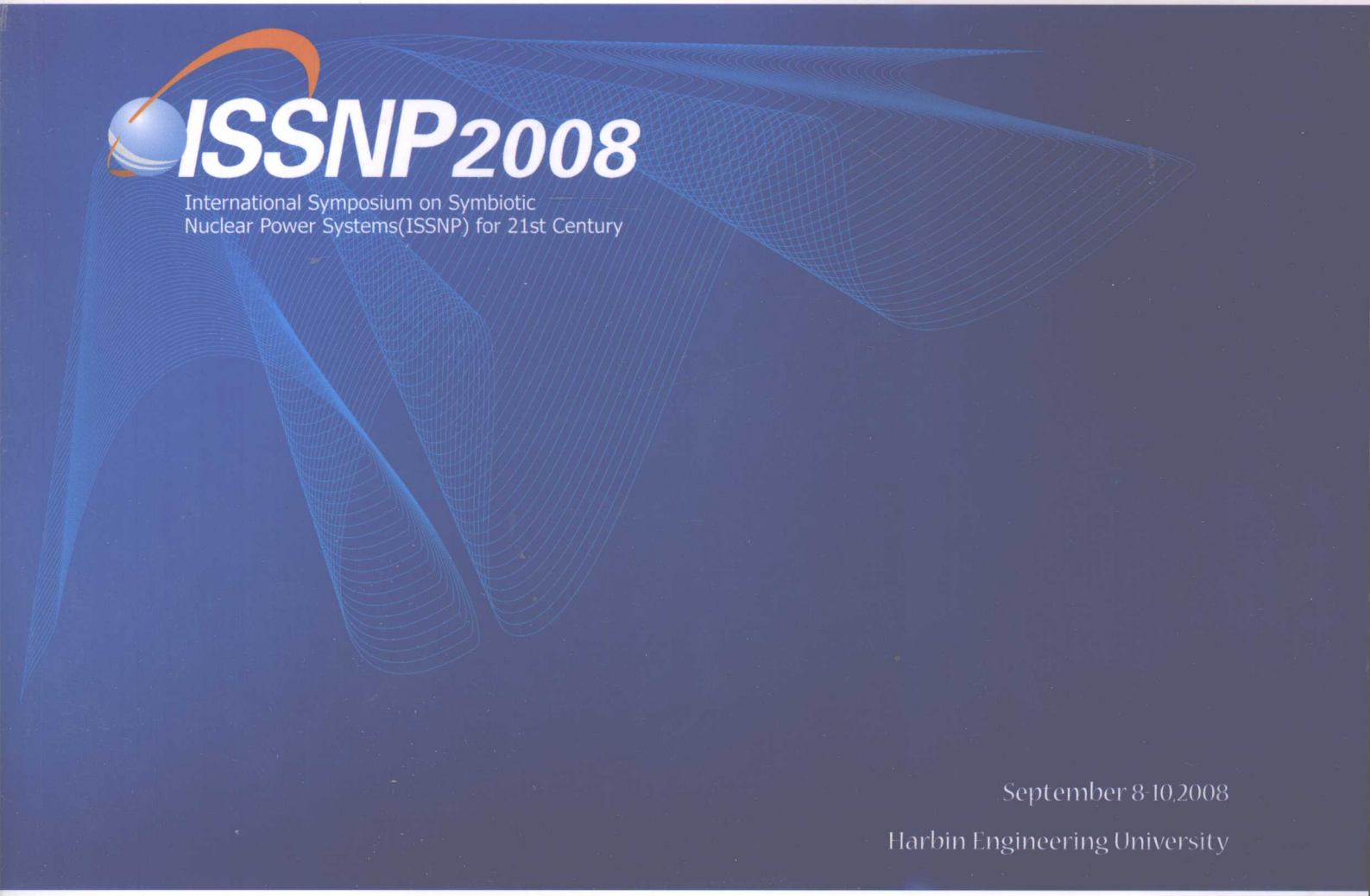
Toward Innovative Nuclear Safety and Simulation Technology

Joint International Symposium of ISSNP2008/CSEPC2008/ISOFIC2008



Harbin Engineering University Press

Toward Innovative Nuclear Safety and Simulation Technology

(Volume 2)

