CHEMICAL ENGINEERING TRANSACTIONS
VOL. 77, 2019

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Genserik Reniers, Bruno Fabiano

ISBN 978-88-95608-74-7; **ISSN** 2283-9216

DOI: 10.3303/CET1977027

Challenge Pressure Surge – Which Tasks Have Engineering and HAZOP?

Oliver Wichmann*, Volker Stellmacher

Covestro Deutschland AG, 51365 Leverkusen
oliver.wichmann@covestro.com

Pressure surges can damage pipeline systems and result in leakages which can cause considerable harm to people and the environment. Therefore it is a process safety topic directly related to the HAZOP.
But is it just the responsibility of the HAZOP-team to identify, evaluate and implement measurements against potential pressure surges? Or is it already the task of the engineering department to design the process adequately? The answer must be: both.
On the one hand it is engineering which has to design the plant so that it runs within the allowable range. On the other hand it is the HAZOP-team which cross-checks the process with a risk-based screening method within the safety review process.

1. Introduction

To answer the question "Who is responsible for the pressure surge topic?" it is helpful to understand how Project Management and Process Safety Review Management typically functions in industry. Furthermore, the pressure surge phenomena and the potential counter measures to reduce the consequences are explained.

2. Project management

It is important to optimize the project management process, including key aspects like capital efficiency, a fast project life cycle and to reduce risk during execution of the project.
Therefore Covestro implemented a process to describe a structured way of executing investment projects. The phases of this process are shown in Figure 1. It is based on international common standards for project execution.

Figure 1: Phases in project management

1. Concept & scope phase:
   Concept phase:
   In the concept phase the development of a business case supported by a technical concept will be done. A cost estimation with a very rough accuracy should exist. At the end of the concept phase a feasibility check of a project proposal is carried out. Alternatives are shown and the preferred option is pre-defined and only process and layout items need to be elaborated and evaluated in the

Paper Received: 5 December 2018; Revised: 7 April 2019; Accepted: 2 July 2019

Please cite this article as: Wichmann O., Stellmacher V., 2019, Challenge pressure surge – which tasks have engineering and HAZOP?, Chemical Engineering Transactions, 77, 157-162 DOI:10.3303/CET1977027

following scope phase. This minimizes engineering effort and cost, but requires clear definition of business goals in an early stage of the project.

Scope phase:

In the scope phase the concept will be further developed with regard to the scope selection. Key performance indicator definition takes place here and cost estimation with more accuracy should exist. At the end there will be the final decision on the fixed scope. From this moment on the scope of the project is “frozen”.

2. Basic engineering:
   In this phase deliverables and the execution strategy will be defined and cost estimation with a high accuracy should exist. A final check is done if all scope assumptions are still valid. Ideally the final budget for the project just needs to be confirmed. Only if significant changes to the scope assumptions occur will a project be stopped. At the end the financial resources for supply hardware and engineering are granted. The basic engineering takes place. This includes defining equipment, instrumentation, piping, valves etc. with regard to standards, best-practices and design codes.

3. Detail engineering:
   The detailed engineering starts in this phase, creating the basis for the execution of purchasing. Here, for example, the dimensions, maximum allowable working conditions, control concepts and materials of construction will be described.

4. Procurement & Construction:
   Construction begins when the different equipment for the project is received. The construction phase ends when all the defined equipment has been implemented.

5. Start-Up phase:
   In the start-up phase the handover of all documentation to the owner is carried out. The commissioning is done, and after the validation of the production readiness the production plant can start-up.

3. Safety Review Management

An overall safety concept is essential for the safe design and operation of processes and plants.
The elements of an overall safety concept are shown in Figure 2.

The overall safety concept consists of the following elements:

- operational concept
  A plant is operated stably by means of a sound operational concept. It controls the process in order to economically and reliably manufacture in-specification products in a repeatable manner. The potential risk with the operational concept in place is defined as process risk.
- prevention concept
  The prevention concept is developed on the basis of the operational concept. It is designed to prevent a loss of substances or energies in an uncontrolled manner which could harm people or the environment.
- mitigation concepts
  Mitigation concepts are designed to mitigate the severity of consequences in case of a loss of containment and thereby further reduce potential risks. Their design is mainly specified by rules based on good engineering practice or standards.

Overall, the safety concept shall reduce the risk of the process to a broadly acceptable level. The remaining risk level with all preventive and mitigating measures in place is defined as residual risk.
An overall safety concept shall be systematically developed, implemented and maintained for all processes and plants. This means that safety reviews shall be performed systematically. The core activity and main purpose of a safety review is to review the specific prevention concept. Its objectives are to identify potential hazards, evaluate the corresponding risks and define appropriate safety measures which must be properly designed and implemented to ensure that they are available and functioning correctly on demand. The integrity of safety concepts is ensured by a robust life cycle management of safety measures.

