VIRTUAL REALITY-BASED TRAINING SYSTEM FOR COMPLEX ENGINEERING PROCESSES ON THE EXAMPLE OF A FRACTIONATING COLUMN

Nicol Mencke[1], Markus Vondran[1], Nicole Vorhauer[2], Evangelos Tsotsas[2]

[1]Fraunhofer Institute for Factory Operation and Automation IFF Magdeburg (GERMANY)
[2]Otto von Guericke University Magdeburg (GERMANY)

Abstract

The knowledge transfer of complex processes in the context of higher education is a constant challenge. The structural construction and the inherent processes reach a complexity that cannot be adequately communicated to the targeted audience with purely textual but also two- or three-dimensional representations. By immersion, interaction and imagination [1], Virtual Reality (VR) technologies can go beyond traditional learning media and result in significant academic achievements ([2], [3]).

By using a realistic, three-dimensional interactive model in virtual space, a VR-based training system was developed and enriched with specific features and functions to such an extent that it serves as a supplement to the classical teaching material to learn about a fractionating column.

Keywords: Virtual Reality, training system, process engineering, fractionating column

1 INTRODUCTION

There is a large number of technical systems in process engineering, which are complex in application and which can benefit significantly from a VR-based knowledge transfer. An example of this is the fractionating column. This is a process-engineering apparatus that enables various liquids to be separated almost completely thermally from each other [4] - for example, for crude oil distillation and ethanol production.

Within the framework of a cooperation between the Fraunhofer IFF Magdeburg and the Otto-von-Guericke-University, such a VR-based training system was developed and enriched with specific features and functions to such an extent that it serves as a supplement to the classical teaching material [5]. In the first phase of realisation, the various necessary models were defined. The static and dynamic model form the basis of the visual representation of the technical content – the virtual representation of the real objects and the embedding of the relevant processes over time. These subject-specific basics are integrated into the VR training system. Taking into account a didactic model, the three-dimensionally modelled components and the integrated functions, it is possible to give each learner the opportunity to interact independently and to progress individually taking into account the didactic model. By this, individual preferences in terms of learning speed and content are taken into account.

2 FUNDAMENTALS

This section provides fundamental information about complex engineering process, the fractionating column and Virtual Reality that is necessary to understand the remainder of this paper.

2.1 Complex engineering processes

The engineering training in process engineering puts - at an early stage of training - great emphasis on the ability to understand complex manufacturing processes of technical products. This involves a fundamental understanding of the underlying devices that are used for the large-scale implementation of these manufacturing processes in the industry. In addition to countless individual solutions, which are used for a special technical application, there are numerous apparatuses that can be used in a comprehensive process. An example of this are apparatuses for the classical thermodynamically controlled separation processes absorption, extraction and distillation including rectification (e.g. [6], [7], [8], [9], [10]), which, due to their importance are a major focus in the study of a process engineer.

One of these plants is the rectification column. It is used in a variety of chemical manufacturing processes. The column works according to the principle of thermal separation of fluid mixtures, also known as distillation. The column represents a special form of distillation in which a cascade is realised: it is continuously distilled in the interior of the apparatus over several steps. This allows a very good separation of the different fluids. The rectification is carried out in filler and bottom columns. Both types differ in their internal structure and the associated fluid guidance. In the following, the bottom column is examined.

