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Web-based multi-dimensional education system for the simulated moving bed process

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Abstract−This paper describes the development of an operator-education program for a simulated moving bed (SMB) pilot plant that separates para-xylene isomer from mixed xylenes. The education program was motivated from reliable and safe operations for a newly developed SMB technology, in particular, a priori education on preventing accidents such as explosion, fire and toxic material release, most of which result from the lack of understanding of the processes being operated. This SMB process education program has overall SMB process description, sixteen operating screen and response procedure for accident of leak and explosion. The proposed system was implemented based on client/server architecture in company-wise LAN environment and applied previously operator heuristics. In addition, it features multi-dimensional animation for virtual reality of process flow, using multi-media techniques. Operators are expected to benefit from education that is free of time and space constraints. The education system for the pilot plant will contribute to keeping the full scale SMB operation workforce performing at a high level of proficiency as well as refreshing the operational skills of senior operators.

Keywords: Safety Education System, SMB Process, Network-base System, Simulated Moving Bed, Process Safety

INTRODUCTION

SMB (simulated moving bed) is a counter-current separation technique using the chromatography method that is used in the separation of pharmaceuticals, petrochemicals and organic chemicals. The SMB process of the petrochemical industry is an innovative separation method for para-xylene recovery from mixed xylene including ethyl benzene, para-xylene, meta-xylene and ortho-xylene. The advantages of SMB process include much higher productivity, ninety percent reduction in solvent consumption, reducing packing material cost and easier to remove solvent. Construction of new SMB process considering safety in petrochemical company is new challenge. First, the development of the SMB process education program is very important to improve process operation and safety.

Various industrial training systems have been introduced. Dudley et al. [2] developed an operator training simulator system for the pebble bed modular reactor. The increasing complexities and integration of chemical processes led to automation, advancement and refinement of process plants, and thereby new and even senior operators became exposed to ill-preparation for a safe and reliable operation. This trend has made the need for well-trained operators continue to increase over the past decades. A large number of extensive researches on computer-based training or educating systems in various fields have been reported, applying a set of latest technologies such as web, multi-media, speech recognition, and virtual reality related techniques. The survey of operator training systems in this article is limited to the applications of chemical or related processes. A pebble bed modular reactor (PBMR) demonstration power plant under construction has been tested and validated at the design stage of the plant [1]. Yang et al. [3] proposed a dynamic operator training simulator which can be used to explore start-up, shutdown and emergency operations procedures, to experience various operations and to evaluate safety. It was applied to the new methyl tertiary butyl ether (MTBE) process [2]. An operator training system for educating the operation of a specific fired-heater used in a refinery plant, yFES (Yonsei Furnace Education System) was developed, applying multi-media and virtual reality technologies. It has been tested and proven effective to improve the safe operation in a refinery plant [3]. There are combined simulator and tutoring systems. Also, yOTS (Yonsei operating training system) system is operator training education for a chemical process [4]. Shin and Venkatasubramanian [6] developed a prototype for an intelligent training system (ITS) that integrates a tutoring system to a dynamic simulator, aiming to help operators for diagnostic problem solving [5]. Another intelligent tutoring system combined with a simulator designed for thermal power plants is implemented, using artificial intelligence (AI) techniques such as heuristic cognitive diagnosis, dynamic monitoring and objected-oriented knowledge representation [6]. Interestingly, it provides both qualitative and quantitative process models and is evaluated by multi-level trainees and human instructors of the plant. Lastly the National Energy Technology Laboratory (NETL), part of the US Department of Energy's (DOE) national laboratory system uses Invensys's SimSci-Esscor DYNSIM dynamic simulation and EYESim 3DVR technologies to help develop the next-generation integrated gasification combine cycle (IGCC) zero-emission power plant, and also uses the simulator to train operators [7]. Most academic prototypes focus on the development of education systems for general-purpose rather than domain-specific, apply-

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ing web, virtual reality or multi-media technologies [8,9].

This article is concerned with a prototype of an operator education system for an SMB-based pilot plant to separate para-xylene from mixed xylenes, which is used as a raw material to manufacture polyethylene terephthalate (PET). The proposed SMB pilot plant in this paper largely consists of twenty-four absorption beds and on-off valve. A petrochemical company in Korea has developed its own SMB technology and a pilot plant is being built. New operators are highly exposed to ill-preparation for a safe and reliable operation. The systematic education environment for operators becomes one of the hot issues for a successful and safe operation. The proposed system is intended to be used for educating new operators the newly developed SMB process at pilot plant scale and then will be extended to develop the next version of the system for full manufacturing scale.

PROGRAM CONTENTS

Process contents comprise three sections, such as process description, operation and safety sections.

The operation section covers information on what needs to be prepared for startup, normal operation, startup and shutdown. The safety section is divided into two subsections, such as safety for SMB and general safety issues for chemical processes.

1. Process Description Section

Para-xylene is a major raw material for polyethylene terephthalate (PET) which is used to manufacture polyester fibers, molded plastics and films. The separation of para-xylene isomer from mixed xylene has been historically studied and commercialized in the petrochemical industry. SMB technology has been employed for para-xylene separation instead of conventional distillation, due to very close boiling points of isomers. The solid and liquid phases with countercurrent movement are operated switching the valves of the interconnected beds in the direction of the liquid flow to obtain a SMB. Universal Oil Products initially licensed SMB in the 1960s. Currently available industrial SMB technologies include UOP's Parex, IFP's Eluxyl, and Toray's Aromax. The main difference in the three processes is the periodically switching method of inlet and outlet position.

The process description section contains general information on SMB technology covering over five subsections. The contents include introduction, theoretical background, and details of main equipment in terms of design specifications and major operating variables, parameters and its relationships affecting para-xylene recovery efficiency.

