A Report on

"Visualization of Process Engineering Applications:

Granulation of cocoa powder"

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1. Introduction

1.1 Goals

Every process and apparatus in industrial engineering has a high level of technical complexity. Theoretical lectures, workshops, and laboratory work are given to students for academic purposes in order to help them understand the vast number of processes available in the industry. The goal of this project is to impart the knowledge through practical sessions. The time and energy needed to impart information through practical sessions become constrained as the number of students scales up on a yearly basis. An application-based approach would not only enable the Faculty of Process Systems Engineering to teach students about different processes but also to virtually visualize and experiment the process with different values, which is especially useful in time of such an ongoing pandemic. As team members, our responsibilities were based on the visualization process we selected, Granulation. At a suitable point, the app's objectives are as follows:

- Visualize the Granulation Process.
- View the designed process setup based on the real values.
- Scope for parameter manipulation.
- Describe the process in a short and crisp way.
- Explain the parts of the apparatus in detail.

1.2 Project Tasks and Plan

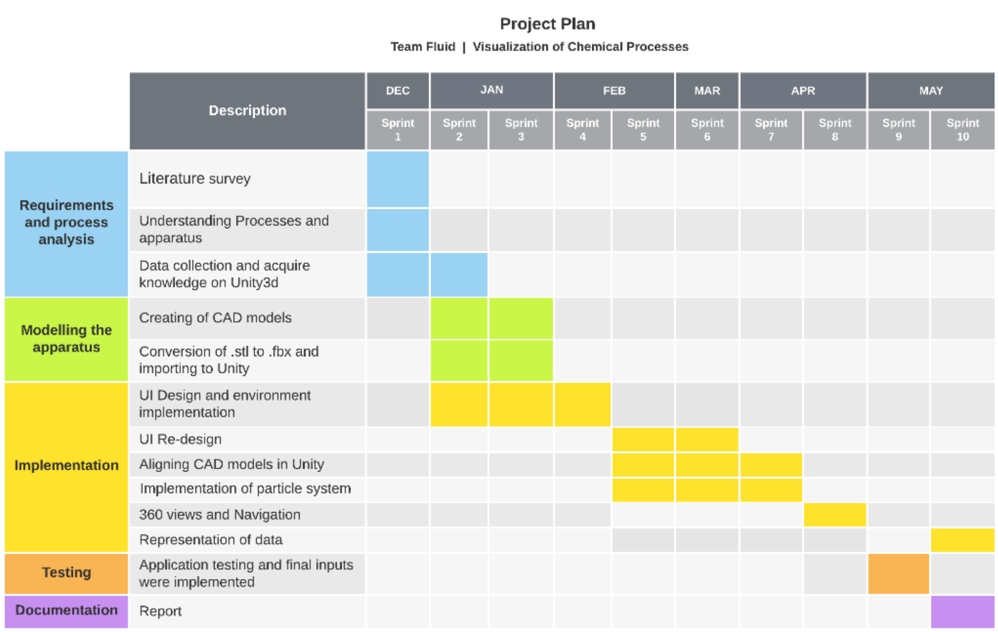

Figure 1 Project plan and overview

1.3 Project Outline

This project, essentially an application built universally for Windows and Android, emphasizes on the visualization or virtualization of Granulation of cocoa powder as realistically as possible. The visualization is reinforced by textual descriptions and graphical representations along with a very user-friendly and comfortable user interface. The project's main goal is to assist the user in visualizing this process while also providing in-depth information about the process' implementation, primarily focusing on front-end operations, in order to provide a positive learning experience.

1.4 Process Description

Granulation is an industrial process where fine particles are treated with liquid in order to form larger granules. Primary applications of the granulation include the manufacture of pharmaceutics and the production of cosmetics, chemicals, detergents, and fertilizers. Granulation helps in improving properties like flowability, compressibility, uniform product composition. In chemical applications, granulation is frequently used in production of raw ceramic mixes, formation of granules from various powders for domestic as well as industrial use, preparation of detergents and surfactant components [2].

Granulation goes hand in hand with agglomeration, where the atomized binder fluid is sprayed and deposited on the granules, usually a dry powder which mixes up with liquid binder. In the formation of granules, forces like surface tension, capillary forces, coalesce, and viscous dissipation are involved. The binder fluid allows the agglomerates to coalesce and to grow in size as shown in Fig 2, with the help of all the forces involved. Coalescence occurs when liquid bridge forms between the particles. These liquid bridges form solid bridges by crystallization and mechanical interlocking of particles within agglomerates [3][6].

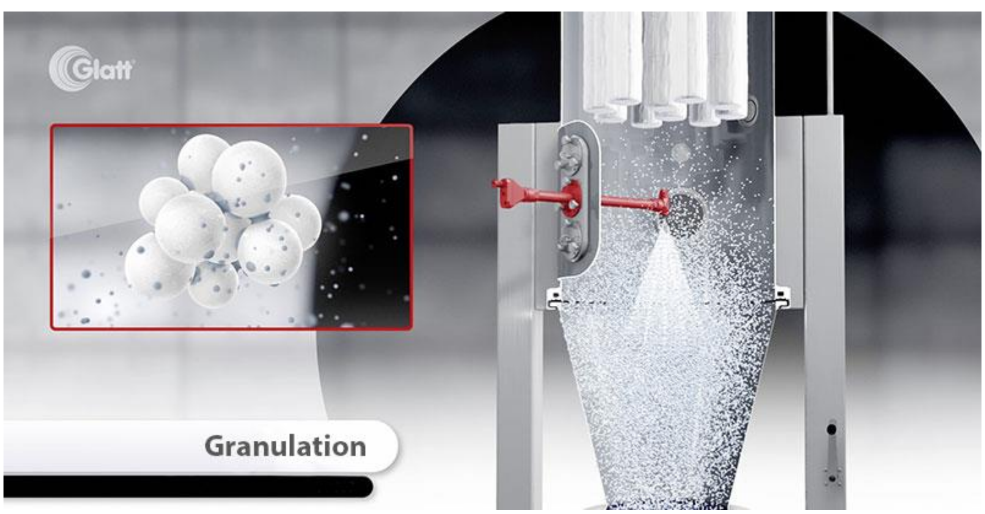

Figure 2 Visualization of Granulation [i]

1.5 Experimental Setup

Following are the most vital components in an experimental setup for granulation:

- Product chamber
- Filter assembly & charge inlet
- Process chamber
- Sieve plate
- Spray nozzle

