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Process Safety Knowledge Management in the Chemical Process Industry

Mingliang Chen

Department of Chemical Engineering, Tsinghua University, Beijing, China

Email address:
chenml_js@126.com

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Abstract: Chemical process industry is a high risk industry which can result in catastrophic casualties, loss of properties, and environment damage. Process safety should always come first in the chemical process industry. Researchers have made great efforts to make the chemical process industry safer for people and the environment. Effective process safety management is the guarantee for process safety. Key elements of process safety management and risk based process safety are presented and discussed. Sometimes process safety knowledge is not utilized effectively in implementing process safety management. Knowledge and knowledge management are introduced. Various process safety knowledge sources are analyzed. A knowledge management framework is proposed to utilize process safety knowledge. With the proposed knowledge management framework, process safety knowledge can be used to prevent chemical accidents, mitigate the consequences, and reduce risk in the chemical process industry.

Keywords: Process Safety, Process Safety Management, Knowledge, Knowledge Management

1. Introduction

In the last decades, there are many catastrophic accidents in the chemical process industry, such as: Flixborough explosion in 1974, Seveso disaster in 1976, Bhopal disaster in 1984, Texas City Refinery explosion in 2005, Jilin chemical plant explosions in 2005, and Zhangzhou PX plant explosion in 2015, etc. These serious accidents caused fatal casualties, loss of properties, and environment damage.

Table 1. *Some major accidents in the chemical process industry.*

Year	Place	Accident	Consequence
1974	Flixborough	Explosion	28 fatalities
1976	Seveso	Toxic release	Irreversible environmental harm
1984	Bhopal	Toxic release	More than 2000 fatalities
1989	Pasadena	Explosion	23 fatalities
2005	Texas City	Explosion	15 fatalities, 180 injured
2005	Jilin	Explosion	8 fatalities, more than 60 injured, severe environmental pollution
2006	Sheyang	Explosion	22 fatalities
2006	Dangtu	Explosion	10 fatalities, 30 injured
2008	Guangxi	Explosion	20 fatalities, more than 11500 emergency evacuation
2010	Nanjing	Explosion	13 fatalities, 120 injured
2012	Zhaoxian	Explosion	25 fatalities, 46 injured
2013	Waco	Explosion	15 fatalities, 200 injured
2014	Nantong	Explosion	8 fatalities, 9 injured
2015	Zhangzhou	Explosion and fire	6 injured, severe environmental harm

In Table 1, some major accidents from 1976 to 2015 that caused fatal casualties, affected neighboring communities, received extensive publicity, and may have directly influenced new governmental regulations are listed [1-2].

Some governmental regulations have been created in response to major fires, explosions, and toxic releases [3], such as: European Union's Seveso Directive and Occupational Safety and Health Association (OSHA)'s process safety management standard 29CTR1910.119.

As chemical process technology becomes more complex, chemical engineers will need a more detailed and fundamental understanding of safety. Safety used to mean the older strategy of accident prevention through the use of hard hats, safety shoes, and a variety of rules and regulations. The main emphasis was on worker safety. Much more recently, safety has been replaced by "loss prevention". This term includes hazard identification, technical evaluation, and the design of new engineering features to prevent loss [1].

Process safety should always be the first in the chemical process industry. But in the implementation of process safety management, sometimes knowledge of process safety management isn't utilized effectively.

There is increasing interest in knowledge management in high risk industries. For process safety management, the knowledge management should be used to prevent chemical accidents and guarantee process safety.

The rest of this paper includes the following structure. Different process safety management standards by different governments and related petrochemical companies are presented and compared in Section 2. Section 3 introduces the concept of knowledge and knowledge management. In Section 4, the proposed process safety knowledge management framework is illustrated. Finally, conclusions are developed in the last section.

2. Process Safety Management

As mentioned above, chemical process safety risk reduction journey has been filled with significant accidents that have caused fatalities, damaged the environment, and destroyed facilities [3]. These accidents result from the loss of containment of hazardous materials and energies. Some critical factors have been recognized as the root cause of these accidents, such as: technical factors, human errors, and management and organization factors.

