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Integrated design of process and operation considering local risks and global impacts: A case study on metal-degreasing process design

Yasunori Kikuchi,[a] Masahiko Hirao,[a]

[a]*Department of Chemical System Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan,kikuchi@pse.t.u-tokyo.ac.jp*

Abstract

A framework for integrated design of process and operation is proposed for metal-degreasing process in metal processing. In metal degreasing, a significant amount of cleansing agents is released to the environment, and local risks and global impacts originated in the cleansing agents have been crucial issues. The framework enables the engineers on site to perform rigorous risk assessments by using their available knowledge and information and to execute the risk-based design. A case study demonstrating risk-based design of a metal degreasing process using obtained process information through investigation of actual metal-degreasing site is presented.

Keywords: Integrated design, Risk-based design, Local risk, Global impact

1. Introduction

Both process design and operation are strongly connected to chemical risks originated in processes. Risk-based design in which these adverse effects are identified and evaluated requires a set of models describing relations between process parameters and chemical risks due to use of chemicals. These relation models are used to evaluate alternatives and to make decisions. However, a significant amount of information related to chemical risks is required and organized to perform the risk-based design.

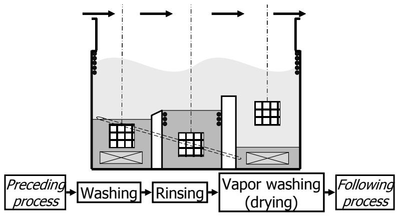

Figure 1 Open-top washing machine

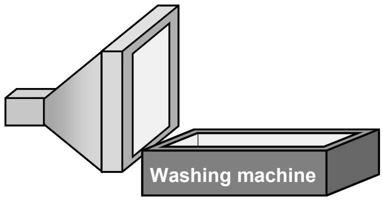

Figure 2 Exterior hood type ventilation system

In ordinary metal processing, metal parts are greased to avoid possible friction and confrontation by pressing or cutting. The process oil for greasing is regarded as an impurity in the following process. Therefore, a cleaning process for metal degreasing is inevitable before sending to the following process. In a cleaning process, however, a cleansing agent is used and a significant amount of the cleansing agent is released to the environment [1]. Many cleaning sites are using dichloromethane with a primitive open-top washing machine and an exterior ventilation system as shown in Figs. 1 and 2 respectively. Dichloromethane is volatile and human toxic, though it is inexpensive, nonflammable and very capable for cleaning. While the vaporized dichloromethane layers in a washing machine and condenses near the cooling pipes, a significant amount of the vapor releases from the top of the machine.

Although many alternative technologies including both of material and process have been developed for the risk reduction, the proper alternatives cannot be decided without appropriate risk assessment under individual conditions. When we design a metal degreasing process, process apparatuses and operations should be taken into account and evaluated. For that purpose, the proposed framework includes standard measures for evaluation and alternative generation considering the risks associated with operational conditions.

In this study, a framework for integrated design of process and operation considering local and global effects is proposed on metal-degreasing process. The framework includes both of a model which represents practical activities, information, tools and interrelations among these components, and support mechanisms which enables the activities. A case study is performed to demonstrate actual procedure and profits of integrated design with proposed framework on a metal degreasing process using obtained process information through investigation of actual metal-degreasing site.

2. Framework of integrated risk-based design on metal degreasing

An activity model for engineers on metal degreasing site to design process was constructed using the IDEF0 function modeling method [2]. Activities to be performed, information and tools to be used, and interrelations among these components are clearly described by this model. All administration and operation procedures are broken down into "activities" and systematic