Harbin Engineering University Press

内容简介

This book summarizes proceedings of the invited papers presented at the Joint International Symposium of "The 2nd International Symposium on Symbiotic Nuclear Power Systems for 21st Century (ISSNP2008) Embedded with the 4th International Symposium on Cognitive Systems Engineering for Process Control (CSEPC2008) and the 3rd International Symposium on Future I&C for Nuclear Power Plants (ISOFIC2008)", held in Harbin, China on September 8 – 10, 2008. The symposium focuses on the newly developed technologies in nuclear safety and simulation research areas, including "Methods of Sensing, Monitoring and Processing for Control and Communication", "System Simulation Technologies", "Cognitive Systems Engineering Approach to Process Control", "Future I&C for Nuclear Power Plants", and "Symbiosis of Technology with Society and Environment".

图书在版编目(CIP)数据

Toward Innovative Nuclear Safety and Simulation Technology.2:英文/《创新型核安全与仿真技术》编委会编.—哈尔滨:哈尔滨工程大学出版社,2008.8
ISBN 978-7-81133-306-0

Ⅰ.面… Ⅱ.面… Ⅲ.核工程-安全技术-文集-英文
Ⅳ.TL7-53

中国版本图书馆 CIP 数据核字(2008)第 132500 号

出版发行 哈尔滨工程大学出版社
社　　址 哈尔滨市南岗区东大直街 124 号
邮政编码 150001
发行电话 0451-82519328
传　　真 0451-82519699
经　　销 新华书店
印　　刷 哈尔滨工业大学印刷厂
开　　本 889mm×1 194mm 1/16
印　　张 22.5
字　　数 640 千字
版　　次 2008 年 8 月第 1 版
印　　次 2008 年 8 月第 1 次印刷
印　　数 1—500 册
定　　价 1500.00 元(全 1,2 册)
http://press.hrbeu.edu.cn
E-mail:heupress@hrbeu.edu.cn

Toward Innovative Nuclear Safety and Simulation Technology

—Proceedings of

- 2nd International Symposium on Symbiotic Nuclear Power Systems for 21st Century (ISSNP2008)
- 4th International Symposium on Cognitive Systems Engineering Approach to Power Plant Control (CSEPC)
- 3rd International Symposium on Future I&C for Nuclear Power Plants (ISOFIC2008)

Harbin Engineering University, Harbin, China
September 8 – 10, 2008

(Volume 2)

Session C: Cognitive Systems Engineering Approach to Process Control
Session D: Future I&C for Nuclear Power Plants
Session E: Symbiosis of Technology with Society and Environment

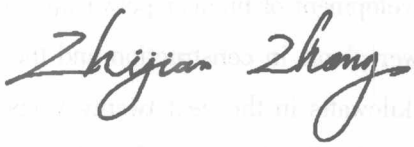
Preface

These days, high demands of energy and environmental protection have promoted the revival and fast development of nuclear power around the world. Only in mainland China, there will be 50 nuclear power plants in construction and the new installed nuclear power capacity is expected to be 60 million kilowatts in the next twenty years. The safe and economical operation of nuclear power and therefore the development of nuclear power in harmony with human and environment can be achieved only through the development of advanced nuclear energy technologies because nuclear safety is the precondition and basis of the existence and development of nuclear power.

The joint international symposiums of "ISSNP2008/CSEPC2008/ISOFIC2008" are organized to promote academic exchanges on the topics of innovative nuclear power safety and simulation technology from the following five areas: 1) Methods of Sensing, Monitoring and Processing for Control and Communication, 2) System Simulation Technologies, 3) Cognitive Systems Engineering Approach to Process Control, 4) Future I&C for Nuclear Power Plants, and 5) Symbiosis of Technology with Society and Environment. For the final program, 111 technical papers from 11 countries and international organizations, including China, Japan, Korea, U. S. A, France, Norway, Denmark, Canada, Switzerland, IAEA and OECD, were selected and retrieved in the conference proceedings. The authors backgrounds are diversified, including not only the experts being a long time engaged in nuclear power engineering, but also the students pursuing their master's or doctor's degree. Therefore, papers retrieved in this conference proceedings are also pretty diversified, but the level of all papers meet the two objectives of the conference that it would like to promote the academic exchanges between international professionals and the cultivation of young talents for nuclear engineering. I believe that this conference will contribute to the peaceful use of nuclear energy and to the development of nuclear energy in harmony with human society.

