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Operator training simulator for biodiesel synthesis from waste cooking oil

Ahmad Z.[a], *Dipesh S. Patle*[b,*], *G.P. Rangaiah*[c]

[a] *School of Chemical Engineering, Engineering Campus, Universiti Sains Malaysia, Nibong Tebal, Penang 14300, Malaysia*
[b] *Chemical Engineering Division, School of Mechanical and Building Sciences, VIT University, Vellore, Tamilnadu 632014, India*
[c] *Department of Chemical & Biomolecular Engineering, National University of Singapore, Engineering Drive 4, 117585, Singapore*

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ABSTRACT

In this study, an operator training simulator (OTS) has been developed for the homogeneously catalyzed two-step biodiesel production from waste cooking oil (WCO). Biodiesel from WCO leads to cheaper production and also protects the environment by utilizing WCO effectively and producing non-polluting biodiesel. Currently, many biodiesel producers use homogeneous catalyst for biodiesel production due to faster reaction and moderate operating conditions. Process safety and efficient process operations require skilled operators. OTS is crucial in operators' training as on-job training is often costly, risky and incomplete. The developed standalone OTS has been investigated for a number of abnormal process scenarios. Each scenario can be inserted by an Instructor as and when it is desired. This study demonstrates the capability of a commonly used process simulator 'Aspen Plus Dynamics' (APD) and 'Aspen OTS Framework' in OTS development for the complex biodiesel process. Process model is developed in a modular fashion that facilitates easy addition or removal of any unit operation(s) in case of process modifications in the future.

1. Introduction

Non-renewable fossil fuels and their highly polluting nature make the search for alternative fuels inexorable. Among several alternatives, biodiesel is one of the most promising fuels (Daud et al., 2015). This is evident from the increasing interest in the world in replacing petroleum-based diesel by biodiesel. Main characteristics of biodiesel are: environment friendly, non-toxic, renewable and biodegradable (Amani et al., 2014; Atapour et al., 2014). Biodiesel (i.e. fatty acid methyl ester) is synthesized by chemically reacting lipids such as vegetable oil with the alcohol (Theam et al., 2015). Biodiesel can be synthesized economically by using waste cooking oil (WCO), which is cheaper than pure vegetable oils; this also facilitates better utilization of WCO as its direct disposal to the environment has adverse effects (Patle et al., 2014a; Hamze et al., 2015). Biodiesel synthesis by the transesterification of oil is efficient and faster with an alkali catalyst compared to an acid catalyst. However, the high free fatty acid (FFA) content in WCO leads to the saponification in the presence of an alkali catalyst. Thus, FFAs need be pre-treated with acid catalyst before performing transesterification. Canakci and Van Gerpen (2001) used a two-step process, where transesterification is performed after the esterification.

A two-step biodiesel synthesis from WCO includes many processes with several recycles. Such intricacy poses a tough challenge in safe and efficient operation of the process. Hazard-free and efficient process operation inevitably

* *Corresponding author*. Tel.: +91 416 2243091; fax: +91 416 2243092.
E-mail address: dipesh.patle@vit.ac.in (D.S. Patle).
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demands skilled operators. Nazir et al. (2012) reported that there is a need for developing an improved methodology to train operators efficiently as their performance directly influence the safety, productivity, profitability, stability and controllability of the process. Earlier, Drozdowicz et al. (1987) stated that training on the job under experienced operators' supervision does not enhance operators' skills adequately. Even experienced operators may lose their feel for the process eventually. Therefore, training using an operator training simulator (OTS) becomes useful as it takes care of these gaps by combining theoretical exercises and hands-on practice.

Our previous article (Patle et al., 2014b) presents a comprehensive review of OTS applications in the chemical industry from 1990 to mid-2013. We discussed in detail the need and applications of OTS in the chemical industry, issues related to OTS, salient features of a good OTS, commercial software packages used to build OTS, and training configurations. Yang et al. (2001) reported that substantial percentage of property losses in the hydrocarbon processing industries is attributed to the operational errors or process upsets. This emphasizes the necessity of skilled operators.

Dudley et al. (2008) reported that the increasing interest among process industries in utilizing OTS is due to the need for safe/accident-free operation, rapid evaluation of operating procedures, training operators for infrequent scenarios, reducing startup/shutdown times, maintaining on-spec production, effective controller tuning and what if analysis. Burkolter and Kluge (2012) found that the analysis of moderator effects between individual difference variables and process control performance is a promising way to enhance the understanding of trait variables (e.g. individual difference) and process control performance. Process control performance was analyzed by studying moderator effects of general mental ability and need for cognition on risky decision making and performance. Manca et al. (2013) presented the benefits of integrating a dynamic process simulator with a dynamic accident simulator in OTS training. Balaton et al. (2013) developed an OTS for a batch processing unit, where the process model was built in UniSim.

