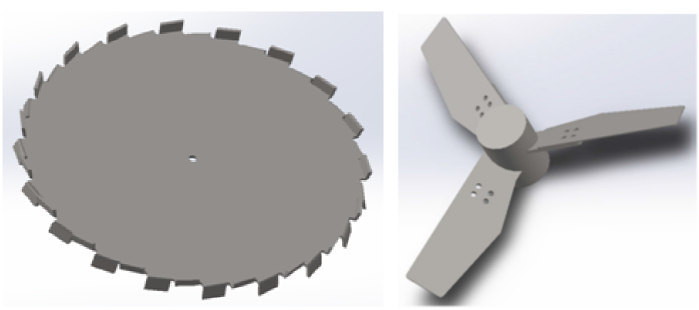
The fluid flows parallel to the axis of rotation of the impeller when the axial flow impellers are used for mixing, and it flows perpendicular to the axis of rotation of the impeller when the radial flow impellers are used. Fig. 1 shows the flow circulation, for these types of fluid flow.



(a) purely axial flow with a hydrofoil (b) double circulation loops with a radial impeller

Fig. 1. Flow types [2]

Dispersion type impellers are the radial type of impeller and rotate at high rpm values. Hydrofoil type impellers are the axial type of impeller and generally are selected for the low viscosity mixing process. Most of these impellers have three or four blades. The width and shape of the blades may vary considerably depending on the manufacturer and application [3]. An example of dispersion and hydrofoil type impeller can be seen in Fig. 2.



(a) dispersion type impeller (b) hydrofoil type impeller

Fig. 2. Impeller types

There are several researches about parametric design and mixing machines. In [4], the author studied feature-based design. He observed two kinds of modeling:

synthesis and destructive modeling and two principal techniques, generative and variant design methods. In [5], authors studied the parametric design of straight bevel gears based on SolidWorks®. The Visual Basic program was developed for the parametric design. Each control point was determined in a Cartesian coordinate system. In [6], authors proposed explicit integrated (reference) modeling for complex parts modeling in the parametric CAD system. The modeling time was used to demonstrate the effectiveness of the study. In [7], authors aimed at developing a software application for product design. They used SolidWorks® application programming interface (API) for CAD model updating by automating repetitive tasks. They carried out studies on Winding Machine and they developed a program using Visual Basic language. In [8], authors examined three major modeling methodologies: horizontal modeling, explicit reference modeling, and resilient modeling by using three industrial CAD models with different levels of complexity designed with SolidWorks®. In [9], authors used the three-compartment model to study nonhomogeneity of mixing in a fully baffled stirred tank. They used multiple reference frame (MRF) technique for calculations.

In [10], authors investigated the impeller power versus rotational speed relation on a dispersion type impeller with 538 mm diameter at different rotational speeds. However, in this study, both dispersion and hydrofoil type impellers are designed parametrically and then analyzed with SolidWorks® Flow Simulation software. Furthermore, the impeller diameter is increased gradually and the analyses are broadened. Flow trajectories are observed for both impeller types. Also, frequency analyses are conducted.

Within the scope of this paper, firstly, Visual Basic programming language is used to develop the codes. With the help of these codes, dispersion and hydrofoil type impeller are designed parametrically. The parameters used in the codes can be changed using the text file containing the design parameters. By this means, the dimensions of the impeller can be changed easily. So, the design can be changed for desired features. In this study, SolidWorks® is used as three-dimensional CAD software and interacted with Visual Basic programming language. In this way, the advantages of these two programs are utilized. In the flow and frequency analysis, the height of the control volume is 3 times greater than the impeller diameter. The aim of this study is the calculation of the required power at different rotational speeds and impeller diameters for dispersion and hydrofoil type impellers. Also, velocity values are investigated and flow trajectories are observed. Furthermore, the natural frequency values are investigated by using finite element software.

2. Parametric design

In traditional CAD systems, it is necessary to know the exact specifications of the geometry in order to create the 3D model. However, design changes can be required during production. The parametric design allows designers to make modifications to the existing designs by changing parameter values, thus making it possible for them to create shapes without knowing precisely how they will be configured in the final design [11]. In search of solutions to design problems, changes in the design are an essential part of this process. Design variations ensure the improvement of the design, so the quality of the design improves [12, 13]. Designers need complex thinking for defining relationships, and this is necessary in order to create an efficient parametric model. The parametric design ensures that the changes made in the design process are less difficult. Designers change the parameters used in the parametric model to search for alternative solutions. Parametric modeling is a process that controls the changes in model shape, but there is no change in the number of components [13].

A parametric design change cannot be accomplished if only dimensional changes are made in a model. Modeling errors can be avoided with the help of the constraints [14]. Parameterized geometric models are used because they allow the geometry to be easily edited, they inherently include design intent information, and allow a family of different sized parts to be represented by a single model [15]. A constraint is a relation that limits the behavior of an entity or a group of entities. Examples of constraints are: a group of lines constrained to be parallel or perpendicular or collinear, a line constrained to be tangent to an arc, two cylinders constrained to be concentric, a dimension constrained to be less than a particular magnitude or equal to a multiple of a particular magnitude [12, 16].

