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Study of compression system Check Valve failure hazards

Realised by:

- GASMI Abdelouahab
- BOULIFA Saber

Supervised by:

Mr. KROBBA Abdelkader

Juri members:

Dr. KEBDI Soumia	University of Ouargla	President
Dr. TOUAHER Bashir	University of Ouargla	Examiner
Dr. BENAZOUZ Fouzi	University of Ouargla	Overseer

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Abstract:

The check valve is an important equipment in the context of security and safety at a gas compressor station or gas re-injection. It allows for the passage of compressed gas in the desired direction and prevents the inverse flow of gas which is the result of pressure difference for many factors related to the situation of the compressor operation and the state of the equipment. Therefore, it is necessary to install the check valve as a fixed barrier that supports safety along with automatic systems.

Key words: Check valve, HAZOP, compressor, reverse flow, compressed gas.

الملخص:

يعتبر صمام الفحص من المعدات الهامة في سياق الامن والسلامة في محطة ضغط الغاز، فهو يسمح بمرور الغاز المضغوط في الاتجاه المرغوب ويمنع التدفق المعاكس للغاز الذي يكون نتيجة فرق الضغط لعدة عوامل مختلفة تتعلق بوضع تشغيل الضاغط وحالة المعدات، لذلك من الضروري تركيب صمام الفحص كحاجز ثابت يدعم السلامة في محطة الضغط الى جانب الأنظمة الأتوماتيكية.

الكلمات المفتاحية: صمام التدفق الأحادي، الضاغط، التدفق العكسي، غاز مضغوط.

Résumé:

La clapet anti-rotor est un équipement important dans le contexte de la sécurité à une station de compression ou de la réinjection de gaz. Il permet le passage du gaz comprimé dans la direction souhaitée et empêche le flux de gaz défavorable qui est le résultat d'une différence de pression pour plusieurs facteurs différents liés à la stuation du fonctionnement du compresseur et l'état de l'équipement. Par conséquent, il est nécessaire d'installer la clapet anti-rotor comme barrière fixe qui support la sécurité à la station de compression avec des systèmes automatiques.

Les mot clés: clapet anti-rotor, HAZOP, compresseur, flux inverse, Gaz comprimé.

Table of contents:

Acknowledgement I

Abstract: II

Table of contents: III

Table of figures VIII

Table of tables: IX

Acronyms and abbreviations: X

General Introduction 1

CHAPTER 01: Introduction to SIC plant & basic concepts of compressors and check valves ....

Introduction: 4

SECTION 01: Company presentation 5

1. HASSI MESSAOUD region: 5

2. Sonatrach presentation: 5

1) Overview: 5

2) The two SIC and NAIC complexes: 6

3) Description of SIC: 7

3. Gas compression station: 8

1) Compression stations in SIC: 8

2) Re-injection station sections: 9

4. compression services in SIC: 10

1) Compression Service 01: 10

2) Compression Service 02: 10

3) Power supply to compression units: 10

4) Process description: 10

SECTION 02: Basic concepts of compressors 12

1. Overview of Compressors. 12

1) Definition: 12

2) Its application: 12

3) Compressor classification: 13

2. Description and principle of operating of centrifugal compressors: 15

1) General description: 15

2) Centrifugal compressor components: 16

3) Types of centrifugal compressors built by NUOVO PIGNON: 17

4) The systems protections used for the centrifugal compressor. 17

SECTION 03: Basic concepts of check valves 19

1. Description of check valves: 19

2. The working principle: 19

3. Types of check valves: 20

1) Swing check valve: 20

2) Lift check valve: 22

3) Butterfly check valve: 23

4) Stop Check Valve: 24

5) Dual plate check valve: 24

Conclusion: 26

CHAPTER 02: Principles of conducting Hazard and Operability study (HAZOP)

Introduction: 28

SECTION 01:Basic notions of risk assessment 29

1. Hazard: 29

2. Risk: 29

3. Safety: 29

4. Dammage: 29

SECTION 01: Description of HAZOP. 30

5. HAZOP History: 30

6. Domain of application: 30

7. Purposes of the method: 31

SECTION 02:HAZOP Study process 32

1. HAZOP principible: 32

2. Phases of HAZOP analysis: 33

1) Preparation phase: 33

2) Examination Phase: 33

3) Documentation and Follow-up Phase: 33

3. Conduct of HAZOP study: 34

1) Definition of parameters and operations : 35

2) Definition of guide words and deviations: 36

3) Identifying the causes and the results of deviations: 37

4) Examination of safe-guards: 38

5) Estimation of the risk: 39

6) Recommendations for improving the system: 40
SECTION 03: HAZOP advantages and limitations 41
1. HAZOP advantages: 41
2. HAZOP Limitations: 42
3. HAZOP future: 42
Conclusion: 44
CHAPTER 03: Case study based on a real system
Introduction: 46
SECTION 01: Description of study system 47
1. Identification of the system: 47
2. Overview of study system process: 48
3. Equipment functions: 48
4. Risk factors: 49
SECTION 02:Results of HAZOP Procedure 51
1. Purpose of the study: 51
2. The main parameter and its deviation: 51
3. The causes of reverse flow : 52
a) Pressure imbalance: 52
b) Back pressure of downstream systems: 52
c) Failure of control system: 52
4. The action of check valve: 53
5. The severity of results: 53
a) Equipment damage: 53

b) Efficiency loss: 54

c) Safety hazards: 54

d) Operation disorders: 54

SECTION 03: Check valve failure description and recommendations 55

1. check valves failure discovery: 55

2. check valves failure mode: 56

3. check valves failure cause: 57

4. check valves failure results: 57

5. Recommendations: 58

Conclusion: 60

General conclusion 61

Bibliography 62

Annexces 63

Table of figures:

Figure (1-1): Map of Hassi Messoud field. 5

Figure (1-2): SIC plant. 8

Figure (1-3): P&ID scheme of compressor station CS 2 in SIC. 9

Figure (1-4): a compressor using in LPG 2 unit at SIC. 13

Figure (1-5): Mechanism of positive displacement compressor. 14

Figure (1-6): Mechanism of dynamic -centrifugal- compressor. 15

Figure (1-7): Centrifugal compressor components. 16

Figure (1-8) : Dry powder extinguishing system. 18

Figure (1-9): the working principle of check valve. 20

Figure (1-10): swing check valve diagram. 21

Figure (1-11): Top hinged check valve diagram. 21

Figure (1-12): Top hinged check valve diagram. 22

Figure (1-13): Lift check valve. 22

Figure (1-14): ballcheck valve. 23

Figure (1-15): butterfly check valve and its components. 24

Figure (1-16): butterfly check valve and its components. 24

Figure (1-17): Dual check valve and its components. 25

Figure (2-2):Risk matrix. 39

Figure (3-1): P&ID of compression station CS 04 in SIC. 47

Figure (3-2): P&ID of the main study system. 48

Figure (3-3): Maintenance of the check valve in SIC plant. 55

Figure (3-4):Check valve failure descovry. 56

Table of tables:

Table (2-1): Example of HAZOP template. 32

Table (2-2): Examples of deviations 37

Table (3-1): Table of equipment functions in study system. 49

Acronyms and abbreviations:

SIC: South Industrial Complex in Hassi Messoud.