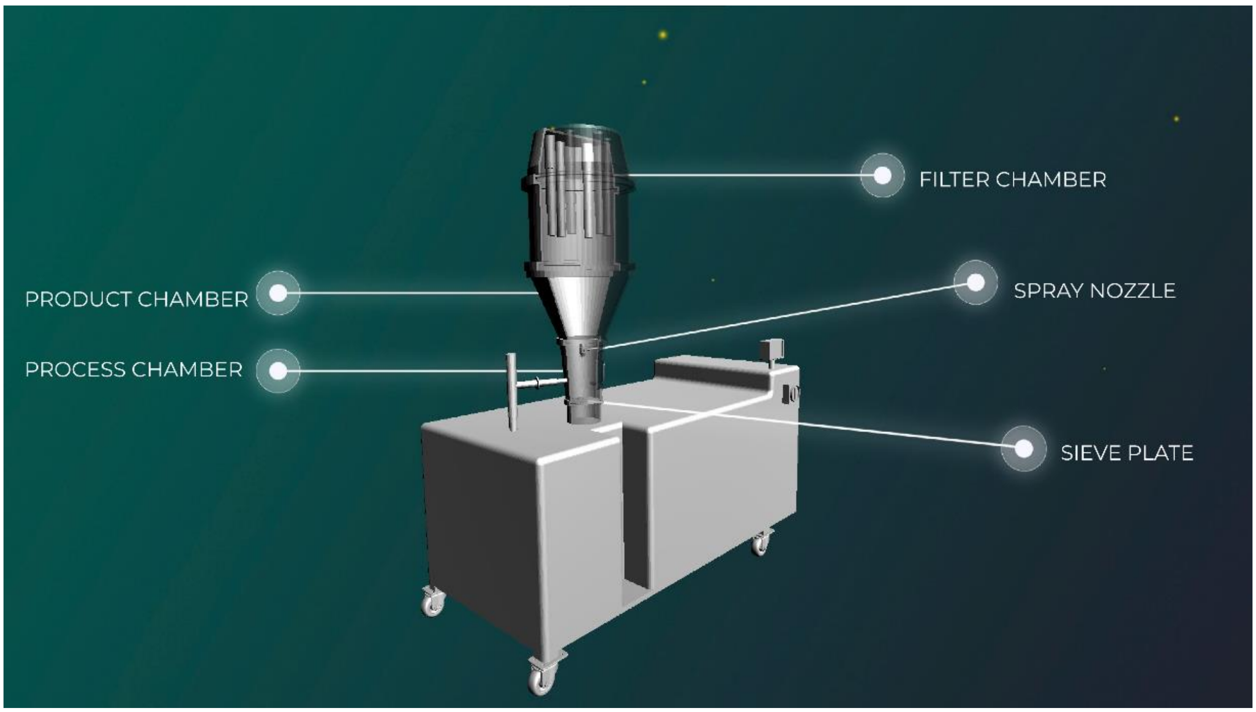

Figure 3 Apparatus Setup

Product chamber: It is a part of the granulator that feeds the actual product for granulation and connects the filter chamber to filter the extra air flown after the drying phase.

Exhaust filter: The cartridge filters in this chamber filters the excess airstream that is guided towards the granulated particles during the drying process. Typically, they are a textile-based filter.

Process chamber: The crucial aspect of the granulator, where the entire process is carried out. After the granulation process, the drying process is carried out to remove any residual moisture from the granulated cocoa powder.

Sieve filter: The unprocessed cocoa powder is collected on this tray, which is mounted at the bottom of the granulator. This filter consists of fine mesh that allows only air to flow through it.

Spray nozzle: It is a nozzle which is mounted in the process chamber at certain height for spraying the binder liquid into the air and cocoa powder stream. A top spray nozzle was used in this operation.

Air compressor: An air compressor is placed at the bottom of the process chamber and it has a hose to flow air into the chamber at certain flow-rate, which is also used for the drying process. However, this part is missing from Fig 3.

Process parameters:

- Mass of cocoa powder 1500 – 2000 g
- Product temperature 35 - 40˚C
- Spray rate of binding liquid 30 – 35 g/min (for 1000g of water)
- Spray pressure 0.8 – 1.2 bar
- Air flow rate 0.08 m^3/s

1.6 Empirical Values and Statistics

As discussed earlier, the main objective of this project is to visualize rate of granulation with respect to the air flow rate which will be varied.

Usually at optimal operating conditions the air flow rate is 0.08 m^3/s and in order to show the variation of granulation rate air flow rate will decreased to 0.04 m^3/s. As air flow is th3e main constraint that changes the output of the granulation process [1][8][9].

To determine the granulation rate, the values of the batch sizes are to be known.

Minimum batch size can be obtained by using the formula:

$S_{min} = V*0.4*BD*W_1*\text{spraying rate}$ [1][9]

$S_{min} = 12*0.4*0.7*200*0.5$

$S_{min} = 336$ g

Where,

V = Total volume capacity of the process chamber, (L)

BD = Bulk density (g/ml) which usually multiplied with spray rate (30 g/min),

W_1 = Sample weight (cocoa powder) (g)

Maximum batch size:

S_{max} = V*0.8*BD*W_1*spraying rate

S_{max} = 12*0.8*0.7*200*0.5

S_{max} = 672 g

As process includes drying as well, the Loss of Drying (LOD) has to be calculated.

Loss of Drying is given by:

LOD = $\frac{\text{weight of sample} - \text{weight of the sample after drying}}{\text{weight of sample}} * 100$ [10]

Weight of the sample after drying W_2 is given by:

W_2 = Spray quantity*0.4*BD

W_2 = 333*0.4*0.7

W_2 = 93.24 g

LOD = ((333 – 93.24) /333) * 100

LOD = 72 g

Granulation rate can be calculated by using the formula:

Granulation rate[1] = W* BD* t*Spraying rate* airflow rate

= 432*0.7*10*0.5*2.4

= 3628.8 g/min

Granulation rate[2] = S_{mean} *BD *t* Spraying rate* airflow rate in min

= 432*0.7*10*0.5*4.8

= 7257.6 g/min

Where,

W = final weight of the sample (S_{mean} - LOD).

Granulation rate calculated here gives the rate of granulation for assumed quantity used for the GPCG 5 (mini-Glatt) 10-12kg.

Table 1

Batch size g	Air flow rate	LOD g	Granulation rate g/min	Bulk density g/ml	Sample weight g	Volume l
336	0.04	72	3628.8	0.7	200	0.5
672	0.08	72	7257.6	0.7	200	0.5

The difference of the granulation rate with respect to the air flow rate can be seen in the above calculations; the granulation rate was approximately half that of the ideal air flow rate for the low air flow rate.

The granulation rate increases as the air flow rate increases, but the granules produced have very low solubility properties and an inadequate particle size distribution, so industrial processes prefer the optimum air flow rate [7][9].

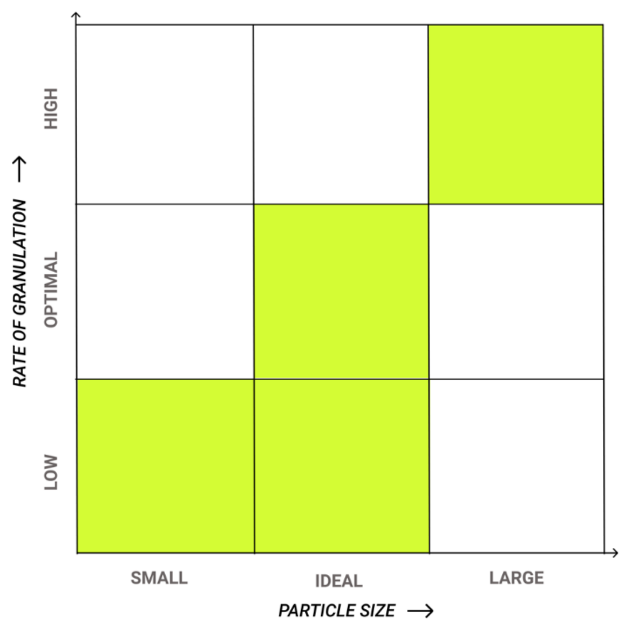

Figure 4 Comparison of rate of granulation against particle size as visualized

Fig 4 indicates the following:

- At high rate of granulation, the particle size is shown as high, formed due to improper granulation
- At optimal levels, the particle sizes are shown to be ideal
- Due to low air flow, the particles are unevenly formed, which consist of different sizes.

2. User Documentation

The general specifications, guidance, and use of the application on the Windows and Android platforms are covered in this section. This segment assists the user in navigating the application and comprehending the scene as well as the detailed overview.

2.1 Required Device Specifications

Table 1: Minimum system requirements:

The application is built on Unity for both Android and Windows considering the majority and ease of access from the users' perspective, the minimum specs required are mentioned below.

Desktop/PC	Android
• Windows 7 [x32]. • 4 Gigabytes of RAM. • Intel i3 or equivalent processor. • Intel HD Graphics or equivalent.	• Android 4.1 • 2 Gigabytes of RAM • Snapdragon 630

Table2 : Ideal system requirements:

The Recommended specifications however vary as to ensure best performance.

Desktop/PC	Android
• Windows 10 [x64]. • 8 Gigabytes of RAM. • Intel i5 or equivalent processor. • Graphic card equivalent of 2GB and above.	• Android 10 • 6 Gigabytes of RAM • Snapdragon 855 • 6.1" screen

Graphic settings have been included that can be changed to get fair performance even on low-end devices.

2.2 Installation and Configuration

- **Windows**: A compressed file is meant to be downloaded and extracted to the location of choice. The application file, *.exe*, will be available which can be used to run the app.

- **Android**: A *.apk* file is meant to be downloaded and installed on the smartphone, by enabling "installing from unknown sources". The application would be available in the Google play store or GitHub eventually.