The modern design facilitates the designer's work by reducing the time required for the design process and ensuring the proper use of resources. The products which have similar mechanical characteristics and shapes can be created through parametric design by using SolidWorks® and Visual Basic. This can improve design efficiency and simplify design work [17]. An application programming interface is a tool to write a code in a programming language within another application. As a result, direct integration between different applications can be developed [18]. Using the API, model files created in SolidWorks® can be manipulated directly inside a control program such as Excel and the resulting altered parameters can be returned for further review [19].

SolidWorks® and Visual Basic programs are used together in the design phase. Firstly, the parameters that determine the dimensions of the design are defined and saved in a text file. The text file is read with the execution of the codes developed in the Visual Basic program. With the help of this text file, the parameters can be changed according to the existing conditions and requirements. It gives the users a chance to create models with different sizes. As a result of parametric modeling, by using these parameters, design codes are developed with Visual Basic programming language. After the two programs interact with each other, a plane must be selected to open a sketch. During the sketch creation process, constraints must be identified. With the help of these constraints and design parameters, a fully-defined sketch can be created. If the constraints weren't be used, the part might be deteriorated when making some changes in the solid part. After making a fully-defined sketch, the part can be created by extruding the sketch. Fig. 3 and Fig. 4 show the models created by

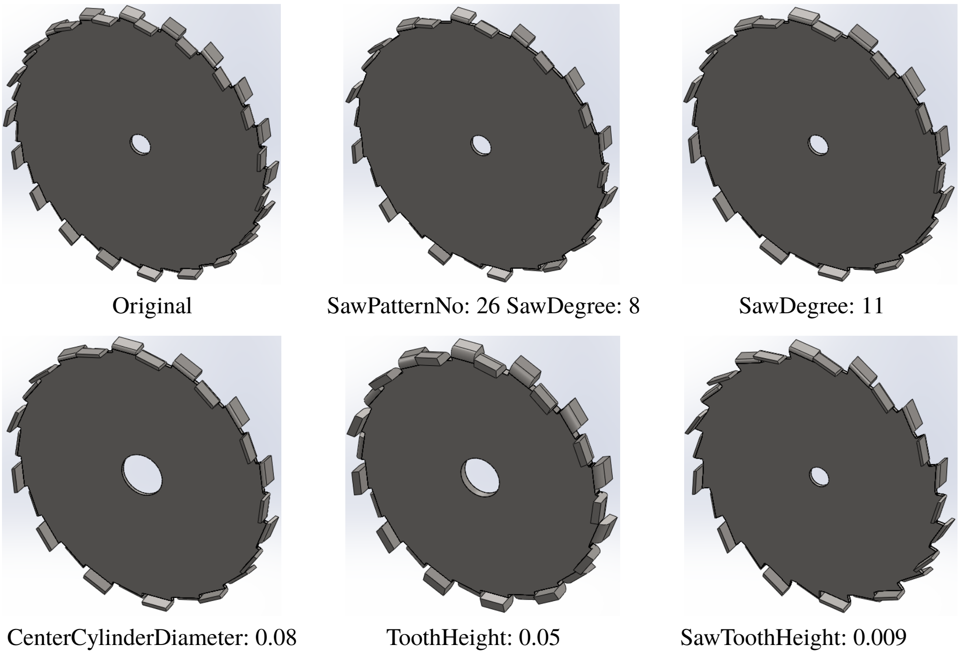


Fig. 3. Models created by changing parameters for dispersion type impeller

