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Design of SCADA Failsafe Industrial Valves for Hazardous Chemicals from Chemical Kinetics Perspective

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ABSTRACT

Safety in industrial processes is the contemporary trend observed in the context of industrial automation and internet of things using smart systems. Every process industry uses certain chemicals to obtain its output. Depending upon the guidelines lay down by the industries; these chemicals may be hazardous or otherwise. Industrial automation applied to actuation of Industrial valves can be an emerging area of study considering handling hazardous chemicals. This paper intends to propose a supervisory control and data acquisition system for handling of hazardous chemicals using automated industrial valves. Initially the requirements for handling of hazardous chemicals shall be summarized and the process parameters governing the same shall be elaborated. Thereafter the role of industrial valves and their applicability shall be communicated with the intention to introduce automation in valve actuation. On establishing a premise in this manner, the latter part shall comprise design considerations to initiate, develop and execute supervisory control and data acquisition systems to suit the aim of this work. Certain challenges and suggested measures to mitigate the same shall be presented towards the end to ensure practicality of the topic. Industries handling hazardous chemicals are at times at a risk of incidents or accidents owing to failure of power distribution or compressed air distribution systems. In order to counter the undesirable effects of such failures, failsafe systems are employed. However in handling of hazardous chemicals, supervisory control and data acquisition systems can be linked with the chemical kinetics of the flow media and can be implemented to ensure overall industrial safety. This paper shall initially elaborate the flow through industrial valves, concepts of actuation and automation, failsafe systems and chemical kinetics. Failsafe systems considering various factors affecting rate of reactions shall elaborate the system requirements for a robust design. Principles of thermodynamics and thermo-chemistry shall be a reference to comprehend the qualitative effects. These enable the designer to select the appropriate failsafe action. Design considerations and significance of the topic with respect to industrial safety shall be put forward towards the conclusion.

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A. INTRODUCTION

Smart systems have been in demand in the recent times in context of a huge number of process industries. When it comes to handling of hazardous materials, it is necessary that the systems be so designed that simultaneously, local regulations are catered and the system optimization is left unhindered. However, it would be technologically recommended in the contemporary scenario, that the systems handling hazardous chemicals are governed by smart systems like supervisory control and data acquisition systems. Automated industrial valves play the role of key facilitators of the reactions that may take place throughout the line. This work shall throw light on design of supervisory control and data acquisition (SCADA) systems employing automated industrial valves for handling of hazardous chemicals. SCADA has in recent times become an area of prime interdisciplinary interest with a pervasive prospect of catering to the customized needs of the modern day process industries. Every manufacturing industry uses certain materials that are categorized as hazardous according to the aspect-impact analysis of the processes. With reference to the occupational health and safety, it is necessary to undertake adequate precautions while handling such materials. The term hazardous can be defined differently for different industries depending upon the severity, impact and applicability. However, the underlying requirement is that of a system that would effectively hazardous chemicals with minimum human intervention using smart systems and internet of things so as to improve the process efficiency and ensure safety of all the equipment and human resource involved as a support system.

Whenever it comes to automation, it is generally perceived that the system be so designed as to accommodate all kinds of worst case scenarios. With this thought in mind, this paper intends to propose a design of supervisory control and data acquisition (SCADA) systems to govern the failsafe action during handling of hazardous chemicals from the perspective of chemical kinetics. Industrial safety is a collective result of safety of individual equipment. In order to ensure safety of a plethora of equipment, smart systems without much of human interference are necessary. SCADA systems may be programmed to work as per the application requirements so as to deliver the end result.

B. Types of Industrial Valves

An industrial valve is defined as a mechanical device used to regulate flow through a pipeline. The word regulate is pervasive of three types of regulation viz. starting or stopping a flow, flow control and directional flow control. Valves used in either starting or stopping a flow are also known as block valves. These are not designed for throttling operations and are generally incapable of controlling the flow rates. These are most suitable in dead end services and isolation services. Valves used to start, stop and control the fluid flow through a pipeline are also known as flow control valves. These valves are designed for throttling and are capable of effectively control the flow rate of fluid through the pipeline. Valves are also used to control the direction of flow. This can either be achieved by means of a mechanism or with the help of certain potential difference in a particular physical quantity like pressure. These valves are termed as check valves as they allow unidirectional flow.