NAIC: Naili-Abdelhalim Industrial Complex.

LPG: Liquefied Petroleum Gas.

CS: Compression station.

HPDL: High Pressure Direct Line.

MPDL: Medium Pressure Direct Line

LPDL: Low Pressure Direct Line

LP: Low Pressure.

HAZOP: Hazard and Operability Study.

Nm3/d: Normal cubic meter / day.

RPM: Revolutions Per Minute.

STdm: Standard Cubic Meter.

MAWP: Maximum Allowable Working Pressure.

General Introduction

The safety and security rules of industrial stations are the basis of productivity, quality of work and the welfare of workers. To this end, the design of the workplace includes many means, systems, safety mechanisms and risk prevention. The size and number of such equipment increases depending on the type of system and the size of the risks that may occur.

Gas compressor stations are workplaces where the risk is high due to the presence of high pressure gas pipes and the likelihood of fire, explosion or operating problems are contained at any time. Therefore, the design includes automatic protection systems such as anti-fire system, anti-surge system of compressor and pressure control systems, as well as fixed protection equipment, the most important of which is the inspection valve.

The problem of the study is to determine the purpose and possible consequences of the installation of the check valve at the gas compressor station and the problems resulting from its failure, and the study depends on the outputs of the applied internship we did at the compressor station in SIC plant in Hassi Messoud.

We aim to confirm the need for the check valve at the gas pressure station as a supporter of safety automatic systems while clarifying the status of the system when it is absent. We also seek to identify the basic recommendations to ensure the continuity of the successful performance of this element in particular and to ensure the continuous productivity of the station in general.

The importance of the study relates to the importance of this thoughtful equipment, as we will explain the severity of disasters that may occur in the event of its absent or its failure, given the nature of the plant, its complexity and the high pressure of the gas.

The difficulties of the study relate to the complexity of this industrial system at the gas compressor station and the presence of many overlapping systems and the privacy of data related to the system's failure. The duration of our internship study was not sufficient to obtain all the important details related to the check valve and the causes of failure according to the nature of the station studied.

Regarding the plan of our thesis.In first chapter,we will present the most important information about Sonatrach and the SIC plant. We will also explain the most important details about compressors and their pivotal role in the compressor stations or re-injection of gas with a focus on the centrifugal compressor and then we will describe the check valve, its mechanism and types.

In second chapter , we will explain the HAZOP method in the risk assessment process with its principles, positives and limits of use.

In the third chapter, we will explain the applied aspect of the thesis where we will address the problem of the study according to the HAZOP methodology and determine the final results.

CHAPTER 01:

Introduction to SIC plant & basic concepts of compressors and check valves.

Introduction:

In order to study the risks of the failure of the check valve on a real industrial system and determine its causes and results according to the real condition of operating, we conducted an applied internship at the Southern Industrial Complex in Sonatrach - Production Department.

This plant includes LPG processing activities, petroleum refining operations, storage, etc. It also includes gas re-injection plants in wells, according to an accurate automatic operating system and monitored with many systems and equipment for safety, gas risk prevention and disaster prevention. The check valve is one of the most important.

In this chapter, we will define Sonatrach Foundation with a description of the SIC station and compressor stations or re-injection gas stations according to the knowledge output of this internship, Then we will explain briefly about the compressors while clarifying the centrifugal compressor and the lead of its work,We're going to finish this chapter by describing the check valve, its mechanism, its types and applications and its important role in industrial systems in general and gas compressor station in particular.

<u>SECTION 01:</u> Company presentation

1. HASSI MESSAOUD region:

Hassi messaoud is an Algerian desert area located in Ouargla, an industrial zone located 850 km south of Algiers and 80 km south-east of Ouargla, It contains a large stock of hydrocarbons and is renowned for having many oilfields. Sonatrach is the lead manager for Oil Well Exploration, Drilling, Production, Processing and Transportation and cooperates with several national and foreign companies.

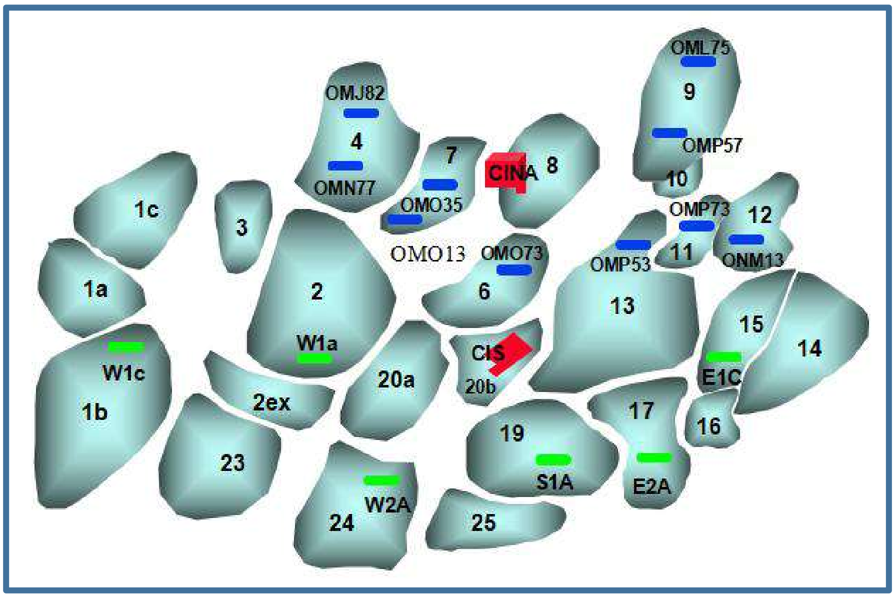

Figure (1-1): Map of Hassi Messoud field.

2. Sonatrach presentation:

1) Overview:

According to Sonatrach internal references, itis the national company specializing in the exploration, production, transport, processing and marketing of hydrocarbons "petroleum and natural gas".

