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Using modified HAZOP Methodology for environmental risk assesment in industrial plants

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ABSTRACT

This paper aims at drawing attention to the possibility of a modified HAZOP Methodology when checking environmental risks in the stage of designing new plants and facilities and analyzing environmental risks of the existing plants and facilities. The modified HAZOP Methodology, called Green HAZOP, has been in use for the past ten years intended for checking the relation between the design of plants and facilities in operation and environmental risk. This is a simple and useable tool allowing for a relatively quick assessment of the chemical and energy plants' design from the enviromental aspect. The application of this tool may be extended to other industries with a necessary education and training of HAZOP leaders and a team of designers, that is, process owners. The application of this method to the assessment of Action Plans for receiving an environmental permit and a Study of Environmental Impacts, during an assessment procedure, which lasts unusually long, may be significantly improved and accelerated.

Keywords: Standard BS IEC 61882:2001, HAZOP Methodology, Green HAZOP, HAZOP leader, HAZOP team.

Introduction

The term "sustainable development" has become the key word in designig and operation of chemical and energy plants and facilities. There are several proven successful methodologies already providing improved safety in the design stage. Nowadays, HAZOP Study is most probably the most used methodology for the identification of risks in the processes throughout the world. The British Standard BS IEC 61882:2001 standardized this methodology and, as such, it is widely applied for risk analysis at designing plants of oil and chemical industries. For a majority of developed countries, HAZOP methodology is prescribed by law and is a condition to obtain building permits and bank loans. Over time, this methodology has been amended and adjusted to the requirements of individual processes and thus the following methodologies were developed:

- HAZAN methodology for risk analysis
- HAZID methodology for risk identification
- GENHAZ procedure for biotechnology (Royal Commission on Environmental Pollution (1991).

Positive experiences gained so far in the implementation of HAZOP studies on risk assessment at building energy and processing plants show that this methodology is very useful and efficient at detecting risks of accidents and deviations from safety requirements already in an early design stage. This paper has a purpose of demonstrating the fundamentals of HAZOP methodology application and indicates a possibility of its simple modification and applicability at checking environmental risks in all the phases pertaining to the project realization and in the plant management phase. The use of this simple and efficient tool should be certainly expanded and its performance will be constantly improved through practice. In this work, the process of conducting a HAZOP study is shown in more detail as this is a relatively unknown method here. The basic HAZOP methodology is a structured systematic technique for checking a certain system with a purpose of:

- Identifying potential risks within the system. These risks may include anything which is essentially related to the system observed and in addition, cover a wider area that may have an impact on the system (e.g. environmental risks);

- Identifying a potential problem in system operation (operability) and, in particular, identifying the cause of operable non-compliances and deviations in the production which results in a non - compliant product.

Green HAZOP is an attempt to modify this basic methodology and to adjust it to the environmental risks assessment. Both standards require a documented approach, audit performance and continuous improvements. In the first part of this paper, fundamental requirements of BS IEC 61882:2001 standard are presented and advantages of this methodology identified; further on, the required modifications with a purpose of its simple application to environmental risks are also presented.

Standard BS IEC 61882:2001 hazard and operability studies (HAZOP studies)

In order to view the possibilities for the application of this methodology on environmental risk analysis, we should first (briefly) view what BS IEC 61882:2001 Standard prescribes when it comes to the implementation of HAZOP studies. Standard BS IEC 61882:2001 provides instructions as to the implementation of HAZOP studies, a procedure that uses the methodology of brainstorming and guide words for the identification of major risks and then defines the procedures for a practical implementation of these studies. Fundamental characteristics of HAZOP analysis are, as follows:

- Analysis is a creative process! Analysis is performed systematically by using guide words in order to identify potential deviations.

From the basic design intent regarding safety, such deviations are later used on as triggers to encourage the team members to perceive any potentially weak spots and to define the consequences.