C. Flow through Industrial Valves

An industrial valve is a mechanical device that may be actuated by mechanical or other means, which is used to regulate the flow of fluid through a pipeline. The word regulate is pervasive of starting, stopping and controlling the flow. While doing so in the regular operation, it is intended that there is minimum pressure drop and corresponding head loss. The design of flow path in industrial valves is such that violent eddys are not introduced. Based on the type of action intended to be derived from the valve, there are three types viz. Block, flow control and check valves. Block valves have a primary function of starting and stopping the flow. Flow control valves are made essentially for controlling the rate of flow of the fluid through a pipeline. Check valves are used to restrict the flow in a particular direction such that there is no reverse flow. This paper shall consider block valves and flow control valves only as failsafe systems are not applicable for check valves.

D. Flow control using Industrial Valves

Flow control is achieved by effective use of the actuation systems. Actuation systems involve the conversion of one type of energy into another such that the flow area is uncovered to the required extent to allow flow of the working fluid at the desired rate as per the process requirements. Industrial valves may be actuated using muscular energy, pneumatic or hydraulic energy and electrical energy. Use of muscular and electrical energy involves application of torque while fluid actuation which involves pneumatic or hydraulic actuation involves application of thrust in order to initiate the action of opening or closing of the valve. Fluids are largely used in the process industries to carry out various processes. Depending on the parameters laid down by the respective industry, the chemicals may be hazardous or otherwise.

E. Handling of Hazardous Chemicals

Chemicals are used in industries to facilitate a wide palette of functions. Pipelines are so designed that the purpose of the chemicals being used is served to the most effective extent. Industrial valves are imperative when it comes to regulation of flow and as in case of hazardous chemicals, it is initially necessary to comprehend the nature of flow of hazardous chemicals through different types of valves. Block valves or On/Off valves are used to initiate or terminate a flow. The valves may also be used in dead end services in discharge of petroleum fuels for transport through railways. Flow control valves play a vital role in the kinetics f the chemical reactions as they control the discharge and various other parameters. Check valves are rarely used to handle hazardous chemical due to the potential risk of back flow and are hence out of purview of this paper. While handling the chemicals deemed to be hazardous, there are certain key process parameters that require attention. These parameters largely govern the effectiveness of the process.

F. Actuation by automation

An industrial valve can be further understood by dividing into three basic parts viz. the body, trim and the yoke. Body refers to the housing that facilitates the regulation of fluid flow. Trim comprises of the mechanism used to regulate the flow like the seat, gate or disc and the yoke comprises of a mechanism used to operate the trim components that can facilitate sealing action. Actuation systems can be manual hand wheel or gear operated, pneumatic cylinder operated and electrical operated to name a few. Since this discussion is about SCADA, manual actuation shall be out of purview of this paper. Pneumatically actuation systems employ a single or double acting pneumatic actuator which can be controlled by a solenoid operated direction control valve. Automation in this can be achieved by integrating the input signals to the direction control valve with a programmable logic controller (PLC). Electrically actuated systems employ a motor connected to a gearing arrangement which in turn is connected to the driving mechanism. It may be noted that, these actuators can also be integrated with PLCs to achieve the desired level of automation.

G. Process parameters for safe handling

Temperature, Pressure, Flow Rate, Composition, Concentration, Reactivity, Leakage detection, Global warming potential, Ozone depletion potential, health and safety hazards. Handling of hazardous chemicals involves process parameters which have been elaborated as follows. Temperature of the fluid refers to the average kinetic energy possessed by the molecules of the fluid. It is necessary that certain chemicals are strictly maintained in a certain temperature range. Fluids like refrigerants need comparatively lower temperatures as compared to organic fluids. Fluctuation in temperature of hazardous fluids may lead to issues like change of phase of the fluid wherein in event multiple phases co-exist, there are chances of aggravation of further reactions depending on the nature of the fluid. Pressure of the fluid refers to the overall line pressure at which the fluid is being moved from one point to the other. Since pressurized gases can be easily transported in the form of liquids, it is necessary to maintain the same pressure to avoid change of phase. Flow rate refers to the quantity of fluid that passes through a section of a pipeline in unit time. It can mainly be governed at the wish of the operator or at a pre set value. The chemical composition plays a vital role in deciding the reactivity of the fluid. Leakage detection of the chemical is an essential parameter so that safety is not compromised. When it comes to refrigerants, there are two more parameters called Global Warming Potential (GWP) and Ozone Depletion Potential

(ODP). These are indicators of the hazardous nature of the refrigerant with respect to the environment and need to be as low as possible considering the global energy requirements.

