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A Study on Initiating Events Identification of the IS Process

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Abstract : There has been an increasing need for substitute energy development due to the dry up of the fossil fuel and environmental problems. Among the substitute energy under consideration, producing hydrogen from water without the accompanying release of carbon has become a promising technology. Also, Iodine-Sulfur (IS) thermochemical water decomposition is one of the promising processes that can produce hydrogen efficiently using the high temperature gas-cooled reactor (HTGR) as an energy source capable of supplying heat at over 1000. In this study, to effect an initiating events identification of the IS process, Master Logic Diagram (MLD) was used and 9 initiating events that cause a leakage of the chemical material were identified.

Key words: initiating events identification, IS (iodine-Sulfur) process, MLD (master logic diagram)

1. Introduction

Hydrogen is very attractive as a future secondary energy carrier considering environmental problems. It is important to produce hydrogen from water by use of carbon free primary energy source. The thermochemical water decomposition cycle is one of the methods for the hydrogen production process from water. [1] Japan Atomic Energy Research Institute (JAERI) has been carrying out an R&D on the IS (iodine–sulfur) process that was first proposed by GA (General Atomic Co.) focusing on demonstration the "closed-cycle" continuous hydrogen production on developing a feasible and efficient scheme for the HI processing, and on screening and/or developing materials of construction to be used in the corrosive process environment. [2] The successful continuous operation of the IS-process was demonstrated and this process is one of the thermochemical processes, which is the closest to being industrialized. [3]

Currently, Korea has also started a research about the IS process and the construction of the IS process system is planned. In this study, for risk analysis of the IS process, initiating events of the IS process are identified by using the Master Logic Diagram (MLD) that is method for initiating event identification.

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2. Methods and Result

2.1 IS Process

A scheme of the IS process is shown in Fig. 1. The process is composed of the following chemical reactions:

$$I_2 + SO_2 + 2H_2O = 2HI + H_2SO_4 \text{ (Bunsen reaction)} \quad (1)$$

$$2HI = H_2 + I_2 \quad (200\sim500^{\circ}C) \quad (2)$$

$$H_2SO_4 = SO_2 + 0.5O_2 + H_2O \ (800^{\circ}C) \quad (3)$$

The so-called Bunsen reaction (1) is an exothermic sulfur dioxide gas-absorbing reaction in an aqueous phase. The hydriodic acid and the sulfuric acid formed are separated by a liquid–liquid phase separation phenomenon that occurs in the presence of an excess of iodine. The separated hydriodic acid dissolves the iodine and is denoted as the HIx phase. After purification, hydriodic acid is separated from iodine by distillation. The HI is then decomposed to produce hydrogen (2). Similarly, the separated sulfuric acid denoted as the sulfuric acid phase is purified, concentrated, vaporized and decomposed to produce oxygen. Here, the decomposition reaction (3) proceeds endothermically in two stages: firstly, the sulfuric acid decomposes spontaneously into sulfur trioxide and gaseous water at ca. 400, and secondly, at higher temperatures, the sulfur trioxide

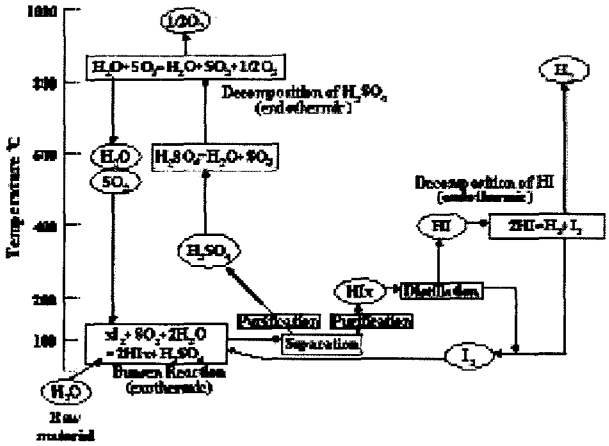

Fig. 1. Reaction scheme of the IS process

decomposes into sulfur dioxide and oxygen in the presence of a solid catalyst. Thus, these three reactions make a chemical cycle that is an energy converter from heat to hydrogen. [4]

2.2 Initiating Event Identification Using the Master Logic Diagram (MLD) in IS Process

The Master Logic Diagram technique is a basic approach for initiating event identification. It is a Logic Diagram that resembles a fault tree but without the formal mathematical properties of the latter. It starts with a "Top Event" which is the undesired event (like "Leakage of the chemical material") and it continues decomposing it into simpler contributing events in a way that the events of a certain level will in some logical combination, cause the events of the level immediately above. The development continues until a level is reached where events directly challenging the various safety functions of the plant are identified.

The starting point of MLD development is begun by defining the top event. In this study, top event is defined to containment failure that can induce the stopping of the system and cause risk. And then, the deductive decomposition is carried out through the following step.

2.2.1 Identification of critical areas

A critical area of the plant is one containing an each other different chemical material.