- Analysis is conducted under the leadership of a qualified expert (HAZOP Leader) who is supposed to ensure that the entire system is covered and tested using a logical and analytical approach. A qualified note taker should be assigned to the Leader who will record all risks identified and operable impediments that will have to be resolved and removed later.
- Analysis is conducted in various fields for which appropriate specialists-team members have been assigned who should be well familiar with the problem and have an ability of clear judgment.
- Analysis should be conducted in a positive work

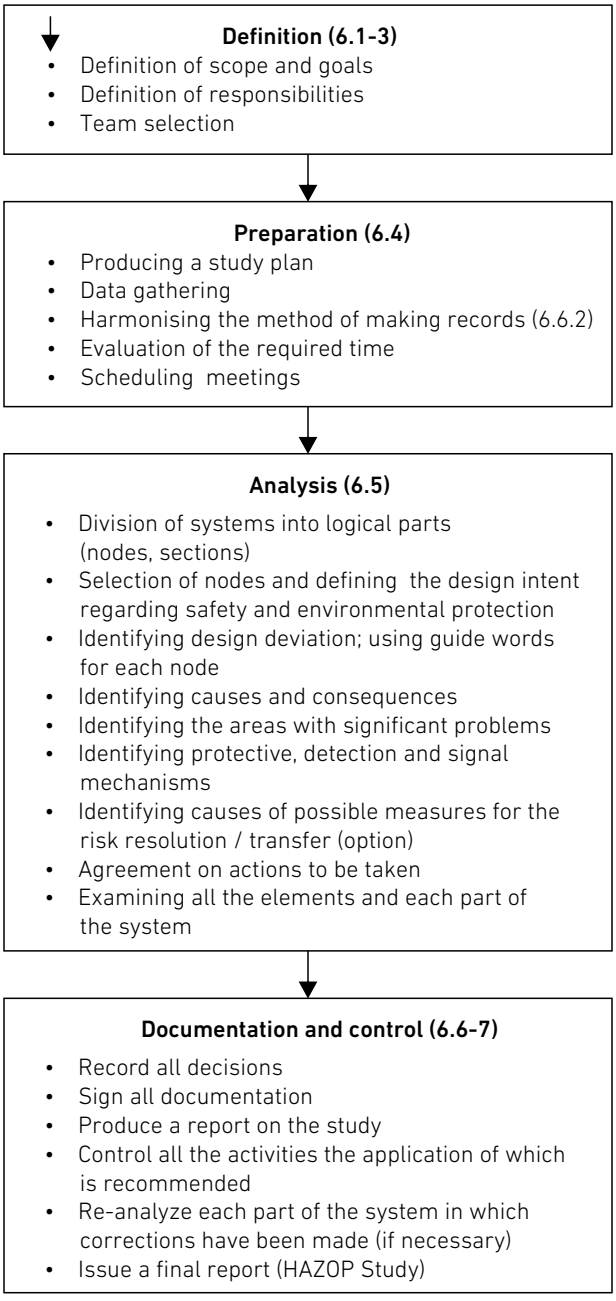

Diagram 1: The process of implementing HAZOP Studies

atmosphere where a positive way of thinking and a well-intended discussion will prevail. Once the problem is identified, it should be recorded so that its difficulty can be assessed later on and a recommendation for the resolution thereof provided.

- To resolve the identified problems is not a primary task of HAZOP analysis; they get recorded in order to be resolved later on by those responsible for the design. The HAZOP Studies implementation consists of the basic steps shown in Diagram 1.

Principles of the analysis

The basis of HAZOP is "guide words" with the help of which deviations from the core design intent are identified. The system is divided into parts the size of which depends on the system complexity and the size of potential risks and one should adhere, wherever possible, to a natural division determined by the design itself. It is necessary to define the elements participating in that part of the system and the characteristics and quantities thereof (e.g. materials, temperature, pressure, flow, etc.) The choice of guide words should encourage inventive thinking and allow for the implementation of a complete and comprehensive analysis. The following table provides some guide words with the explanation of their meaning.