The conference is held jointly by China Nuclear Energy Association, Symbol Community Forum, Research Division of Human-Machine System Atomic Energy Society of Japan, Human Factors Division America Nuclear Society, Human Factors Division Korea Nuclear Society, Man-Machine System Division Society of Instrument & Control Engineers, Kyoto University Global COE Program "Energy Science in the Age of Global Warming-Toward CO_2 Zero-emission Energy System", OECD/Halden Reactor Project, "111 Project" on "Nuclear Power Safety and Simulation" and Key Laboratory of Nuclear Safety and Simulation Technology for National Defense. Sincere thanks are given to all the members of the co-organizers, technical committee, international board and the local co-ordinate committee, and also to the Nuclear Power Institute of China, China

Nuclear Power Design Co., LTD and GSE Systems, Inc. for their kind financial support. Lastly, I would like to express my special thanks to Prof. Hidekazu Yoshikawa and Assoc. Prof. Ming Yang for their great efforts for the conference and the publication of the conference proceedings.



Zhijian Zhang
General Chair, ISSNP2008
Dean & Professor,
College of Nuclear Science and Technology,
Harbin Engineering University

Contents

Session C

Cognitive Systems Engineering Approach to Process Control

A Goal Based Methodology for HAZOP Analysis

Netta Liin Rossing, Morten Lind, Niels Jensen and Sten Bay Jørgensen

1. CAPEC, Chemical and Biochemical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark
2. Department of Electrical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark
3. Safepark Consultancy, Kannikestræde 14, DK-3550 Slangerup, Denmark

Abstract: This paper presents a goal based methodology for HAZOP studies in which a functional model of the plant is used to assist in a functional decomposition of the plant starting from the purpose of the plant and continuing down to the function of a single node, e.g. a pipe section. This 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 variables and deviation variables follow directly. The knowledge required to perform the pre-meeting HAZOP task of dividing the plant along functional lines is that of chemical unit operations and transport processes plus a some 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.

The goal based methodology lends itself directly for implementation into a computer aided reasoning tool for HAZOP studies to perform root cause and consequence analysis. Such a tool will facilitate finding causes far away from the site of the deviation. A Functional HAZOP Assistant is proposed and investigated in a HAZOP study of an industrial scale Indirect Vapour Recompression Distillation pilot Plant (IVaRDiP) at the DTU-Dept. of Chemical and Biochemical Engineering. The study shows that the goal based methodology using a functional approach provides a very efficient paradigm for facilitating HAZOP studies and for enabling reasoning to reveal potential hazards in safety critical operations.

Keywords: Risk Assessment, Systems Engineered HAZOP Analysis

Introduction

Hazard analysis provides a systematic methodology for identification, evaluation and mitigation of potential process hazards which can cause serious human, environmental and economic losses. Different methods are practiced at various stages during the plant life cycle. Most methods require considerable time and resources. Consequentially research has been stimulated to develop computer aided tools to assist in or even aiming at automating hazard analysis.

Venkatasubramanian, Zhao and Viswanathan (2000) reviewed development of knowledge based systems for automating HAZOP analysis. Venkatasubramanian and Vaidhyanathan (1995) describe a knowledge based framework, which addresses the issues of representation of process specific and generic knowledge in the automation of HAZOP studies. The HAZOP knowledge, which is generic and hence applicable to a wide variety of flow sheets, is called process general knowledge, while the remaining HAZOP knowledge is considered specific to a particular process, and is called process specific knowledge. Bragata et al. (2007) build upon the notions introduced above and exploits process knowledge with the aim to develop tools for the experts to reveal potential hazards, rooted in a function based taxonomy for equipment and instrumentation. Thus their system includes a dictionary, the plant information database, a reasoning and analysis engine and a knowledge repository. The dictionary permits linking between the terminology used in hazard analysis and a particular application area. In their system objects are categorized according to a hierarchically organised functionality based taxonomy, which can be mapped to the corresponding STEP data definition (STEP, 1994). Thus each item is classified in terms of super-function, function, and type and with an associated set of

functional parameters.