Sonatrach is a key player in meeting domestic energy demand, operating under its export strategy for several regions of the world: in Africa, Europe, Latin America and the United States of America, with export sales of approximately US $56.1 billion in 2010.

It is preparing for the future to discover new oil or gas fields in different national regions and exploit energy resources in the context of its own initiative or projects with different companies.

Ensuring energy security for future generations through the development of national hydrocarbon resources, wealth creation and action for the country's economic and social development are the most important challenges and tasks of Sonatrach.

- 1st African Company.
- 14th International Oil Company.
- 13th World Company on Liquid Hydrocarbon Production.
- 6th World Natural Gas Company (Reserves & Production).
- 5th World Natural Gas Source.
- 4th World Source of Liquefied Natural Gas.

2) The two SIC and NAIC complexes:

According to our internship outputs, The two SIC and NAIC complexes composed of more or less complex process chain, are responsible for the treatment of effluents from the producing wells. These processes are made to support:

- Oil treatment: oil- water- gas separation, desalination, and stabilization.
- Treatment of associated gases for the production of LPG and condensate.

- Treatment of oily water for environmental protection.
- Refining a portion of the crude for fuel production.
- Re-injection of residual gases to maintain reservoir pressure.
- Water injection to maintain reservoir pressure.

3) Description of SIC:

The South Industrial Complex (SIC) located south of the Hassi Messoud field, receives the total oil production of the southern zone, this production comes mainly from satellite units on the one hand and directly from wells in HPDL (high pressure direct line), in LPDL (low pressure direct line) and MPDL (medium pressure direct line).

SIC composed of:

- 06 satellite units (satellite fields).
- 01 crude oil treatment unit (separation, desalination and stabilization).
- 07 gas boosting units (MP - HP).
- 03 LPG and condensate recovery units.
- 11 re-injection gas compression stations.
- 01 water injection unit.
- 02 refining units.
- 01 oily water treatment unit.
- 03 industrial water treatment units.
- 01 central air.
- 03 waste oil treatment units.

Figure (1-2): SIC plant.

3. Gas compression station:

Compression or re-injection stations is defined as those installations which are used to compress the gas at high pressure in order to re-inject it into the wells, They draw the gas to 28 bar and compress it to 420 bar in four stages, for re-injection into wells to maintain reservoir pressure and thus increase production.

1) Compression stations in SIC:

The SIC has 11 gas re-injection stations:

- The CS 2 is a re-injection unit made in 1972 to compress a flow of 3.5 million Stdm3/d of gas of a PM of 22 g/mole, coming from the 28 bar manifold (II), note the figure (1-3).
- The CS 4/3 are re-injection units realized in 1976 to compress each a flow of 5.5 million Stdm3/d of gas of a PM of 21 g/mole, coming from the 28 bar manifold (II).
- The CS 5/6 are re-injection units made in 1987 to compress each a flow of 5.5 million Stdm3/d of gas of a PM of 21 g/mole, from the 28 bar manifold (II).

- The CS 8/7 are re-injection units realized in 1991 to compress each a flow of 5.5 million Stdm^3/d of gas of a PM of 21 g/mole, coming from the 28 bar manifold (II).
- The CS12/11/10/9 are re-injection units carried out in 2001 to compress each a flow of 9 million Stdm^3/d of gas with a PM of 21 g/mole, from the 28 bar manifold (II).

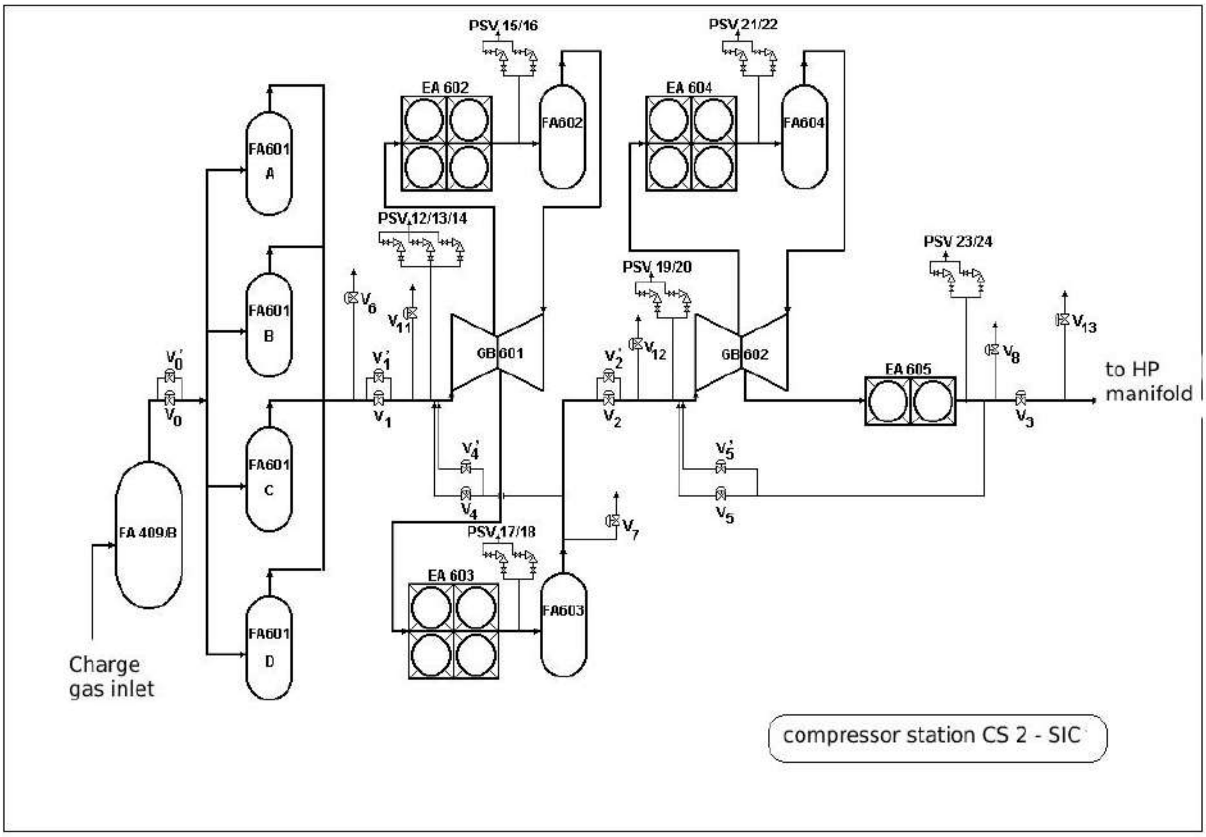

Figure (1-3): P&ID scheme of compressor station CS 2 in SIC.