Table 1: Basic guide words and their generic meaning

Guide word	Meaning
NO (NOT, NONE)	Complete negation of the design intent
MORE	Quantity is increased
LESS	Quantity is decreased
AS WELL AS	Quality modification/increase
PART OF	Quality modification/decrease
REVERSE	Logical opposite of the design intent occurs
OTHER THAN	Complete substitution

Apart from the above, additional "complementary guide words" are in use required to define the time for any sequence observed.

Table 2: Guide words related to the temporal progression of activities (timetable)

Guide word	Meaning
EARLY	Related to the timing
LATE	Related to the timing
BEFORE	Related to the order or sequence
AFTER	Related to the order or sequence

There are many possibilities for interpreting the guide words specified in Table 1 so that additional guide words are used to direct the train of thought properly, in order to identify the deviation more easily. Guide words need to be chosen prior to the analysis commencement.Each guide word should be applicable to each element within the node with a view of detecting a prospective possibility of the design deviating from the desired intent or required safety conditions.

The application of guide words to certain components is outlined as a matrix, so that guide words are in rows whilst the analyzed elements are placed in columns. In order to perform an applicable risk identification, it is necessary to cover individual elements and their accompanying characteristics with all the relevant design aspects and guide words signifying certain deviations from the designer's intent.

It is necessary to clarify the term "design intent" more thoroughly. The designer develops a system design (basic or detailed design) on the basis of input and desired outcomes specified in advance. By developing the system, the designer starts with desired functions often anticipating that in the course of the system's life cycle and its long-term operation, certain undesired work conditions may occur and the system may undergo radically different work conditions (caused by human or technical error). This would mean that his "initial design intent" when assembling the elements into a system has not been met, that is, the system consisting of a large number of parts nodes contain would not operate any more as originally conceived. This is particularly important from the aspect of risk as designers are mainly preoccupied with technical and economic issues and tend to "forget" about the safety degree and a possibility that it may happen that the system works under completely irregular circumstances.

Managing HAZOP studies

Fields of application

Originally, the HAZOP procedure was developed for the system in processing industries (oil and chemical) including liquid media and their flows through processes. In time, due to its simplicity and practicability, the methodology was spread to almost all the fields of human activities. It may be applied in the phase of design, more detailed designing, trial operation and at regular operation and maintenance of plants.

Launching the study

The study is launched by the person responsible for the project (Project Manager). He / she shall determine when and for which purpose the study is being produced, summon the Leader and provide conditions for the study, Together with the Leader, the Project Manager defines the scope and goals and produces the study plan. The scope and goals are interdependent and cannot be defined independently and separately. It is necessary to clearly define:

- System borders and its interfaces with other systems and the environment
- Any initial wanderings of the team and wasting time on secondary problems need to be avoided; the team needs to be focused on relevant matters.

Defining the study goals

It is necessary to define the study goals and delegate responsibilities for individual entities and to determine as to how the study results will be used. Apart from this, the following elements should be defined:

- The life cycle phase that will be covered by the study
- Persons, i.e. assets exposed to risk, environment and neighborhood
- Problems of operability that may affect the product quality
- Standards that should be applied to the system from the aspects of operability and safety

Responsibilities and competencies

Roles of the team members, their responsibilities and competencies have to be clearly defined prior to the commencement of their work. The Leader is the one who should be thoroughly acquainted with the design and should assign roles and responsibilities to the team members. He should also ensure that there are qualified and educated team members by certain fields of expertise. The HAZOP study is teamwork and as such it requires each team member to do his part of work:

- The Study Leader should be thoroughly acquainted with the design and be familiar with the process of conducting a HAZOP study. He is bound to ensure a constant flow of communication between the project management and HAZOP team. He plans tasks and co-ordinates the selection of team members. His responsibility is to propose guide words and clarify their appropriate interpretation to team members. He leads the team through the entire study and makes sure conclusions are appropriately entered into the minutes and is also responsible for the creation of final documents.
- Note taker (Secretary) is bound to follow the entire procedure in records. He processes all the study documents, helps with the formulation and definition of conclusions and has other administrative tasks.
- The Designer should explain the design and measures foreseen within the system as prevention or risk response.
- Project beneficiary and maintenance personnel are tasked with management and maintenance, i.e. any problem that may be expected in the course of operation.
- Specialists, including quality and environment managers make sure that any problem is viewed from the expert's point of view, prospective environment risks evaluated and risk reduction measures recommended (not obligatory, though).