The separation of the SMB process takes place in the two adsorption chambers. Each adsorption chamber consists of twenty four adsorbent beds. Each adsorbent is operated to produce high efficient flow distribution. Each internal device is connected to the on-off valve by bed pipe lines. The four valves between each adsorbent bed are used to withdraw or inject liquid from the adsorption chambers during simultaneously collecting liquid from the adsorbent beds above and redistribution of the liquid over the adsorbent bed below SMB operating principle can be easily understood in TMB (true moving bed) reference process. TMB is the solid and liquid phase flow in opposite directions and consists of four zones. In zone1 is selected net flow rate in order to ensure the regeneration of adsorbent. Zone 2 adsorption of the less strongly adsorbed component occurs. In zone 3 adsorption of the more strongly adsorbed component occurs. Finally, zone 4 regenerates eluent. Fig. 2 shows the SMB and TMB process diagram.

Process description of SMB education system: The xylene separation of the SMB process between adsorption chamber and adsorp-

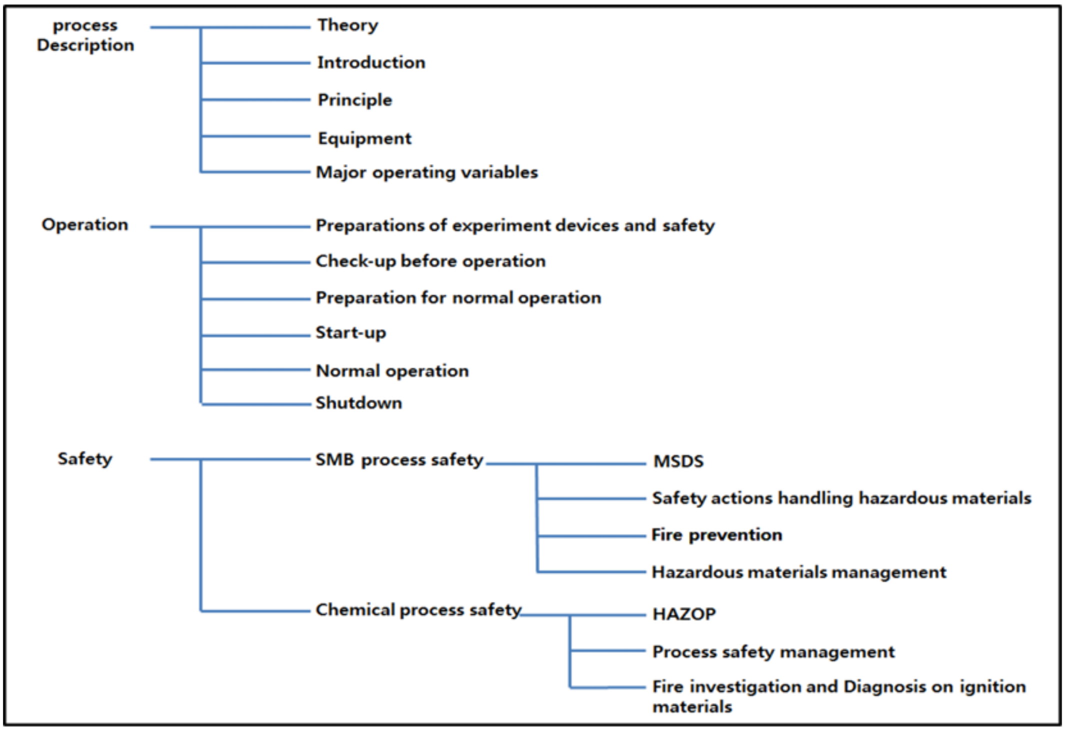

Fig. 1. Major structure of training scenarios in SMB education system.

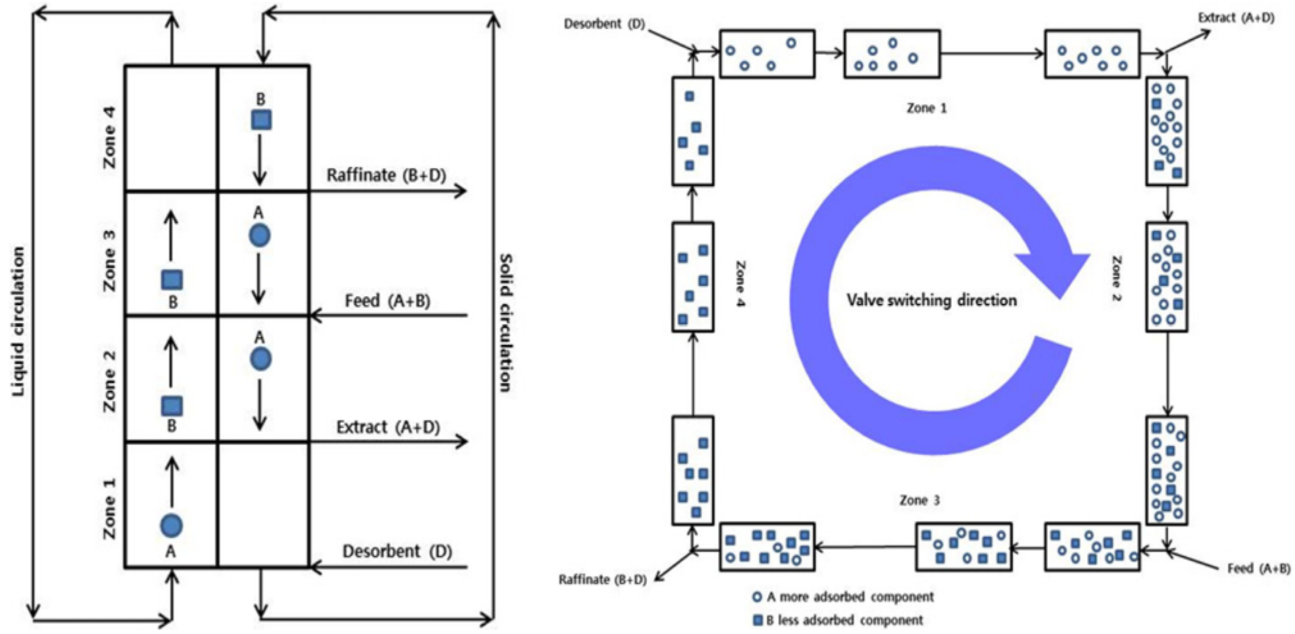

Fig. 2. Schematic diagram of TMB and SMB process.