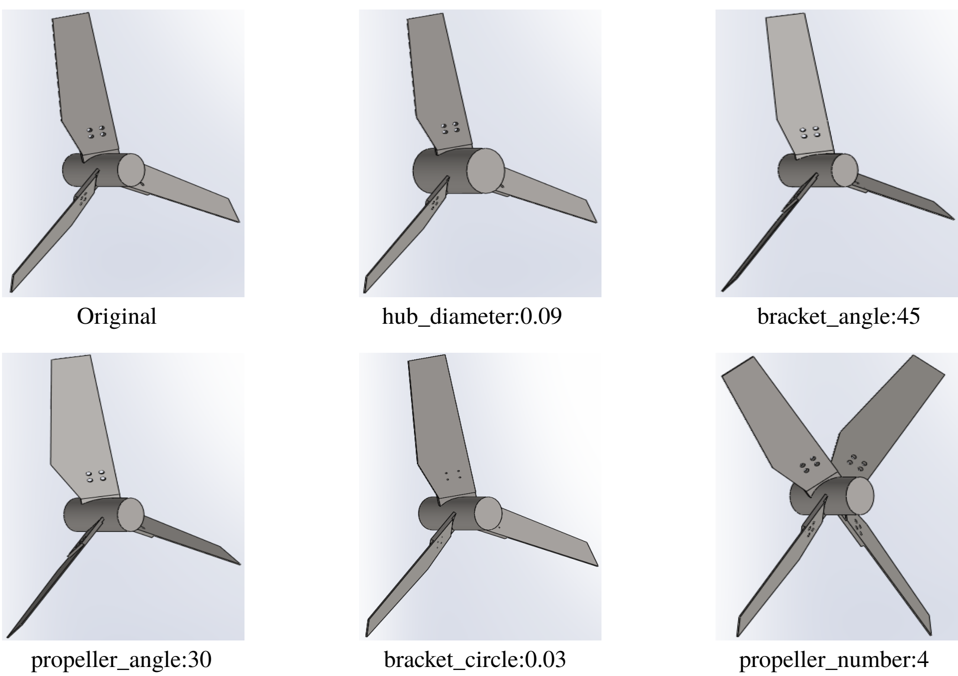


Fig. 4. Models created by changing parameters for hydrofoil type impeller

changing parameters for dispersion and hydrofoil type impeller, respectively. Fig. 5 shows the parameters which are used in the Visual Basic programming language to create a part that has the desired sizes in SolidWorks®.

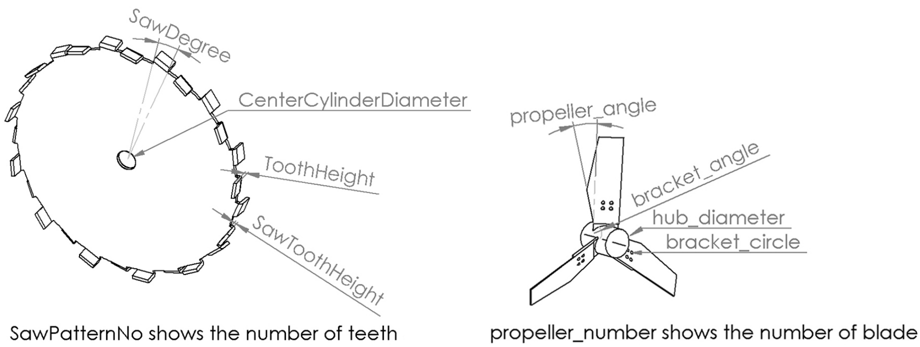


Fig. 5. Parameters used for dispersion and hydrofoil type impeller

3. Analysis and results

Flow analysis is essential for virtual testing and prediction of system behavior. Fluid flow analysis is used to improve the design and the performance of the system. Dimensional relations between the impeller and the control volume are shown in Fig. 6. Before the analysis of the system, all parts must be assembled as shown in Fig. 6.

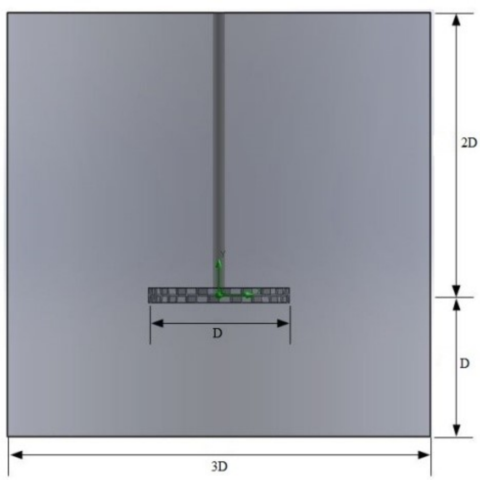


Fig. 6. Dimensions of the impeller and the control volume

The dye should be defined within the control volume. Environmental pressure must be defined at the top surface of the control volume which represents the tank in the system. The other surfaces of the control volume are defined as an ideal wall. The rotational speed is defined by selecting the rotational area, and the goals must be defined. Setting up the flow simulation solver, internal analysis is performed on SolidWorks® Flow Simulation software, and the cavities are excluded without flow conditions. Gravity is applied to the system on the y-axis as -9.81 m/s^2. Turbulence intensity is set 2% and turbulence length is set 0.01536 m in general settings phase of the SolidWorks® Flow Simulation software as the initial conditions. In this study, the velocity profile around the impeller and moment/torque values required for mixing operation are determined. Fig. 7 shows the preparation phase of the system for the analysis. Dynamic viscosity and density of the dye used in analyses are 1.2 Pas and 1200 kg/m^3, respectively.