Nazir et al. (2013) proposed the plant simulator (PS) consisting of a dynamic process simulator and a dynamic accident simulator interlinked in an Immersive Virtual Environment (IVE). They showed that the adoption of a PS can increase the efficiency of the overall process safety through the enhancement of the process understanding, situation awareness, responsiveness, and the decision making processes of plant operators. Subsequently, Nazir and Manca (2014) presented a solution for immersive training of industrial operators that allows experiencing the multi-faceted scenarios of the real plant operations. They used a PS to simulate both normal and abnormal/accident scenarios dynamically, and showed its effectiveness in achieving process safety with the help of two case studies. Hass et al. (2014) proposed an OTS for a bioethanol plant to conduct resource efficiency studies. Kluge et al. (2014) suggested that current OTS training can be advanced in the light of distinct challenges that have arisen due to advancement in the control technology and the required crew coordination by using recent training environments, such as virtual reality training simulators. Nazir et al. (2015) presented the application, adaptation and influence of distributed situation awareness (DSA) in process industry. They proposed a measurement method for DSA and identified

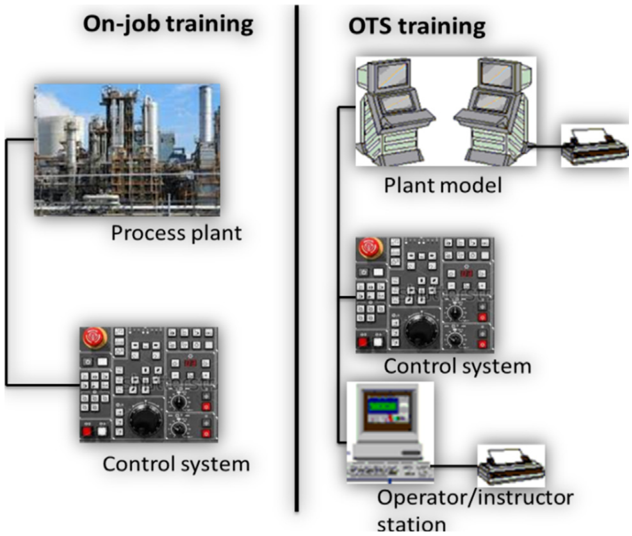

Fig. 1 – Comparison between on-job training (left) and OTS training (right).

specific DSA indicators taking a case study of a refinery subsection. This can enhance the learning curve significantly. Earlier articles on OTS for chemical processes (Zhiyun et al., 2003; Rao et al., 2003; Pereira et al., 2009; Bessiris et al., 2011) are briefly discussed in Patle et al. (2014b).

Other important uses of OTS are: evaluation of operators' ability, supporting engineering tasks such as investigating alternate control mechanisms and performing safety tests without endangering the real process (Fürcht et al., 2008; Rey et al., 2008). Performance evaluation algorithm can be developed and linked with OTS. For example, Lee et al. (2000) proposed a method of evaluating operators' plant manipulation capability by using an OTS. They developed task evaluation algorithm (TEA) to analyze and evaluate the operators' training results automatically after one finished the training by using GUI emulation of DCS. TEA includes two main modules: sequence evaluation module (SEM) and quantity evaluation module (QEM). The former indicates whether the operator follows the correct operating sequence that is prepared in advance. On the other hand, QEM gives the deviation of each operator's task from the standard operating procedure. TEA was shown to be efficient and effective in analysing the operator's capability.

Ayral and De Jonge (2013) estimated the total annualized benefits from an OTS for a 100,000 bpd refinery to be 4.9 million dollars. Fig. 1 demonstrates the comparison between on-job training and OTS training. Classically, the simulator includes a replica of the plant's control room (interfaces, hardware, screens, printers, etc.) and a software emulation of DCS coupled with process models (Spanel et al., 2001).

OTS development for biodiesel production from WCO is not available in the open literature. Also, application of Aspen Plus Dynamics (APD) with Aspen OTS Framework in OTS development is rare to find in the published articles. Hence, this study develops a standalone OTS for a two-step biodiesel production from WCO. This process has been simulated using Aspen Plus Dynamics V8.0. Optimal process parameters were determined using the elitist non-dominated sorting genetic algorithm (NSGA-II) in our previous study (Patle et al., 2014a). Later, the plantwide control (PWC) structure has been developed using the integrated framework of simulation and heuristics (IFSH), and has been implemented in APD (Patle et al., 2014c). Aspen OTS framework has been used on the top of APD simulation