2.3 Scene Description

Once the user runs the application, they are treated with a series of splash screens.

Figure 5 Splash Screen

2.3.1 Landing Page

On the landing page, as shown in Fig 6 the user can choose to go to multiple options which are the process page, the view page, the process description page, the settings page and the about page or choose to exit the application.

Figure 6 Landing Page

2.3.2 Process Page

The user will be directed towards a lab environment, as shown in Fig. 7, where on clicking start, will be directed to the page where the process is visualized, as shown in Fig. 8.

Figure 7 Lab Environment

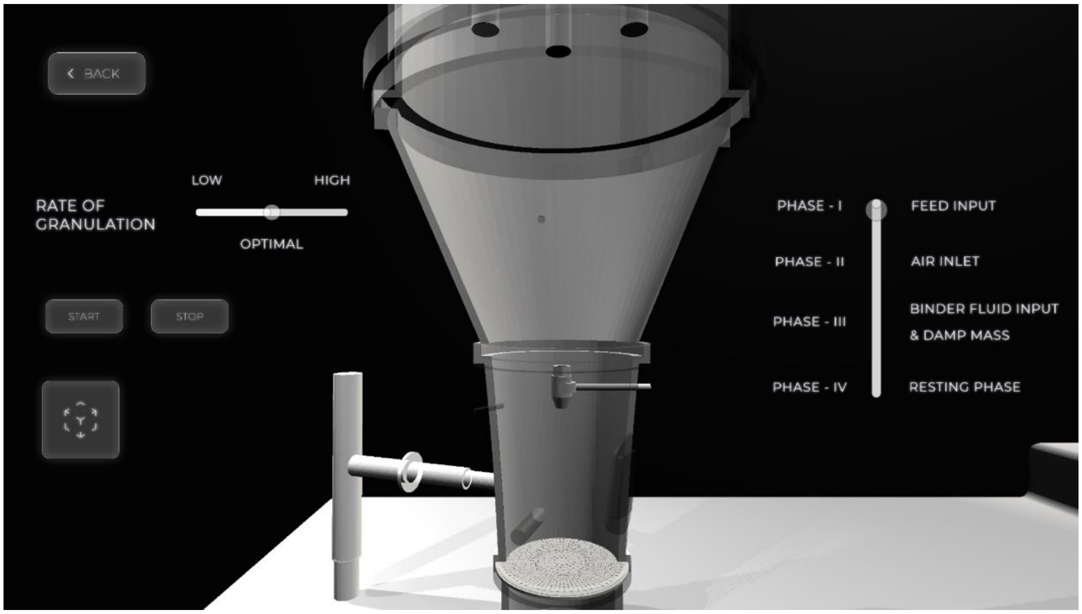

Figure 8 Process Page

2.3.3 View Page

From the view page, Fig. 9, the user can access the crucial parts of the apparatus, where the user can not only get a description of the said part, but also interact with the 3D part, to have a 360˚ view, as shown in Fig. 10. A button has been included to navigate to the process directly.

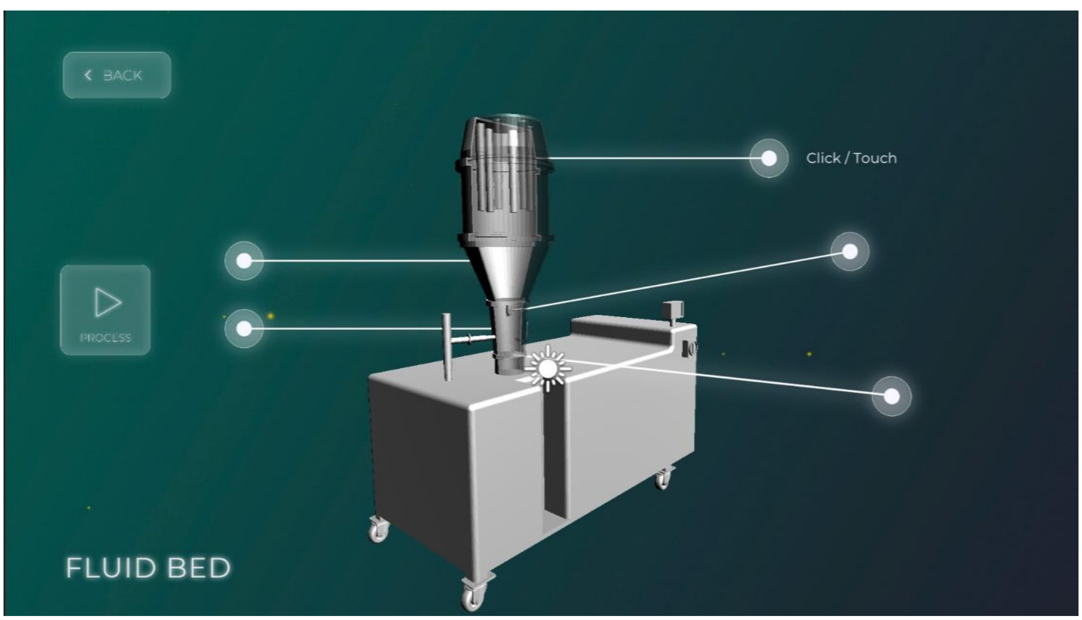

Figure 9 View Page

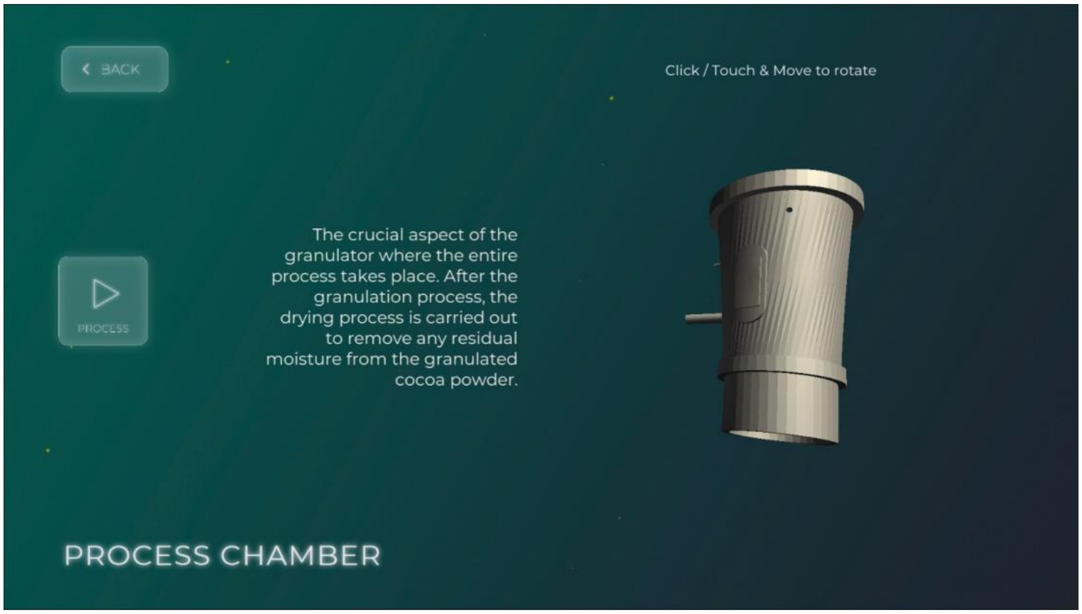

Figure 10 Sample part view and description

2.3.4 Process Description Page

In the process description page, as shown in Fig. 11, as the name suggests, information about the granulation process is shown, along with process parameters.

Figure 11 Process description page

2.3.5 Settings Page

In, Fig. 12 , the settings page, the user can adjust the graphic quality as per requirement. Also, the user can switch between a full screen view or a minimized view.

