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Scientific Research and Essays

Full Length Research Paper

Modeling teachers' influence on learners' self-directed use of electronic commerce technologies outside the classroom

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Nowadays, Electronic Commerce (EC) course is becoming one of the most important taught courses at all business schools due to increased businesses over the Internet network by utilizing all available technologies. However, the success of such courses cannot be measured by number of students who pass or fail but rather by how such courses influence and can change the daily life of these students. Previous literature stressed on the important role of the teacher in developing students' skills and knowledge and transferring this expertise outside the classroom. This study explores the factors explain teachers' influence on learners' use of EC technology outside the classroom. A questionnaire (survey) was developed and distributed to the students enrolled in the "introduction to EC" course at the Jordan of University. Using structured equation modeling (SEM) a total of 545 valid questionnaires were retrieved and analyzed. The results of the study showed that teachers' capacity support and behavior support are significant factors that established a facilitating condition which have a significant impact on students' computer self-efficacy. On the other hand, teachers' affection support and computer self-efficacy are found to be significant factors that strengthened students' perceived usefulness which supported the use of EC technology outside the classroom. As a result of increased students' computer self-efficacy and perceived usefulness, the empirical analysis revealed positive significant effect on students' use of EC technologies outside the classroom. This research presented a set of recommendations and polices that are very handful in developing successful EC courses that support the teachers' role, leverage student knowledge that goes beyond the classroom settings.

Key words: Electronic commerce, student skills, teacher influence, technology.

INTRODUCTION

Since the introduction of the Internet, electronic commerce (e-commerce or EC) grew vastly to dominate many aspects of how we buy and sell as both end customers and businesses. E-commerce is seen as the application of technology toward the automation of business transactions and workflow where money, information, services, and products are exchanged over the internet, networks, and other digital technologies

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(Whinston, 1997, Laudon and Laudon, 2004). In fact, e-commerce has become one of the most critical aspects of managerial strategy as organizations search for ways to compete more effectively in the global marketplace (Maqableh, 2010; Rezaee et al., 2005).

Recognizing the importance of e-commerce and to meet changing business environment and due to the lack of adequate course that tackle e-commerce, University of Jordan (UJ) has introduced an elective course for all university students run by Management Information Systems Department at the Business School. The course includes ten modules that cover: basic e-commerce concepts and models, e-commerce infrastructure, social commerce, e-marketing, e-payment methods and technologies, e-commerce security, mobile commerce, e-governments, e-business ethics and emerging e-commerce technologies (Maqableh, 2012; Masa’deh et al., 2013b). The lectures are normally three times a week, which are equal to 3 credit hours conducted in traditional class rooms not in labs. Thus the lecturers use classical teaching method while they strive to utilize case study and homework as a way to leverage the students’ practical experience.

In fact, e-commerce plays a very critical role in empowering young generation not only to enhance their educational skills inside the class rooms but more importantly to leverage and empower them in their daily lives. Hence it is very important for faculty members (teachers) not only to make sure that they introduce their students to e-commerce education in the class room but also to influence their students to utilize e-commerce services and technologies outside the class rooms. Furthermore, teachers represent important mediators for transferring the knowledge outside the classroom to real life practice (Davis, 2003; Masa’deh et al., 2013a; Katyal and Evers, 2004). However, the factors that influence students’ use of e-commerce outside the classroom can range from teachers' expectancies, peers' encouragement and support, encouragement, guidance and learning materials (Lai, 2015).

Yet, investigating the factors that define how teachers influence their students outside the classroom especially in an essential topic like e-commerce and in a developing country context can reveal very interesting results. Consequently, this work seeks to contribute to the literature by modeling teachers' influence on students' use of e-commerce outside the classroom in University of Jordan as a case that can be replicated to other developing countries.

THEORETICAL BACKGROUND AND HYPOTHESES DEVELOPMENT

Although the theoretical framework of this study was adopted from Lai (2015) (Figure 1), a number of significantly related studies that provide additional support for the theoretical foundation while seeking to explore the attributes that influence learners' use of e-Commerce technologies outside the classroom were reviewed. Here, two key aspects which are the focus of the model will be discussed, viz: the key theories of technology adoption and use and teachers role (affection, capacity and behavior) in supporting learners’ use of technology.

E-commerce has long been recognized as one of the most significant technologies that have received very little attention in higher education and academia. In fact, Rezaee et al. (2005) have explicitly stressed that e-commerce education has not received adequate coverage despite the high demand and interest in e-commerce education and the importance of integration e-commerce education where the exponential growth in e-commerce increases the demand for individuals possessing sufficient knowledge and experience in e-commerce. However, introducing an e-commerce course at the University level course may not enough to produce such qualified e-commerce individuals or meet the market demand. In fact, teachers and students have to work together to carry out the knowledge from the classroom to the daily life. Such approach in teaching e-commerce can help transform the learning experience and heavily influence the success of the learners' in their personal life as more business and work activities are based on e-commerce technologies.

Many factors control learners’ use of e-commerce technology or any other technology outside the classroom in the daily life. In fact, when it comes to technology use, a large number of previous studies rely on the grounded theories of technology adoption and use. Technology Acceptance Model (TAM) is one significant technology acceptance and usage models that was developed by Davis et al. (1989). TAM was the first to introduce two main concepts namely: “perceived usefulness” and “perceived ease-of-use” as the main factors that contribute to technology acceptance and use. While TAM itself was an extension theory of reasoned action (TRA) (Ajzen and Fishbein, 1980), an important theory and extension to the TAM was later developed by Venkatesh et al. (2003) known as the unified theory of acceptance and use of technology (UTAUT) model. UTAUT defined four determinants of technology usage intention and use behavior, namely: 1) performance expectancy, 2) effort expectancy, 3) social influence, and 4) facilitating conditions.

TAM, UTAUT and many other variation, extensions and models were used and developed to explore and define the factors that influence teachers and learners use of technology in and outside the classroom. For instance, Hsu et al. (2009) used a modified Technology Acceptance Model (TAM) model to explore the factors that control business students learning and use of statistical software. Their results showed that computer attitude and statistical software self-efficacy have

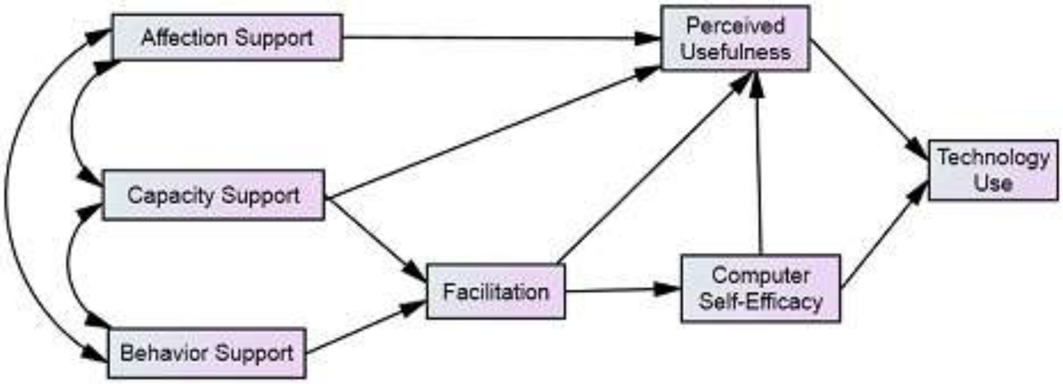

Figure 1. Theoretical model (Adopted from Lai, 2015).

significant, positive effects on perceived usefulness, while perceived usefulness and perceived ease of use positively affect learners' intentions to use statistical software. In a related study by Mohammadi (2015) in which he studied the impact of quality features, perceived ease of use, perceived usefulness on the intention to use e-learning technologies in Iran and found that intention to use, user satisfaction, system quality and information quality are key factors driving users use and satisfaction of e-learning. In another work by Mohammadyari and Singh (2015) using Unified Theory of Acceptance and Use of Technology (UTAUT), revealed a clear relation between an individual's level of digital literacy (defined as the ability to understand, analyze, assess, organize and evaluate information using digital technologies) and individuals' performance and using of e-learning technologies.

In the last few years, many researchers have focused on how student put the education they receive in the class room into practice outside the classroom and explored the factors that control this process. For instance, Lai et al. (2012) in their study titled "What factors predict undergraduate students' use of technology for learning? A case from Hong Kong", found that compatibility of technology, learning styles, availability of encouragement and support from peers and teachers, and attitudes toward technology use were dominant predictors of students' technology use for learning. However, their work revealed that perceived usefulness and ICT literacy skills had less predictive power that contribute to students' technology use for learning.

Research has accumulate evidence that some key factors that influence students' use of technology inside and outside the class room include; the learning value and subject, influence from peers, parents and community scientific literacy, users interest access to ICT, students' background, school/home environment, computer self-efficacy and individuals' past experience (Erdogdu and Erdogdu, 2015; Compeau and Higgins, 1995; Chan et al., 2015; Fauville et al., 2015; Bandura, 1977). In general, Kopcha (2012) defined three general "categories" of factors that can be either barriers or enablers for technology integration and use inside and outside the classroom namely: teacher-related behavior, technology use, and student-related behavior, yet as many researcher argue, teacher role remains the most single important factor that can heavily contribute to the successful use of technology by learners inside and outside the classroom. Yet, teachers' role is dependent on many aspects that are related to them. In fact, teachers' beliefs, skills, leadership and characteristics are just some of these critical aspects that affect learners' use of technologies in and outside the classroom.

Ertmer et al. (2012) examined teacher beliefs and their effect on their technology integration and practices and found teachers' beliefs and attitudes were perceived as having the biggest impact on student success while factors such as passion for technology, problem-solving mentality, and support, played a role in shaping their practices. In conclusion, the authors highlighted that the attitudes and beliefs toward technology, their knowledge and skills are either the key enablers or barriers for integration technology in the teaching and learning process.

Another related study that deals with teachers' beliefs and technology integration, Kim et al. (2013) found that teacher beliefs about the nature of knowledge and learning (epistemology), Teachers' beliefs about effective ways of teaching (conceptions), and technology integration practices are important attributes when seeking to integrate technology practice. Another study entitled "Identifying discriminating variables between teachers who fully integrate computers and teachers with limited integration" by Mueller et al. (2008) found that teacher's comfort with computers, beliefs of computers as an instructional tool, training, motivation, support, and teaching efficacy are primary factors that have positive influence on learners and teachers.

