A Functional approach to HAZOP studies

Netta Liin Rossing, Morten Lind*, Johannes Petersen*,
Sten Bay Jørgensen and Niels Jensen[1]
CAPEC, Dept. of Chemical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark
*Ørsted-DTU, Technical University of Denmark, Kgs. Lyngby, Denmark

This paper presents a functional approach to HAZOP studies in which the plant is divided along strictly functional lines starting from the purpose of the plant and continuing down to the function of a single node, e.g. a pipe section. The approach leads to nodes with simple functions such as liquid transport, gas transport, liquid storage, gas-liquid contacting etc. From the functions of the nodes the selection of relevant process parameters and deviation variables follow directly. The knowledge required to perform the pre-meeting task of dividing the plant along functional lines is that of chemical unit operations and transport processes plus a little familiarity with the plant a hand. Thus the preparatory work may be performed by a chemical engineer with just an introductory course in risk assessment.
In any given plant there will be several nodes with the same function, e.g. gas transport. These nodes are analysed together, which removes some of the repetitive nature of the HAZOP meeting. The functional approach lends itself directly for implementation into a computer aided tool for HAZOP studies. Such a tool will facilitate finding causes far away from the site of the deviation.
The approach is exemplified by a HAZOP study of an industrial scale heat integrated distillation pilot plant HIDiP at the Dept. of Chemical Engineering. The purpose of the plant is to separate a binary mixture into pure products using the least amount of energy. This plant is divided into 8 sections, which are further divided into 20 nodes. Typically in this pilot plant a section is divided into 1-5 nodes. Several of the nodes have a similar function, e.g. transport of liquid. Two HAZOP studies of a section of the plant are compared, i.e. one traditional with one one based on the functional approch.

Introduction

Since the development of hazard and operability (HAZOP) studies by ICI in the mid 60's they have been a cornerstone in risk assessment of process plants. The purpose of the HAZOP study is to investigate how the facility responds to deviations from design intent or normal operation, e.g. to find out if the plant has sufficient control and safety features to ensure, that it can cope with expected deviations encountered during normal operations. The HAZOP study is traditionally performed as a form of structured brainstorming exercise facilitated by a HAZOP study leader and the experience of the participants. A traditional HAZOP study has the following phases (Skelton, 1997):

---

[1]Presenting and corresponding author – e-mail: nj@kt.dtu.dk

- Pre-meeting phase: The purpose and objective of the study is defined. The leader of the HAZOP study gathers information about the facility, such as process flow diagrams (PFD), process & instrumentation diagrams (P&EI), plant layouts, chemical hazard data etc., and proposes a division of the plant into sections and nodes. For each node - or for the plant as a whole - the leader identifies relevant process parameters and deviations from design intent or normal operation based on either past experience or company guidelines.

  The leader also identifies the participants, who will participate in the review of the different sections of the plant, and ensures their availability. Typically this includes the process design engineer, the control engineer, the project engineer and an operator besides the experienced team leader. All these people with large demands on their time during a project. The team leader schedules a sufficient number of half day HAZOP meetings.
- Meeting phase: At the start of the HAZOP meeting the technique is briefly reviewed, and the specific scope of the present study is stated. The overall facilities are described e.g. using a 3D computer model. Then the team considers each P&ID or PFD in turn. The team leader ensures, that process parameters and deviations are considered in a rigorous and structured manner, that results are recorded, and that all areas meriting further consideration are identified by action items.
- Post-meeting phase: After the HAZOP meeting all actions items are followed up by the persons assigned to them during the meeting, and the results of the follow-up is reported to the team leader. The team might call a review meeting to determine the status of all actions items, and decided if additional efforts are needed.

Traditionally the division of the plant into sections may be done by defining each major process component as a section. A section could also be a line between each major component with additional sections for each branch off the main process flow.

Usually the function of a section or of a node is not directly specified, many HAZOP forms only identifies the part of the process considered by project number, P&ID number and line number. The design intent of the node may go unrecorded, even though the purpose of the HAZOP study is to consider deviations from design intent. In the following section a functional approach to dividing the plant is presented, which allows meaningful participation of less experienced personnel in all phases of a HAZOP study. Following a HAZOP study of a pilot plant using this functional approach is presented, and compare with results from a traditional approach. Finally the some possibilities opening up by introduction of functional models of process plants and automatic reasoning systems are outlined.

Functional HAZOP

The functional HAZOP provides a structured approach for dividing the plant into sections and the sections into nodes. The procedure involves the following steps:

- State the aim or purpose of the plant.
- Devide the plant into sections each of which has a clear sub-purpose or -aim in contributing to the overall purpose of the plant.