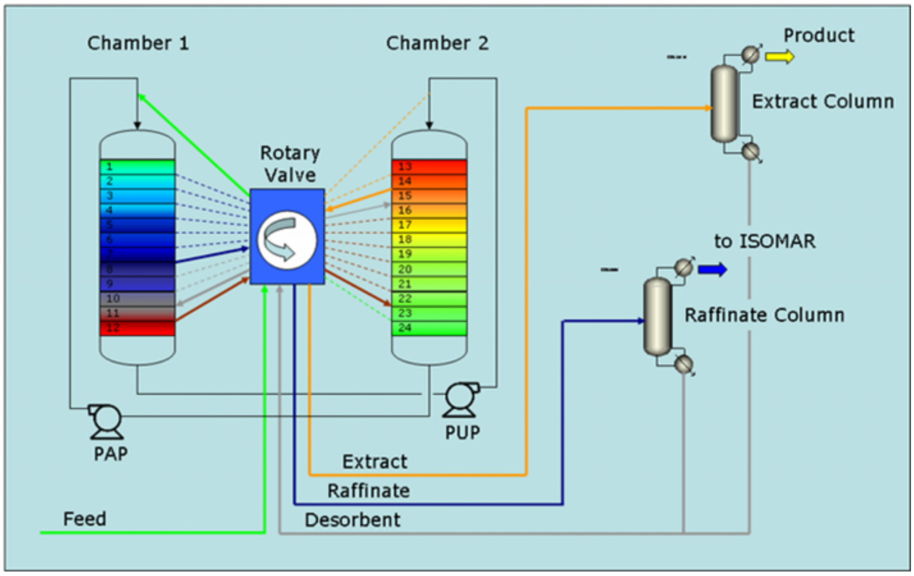

Fig. 3. SMB process for para-xylene separation.

tion chamber is operated with twenty-four adsorbent beds. Each adsorbent bed is designed to produce high purity and recovery with flow distribution. Also, the beds are connected to inlet and outlet line through an on-off valve. Instead of moving the beds, the various valves are opened and closed to the movement. Fig. 3 shows a typical SMB process, which has twenty-four beds in two adsorbent chambers and on-off valve connecting twenty-four beds pipe lines. The SMB process consists of four major streams that are distributed to two adsorbent chambers with a rotary valve. Four major flows are mixed xylene feed, extract out for para-xylene diluted with desorbent, raffinate out for meta-xylene and ortho-xylene diluted with desorbent and recycle desorbent.

The on-off valve of the representative main equipment, such as rotary valve, is used for periodically shifting the position for the inlet and product outlet as the chemical composition distribution moves down the chamber. This process has two pumps; the first pump performs circulation from the first adsorbent chamber bottom to the second chamber top, and the second pump performs circulation from the second adsorbent chamber bottom to the first chamber top. Two adsorbent chambers are composed for a continuous process of twenty-four adsorbent beds.

2. Operation Section

The operation section is a kind of operation manual or guide for a set of different operation types, comprising six subsections as follows.

• Check-list for the preparation of experiments which includes a set of notices on adsorbent storage, safety, nitrogen purge, adsorbent unloading, line connectivity and the calibration of levels in drums. Operator and managers should be fully aware of MSDS related to the material used. In particular, operators should be careful in contact with the intake or eyes when absorbent is loading and unloading. Nitrogen purge is supplied to maintain constant pressure about the overall process after bed temperature maintains at 80 °C. If nitrogen purge is completed, each bed pressure drop to atmospheric pressure and operators are unloading existing adsorbent. In addition, a set of procedural commitment items that operators must confirm prior to starting experiments are described.

• A checklist that operators must confirm before running an operation is presented in terms of operability of equipment, leak test and detailed procedure for purge. Operators confirm on or off the pump, measure temperature after confirming steam supply and normal operation of safety devices. If the pressure is reduced, a leak test is conducted using soapy water about connecting lines and bed flange bolt part. The detailed procedure for purge is as follows. First, each bed temperature is maintained at 80 °C. Second, the drum ball valve connected to the underbody of the feed drum and desorbent drum is closed. Third, total KV valve connecting the absorption beds is opened. Fourth, nitrogen line ball valve connected to the underbody of the feed drum and desorbent drum is opened. Fifth, the overall process is purged of supplied nitrogen during eight hours. Finally, the nitrogen line ball valve connected to the underbody of feed drum and desorbent drum is closed.

• The preparations for running normal operation are itemized including charging feed, 2nd feed and desorbent to drums, respectively.

• To-do list for operators during normal operation is detailed, including sampling and a set of notices and checkup items for four drums. Pressure of the outlet drum set up 6.5 KG to inflow nitrogen. Set temperature of the heat exchanger is 177 °C. And then steam is supplied. KV valve connected to bed is opened and feed flows at constant flow rate by driving pump. If liquid in the system is full, extract and raffinate lines are drained of liquid. Excreted fluid enters the outlet drum and circulation pump is operated after the temperature of absorption bed is maintained at 177 °C. Fluid from outlet drum is sent to the para-xylene commercial plant after outlet drum set up level and operating pump.

• The detailed procedure for startup is described. The detailed procedures for two types of shutdown such as planned and emergency are presented, respectively, including must-do action items in case of emergency. Interlock system screen collects the interlock situation of the SMB pilot process and consists of seven scenarios. The seven scenarios are as follows;

- Absorption bed temperature is too high.
- Feed supply temperature is too high.
- Desorbent supply temperature is too high.
- Absorption bed pressure is too high.
- Pump incurs mechanical failure.
- Level of feed and desorbent drum is too high or too low.
- Level of outlet drum is too high or too low.

Fig. 4 shows PFD of proposed SMB pilot plant to understand operation section.