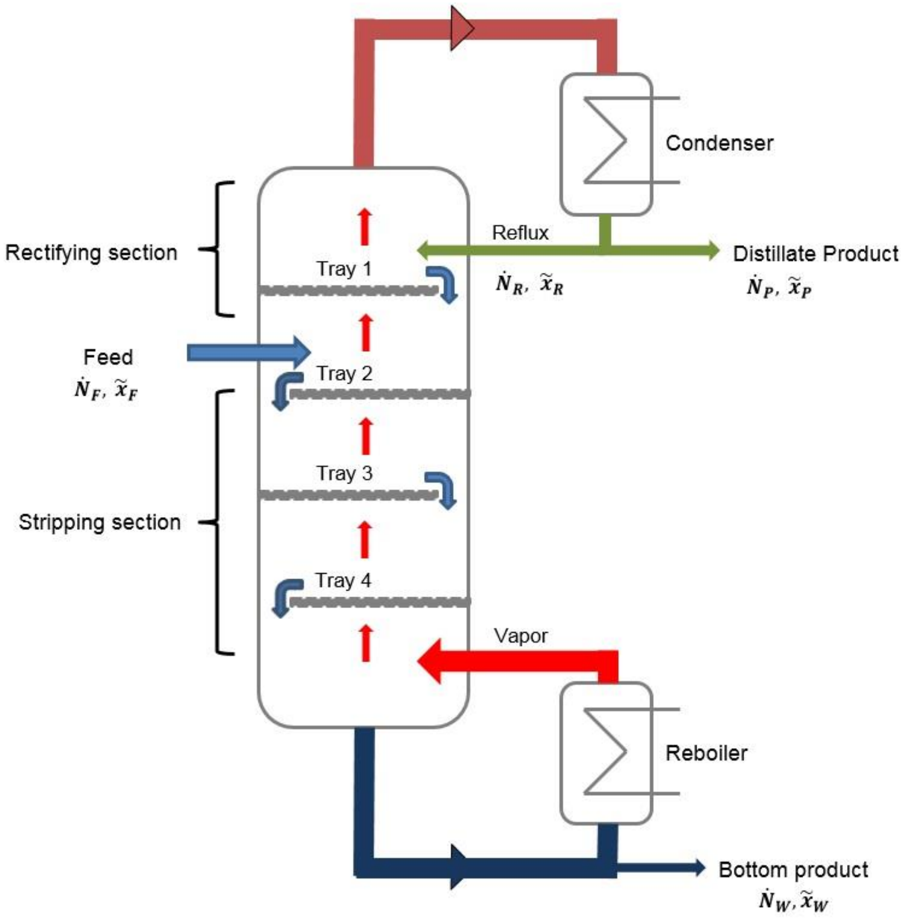

Figure 1: Schematic structure of a rectification column [9].

The basic component of such a column is a cylindrical mantle in which trays are installed at regular intervals (e.g. [6]). On these trays, the fluid to be separated gradually flows downwards in the column. At the bottom, the fluid enters the evaporator and is transferred to the steam-shaped phase. The resulting steam is fed back into the column and flows upward through special openings in the trays. The fluid flowing downwards and the steam rising upward come into contact. This heats the fluid and cools the steam upwards. Through the trays and the openings therein, the contact area between the gaseous and liquid phase is considerably increased, which significantly improves the separation effect (e.g. [9]). By the described forced flow of the two different state phases of the fluid to be separated and the upward deposition of the temperature profile of the steam, it is possible to the lighter boiling component in the material mixture to be separated upwards. The steam is then routed to the capacitor at the upper end of the system and completely transferred to the liquid phase. A part of this liquid is returned back into the plant in order to improve the overall efficiency. The remaining part of the condensed fluid is taken from the process as a head product. This proportionally has a much higher percentage of the lighter boiling component than the initial mixture. The counterpart to this collection point is located at the base of the column. There, a part of the fluid is dissipated, which has proportionally much more of the heavier boiling component, referred to as a swamp product. The column is continuously operated, so the output mixture is constantly fed and the two described products are dissipated (e.g. [10]).

The rectification column is used, for example, to disassemble crude oil into its fractions, including petrol (e.g. [11], [12]). But also ethanol can be produced with this plant (e.g. [13]). In addition, air in rectification columns can be broken down into its constituents in the low-temperature range in order to obtain technically important gases in a high purity (e.g. [14]).

2.2 Virtual Reality

The Virtual Reality is becoming increasingly important due to advances in the areas of 3d modelling and (mobile) hardware. 3-dimensionality, virtuality and interactivity of this technology enable a particularly easy access to information presentation. Virtual Reality is a human-computer interface that links real-time simulation and interactions through multi-sensory channels [1] to form a computer-generated environment that can be characterised by the three parameters of immersion, interaction and imagination.

Immersion and interaction are to be understood as assessment variables, with which the user can assess the extent to which the virtual world corresponds to reality. The immersion describes the degree of psychological and physical involvement of the user in the virtual world, which ideally can lead to the perfect forgetting of the real environment. This impression is generated by the supply of human organs of perception with synthetic information. Special devices have been developed for the stimulation of the corresponding sensory organs. Through the respective interactions, the user is given the possibility to manipulate the virtual environment and to use or modify the virtual objects contained within it. The third aspect is the imagination of the user. It is only through them that the experience arises to be part of a virtual world that exists only in the computer. The imagination depends to a great extent on the quality of immersion and interaction.