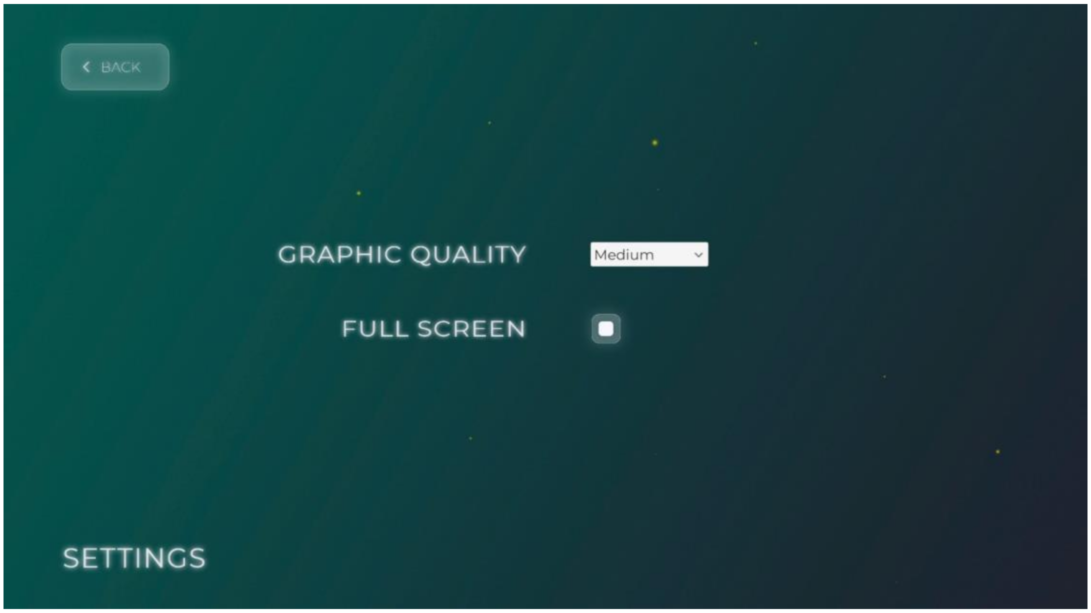

Figure 12 Settings page

2.3.6 About

On the about page, as shown in Fig. 13, the user has access to the team and application information.

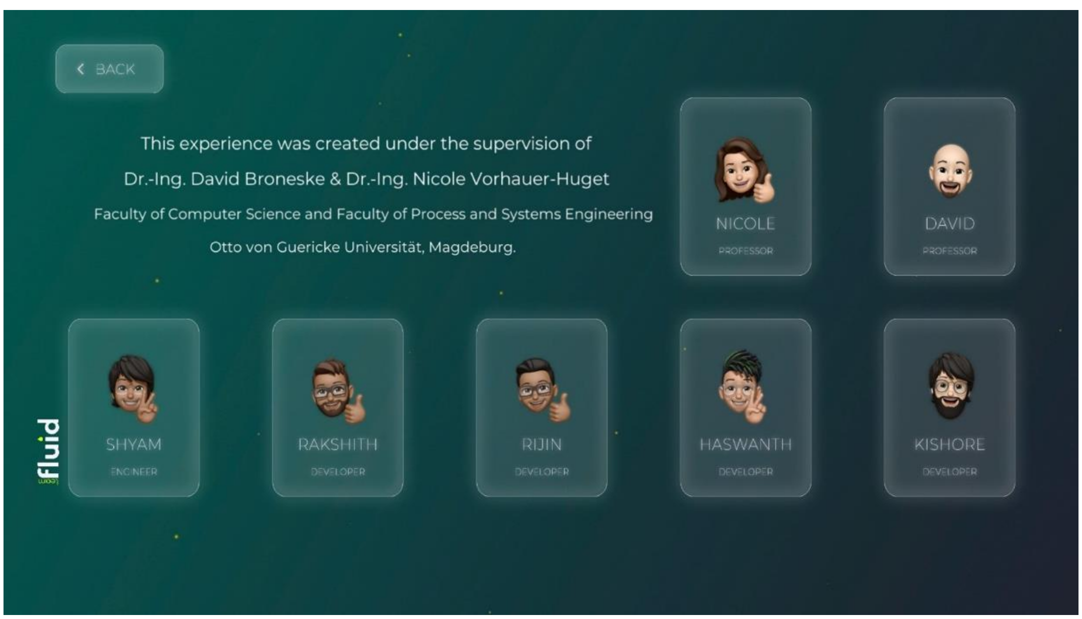

Figure 13 Info page

2.3.7 Exit

Exit screen is a pop-up window, as shown in Fig. 14, which lets the user confirm before quitting the application.

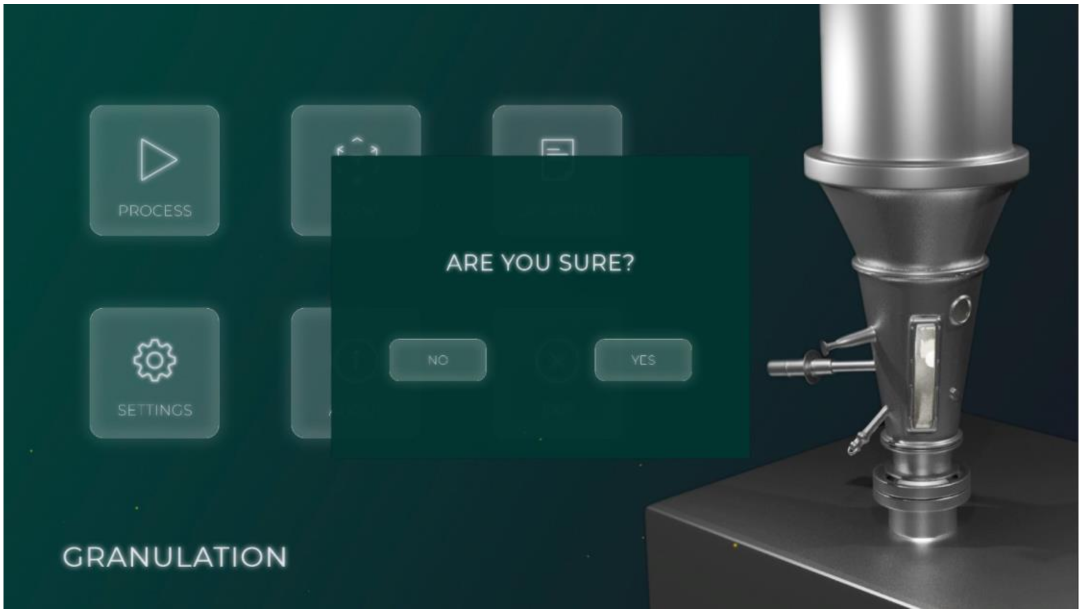

Figure 14 Quit application pop-up

2.4 Process Page Navigation and Interaction

2.4.1 Rate of granulation slider

The user has to initially set the rate of granulation by moving the slider, in Fig. 15, to appropriate position.

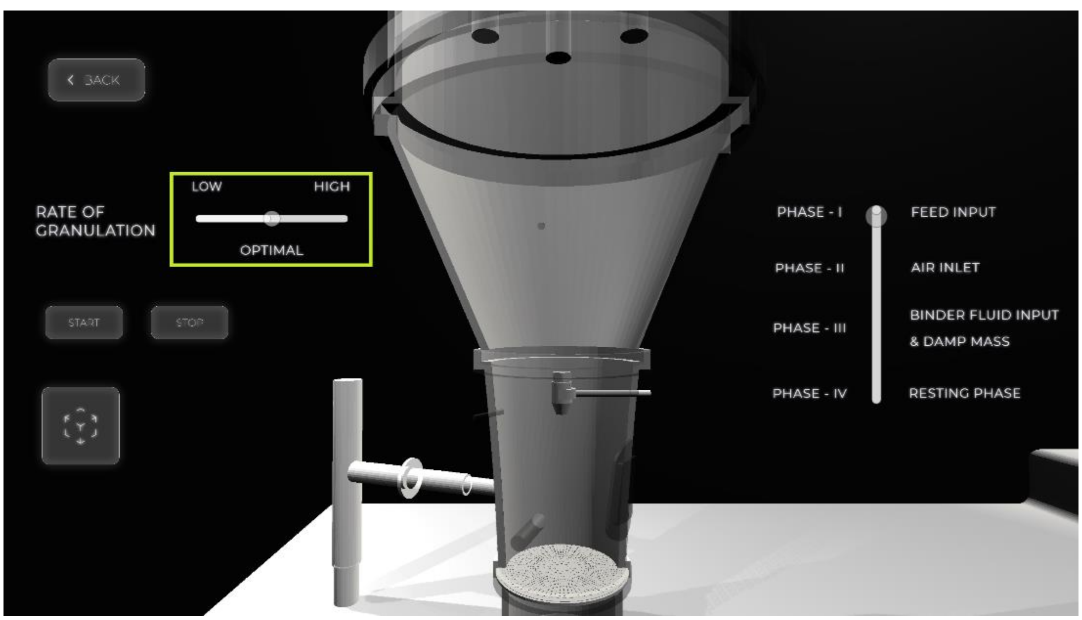

Figure 15 Rate of granulation slider

2.4.2 Start, stop and pause/resume buttons

- In Fig 16(a), the start button is used to begin the visualization of granulation, it is inactive once clicked until the stop button is clicked or until the process is completed.
- In Fig 16(b) the pause/resume button is used to freeze the scene which in-turn pauses the process and resume it. The resume button is activated once the pause button is clicked upon.
- In Fig 16(c), the stop button is used to reset the entire scene, which also resets the user input in the rate of granulation slider.