However, teachers' belief is not only enough, teachers' skills and the way of they present and deliver materials

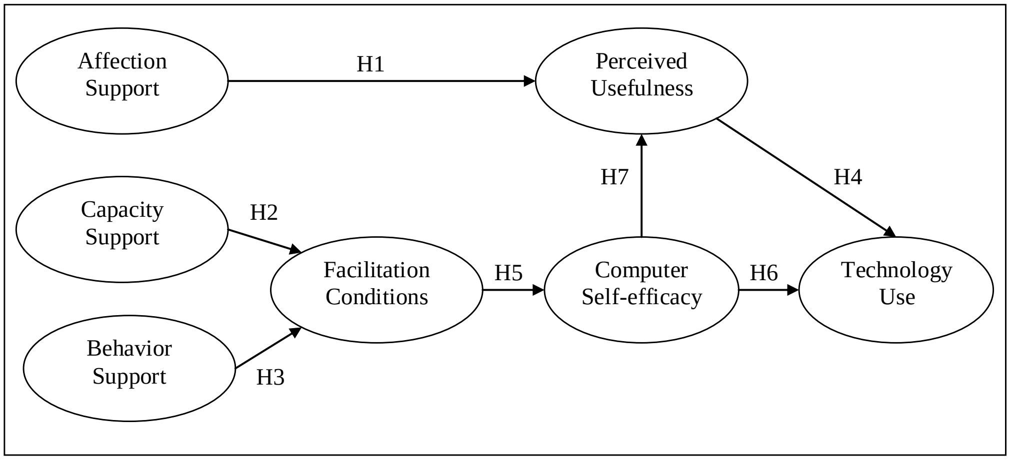

Figure 2. Research model.

can be significant factors. In fact, Ottenbreit-Leftwich et al. (2010) showed that technology use is dependent on creating customized classroom materials, improving classroom management, enhancing student comprehension, with technology skills, and promoting student learning. Moreover, Hao and Lee (2015) in their study on integrating Web 2.0 technologies in the process of learning and teaching, found that teachers' characteristics such as levels of Web 2.0 usage in instruction, gender, and discipline area explain the usage and integration stage of web 2.0 technology that varies from just informational to become knowledge and collaboration usage.

Furthermore, Hung and Chou (2015) in their study on students and teachers behavior in blended and online learning environments found that course designer and organizer, discussion facilitator, social supporter, technology facilitator, and assessment designer are key factors in both environment and were similar across the blended learning and online learning. Although, students exhibited the greatest weight for the course designer and organizer dimension, followed by the technology facilitator and discussion facilitator dimension, in the online learning environments discussion facilitator dimension was more critical. Yet, in any case using technology tools will always be rewarding. In fact, a study by Chuang, et al. (2015) explored teachers' technology integration practice and its relation to their technological pedagogical content knowledge (TPCK) and found that teachers' technology integration practice with ICT tools is linked directly to TPCK scores and more importantly they revealed the link between social media and self-assessed TPCK.

However, the teaching and learning process is changing. Universities role is shifting dramatically from their traditional teaching and learning delivery models to an online version enabled by Web 2.0 technologies and led by groups and communities characterized by increase knowledge sharing and self-learning (Kulakli and Mahony, 2014). Hence, some may argue that teachers' role and influence may be diminishing. Up-to-date many of the previous studies revealed the contradictory. In fact, although learning using Web 2.0 technologies have dramatically broaden the classroom environment allowing more learners' participation and increasing creative behavior while transforming education research and practice (Greenhow et al., 2009) and creating greater autonomy in students' learning, teachers' leadership and guidance still have an important impact on students' engagement and learning experience in and outside the classroom (Katyal and Evers, 2004).

Deepwell and Malik (2008) investigated how students utilize learning technology for self-directed learning, where they examined; student expectations of the technology, lecturers' engagement and technology support of education process and revealed that academic guidance, effective technology use, and lecturer role are significant factors for students' self-directed learning in and out-side the class rooms.

In summary, whatever the teachers' role entail from behavioral, capacity and affection support, their role remain the one of the most profound aspects that promote and support students' inside and most importantly outside classroom (Lai, 2015).

Based on previous literature review and the work of Lai (2015), Figure 2 demonstrates the research's conceptual framework and the hypothesized relationships between the adopted constructs.

H1: Affection Support will have a positive effect on Perceived Usefulness.

H2: Capacity Support will have a positive effect on Facilitation Conditions.
H3: Behavior Support will have a positive effect on Facilitation Conditions.

Table 1. Constructs and measurement items.

Construct	Measurement Items
Affection Support (AS)	AS1: My teacher encourages us to use electronic commerce technology outside the classroom. AS2: My teacher discusses with us how to use electronic commerce technological resources or tools outside the classroom.
Capacity Support (CS)	CS1: My teacher shares with us useful electronic commerce technology resources/sites/tools. CS2: My teacher shares tips/strategies on how to use electronic commerce technology resources or tools.
Behavior Support (BS)	BS1: My teacher often uses electronic commerce technology resources or tools in her/his classes. BS2: My teacher engages us with activities that involve the use of electronic commerce technology resources or tools. BS3: My teacher assigns class assignments that are based on electronic commerce technology resources.
Facilitation Conditions (FC)	FC1: I have the resources necessary to use electronic commerce technologies. FC2: I have the knowledge necessary to use electronic commerce technologies. FC3: When I need help on using electronic commerce technology, someone is there to help me.
Perceived Usefulness (PU)	PU1: This course enhances my electronic commerce knowledge. PU2: This course improves my electronic commerce experience. PU3: This course helps monitor my electronic commerce learning progress. PU4: This course sustains or enhances my motivation and interest in using electronic commerce. PU5: This course expands my electronic commerce learning resources and venues. PU6: This course expands my electronic commerce use opportunities.
Computer Self-Efficacy (CE)	CE1: I am confident with my abilities in using electronic commerce technologies effectively. CE2: I am confident with my abilities in selecting appropriate electronic commerce technologies for my needs. CE3: I am confident with my abilities in using electronic commerce technologies to create enjoyable experience.
Technology Use (TU)	TU1: I use electronic commerce technology in real life outside class room. TU2: I use electronic commerce technology to help me achieve my goals. TU3: I use electronic commerce technology to help me progress. TU4: I use electronic commerce technology to seek new business strategies and tips. TU5: I use electronic commerce technology to expand my business opportunities. TU6: I use electronic commerce technology to sustain/enhance motivation and interest me in business. TU7: I use electronic commerce technology to seek engaging in business activity or experience.

H4: Perceived Usefulness will have a positive effect on Technology Use.
H5: Facilitation Conditions will have a positive effect on Computer Self-efficacy.
H6: Computer Self-efficacy will have a positive effect on Technology Use.
H7: Computer Self-efficacy will have a positive effect on Perceived Usefulness.

METHODOLOGY

This research uses structural equation modeling (SEM) approach based on AMOS 20.0 to study the relationships and to test the hypotheses between the observed and latent constructs in the proposed research model. SEM is a statistical methodology that uses a confirmatory (that is, hypothesis-testing) approach to the analysis of a structural theory, bearing in mind certain phenomena. Normally, this theory embodies ‘causal’ processes that make observations on multiple variables (Bentler, 1990). Furthermore, the structural equation modeling process consisted of two components: validating the measurement model and fitting the structural model. While the former is accomplished through exploratory factor analysis, the latter was accomplished by path analysis with latent variables (Kline, 2005). Using a two-step approach assures that only the constructs retained from the survey that have good measures (validity and reliability) will be used in the structural model (Hair et al., 2010).

The basis for data collection and analysis is a field study in which respondents answered all items on a five point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Based on the theoretical framework of this study adopted from Lai (2015), research elements provided a valued source for data gathering and measurement as their reliability and validity have been verified through previous research and peer reviews. Table 1 shows the measured constructs and the items measuring each construct.

Sample and procedure

Empirical data for this study were collected through computer-based survey in Jordan. Specifically, survey questionnaire was

Table 2. Demographic data for respondents.

Category	Frequency	%
Gender		
Male	175	32.1
Female	370	67.9
Total	*545*	*100*
Age		
17 years- less than 20	173	31.7
20 years - less than 23	338	62.0
23 years - less than 26	25	4.7
26 years - less than 30	5	0.9
30 years and above	4	0.7
Total	*545*	*100*
Academic Level		
Year 1	31	5.7
Year 2	226	41.5
Year 3	191	35.0
Year 4	77	14.1
Year 5	20	3.7
Total	*545*	*100*
Number of daily hours using different types of Information Technology		
Less than half an h	24	4.4
Half an hour – 1 h	76	13.9
1 h - less than 3 h	219	40.2
3 h and above	226	41.5
Total	*545*	*100*

used to gather data for hypotheses testing from University of Jordan. Before implementing the survey, the instrument was reviewed by four lecturers who are specialized in the Management Information Systems (MIS) discipline in order to identify problems with wording, content, and question ambiguity.

The population of this study consists of all students from Business School at the University of Jordan located in Jordan, which counts are more than 6000 according to the university's registration unit. The students from Jordan University Business School were selected as sample using simple random sampling method (that is, probabilistic sampling) by which the elements do not have a known or predetermined chance of being selected as subjects. The sample size of this study was determined based on the rules of thumb for using SEM within AMOS 20.0 in order to obtain reliable and valid results. Kline (2010) suggested that a sample of 200 or larger is suitable for a complicated path model. Furthermore, taking into account the complexity of the model which considers the number of constructs and variables within the model and after eliminating the incomplete responses surveys (24), our sample size (545) meets the recommended guidelines of Kline (2010), Krejcie and Morgan (1970) and Pallant (2005). The demographic data of the respondents are reported in Table 2.

As shown in Table 2, the demographic profile of the respondents for this study revealed that the sample consisted of more females; most of them between 17 and less than 23 years old, in their second and third academic years, and most of them use different types of IT more than 3 h.

RESEARCH RESULTS

Descriptive statistics

Several statistical methods take account of outliers (that is, cases with values well over or well under the majority of other cases), since the latter might affect the validity and reliability of the data (Pallant, 2005). Outliers were examined by using the box-plot method to determine them, and then compared the original mean with the 5% trimmed mean, to identify whether the outlier scores have a lot of impact on the mean. However, after careful examinations, no noticeable outliers were found from the 545 valid cases. As a result, it was decided to proceed to further examination using the 545 valid dataset. All the 26 items were tested for their means, standard deviations, skewness, and kurtosis.

The descriptive statistics presented below in Table 3 indicate a positive disposition towards the items. While the standard deviation (SD) values ranged from 0.74902 to 0.99540, these values indicate a narrow spread around the mean. Also, the mean values of all items were greater than the midpoint (2.5) and ranged from 3.7394 (BS1) to

Table 3. Mean, standard deviation of scale items.

Construct/Items	Mean	S.D	Order	Rank	Skewness	Kurtosis
Affection Support						
AS1:	4.1064	0.88058	1	High	-1.084	1.342
AS2:	3.9872	0.91847	2	High	-0.989	0.915
Capacity Support						
CS1:	4.1872	0.82126	1	High	-1.218	2.057
CS2:	4.1046	0.84783	2	High	-1.109	1.546
Behavior Support						
BS1:	3.7394	0.99540	3	High	-0.649	-0.780
BS2:	3.9266	0.92659	1	High	-0.828	0.405
BS3:	3.8624	0.98582	2	High	-0.918	0.228
Facilitation Conditions						
FC1:	3.9266	0.93253	3	High	-0.959	0.849
FC2:	3.9321	0.84289	2	High	-0.814	0.808
FC3:	3.9651	0.91187	1	High	-0.982	1.138
Perceived Usefulness						
PU1:	4.0495	0.90511	1	High	-0.979	0.911
PU2:	4.0459	0.92539	2	High	-1.069	1.103
PU3:	3.9982	0.95390	4	High	-1.119	1.265
PU4:	4.0220	0.91529	3	High	-1.141	1.476
PU5:	3.9817	0.92932	5	High	-1.108	1.323
PU6:	3.9431	0.89857	6	High	-0.926	0.991
Computer Self-Efficacy						
CE1:	3.9596	0.87564	3	High	-1.026	1.478
CE2:	3.9598	0.83700	2	High	-0.943	1.323
CE3:	4.0183	0.78803	1	High	-0.983	1.825
Technology Use						
TU1:	4.1615	0.86368	3	High	0.531	1.199
TU2:	4.1619	0.82224	2	High	-0.627	1.323
TU3:	4.2000	0.74902	1	High	-0.564	1.413
TU4:	4.0532	0.82187	6	High	0.531	1.713
TU5:	4.0734	0.87559	5	High	-0.627	1.361
TU6:	4.1119	0.82490	4	High	-0.627	2.100
TU7:	4.0202	0.83883	7	High	-0.564	0.887

4.2000 (TU3).