Process safety is a relatively young and evolving field largely - and unfortunately - advanced by tragic events that, ironically, underscore the importance of the field only after the fact [4]. In order to preventing accidents in the chemical process industry, governments and chemical companies published many safety management standards. After the Seveso disaster, Commission of the European Communities adopted the "Council Directive 82/501/EEC on the major-accident hazards of certain industrial activities" (Seveso I) to prevent major accidents involving dangerous substances and limit the possible consequences of such accidents for human health and the environment [5]. Subsequent chemical accidents led to continuous revision to the Seveso Directive. The Seveso II and Seveso III was adopted eventually in 1996 and in 2012, respectively. In 1986, Australia issued the AS 1470-1986 "Health and safety at work – Principles and practices" [6]. Occupational Safety and Health Association (OSHA) published "Process safety management of highly hazardous chemicals" in 1992 [7]. China Petroleum and Natural Gas Corporation established industry standard SY/T 6276-1997 "Petroleum and natural gas industries – health, safety and environment management system" [8]. After the Texas City Refinery explosion in 2005, Center for Chemical Process Safety (CCPS) proposed risk based process safety (RBPS) management approach to update the process safety management framework [9]. State Administration of Work Safety of China issued AQ/T 3034-2010 "Guidelines for process safety management of petrochemical corporations" [10]. In 2012, Organization for Economic Co-operation and Development (OECD) issued "Guidance for senior leaders in high hazard industries" [11].

Series of Seveso Directive aim at controlling major accidents of specific equipment and improving the safety of sites containing large quantities of dangerous substances. For this purpose, companies must set out safety reports, safety management system, emergency plan, site location research, and risk awareness of public.

The purpose of the AS 1470-1986 "Health and safety at work – Principles and practices" is to outline the action which should be taken by employers and employees which aimed at promoting the health, safety and well-being of persons in the workplace.

OSHA's process safety management refers to a set of interrelated approaches to managing hazards associated with the process industries and is intended to reduce the frequency and severity of incidents resulting from releases of chemicals and other energy sources [7]. The process safety management program includes 14 elements: process safety information, process hazard analysis, operating procedures, training, contractors, mechanical integrity, hot work, management of change, incident investigation, compliance audits, trade secrets, employee participation, pre-startup safety review, and emergency planning and response.

Industry standard SY/T 6276-1997 "Petroleum and natural gas industries – health, safety and environment management system" stated necessary elements used to establish, implement, and maintain health, safety, and environment system. There are seven key elements: leadership and commitment, policy and objective, organization and resource, risk management, planning, implementation and audit, check and review.

The purpose of CCPS's RBPS guidelines is to provide chemical-related organizations with methods and ideas to design process safety management system, correct a deficient process safety management system, and improve process safety management practices [9].

Like OSHA's process safety management program, there are 12 elements in AQ/T 3034-2010 "Guidelines for process safety management of petrochemical corporations". They are: process safety information, process hazard analysis, operating procedures, training, contractor management, pre-startup safety review, mechanical integrity, hot work, management of change, emergency management,

accident/incident management, and compliance audits.

According to OECD's "Guidance for senior leaders in high hazard industries", there are five essential elements of corporate governance for process safety management: leadership & culture, risk awareness, information, competence, and action. Among these five essential elements, strong leadership is vital, because it is central to the culture of an organization, and it is the culture which influences employee behavior and safety [11].

Culminating with the issuance of the OSHA's process safety management standard, the chemical process industry embarked upon a path that world forever changes the way we viewed, understood, and responded to the challenges of chemical process safety [12]. Most professionals agree that the correct application of process safety management will prevent major chemical process accidents [13]. Because the OHSA's process safety management standard and the AQ/T 3034-2010 are very similar, the comparison between OSHA's process safety management and the AQ/T 3034-2010 is illustrated in table 2.