2) Re-injection station sections:

The compression or Re-injection station process consists of the following sections:

- Preliminary Separation Section.
- Low pressure compression section.
- High pressure compression section.

- Section fuel gas and starting gas.
- Torch system.
- Condensed collector.
- Lubricating oil circuit.
- Sealing oil circuit.
- Fire suppression system.

4. compression services in SIC:

1) Compression Service 01:

It is composed of seven stations (CS 08/07/06/05/04/03/02); each station re-injects, by means, $5{,}5.10^{6}$ Nm3/d.

2) Compression Service 02:

The compressor station 2 consists of four sections (12/11/10/9) each station re-injecting 10 million Nm^3/d.

3) Power supply to compression units:

The power supply for the compression services comes from the LP manifold which groups the following arrival lines:

- Local Gas Lines: Satellite Fields - LPG 2/1 - CINA North Compression Line - HPDL (crude oil processing).
- Gas lines marketed: GR1 and GR-Guassi Touil line GT.

4) Process description:

The compression station process is described as we noticed during our internship as follows:

The gas to be compressed comes from the manifold LP at 28 bar to the three-phase separator balloons (scrubbers) to separate the liquids (water and condensate) from the gas; the condensates are sent to a condensate recovery balloon and then to the treatment centre; the water collected in the apindices is sent to the water treatment unit; while the gas is sent to the low pressure compression section.

The LP section consists of a gas turbine and a two-stage compressor. The gas is compressed in the 1st stage from 28 to 55 bar, cooled in air cooler, then passed in a flask to remove condensed liquids; then it is compressed from 55 to 106 bars in the 2nd stage before being cooled in air cooler and eliminated from condensed liquids.

The LP sections push the gas back into a manifold called the banalization line, in order to have a better operating autonomy of the machines. The gas then enters the high pressure compression section.

The HP section is composed of a turbine and two 1-stage compressors; the exhaust gas from the 106 bar banalization manifold is compressed in the 1st compressor up to 225 bar, cooled in an air cooler, eliminated condensed liquids before being subjected to a 2nd compression in the 2nd compressor up to 400 bar, then it is cooled.

Finally the gas reaches the high pressure manifold HP before being re-injected into the re-injectors wells.

Note the first annex.(Annex 01)

SECTION 02: Basic concepts of compressors

1. Overview of Compressors.

1) Definition:

Compressors are receiving machines, which transform the mechanical energy provided by the drive motor into pressure energy. They are considered the most answered in the oil and petrochemical industry, and are widely used in systems: automatic; pneumatic and especially in compressor stations (shipping and gas injection)..etc.(Boulahdid)

The role of compressors is crucial in the field of industrial activity, they accelerate production cycles.

2) Its application:

Compressors are used in all branches of the oil industry because of their simple construction and easy operation, Compressor applications are very diverse. The following list gives examples of the use of these machines (Boulahdid):

- Manufacture of compressed air (air instrumentation, parts cleaning, paint...).
- Compression and displacement of process gases.
- Transport of powdery materials (“pneumatic” transport of powders).
- Realization of vacuum and depression (distillation, crystallization under vacuum, evaporation...).
- Sanitation of the premises (ventilation, air conditioning...).

- Brewing of fermentation tanks.

Selection criteria:

- Gas quality.
- Cleanliness of the gas.
- Harmfulness of gas.
- Flow rate, pressure (compression ratio).

Figure (1-4): a compressor using in LPG 2 unit at SIC.

3) Compressor classification:

Compressors are classified according to the mode of operation.

There are:

a. **<u>Positive displacement compressors:</u>** Reciprocating and rotary compressors.

In reciprocating compressors, the movement of the gas is done by the reciprocating rectilinear movement of the piston (membrane) driven by the connecting rod - crank mechanism.

In rotary compressors, the movement of the gas is carried out by the rotation of the discharge element (worm-screw; pallet type ...etc).

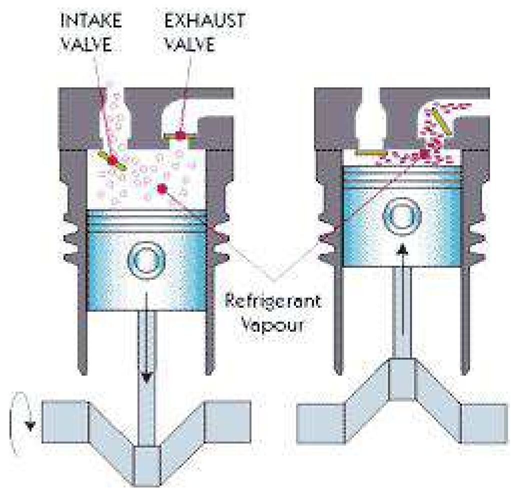

Figure (1-5): Mechanism of positive displacement compressor.

b. <u>Dynamic compressors:</u> Centrifugal and axial compressors.

In centrifugal compressors, the gas movement is ensured by the rapid rotation of the impeller (under the action of centrifugal forces).

In axial compressors, gas moves along the axis of rotation of the rotor blades.

When studying compressors, it is important to know both the normal operating conditions (suction pressure, discharge pressure) and the variations of these conditions to determine the type and characteristics of a compressor.

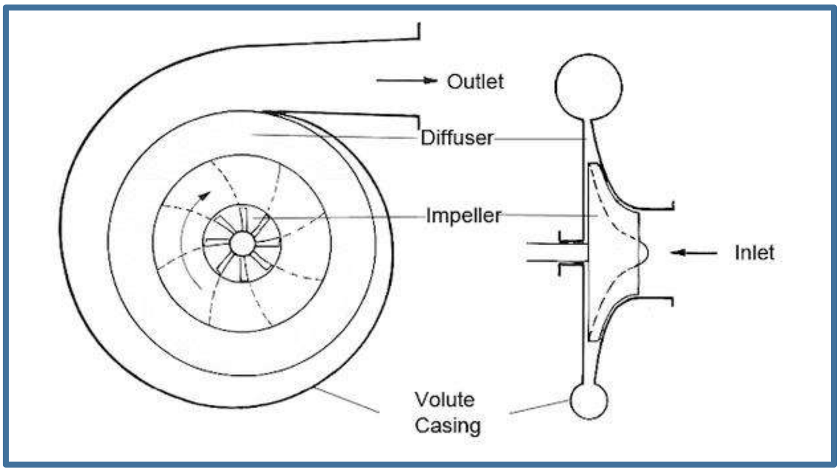

Figure (1-6): Mechanism of dynamic -centrifugal- compressor**.**

2. Description and principle of operating of centrifugal compressors:

The centrifugal compressor is the main type of gas compressors that using in the re-injection stations in SIC plant.