The SMB pilot process consists of sixteen operating screens (PFD, SMB, Drum, Bed etc.). PFD screen shows an overview of the entire process. For example, most operating control except for the highly complicated absorption bed is worked on the PFD screen. The absorption bed represents another screen with open or close of on-off valves of the absorption bed, circulation flow rate, temperature of each bed and pressure. Major operating variable screen of SMB absorption bed is divided into four items and can specify an absorbent characteristic value. Equipment screen including three drum shows information related to feed and desorbent input of the SMB process; control of this screen starts pump operation. Valve control screen is expressed as on-off valves. The operator can grasp the on-

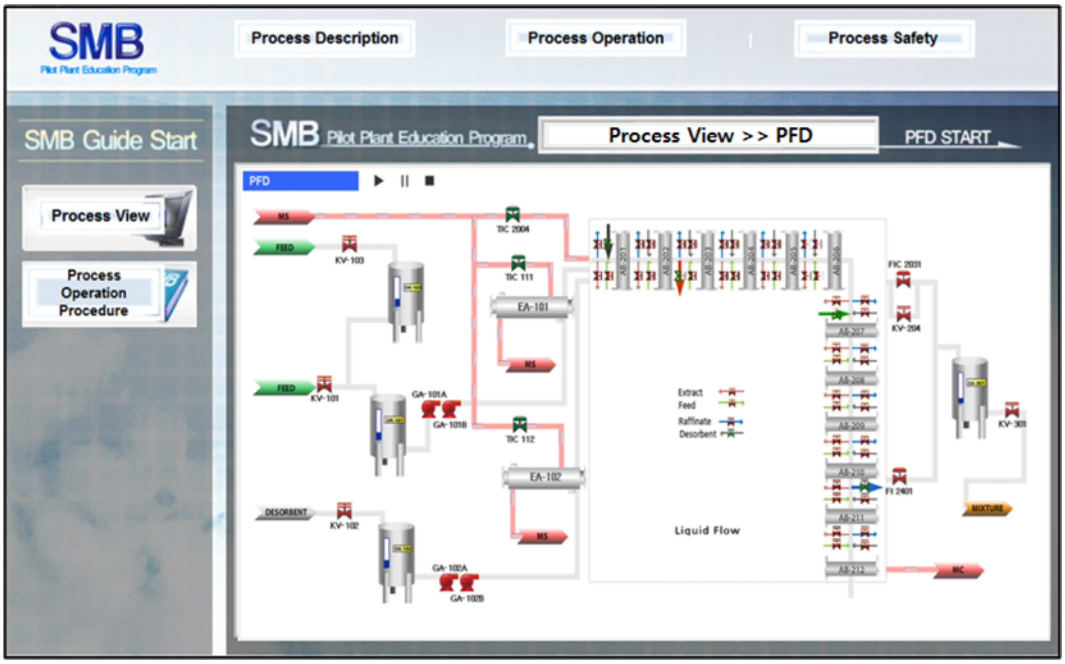

Fig. 4. A snapshot of PFD of SMB pilot plant process.

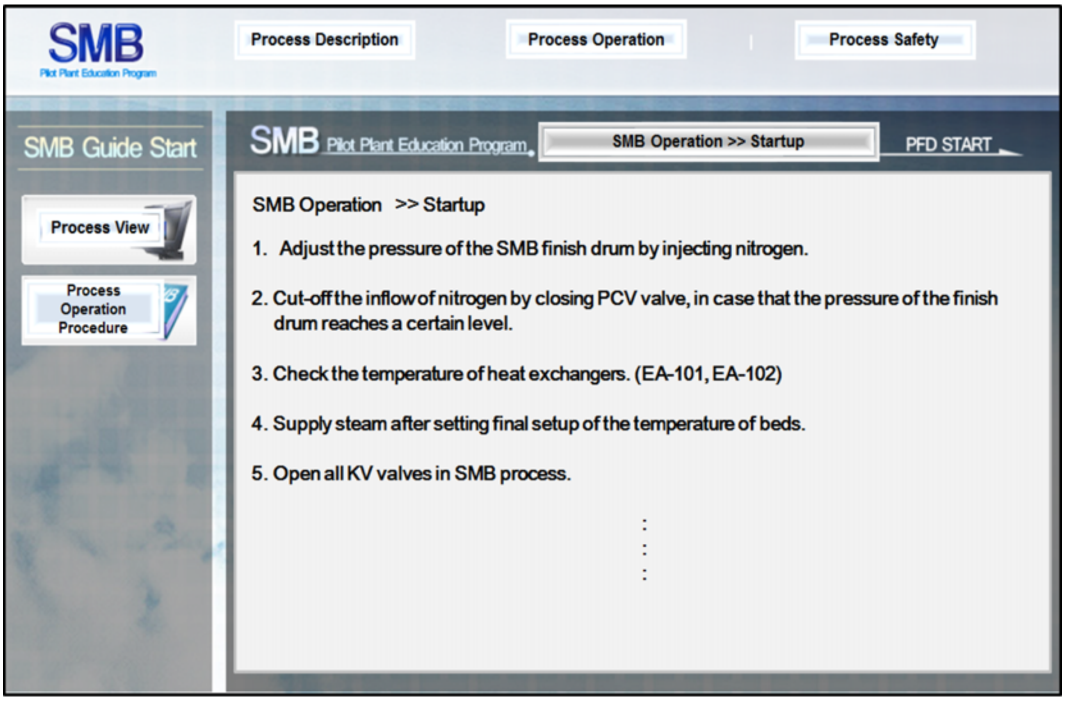

Fig. 5. A screen of startup procedure for SMB process.