However, after careful assessment by using skewness and kurtosis, the data were found to be normally distributed. Indeed, skewness and kurtosis were normally distributed since all of the values were inside the adequate ranges for normality (that is, -1.0 to +1.0) for skewness, and less than 10 for kurtosis (Kline, 2010). Furthermore, the ordering of the items in terms of their means values, and their ranks based on three ranges (that is, 1 – 2.33 low; 2.34 – 3.67 medium; and 3.68 – 5 high) are provided.

Table 4 shows different types of goodness of fit indices in assessing this study initial specified model. It demonstrates that the research constructs fits the data according to the absolute, incremental, and parsimonious model fit measures, comprising chi-square per degree of freedom ratio (x^2/df), Incremental Fit Index (IFI), Tucker-Lewis Index (TLI), Comparative Fit Index (CFI), and Root Mean Square Error of Approximation (RMSEA). The researchers examined the standardized regression

Table 4. Measurement model fit indices.

Model	x²	Df	P	x²/df	IFI	TLI	CFI	RMSEA
Final model	809.195	278	0.000	2.911	0.94	0.93	0.94	0.059

weights for the research's indicators and found that all indicators had a high loading towards the latent variables. Moreover, since all of these items meet the minimum recommended value of factor loadings of 0.50; and RMSEA less than 0.10 (Newkirk and Lederer, 2006), they were all included for further analysis. Therefore, the measurement model showed a better fit to the data (as shown in Table 3). For instance, x²/df was 2.911, the IFI = 0.94, TLI = 0.93, CFI = 0.94; and RMSEA 0.059 indicated better fit to the data considering all loading items.

Measurement model

Confirmatory factor analysis (CFA) was conducted to check the properties of the instrument items. Indeed, prior to analyzing the structural model, a CFA using AMOS 20.0 was conducted to first consider the measurement model fit and then assess the reliability, convergent validity and discriminant validity of the constructs (Arbuckle, 2009). The outcomes of the measurement model are presented in Table 5, which encapsulates the standardized factor loadings, measures of reliabilities and validity for the final measurement model.

Unidimensionality

Unidimensionality is the extent to which the study indicators deviation from their latent variable. An examination of the unidimensionality of the research constructs is essential and is an important prerequisite for establishing construct reliability and validity analysis (Chou et al., 2007). Moreover, in line with Byrne (2001), this research assessed unidimensionality using the factor loading of items of their respective constructs. Table 5 shows solid evidence for the unidimensionality of all the constructs that were specified in the measurement model. All loadings were above 0.50 which is the criterion value recommended by Newkirk and Lederer (2006). These loadings confirmed that 26 items were loaded satisfactory on their constructs.

Reliability

Reliability analysis is related to the assessment of the degree of consistency between multiple measurements of a variable, and could be measured by Cronbach alpha coefficient and composite reliability (Hair et al., 1998). Some scholars (e.g. Bagozzi and Yi, 1988) suggested that the values of all indicators or dimensional scales should be above the recommended value of 0.60. Table 5 indicates that all Cronbach-α values for the seven variables exceeded the recommended value of 0.60 (Bagozzi and Yi, 1988) demonstrating that the instrument is reliable. Furthermore, as shown in Table 5, composite reliability values ranged from 0.75 to 0.93, and were all greater than the recommended value of more than 0.60 (Bagozzi and Yi, 1988) or greater than 0.70 as suggested by Holmes-Smith (2001). Consequently, according to the above two tests, all the research constructs in this study are considered reliable.

As shown in Table 5, since the measurement model has a good fit; convergent validity and discriminant validity can now be assessed in order to evaluate if the psychometric properties of the measurement model are adequate.

Content, convergent, and discriminant validity

Although reliability is considered as a necessary condition of the test of goodness of the measure used in research, it is not sufficient (Creswell, 2009; Sekaran, 2003; Sekaran and Bougie, 2013), thus validity is another condition used to measure the goodness of a measure. Validity refers to which an instrument measures is expected to measure or what the researcher wishes to measure (Blumberg et al., 2005).

Indeed, the items selected to measure the seven variables were validated and reused from previous researches. Therefore, the researchers relied upon in the validity of the scale that was a pre-used scale that was developed from other researchers. In addition, the questionnaire items were reviewed by four instructors of the Business Faculty at University of Jordan. The feedback from the chosen group for the pre-test contributed to enhanced content validity of the instrument to confirm that the knowledge presented in the content of each question was relevant to the studied topic.

Furthermore, as convergent validity test is necessary in the measurement model to determine if the indicators in a scale load together on a single construct; discriminant validity test is another main one to verify if the items developed to measure different constructs are actually evaluating those constructs (Gefen et al., 2000). As shown in Table 5, all items were significant and had loadings more than 0.50 on their underlying constructs.

Table 5. Properties of the final measurement model.

Constructs and indicators	Std. loading	Std. error	Square multiple correlation	Error variance	Cronbach-α	Composite reliability	AVE
Affection Support					0.760	0.80	0.66
AS1	0.770	***	0.593	0.315			
AS2	0.796	0.063	0.634	0.308			
Capacity Support					0.811	0.86	0.76
CS1	0.827	***	0.683	0.213			
CS2	0.825	0.052	0.681	0.229			
Behavior Support					0.745	0.76	0.52
BS1	0.636	***	0.404	0.589			
BS2	0.817	0.087	0.668	0.285			
BS3	0.671	0.084	0.451	0.533			
Facilitation Conditions					0.782	0.93	0.67
FC1	0.761	***	0.580	0.580			
FC2	0.776	0.052	0.602	0.602			
FC3	0.686	0.056	0.471	0.471			
Perceived Usefulness					0.923	0.93	0.71
PU1	0.790	***	0.624	0.308			
PU2	0.814	0.050	0.663	0.288			
PU3	0.871	0.050	0.758	0.220			
PU4	0.851	0.049	0.724	0.231			
PU5	0.818	0.050	0.668	0.286			
PU6	0.761	0.049	0.578	0.340			
Computer Self-Efficacy					0.860	0.75	0.50
CE1	0.753	***	0.567	0.567			
CE2	0.859	0.054	0.738	0.738			
CE3	0.855	0.051	0.731	0.731			
Technology Use					0.905	0.75	0.50
TU1	0.699	***	0.489	0.380			
TU2	0.771	0.062	0.594	0.274			
TU3	0.779	0.057	0.607	0.220			
TU4	0.778	0.062	0.606	0.266			
TU5	0.796	0.066	0.633	0.281			
TU6	0.777	0.063	0.604	0.269			
TU7	0.735	0.063	0.540	0.323			

Moreover, the standard errors for the items ranged from 0.050 to 0.087 and all the item loadings were more than twice their standard errors.

Discriminant validity was considered using several tests. First, it could be examined in the measurement model by investigating the shared average variance extracted (AVE) by the latent constructs. The correlations among the research constructs could be used to assess discriminant validity by examining if there were any extreme large correlations among them which would imply that the model has a problem of discriminant validity. If the AVE for each construct exceeds the square correlation between that construct and any other constructs then discriminant validity is occurred (Fronell and Larcker, 1981).

As shown in Table 5, this study showed that the AVEs of all the constructs were above the suggested level of 0.50, implying that all the constructs that ranged from

Table 6. AVE and square of correlations between constructs.

Constructs	AS	CS	BS	FC	PU	CE	TU
AS	0.66						
CS	0.64	0.76					
BS	0.59	0.61	0.52				
FC	0.57	0.58	0.49	0.67			
PU	0.55	0.56	0.47	0.59	0.71		
CE	0.51	0.44	0.47	0.60	0.54	0.50	
TU	0.58	0.53	0.49	0.62	0.58	0.47	0.50

Diagonal elements are the average variance extracted for each of the seven constructs. Off-diagonal elements are the squared correlations between constructs.

Table 7. Summary of proposed results for the theoretical model.

Research proposed paths	Coefficient value	t-value	p-value	Empirical evidence
H1: Affection Support → Perceived Usefulness	0.360	11.766	0.000	Supported
H2: Capacity Support → Facilitation Conditions	0.255	7.002	0.000	Supported
H3: Behavior Support → Facilitation Conditions	0.288	7.975	0.000	Supported
H4: Perceived Usefulness → Technology Use	0.339	10.962	0.000	Supported
H5: Facilitation Conditions → Computer Self-Efficacy	0.728	24.391	0.000	Supported
H6: Computer Self-Efficacy → Technology Use	0.355	11.406	0.000	Supported
H7: Computer Self-Efficacy → Perceived Usefulness	0.456	13.274	0.000	Supported

0.50 to 0.76 were responsible for more than 50% of the variance in their respected measurement items, which met the recommendation that AVE values should be at least 0.50 for each construct (Bagozzi and Yi, 1988; Holmes-Smith, 2001).

Furthermore, as shown in Table 6, discriminant validity was confirmed as the AVE values were more than the squared correlations for each set of constructs. Thus, the measures significantly discriminate between the constructs.

Structural model and hypotheses testing

In order to examine the structural model it is essential to investigate the statistical significance of the standardized regression weights (that is, t-value) of the research hypotheses (that is, the path estimations) at 0.05 level (Table 7); and the coefficient of determination (R^2) for the research endogenous variables as well.

The coefficient of determination for Facilitation Conditions, Perceived Usefulness, Computer Self-Efficacy, and Technology Use were 0.17, 0.37, 0.52, and 0.46 respectively, which indicates that the model does account for the variation of the proposed model. Nevertheless, the significant yet limited predictive power R^2 of our model indicates high potential to better understanding the relationships among the research variables through incorporating additional variables and exploring factors that could impact the endogenous variables.

DISCUSSION

The results of this study provided empirical support for all research hypotheses. However, the level of support and influence for each hypothesis display some diversity in the model.

H2, and H3 capacity support and behavior support suggests teachers support and use of EC technology play a significant role in equipping the students with the necessary capability and knowledge required to use EC inside and outside the classrooms. In another word, those teachers sharing EC resources such as useful websites and tools along with EC tips and strategies will grow students EC and competence and facilitate their use of EC inside and outside the classrooms. As well, teacher's who actually use EC technology in their classes and involve their students in these activities or give them as assignments in these courses are more likely to increase students' competence, capabilities and likelihood to use EC technologies outside the classrooms. In fact, previous literature provides numerous researches to support this argument. For instance, Kopcha (2012), Ertmer et al. (2012), Ottenbreit-Leftwich et al. (2010) and many others showed the importance role of teachers' inside the classroom in supporting the use of technology and how their behavior can facilitate and support students use of technology as they will be more familiar and capable of using technology. Moreover, Deepwell and Malik (2008) as well as Lai (2015) reported that teachers recommendation and guidance on how to use the resources affects their students' self-directed use of technology while increasing their perceived usefulness of such resources and improving their know-how and experiences of technologies in and out of classrooms.