Application of guide words and deviations

Guide words need to be carefully selected to trigger a discussion in the right direction and to limit it to specific problems. They should not encourage team members to have ideas not in compliance with the study goals. The Leader has a great deal of responsibility, based on his experience, to propose those guide words that will yield efficient result. Table 3 gives an example of some process deviations and the application of guide words to them.

Table 3: Process deviations and application of guide words

Type of deviation	Guide word	Example for the application in processing industries
Negative	NO	Intent not achieved (e.g. no flow)
Change of quantity	MORE	Quantity is increased (e.g. higher temperature)
	LESS	Quantity is decreased (e.g. Lower temperature)
Change of quantity	AS WELL AS	Impurities present Some other operation / step occurring in parallel
	PART OF	Only one part of the required has been achieved (e.g. fluids do not come in the required quantity)
Replacement	REVERSE	Covers the reverse flow in the pipeline and reverse chemical reactions
	OTHER THAN	Results are different from what should have been achieved (e.g. wrong material added)
Time	EARLIER	Something happened earlier than it should have happened regarding the timing (e.g. cooling, filtering).
	LATER	Something happened later than it should have happened regarding the timing (e.g. cooling)
Order or sequence in process	BEFORE	Something happened too early as a sequence (e.g. mixing or heating)
	AFTER	Something happened too late as a sequence (e.g. mixing or heating).

It should be noted, however, that the guide words may be completely differently interpreted when analyzing another system. Sometimes it may happen that the application of certain guide words will not give a sensible result.

Also, sometimes there will be several different interpretations, but all of them should be analyzed and recorded. The flow of analysis with the application of guide words is depicted in Diagram 2.