By comparing the OSHA's process safety management standard and AQ/T 3034-2010, we can found that there are only 2 elements which appear within OSHA's process safety management standard and without the AQ/T 3034-2010. These 2 elements are: trade secrets and employee participation.

The RBPS approach is built on four pillars: commit to process safety, understand hazards and risk, manage risk, learn from experience. The four pillars are further divided into 20 RBPS elements build and expand upon the previous work. These 20 RBPS elements include: process safety culture, compliance with standards, process safety competency, workforce involvement, stakeholder outreach, process knowledge management, hazard identification and risk analysis, operating procedures, safe work practices, asset integrity and reliability, contractor management, training and performance assurance, management of change, operational readiness, conduct of operations, emergency management, incident investigation, measurement and metrics, auditing, management review and continuous improvement. The relationship of four pillars and 20 elements is illustrated in Figure 1.

Table 2. *Comparison between PSM and AQ/T 3034-2010.*

PSM	AQ/T 3034-2010
process safety information	process safety information
process hazard analysis	process hazard analysis
operating procedures	operating procedures
training	training
contractors	contractor management
mechanical integrity	mechanical integrity
hot work	hot work
management of change	management of change
incident investigation	accident/incident management
compliance audits	compliance audits
trade secrets	-
employee participation	-
pre-startup safety review	pre-startup safety review
emergency planning and response	emergency management

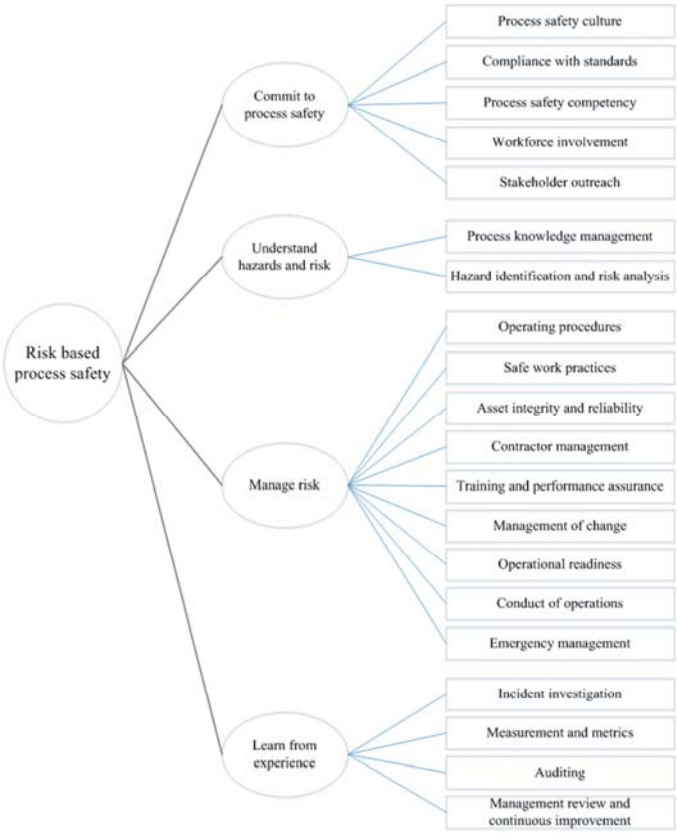

Figure 1. *Elements of risk based process safety.*

3. Knowledge Management

Knowledge is one of the most important sources to prevent accidents and guarantee process safety in the chemical process industry. There are numerous definitions of knowledge in the knowledge management domain. Knowledge is a fluid mix of framed experience, values, expertise, contextual information and insight that provides a suitable environment and a structure for evaluating and incorporating new information and experiences [14]. There is clear distinction between data, information, and knowledge. Data has commonly been seen as simple facts that can be structured to become information [1]. Data are facts, measurements, and statistics while information is organized or processed data that is timely and accurate [1]. Information, in turn, becomes knowledge when it is interpreted, put into context, or when meaning is added to it. Knowledge is neither data or information, though it is related to both [17]. In fact, knowledge includes data and information, and knowing how to apply and use that information and data. The relationship of data, information, and knowledge is illustrated in Figure 2.