As a result of increased capacity support and behavior support that create a facilitating support through increase student competence, capabilities and likelihood to use EC technologies, H5 showed that these facilitation conditions have a positive effect on computer self-efficacy. This indicates that students will have greater self-confidence in their abilities and capabilities to select and use of proper electronic commerce technologies while enjoying this experience. The same was reported by Chang and Tung (2008), Compeau and Higgins (1995) as well as in the work of Hsu et al. (2009). It is expected that students' confidence will very much increase in their ability to select and use proper technologies effectively if they are given the right practical education and guidance especially in age characterized by overwhelming diversity in technologies available at hand (Levy, 2009). Hence it is no wonder that facilitating conditions are established as moderator that influence students skills, confidence and hence their computer self-efficacy which will later influence the use and adoption of technology (Yousafzai et al., 2007).

The results of H1 and H7 revealed a significant positive impact of affection support and computer self-efficacy on perceived usefulness. In fact, the results indicate that teachers' encouragement and actual use of EC technologies in this EC course in addition to students' confidence in selecting and using suitable EC technologies that fit their needs will leverage students' perceived usefulness of these technologies. This means that students' believe that such EC course improved their knowledge, experience and interest while expanding their EC resources and chances to use EC technologies inside and outside the classroom. A number of researchers have revealed the importance of both teachers encouragement and students' confidence and in their study on students' perceived usefulness for using learning such technologies inside and outside the classroom (Deepwell and Malik, 2008; Yousafzai et al., 2007). Ertmer et al. (2012), Lai (2015), Katyal and Evers (2004) and many others suggested a positive effect for affection support and computer self-efficacy on technology use and adoption by building up perceived usefulness.

Finally the results form H4 and H6 as many previous literature showed clearly that perceived usefulness and computer self-efficacy have a positive effect on EC technology use inside and outside the classroom. The results indicate that the course increased students' knowledge, experience and interest in using EC while increasing their confidence.

Consequently, this influence students EC technology use outside the classroom and in real life to progress, widen their opportunities and engages in new activities or experiences. As a matter of fact, perceived usefulness has long been considered a key factor that influences technology adoption since the introduction of the TAM Models (Davis et al., 1989; Davis, 2003; Venkatesh et al., 2003). At the same time many previous studies such as Yousafzai et al. (2007) revealed that computer self-efficacy can heavily affect the adoption and use of technology.

In particular, the work of Moss and Azevedo (2009) exposed a clear effect of computer self-efficacy on learning and use of technology in the learning environments. Hence, it is very important for students get the motivation, confidence and skills needed to utilize EC technologies outside the classrooms.

RECOMMENDATIONS AND CONCLUSIONS

Based on previous discussion and research results, the following recommendations can be considered:

1) To boost affection support, teachers need to use different motive tools to encourage their students to use EC technologies outside the classrooms. These include: extra curriculum activities, EC website use, homework's, extra grades, group discussions, group projects and EC case study analysis.

2) To build up Facilitation Conditions (FC) through capacity and behavior support, teachers have to use teaching by example approach and keep updating their students with the latest and useful EC technologies and tools. Hence, classrooms need to be equipped with computers or laptops along with internet connections so the teachers can illustrate and show their students EC in action. At the same time, teachers need to keep up-to-date information on latest EC technologies while developing their skills and accumulating EC resources. Most importantly, teachers are required to engage their students in these activities so they develop their skills, knowledge and practical experience in utilizing EC technologies.

3) In order to keep the perceived usefulness of EC technologies especially outside the classroom, such courses need to have a combination of interesting and useful EC resources and illustration. This will help both the teachers and students to take what they learn to the next level. Moreover, if such courses are associated with practical labs or at least pre-defined mandatory lab visits, they will definitely enhance students experience and knowledge while improving their learning process and outcomes.

4) Teachers play a significant role in developing students'

self-esteem and confidence to us and utilize EC technologies not only inside classroom but also outside the classroom. Hence, teachers need to understand that their role exceeds transferring knowledge, expertise and skills, but they have to keep in mind that they have to work on the moral and psychology of their students in ways that increase their self-confidence in using such technologies especially in eastern cultures such as Jordan were the culture of using EC technologies is still uncommon and not supported.

5) Finally, in order for students use to EC technologies outside the classrooms, they need to find them useful, helpful and full opportunities for them to progress. Therefore, the class settings, materials, and most importantly the teachers have to be structured around its utility for the students and community. Thus, a systematic review and evaluation not for the student utility but for the course materials and teachers as well need to be in place. Additionally, a regular update of at least course materials and resources is needed to keep the course useful, interesting and practical particularly in this age of rapid technology developments.

In summary, this research explored the factors and role of teachers in encouraging and developing students' skills and knowledge to use EC technologies outside the classroom. The results of the study revealed the important role of teachers in leveraging students' capacity and developing their positive behavior to use EC technologies through the advancement of their computer self-efficacy. At the same time, the results showed a significant impact for teachers' encouragement and support in increasing students' confidence and perceived usefulness of EC technologies and tools outside the classroom. Hence, developing successful EC courses that expand the walls of the classrooms require proper teachers' development and support, increased students' role and updated practical materials that are useful for the students' in their education, daily life and future plans.

LIMITATIONS AND FUTURE WORK

This study has some limitations that need to be addressed in future studies. First and for most, since the model is very holistic and general other factors that account for country specific and cultural aspects should be tested. Moreover, as such courses are taught by different teachers, teachers' characteristics and teaching styles need to be considered as well. Hence, an extended model can be developed to account for these aspects and later compared with this study model and results.

Another limitation of this study is the study time line and sample; future work should be extended to cover a time series and new groups of students to validate and confirm this study results while reducing any bias in survey research. Altogether, these are some of the challenges that represent noteworthy future work that may lead to interesting findings.

Conflict of Interests

The authors have not declared any conflict of interests.

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Scientific Research and Essays

Full Length Research Paper

On the computational fluid dynamics (CFD) analysis of the effect of jet nozzle angle on mixing time for various liquid heights

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In the present work, the effect of nozzle angle (22.5º, 45º and 67.5º) on mixing time for jet mixing tanks with the various ratios of liquid height (*H*) to tank diameter (*D*), including 0.5, 1, and 1.5, are studied by using computational fluid dynamics (CFD). The results revealed that CFD model with standard k-epsilon is successfully employed to predict the concentration profiles and mixing time by using the fine mesh and second order upwind scheme. The simulated results showed that the different jet nozzle angles result in different flow patterns. The results also indicate that the mixing time is mainly a function of the jet potential core length. Moreover, the jet path length or jet centerline velocity (jet kinetic energy) is considered as the secondary effect on mixing time, which depends on the tank geometry.

Key words: Computational fluid dynamics (CFD), jet, mixing, turbulence, k-epsilon model.

INTRODUCTION

Mixing is one of the most important processes in chemical engineering. The jet mixer is the simplest mixing device, commonly used to achieve mixing in a storage tank. In such a tank, the liquid is drawn into the pump and returns as high velocity jet through a nozzle into the tank. This jet entrains the surrounding liquid and generates the fluid circulation in the vessel. Thus, the different components in the tank are mixed.

Jet mixed tanks are more efficient as compared to the conventional impeller mixers (Fossett, 1951). The jet mixing tanks are cheaper and easier to install, and may not require the additional support for the tank structure. Moreover, the jet mixing tanks are also easier for maintenance due to the absence of moving parts. The jet mixing tanks can be employed to stop the runaway reactions (Hoffman, 1996). Further, the jet mixing tanks are also used as emergency cooling systems (Schimetzek et al., 1995) and reactor in many processes (Simon and Fonade, 1993; Baldyga et al., 1994).

There are many studies in jet mixing tanks, including experiment and simulation. The original studies in jet mixing tanks are experimental. The influence of different parameters, such as liquid height, jet nozzle angle, jet Reynolds number, etc., are investigated. Fossett (1951)

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has found that the mixing time obtained by jet mixing tank was shorter than by conventional impeller. Fox and Gex (1956) investigated the mixing times in tank with the different ratio of liquid height (*H*) to tank diameter (*D*), and found that the mixing time was dependent on the momentum flux added to the tank.

Okita and Oyama (1963) investigated the mixing time in jet mixed tank by varying jet nozzle angle. They showed that the mixing time is independent of the jet injection angle. Lane and Rice (1981) studied a vertical jet mixing in a hemispherical base tank and observed that the mixing time strongly depended on jet Reynolds number in the laminar regime, but slightly depended on turbulent jet Reynolds number. Further, Lane and Rice (1982) proposed that the tank with the longest jet path length (the tank with nozzle angle of 45º) shows the minimum mixing time, which is similar to the previous work of Coldrey (1978).

Maruyama et al. (1982) experimentally investigated the jet mixing time and found that the mixing time depended on liquid depth, nozzle height, and nozzle angle. Maruyama (1986) studied the blending times of jet mixing tanks for different injection angles. The experimental data showed that the injection angles of 0º, 45-50º, and 90º exhibit the maximum blending time, while the angles of 25-30º and 75º showed the local minimum blending time.

Grenville and Tilton (1996) studied the mixing time of the tank with $H/D \leq 1$ and proposed the correlation of mixing time, based on the turbulent kinetic energy dissipation rate at the jet path end. Grenville and Tilton (1997) propounded the correlation based on jet nozzle angle and compared their model with the circulation time model and found that both models can be used to predict accurate mixing time in the tank with $H/D \leq 1$. They also showed that the mixing time is significantly increasing when the injection angle is less than 15º. Further, Grenville and Tilton (2011) extended their works by studying the mixing time in various tank geometries ($0.2 < H/D < 4$). They found that their jet turbulence model fitted all data for $0.2 < H/D < 3$.

Patwardhan and Gaikwad (2003) studied the effects of various parameters, including nozzle diameter, jet nozzle angle, and jet velocity, on mixing time. They found that the mixing time of horizontal jet was larger than the inclined jet. The mixing time of jet angle of 45º was shorter than jet angles of 30º and 60º. Further, an increase in nozzle diameter was found to reduce the mixing time.

Generally, the empirical correlations are based on experimental data. However, the universal relation of mixing time prediction does not exist. Hence, the computational fluid dynamics (CFD) simulation is also integrated to study the jet mixing tank, because it provides clear insight into fluid flow phenomena with inexpensive operating cost. Here, the studied parameters are not only tank geometries and operating conditions but also turbulence conditions.

Patwardhan (2002) employed the k-epsilon turbulence model in simulation and showed that the CFD model predicts the overall mixing time well, but the predicted concentration profiles were not in good agreement with experiment. Moreover, he found that these incorrect concentration profiles can be improved by changing the turbulence parameters.

Zughbi and Rakib (2004) adopted the standard k-epsilon and Reynolds stress model (RSM) to simulate jet mixing tanks. The predicted mixing times were in good agreement with the previous experiment of Lane and Rice (1982). The results revealed that the final mixing times obtained by two models were slightly different, and the computational time of RSM is larger than the k-epsilon model. Further, the minimum and maximum mixing times were obtained by the jet nozzle angles of 30º and 45º, respectively.

Zughbi and Ahmad (2005) used four different models, including standard k-epsilon model, realizable k-epsilon model, renormalization group (RNG) k-epsilon model, and Reynolds stress model (RSM), to simulate the turbulence in jet mixing tank. Good agreement was achieved between the numerical results and experimental data. Further, they concluded that the standard k-epsilon was the optimal turbulence model because of its accuracy and time efficiency. For round free jet simulation, the effect of RANS turbulence model on jet flow behavior is investigated by many researchers. Ghahremanian and Moshfegh (2011) studied the flow behavior of round jet by using three dimensional simulation of the whole domain, including initial, transition, and fully developed regions. The low Re k-epsilon, SST k-omega, k-kl-omega, and SST eddy-viscosity turbulence models were employed to study jet flow characteristics. The results revealed that the SST k-omega gives good agreement with mean longitudinal velocities obtained by hot-wire anemometry. Further, Ghahremanian and Moshfegh (2014) also showed that the low Re k-epsilon shows the best overall performance in whole field prediction as compared to transition models in terms of accuracy, computing efficiency, and robustness.