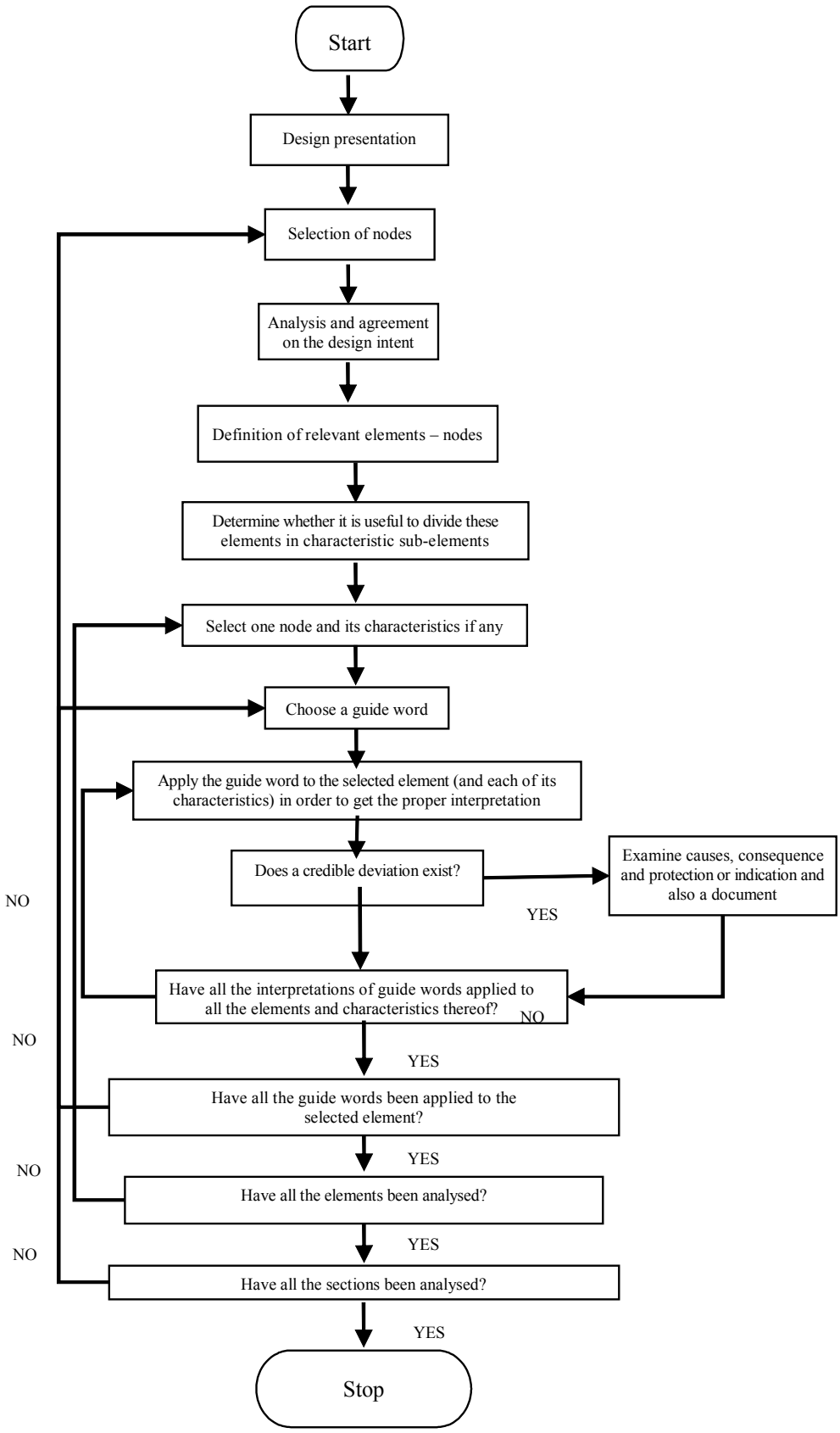

Diagram 2: A diagram of the procedure flow for HAZOP — application of guide words

Documentation

The main strength of HAZOP lies in the fact that it is a systematic, disciplined and documented procedure. In order to obtain the proper result, HAZOP needs to be completely documented. The Leader is bound to ensure that there are quality records from the team sessions. The Note taker (Secretary) needs to be a qualified and experienced person with a good knowledge of the working language. There are two acceptable methods of recording:

- Make complete records on everything said during the application of guide words to individual elements of the system which meets all the audit requirements and provides a detailed overview of the session.
- Make a note of deviations, identified risks and operating problems along with actions recommended only. In this case, the document is smaller and easier for processing it later though less useful during a subsequent audit.

The study result should be a detailed report containing the following:

- Details of all the identified risks and operable problems together with the details for their resolution or transfer;
- Recommendations for the future analyses of specific aspects of the design using different techniques if necessary,
- Actions required to address identified uncertainties,
- Recommendations for the transfer of identified problems based on the team's knowledge and experience,
- Records and especially perceived spots that may cause problems for the plant and maintenance,
- List of team members.

Such documentation should ensure the discovery and interconnection among all the identified risks with the system elements. Each of the recorded risks and operable problems should be separately recorded and marked and each question posed should be traced to the name and surname of the person posing it. Each problem and resolution thereto has to have a possibility of a single - meaning identification. Finally, all the documents have to be agreed on, accepted and signed.

Control and responsibilities

HAZOP study's aim is not to redesign the system, nor does the Leader have such authority to ensure the implementation of the recommended for removal or transfer of risks and operable problems. The project manager is responsible for the implementation of the study recommendations. In some cases, the Project Manager may authorize the team to have such recommendations implemented. In this case, the team should request the following additional tasks to be conducted:

- Agreement on the definition of major problems identified should be reached, the design, all work and maintenance procedures should be modified accordingly;
- The team should verify all such modifications, present them to the Project Manager and obtain the approval thereof;
- A HAZOP study procedure for the reviewed design including the system interfaces should be carried out again.