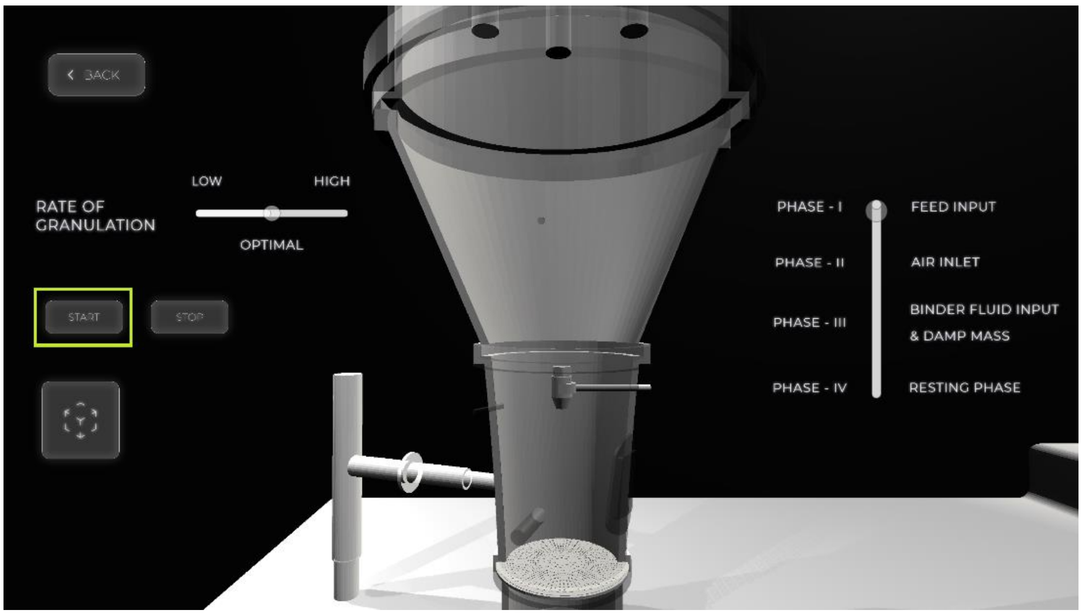

Figure 16(a) Start button

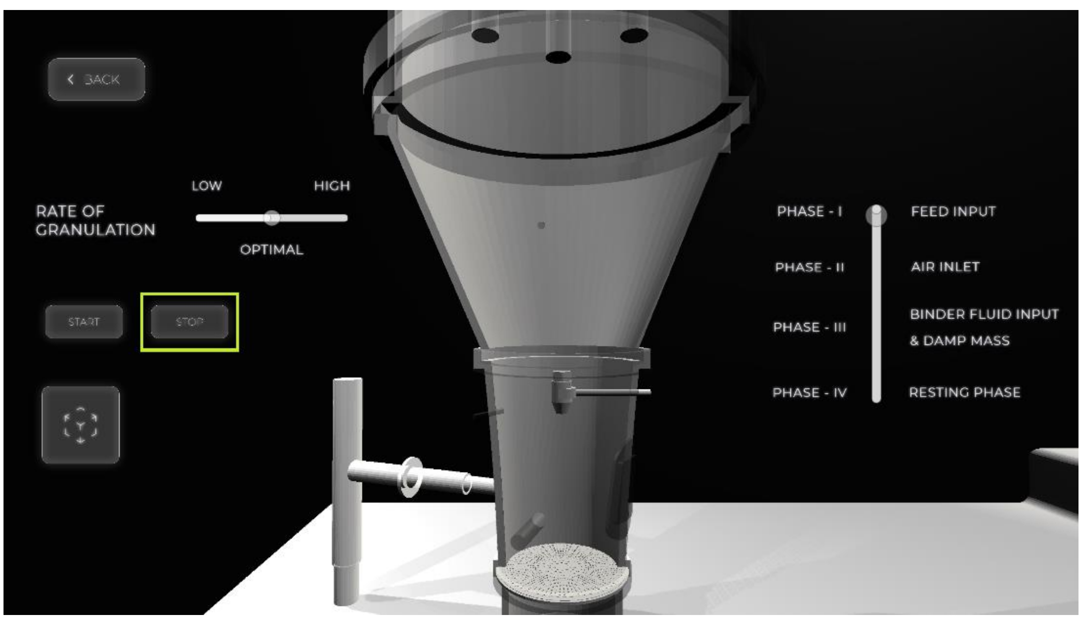

Figure 16(b) Stop button

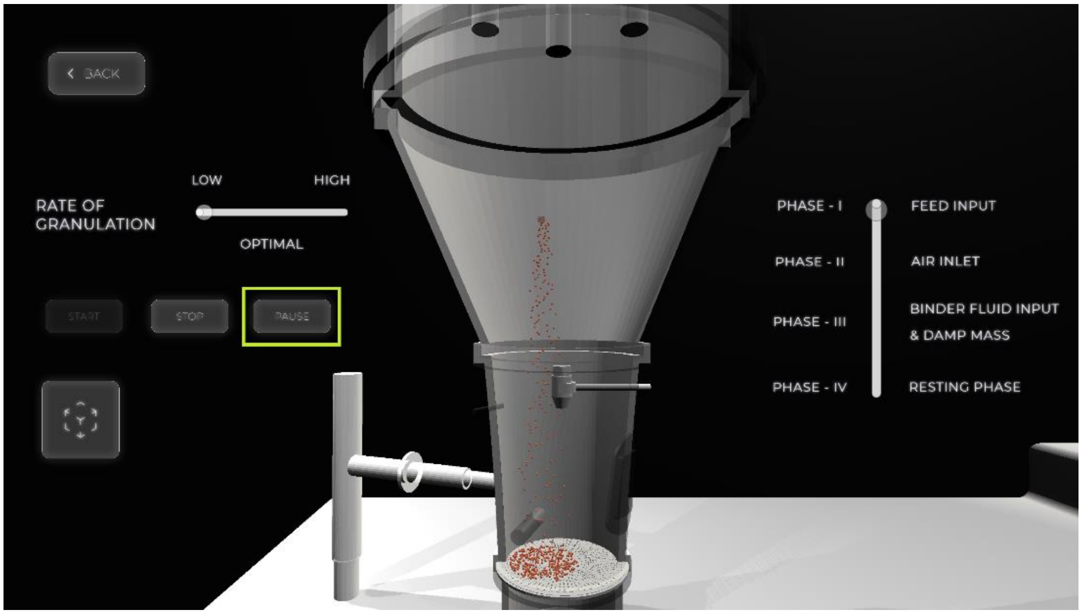

Figure 16(c) Pause/ Resume button

2.4.3 Phases

Fig. 17 shows the progress of the granulation is shown in terms of phases and a slider movement.