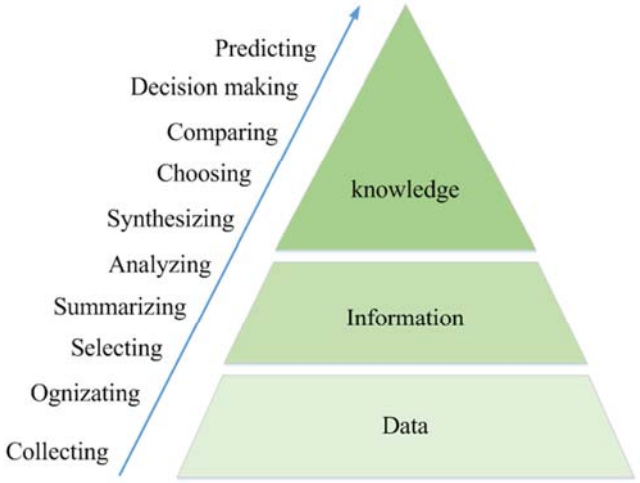

Figure 2. *The relationship of data, information, and knowledge.*

Knowledge is a crucial organizational asset which will create value for improving organizational competitive advantages and safety level [18-19]. Among knowledge dimension, there are two kinds of knowledge: explicit knowledge and tacit knowledge. Explicit knowledge consists of facts, rules, relationships and policies that can be faithfully codified in paper or electronic form and shared without need for discussion [1]. Tacit knowledge represents knowledge based on the experience of individuals [21]. Tacit knowledge is knowledge housed in the human brain, such as expertise, understanding, or professional insight formed as a result of experience [22]. Tacit knowledge is highly personal, context-specific, and therefore hard to formalize and communicate. Nonaka figured that organizations create and make use of knowledge via the interaction of tacit knowledge and explicit knowledge, which is called knowledge conversion process [22]. As defined by Nonaka, the knowledge conversion process consists of socialization (tacit to tacit), externalization (tacit to explicit), combination (explicit to explicit), and internalization (explicit to tacit). The interactions between explicit and tacit knowledge lead to the creation of new knowledge. The combination of the two types of knowledge-explicit and tacit-makes it possible to conceptualize four conversion patterns or knowledge conversion process [24].

The representation form of knowledge plays an important role in the knowledge management. A good representation enables fast and accurate access to knowledge and understanding of the content. There are many representation forms of knowledge, such as: predicate logic representation, production rule, framework representation, semantic network, Ontology, etc. The knowledge representation selection depends on the knowledge represent ability, the applicability of knowledge using and the applicability and difficulty of the knowledge maintenance. Among these knowledge representation forms above, predicate logic is not suitable for identified knowledge and does not have an integrated structure; the disadvantages of production system is difficult to weave rules into a complicated knowledge net or to represent knowledge hierarchies; framework representation can't represent the knowledge about processes or procedures; object-oriented representation can't represent relations between concepts very well; semantic networks are intractable for large domains, and they do not represent performance or meta-knowledge very well.

Inkpen [25] defined knowledge management as deliberate coordination and management of knowledge processes, and argues that the ultimate goal of knowledge management is creating new knowledge and making innovations in order to gain competitive advantage. According to Swartz, knowledge management is a process that help defining, selecting, organizing, diffusing and transferring critical information and expertise which inside reside in the organization in an unstructured manner, as a significant part of the organization memory [26]. Girard et al. have collected over 100 definitions of knowledge management in different disciplines, such as artificial intelligence, information management, human resources, etc. By only considering the words that appear at least 30 times in these over 100 definitions, then the definition of knowledge management may be: knowledge management is the process of creating, sharing, using and managing the knowledge and information of an organization [28]. Knowledge management comprises a range of strategies and practices used in an organization to identify, create, represent, distribute, and enable adoption of insights and experience. Such insights and experiences comprise knowledge, either embodied in individuals or embedded in organizations as processes or practices.