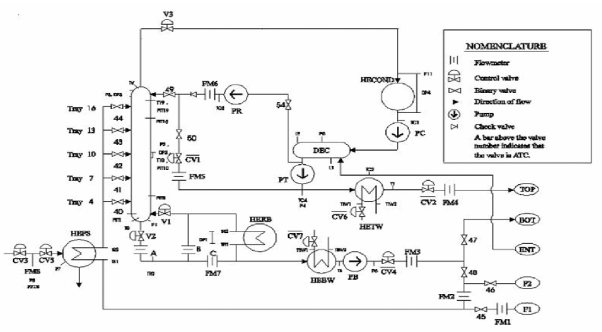
- Devide each section into nodes, the function of which can be directly described by a physical or chemical phenomena. Examples of such nodes are: gas transport, liquid transport, liquid storage and gas-liquid contact.
- For each type of node, i.e. each physical or chemical phenomenon, describe the process parameters, which identifies design intent or normal operation. For a node with the function 'gas transport' normal operation could be described by flow rate, temperature, pressure and number of phases.
- For each process parameter specify the relevant deviations. For flow relevant deviations are more, less and reverse. In this work the deviation 'no flow' is considered a limiting situation of 'less flow', and hence is not considered separately.

The aim of the plant could be to produce 50 tons of PE per hour. In order to achieve this we need sections which: feed reactants to the reactor, feed catalyst to the reactor, reaction, remove excess heat from the reactor, remove product from the reactor, remove of unreacted hydrocarbons from product, add additives to virgin PE etc. The reaction section could be considered as a single node with the purpose of providing conditions, such that raw materials react to form products. For a Unipol PE reactor this would require maintaining fluidization of the PE particles to facilitate their growth as well as the transport of heat of reaction away from the PE particles to ensure they don't melt or fuse together.

Using this approach to dividing the plant all that is needed is a basic understanding of chemical unit operations, their purposes and the fundamentals on which these purposes are built. This means, that the preparations for a HAZOP study may be performed by less experienced personnel. Indeed, it is believed, that using this more structured approach makes is possible for any chemical engineer to contribute in a meaningful way to a HAZOP study. The following section will demonstrate the functional HAZOP on the distillation pilot plant at DTU.

Functional HAZOP of distillation pilot plant

The heat integrated distillation pilot plant (HIDiP) at the Dept. of Chemical Engineering consists of a distillation column and a heat pump. Process schematics of the column and the heat pump are shown in figures 1a and 1b respectively



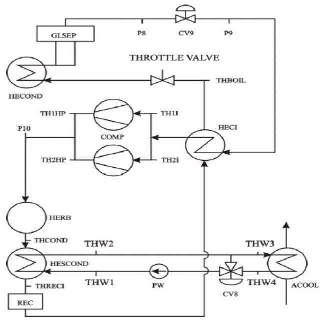


Figure 1. Process diagram of heat integrated distillation pilot plant. On the left the column and on the right the heat pump. See Rossing (2006) for more information.

The purpose or aim of the column is to separate a feed stream into 2 product streams while minimising energy used. To accomplish the aim of the plant aim the following subsystems are needed:

- Column section.
  Aim or purpose: Gas-liquid contact to facilitate separation.
- Re-flux section.
  Aim or purpose: Provide a liquid stream to the column and remove excess liquid as top product.
- Feed section.
  Aim or purpose: Provide a feed stream as close as possible to the conditions on the feed plate.
- Re-boiler section.
  Aim or purpose: Provide a gas stream to the column and remove excess liquid as bottoms product.
- Low pressure heat pump section.
  Aim or purpose: Transport energy from re-flux section to compressors.
- High pressure heat pump section, including compressors.
  Aim or purpose: Transport energy from compressors to re-boiler.
- Excess heat removal section.
  Aim or purpose: Transport of excess energy from the heat pump to the environment.
- Tank park.
  Aim or purpose: Provide storage for feeds and products.

Thus the distillation pilot plant is divided into 8 sections in step 2 of the functional HAZOP approach. In the next step each section is further divided into nodes according to their function. For example the re-flux section, which consists of the piping from the top of the column through the condenser and accumulator back to the column as well as the piping from the accumulator to the top product storage tank, is divided into the following nodes during step 3:

- Node 1. Function: Gas transport.
  Piping from the column to the condenser (HECOND) including the emergency shutdown valve (V3) and other instrumentation.
- Node 2. Function: Liquid transport.
  Condenser and piping from condenser to accumulator including a pump (PC) and other instrumentation.
- Node 3. Function: Liquid storage.
  Accumulator (DEC) and associated instrumentation.
- Node 4. Function: Liquid transport.
  Piping from accumulator to top product storage including the product pump (PT) and product cooler (HETW) and an associated instrumentation.
- Node 5. Function: Liquid transport.
  Piping from the accumulator to the column, where re-flux enters, including the re-flux pump (PR) and associated instrumentation.