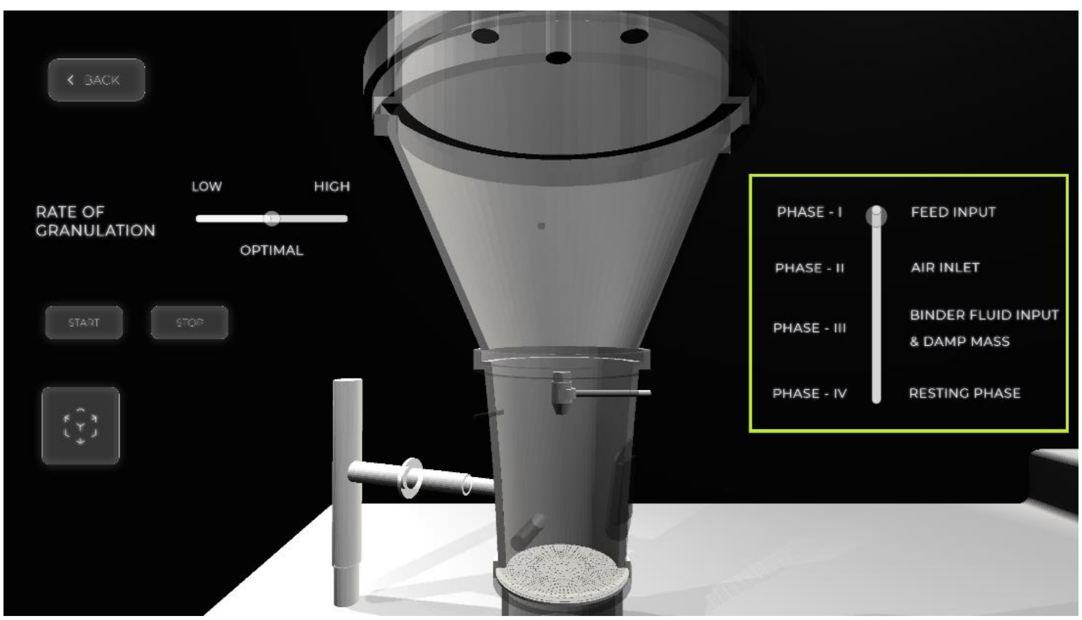

Figure 17 Phase indicator panel

2.4.4 View Button

The view page, shown in Fig. 18 is linked with the process page so that the user can access the view page directly without navigating back to the home page.

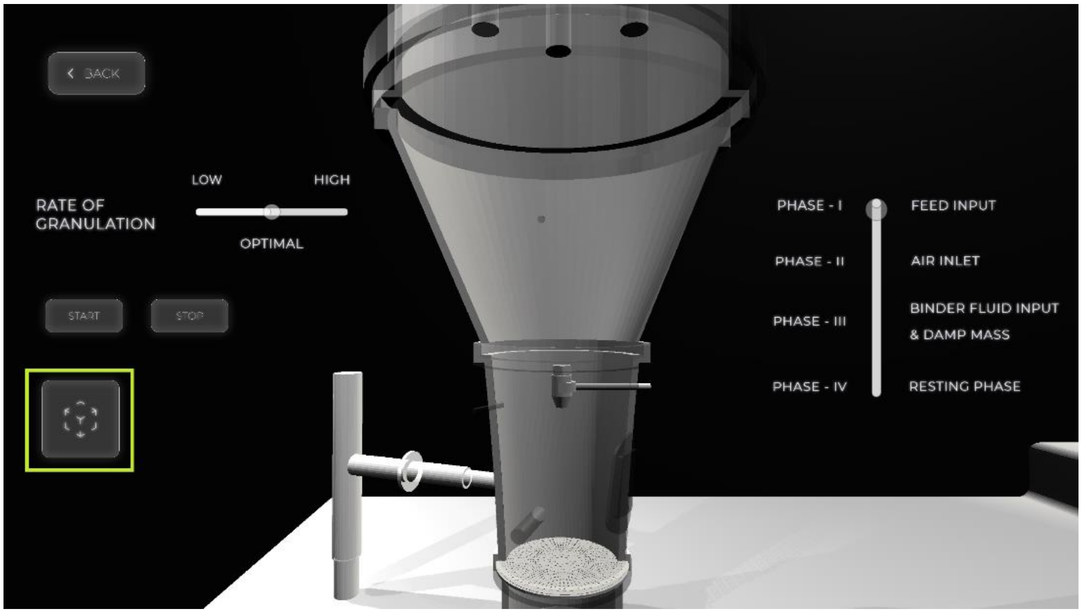

Figure 18 View button in process page

2.4.5 Back Button

User can navigate back to the home page, as shown in Fig. 19. This button is common in all the pages.

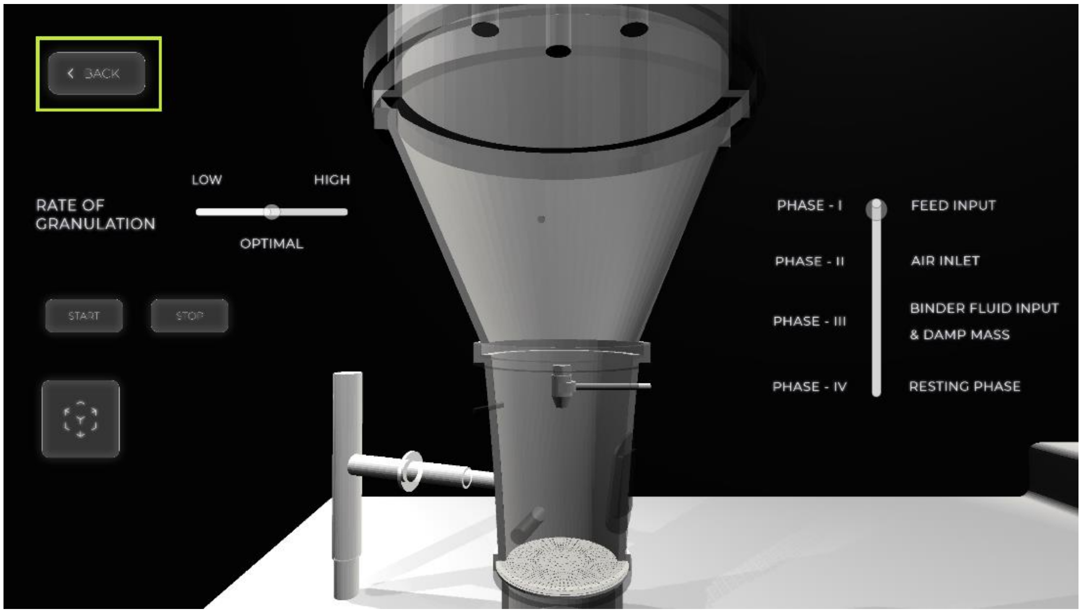

Figure 19 Back to home page button

2.5 Phase Description

Following are the phases visualized in the project, which have been shown along with a movement of a slider to indicate progress.

2.5.1 Phase I - Feed input:

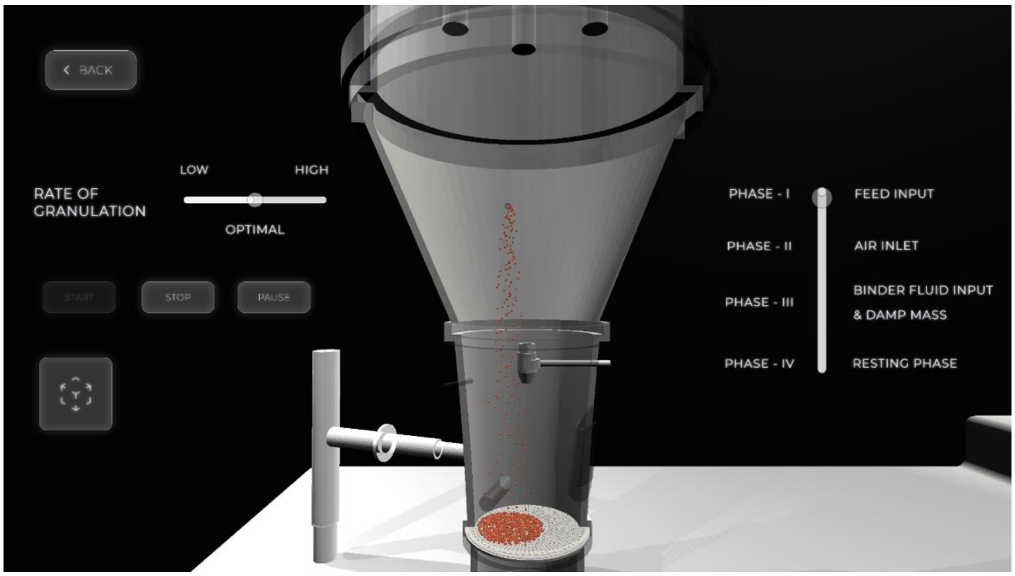

Figure 170 Phase I of granulation

According to Glatt, an optimal quantity for the testing in an industrial chemical process is 0.5L, as the appropriate quantity of charge, for testing is fed into the product chamber, this is visualized in Fig. 20 .