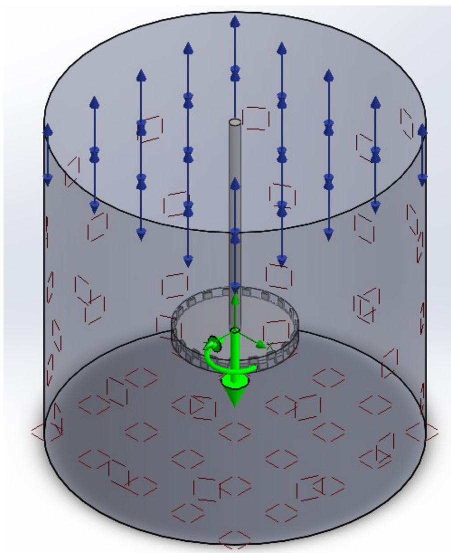


Fig. 7. Preparation for the analysis

In Fig. 8, there is shown the mesh independence study for both hydrofoil and dispersion type impellers. The rotational speed and impeller diameter used in the mesh independence study are 100 rpm and 538 mm, respectively. For hydrofoil and dispersion type impellers, mesh3 and mesh4 are selected for the analysis, and they represent the mesh 3 and mesh 4 level resolution on the SolidWorks® Flow Simulation software, respectively. The analyses converge for these mesh values, as seen in Fig. 8. These mesh levels are selected due to the computational cost, because increasing the number of mesh does not contribute to the development of the solution. The number of mesh used in mesh independence study can be seen in Table 1. In Fig. 8, the length shows the line between the origin of the impeller and the tank wall. The velocity values shown in Fig. 8 increase linearly starting from the origin to the tip of the impeller based on the linear velocity calculation. One can see that the velocity decreases after the tip of the impeller, and the maximum velocity value is reached at the tip of the impeller.

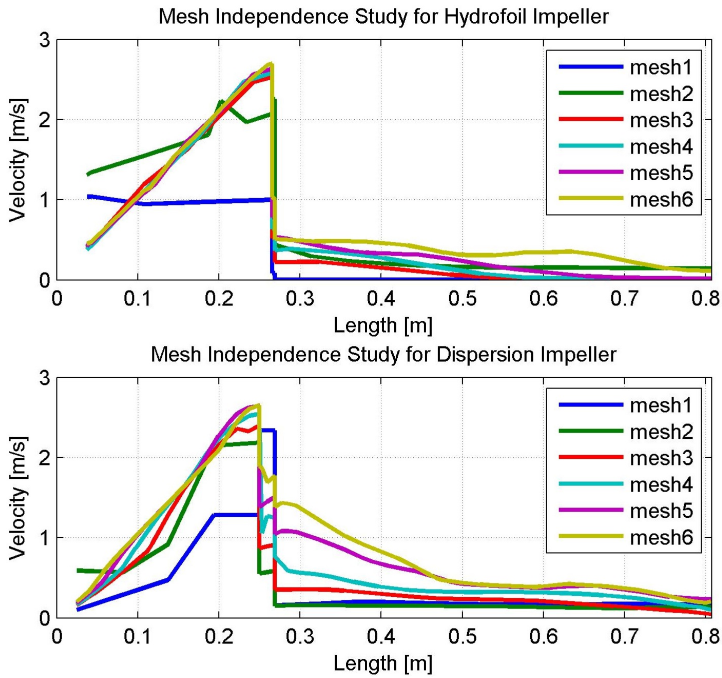


Fig. 8. Mesh independence study

Table 1.

The number of mesh used in mesh independence study

	Hydrofoil Type Impeller		Dispersion Type Impeller	
	Total Cell	Contacting Cell	Total Cell	Contacting Cell
mesh1	224	168	224	168
mesh2	493	316	494	316
mesh3	**3813**	**1631**	3428	1476
mesh4	8253	3092	**7722**	**3036**
mesh5	19311	6441	18200	6212
mesh6	43455	12318	39348	12240

3.1. Results of dispersion type impeller

The following results have been obtained for the 538 mm impeller diameter at different rpm values. Table 2 shows the results obtained from SolidWorks® Flow Simulation software. Fig. 9 shows the required impeller power versus rotational

Table 2.

Results for dispersion type impeller

	100 rpm	200 rpm	300 rpm	400 rpm	500 rpm	600 rpm	700 rpm	800 rpm
ω [rad/s]	10.472	20.944	31.416	41.888	52.360	62.832	73.304	83.776
v [m/s]	2.817	5.634	8.451	11.268	14.085	16.902	19.719	22.536
v' [m/s]	2.794	5.588	8.382	11.175	13.969	16.763	19.557	22.351
T [Nm]	7.260	20.419	36.644	54.941	78.472	101.924	131.016	166.600
P [W]	76.027	427.656	1151.208	2301.368	4108.794	6404.089	9603.997	13957.082

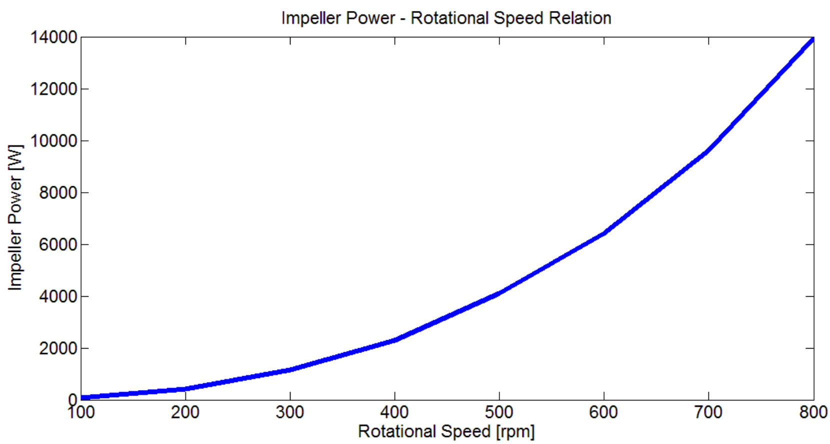


Fig. 9. Impeller power – rotational speed relation for dispersion type impeller

speed. In the tables, except Table 4 and Table 7, v' represents linear velocity results and T represents torque values on the y-axis for the impeller at the SolidWorks® Flow Simulation and v represents the theoretical linear velocity values at the tip of the impeller. Fig. 10 represents the flow trajectories for different rpm values for the 538 mm impeller diameter. As can be seen in Fig. 10, especially from the front view of the control volume, the velocity values around the impeller increase, which is denoted by color change.