Audit

The program and results of the HAZOP study may be checked by means of performing an internal audit by thus authorized persons form the company. The criteria and contents of such an audit should be prescribed by the company's procedures.
The audit may include the following: staff, procedure, documentation and supervision of the implementation.

Example

Put simply, the entire procedure may be viewed through an example. Picture 1 provides a very simplified example from the processing industry. Material A is transported without stoppage by means of Pump E'3 from Reservoir E-1 and other Material B by the means of Pump E-4 from Reservoir E'2. Both materials go to Reactor E-5 where these are mixed and subject to a chemical reaction with a view of obtaining material C. Let us assume that at all times, there should be much more of Material A in order to evade a threat of a possible explosion in the Reactor. The real design contains much more details about pressure, speed of mixing, time of reaction, etc.; however, these will be disregarded in this example and only a simplified overview is taken.

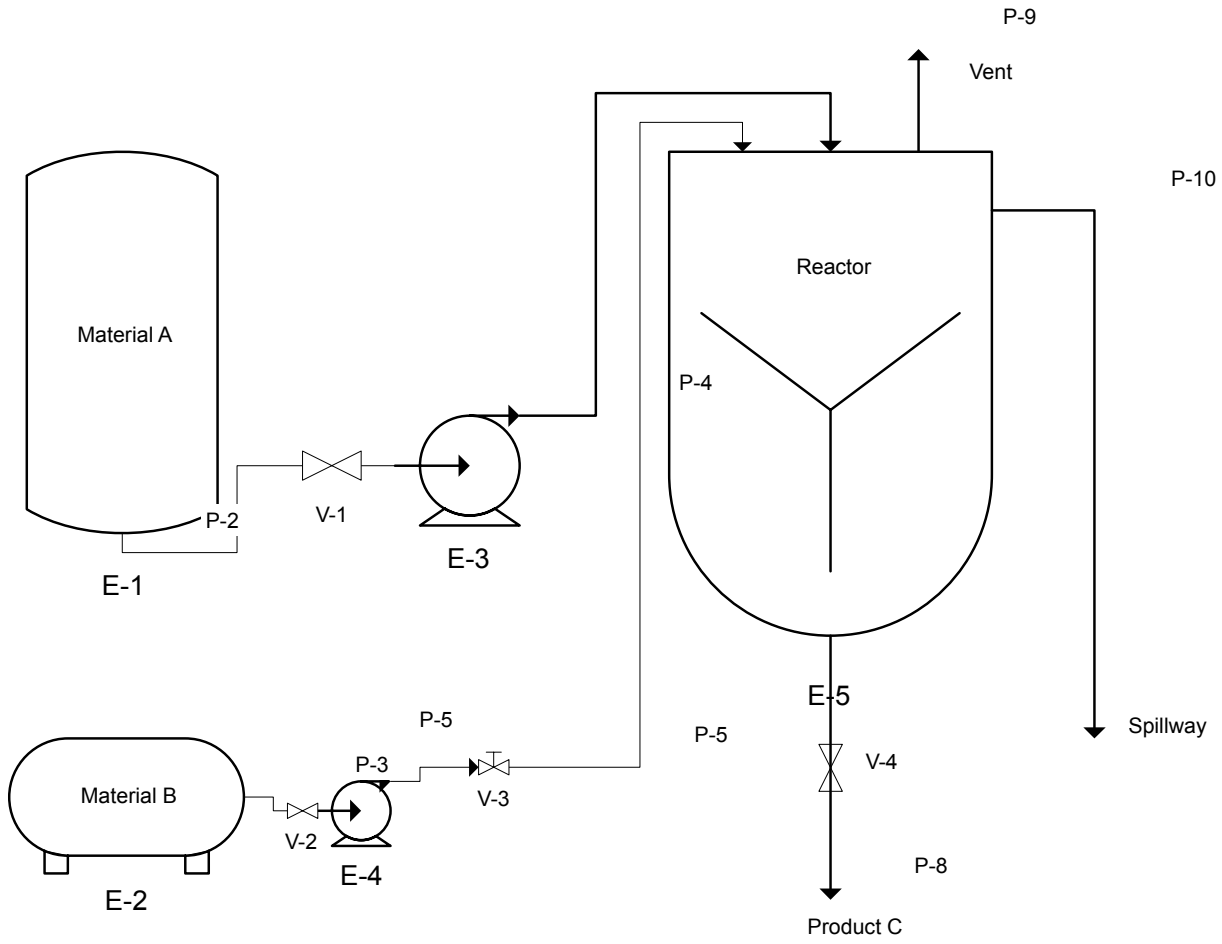

Figure 1: A Simple Process and Instrumentation Diagrams (P&IDs)

The part we are analyzing is that line from the Reservoir of Material A to the Reactor including Pump E'3. The intent of the design was to provide the delivery of Material A in a greater quantity than that of Material B. This can be shown in Table 4.

Table 4: Path from the Reservoir of Material A to the Reactor

Material	Activity	Source	Destination
Material A	Transport (in the quantity >B)	Reservoir of Material A	Reactor

Each guide word from Table 1 (and all those adopted by the team in the session beginning) was applied to each element and everything was recorded in HAZOP records shown on the next page. The style of recording used here is that with analysis results only.

HAZOP Methodology and guide words

As explained earlier, the HAZOP Methodology is related to brainstorming. Brainstorming is a very powerful technique, but it is quite difficult to ensure this technique to be serious enough when it comes to the problems of safety and operability. One of the aforementioned requirements applies to the size and ability of the team. Another requirement applies to an appropriate set of guide words that should be applied to all the relevant parameters and identify all deviations from and deficiencies of the design, from the aspects of safety and operability. The standard recommends seven guide words as a basis. There is a problem with completeness contained in the identification of key parameters to which guide words should be applied. The method applied by almost everyone organizing HAZOP studies is that they ask the team what are the key parameters and then they