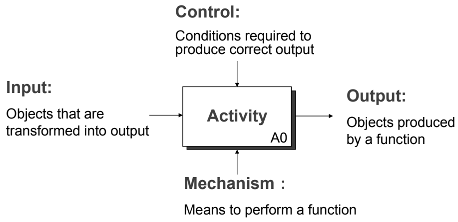

Figure 3 Elements of IDEF0 function model

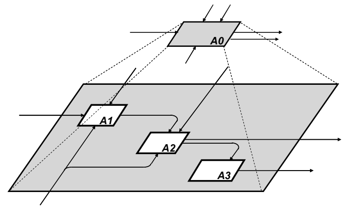

Figure 4 Hierarchy of activities in IDEF0

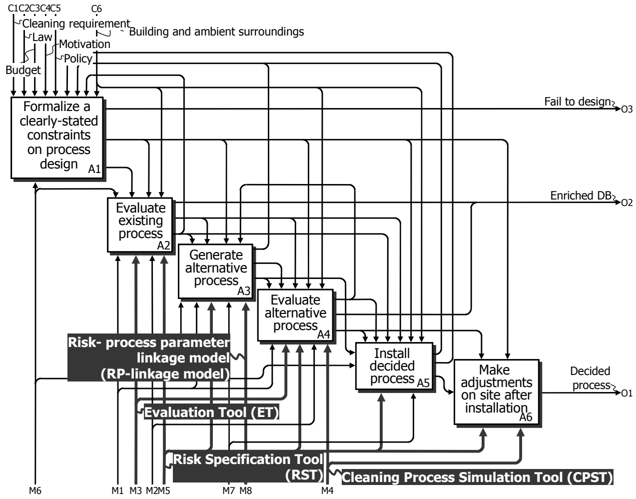

Figure 5 IDEF0 activity model for A0 layer on integrated design of metal degreasing process

relationships among them are described by ICOM: Input, Control, Output and Mechanism, as shown in Fig. 3. Each activity can be hierarchically decomposed into subactivities as show in Fig.4.

Figure 5 shows the basic IDEF0 diagram representing design activities of metal degreasing. The function of activities and ICOMs are systematically and explicitly visualized. For example, the activity of generating alternative processes is constrained by the results of evaluation which are outputted by performing the activity of evaluating existing process. The viewpoint of this function model is decision-makers on metal-degreasing sites who want to reduce chemical risks associated with the site. The objective of this function model is to decide an alternative process, a cleansing agent and operations under the conditions existing at the site. In this function model, a top activity “A0: Decide alternative metal degreasing process to reduce chemical risks associated with industrial cleaning” is composed of subactivities A1 to A5. Using this function model, required support mechanisms can be discussed and defined functionally for risk-based design. The framework including activity model and support mechanisms enables the engineers on site to perform risk-based design.

2.1. Risk Specification Tool

Risk Specification Tool (RST) specifies the risks originated in a metal-degreasing process by using databases accumulating evidences on the relation between chemical risks and process parameters in A2, A4 and A6. Based on the information, RST can make a recommendation of adverse effects to be assessed with available indicators of them for a certain process. At the same time, RST can also distinguishes the risk indicators on the basis of their characteristics; acute/chronic, potential/actual, local/global. The distinguished indicators enable the engineer on the site to perform risk-based design.

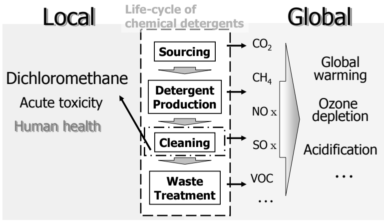

Figure 6 Life cycle of cleaning agent and associated chemical risks

2.2. Evaluation tool

Evaluation Tool (ET) can evaluate the specified adverse effects by RST. There are mainly two categories of adverse effect to be evaluated.

- Local chemical risks Cleansing agents have intrinsic hazardous properties such as acute/chronic toxicity, flammability and explosive possibility. These hazards cause chemical risks at cleaning site and ambient surroundings of it, e.g. human health risk on workers and neighbors, extinction of animals in the local ecology such as river, mortal damage to the site and surroundings caused by fire/explosion.
- Global environmental impacts Cleansing agents also have potential to cause adverse effects globally. For example, some cleansing agents potentially deplete the ozone layer, others contribute to global warming. Although these impacts may not be caused directly and immediately, the responsibility to them exists in industrial cleaning.

There is a possibility of an increase in chemical risk elsewhere in the life cycle of cleansing agents, and thus, the life cycle of cleansing agent should be taken into account to assess industrial cleaning process. Figure 6 schematically shows the life cycle of cleansing agent and its relation with chemical risks. The local chemical risks and global impacts are evaluated by risk assessment [3] focused on source conditions and life cycle assessment with LIME method [4] respectively.