According to previous works, there are shortfalls of CFD simulation in jet mixing tanks:

(i) The CFD modeling of jet mixing tanks have been simulated with only small number of nodes (< 350,000 nodes (Patwardhan, 2002; Zughbi and Ahmad, 2005).
(ii) There have been no attempts to improve the concentration profile without adjusting the model parameters.
(iii) There have been no attempts to illustrate the CFD simulation of jet for different liquid heights, especially the tanks with $H/D < 1$.

Thus, the aim of the present work is to address these shortfalls. Further, the jet characteristics, including jet centerline velocity, potential core length, and transverse

Table 1. Details of variables for continuity and momentum equations.

Equation	ϕ	Γ_φ	S_φ
Continuity	1	0	0
Momentum	U_i	μ	$-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu_t\frac{\partial U_i}{\partial x_j}\right]+S_{M,i}$

Table 2. Details of variables for standard k-epsilon model (ANSYS Inc., 2013).

Equation	ϕ	Γ_φ	S_φ
k-transport	k	$\mu+\frac{\mu_t}{\sigma_k}$	$G_k+G_b-\rho\varepsilon-Y_M+S_k$
ε-transport	ε	$\mu+\frac{\mu_t}{\sigma_\varepsilon}$	$C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon$

velocity gradient, inside the tank, which are achieved by RANS-based turbulence model, are also conducted to obtain the clear understanding in jet mixing time.

DESCRIPTION OF CFD MODELING

Selection of the turbulence model

There are many different types of turbulence models, such as k-epsilon model, k-omega model, RSM, etc. Among those turbulence models, the k-epsilon model is the most commonly used one because it provides a reasonable result with inexpensive simulating cost (Paul et al., 2004). For jet mixing tank modeling, the standard k-epsilon model was suggested by many researchers that it is a suitable model (Zughbi and Rakib, 2004; Zughbi and Ahmad, 2005). Further, for round jet simulation, the results obtained by low Re k-epsilon model showed good agreement with the experimental data for a whole domain (Ghahremanian and Moshfegh, 2014). So, in this study, the standard k-epsilon model with its original model constants was conducted to simulate the turbulence in the tank.

Governing equations

Modeling of water flow

The general form of Reynolds average equations for conservation of mass and momentum can be written in compact form as

$$\frac{\partial(\rho\phi)}{\partial t}+\frac{\partial(\rho\boldsymbol{U}\phi)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\Gamma_\varphi\frac{\partial\phi}{\partial x_j}\right]+S_\varphi \tag{1}$$

where ϕ is a universal dependent variable, $\boldsymbol{U}$ is mean velocity vector, Γ_φ is the diffusivity, and S_φ is the source term. The details of variable for continuity equation and momentum equations are expressed in Table 1. Generally, the values of eddy viscosity or turbulent viscosity (μ_t) in Table 1 are obtained by using turbulence fields.

Modeling of turbulence

The k-epsilon model includes two extra transport equations to represent the turbulent properties of the flow. The original model was proposed by Launder and Spalding (ANSYS Inc., 2013). Transport equations are resorted to resolving the turbulent kinetic energy (k) and the dissipation rate of turbulent kinetic energy (ε).

According to the general Reynolds average equation (Eq. (1)), the details of variables for standard k-epsilon model are expressed in Table 2. Furthermore, the model constants $C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$, σ_k, and σ_ε are 1.44, 1.92, 0.09, 1.0, and 1.3, respectively (ANSYS Inc., 2013).

Modeling of species transport

In order to obtain the tracer concentration in the tank, the species transport equations without reaction were employed. In FLUENT, the general species transport equations (ANSYS Inc., 2013) can be written as

$$\frac{\partial(\rho Y_i)}{\partial t}+\frac{\partial(\rho\boldsymbol{U}Y_i)}{\partial x_j}=\frac{\partial\boldsymbol{J}_i}{\partial x_j}+R_i+S_i \tag{2}$$

where Y_i is the local mass fraction of species i, $\boldsymbol{J}_i$ is the diffusion flux of species i, R_i is the net rate of production of species i by chemical reaction, and S_i is the source term of species transport equations.

Configuration of the jet mixing tank

The jet mixing tank was set up based on the previous work reported by Patwardhan and Gaikwad (2003). The details of eleven tested jet mixing tanks are given in Table 3.

Table 3. Geometrical dimensions of the tested jet mixing tanks.

Dimension	Tank	Dimension/*D*	Nozzle angle (*θ*) / degree
Tank diameter (*D* = 0.5 m)		1	
Outlet pipe diameter (d_o = 0.0381 m)		0.0762	
Nozzle diameter (*d* = 0.008 m)		0.016	
Liquid Height (*H*)	L1	0.5	22.5
	L2	0.5	45
	L3	0.5	67.5
	L4	0.5	26.565[b]
	S1	1	22.5
	S2	1	45[a,b]
	S3	1	67.5
	T1	1.5	22.5
	T2	1.5	45
	T3	1.5	67.5
	T4	1.5	56.31[b]

[a] Standard jet mixing tank (Patwardhan and Gaikwad, 2003); [b] The tank with a diagonal nozzle angle.

Boundary conditions

A velocity inlet boundary condition was used at jet nozzle inlet, meaning that a velocity normal to the inlet was specified. The inlet velocity magnitude and turbulence intensity were 4.4 $\text{m}\cdot\text{s}^{-1}$ and 10%, respectively. A pressure outlet boundary condition was applied at the tank outlet. The symmetry boundary condition (no flow across the boundary and zero normal scalar flux) was adopted at the top of tank. At the wall, no-slip boundary condition was employed. The water density and water viscosity were 998.2 $\text{kg}\cdot\text{m}^{-3}$ and 0.001003 $\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$, respectively.

Numerical schemes

The pressure-velocity coupling of this simulation was SIMPLE, which stands for Semi Implicit Method for Pressure-Linked Equations. The numerical scheme for pressure was standard. For momentum, turbulence quantities, and mass species, the interpolation schemes were second order upwind. For unsteady state simulation, the transient formulation was first order implicit.

Investigation of mixing time

In experimental work of Patwardhan and Gaikwad (2003), the dilute NaCl was injected at the top liquid surface center. The four conductivity probes were employed to obtain the concentration distribution and mixing time. The four probes were located at different positions as shown in Figure 1. The mixing time was considered as the time required for the concentration (c) to reach within 95% of the fully mixed value ($\bar{c}$). The mixing time ($t_{95\%}$) can be decided by the following definition:

$$t_{95\%} = \text{time for } \left|\frac{c-\bar{c}}{\bar{c}}\right| \leq 0.05 \tag{3}$$

In this research, the tracer with a volume of 7.854 mL was injected at the center of top liquid surface. The properties of tracer and water were assumed to be identical. The concentrations of four different probes were monitored and used (Equation 3) to evaluate the mixing time for these probes. The longest mixing time was adopted to identify the mixing time in the tank.

Strategy of jet mixing tank simulation

This simulation was distinguished into two parts. First, the three-dimensional steady state was simulated to obtain the steady state flow field of water jet. Second, the three-dimensional unsteady state simulation was employed to achieve the concentration field of tracer in the tank. The average residence time in the tank was adopted to determine the time step size of unsteady simulation. The average residence time was calculated by using the inlet volumetric flow rate of water (Q_{in}) and tank volume (V). The residence time, t_{res} ($t_{res} = V / Q_{in}$) of standard tank (S2) was 445.175 s. This value was employed to select the time step.

The time step size of the unsteady simulation should be a small fraction of the average residence time (Elsayed and Lacor, 2011, 2012). The small time step size is also conducted when the concentration gradient is large (Patwardhan, 2002). Moreover, Zughbi and Ahmad (2005) showed that the time step size of 1 s is sufficient to simulate jet mixing tank. So, in order to eliminate any uncertainty, the time step size of 0.0025 s was selected because it is very small as compared to the average residence time and the previous work of Zughbi and Ahmad (2005). The scaled residual of 10^{-5} was set to get the accurate results.

CFD grid

The jet mixing tanks and their grids were generated by using GAMBIT. The high grid density for these tanks was generated at the jet nozzle exit region. The grid generation of standard jet mixing tank (S2) is shown in Figure 2.

In order to eliminate the numerical uncertainty, the grid independent test has been applied to the standard jet mixing tank (S2). Four levels of grid for jet mixing tank, including 680,997, 737,707, 908,809, and 1,110,432 nodes, were studied. The jet

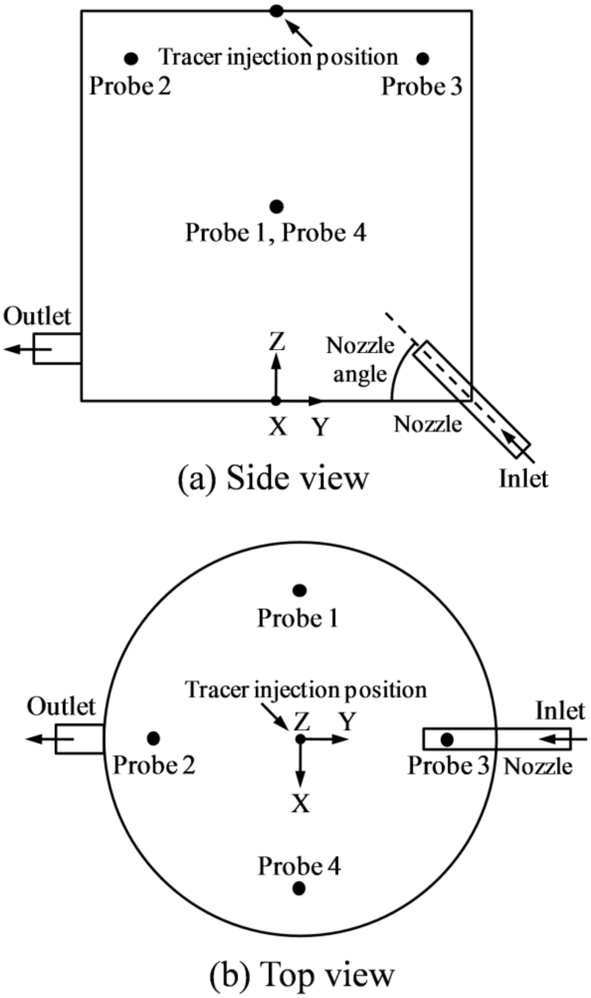


Figure 1. The four different probe locations.

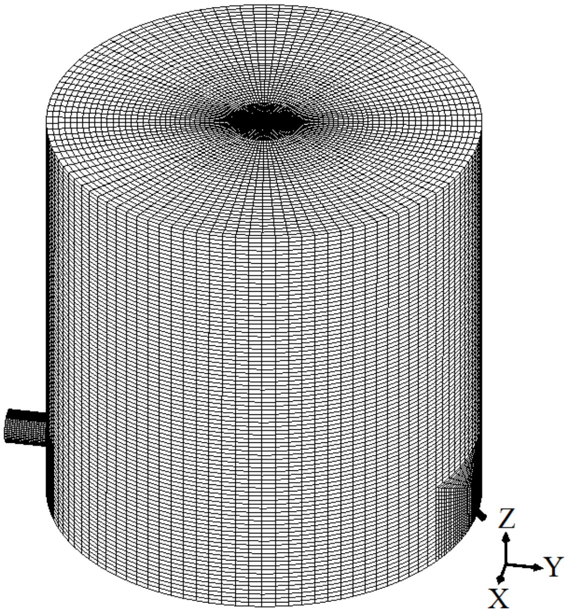


Figure 2. The surface grid of jet mixing tank.