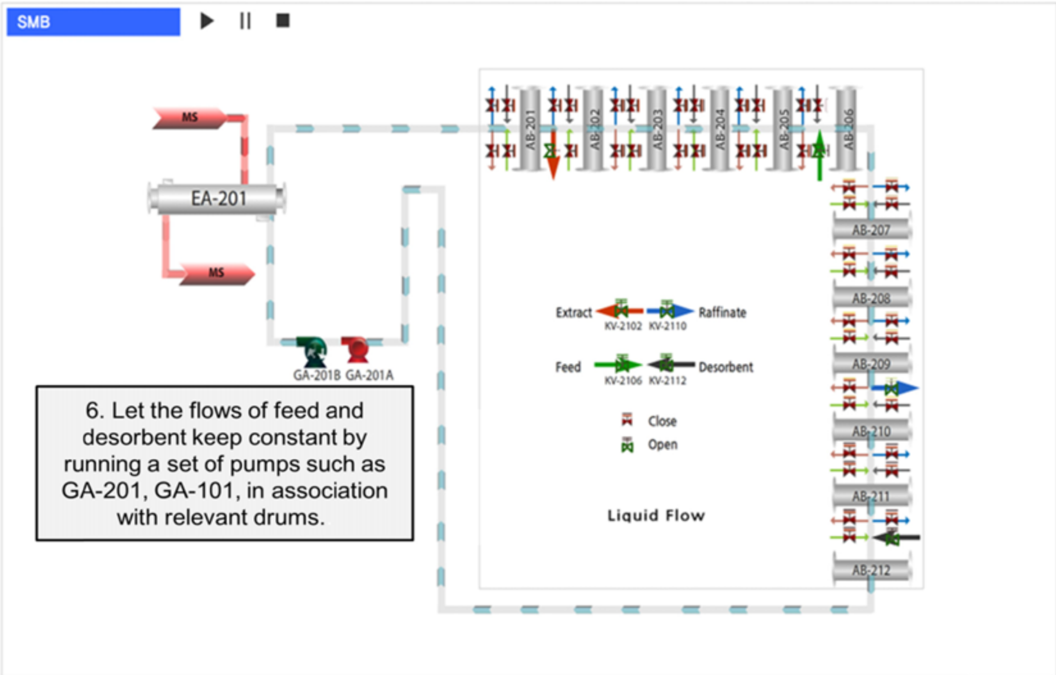

Fig. 6. A snapshot of step 6 in start-up procedure.

off of a valve and forty eight valves open all at once.

Fig. 5 shows a snapshot of the startup procedure in the operation section. Meanwhile, Fig. 6 specifically presents step 6 out of the start-up procedure shown in Fig. 5.

This part involves an instant process flow, representing that feed and desorbent are making constant flows out of a couple of relevant drums by running pumps, GA-201 and GA-101. The entire set of on-off valves are operated in a way that only a fixed set of valves associated with a currently active simulated moving bed are in open mode; meanwhile, all other sets of valves are closed. In Fig. 4, KV-2102 valve of extract, KV-2110 valve of raffinate, KV-2106 valve of feed and KV-2112 valve of desorbent between adsorption beds are in open mode while all other valves are closed. Additionally, Fig. 7 represents the emergency shutdown when unexpected acci-

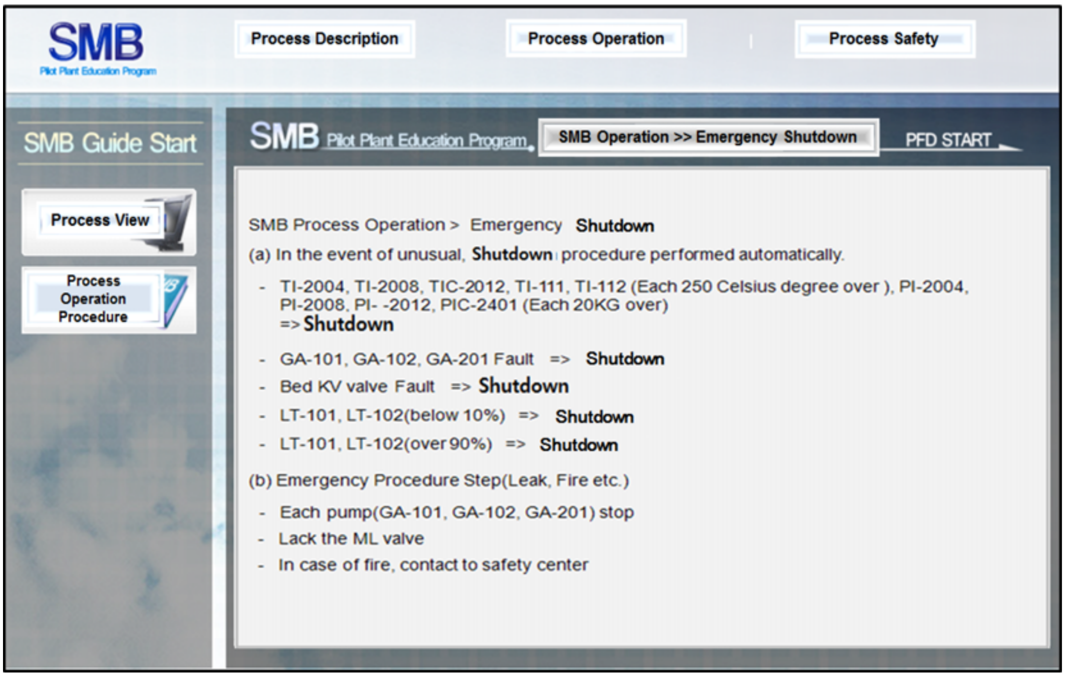

Fig. 7. A screen of emergency shutdown for SMB process.

dents occur.

3. Safety Section

As mentioned, the major goal of this system is to educate operators SMB process operation, together with an emphasis on safety. The safety section is divided into three parts: safe for SMB, general safety issues, and emergency management for chemical processes. The SMB safety subsection comprises Material Safety Data Sheet (MSDS) for xylene isomers, toluene and p-diethyl benzene, safety notices for the use and storage of hazardous materials, fire protection and actions in case of fire, and tips for the safety of chemical compounds. The general safety issues for chemical processes section deals with Hazard and Operability Analysis (HAZOP) for evaluating the safety and risk, the safety management of process operation, tips for fire investigation, and diagnosis for ignition materials. HAZOP is a systematic approach to risk management and is used for potential hazards in a process system or operability problems in terms of plant