In Figure 1 the correlation between the target variables is clarified, in particular the dependence of the immersion from interaction and imagination. The degree of immersion determined decisively by the interaction techniques used in cooperation with the imagination.

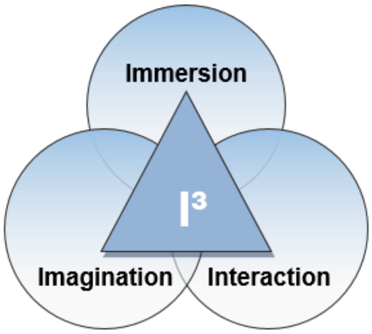

Figure 2. The three "I" of Virtual Reality according to [1].

The focus of a VR application is man. From this perspective, a VR system must be able to ensure the supply of human perceptions with appropriate information in order to make it accessible to the virtual environment [15]. At the same time, the system has to implement the evaluation of the user's actions in order to be able to initiate appropriate reactions. A VR system is mostly composed of the basic components visualised in Figure 3 [16].

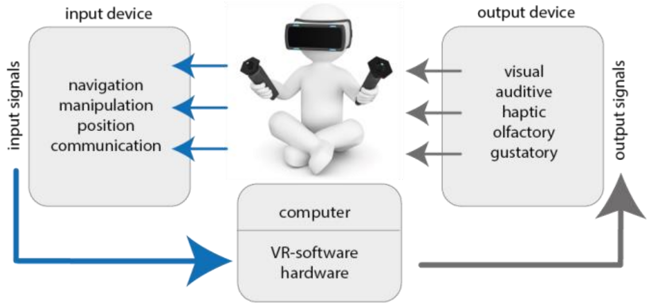

Figure 3. VR system architecture [15].

3 RELATED WORK

VR-based learning systems are not a new technique. Several approaches have been proposed in literature. Most approaches currently lack targeted support through didactic approaches or do not specialise in the use of a rectification column in university teaching to impart knowledge.

The authors of [17] describe an approach that exemplifies the use of Virtual Reality technologies in manufacturing as Virtual Manufacturing (VM). They define VM as a computer system that is capable of simulating a real production environment in virtual space. The properties of the real system are almost retained in order to completely plan and simulate the production of future products on the computer. This is intended to significantly improve the quality of the new products as well as to significantly shorten the development time from the idea to implementation.

A concept for training technical personnel in a virtual interactive training environment in the field of process engineering, especially in the chemical process industry, is presented in [18]. Great emphasis is placed on the experienceability of the system in the virtual space, so that the user can immediately grasp its purpose. This should facilitate the learning of prescribed procedures at the plant, which must be mastered at all times by the technical personnel in certain hazardous situations. In addition, it is possible to sensitise the technicians to be trained to recognize dangerous situations at an early stage and to avert serious consequences for life.

A simulation platform especially suited for beginners is presented in [19]. For this purpose, a three-dimensional model was coupled with an existing plant in the chemical industry using, so that a virtual twin of the plant was created with this simulation platform. This can then interact with the virtual model in real time. This means that process parameters can be changed and tested on the model. The values determined in this way are then transmitted to the real system. The authors have shown in their own studies that such control of chemical plants is much more user-friendly and accurate for operator training. In addition, the safety of the entire process is increased, since critical process constellations are already detected in the model and thus damages can be limited within the actual plant.

A contribution to more safety in process industry is described in [20]. Their concept provides for simulable, experimental approach that can be used specifically to manage the competencies of plant operators in the chemical industry. The result of these investigations is a Plant Simulator. It can support plant operators in making decisions on safety-relevant issues. Furthermore, this tool offers the functionality to train not only individuals but also whole teams. This makes it possible to train group dynamics of working groups to raise awareness of safety and risk avoidance.

In their contribution, the authors of [21] present a prototype of a virtual welding simulator for the interactive training of a welding process in their contribution. The focus is on the difficulties in training tasks of the welding process, which are to be overcome by the use of VR technologies. In addition to the technical aspects of the system design and its implementation, the real-time simulation and visualization of the weld bead as well as the provision of realistic experiences through multimodal 3D interaction are explained in more detail. The initial results confirm that the use of the prototype is very conducive to the training of welding tasks - especially with regard to the provision of visual training manuals and the immediate evaluation of training.