However these methods relate the concept of function directly to a physical implementation and therefore they limit the possibility to abstract from one layer in a goal hierarchy to another. Consequently it is desirable to develop a HAZOP analysis methodology based upon a model representation which can encompass the operational goal hierarchy for the plant. Such a functional model should represent the system using the means-end concepts, where a system is described using goals and purposes in one dimension; whole-part concepts in another dimension. Such a functional modeling approach lends itself directly for implementation into a computer aided reasoning tool for HAZOP studies to perform cause and consequence analysis. Thereby functional modelling can provide a systematic methodology for computer assisted HAZOP studies, thus potentially relieving the engineers from a major part of a rather cumbersome task and instead permitting them to focus attention where significant problems may be uncovered.

The purpose of this paper is to present the background for development of a functional model based reasoning system for assisting in a goal based methodology for HAZOP analysis. The resulting tool is called a Functional HAZOP Assistant. This will be illustrated on an Indirect Vapour Recompression Distillation Pilot Plant (IVaRDiP) located at the Department of Chemical Engineering, at the Technical University of Denmark. The following section briefly introduces a traditional HAZOP, then the functional modeling methodology and the associated reasoning engine are described. The goal based HAZOP analysis methodology uses a functional model based HAZOP which leads to the Functional HAZOP Assistant is presented next. The Functional HAZOP Assistant is demonstrated on the case study. Finally the presented methodology is discussed and the conclusions are drawn.

Methods

The proposed methodology is based upon experiences from traditional HAZOP studies. The procedure for such studies is described before introducing a functional modeling paradigm and a workbench for model building and a reasoning engine.

Traditional HAZOP Procedure

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 (Crawley & Tyler, 2003, Lees, 1980). The purpose of the HAZOP study is to investigate how a facility responds to deviations from design intent or from normal operation, i. e. to reveal if the plant has sufficient control and safety features to ensure, that it can cope with expected deviations normally encountered during operation. The HAZOP study is traditionally performed as a structured brainstorming exercise facilitated by a HAZOP study leader and exploiting experience of the participants. A traditional HAZOP study has the following phases (Skelton, 1997):

• 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), piping & instrumentation diagrams (P&ID), a plant layout, 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 variables 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 have 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 variables 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 decide if additional efforts are needed.

Thus a HAZOP study requires considerable time and resources whenever it is carried out during the plant life cycle. Consequentially research has been stimulated to develop computer aided tools to assist in or even aiming at automating hazard analysis and especially HAZOP studies.

Although HAZOP analysis is a well accepted tool for risk assessment in many industries very little has been published on a theoretical basis for HAZOP studies. HAZOP studies are used to investigate deviations from a norm: the normal operating conditions or the design intent, i.e. the goal of the system. This is traditionally done by asking questions such as what deviations can occur? Why do they occur? (causes), How are they revealed? (consequences). These questions are asked after first dividing the whole system into its constituent parts. The questions stated relate to the goal of the system while the process represents the means for achieving these goals. Therefore it seems highly relevant to develop a HAZOP assistant based upon means-ends combined with whole-parts concepts to grasp the different levels of abstraction when needed. Thus models based on these concepts, such as functional models will form a convenient basis for an HAZOP assistant. The HAZOP assistant developed in this work uses a functional model to combine the system goal structure with the means to achieve these goals.

In the following section a HAZOP assistant using a functional model builder to build an MFM model of the system and a reasoning engine are presented before the goal based methodology for HAZOP analysis using a functional approach is proposed.

Functional Modelling Methodology

In this paper Multilevel Flow Modeling (MFM) is used to combine the means-end dimension with the whole part dimension, to describe the functions of the process under study and to enable modelling at different abstraction levels. MFM is a modeling methodology which has been developed to support functional modeling of process plants involving interactions between material, energy and information flows[8,9]. Functions are here represented by elementary flow functions interconnected to form flow structures representing a particular goal oriented view of the system. MFM is founded on fundamental concepts of action developed by VonWright[17]. Each of the elementary flow functions can thus be seen as instances of more generic action types (see. e. g.[9].). The views represented by the flow structures are related by means-end relations and comprise together a comprehensive model of the functional organization of the system. The basic modeling concepts of MFM comprises objectives, flow structures, as set of functional primitives (the flow functions) and a set of means-end relations and causal roles representing purpose related dependencies between functions. The functions, the flow structures and the relations are interconnected to form a hypergraph like structure.

