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Risk assessment and quality improvement of liquid waste management in Taiwan University chemical laboratories

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ABSTRACT

The policy of establishing new universities across Taiwan has led to an increase in the number of universities, and many schools have constructed new laboratories to meet students' academic needs. In recent years, there has been an increase in the number of laboratory accidents from the liquid waste in universities. Therefore, how to build a safety system for laboratory liquid waste disposal has become an important issue in the environmental protection, safety, and hygiene of all universities. This study identifies the risk factors of liquid waste disposal and presents an agenda for practices to laboratory managers. An expert questionnaire is adopted to probe into the risk priority procedures of liquid waste disposal; then, the fuzzy theory-based FMEA method and the traditional FMEA method are employed to analyze and improve the procedures for liquid waste disposal. According to the research results, the fuzzy FMEA method is the most effective, and the top 10 potential disabling factors are prioritized for improvement according to the risk priority number (RNP), including "Unclear classification", "Gathering liquid waste without a funnel or a drain pan", "Lack of a clearance and transport contract", "Liquid waste spill during delivery", "Spill over", "Decentralized storage", "Calculating weight in the wrong way", "Compatibility between the container material and the liquid waste", "Lack of dumping and disposal tools", and "Lack of a clear labels for liquid waste containers". After tracking improvements, the overall improvement rate rose to 60.2%.

1. Introduction

To improve higher education and research environments in Taiwan, Taiwanese education management institutions have made a series of policies to promote the establishment of new universities, departments, and research institutes in recent years, which has indirectly accelerated the development of new technologies. The number of Taiwanese universities has increased by 27, from 137 in 1996 to 164 in 2007, which reaches an historical peak (Hsu and Hsieh, 2016). As the number of universities and research institutes increases, it is necessary to provide laboratories for students to conduct experiments or research, and thus, improve their skills and abilities. While the objective of this study is 216 laboratories, focus is placed on 68 laboratories for chemical engineering that generate liquid wastes. This study identifies the risk factors of liquid waste disposal, and presents a practice agenda to laboratories managers. This paper contributes to the knowledge of practices to improve laboratory liquid waste management. However, the continuous increase in the number of laboratories in universities and research institutes in recent years has resulted in a greater number of industrial wastes, such as waste, liquid waste, and effluent. The increasing number of laboratories has caused an increase in industrial waste, as well as complex management issues. In particular, the follow-up disposal of the liquid waste generated by school laboratories has gradually attracted social attention in recent years; therefore, the industrial management institutions responsible for waste disposal have collaborated with universities to take relevant management measures to meet the social expectations on universities.

Most universities in Taiwan are equipped with a laboratory. According to Article 2 of the *Waste Disposal Regulations* in the revised announcement on October 24, 2001, school laboratories have become a business designated by the law, and schools must report their waste disposal online since July 1, 2005. In other words, the liquid waste discharged by the laboratories of academic or research institutes has been listed as an object to be strictly

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controlled, and must be well disposed of in accordance with relevant regulations for industrial waste management, as stipulated in the Waste Disposal Regulations. There are regulations related to the management of waste; regulations related to academic institutions include: Waste Disposal Act, Waste Disposal Act Enforcement Rules, Methods and Facilities Standards for the Storage, Clearance and Disposal of Industrial Waste, Measures for the Administration of the Common Disposal of Waste Disposal of Educational Institutions, Notice on the Required Waste Clearance Plan, Notice on the Regulation that the Waste Production, Storage, Clearance, Disposal, Recycling, Input and Output Should Be Reported by Network Transmission, Resource Recycling Act, The handling of toxic chemical substances by academic organizations management method, and Standards for Defining Hazardous Waste. Inspection regulations for the waste management of for-profit institutions are stringent, while not-for-profit university laboratories are managed by means of self-regulation due to their small size. The aspect of "waste management" is, however, marginal and relegated to the administrative field due to very small quantities, which do not represent a serious management problem. However, a lot of the accidents and personal injuries that have occurred in university laboratories or not-for-profit laboratories were caused by improper handling of waste from academic chemical laboratories. This reveals that the disposal of the waste of school laboratories has been controlled and standardized by relevant laws and regulations in Taiwan.