On one hand, Nielsen pointed out that knowledge management process consisted eight activities: knowledge creation, knowledge acquisition, knowledge capture, knowledge assembly, knowledge sharing, knowledge

integration, knowledge leverage, and knowledge exploitation [29]. On the other hand, Zaim et al. argued that knowledge management process consists of four activities: knowledge creation, knowledge storage, knowledge sharing, and knowledge utilizing [30-31]. Knowledge sharing is recognized as one of the most critical components of knowledge management to a firm's success in highly competitive environment [32-33].

As research continues, there are many knowledge management models proposed by researchers and practitioners in different disciplines. These models include: philosophy-based model, cognitive model, community of practice model, network model, quantum model, etc.

Chemical process hazards at a chemical plant can give rise to accidents that affect both workers inside the plant and members of the public who reside nearby [34]. Process safety management is critical in the chemical process industry. Improving organizational knowledge and knowledge management capabilities is an important means to prevent chemical accidents and improve organizations' safety level [35]. In order to utilize the knowledge of process safety management program, a knowledge management framework which considering characteristics of process safety knowledge should be developed.

4. Knowledge Management Framework

As mentioned above, process safety knowledge can be classified as explicit knowledge and tacit knowledge. By comparing the OSHA's process safety management program, AQ/T 3034-2010, and the RBPS, we can found that there are 14 elements, 12 elements, and 20 elements, respectively. But some of these elements are same or similar. We can find that there are explicit or tacit process safety knowledge embedded in these elements. Further, process safety experts play an important role to facilitate the production and ensure safety. According to Koskinen et al., on a practical level many experts are often unable to clearly express all they know and can do, and how they make their decisions and come to conclusions [20]. It means that process safety experts have tacit process safety knowledge. In addition, process safety experts come from different location and business unit. Their position and core discipline are different. They also have much explicit process safety knowledge. Thus, the process safety knowledge sources which contain explicit knowledge or tacit knowledge is illustrated in Figure 3.