A VR & AR Combi Instruction Manual (VAMOIS), which helps technicians to perform manual operating procedures, is presented in [22]. Both, the contents of the construction site and the virtual instructions are presented synchronously and in real time. With the system, a virtual hands tutor was developed, which shows the trainees in VR-based planning lessons the movement and attitude of the required parts and tools in the correct position. The collected results demonstrate that the resulting system improves the efficiency of manual operation compared to traditional training methods.

The educational platform “VREX” (Virtual Reality Based Education Expansion) to improve the curriculum and teaching experience, is presented in [23]. The author’s studies propose that using VR can enhance the effectiveness of the curriculum in an immersive environment because learners have an intuitive sense of understanding abstract knowledge.

4 VR-BASED LEARNING SYSTEM FOR THE FRACTIONATING COLUMN

For the implementation of the VR-based learning system for the rectification column, further requirements have to be taken into account in addition to the content issue. This includes aspects such as the future application and user area, as well as the intended time window for the end users and the integration process in the courses. Furthermore, it is necessary to define the level of detail of information, interaction and visualisation, as well as the technical system requirements and the didactic concept for teaching the learning content.

4.1 Process of realisation

The realisation process for a VR-based learning environment for the operation of a rectification column can be divided into several steps (cf. Figure 4). Based on a preceding concept, these are:

1. Modelling of the necessary components and transfer to a suitable visualisation program:
2. Development of the didactic approach
3. Realisation of the necessary functionalities for interaction and information provision

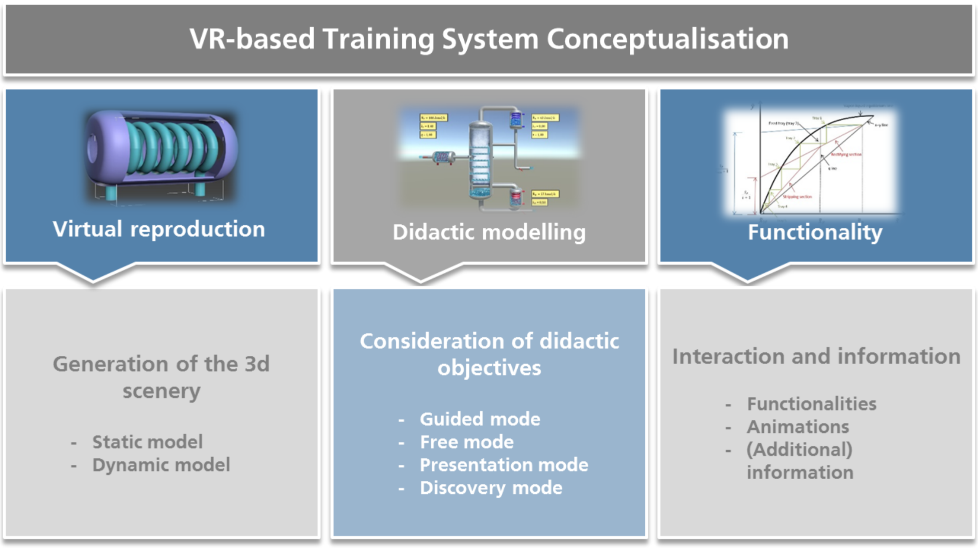

Figure 4. Realisation process of the VR learning system.

For the rectification column, this means that the resulting visualisation is integrated into the lecture content of a university course as supplementary material. Thus, the end users are the students registered in this subject and the associated lecturers of lectures and exercises. Since both the structure and the mode of operation are to be learned, a high degree of detail of the resulting visualisation is required, in which components and functions are explained.

The basis for the realisation of a VR-based learning system for the rectification column is a realistic three-dimensional representation of an ideal rectification column. Its modelling and transfer to the virtual world is the first step in the implementation process. In the next step, the created 3D model is transferred into the virtual world of a suitable visualisation system and a dynamic model is developed from the static one with selected suitable animations.

For the implementation, it must be possible to create an independent stand-alone solution independent of third-party software. This allows the user to use the interactive tool without any additional software. For the intended mobile version of the learning system it is also necessary that an installation file can be created, which can be installed on mobile devices. For the implementation of the VR-based learning system, the following additional requirements led to the identification and use of the visualisation software "Unity":

- High-quality graphic visualisation
- Creation of functionality and animations must be possible
- Provision of a compact learning software with a small amount of data
- License free

Based on the functional and technical requirements and the possibilities of Unity, didactically applicable concepts were developed, which can be used according to different learning and teaching methods.