(1) Bunsen Reaction Step
(2) H_2SO_4 Decomposition Step
(3) HI Decomposition Step
(4) H_2 Step

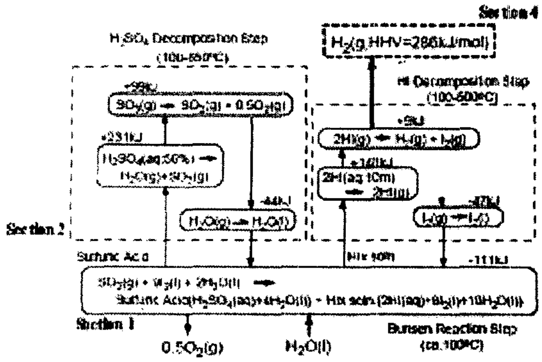

Fig. 2. Schematic diagram of the IS process

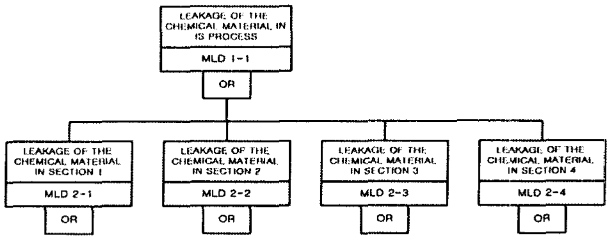

Fig. 3. MLD of the IS process

These four sections have been identified as possible sites of chemical material release. A schematic representation of the division of the IS process plant in the four sections is given in Fig. 2.

The first level of decomposition was along the four possible sites of chemical material release as shown Fig. 3.

2.2.2 MLD of the Bunsen reaction section

Fig. 4. gives MLD of the Bunsen reaction section.

The reasons that Bunsen reaction section may fail have structure failure and bypass. Structure failures

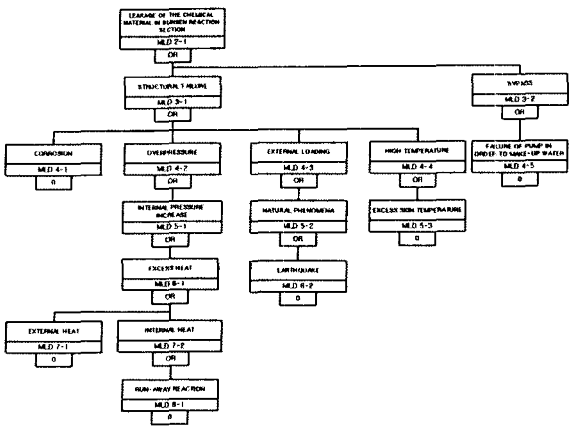

Fig. 4. MLD of the Bunsen reaction section

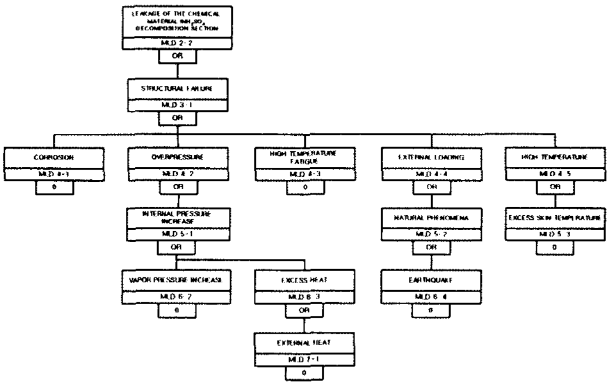

Fig. 5. MLD of the H_2SO_4 decomposition section

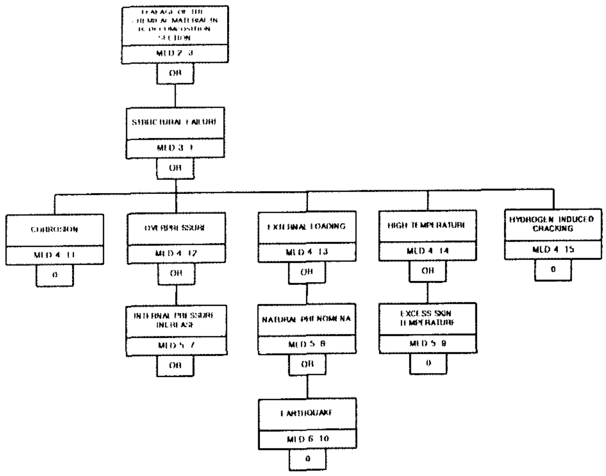

Fig. 6. MLD of the HI decomposition section

occur in corrosion by H_2SO_4, overpressure, external loading and high temperature. Overpressure in Bunsen reaction may occur in fire and run-away reaction. An earthquake is the only natural phenomenon considered which might cause loss of containment. All the others flooding and high winds have been neglected, because this particular system is surrounded to the outside building. High temperature may occur in external fire.

Bypass in the Bunsen reaction happens due to the failure of the pump to provide the water.

2.2.3 MLD of the H_2SO_4 decomposition section

Fig. 5 gives the MLD of the H_2SO_4 decomposition section.

