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Risk based decision making. Discussion on two methodological milestones

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A B S T R A C T

Through the application to the risk based design of an Allyl Chloride production plant, the authors would like to illustrate the methodological approaches developed by two process safety pioneers, Norberto Piccinini and Remo Galvagni, both scientists and gentlemen, who devoted their professional lives to develop novel approaches to enhance accident prediction and prevention and to train young scientists.

In particular, Norberto Piccinini has to be mentioned to have developed the Recursive operability analysis, a step ahead in the HazOp techniques, able to directly obtain the Logic Trees from the tables of the operability analysis, thus guaranteeing the coherence between the hazard identification step and the quantification step in the quantitative risk assessment.

Remo Galvagni instead conceived and developed the integrated dynamic decision analysis (IDDA), an Event Tree empowered with conditionings, both logic and probabilistic. The tool, aimed to a correct and coherent application of probability theory according to the De Finetti's principles, allows the logical-probabilistic model to run integrated with a deterministic model of the plant to have guarantees of consistency and completeness in a risk assessment used as a basis for a proper plant design.

Comparing the qualitative and quantitative results of the two methods applied to the same case study allows discussing their effectiveness in supporting the risk based decision-making.

1. Introduction

An adequate safety level can only be reached through a constant effort to verify plant equipment and its management, applying all the required modifications needed to reduce risks. It is clear that this verification will only be effective if the objectives to be reached are well defined and if any differences from the existing situation can be assessed and measured. Those who design, construct and run an industrial plant must take into account the risks associated with its processes from the initial stages of its development to the start-up of its equipment.

Systematic risk analysis at each stage of the initial project will show throughout the service life of a plant whether all the objectives laid down by the regulations and good design practice have been achieved (CCPS, 2008; Lawley, 1974).

It can thus be deduced that designing, constructing and operating a plant to have a tolerable level of risk means:

1. defining what *risk tolerability* means (this requires the quantification of the risk itself);
2. having the chance of systematically comparing the state and evolution of the system with the risk tolerability criteria.

The full integration of qualitative and quantitative methods ensures the essential features for probabilistic safety analysis; namely, in qualitative terms, systematicity, completeness and congruence; and, in numerical terms, reliability and verification.

In particular this can be achieved through the use of the Recursive operability analysis (ROA), a step ahead in the HazOp techniques, able to directly obtain the Logic Trees from the tables of the operability analysis, thus guaranteeing the coherence between the hazard identification step and the quantification step in the quantitative risk assessment (Piccinini & Ciarambino, 1997; Piccinini, Scarrone, & Ciarambino, 1994).

As discussed earlier, the classical HazOp methodologies associated with the Fault Tree Analysis, allows to identify the possible

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accidents (Top Event, TE) that could occur in a process plant and to quantify their frequency of occurrence. But in the presentation of results in terms of Minimal Cut Sets (MCS), obtained from the logical solution of the Fault Tree, the information about the sequence of events bringing to the TE is lost.

The IDDA method (Clementel & Galvagni, 1984; Galvagni & Clementel, 1989), instead, requires the description of the whole plant and produces a full set of alternative (mutually self excluding) sequences of events that could occur during the plant life (constituents of a partition, whose probability sum up to 1). Furthermore IDDA method allows the interfacing of the probabilistic description of the system, with the one of its physical behaviour, e.g. interfacing the logic-probabilistic model with a process simulator, in order to assess the status of each relevant process variable with reference to the failure sequence identified. This allows to obtain a more effective scenario in form of a logical trajectory represented both through its logical-probabilistic and its physic-phenomenological evolution, otherwise impossible. Thus it allows addressing those problems related to the mutual interactions of the hardware components and the physical evolution of the plant.

Availability of the full set of alternative allows the complete spectrum of possible probability-consequence conditions to be used as a basis for decisions in risk reduction and control.

Strong efforts have been recently spent to develop dynamic risk assessment methodologies, as: in Bucci et al. (2008), Cepin and Mavko (2002), Kalantarnia, Khan, and Hawboldt (2009), Meel and Seider (2006), Swaminathan and Smidts (1999), and more recently, in Paltrinieri, Tugnoli, Buston, Wardman, and Cozzani (2013), but the dynamic features of IDDA, even if available, are out of the purpose of this paper.