The following results have been obtained for different impeller diameter at 100 rpm. Table 3 shows the results obtained from SolidWorks® Simulation software. Fig. 11 shows the impeller power versus impeller diameter relation for a dispersion type impeller. As expected, impeller power increased with the increased impeller diameter, as seen in Fig. 11.

Fig. 12 shows the frequency response graph of a dispersion type impeller for 538 mm impeller diameter. Frequency response is obtained from SolidWorks® Linear Dynamic Analysis results. The natural frequency value is 12.952 Hz for the impeller system. It is important to know the frequency values to avoid the resonance situation. Table 4 shows the frequency values in Hz units for different

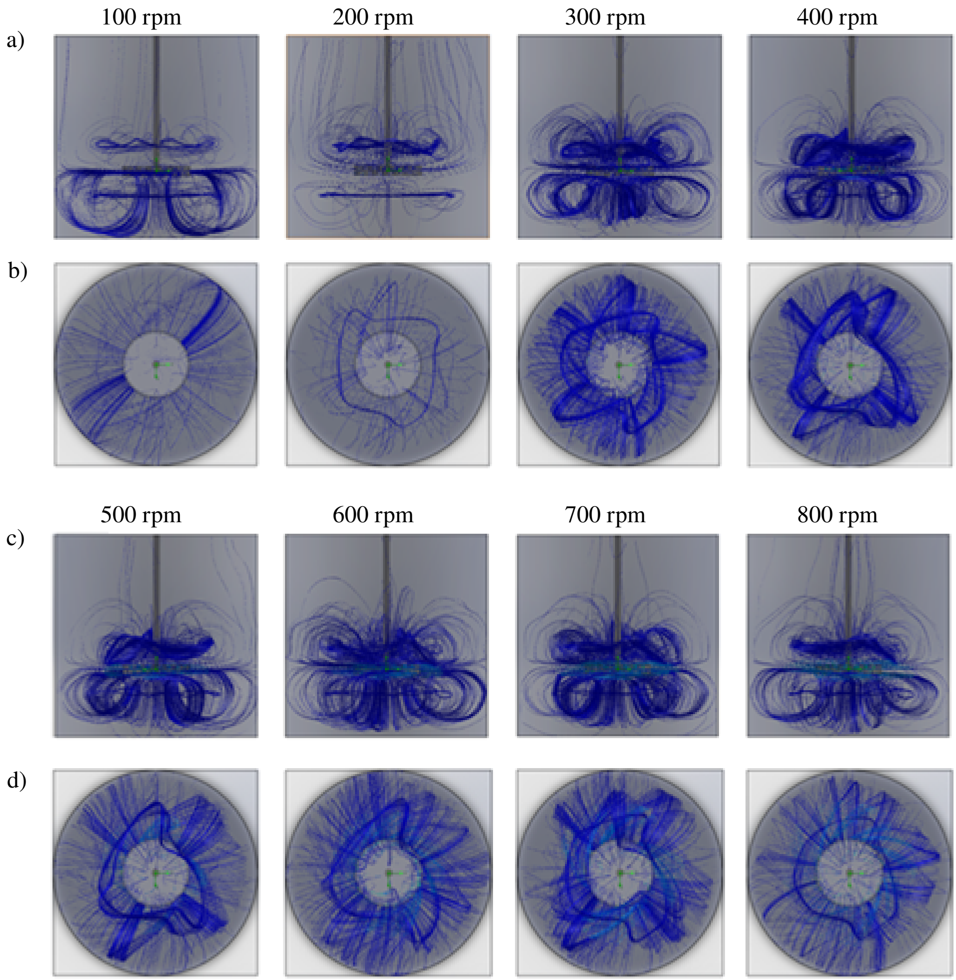


Fig. 10. Flow trajectories for dispersion type impeller: a, c) front view; b, d) top view

Table 3.

Results for different impeller diameter at 100 rpm for dispersion type impeller

	538 mm	588 mm	638 mm	688 mm
v [m/s]	2.817	3.079	3.341	3.602
v' [m/s]	2.794	3.056	3.319	3.565
T [Nm]	7.260	12.790	14.632	29.346
P [W]	76.027	133.939	153.226	307.311

impeller diameter and the height of the shaft (L) is 2D. The values are listed for 5 modes. As can be seen in the table, the values decrease with the increased impeller diameter, because mass values increase with the increased part dimensions.