In the final step, further functionalities are added so that the rectification column, which has been transformed into Virtual Reality, can be used in the context of knowledge transfer. Based on the didactic concept, the necessary steps and processes are implemented in the Unity engine.

The following sections describe the individual implementation steps in more detail.

4.2 Static and dynamic model

According to the conceptual design derived from the requirements, a three-dimensional model of a rectification column in virtual space is necessary. To this end, it must first be decided how the process-relevant individual components of the entire plant to be represented can be mapped. The degree of abstraction depends on the relevance of the component. Once this process is complete, the model that will be visible later can be created using a modelling software. Preferably, a polygon-based system serves this purpose, as it enables realistic representations combined with the required small data size of the model (cf. Figure 5). This model is processed by means of various modifiers in such a way that it comes close to a real plant in structure, as well as in optical properties. This also includes the use of realistic textures and materials.

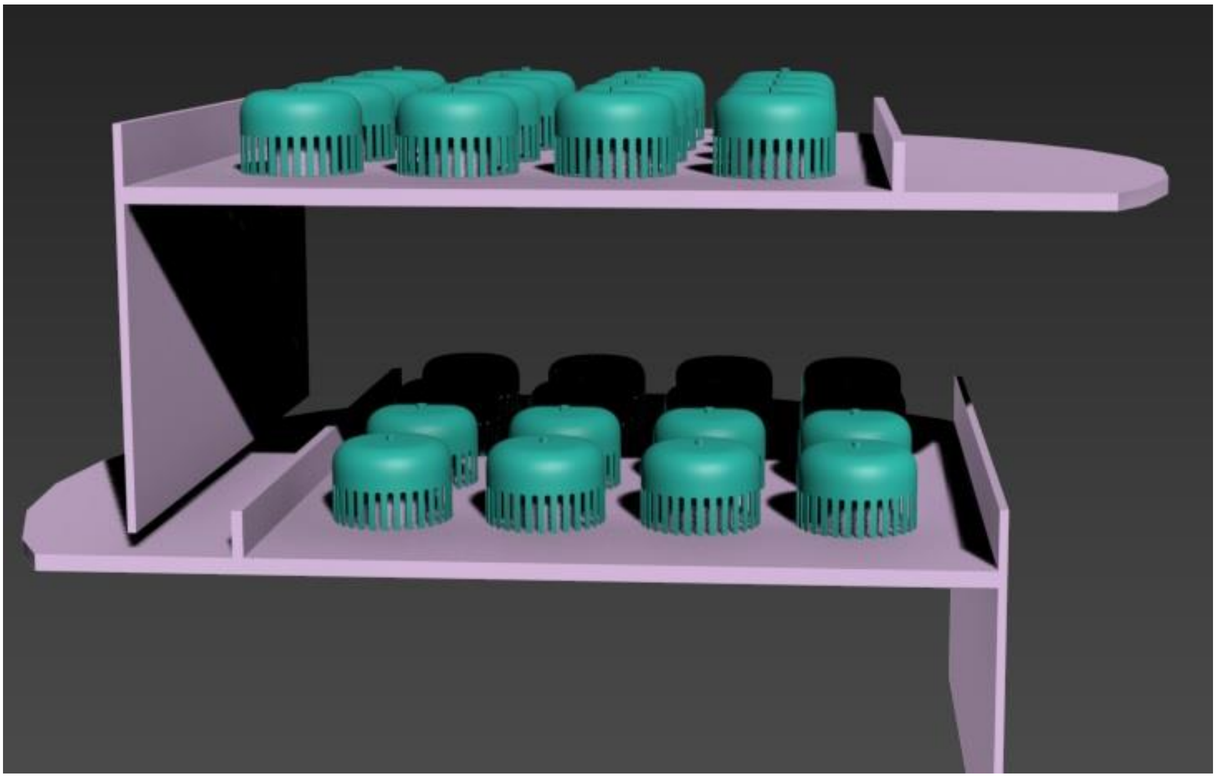

Figure 5. Static Model of several bubble trays.

Once the static model has been completed, a dynamic model can be developed. This requires knowledge of the functionality and physical properties of the system.