2.5.2 Phase II - Air inlet:

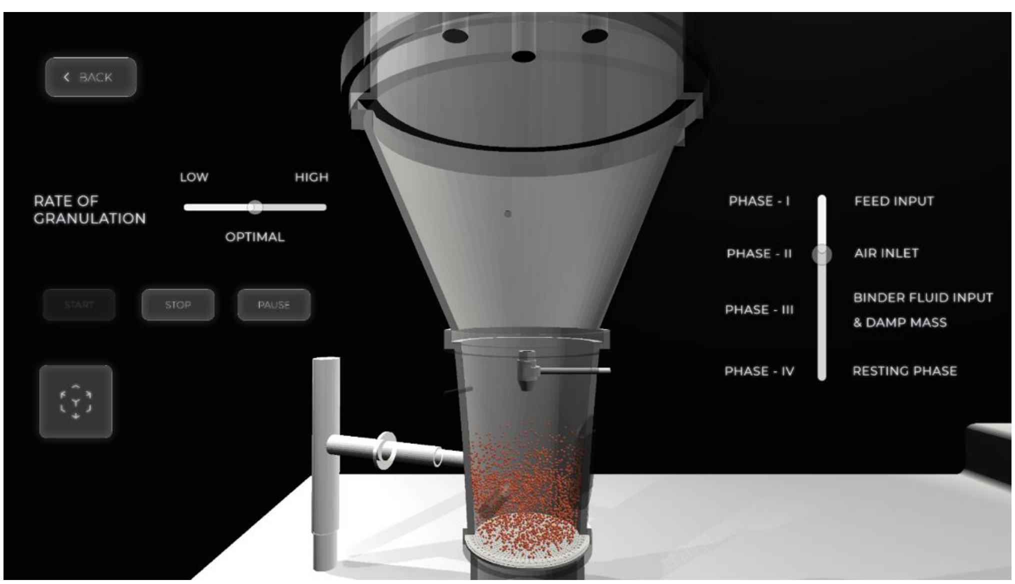

Figure 21 Phase II of granulation

After the cocoa powder is fed into the process chamber, few seconds are given to ensure the cocoa powder settles down. Then, a constant air steam is supplied from the air compressor as shown in Fig.21.

2.5.3 Phase III - Binder fluid input:

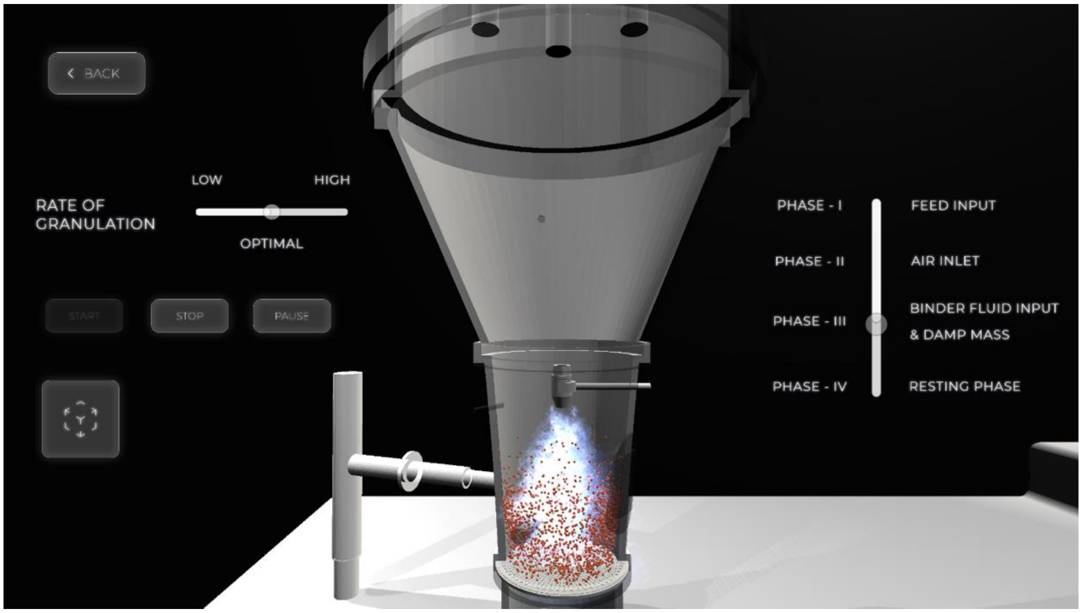

Figure 22(a) Phase III of granulation

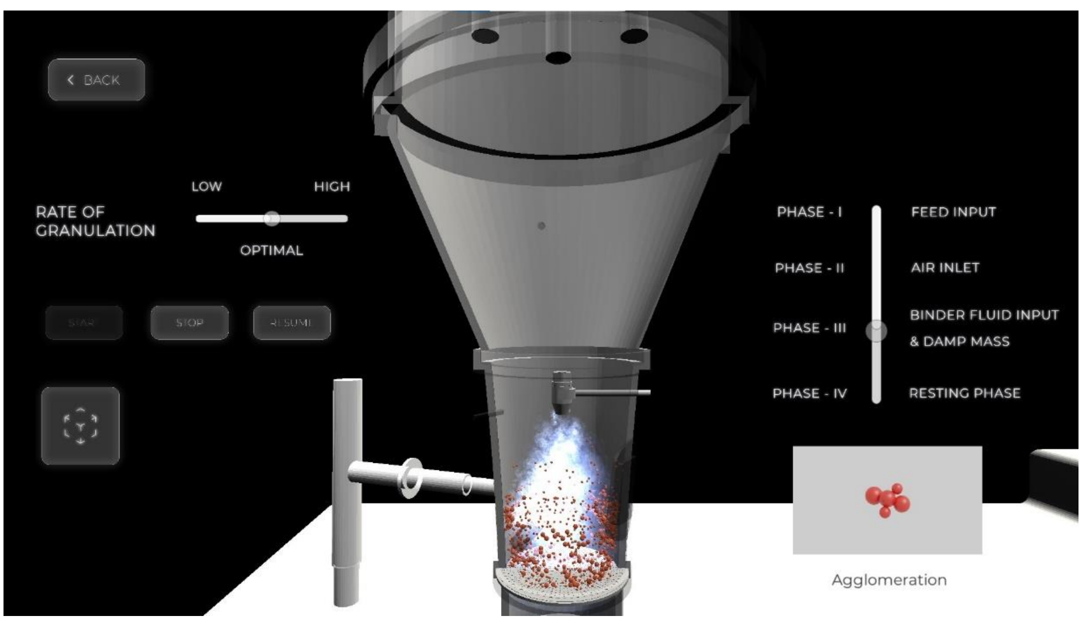

Figure 22(b) Phase III of granulation with particle animation

Here in this phase, next to the air inlet, Fig. 22(a) shows binder fluid being sprayed into the stream of the air and cocoa powder, at a rate of 30 – 35g/min by the means of a top spray nozzle. At initial state, binder fluid sticks on to the powder particles and forms solid bridges which form agglomerates. Following this process, with the aid of kinetics, capillary forces, coalesce and viscous dissipation, agglomerates are formed into fine granules which is known as granulation, shown in Fig. 22(b).

2.5.4 Phase IV - Resting Phase:

Figure 23 Phase IV of granulation

Fig. 23 shows that when the binder fluid phase is completed, the particles are again given few seconds with the airflow still functional. This allows the wet particles to dry up. Temperature is maintained constant in this phase for this visualization, after which the particles are allowed to settle down.