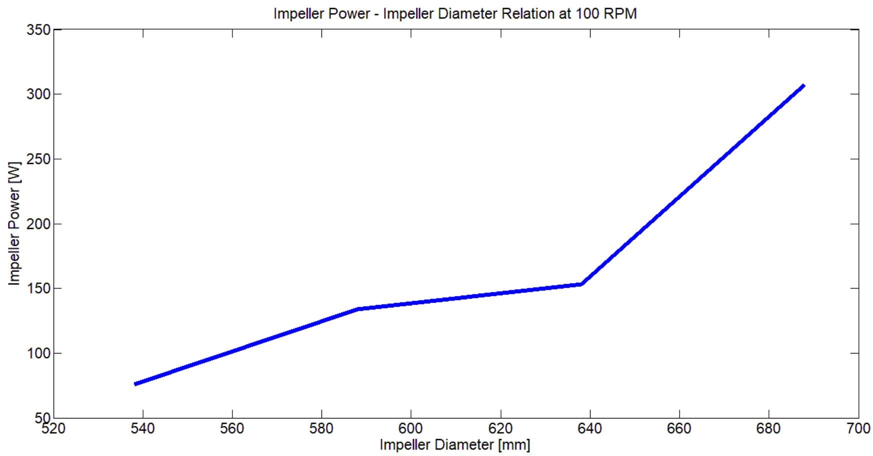


Fig. 11. Impeller power – impeller diameter relation for dispersion type impeller

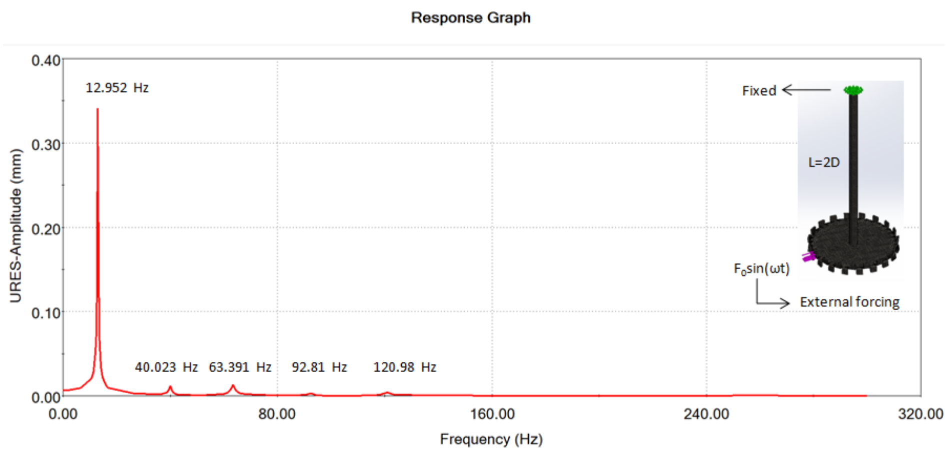


Fig. 12. Frequency response graph for 538 mm dispersion type impeller system

Table 4.
Frequency results for 5 modes and different impeller diameter for dispersion type impeller system

Mode No.	538 mm	588 mm	638 mm	688 mm
1	12.952	10.501	8.6543	7.2348
2	12.952	10.502	8.6551	7.235
3	40.023	32.299	26.527	22.08
4	63.388	52.45	43.665	37.272
5	63.391	52.481	43.751	37.315

3.2. Results of hydrofoil type impeller

The following results have been obtained for the 538 mm impeller diameter at different rpm values. Table 5 shows the results obtained from SolidWorks® Flow Simulation software. Fig. 13 shows the impeller power versus rotational speed relation and Fig. 14 represents the flow trajectories for different rpm values for the 538 mm impeller diameter.

Table 5.

Results for hydrofoil type impeller

	50 rpm	100 rpm	150 rpm	200 rpm	245 rpm
ω [rad/s]	5.236	10.472	15.708	20.944	25.656
v [m/s]	1.408	2.817	4.225	5.634	6.902
v' [m/s]	1.391	2.782	4.174	5.565	6.817
T [Nm]	1.521	1.625	1.964	2.325	2.750
P [W]	7.964	17.017	30.851	48.695	70.554

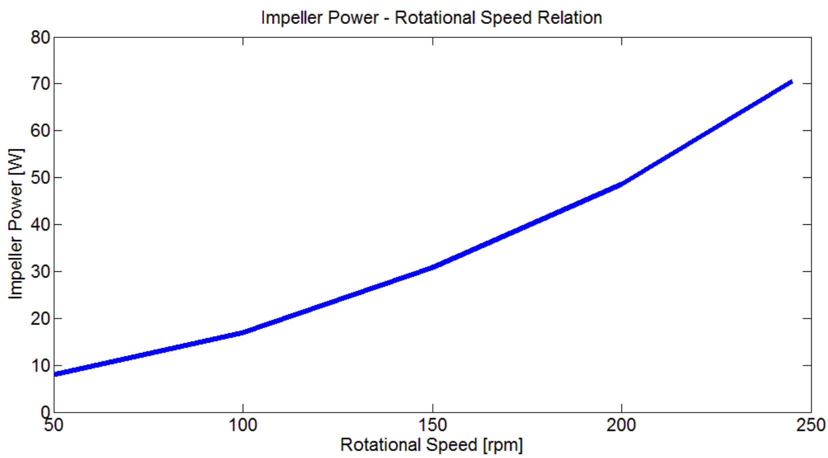


Fig. 13. Impeller power – rotational speed relation for hydrofoil type impeller

The following results have been obtained for different impeller diameter at 100 rpm. Table 6 shows the results obtained from SolidWorks® Simulation software. Fig. 15 shows the impeller power versus impeller diameter relation for hydrofoil type impeller. As expected, impeller power increased with the increased impeller diameter as seen in Fig. 15.