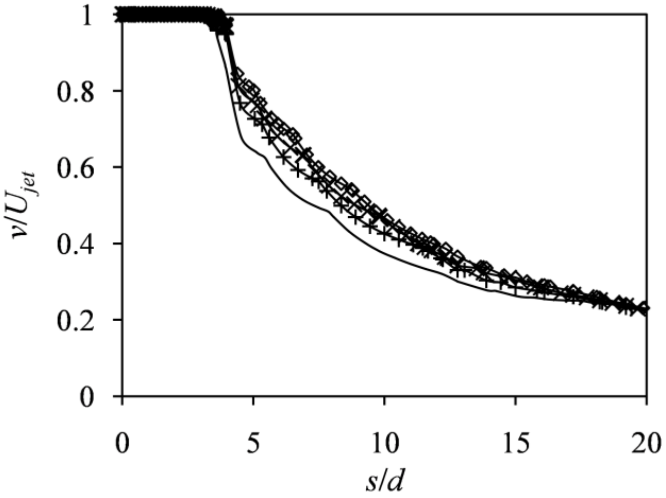


Figure 3. The profiles of dimensionless axial velocity along the jet centerline for different grid numbers: —— 680,997 nodes; —+— 737,707 nodes; —×— 908,809 nodes; —◇— 1,110,432 nodes.

centerline axial velocity profiles were compared and represented in dimensionless form as shown in Figure 3. The dimensionless velocity was defined as the ratio of jet axial velocity (*v*) to jet discharge velocity (U_{jet}). Furthermore, the dimensionless longitudinal jet distance was defined as the ratio of longitudinal jet distance (*s*) to jet diameter (*d*).

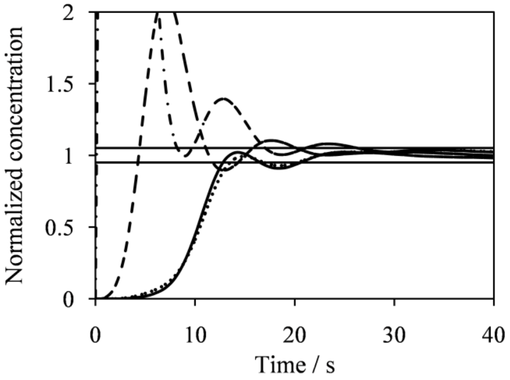
In Figure 3, it has been observed that the jet axial velocity of 680,997 nodes decay faster than the other grid levels. Moreover, the axial velocity profiles obtained by 737,707, 908,809, and 1,110,432 nodes are slightly different. However, in order to exclude any uncertainty, the simulations were performed using 908,809 nodes.

RESULTS AND DISCUSSION

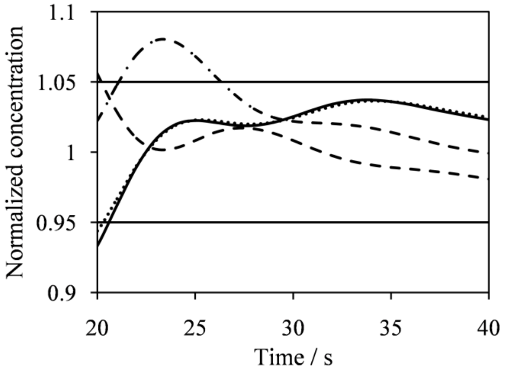
Validation of the model

The standard jet mixing tank (S2) with 908,809 nodes was simulated by using standard k-epsilon turbulence model. The simulated results were compared with the previous work of Patwardhan (2002). The predicted concentration profiles of different probes were represented in dimensionless form as depicted in Figure 4. The normalized concentration was defined as the ratio of the local concentration to the well-mixed concentration.

In Figure 4, the 95% approach to the well-mixed concentration leads to different mixing time for different probe locations. The normalized concentration profiles of probe 1 and probe 4 are slightly different because their probe locations are symmetrical as shown in Figure 1.

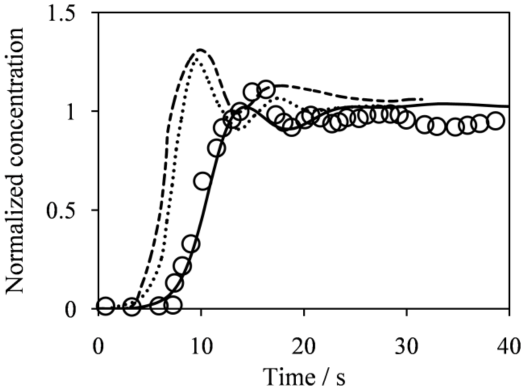


(a) Overall normalized concentration profiles

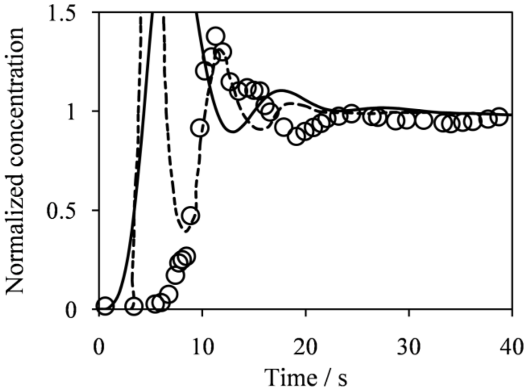


(b) Normalized concentration profiles enlargement

Figure 4. Normalized concentration profiles of 4 different probe locations: —— probe 1; - - - probe 2; -·- probe 3; ········ probe 4.



(a) Probe 1



(b) Probe 2

Figure 5. Comparison between predicted normalized concentration and experimental data: —— Present CFD; - - - CFD with standard constants; ········ CFD with modified constants; ○ Experiment (Note: The results of CFD with modified constants of probe 2 are unavailable).

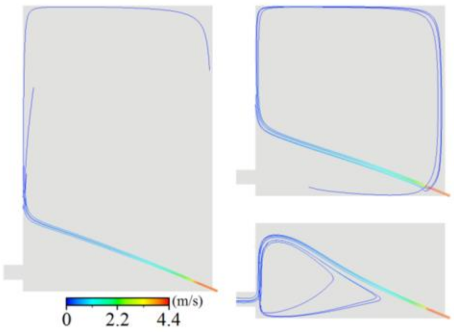
Probe 3 represents the largest mixing time. In this study, the largest mixing time was adopted to identify the mixing time of the jet mixing tank. The predicted mixing time obtained by probe 3 and experimental mixing time are 26 s and 30 s, respectively. The error between simulation and experiment is 13.3%. This shorter predicted mixing time is due to an overprediction in the extent of turbulent dispersion. That is, the predicted turbulent diffusivity would be higher than experiment.

Further, the simulated normalized concentration profiles of probes 1 and 2 were compared with the two different previous CFD results (216,000 computation nodes), including the model with C_μ of 0.09 and $C_{1\varepsilon}$ of 1.44 (standard model constants) and the model with C_μ of 0.135 and $C_{1\varepsilon}$ of 1.31 (modified model constants), and the experimental data reported by Patwardhan (2002) as depicted in Figure 5. It can be seen that the present predicted normalized concentration profile of probe 1 are much closer to the experimental data than two different previous CFD results.

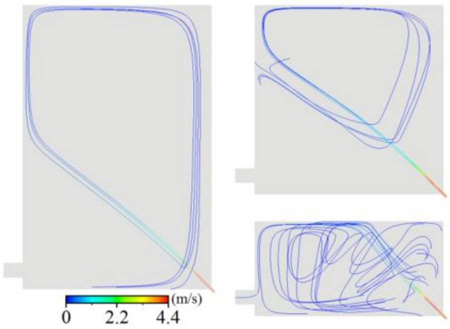
For probe 2, it can be observed that the CFD results during 0 to 14 s deviate from the experiment because the flat liquid surface with symmetry boundary condition was assumed. However, these simulated results of probe 2 approach the experimental data, at least, time after 20 s.

According to these results, it can be concluded that the prediction of normalized concentration profile can be improved by increasing number of nodes or decreasing the mesh size and using the second order upwind discretization scheme.

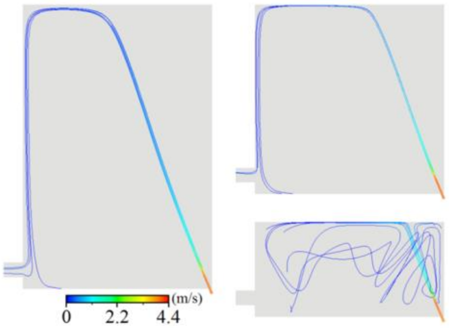
These results also referred that the poor predicted normalized concentration profiles obtained by previous studies may be due to the numerical errors rather than inadequacies in the standard k-epsilon turbulence model. Hence, this normalized concentration profile improvement method is more realistic than other methods because a good agreement between predicted normalized concentration profile and experimental data is observed without adjusting the model parameters (no longer fine tuning). Moreover, for mixing time, the agreement between simulation and experiment is acceptable. Thus, this simulation methodology is reasonably adopted to simulate



(a) Nozzle angle of 22.5º



(b) Nozzle angle of 45º



(c) Nozzle angle of 67.5º

Figure 6. The jet stream lines for different *H*/*D* and jet nozzle angles.

the jet mixing tanks.

Effect of jet nozzle angle on mixing time

In order to investigate the effect of jet nozzle angle on mixing time for different liquid heights, the tanks with various ratios of liquid height (*H*) to tank diameter (*D*), including 0.5, 1, and 1.5, were simulated by varying the jet nozzle angle of 22.5º, 45º, and 67.5º, respectively. As reported by previous works, the mixing time was found to be inversely proportional to the jet path length (*L*) (Maruyama et al., 1982; Grenville and Tilton, 1997), which is defined as a distance between jet nozzle exit and tank wall or liquid surface, meaning that the higher jet path length results the shorter mixing time. It seems logical to define the jet path length as reported by previous works. However, this definition is only a geometric parameter, which is not an actual jet path length. Therefore, in this study, the jet stream lines of nine different tanks as shown in Figure 6 were directly employed to measure the jet path lengths. The jet path lengths were measured by the jet streamlines from the center of jet nozzle exit to the position where the streamlines hit the tank wall or top liquid surface. These jet path lengths were represented in dimensionless form, which defined as a ratio of jet path length to jet nozzle diameter, as shown in Table 4. Further, the details of these tanks, including ratio of *H*/*D* and nozzle angle, and their simulated mixing times were also summarized as shown in Table 4.

From Figure 6, the results revealed that the jet flow patterns depended on the jet nozzle angle and *H*/*D* ratio. Moreover, these jet streamlines ensured that these jets hit the opposite boundaries. In Table 4, it is showed that the mixing times are found to increase with increasing *H*/*D* ratio because the larger tank volume requires more jet energy and the tanks with nozzle angle of 45º show the smallest mixing time regardless of *H*/*D* ratios. Further, the *L*/*d* ratios of these tanks are less than 100.