add to the list of guide words. In practice conducted by chemical and oil industries, a set of 20 words is mainly in use. The Leader has to check the list of guide words he believes are sufficient and then re-check it with the team. When it comes to some non-standard equipment or special processes depending on the human factor, it is necessary to organize a special training in order to get that set of appropriate guide words.

Completeness and appropriateness of guide words is the key factor in creating an appropriate scenario and a basis for the HAZOP study success.
It is decisive for the quality of HAZOP studies to select a sufficient number of guide words that will be corresponding to the system analyzed and check all the scenarios relevant for safety. The list of words recommended by BS IEC 61882:2001 Standard is not adequate for the quality performance of the Study; however, a list of guide words recommended by experienced consultancy companies (Den Norske Veritas) is provided for oil and chemical industries.

Completness and coverage

All the above recommended procedural steps have to be taken even prior to viewing all the contents to be covered by the study. It may happen that some of the P/ID drawings or some sections thereof are missed. Also, it may happen that out of date and invalid documentation without the latest updated design modifications is analyzed. The HAZOP procedures should prescribe the production of all valid P&ID drawings. To omit the analyses of individual drawings shall be permitted only if the entire team agrees on this, which will require a thorough justification in writing. The Leader has to make sure that all the equipment on the drawing observed is analyzed.

In order to monitor this he should mark, on the master drawing, each piece that has been completed and to transfer it to the list of documentation and drawings. Therefore, there should be a document proving that the complete drawing has been analyzed by the team.

When it comes to the existing plant for which the Leader has not received the current P/ID drawings (and the team members have warned him of this), it is necessary for him to put such drawings aside until such time they are marked or made current. He cannot allow the team members to mark the drawings. To check physically on the very spot is of essence.