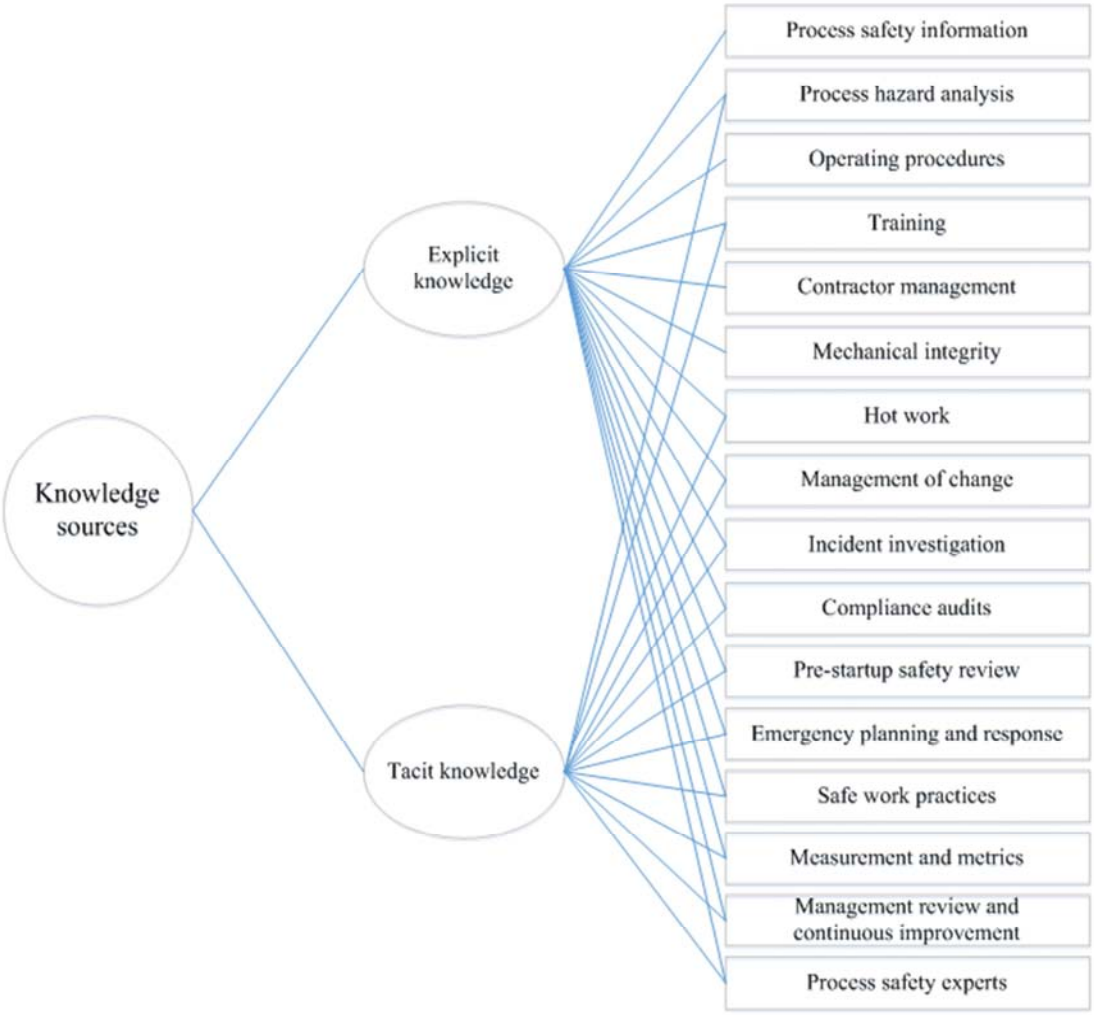

Figure 3. *Process safety knowledge sources.*

According to Figure 3, explicit process safety knowledge can be obtained from: process safety information, process hazard analysis, operating procedures, training, contractor management, mechanical integrity, hot work, management of change, incident investigation, compliance audits, pre-startup safety review, emergency planning and response, safe work practices, measurement and metrics, management review and continuous improvement, and process safety experts. On the other hand, tacit process safety knowledge can be obtained from: process hazard analysis, training, hot work, management of change, incident investigation, compliance audits, pre-startup safety review, emergency planning and response, safe work practices, measurement and metrics, management review and continuous improvement, and process safety experts. It means that there is explicit and tacit process safety knowledge for some elements at the same time. These elements include: process hazard analysis, training, hot work, management of change, incident investigation, compliance audits, pre-startup safety review, emergency planning and response, safe work practices, measurement and metrics, management review and continuous improvement, and process safety experts.

In order to utilize process safety knowledge effectively, a process safety knowledge management framework is proposed as Figure 4.