1) General description:

A centrifugal compressor is a high-speed rotary machine (typically ranging from 6,000 to 30,000 RPM) in which one or more impellers provide the energy required for gas transfer. When a significant amount of pressure energy is needed, multiple impellers (multi-stage) are necessary. This can sometimes lead to solutions involving machines with multiple stages to address issues such as discharge temperature and efficiency, or even multiple bodies to resolve mechanical stability problems that would arise from excessively long rotors.(Boulahdid)

2) Centrifugal compressor components:

It consists of many pieces and components, Note the figure (1-6):

1. Second-stage variable inlet guide vane.
2. First-stage impeller.
3. Second-stage impeller.
4. Water-cooled motor.
5. Base, oil tank, and lubricating oil pump assembly.
6. First-stage guide vanes and capacity control.
7. Labyrinth seal.
8. Cross-over connection.
9. Guide vane actuator.
10. Volute casing.
11. Pressure-lubricated sleeve bearing.

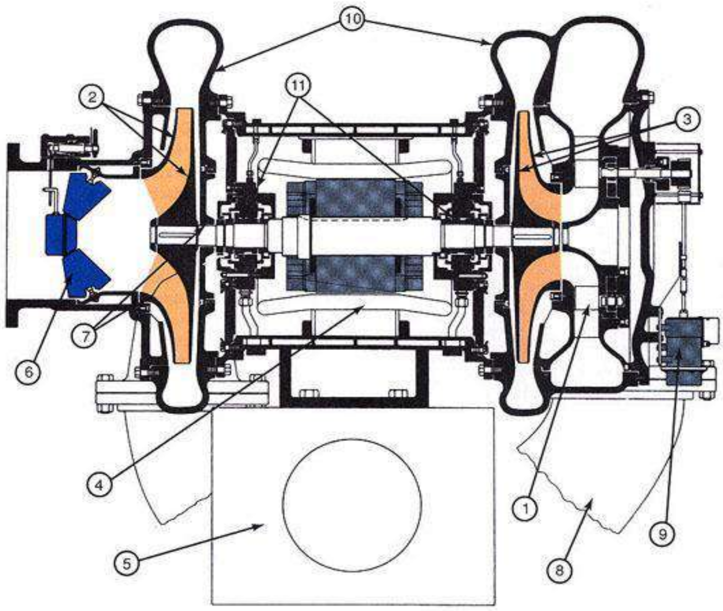

Figure (1-7): Centrifugal compressor components.

3) Types of centrifugal compressors built by NUOVO PIGNON:

NUOVO PIGNONE, an Italian company specialized in the manufacturing of compressors and other industrial equipment, offers several types of centrifugal compressors. Here are some of the commonly built types by NUOVO PIGNONE:

- Centrifuge Compressor - MCL.
- Centrifuge Compressor - 2MCL.
- Centrifuge Compressor - 3MCL.
- Centrifuge Compressor - BCL.
- Centrifuge Compressor - 2BCL.
- Centrifuge Compressor - PCL.

Centrifuge Compressor - BCL is the main type used in the re-injection stations in SIC plant.

4) The systems protections used for the centrifugal compressor.

The compressor is the primary equipment in the gas compressor system and any fault that occurs will be huge and comprehensive results for all the station, so it is necessary to ensure the effective performance of the automatic and physical safety systems that surround the compressor.

The centrifugal compressor at the compression station is protected by a fire protection system consisting of:

- Dry powder extinguishing system, Note the figure (1-8).
- Gas detection system.
- Fire water network.

- Fire extinguishers.
- Display and control panel in the control room.

These components work together to ensure the safety of the compressor and surrounding areas in case of a fire. The dry powder extinguishing system is designed to suppress and extinguish fires using dry chemical agents. The gas detection system monitors for the presence of flammable gases and triggers alarms or activates fire suppression measures if detected. The fire water network provides a water supply for firefighting purposes, such as sprinkler systems or hose reels. Fire extinguishers are handheld devices used to extinguish small fires. The display and control panel in the control room allow operators to monitor and control the fire protection system.(Lüdtke 2004)

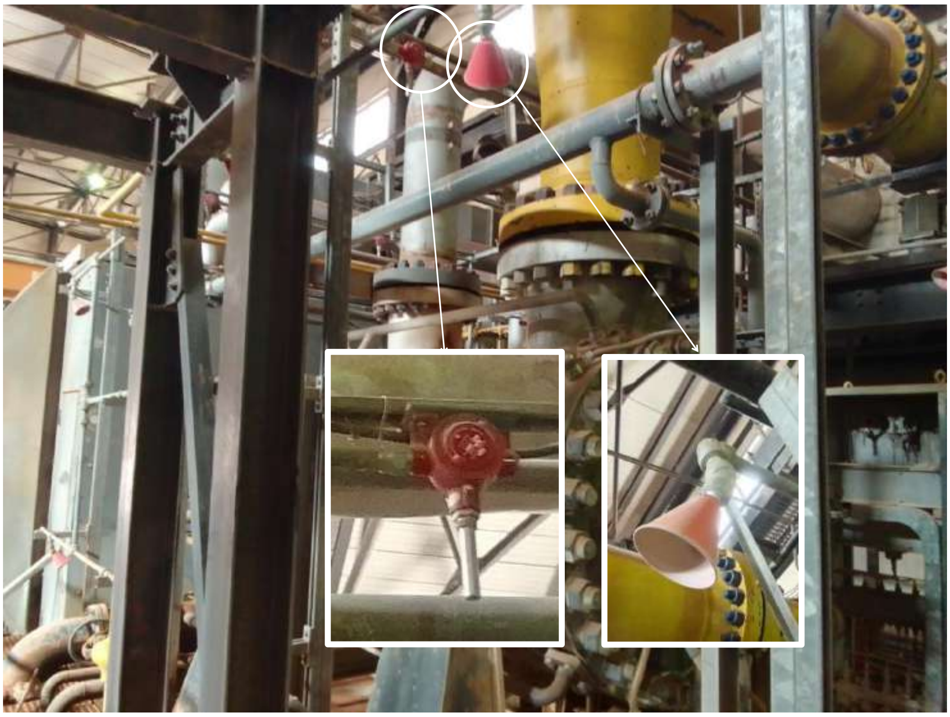

Figure (1-8) : Dry powder extinguishing system.