H. Design of SCADA systems for handling of hazardous chemicals

SCADA comprises of an array of sensors, actuators and intermediate modifying devices connected to a human machine interface controlled by a human from a booth located at a remote location. The key advantage of employing SCADA systems is the ability to control equipment placed at remote locations by means of electronic signals which may be sent by wireless communication devices. In order to design SCADA systems for handling of hazardous chemicals, the process parameters considered earlier shall be taken up serially and the design considerations shall be put forward. While governing the temperature, thermal sensors can be used and the feedback from the same can be used to regulate and maintain the temperature at which the system is intended to run. Auxiliary cooling or heating systems may form a part of this loop. Pressure regulation can be ensured by pumping in or discharging the required quantity of fluid such that the fluid is maintained at uniform pressure throughout the process. Flow rate is a function of the opening of the flow control valve. Flow measuring instruments can accurately provide the feedback to the flow control valves. Actuation systems can be automated by use of additional equipment like electro pneumatic positioners and flow control valves to facilitate the required flow rate. However, the flow rate is an indicative parameter of the rate of production and hence it needs manual intervention at times. Thus flow rate can be kept as a reference to decide other parameters. Composition of the chemicals used is a property of the fluid and cannot be initially controlled. However, at periodic intervals, sensors may be used to carry out chemical analysis to check the presence of key constituents. This can be facilitated to ensure that the end product has the composition as designed. Concentration and reactivity are parameters liked to the chemical kinetics of the reaction and need to be studied in advance with the flow line design. Leakage detection can be an important function of the SCADA systems. Since hazardous chemicals may at times be odourless and if employed at remote locations, it is necessary that as a part of risk assessment, all potential leakages are studied well in advance and respective sensors are in place. Global Warming Potential (GWP) and Ozone Depletion Potential (ODP) is generally an important parameter in industrial refrigeration systems. As a part of design, one can use refrigerants with low GWP and low ODP in addition to which, with experimentation, one can link the ambient temperature with the potential of the hazardous chemical to cause environmental hazards. The system may be fed with potential health and safety hazards and alarms can be set to ensure that the interested parties are warned well in advance.

I. Failsafe systems in actuated valves

According to the International Organization for Standardization (ISO) standards ISO 9001:2015 and ISO 45001:2018, it is a system requirement that adequate Risk Assessment of all the activities is done to avoid any kind of non compliance. Keeping this in mind, it has been proposed to design a SCADA system for the failsafe systems which, in this current scenario are governed by certain manual intervention. In operation, there are three scenarios in which a failsafe action is required. Firstly, there may be an electrical power supply failure. Secondly, there can be a failure of air supply which is applicable to pneumatically actuated valves and thirdly, there can be a combined failure. As a part of risk assessment, it is necessary to design failsafe systems for three conditions viz. fail to stay put, fail to open and fail to close. The question as to which is appropriate depends on the kinetics of the chemicals in the pipeline.

J. Chemical Kinetics of Hazardous Chemicals

Hazardous chemicals can be comprehended as those that bear a potential to cause incidents or accidents like release of poisonous fumes or gases, explosions, coagulation and so on if not handled in accordance with the safety guidelines as enumerated as a result of years together of research. Chemical kinetics deals with the study of the rate of reactions, their mechanism and certain factors affecting the reactions. Rate of reaction refers to the velocity at which the concentration of reactants or products changes with time. There are three major factors that shall be considered to design the failsafe systems. The first factor is the concentration or pressure of the reactants. Rate of reaction is directly proportional to this factor. The second factor is the temperature of reactants which is also directly proportional to the rate of reaction. The third factor is catalysis. Catalysts can be of three types. Positive catalysts can speed up the rate of reaction; negative catalysts can slow down the rate of reaction while neutral catalysts can help maintain the rate of reaction. The following sections shall elaborate on this aspect.

K. Failsafe systems considering multiple factors

The rate of reaction is directly proportional to the concentration or pressure of the reactants. If the flow media contains mixtures at high concentration it is advisable that the necessary failsafe action implemented is that of fail to open. In event of failure of power supply or air supply or both, there may be certain reactants that may have the property of causing potential damage if withheld in location. In such cases, it is necessary to facilitate a fail to open action wherein the high concentration reactants can be flushed further and certain negative catalysts can be added to slow down the rate of reaction. This can be alternately done by providing auxiliary cooling systems as well. In event the concentration of reactants is not relatively high and if the products of the reaction may not be subject to coagulation, one can implement fail to close action. Certain other considerations like handling capacity may lead to a requirement of providing fail to stay put condition to ensure that pressure is not built up in a particular section which may be critically hazardous in case of reactive fluids.