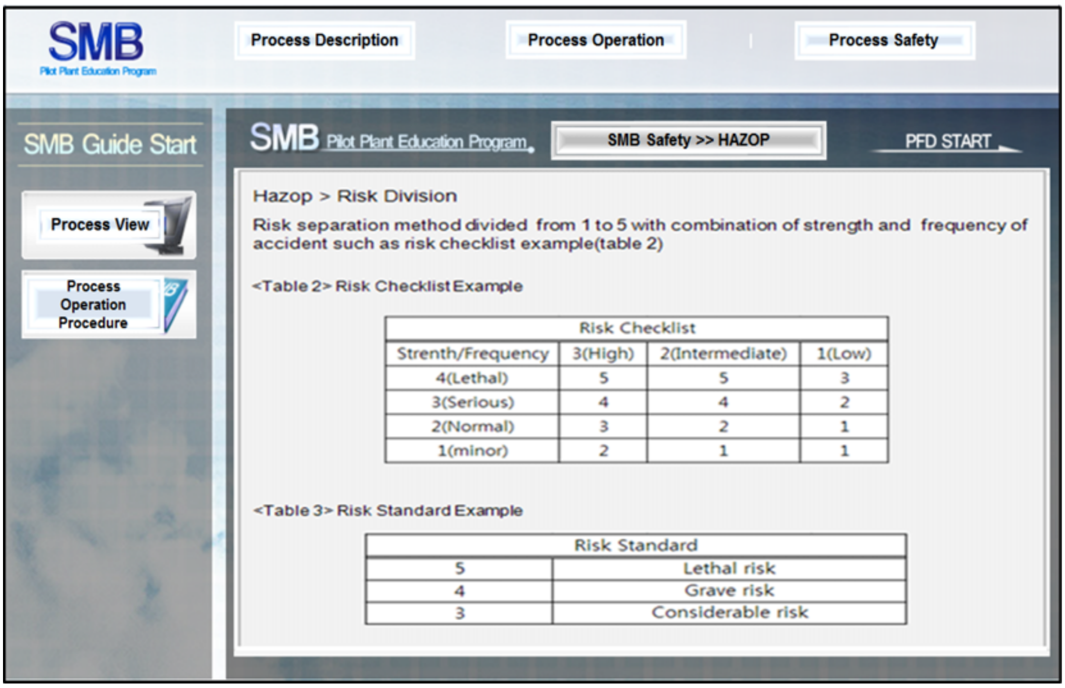

Fig. 8. A screen of risk division of HAZOP.

design. HAZOP includes guidewords, causes, consequences, safeguards, recommendations and action. Fig. 8 shows the risk division of HAZOP in the process safety section.

Emergency management is applied to two accident scenarios. The accident that occurred in the SMB process is largely a leak and explosion. Accident scenario is summarized broadly as two cases. First scenario is exposure when the work involves adsorbent loading and unloading. Second scenario is nitrogen explosion occurring between the pipe lines when nitrogen purge is started. This study supposed that the emergency response was for a severe accident in the petrochemical industry.

Two hypothetical scenarios required efficient emergency response plan caused by toxic materials. For a basic understanding of the accident, the following questions are very important (When and where does the accident occur? What type of accident is it? Leak or explosion? What kind of accident material is involved? What is the damage to the accident site?). Accident site management largely involves three parts: hot zone, warm zone and cold zone. The hot zone is the area of high contamination concentration accessible only to rescue workers. The warm zone is the established emergency medical office and support decontamination of a dangerous site with workers. The cold zone is a safe site to wait for accident response with workers. Fig. 9 shows the accident response procedure.

When accident occurs, such as leakage of hazardous materials and explosion in SMB process, the accident witness takes the following actions. 1) Judgment of accident types (leakage, fire and explosion, 2) Push of emergency button on main screen at control room, 2) Electricity interception related to the SMB process system, 3) Contact of the process manager, employee and safety team, and 4) Contact of the police and fire station. Operators press the emergency shutdown button on the operating screen of the control room and contact the operating director managing the SMB pilot plant. The emergency button includes electricity interception, alarm, shutdown of operation, cutting off the feed and stopping pump operation. It presses the following situation: 1) Temperature of feed and final drum increasing dramatically, 2) Non-ideal operation and fault of the pump, and 3) on-off valve fault. The safety manager reports to the head office about the current situation of the accident and directs the process manager to the recovery accident site. A safety supervisor informs of the emergency through broadcasting in the company. Electricity supply cuts off, causing sparks by firearms and electrical devices. The process manager reports to the safety manager regarding the accident site situation in real time and directs employees near accident site to escape. Also, process team members request a professional engineer to repair the equipment. Employees evacuate in the opposite direction to the wind due to the secondary disaster of fire and explosion by inflammable materials. Injured employees are transported to medical facilities. In the event of a leakage and explosion, safety department, fire and police station should be contacted.

MULTI-DIMENSIONAL PROCESS FLOW ANIMATION

The SMB process operation features frequent and rapid process flow swings in association with the opening and closing of 48 valves, which makes it difficult for new operators to comprehend the overview of SMB process. PFDs that show the animation of process