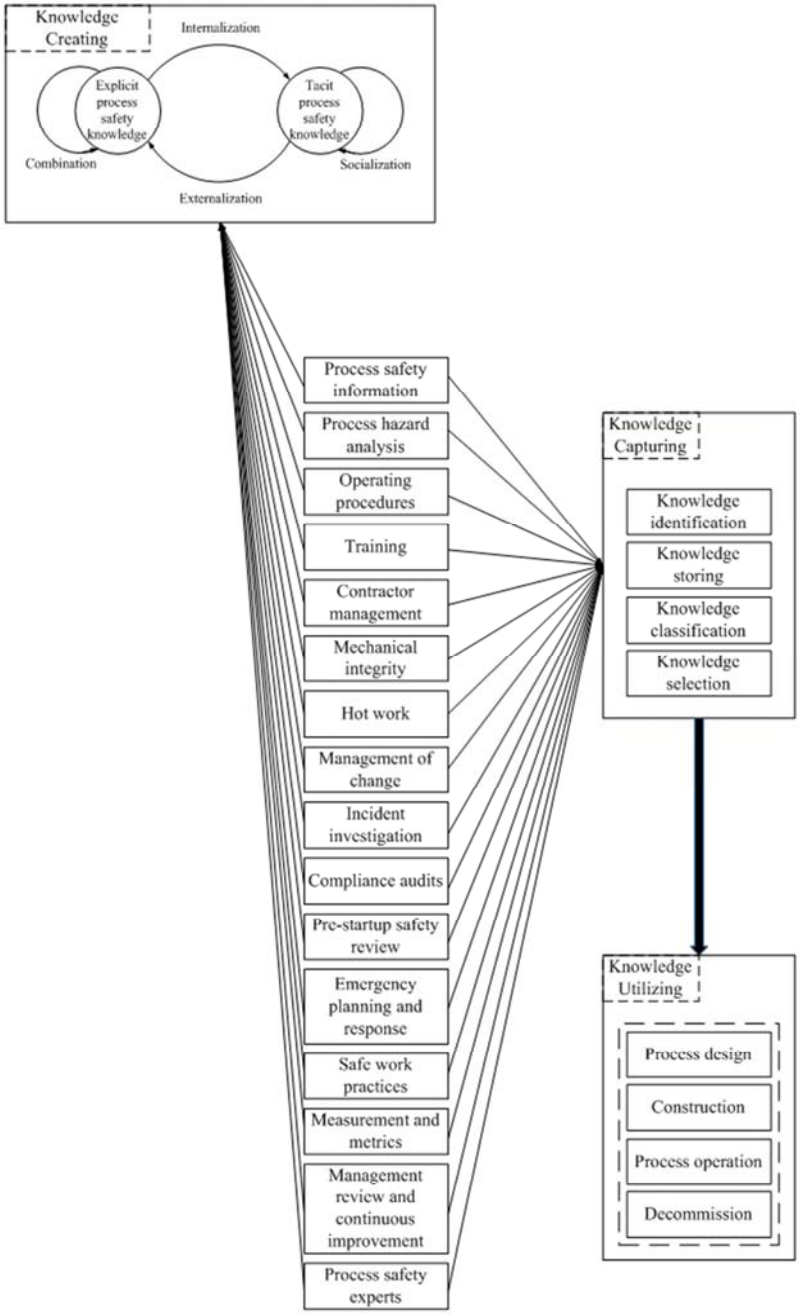

Figure 4. *Process safety knowledge management framework.*

In the proposed process safety knowledge framework, all the chemical process safety knowledge sources will create new knowledge through the knowledge creating process. Explicit process safety knowledge will transfer to tacit knowledge by "Internalization" process or transfer to explicit knowledge by "Combination" process. Tacit process safety knowledge will transfer to explicit knowledge by "Externalization" process or transfer to tacit knowledge by "Socialization" process. In addition, all the chemical process safety knowledge sources will be utilized by the knowledge capturing process. In the knowledge capturing process, there are: knowledge identification, knowledge storing, knowledge classification, and knowledge selection. Useful process safety knowledge will be captured from process safety knowledge sources by using knowledge capturing process. In the knowledge utilizing process, useful process safety knowledge captured will be reused in the whole life cycle of chemical process: process design, construction, process operation, and decommission. Useful process safety knowledge can help chemical companies to prevent accident and improve safety level.

5. Conclusion

Process safety is the most important thing in the chemical process industry. In order to improve the safety level of chemical process industry, governments and chemical companies have issued some process safety management standards or guidance. In the implementation process of these standards, sometimes useful process safety knowledge is not utilized effectively. Some major accidents in the chemical process industry were summarized. The elements of OSHA's process safety management program, AQ/T 3034-2010 of China, and CCPS's RBPS were analyzed. The knowledge hierarchy, knowledge types, knowledge representation form and knowledge management process were introduced. The explicit and tacit process safety knowledge sources selected from process safety management elements were given. A process safety knowledge framework was proposed to reuse useful process safety knowledge captured from process safety knowledge sources. With this process safety knowledge management framework, process safety knowledge from different sources can be utilized effectively in the chemical process industry.

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