The rate of reaction is directly proportional to the temperature of the reaction. Fail to open condition is ideal when the reactants may heat up beyond the rated temperature of the reaction. Similarly, fail to close condition is suitable is ideal when the cooling down of reactants cannot be afforded. Thermo-chemistry plays a major role in determining the course of reaction as it is known that every reaction progresses in the direction of decreasing energy to gain stability. However, depending on the process parameters, necessary failsafe action can be employed to maintain the required temperature conducive to sustain the desired path of the reaction.

Catalyst added to reactants can be of three types. Positive catalyst speeds up the reaction, negative catalyst slows down the reaction while a neutral catalyst maintains the rate of reaction throughout the process. Considering the thermodynamics perspective, catalysts play a vital role in determining the rate of reaction thereby directing the reaction in the direction of decreasing energy.

L. Design of SCADA to accommodate failsafe systems considering chemical kinetics perspective

SCADA comprises of an array of transducers connected to the end effectors interfaced with the control room where the required programming can be introduced into the system. Design considerations are a part of the logic and have been discussed as follows. Taking into consideration all the aspects elaborated till this point, following paragraphs may summarize the design requirements of SCADA to accommodate failsafe systems from the perspective of chemical kinetics. For high concentration reactants, fail to open action is recommended with a further addition of negative catalyst or cooling systems to bring down the rate of reaction. For reactants with the potential of building up pressure or in case of a pressure regulation requirement, fail to stay put condition needs to be employed. For high temperature reactions, fail to close systems are recommended to avoid retardation of reactions while for low temperature reactions, fail to open systems are recommended to avoid addition of heat due to stagnation. For reactants mixed with positive catalysts, the fail to open condition is recommended as the reaction may pose a danger to safety if the valve remains closed. For those mixed with negative catalysts, the fail to close condition is recommended as the catalyst can slow down the rate of reaction until the system can resume normal operation.

M. Significance with respect to Industrial Safety

Industrial safety has been emphasized by various international standards considering the growing global demand and its effect on the exponential increase in the rate of production. When it comes to handling of hazardous chemicals, in addition to various standard operating procedures in place, it is necessary that with least human interference, automation can take care of the required level of safety. With this rather than substitution, engineering controls can be applied. Failsafe systems when designed to suit properties of the flow media can facilitate such engineering controls. SCADA designed to accommodate failsafe systems can further reduce human interference and lead to efficient automation with respect to internet of things from the industrial view point.

N. Security and safety challenges with mitigation measures

Whenever it comes to any smart systems that use internet of things, there are challenges like breach of data encryption which if done by destructive minds, can lead to incidents or accidents. Thus system security should be both physical and virtual. While the physical security can be ensured by physically securing the SCADA servers, virtual security required periodic upkeep and verification of data so as to ensure that all the feedback loops are working as designed. Breach in security leads to a risk with regards to safety. In this there are two things. One is the safety of the equipment and the other is safety of the human resource. SCADA systems are fully automated and work according to pre set programs according to the inputs received from the user interface which is also known as the human machine interface. It is necessary that the system is smart enough to detect wrong commands and suggest modifications in the inputs so that there is no compromise on safety. In order to avoid any kind of deliberate actions to cause incidents or accidents, measures like single user interface and process interlink can be most efficacious. Safety of the human resource is equally important as the safety of the equipment because towards the end, it is the human mind that can design better systems as a part of continuous improvement. Leakage or spillage of hazardous chemicals is a risk that needs to be mitigated. It is practically difficult to completely eliminate the occurrence of a risk but steps can be undertaken to reduce the same. Thus by employing security layer, one can ascertain safety and security of both, the equipment as well as the human resource.

Conclusion

Thus it can be concluded that the key process parameters required to design a supervisory control and data acquisition system for handling of hazardous chemicals have been enumerated and the corresponding design considerations have been discussed accordingly. SCADA can be designed with the aid of certain basic design requirements as enumerated and found suitable. SCADA for failsafe systems considering factors affecting rate of reaction can be useful in ensuring industrial safety as well as process efficiency.

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