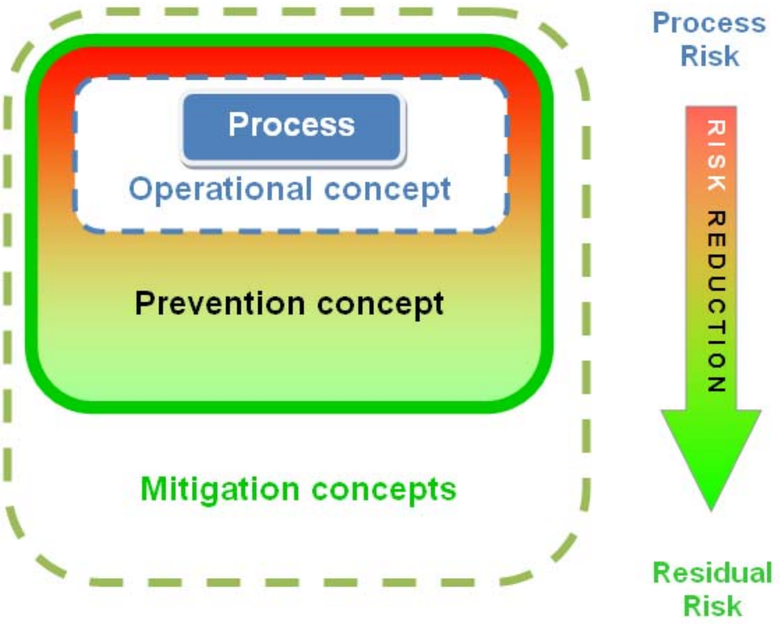

Figure 2: Elements of an overall safety concept

Therefore Covestro implemented a process to describe a structured way of executing safety concept management. The phases of this process are shown in Figure 3. It is based on international common standards for safe concept management execution.

Figure 3: Phases in safety concept management

1. Preliminary Safety Analysis
   At the process research, process development or project concept stage, a safety analysis shall be performed in order to develop the basic safety concept. The objective is to determine whether a sound safety concept is feasible in principle, or whether alternative processes or synthesis routes shall be considered.

2. Basic Safety Review
   At the project or plant design stage, a systematic basic safety review shall be performed on the basis of site plans and process flow sheets, which addresses all main process and plant safety issues. By the end of this step all key safety aspects and relevant information that are necessary for the commencement of the detailed design phase should have been compiled and the basic safety concept developed considering inherently safer design.

3. Detailed Safety Review

At the safety review stage, a comprehensive safety review of the process or plant shall be performed using detailed documents. In this stage, a detailed safety review based on a hazard field analysis is required. Typically, the Covestro modified HAZard and OPerability (HAZOP) - Approach is the most useful methodology. The detailed safety review has to be documented. Defined measurements have to be implemented after this review.

4. Pre-Start up safety review
   During this safety review step it is checked whether all defined measures which were specified in the detailed safety review have been implemented and the plant is built as discussed. This is done through plant inspections, checks and functional equipment testing.

For processes or plants in operation, the safety concept in place, the status of its implementation and the safety review documentation shall be revalidated regularly.

4. Pressure surge

4.1 Basics

Pressure surge is a pressure wave, resulting from rapid changes in the flow rate in the pipe, which is characterized by the transformation of kinetic energy of moving fluid into pressure (Yang et al., 2017). The resulting pressure amplitudes are in this case much higher than during normal operating conditions.
The closing of a valve leads to a rapid increase in pressure upstream of the valve - pressure surge. When the vapor pressure of a homogenous fluid behind the closing valve is reached, a vapor bubble will be formed and the size increases until the liquid comes to rest. The underpressure in the bubble delivers the braking force and finally sucks the fluid back to the already closed valve. As a consequence, the fluid will be further accelerated. The vapor bubble decreases again, and finally collapses completely. The fluid impinging on the closed valve creates in turn a pressure surge caused by cavitation.
Figure 4 shows the hydraulic effects in the pipeline that can be caused by a rapid valve closure leading to a deceleration of the liquid.