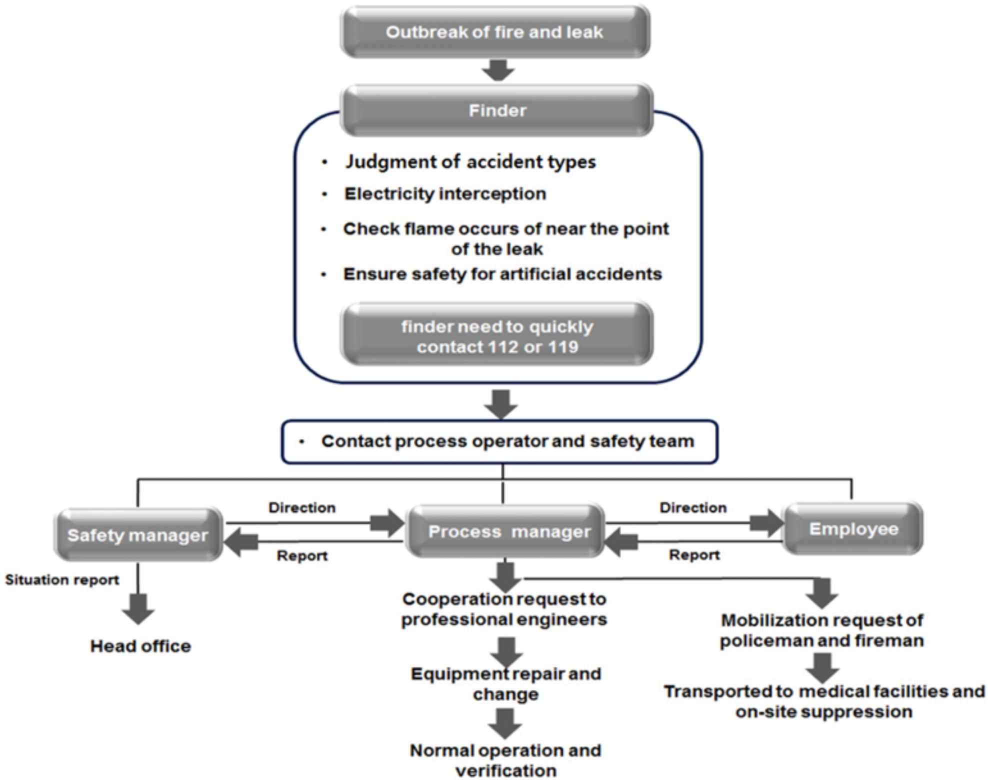

Fig. 9. Flowchart of accident response procedure.

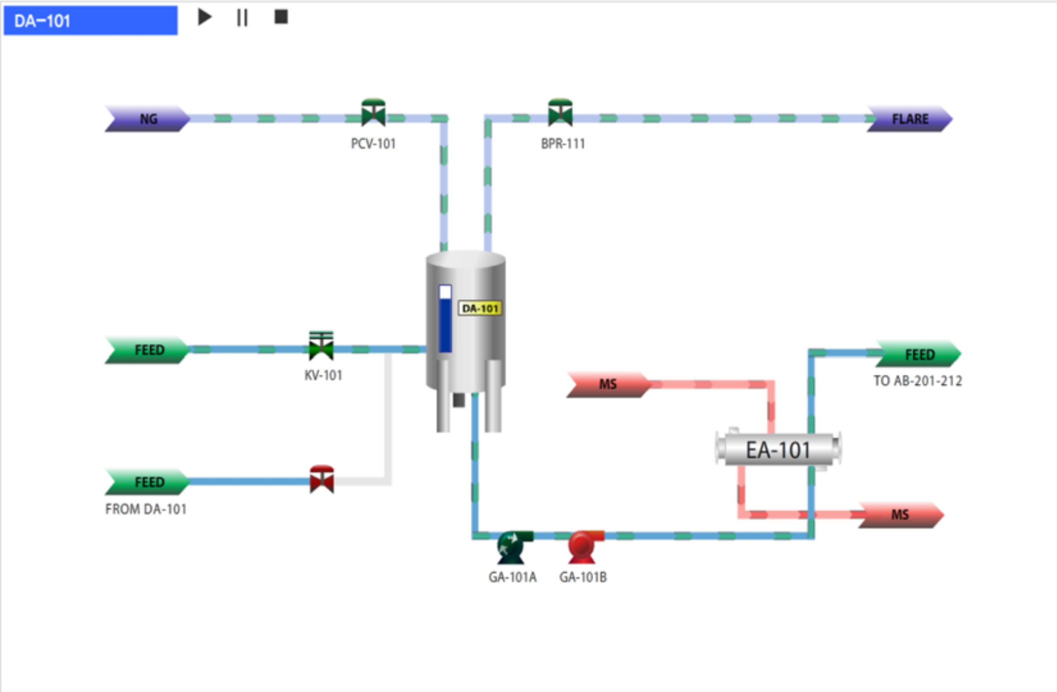

Fig. 10. An example of snapshot of 2D animation.

flow and operations should help new operators understand the overall picture of the SMB process. This system provides seven 2D animations of PFDs based on five zones such as four drums and one adsorption bed: one overall PFD, four PFDs for four Drums (main feed, 2nd feed, desorbent and finish), two PFDs for chromatographic adsorption beds (one showing flow swings by 48 valves; the other showing changes of directions of flow of solids and liquid). With this set of animations, operators can look into the process over different levels and zones of animations by clicking on each PFD icon leading to starting animation. Fig. 10 shows a snapshot of 2D animation.

In addition to 2D animations, 3D PFD animation for the entire process flow is available to bring virtual reality to trainees.

Currently, there is a web-based 3D virtual program hydrogen station. This program aids in improving operator knowledge acquisition

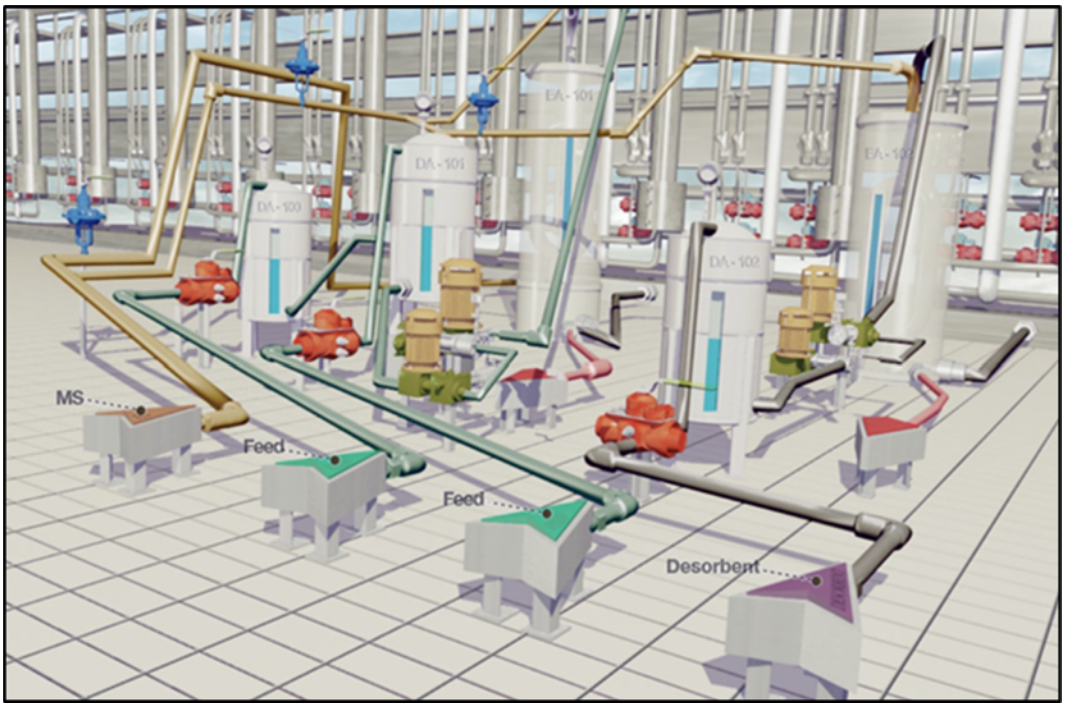

Fig. 11. An example of snapshot of 3D animation.