2. The case study

The allyl chloride is produced by the chlorination of propylene at high temperature (300–600 °C), through the following reactions:

$$CH_2{=}CH{-}CH_3 + Cl_2 \rightarrow CH_2{=}CH{-}CH_2Cl + HCl$$

$$r_1 = 3301562 \exp(-15118/RT) p_{C3H6}\, p_{Cl2}\ [\mathrm{kmol}_{Cl2,reacted}/\mathrm{h\ m}^3]$$

$$\Delta H_{273} = -26800\ \mathrm{kcal/kmol}$$

$$CH_2{=}CH{-}CH_3 + Cl_2 \rightarrow CH_2Cl{-}CHCl{-}CH_3$$

$$r_2 = 1855 \exp(-3811/RT)\, p_{C3H6}\, p_{Cl2}\ [\mathrm{kmol}_{Cl2,reacted}/\mathrm{h\ m}^3]$$

$$\Delta H_{273} = -44100\ \mathrm{kcal/kmol}$$

where r_1 and r_2 are the reaction rates, R is the ideal gas constant, T the temperature, p_{C3H6} and p_{Cl2} the reactants partial pressures and ΔH_{273} the heat of reaction at a temperature of 273 K.

At these temperatures, the chlorination occurs through a radical mechanism where the hydrogen atom in allylic position is replaced preferentially by chlorine giving rise to allyl chloride. Below 200 °C propylene reacts with chlorine mainly by addition to the double bond to give 1,2-dichloropropane; above 300 °C, this reaction is suppressed and the formation of allyl chloride predominates so that 1,2-di chloro propane is only a by-product. The compounds cis- and trans-1,3-dichloropropene arises from a secondary reaction of allyl chloride, in which a further hydrogen atom is substituted by chlorine (Krähling, Krey, Jakobson, Grolig, & Miksch, 2000).

The plant object of this study has been designed for the production of 45,000 ton/year of allyl chloride (Anatra & Malandrino, 1980).

The plant is sketched in Fig. 1.

Propylene and Chlorine, stored in two small vessels (S101 and S102) at a temperature of 25 °C, are sent to two vaporisers (E102 and E103). Propylene is then heated to 250 °C in E104 and sent to a furnace, F101, where it reaches 337 °C.

This propylene stream is mixed with the chlorine stream in a mixer at the top of the reactor R101, reaching a temperature of

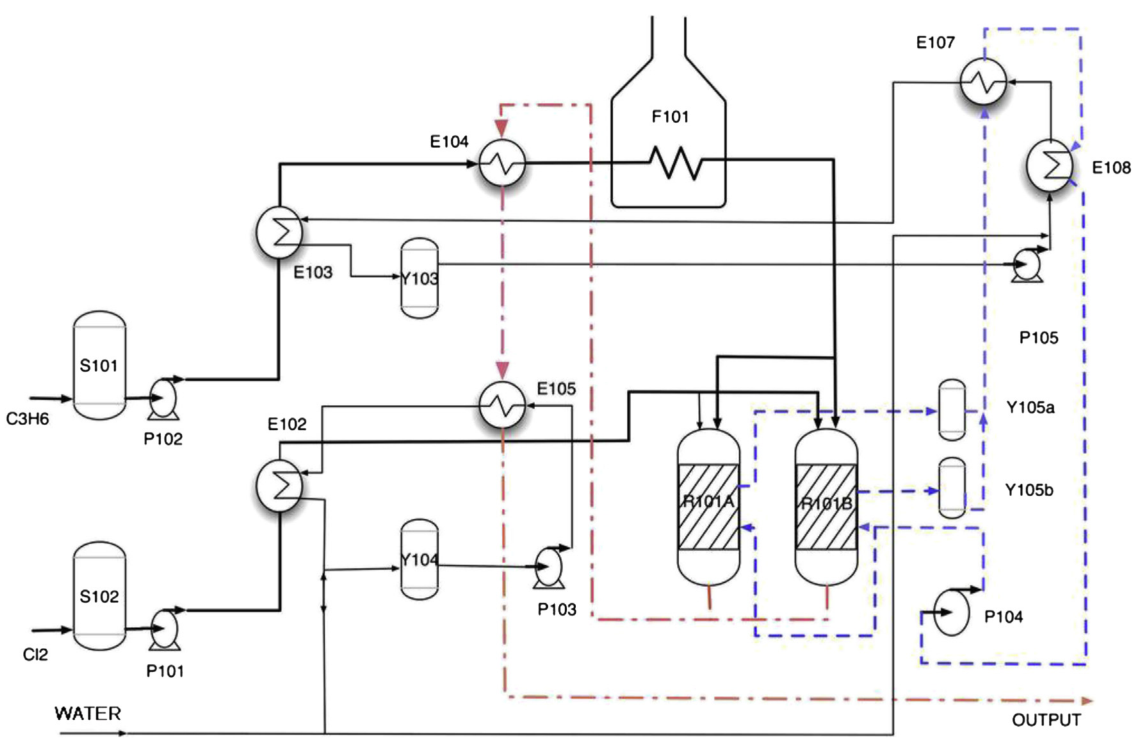

Fig. 1. Plant sketch.