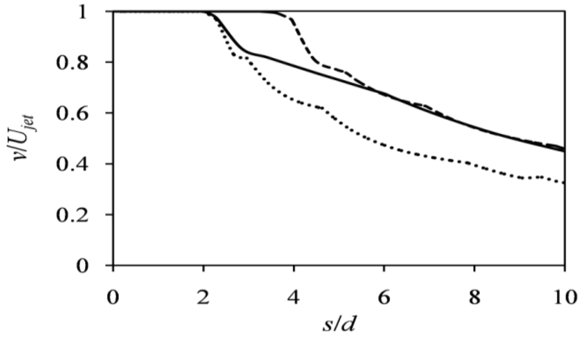
Generally, the surrounding fluid is entrained by jet within *L*/*d* of 400 (Harnby et al., 1997; Perona et al., 1998; Wasewar and Sarathi, 2008). These results ensured that the jets can entrain the external liquid and generate the circulation inside the tanks. When the mixing time and jet path length are viewed together, it can be seen that the mixing time of *H*/*D* of 1 shows inversely proportional to the jet path length. Whereas, the mixing times of other *H*/*D* ratios exhibit the different tendency, which contrast to the previous works (Maruyama et al., 1982; Grenville and Tilton, 1997).

In order to conceive the difference in the mixing time of these tanks, the axial velocities along the jet centerline for different tanks were measured and represented in dimensionless form as shown in Figure 7. The dimensionless jet centerline axial distance was defined as the ratio of the jet centerline axial distance (*s*), which was measured from the jet nozzle exit, to jet nozzle diameter (*d*).

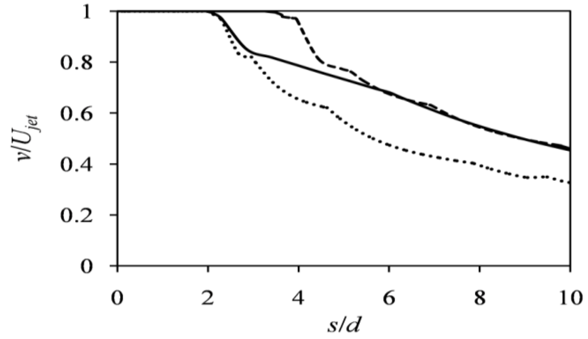
In Figure 7, it can be observed that the dimensionless velocity profiles can be distinguished into two regions. The first region exhibits the constant dimensionless axial velocity, which is known as the zone of flow establishment (ZFE) or potential core (Seok and Il, 2005; Ball et al., 2012). The mixing in this zone is due to the large-scale coherent structures (CS), which is called bulk mixing (Wang and Keat Tan, 2010). The dimensionless velocity profiles of these *H*/*D* ratios are slightly different. These similar profiles for three different *H*/*D* ratios are observed because the results are measured near the jet exit region, where the boundary conditions are identical. These results can be implied that the jet velocity profiles near the jet nozzle exit region are not dependent on the

Table 4. Details and mixing times of the simulated jet mixing.

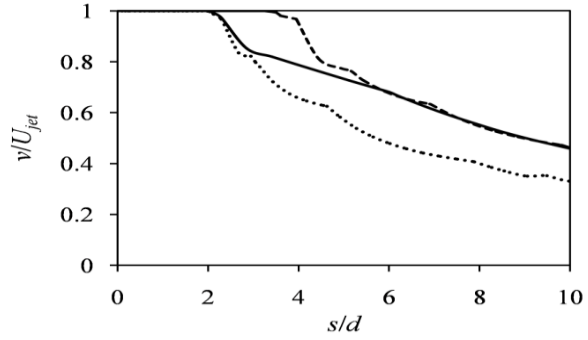
Tank	*H*/*D*	Nozzle angle (θ) / degree	*L*/*d*	Mixing time / s
L1	0.5	22.5	64.397	25
L2	0.5	45	39.304	22
L3	0.5	67.5	29.242	60
S1	1	22.5	62.109	28
S2	1	45	75.968	26
S3	1	67.5	62.516	33
T1	1.5	22.5	63.172	46
T2	1.5	45	77.069	35
T3	1.5	67.5	95.988	36



(a) $H/D = 0.5$



(b) $H/D = 1$



(c) $H/D = 1.5$

Figure 7. The predicted dimensionless velocity profiles along the jet centerline for different *H*/*D*: —— 22.5º; – – – 45º; ……… 67.5º.

liquid height.

Further, the simulated results revealed that the constant dimensionless velocities for nozzle angle of 45º ($s/d \approx 4$) are larger than two other jet nozzle angles ($s/d \approx 2$) for three different *H*/*D* ratios because of the freedom of jet flow, that is, the wall disturbance of the tanks with a nozzle angle of 45º are less than the two other nozzle angles. In the second region, the dimensionless velocities are found to decrease with increasing dimensionless longitudinal jet distance, which is called zone of established flow (ZEF) (Seok and Il, 2005). The smaller scale mixing of this region is driven by turbulent velocity fluctuations (Wang and Keat Tan, 2010). Moreover, it can be seen that the decay in dimensionless velocities profiles for nozzle angle of 67.5º are faster than the others because the jet kinetic energy is partly converted to potential energy.

When Table 4 and Figures 6 and 7 are viewed together the following observations can be drawn:

(i) The different nozzle angles dramatically exhibit the different flow patterns inside the tanks, such as potential core length, jet path length, jet centerline velocity profile, etc. Further, the different flow fields result in the different mixing times. In other words, the mixing time is dependent on flow pattern inside the tank.

(ii) The tanks with nozzle angle of 45º exhibit the shortest mixing time because of their longest potential core zones or their largest mass entrainment. The largest mass entrainment for nozzle angle of 45º can be confirmed and investigated by considering the transverse profiles of jet axial velocity gradient in radial direction (*dv*/*dr*) as shown in Figure 8.

In Figure 8, it can be seen that, for $-0.5 > r/d > 0.5$, the velocity gradient for nozzle angle of 45º is about 10% lower than the others, meaning that the difference in momentum concentration (or mass flux) between inner zone of jet and jet boundary is smaller than two other nozzle angles. In other words, at jet boundary, the jet with 45º nozzle angle entrains more external fluid mass as compared to the others. Moreover, the higher mass entrainment in potential core also results in the higher

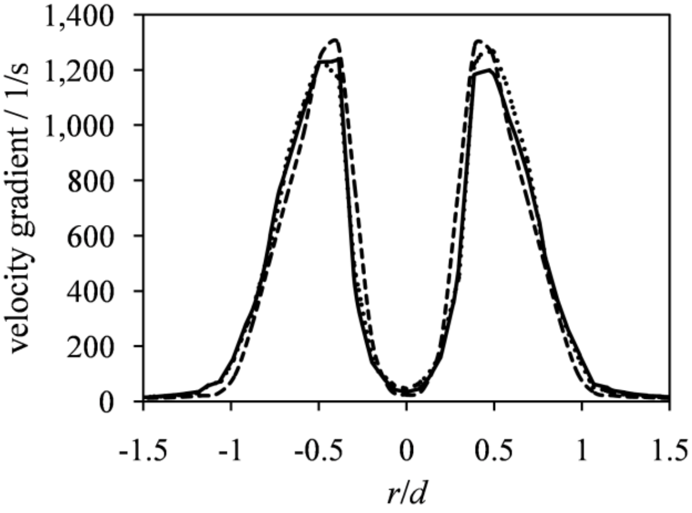


Figure 8. The predicted profiles of velocity gradient in radial direction at *s*/*d* of 2 for *H*/*D* of 1: —— 22.5º; - - - 45º; .... 67.5º.

Table 5. Details and mixing times of the additional jet mixing tanks.

Tank	*H*/*D*	Nozzle angle (*θ*) / degree	*L*/*d*	Mixing time / s
L4	0.5	26.565	60.075	26
T4	1.5	56.31	92.688	35

mass entrainment in far field region (Gutmark and Grinstein 1999).

(iii) For the nozzle angles of 22.5º and 67.5º, it can be seen that the potential core lengths are identical and the longer jet path lengths result in the shorter mixing times. Further, the jet path lengths are slightly different as observed in the tank with *H*/*D* of 1, the higher jet centerline velocity (jet kinetic energy) yields the shorter mixing time.

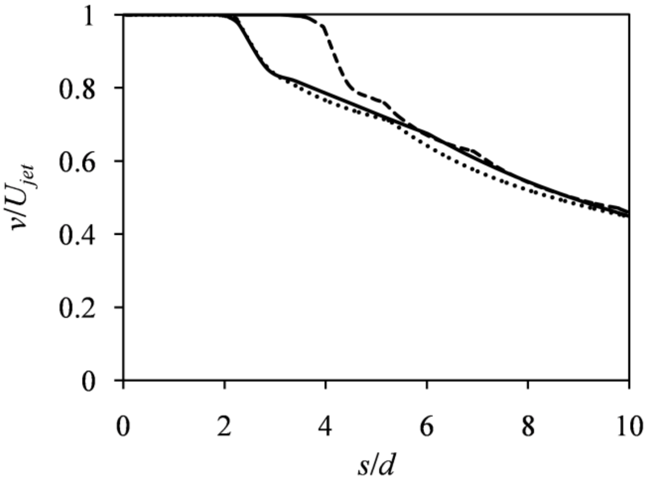
Furthermore, in order to confirm the cause of the difference in mixing time for different tanks, the tanks with the diagonal nozzle angle were also tested. The mixing times and tank descriptions are shown in Table 5. Further the predicted dimensionless axial velocity profiles along the jet centerline are depicted in Figure 9.

From Table 5 and Figure 9, for *H*/*D* of 0.5, although the *L*/*d* ratio of diagonal jet angle tank is longer than the tank with nozzle angle of 45º, the mixing time of diagonal jet angle tank is larger than the 45º nozzle angle tank becuase of its shorter potential core length. Further, the potential core lengths of the tanks with diagonal jet angle and nozzle angle of 22.5º are identical. However, the tank with nozzle angle of 22.5º exhibits shorter mixing time because of its higher jet path length and centerline dimensionless velocity in zone of established flow.

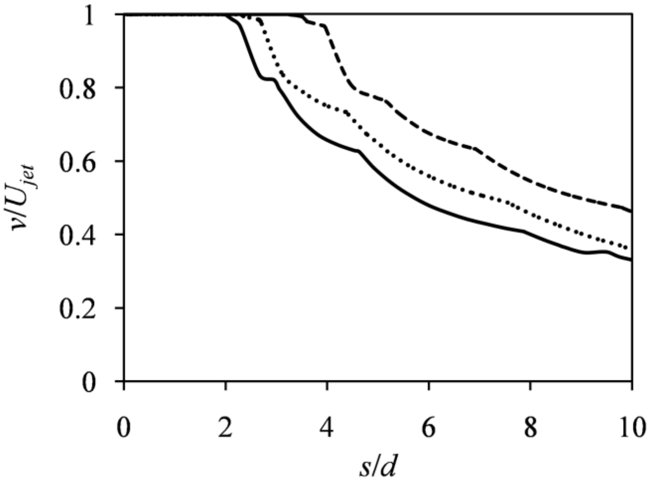
For *H*/*D* of 1.5, the mixing times of the tank with the diagonal jet angle and the tank with the nozzle angle of 45º are identical. While, the potential core length and *L*/*d* ratio of the tank with diagonal jet angle are, respectively, shorter and longer than that observed in the tank with nozzle angle of 45º. The mixing time of the tank with diagonal jet angle is identical to the tank with nozzle angle of 45º because the effective mixing in longer jet path length compensates for poor mixing in shorter potential core length. Moreover, the mixing time for diagonal jet is shorter than the tank with nozzle angle of 67.5º because of its longer potential core length.