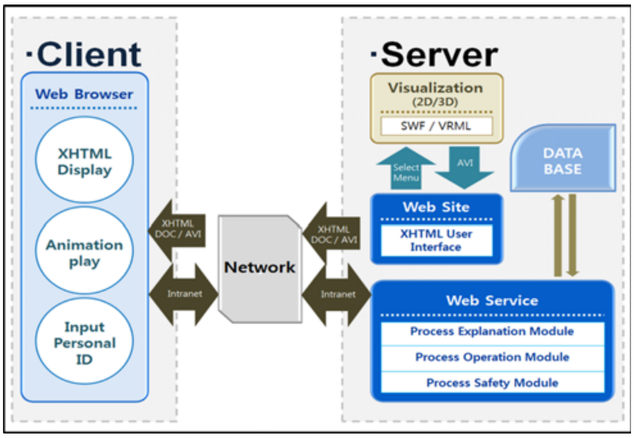

Fig. 12. Architecture of the SMB process education system.

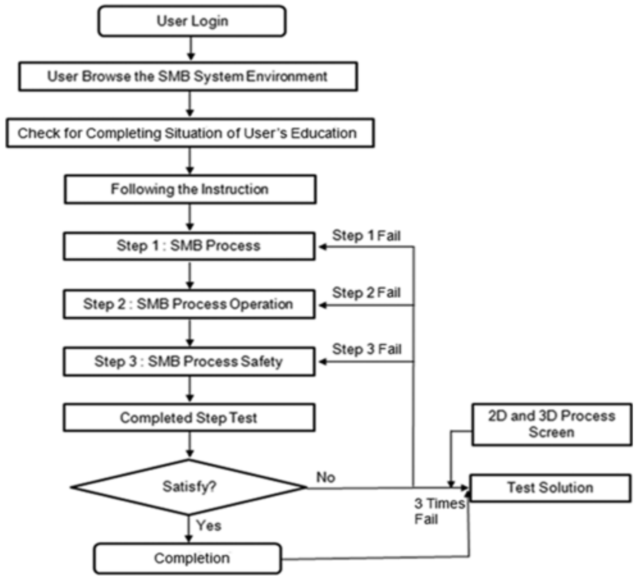

Fig. 13. Simplified flowchart of SMB process safety education system.

and training [10]. An example of 3D animation snapshot is shown in Fig. 11.

IMPLEMENTATION AND EXPECTED EFFECT

As shown in Fig. 12, the proposed education system is based on a client-server local network (LAN) environment, the protocol of which is TCP/IP.

The system is implemented in Extensible Hypertext Markup Language (XHTML). The client makes requests on program content display, animation play and login id check. The server provides a corresponding service requested by the client. The server comprises four components, such as XHTML user interface, 2D/3D animation, three modules for displaying education content and database. For virtual reality of SMB processing, the process flow is animated in multi-dimension using multi-media techniques such as FLASH and 3D-Max. Multi-dimension animations help operators comprehend the entire process flow of operational complexity. The web-based system enables operators to use it anywhere and anytime if they have a desktop or laptop. In addition, new content is easily added to the web page. Operators are asked to log in to use the system. Evaluation on operators as to ability to appropriately operate the SMB pilot plant is made by an examination as well. Fig. 9 shows the overall flowchart of the SMB safety education system for the operator. Once logged into the education system, users can experience the overall environment of SMB safety education system. They can grasp the learning steps by identifying learning completion status. Then, they can go through the learning process according to the education manual. Operators who experience the education system for the first time go through the learning process through Step 2 Process Operation and Step 3 Process Safety after learning the theory of SMB process of the first step. At the completion of all steps, each step is tested, and if test score is 60 points or above, the test is passed. If the test fails, the operator goes back to the failed step, reviews and then takes the test again. The process of review on process and safety through 2D flash or 3D screen is given to operators who have completed all the steps, and those who have failed a particular step three or more times for understanding the process and safety. Fig. 13 shows a flowchart for the SMB safety system.

Additionally, this education system has the following expected outcomes:

- Improvement of operator's indirect experience effect.
- Education possibility regardless of the time and place of the company.
- Improvement of ability to handle problems in a crisis when process emergency situation generated.
- Reduction of education investment expenses and time by online education.
- Decreasing of accident handling expense when process trouble users.
- Commercialization possibility of process education module content.

CONCLUSION

Companies need to ensure that newly developed SMB technology is fully understood by new operators through pilot plant scale education programs, which helps operation at full plant scale go through in a safe, reliable manner. A LAN-based online education system for SMB pilot plant is proposed with an emphasis on safe operation. Multi-dimensional animation of the process flow is provided for virtual reality as well. The proposed system is anticipated to contribute to keeping the full scale SMB operation workforce performing at a high level of proficiency as well as refreshing the operational skills of senior operators. The system is expected to be used for demonstration, education and training services. Operators are to receive education free of time and space restriction within the company. Furthermore, the web-based 3-D animation system is likely to have great motivational appeal for young operators who tend to embrace a web-based education environment. Finally, the web-based system is of easy maintenance in terms of adding new content or extending its applications to other various processes.

As a future work, the next version of the SMB education system will be updated adding to the novelty for detailed operator education and practical operator training procedures.

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