Functional Model Builder and Reasoning System

A MFM model builder has been implemented in MSVisio. Stencils implementing icons for the MFM concepts are used to build a model graphically (Figure 2). The model builder is interfaced with a reasoning system which can generate root causes and causal paths for a given fault scenario i.e. a top event (failed MFM function) and status information for selected flow functions. The reasoning system is implemented using the Java based expert system shell Jess[5]. Rules for reasoning about function states in MFM models are implemented as a Jess rule base.

Results

The functional modelling approach described above forms the basis for a developing a functional HAZOP assistant for a goal based methodology for HAZOP analysis.

A Functional HAZOP Assistant

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 direction. Usually the function of a section or of a node is not directly specified, many HAZOP formats only identify 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.

The goal based methodology for HAZOP analysis provides a structured approach where the study is divided into three phases, corresponding to the traditional approach described above. The first phase corresponds to the premeeeting phase, the second phase to the meeting phase and the third phase to the post meeting phase. Thus the Functional HAZOP assistant involves the following steps:

Phase 1:

1. State the purpose of the plant.

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

3. Divide each section into nodes, the function of which can be directly described by physical or chemical phenomena. Examples of such phenomena are: gas transport, liquid transport, liquid storage and gas-liquid contact.

4. At this point an MFM model may be directly developed using the model builder as described above (in case a model is not already available) provided that the physical and chemical phenomena are included in the existing model set.

5. For each type of node, i. e. each physical or chemical phenomenon, describe the process variable(-s), 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.

6. For each process variable specify the relevant deviations. For flows 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.

Phase 2:

7. Perform the diagnosis on the MFM workbench by working through the plant sections and nodes in sequence and analysing the deviations one by one.

8. Analyse the identified causes of hazardous conditions perhaps by refining the analysis through a more detailed study in case of a serious hazard ot cause.

9. Record the identified causes and the underlying reasoning for later reference.

Phase 3:

10. For identified hazards then investigate and decide how to manage these, through a) definition of an alarm with a consequential response potential for the operator, b) Implementation of on line control of the plant, c) redesign of a part of the plant, or d) another action

11. Record the final decision and the underlying reasoning for later reference.

Phase 1 may be carried out in a straightforward manner by using the functional approach. For example 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 suitable

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 do not 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, i. e. transport phenomena. This means that phase 1 of a HAZOP study may be efficiently performed by less experienced personnel. Phase 2 requires more experience.

The above proposed three step procedure clearly become a significant task even though the HAZOP assistant will enable consistent reasoning not only within the single nodes but also between nodes and sections and thereby facilitate the revealing of more complex causes of deviations than possible using the traditional approach. The workflow during phase 2 would indeed be expected to be significantly facilitated though the HAZOP assistant. During phase three the functional modelling may actually also be utilized. However, this has not been studied in the present work.

The application of the Functional HAZOP assistant is illustrated in the following through performing a HAZOP study on an industrial scale pilot plant at the Technical University of Denmark.

Functional HAZOP of Distillation Pilot Plant

The indirect vapour recompression distillation pilot plant (IVaRDiP) at the Department of Chemical and Biochemical Engineering consists of a distillation column which is integrated with a heat pump. Process schematics of the column and the heat pump are shown in Figure 1.

The purpose of the column is to separate a feed stream into two pure product streams while minimising energy used. To accomplish this the following subsystems are defined:

• Column section. Purpose: Gas-liquid contact to facilitate separation.