Further, these results indicated that (i) When the potential core lengths were identical, the mixing time is dependent on jet path length or centerline jet velocity (jet kinetic energy). (ii) The mixing time of the tanks with short potential core length can be improved by changing the nozzle angle approach to 45º because the effect of wall disturbance on the jet is decreased.

According to these results, it can be summarized that the difference in mixing time is caused by the difference in jet flow pattern inside the tank, which is due to the different nozzle angles and *H*/*D* ratios. The shortest mixing time is achieved by the tank with nozzle angle of 45º because of the largest mass entrainment in potential core region. These results evidenced that the primary effect on mixing time is potential core zone. Moreover, the jet path length or jet centerline velocity (jet kinetic energy) is considered as the secondary effect on mixing



(a) *H*/*D* = 0.5



(b) *H*/*D* = 1.5

Figure 9. The predicted dimensionless velocity profiles along the jet centerline of the additional tanks for different *H*/*D*: —— 22.5º for *H*/*D* of 0.5 or 67.5º for *H*/*D* of 1.5; - - - 45º; ……… diagonal jet angle.

time.

Comparison of previous reports

Here, the present simulated mixing times for *H*/*D* of unity were compared with the previous results of Patwardhan and Gaikwad (2003) and Zughbi and Ahmad (2005) for two different reasons. First, the experimental work of Patwardhan and Gaikwad (2003) is employed to demonstrate the jet mixing times in the tanks with identical power input through the jet nozzle ($P_{jet} = \pi \rho d^2 U_{jet}^3/8 \approx 2.14$ W). Second, the CFD work of Zughbi and Ahmad (2005) is adopted only to compare the difference in mixing time tendency between the jet mixing tank with top solid wall (the tank with nozzle angle of 45º shows the maximum mixing time) and the present open jet mixed tank (the tank with nozzle angle of 45º represents the minimum mixing time).

Due to the difference in tank volume, jet power, and jet Reynolds number of these works, only the tendency of the mixing time, not their values, was compared. The tank geometries of the present work and Patwardhan and Gaikwad (2003) are identical, except the jet nozzle diameter. The tank with top solid wall of Zughbi and Ahmad (2005) is smaller than the other tanks. The details of jet mixing tanks, conditions, and mixing times of the present and previous studies can be sumarized as shown in Table 6. Moreover, the mixing times of these works were plotted against the jet nozzle angle as shown in Figure 10.

In Table 6, the mixing times for differnt jet nozzle angles are found to decrease with increasing jet Reynolds number. These results confirm the previous studies that the mixing time is dependent on jet Reynolds number (Hiby and Modigell, 1978; Lane and Rice, 1981). Further, in Figure 10, the results of the present work and Pawardhan and Gaikwad (2003) revealed that the nozzle angle of 45º exhibits the minimum mixing time and the mixing times are decreased with incresing jet nozzle diameter, which is similar to the previous work of Patwardhan (2002).

In contrast, the mixing time for jet nozzle angle of 45º, which exhibits the longest jet path length, reported by Zughbi and Ahmad (2005) shows the maximum value. This result contradicts the suggestion that the longest jet path length results in the shortest mixing time (Maruyama et al., 1982; Grenville and Tilton, 1997). For the tank of Zaghbi and Ahmad (2005), the top of liquid height is bounded by a solid wall, which is different from the other tanks.

For this 45º tank, the jet diagonally flows through the tank and impinges on the opposite corner. Then, the jet loses its momentum and splits into two streams. These streams move and lose their momentum along the top and side walls. Further, these two weak streams generate poor circulation inside the tank. This flow phenomena indicated that the maximum mixing time of this 45º tank is due to the weak circulation. For other jet nozzle angles, the jet impinges on the opposite side or top wall and creates the stronger fluid circulation as compared to the tank with nozzle angle of 45º (Zaghbi and Rakib, 2004; Zaghbi and Ahmad, 2005). That is, for nozzle angle below 45º, more of fluid volume comes within the upper jet agitated zone.

Moreover, for nozzle angle more than 45º, there is a jet rollover after it hits the top wall. After rollover, the jet drives the liquid to move along the tank wall and agitates the bulk liquid. Hence, the mixing time of these tanks are shorter than that observed in the tank with nozzle angle

Table 6. Details of jet mixing tanks, conditions, and mixing times for various works.

Authors	Geometry and conditions	Nozzle angle (θ) / degree	Mixing time / s
Present	D = 0.5 m, H = 0.5 m, H/D = 1, d = 8 mm; $\mathrm{Re}_{jet} \approx 35{,}000^a$	22.5	28
		45	26
		67.5	33
Patwardhan and Gaikwad (2003)	D = 0.5 m, H = 0.5 m, H/D = 1, d = 5.124-5.596 mm; $\mathrm{Re}_{jet} \approx 31{,}000^a$	30	31
		45	29
		60	39
Zughbi and Ahmad (2005)	D = 0.296 m, H = 0.296 m, H/D = 1, d = 18 mm; $\mathrm{Re}_{jet} \approx 10{,}000^a$	30	55
		45	68
		60	65

[a] $\mathrm{Re}_{jet} = dU_{jet}\rho/\mu$.

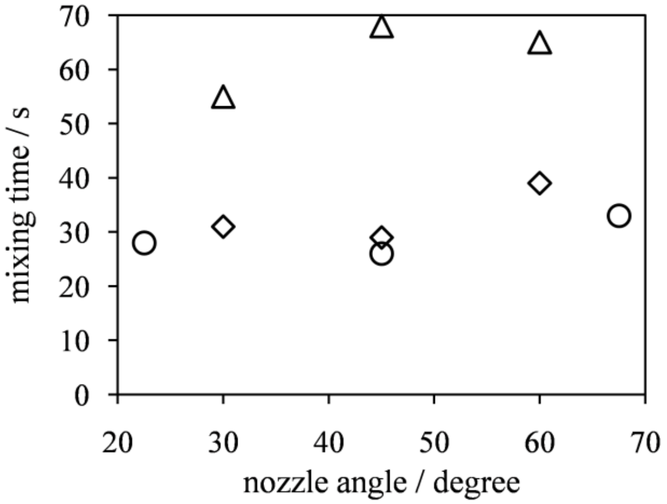


Figure 10. A plot of mixing time versus jet nozzle angle for various works: ○ Present; ◇ Patwardhan and Gaikwad (2003); △ Zughbi and Ahmad (2005).

of 45°.

In this work, the jet mixing tank is an open cylinder tank, which is similar to the experimental work of Patwardhan and Gaikwad (2003). The flow phenomenon inside the tank is somewhat similar to the tank of Zughbi and Ahmad (2005). However, the top liquid circulation is not limited by the solid wall, meaning that the top liquid motion does not lose its momentum due to the absence of the top solid wall.

The top liquid is easily re-entrained by the jet, which increases the effectiveness of the jet as a mixer. So, the concept of jet path length reported by Maruyama et al. (1982) and Grenville and Tilton (1997) is valid for this situation. As mentioned earlier, the tank with nozzle angle of 45° showed the shortest mixing time as compared to the other jet nozzle angles because of the longest jet path length and the longest potential core length.

According to these results, it can be summarized that the top solid wall reduces the effectiveness of the jet as a mixer. Further, the jet path length concept can be adopted only to describe the jet mixing time in the open tank. For the tank with top solid wall, the new definition of jet path length or new parameter should be defined to analyze the jet mixing time.

Conclusions

In this work, the CFD model was developed to study the effect of jet nozzle angle on mixing time for different H/D

ratios. The simulated mixing time and concentration profiles were validated by comparing with the experiment and previous CFD models reported by Patwardhan (2002). The present model with 908,809 nodes exhibited an acceptable value of mixing time as comparing with the experiment. Further, this model successfully improved the accuracy of normalized concentration profile predictions by increasing the computational nodes, especially probe 1, as compared to the previous CFD models.

The nozzle angles of 22.5º, 45º, and 67.5º were employed to study the effect of jet nozzle angle on mixing time for different *H*/*D* ratios. The results revealed that the different nozzle angles are directly affected on the flow pattern inside the tanks and the mixing time. The tanks with nozzle angle of 45º exhibited the shortest mixing time regardless of *H*/*D* ratios because of their highest mass entrainment in potential core region. Further, the results indicated that the mixing time is mainly affected by the potential core length. The secondary effect on mixing time is the jet path length or jet centerline velocity (jet kinetic energy), which depend on the tank geometry.

The comparison between the present work and previous works indicated that the top solid wall reduces the effectiveness of jet mixer. Further, the concept of jet path length is only valid for the open jet mixing tank. In order to analyze the jet mixing tank with top solid wall, the new definition of jet path length or new parameter should be specified.

For future work, the large eddy simulation (LES) would be employed to predict these jet mixing tanks and compare the LES results with the results of k-epsilon model. Moreover, for the tanks with various *H*/*D* ratios, the future work would be directed towards employing the experiment to confirm these CFD simulated results.

Conflict of Interests

The authors have not declared any conflict of interests.

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NOMENCLATURE

Alphabetical symbols

$C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$: k-epsilon model constants
C_{μ}: model constant for eddy viscosity calculation
c: concentration, mol·L^{-1}
$\bar{c}$: fully mixed concentration, mol·L^{-1}
D: tank diameter, m
d: nozzle diameter or jet diameter, m
d_o: outlet pipe diameter, m
G_b: generation of turbulent kinetic energy due to buoyancy, kg·m^{-1}·s^{-3}
G_k: generation of turbulent kinetic energy due to the mean velocity gradients, kg·m^{-1}·s^{-3}
H: liquid height, m
$\boldsymbol{J}_i$: diffusion flux of species *i*, kg·m^{-2}·s^{-1}
k: turbulent kinetic energy, m^{2}·s^{-2}
P: mean pressure, Pa
Q_{in}: inlet volumetric flow rate of water, m^{3}·s^{-1}
R_i: net production rate of species *i* by chemical reaction, kg·m^{-3}·s^{-1}
r: radial distance, m
S_i: species mass transport source term, kg·m^{-3}·s^{-1}
S_k: turbulent kinetic energy source term, kg·m^{-1}·s^{-3}
$S_{M,i}$: momentum source term, kg·m^{-2}·s^{-2}
S_{ε}: dissipation rate of turbulent kinetic energy source term, kg·m^{-1}·s^{-4}
S_{φ}: source term
s: longitudinal jet distance, m
t: time, s
$t_{95\%}$: mixing time, s
t_{res}: residence time, s
U_{jet}: jet discharge velocity, m·s^{-1}
$\boldsymbol{U}$: mean velocity vector, m·s^{-1}
U_i: mean velocity in *i* direction, m·s^{-1}
V: tank volume, m^{3}
v: jet axial velocity, m·s^{-1}
x_i, x_j: distance in *i* and *j* directions, m
Y_i: local mass fraction of species *i*
Y_M: contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate, kg·m^{-1}·s^{-3}

Greek symbols

Γ_φ: diffusivity

ε: dissipation rate of turbulent kinetic energy, $m^2 \cdot s^{-3}$

θ: nozzle angle, degree

μ: fluid viscosity, Pa·s

μ_t: eddy viscosity, Pa·s

ρ: fluid density, $kg \cdot m^{-3}$

σ_k, σ_ε: turbulent Prandtl number for k and ε

ϕ: universal dependent variable

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