The other sections of the distillation pilot plant is divided into nodes using the same basic idea, i.e. that each node relates to a function described by a physical or chemical phenomena. This way a total of 20 nodes are defined. However, several nodes have the same function, as can already be seen from the above sub-division of the re-flux section. In fact 7 of the 20 nodes has the function 'liquid transport'. From the function the node the parameters necessary to describe design intent follows. E.g. the process parameters and deviations relevant for the function 'liquid transport' will be:

- Flow: more, less, reverse, as well as.
- Temperature: lower, higher.

Similarly the function 'gas transport':

- Flow: more, less, reverse, as well as.
- Temperature: lower, higher.
- Pressure: lower, higher

For more information about the functional HAZOP see Rossing (2006).

Comparison of traditional HAZOP and functional HAZOP

Rossing (2006) has compared the result of a traditional HAZOP of the re-flux section of the distillation pilot plant with the functional approach described and found the functional HAZOP to be about half the effort by counting the number of lines in the HAZOP report. This number is assumed to be proportional to the time required for the study. A traditional HAZOP of the mentioned section resulted in 14 lines in the HAZOP report, while the structure approach just 8 lines.

Rossing (2006) also reports, that the functional approach facilitates discovering causes of deviations, which originate far from the node in which the deviation occurs. Some recent loss events in the chemical industry have involved such situations (Mogford, 2005).

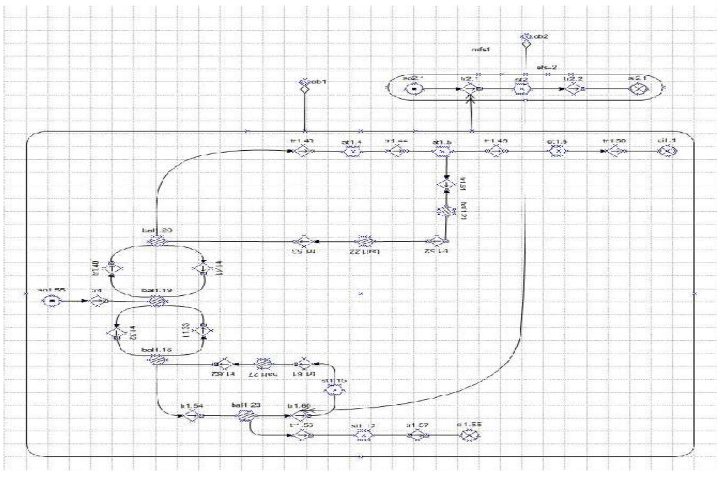


Figure 2. Simple total mass flow MFM model of distillation pilot plant with objectives to maintain constant level in the accumulator and constant energy flow in the heat pump.

Combining functional HAZOP with a functional plant model

Combining a functional HAZOP approach with a functional model of the plant allows the development of reasoning systems, which may assist in HAZOP studies. Multilevel Flow Modelling (Lind, 1990) is an approach to functional modelling. The MFM model describes the system using the concepts of goals and functions. In the means - end dimension a system is described using goals, objectives, functions and components. Rossing (2006) describes the use of GUI based MFM Model Builder and develops a simple total mass flow MFM model of the distillation pilot plant. This model is shown in figure 2.

The ability the MFM diagnostic system to find causes of deviations far from the locus of the deviation has been demonstrated using this model. It has further been demonstrated on a model of just the re-flux section, that the MFM diagnostic system finds the same causes of deviations in this sections as a traditional HAZOP study. The work has demonstrated the usefulness of the functional modelling approach, and have identified areas, were functional modelling methodologies should be extended to handle means - end modelling of chemical plants in a more transparent maner.

Conclusions

A 5 step functional approach to HAZOP has been introduced, which allows any chemical engineer to contribute meaningfully to a HAZOP study. The approach reduce the work involved in a HAZOP of a plant by dividing the plant along functional lines and analysing nodes with the same function once only. This appears to reduce the effort involved.

Furthermore functional models of chemical plants has been demonstrated to provide a useful approach for development of systems for computer assisted HAZOP analysis. On a simple model of a part of a heat integrated distillaton pilot plant the computer assisted HAZOP has been shown to find the same causes as a traditional HAZOP study. It has furthermore been demonstrated, that a computer assisted HAZOP is able to find causes far from the site of the deviation.

References

1. Lind, M. (1990): "Representing goals and functions of ocmplex systems. An Introduction to Multilevel Flow Modellling", Ørsted-DTU, Technical University of Denmark.
2. Mogford, J. (2005): "Fatal Accident Investigation Report", BP, Texas City.
3. Rossing, N.L. (2006): "Method development for systematic risk assessment", M.Sc. Thesis, Dept. of Chemical Engineering, Technical University of Denmark.
4. Skelton, B. (1997): "Process Safety Analysis - An Introduction", IChemE, U.K.