Assesment criteria

Prior to giving its recommendations for changes, the HAZOP team has to decide whether the current situation is acceptable. Nothing is gained if the team is very productive in giving recommendations of doubtful quality. The process of decision-making is quite often the most difficult one as assessment / evaluation criteria have not been determined.
A question is posed from the safety aspect as to whether this consequence will be too serious to be tolerated, to which it may be answered quite simply.

However, the next question "is a probability too high to be tolerated" is much harder to answer. This is the area where the safety specialist and environment manager may help the team define appropriate criteria. To use the risk index may be of help sometimes, but it requires quite a lot of time which we do not have too often. It is much easier for operability to establish criteria as they are based on cost-benefit principles. It is much easier for the team to make recommendations to management if such recommendations generate profits for the company.

Classification of recommendations

Goals are clearly defined so that the HAZOP Leader may expect that recommendations given by the team will have influence, especially so if they are related to the aspect of safety. In many cases, it is the team who identifies adverse effects on environment, which is also important for the decision-making.

The procedure should lead to a properly evaluated difficulty of consequences not reducing the relevance of environmental aspects so that management may accept and implement the recommendations given. It is also required from the HAZOP Leader to make a separate checking with a view of comparing goals and recommendations.

Testing recommendations against goals

Although this is a task of the entire team, the Leader and Secretary should, in the course of the entire study, check each recommendation and compare it with its corresponding basic goal in order to reduce risks to an acceptable level. It means that, after each HAZOP session, the leader and Secretary should check on all the recommendations and if some are identified as inappropriate, this should be resolved in the next session.

Conclusion

There is a need to develop tools that would be of help in the process designing, project evaluation and implementation of project solutions using the criteria of ecological engineering. Green HAZOP is a systematic tool based on the HAZOP studies for incorporation of ecological engineering, starting with the stage of detailed designing and then through the technical acceptance and operational plants. The implementation of such Green HAZOP analysis is aimed at identifying deviations of the design, construction and running of the plant that may be harmful to the environment and occur in every stage of the project implementation in equipment, the works and material. Such deviations may result in negative effects on the environment and sustainable development. Green HAZOP essentially connects the steps of identifying environmental risks and provides an opportunity for preventive actions; therefore, it may be concluded that it could be very useful at assessing the quality of environmental protection and prevention of environmental risks, both for plants to be built and those already in operation. It would be of particular interest to apply it to the analysis of Action Plans and Studies of Environmental Impact which could improve and accelerate the assessment procedure significantly. It is certainly necessary to further develop and elaborate on this methodology in practice in order to obtain a useful tool for the project evaluation from the aspect of environmental risks. However, considering its simplicity and a wide application, the effort will surely pay off.

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Korištenje modificirane HAZOP metodologije za provjeru rizika na okoliš u industrijskim pogonima

SAŽETAK

U ovom radu želi se ukazati na mogućnost izmijenjene metodologije HAZOP-a prilikom provjere postojanja rizika na okoliš u fazi projektiranja novih postrojenja i objekata te analizu ekoloških rizika postojećih postrojenja i objekata. Modificirana metodologija HAZOP-a, zvanog green HAZOP-a, već je proteklih deset godina u upotrebi za provjeru funkcije dizajna pogona i objekata u odnosu na rizik po okoliš. Ovo je jednostavan i upotrebljiv alat koji omogućuje relativno brzu procjenu dizajna kemijskih i energetskih postrojenja s ekološkog aspekta. Primjena ovog alata može se proširiti i na druge industrijske djelatnosti uz potrebna obrazovanja i osposobljavanje voditelja HAZOP-a i dizajnerskih timova, tj. nosilaca ovih procesa. Primjena ove metode je značajna u postupcima izrade akcijskih planova u svrhu dobijanja okolišne dozvole, kao i u aktivnostima prilikom procjene utjecaja na okoliš, koje uobičajeno traju dugo, a ovom metodom se mogu značajno poboljšati i ubrzati.

Ključne riječi: Standard BS IEC 61882: 2001, HAZOP metodologija, zeleni HAZOP, HAZOP lider, HAZOP tim.