SECTION 03: Basic concepts of check valves

1. Description of check valves:

A check valve is a type of valve that permits flow in one direction while obstructing passage in the other direction in pipeline systems. When a compressor shuts down, check valves are frequently employed in compression systems to stop the flow from the high-pressure discharge system into the low-pressure inter-stage and suction systems. They are normally put at suitable points in the system and can help in preventing over-pressure and severely damaged equipment as a result of over-pressure.(Thompson and King 2011)

2. The working principle:

The check valve generally allows the flow and passage of gas, liquid or steam in one direction and prevents automatically and without external interference by workers back-flow in the reverse direction,according to its mechanism, there are many types of check valves and the right type of check valve is selected by system requirements, cost and other standards.(Thompson and King 2011)

It is a simple device consisting of a casing around one or more translating or rotating elements. The situation can be influenced secondarily by springs, counterweight and/or damping device, slowing motion for the element (s), generally only during the last part of the closure.(Kruisbrink 1996)

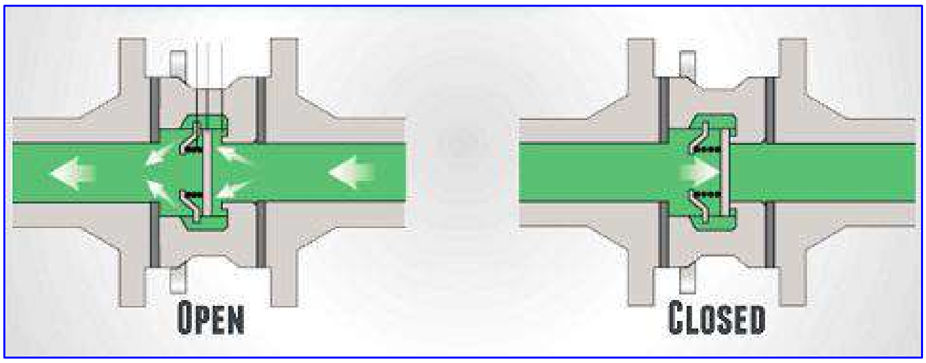

Figure (1-9): the working principle of check valve.

The perfect check valve is that has no resistance against gas flow or liquid when passed in normal direction, Its flow resistance is infinite in the reverse direction, its electricity counterpart is diode that allows electric current to pass in one direction, In addition, the perfect valve closes directly at the moment of flow reflection and the closing speed depends on the mechanism in which it operates.(Kruisbrink 1996)

check valves protect large devices and equipment such as compressors from the risk of reverse flow. This demonstrates the importance of their presence in the pipeline at gas pressure stations and others and confirms their essential role in the safety process.

3. Types of check valves:

A check valves exist in different types according to their built-in configuration, principle of operation or valve disc configuration(Kruisbrink 1996). The most common check valves are:

1) Swing check valve:

A swing check valve is a type of the most commonly used check valve, it is an excellent economic option with a high slamming effect.(Sotoodeh 2018)

The swing check valve mechanism is simple and inexpensive, and depends on the disk or flap inside the valve allows fluid flow or stop, the disk is automatically opened when the fluid passes in the right direction depending on the pressure difference and without interference with any external forces, the disk stays open, and at the low pressure the disk is closed, preventing the passage of fluid in the opposite direction.(MAX 2022)

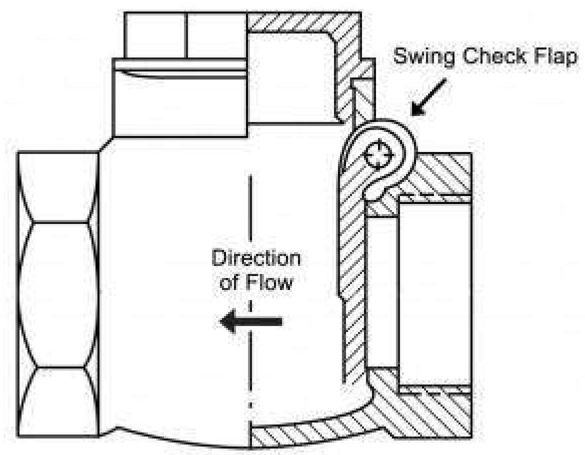

Figure (1-10): swing check valve diagram.

There are two types of swing check valves we should look at:

a. <u>Top-hinged Check Valve:</u>

In this type, the disc is connected to the inside top of the valve with a hinge that allows the disk to open and close with ease.(MAX 2022).

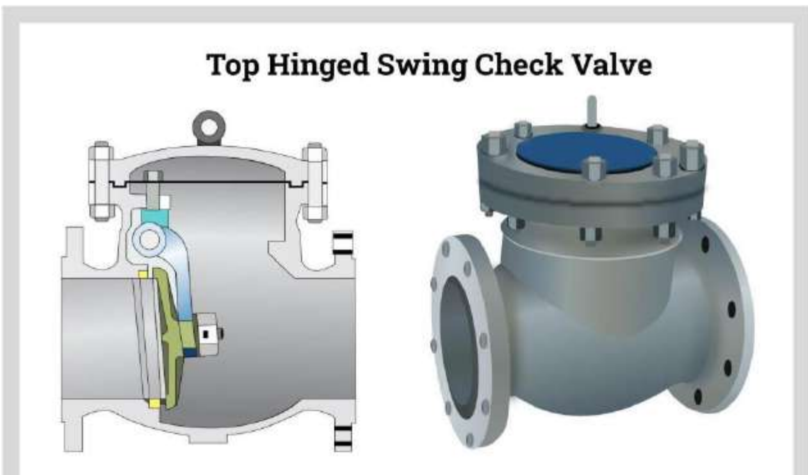

Figure (1-11): Top hinged check valve diagram.

b. <u>Tilting Disc Check Valve:</u>

It is designed in a way that allows full opening at low flow pressure and closing quickly. Using a dome-shaped disc it is loaded with spring in order to make the valve more fast. The disc in this valve floats so that the liquid flows up and down the disk surfaces.(MAX 2022)

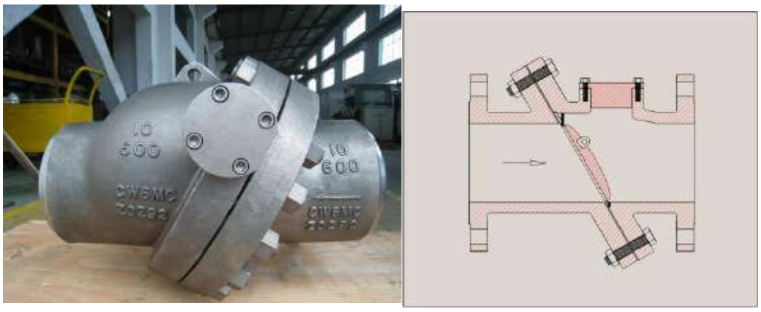

Figure (1-12): Top hinged check valve diagram.