2.6 Parameter Manipulation

In this process the parameters like spraying rate and mass of the charge input are kept constant. In our visualization, the parameter that varies is air flow rate, which indicates the change in rate of granulation from low-optimal-high. With the high air flow rate, the agglomerates are formed with low coalesce and poor mechanical interlocking. The binder fluid which was sprayed in this case gives 40% more weight to the air stream of cocoa powder. So, we can clearly observe that the granule particles are formed with damp masses when the process was run in high air flow rate.

In other case, if the air flow rate is optimal, the agglomerates are formed with perfect liquid bridges and layered together with the good coalesce and maintain strong mechanical interlocking. And the granules formed here are of desired size. In vice-versa if we decrease air flow rate more than required, the granules formed in this case will be inappropriate size even though granulation rate is low. The granules formed in this case have poor solubility properties which is a main property for the cocoa powder [4][5][6][7].

3. Developer Documentation

3.1 Tool Suite

- **Unity and Visual Studio**: The application was built using Unity version 2020.2.1F and 3D project package. C# scripting was done using Microsoft Visual Studio 2019.
- **SolidWorks**: Solid works was used to design the parts of the apparatus, and then have been imported to Blender as an .stl file.
- **Blender**: Blender 2.91 was used to export the designed .stl files of the entire apparatus into .fbx format which is the native format used in Unity3D.
- **Adobe XD**: We have designed the user interface in Adobe XD, which includes textual content, navigation buttons and the background.
- **Cloud Share**: We have used both Google Drive and One drive to create, store and edit documentation and files among ourselves.

3.2 Class Hierarchy

Unity is made up of scenes, each of which contains items known as Game Objects. Textures and materials are used in Game Objects for rendering purposes. The scene's lighting and camera settings are used to generate the rendering. Throughout the game, scripts describe and govern the actions of the game objects. Every script in Unity that needs to be part of a game object should be derived from the *MonoBehaviour* class.

The Entity Component System (ECS) pattern underpins Unity. An entity is an object, a component is data, and a system is the part that performs global actions on the object. This design was used in part in conjunction with the Decorator and Singleton patterns. Since this pattern is generally best suited to game creation when a number of instances are generated for each class, its adoption was not completely possible.

The things to be rendered were partitioned into entities. The entities in this project consist of mainly UI and Particle Systems. Since the visualization mostly consists of particles, in the form of granulates and agglomerates, Unity's built-in particle system with multiple manipulations in the inspector window was used to visualize these animations. A base class was created for each entity along with a manager to control. Although being derived from the *MonoBehaviour* class, there are a few components that are not grouped into entities and are separate criteria that are not governed by managers. When creating a class from a base class, the Decorator pattern is used. Following the Singleton pattern, the manager for each of the entities would be of one instance only.

3.3 Application Flow

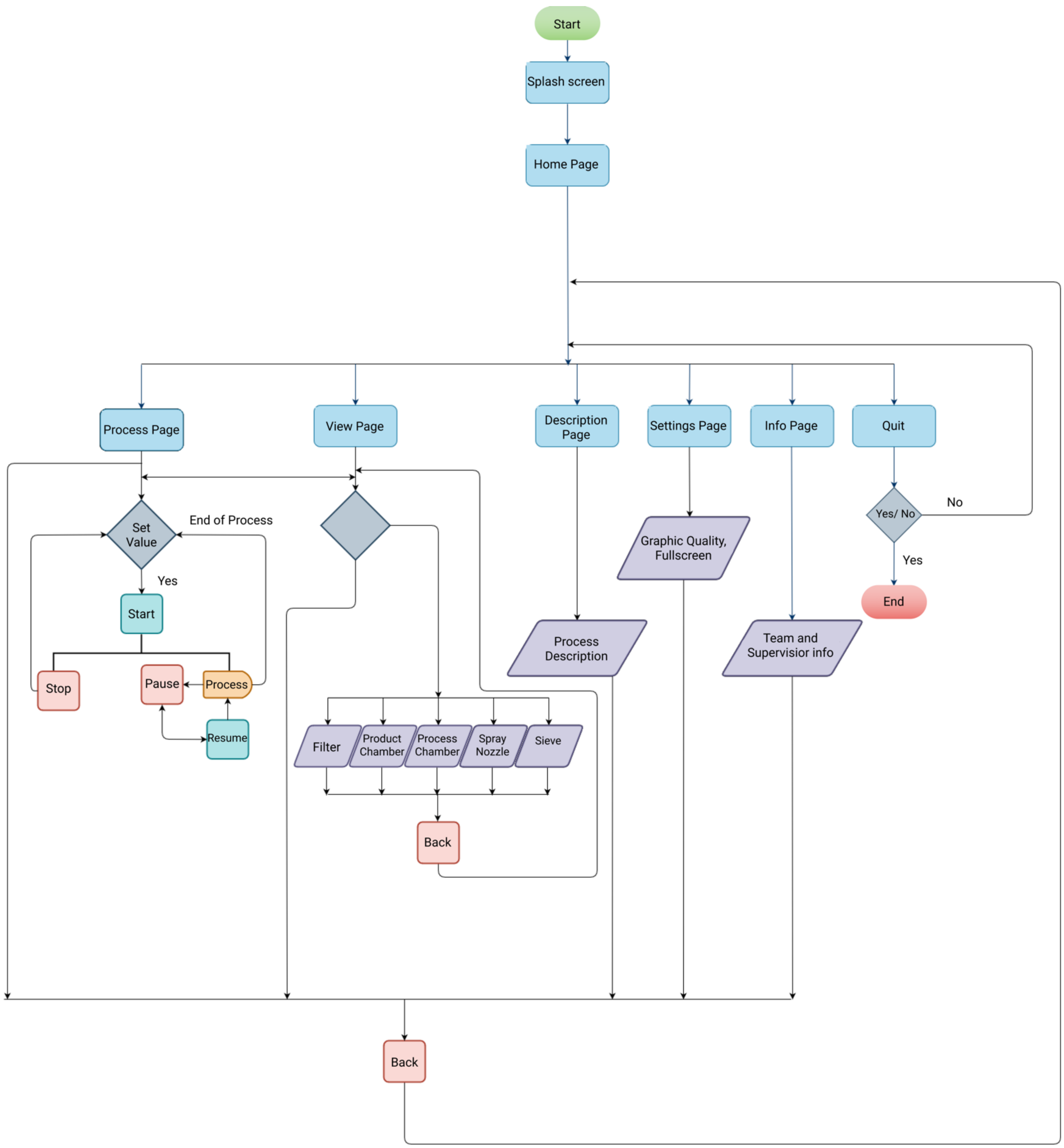

Figure 24 Activity diagram of the application

4. Conclusion and Future Scope

4.1 Summary and Conclusion

The project involved development of an application for the visualizing of a chemical process, which was decided to be Granulation. An extensive development plan was implemented right from the beginning of the project. During the requirement phase, considerable time was spent on brain storming ideas with inputs from the members of Faculty of Process Engineering, and essential and necessary requirements of the application have been charted out. Which in turn have been used as milestones in developing the application.

Unity development suite was used because of the versatile physics engine, which was advantageous in implementing all the necessary requirements for the process granulation. It was also very flexible for importing a custom user interface, which in-turn resulted in segue and professional navigation. A gratifying output was achieved which involved an application for both android and Windows, with most of the previously discussed essential and necessary features. The objective of the project was fulfilled with the apparatus and lab environment set up along with the view pages, giving the user an experience as realistic as possible.

4.2 Future Scope

There is never an end to an idea, which holds true for this project as well. Following, are some of the many possible further developments in this project:

- Possibility of phase interaction while the execution of the process.
- Manipulation of attributes and dynamic graphs.
- Visualization of extended processes like agglomeration.
- Interaction within the lab environment.

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Videos

[I] Getting started with the Particle System | Unite Now 2020: https://youtu.be/hyBbcFCvDR8

[II] C # Translate and Rotate in Unity! - Beginner scripting tutorial: https://www.youtube.com/watch?v=32JkMANaMpk

[III] START MENU in Unity |Brakeys: https://www.youtube.com/watch?v=zc8ac_qUXQY&ab_channel=BrackeysUnityVerified