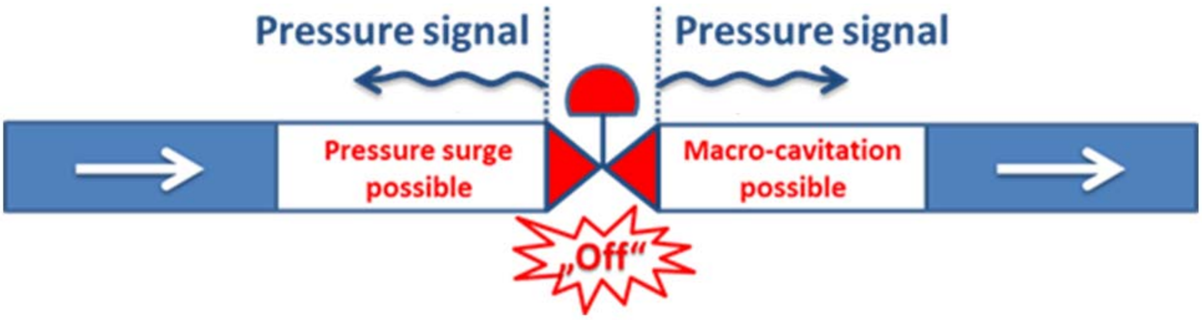

Figure 4: Resulting effects by a fast closing valve in a pipeline

Up- and downstream of the valve the maximum allowable working pressure can be exceeded by the rapid pressure rise. Furthermore the alternating pressure wave amplitude allows vacuum conditions to occur in the piping segment. This can lead to damage of the pipeline and subsequent release of the liquid being pumped. The flow forces in the piping system may cause significant dynamic loads and large reactions on the piping, piping supports and connected equipment. If brittle materials are used, missiles have to be considered. Very often, damage caused by pressure surges is not immediately visible, such as damage of a weld. However, this can lead to a weakening of the overall system.
Significant factors influencing the value of the pressure surge induced pressure wave amplitude are:

- the flow velocity
- the inner pipe diameter
- the thickness of the pipe wall
- the pipe material
- the pipe length
- the piping network which influences the resonance behavior and natural frequency (e.g. dead ends)
- the maximum allowable working pressure of the pipe

- the closing time of the valve
- the closing characteristic of the valve
- the flow coefficient of the valve.

4.2 Preventing pressure surge

First of all, preventing a pressure surge is almost impossible. Each reduction of flow velocity creates a change in pressure which we call pressure surge. It does not matter if the flow velocity is reduced completely by a full closing valve or just partially by an incomplete closing movement of valve. Because it is not possible to run a whole process plant stationary over its entire lifetime, pressure surges can always occur.

The objective in general is not to prevent pressure surges but to identify where pressure surges can occur which exceed the maximum allowable working pressure, and define measurements to reduce the pressure rise appropriately using for example the following options (Hahn, 2009):

- Implement a sufficiently “robust” pipe system (Mechanical Integrity)
- Transfer kinetic energy into potential energy by installing:
    - an air vessel
    - a surge tank
    - an expansion vessel
- Implement a closing-time reducing device for the closing valve
- Implement an orifice to reduce the flow velocity
- Reduce the pressure of the system
    - on the suction side of the pump
    - limit discharge head of the pump

It is important to know that standard safety valves and rupture disks are too slow for pressure surge phenomena.

To decide which option is the best solution, the pressure surge needs to be calculated. This calculation can be done either with modern numerical tools for complex pipe systems or with a much more simple analytical estimation for single line pipes.

The general basis of such an approach is to calculate the reflection time of the wave in the system and compare it with the pressure surge effective closing time of the valve. Depending on this result, the pressure rise due to an pressure surge can be calculated with the Joukowsky equation or a modified Joukowsky equation for linear decreasing velocity with an correction factor for the valve characteristic (Walter 2008).

The following aspects may be a guideline for using a more simple analytical estimation:

- Straight pipeline from one pump to one apparatus (no network)
- No dead ends longer than 50 m
- No change of the diameter
- No change of the pipe material
- The closing angle of the valve is proportional to the closing time.

4.3 Responsibility for the Pressure Surge Topic

As mentioned above each equipment and pipe is defined by the project engineers. Therefore the responsibility is in their area. But most of the relevant parameters will be defined during the engineering process, especially in the basic and detailed engineering. Therefore it is helpful to also integrate the topic “pressure surge” as a “question” in the safety review process.

For the Basic Safety Review the simple question “Is pressure surge applicable?” helps the team not to forget this topic. For the Detailed Safety Review it makes sense to integrate the evaluation of pressure surges and the countermeasures into the documentation of the prevention concept. The topic should also appear in the “hazard and operability study” (HAZOP). For guidance for the involved persons it is also very helpful to have a screening method and “rules of thumb” in place to decide if a system is adequately engineered. For “easy” single line pipe these can be for example:

- Easy calculation equations to estimate the pressure peak conservatively (Walter 2008)
- Use a relation between closing time of the valve and wave reflection time (Hahn, 2009)
- Engineering assessment with defining values of above mentioned pressure surge influencing factors which a risk ranked as non critical.

For economic reasons it is very import to cover the topic as early as possible.

5. Conclusions

To prevent overlooking the pressure surge topic in processes and plants it is necessary that the Project Management and the Safe Review Management use a joined approach. The responsibility for the technical evaluation and counter measurement is in the area of engineering. But it is very helpful to have a crosscheck of this topic also addressed in the safety review. Therefore screening methods and “rules of thumb” are very useful to enable the HAZOP-Team to review the engineered system.

References

Hahn M., 2009, Druckstöße in Rohrleitungen: Störungsszenarien, Sicherheitsbetrachtungen und Gegenmaßnahmen, Chemie Ingenieur Technik, 81, 127-136, DOI: 10.1002/cite.200800158

Walter. W., 2008, Regel- und Sicherheitsarmaturen, 101-113, Vogel- Verlag, Germany

Yang B., Deng J., Liu K., Ye F., 2017, Theory analysis and cfd simulation of the pressure wave generator, Chemical Engineering Transactions, 61, 481-486 DOI:10.3303/CET1761078