Based on the static model, material flows are implemented whose optical and physical properties must be based on the real model. For this purpose, dynamic textures are projected onto polygon-based support bodies that simulate the spatial dimensions of the flow. In the concrete example of the rectification column this refers to fluid flows (cf. Figure 6), which are fed to or discharged from the plant, as well as the representation of all internal material flows. These include the flows on the individual trays and the steam flows that pass through the plant. The representation of the steam flows can be realised via particle systems, whereby a high-quality, very realistic representation degree is achieved. In addition, further dynamic details are worked out in this implementation step, such as movable shut-off valves.

Finally, the static model is modified so that it can be opened later in the application to make all internal components visible. This modularises the learning object to such an extent that its targeted use is made possible on the basis of the didactic model.

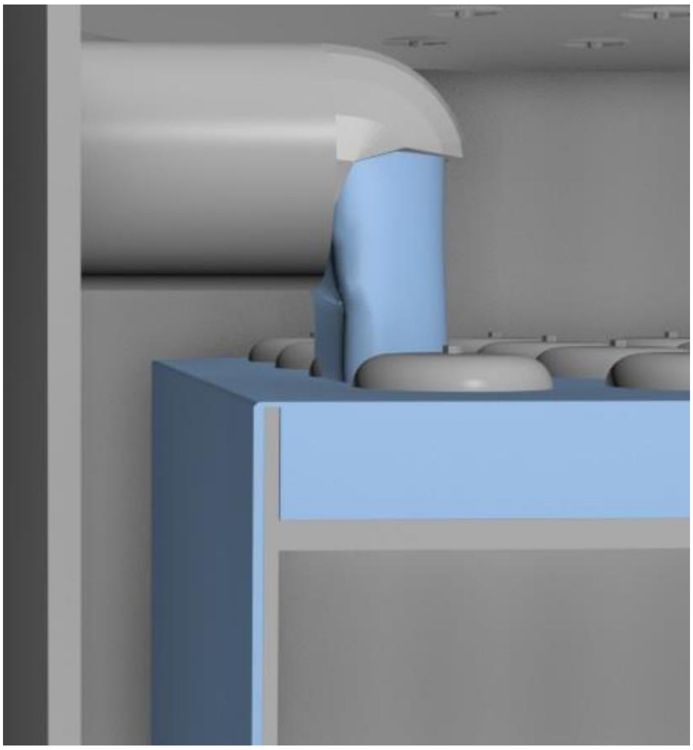

Figure 6. Dynamic Model with inlet liquid, liquid level and falling film.

4.3 Didactic model

In order to convey the learning content of the VR-based solution to learners in a high-quality manner, the use of a didactic model as a basis is required.

Therefore, four different modes are provided: discovery mode, free mode, presentation mode and guided mode ([24], [16]). In discovery mode, users have the opportunity to familiarise themselves with the system, its functions and the content displayed. The presentation mode shows the processes of the learning objective in a sequence of predefined steps - in this case the functioning of the rectification column. Using predefined animations, the behaviour is presented in relation to various parameter settings and explained with text and/or audio comments. The combination of three-dimensional imaging and additional explanations increases the understanding of complex technical structural and process-related information. If necessary, individual learning steps can be repeated.

The learned contents can be applied in guided mode. First a goal or a task is defined and by means of intermediate steps the learner can achieve sub-goals which in their entirety are the solution of the overall task. The system also checks the solution of the subgoals by implementing the substeps. In case of difficulties or problems, the learner can be specifically supported by integrating suggestions for solutions. In free mode, the learner receives a task and decides for himself which substeps he wants to solve this task. Unlike the guided mode, the system only checks whether the final results are achieved. The intermediate steps and the achievement of a partial solution play only a subordinate role.

In the first phase, the focus for the visualisation of the rectification column is on the integration of a presentation mode and discovery mode. In discovery mode, the user can interactively select the parameters of the apparatus and examine the resulting changes to the entire model. The operator can occupy any view position in order to be able to closely observe and investigate the generated behaviour in any part of the plant.

4.4 Functionality implementation for interaction and information

The static model including the dynamic components is transferred to a suitable visualisation platform. This must make it possible to implement the desired operating structure of the later application and to be able to display all components including the modelled objects in a high-quality and realistic manner.