Table 7 shows the frequency values in Hz units for different impeller diameter and the height of the shaft (L) is 2D. The values are listed for 5 modes. As can be seen from the table, the values decrease with the increased impeller diameter, because mass values increase with the increased part dimensions.

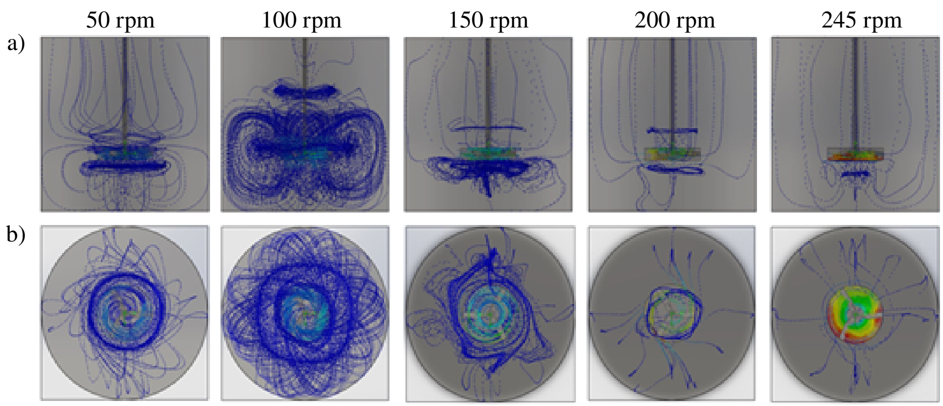


Fig. 14. Flow trajectories for hydrofoil type impeller: a) front view; b) top view

Table 6.

Results for different impeller diameter at 100 rpm for hydrofoil type impeller

	538 mm	588 mm	638 mm	688 mm
v [m/s]	2.817	3.079	3.341	3.602
v' [m/s]	2.782	3.044	3.306	3.567
T [Nm]	1.625	1.820	2.219	2.865
P [W]	17.017	19.059	23.237	30.002

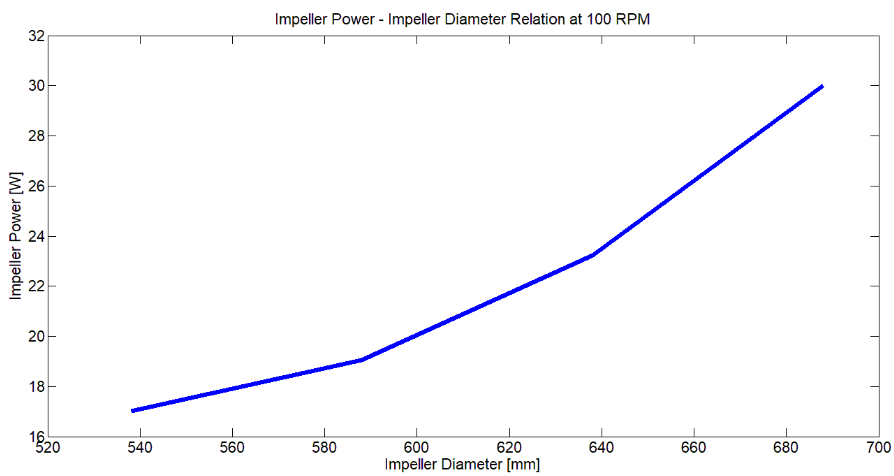


Fig. 15. Impeller power – impeller diameter relation for hydrofoil type impeller

Fig. 16 shows the response graph of hydrofoil type impeller for 538 mm impeller diameter. The natural frequency value of the system is 20.738 Hz. The peak value of the graph shows the natural frequency value. It is important to know the frequency values to avoid the resonance situation.

Table 7.
Frequency results for 5 modes and different impeller diameter for hydrofoil type impeller system

Mode No.	538 mm	588 mm	638 mm	688 mm
1	20.738	17.673	15.24	13.266
2	20.739	17.674	15.242	13.266
3	72.952	54.944	42.719	33.985
4	74.577	55.985	43.366	34.511
5	75.132	56.55	43.866	34.76