2) Lift check valve:

The mechanism of lift check valves adopts a guided disk and arrangement of seats similar to globe valves. The disc is in the form of a piston or ball. The valve body is in three patterns (horizontal, angle and vertical) and can be installed in horizontal or vertical pipe lines, It is particularly suitable in high pressure plants and high flow speeds, and is used in high-rise buildings, power plants, water applications, etc.(MAX 2022)

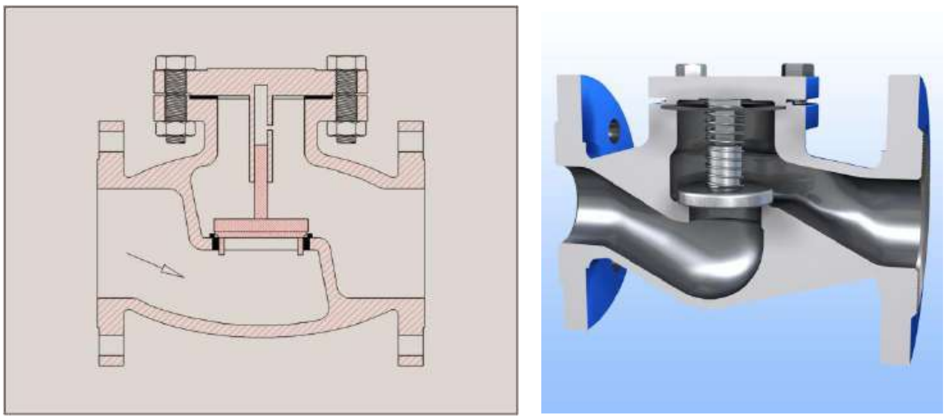

Figure (1-13): Lift check valve.

There are two types of lift check valves:

a. Piston Check Valve:

Also called a plug check valve, controls liquid flow using the linear motion of the piston inside the valve chamber. Sometimes, the piston has a spring connected, this makes it closed in non-use mode.(MAX 2022)

b. Ball Check Valve:

This type simply depends on gravity, where the valve is opened by lifting the ball up when there is sufficient pressure in the flow, and the valve closes when the pressure drops and the ball goes back down, the reverse flow is not allowed to pass.(MAX 2022)

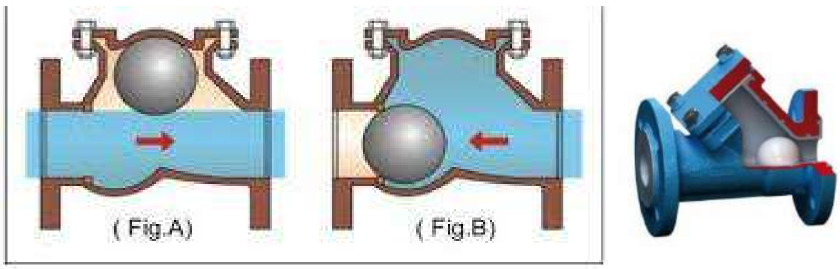

Figure (1-14): ballcheck valve.

3) Butterfly check valve:

Butterfly check valve is also called folding disc check valve or split disc check valve. The mechanism of this type depends on the movement of two halves of the disk towards the central line at the front flow, and with reverse flow two halves open and rest on the seat to close the flow. This type is suitable for liquid systems where the pressure is low, it is lightweight and the cost of its maintenance and installation is less than the rest of the valves.(MAX 2022)

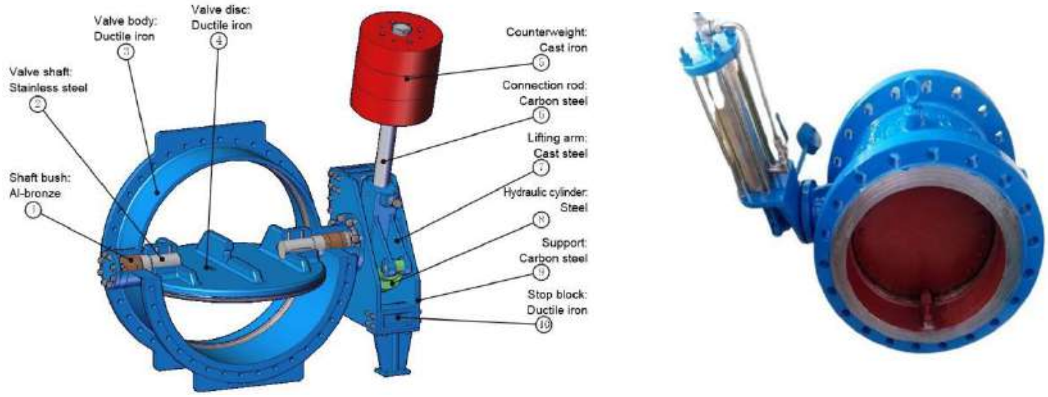

Figure (1-15): butterfly check valve and its components.

4) Stop Check Valve:

A Stop check valve is two valves built into one body, it can be used for isolation or organization purposes, it is considered to prevent back-flow. In addition, this valve has an additional external control mechanism in the vertical or angular direction. It is highly used in power plants, boiler rotation, steam generators, turbine cooling and safety systems.(MAX 2022)

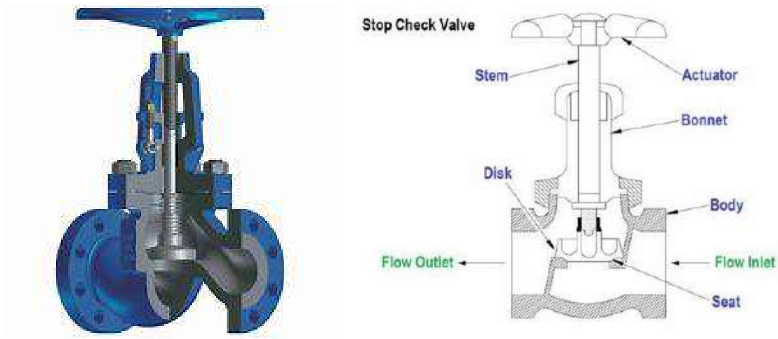

Figure (1-16): butterfly check valve and its components.