After a visualisation software has been selected which fulfils all requirements - in this case Unity 3d - the conceptually developed user interface can be implemented. Before that, all modelled three-dimensional components are transferred to this platform and provided with realistic properties. Then a button constellation is established at the right edge of the screen to be able to control the defined functions. In the next step, these buttons are connected to the dynamic components of the model via programming, so that all desired modifications to the model can be carried out by the user. These include visualisations for the design and function of a rectification column, but also the modification of individual predefined parameters which, due to complex interactions with the column, cause type-related changes to the plant. In detail, the application offers the following specific learning contents:

- Structure of a rectification column
- Variation of feed mole stream
- Variation of the energetic state of the feed
- Variation of the product composition
- Variation of the waste composition
- Variation of the return flow ratio

Furthermore, the movement control for the user is determined by additional programming. The user will be able to move through the model using the arrow keys on his keyboard. The mouse wheel should be able to zoom in and out. In the mobile application, the familiar gesture control is used by different movements of the user's fingers. This minimises the learning curve for operating the app.

Finally, the application can be created as an .exe file for computers and as an .apk file for Android-based mobile devices. The virtual-interactive rectification column is thus ready for use in the technical and university training of prospective process engineers (cf. Fig. 7).

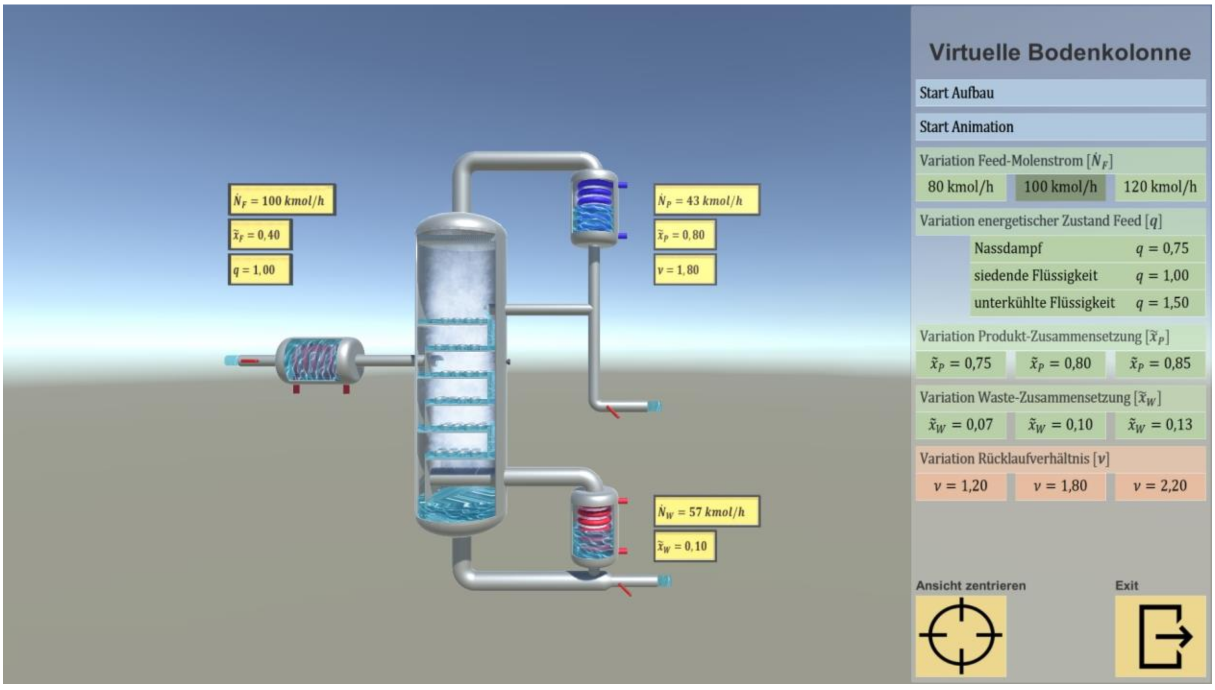

Figure 7. VR-based learning system.

5 CONCLUSIONS

In its entirety, the system makes the technology of a fractionating column available to university teaching in an interactive, modern and didactically prepared form. The proposed three-stage procedure is universally and can be adapted to other complex applications of process engineering as well as other courses.

Possible approaches for a further development of the presented prototypical implementation are the focusing on more details or the consideration of further complex engineering processes. In this way, the model can be further approximated to its real model and provided with additional functions and features. Thus, a qualitative increase of the training contents can be achieved at concretely this apparatus. On the other hand, a further development of the existing concept for other complex processes in the chemical industry and the associated plants is conceivable. These can be provided as learning content in accordance with the concept of the virtual rectification column. This would lead to a quantitative improvement in training.

There is great potential for both ways in university teaching.

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