2.3. Risk – Process parameter linkage model

Based on the evaluation results obtained by ET, alternative candidates should be generated comprehensively to reduce risks. In Risk – Process parameter linkage model (RP-linkage model), the relationships between all process parameters and chemical risks on the basis of the physical phenomena from process parameters

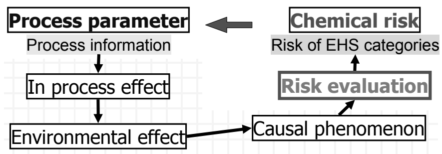

Figure 7 Risk – process parameter linkage

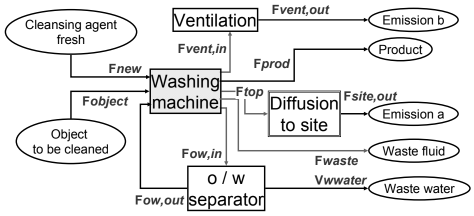

Figure 8 Cleaning process model

to risks as shown in Fig. 7. According to this physical relation, comprehensive alternative generation can be performed.

2.4. Cleaning Process Simulation Tool

Because alternative candidates are not existing processes, detailed process data and inventories must be estimated for source-specific risk assessment. Figure 8 shows the cleaning process model implemented in Cleaning Process Simulation Tool (CPST) which is a tool to estimate the source-specific process data of alternatives such as the amount of needed cleansing agent, occupational exposure and concentration of agent in ambient surroundings. The estimated values are sent to ET, and then the evaluation results will be obtained.

3. Case study on existing process

According to the proposed framework, a case study was performed on an actual metal degreasing site. The evaluated process in use is to degrease connector terminals with fine pore precisely using dichloromethane with open-top washing machine and exterior-hood type ventilation as shown in Figs. 1 and 2. As evaluation items, global warming potential in 100 years (GWP_{100} [4]) for LCA and margin of exposure (MOE) [5] were specified by RST. A smaller MOE implies higher risk in human health. The evaluation results for the existing process are shown in Fig. 9 as base case. Based on these results, large contribution of cleaning process to GWP_{100} and high risk in workers' health were demonstrated. The dominant risk factor of them is empirically regarded as the loss of vaporized agent from washing machine. Through the physical analysis using RP-linkage model, process parameters targeted as alternation could be specified; air flow rate of ventilation and type of ventilation. Therefore, three alternatives were generated; case 1 stops the flow rate, case 2 increases the flow rate and case 3 substitutes the booth type ventilation as shown in Fig. 10. Required process data could be estimated by CPST. The results in Fig. 9 demonstrate that there is trade-off relation between local and global effects. GWP_{100} means the degree of impacts caused potentially by process and MOE means the actual risks comparing epidemiological threshold. The decision-maker can obtain the detailed meaning of indicators from RST.

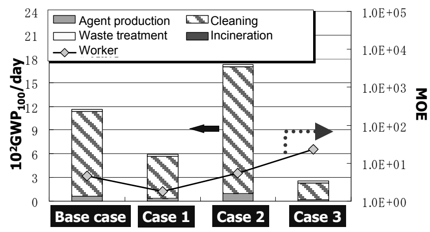

Figure 9 Evaluation results in all cases on the GWP_{100} and MOE of human health

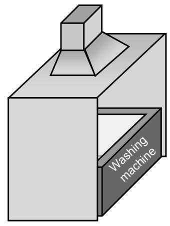

Figure 10 Booth type ventilation system

4. Conclusions

This framework of integrated design on site including an activity model and four mechanisms were developed and proposed. Four mechanisms were devised to enable to perform integrated design of process and operation on metal-degreasing process, which are connected clearly with activities belonging to the design. The activities controlled by the constraints associated with social, economic and technological conditions are enabled by the mechanisms.
An actual design of existing process was performed on the basis of the framework. Three alternative processes could be generated and evaluated. Based on the evaluation results, an interpretation and decision were discussed. This actual design could also demonstrate that the procedure of design in the framework is practical and revealed functional benefit toward integrated design.

Acknowledgements

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