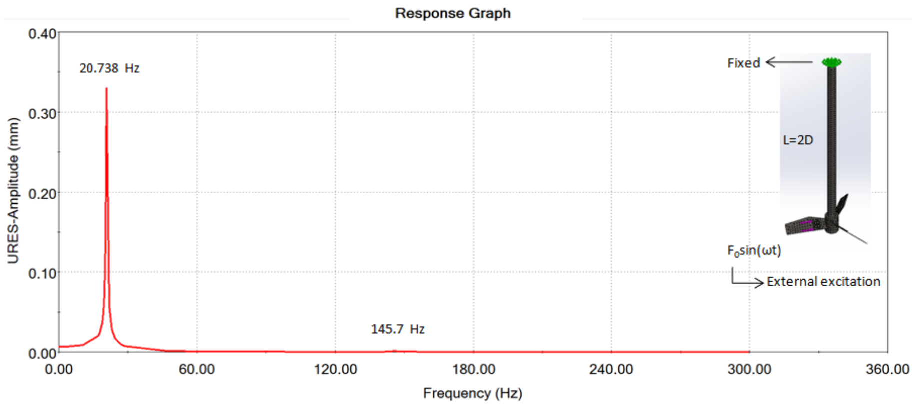


Fig. 16. Frequency response graph for 538 mm hydrofoil type impeller system

As can be seen in Fig. 17, the required impeller power increases with the increased rotational speed for both dispersion and hydrofoil type impellers. In Fig. 18, the required impeller power increases with the increased impeller diameter, as expected.

4. Conclusions

The study presents the parametric study, flow, and frequency analyses for the impellers. A parametric design interface is developed for hydrofoil and dispersion type impeller for the use of industrial applications, and the parametric design provides significant facilitation of the execution of this study in terms of time. So, designing impellers using the parametric design shortens the design phase and it is a remarkable technological novelty for mixing industries. Flow and frequency analyses are conducted, and we have obtained results significant for the industrial applications. Considering the flow trajectories figures (Fig. 10 and Fig. 14) together, one can see that the power values and the trajectories density show acceptable harmony. According to the dynamic analysis results, with the increased impeller diameter, the natural frequency values decrease. This situation can be considered in order to avoid resonance conditions. To show the

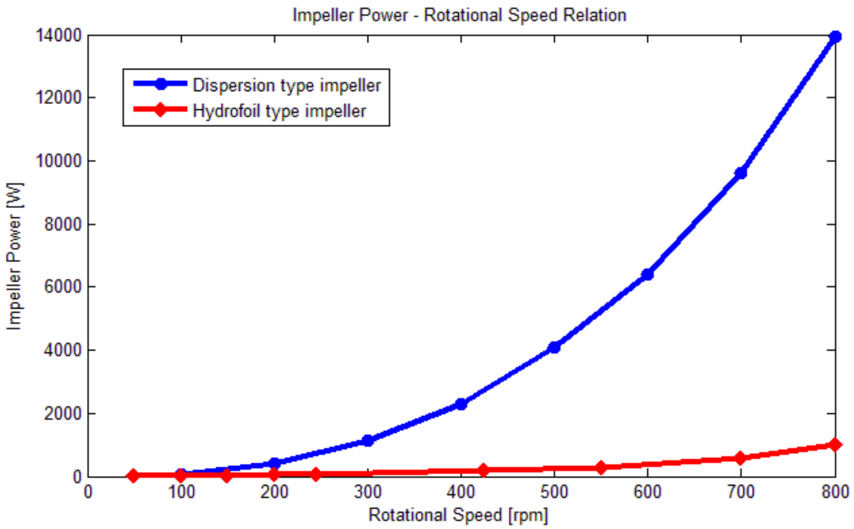


Fig. 17. Impeller power – rotational speed relation for dispersion and hydrofoil type impellers

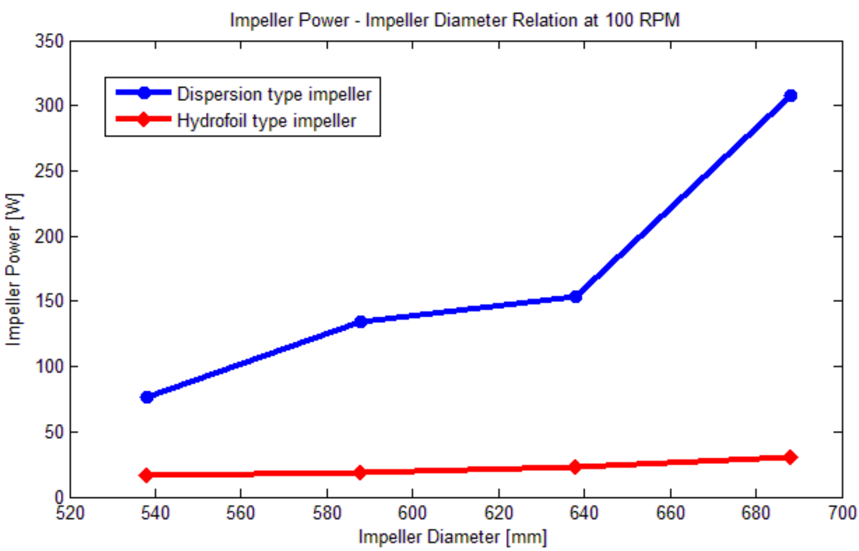


Fig. 18. Impeller power – impeller diameter relation for dispersion and hydrofoil type impellers

change in the impeller power values and the flow trajectories density which affect the mixing process, different impeller diameter and rotational speed are examined in the scope of this study. And, it is observed that the required impeller power increases with the increased impeller diameter and rotational speed for both impellers.

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