The various ways the H_2SO_4 decomposition section may fail namely, internal pressure increase have been further decomposed for each process phase. An earthquake is the only natural phenomenon considered which might cause loss of containment. Internal pressure increase may occur either if there is imbalance of heat removal when gas phase is converted to liquid phase, or direct pressure increase from evaporated SO_2 gas, or excess heat. Excess heat may occur in external fire.

2.2.4 MLD of the HI decomposition section

Fig. 6 gives the MLD of the HI decomposition section.

Structure failures in the HI decomposition section occur in corrosion by HI, overpressure, external loading, high temperature and hydrogen-induced cracking by H_2S. Overpressure in this section may occur in vapor pressure increase, clogged pipe by I_2 concentration control failure and external heat such as fire. Fig. 7 gives the MLD of the internal pressure increase.

As mentioned above, an earthquake is the only natural phenomenon considered which might cause loss of containment and external fire is the reason of the high temperature.

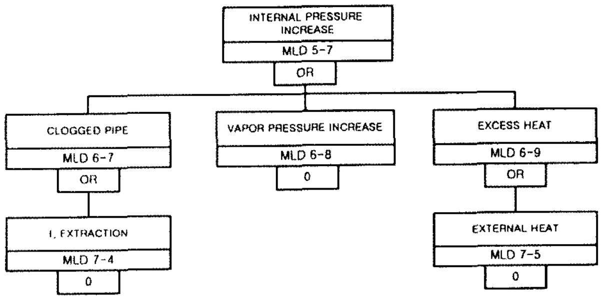

Fig. 7. MLD of the internal pressure increase in HI decomposition section

2.2.5 MLD of the H_2 production section

Fig. 8 gives MLD of the H_2 production section.

The reasons that H_2 production section may fail have structure failure and bypass. Structure failures occur in hydrogen embrittlement, overpressure, external loading

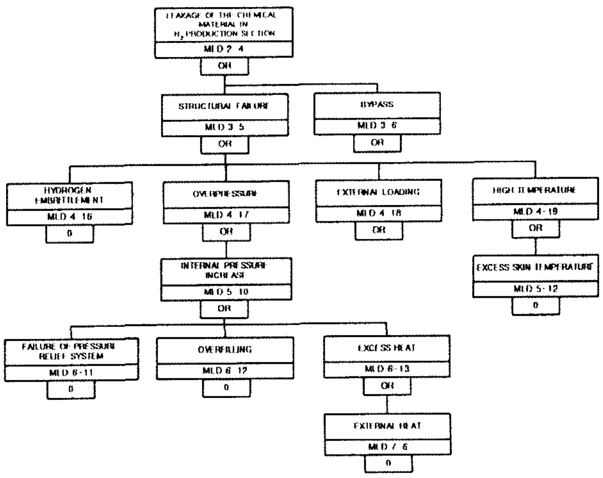

Fig. 8. MLD of the H_2 production section

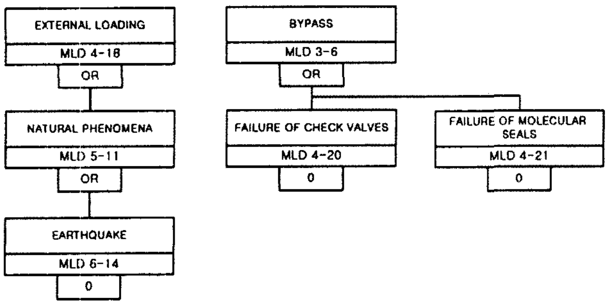

Fig. 9. MLD of external loading and bypass in the H_2 production section

and high temperature. Overpressure in H_2 production may occur in failure of pressure relief system, overfilling and overpressure by fire. High temperature may occur in excess skin temperature by external fire.

Fig. 9 gives MLD of the bypass and external loading. The earthquake to be the natural phenomenon was considered in the reason of the external loading. Bypass in the H_2 production section happens due to the failure of check valves and molecular seals.

2.2 Result

The most important initiating events, which were identified with the application of the Master Logic Diagram to the IS process, are the following:

(1) Pipebreak owing to corrosion, thermal stress, hydrogen embrittlement and hydrogen induced cracking;
(2) Overpressure owing to run-away reaction in the Bunsen reaction;
(3) Vapor pressure increase from a temperature control failure
(4) Direct pressure increase from evaporated gas;
(5) Clogged pipe by I_2 concentration control failure;
(6) Overfilling in storing hydrogen;
(7) Failure of check valves and molecular seals;
(8) Excess external heat such as fire;
(9) Earthquakes.

3. Conclusions

Initiating event identification either uses techniques based on systematic and logical methodology or those based on experience.[5] The MLD technique is a deductive tool using a top-down approach, which can do a formal and logical identification of initiating events. In this paper, initiating event identification of the IS process is carried out by using the MLD. Further, it can be used to make risk assessment for hydrogen production system using IS process. Moreover, it can contribute towards a preliminary design which will enhance the system safety and safety precaution down the line.

Acknowledgement

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