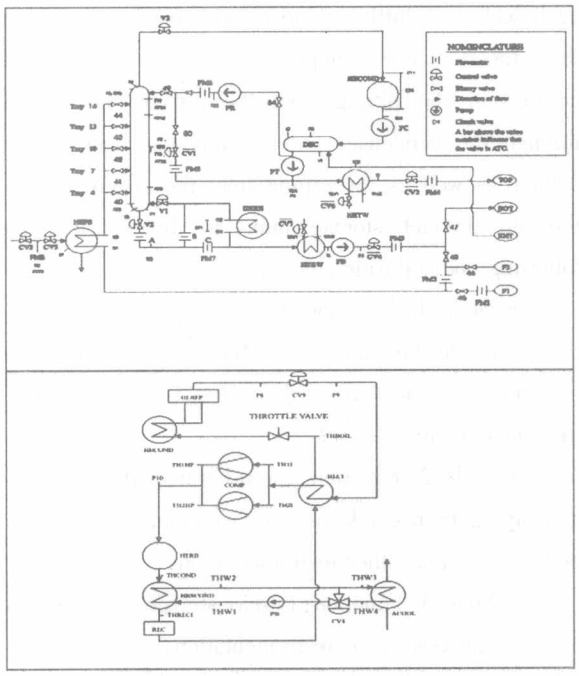


Figure 1. Process diagram of indirect vapour recompression distillation pilot plant. On the top the column and on the bottom the heat pump.

• Re-flux section. Purpose: Provide a liquid stream to the column and remove excess liquid as top product.

• Feed section. Purpose: Provide a feed stream as close as possible to the conditions on the feed plate.

• Re-boiler section. Purpose: Provide a gas stream to the column and remove excess liquid as bottoms product.

• Low pressure heat pump section. Purpose: Transport energy from re-flux section to compressors.

• High pressure heat pump section, including compressors. Purpose: Increase the heat pump fluid energy content by compression and transport energy from compressors to re-boiler.

• Excess heat removal section. Purpose: Transport of excess energy from the heat pump to the environment.

• Tank Park. Purpose: Provide storage for raw material and products.

Building an MFM Model

The IVaRDiP 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) with the 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.

Upon this subdivision of the section it is directly possible to construct the MFM using the MFM workbench described above. The other sections of the distillation pilot plant are similarly divided into nodes, i. e. each node relates to a function described by physical or chemical phenomena. In 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 have the function 'liquid transport'. Having developed the MFM model for the different nodes these are directly concatenated to form the MFM model for the plant. In step from the function of the node the variables necessary to describe design intent follows directly. E. g. the process variables and deviations relevant for the function 'liquid transport' will be:

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

and similarly for the function 'gas transport':

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

Having completed phase 1 it is now possible to enter phase 2, where the reasoning engine is used to perform the actual HAZOP study in step 7. During this step the HAZOP Assistant can be extremely helpful in providing the reasoning necessary to identify potential hazards. At the present time it is recommended to perform the exhaustive evaluation for each variable in each node. Later as experience is accumulated it may be possible to facilitate also this step further. Below two analyses carried out on the IVaRDiP will be described briefly.

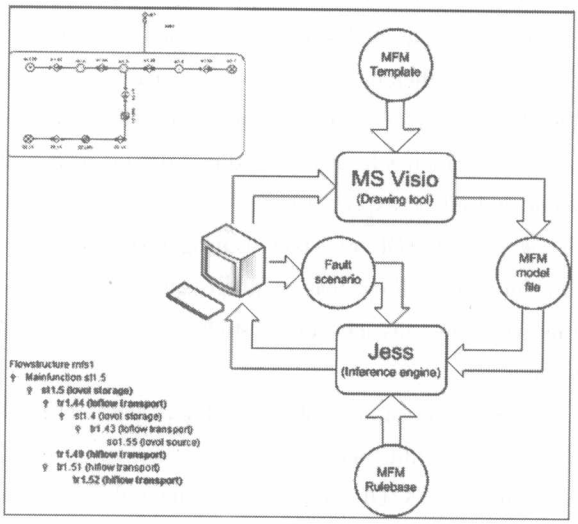


Figure 2 MFM model builder and reasoning system. On the left hand side the decanter section MFM is shown at top, and the HAZOP diagnosis at bottom.

Traditional Versus and Functional HAZOP

The result of a traditional HAZOP of the re-flux section of the distillation pilot plant is compared to the results of the Functional HAZOP Assistant. The results demonstrate that while the traditional approach provides 14 records in the HAZOP, then the Functional HAZOP Assistant only provides 8 records with the same information content. Hence the Functional HAZOP Assistant requires half the effort in evaluating the causes of deviations, i. e. the number of lines in the