According to Kuo (2005), the use of chemicals in school laboratories have the following features: (1) a wide variety, (2) great change, (3) specialty, and (4) small amount. Regarding school laboratories, generation and management may lead to environmental pollution, and the potential risks and hazards caused by inappropriate management and disposal of liquid waste are all related to the hazards of laboratories that use chemicals. Therefore, the lack of effective measures of disposing of hazard wastes may cause environmental pollution and pose harm to laboratory staff. Horng and Kuo (2007) analyzed the 340 cases of chemical storage accidents between 1997 and 2006, and found that 30% were caused by human error; 26% by storage factors; 44% by other problems, such as malfunction of safety equipment and wire fires. While laboratories consume less chemicals than factories, the wide variety, great change, and special uses increase the complexity of the management, storage, and disposal of laboratory chemicals. Worse still, there is an inadequate number of laboratory maintenance staff in schools, and staff management is inefficient. Hence, human errors may be the main causes of laboratory accidents. Jose et al. (2011) found that among the 15 companies studied, only four had adopted a consistent set of diversified management and human resources practices. These four companies were the only companies to affirm that diverse management requires the strong support of top management and continuous organization to sustain efforts toward incorporating diversity.

2. Literature review

According to Taiwan's Ministry of Education (2016), the Department of Statistics website data announced the total number of universities across the nation: 14 junior colleges, 21 technical institutes, 126 universities, and 2 National Open Universities, for a total of 160 higher education institutes. All these schools, especially the departments of science, engineering, and chemistry, are equipped with a laboratory for the internship and practices of students. Chemical experiments in the laboratory would generate liquid waste.

2.1. Laboratories liquid waste

According to the "Improve each university campus pollution control public facilities integrated planning (II)" by Taiwan's Ministry of Education, Li (2000) conducted a questionnaire survey to estimate the quantity of the laboratory wastes of schools at all levels in Taiwan, and the findings showed that the liquid waste of the laboratories of these schools in 2000 was around 1,691,100 liters/year (as Table 1). The estimated quantity of liquid waste of higher education institutes was about 740,100 liters/year, accounting for about 43.76%. The liquid wastes include organic liquid waste, acid and alkaline liquid waste, cyanide liquid waste, heavy metal liquid waste, hexavalent chromium liquid, mercury liquid waste, and others. Specifically, heavy metal liquid waste accounts for 47.9%; organic liquid waste accounts for 32.2%; acid and alkaline liquid waste accounts for 12.4%. According to the research report, most liquid waste is hazardous industrial waste, which affects human health and causes environmental pollution; if appropriate control measures are not taken, such liquid waste will have severe impact on the environment and affect public health.

According to the research data from Ni (2002), there has been great quantities of wastes generated by the laboratories of schools at all levels in Taiwan every year; 92 ± 7% of them were hazardous according to the standards of hazardous industrial wastes; annually, the schools created about 1586 metric tons of hazardous industrial wastes, and 1556 metric tons were the liquid wastes of laboratories. Kuo (2005) summarized the data released by the Ministry of Education, and found that the annual estimated quantity of the liquid wastes of school laboratories across the nation from 2001 to 2005 ranged between 1,650,000 l to 1,700,000 l. These data show that liquid wastes account for a large proportion of laboratory wastes.

The most important result of the comprehensive program for hazardous waste management is the legacy of environmental care imparted to the student community. Lara et al. (2017) the scientific value of this paper is the development of a new classification of hazardous waste, which can be useful in the chemistry departments of universities. Finally, this work acknowledges the challenge for universities and organizations to act, develop sustainability, and change the paradigms and assumptions on which these organizations are currently based.

Chien et al. (2000) argued that the amount of hazardous materials used in university laboratories was small in quantity, but the chemicals are widely varied. Although the experimental procedure is simple, both teachers and students tend to overlook the potential hazards. Yu and Chou (2001) argued that the most common hazard in laboratories was chemicals – meaning immediate harm or

Table 1
Total quantity of liquid waste of laboratories of schools at all levels in Taiwan in 2000.

Variety	Acid and alkaline liquid waste	Heavy metal liquid waste	Hexavalent liquid waste	Cyanide liquid waste	Organic liquid waste	Mercury liquid waste	Other liquid waste	Total
Liters/Year	210,300	809,800	94,700	5,000	544,600	9,900	16,900	1,691,100
Percentage (%)	12.4	47.9	5.6	0.3	32.2	0.6	1.0	100.0

Reference Li (2000).

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