5) Dual plate check valve:

A dual plate check valve is designed with two spring-loaded plates that move towards the center of the valve to prevent the reverse flow. Dual plate check valves are commonly used in the oil and gas industry, as well as offshore applications.(Sotoodeh 2018)

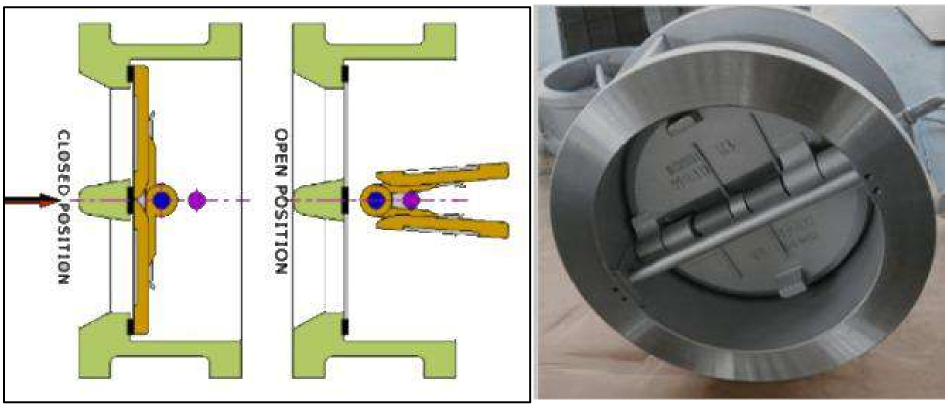

Figure (1-17): Dual check valve and its components.

Conclusion:

In this chapter we learned about the SIC in Hassi Mesoud region that we conducted in applied internship , and explained the most important details and outputs about compression and gas re-injection in Sonatrach.

We learned the most important theoretical details about the check valve and its working principle, as it prevents the reverse flow of gas and protects the plant and its equipment, this important information that will help us to conduct applied study and analyze the risk of the check valve failure.

CHAPTER 02:

Principles of conducting Hazard and Operability study (HAZOP)

Introduction:

In order to manage the risks at the compressor station in general and related to the check valve failure in particular, in order to identify potential risks, negative outcomes and appropriate preventive measures, we will use one of the most important risk assessment methods: HAZOP.

It is necessary to seek the ideal application of risk assessment methods, with a view to identifying disasters that may occur while clearly identifying their main and root causes. This requires a good and best understanding of the theoretical and practical fundamentals and mechanisms of application to simple and complex systems with the use of previous experience to overcome any errors or forget some important details.

In this chapter we will cover the most important details of HAZOP, starting with its basic concepts and conditions of application in different industrial systems, and then its methodology and stages to be followed for the success of the process, as well as the concepts and terminology of HAZOP like: guide word, deviation and parameter and its purpose, finally the advantages and limits of this method and its future.

SECTION 01:Basic notions of risk assessment

Before studying the HAZOP method of risk assessment, it is necessary to understand the key terms in risk management.

1. Hazard:

A potential nuisance that could harm property (deterioration or destruction), the environment, or people. (CEI 61508)

A hazard is a source or situation that is likely to cause injury or injury to health, damage to property and the environment of the workplace or a combination thereof.(OHSAS 18001 version 1999)

2. Risk:

The effect of uncertainty on objectives.(ISO 31001)

The combination of the probability of an event occurring and the severity of the consequences if it does occur.(INRS)

3. Safety:

The prevention of accidents, injuries, and illnesses at work. It is a state of mind that is based on the understanding of risks and the taking of steps to eliminate or reduce them.(INRS)

4. Dammage:

Damage is any physical or psychological injury that occurs as a result of an accident or incident. It can be caused by a variety of factors.(INRS)

SECTION 01: Description of HAZOP.

5. HAZOP History:

Due to increased awareness of the importance of safety and security in the fields of industry and construction, HSE specialists have developed several methodological tools to facilitate the risk assessment process and identify appropriate preventive actions efficiently. HAZOP method has been developed by Imperial Chemical Industries (ICI) during the 1970s (Frank Crawley 2015), their use was further encouraged and developed through the Association of Chemical Industries (CIA) manual published in 1977.

In 1980, the Federation of Industries Chimiques (UIC) published a French version of this method in Safety Booklet entitled "Safety Study on Fluid Flow Scheme"(Debray, Chaumette et al. 2006).

Certainly, scientists and specialists are still developing this method to facilitate its use more and ensure its effectiveness with modern industrial systems, in view of the great importance of occupational safety and its universally adopted principles.

6. Domain of application:

This method has been specially adapted to identify potential hazards and operability problems and to recommend appropriate corrective actions in industrial activities that include termo-hydraulic and chemical systems, for which parameters like flow, temperature, pressure, level, concentration... ,are especially important for the safety of the facility .(Debray, Chaumette et al. 2006)

Recently, HAZOP analysis has increased in fame globally and in various industries due to its important strategy. The main industries are:Chemical, Petro-chemical, Pharmaceutical, Refinery, Food, Oil and gas, Nuclear, Fertilizer, Power plants..ect.

7. Purposes of the method:

The various goals of the HAZOP study approach are all directed toward guaranteeing the effectiveness and safety of chemical process systems. Finding possible risks and operability issues during the project's design phase is one of the main goals.(Frank Crawley 2015)

These problems can be dealt with before they become significant ones during operation through early detection, that is, its purpose is to examine any potential deviations from the design objectives in order to determine if the plant is sufficiently safeguarded and to recommend new safeguards as needed, which can help elevate the design's quality.(Signoret and Leroy 2021)

By locating possible risks and operability issues, the HAZOP research also has the vital goal of improving the performance of the SHE system. In order to protect workers and the environment, it is essential to lower the chance of accidents and incidents occurring while operations are in progress. In order to further increase safety and efficiency, operational procedures and training programs can be created using the HAZOP research as a foundation. Overall, the HAZOP study approach is a useful tool for making sure chemical process systems are efficient and safe.(Signoret and Leroy 2021)

Due to its many uses, it is a crucial component of any project involving chemical processes because it identifies potential problems early on and offers a structured method for resolving them.(Signoret and Leroy 2021)

SECTION 02: HAZOP Study process

1. HAZOP princible:

Its main principle is to study each parameter (temperature, pressure, flow..) Systematically and accurately with a set of guide words to identify any possible deviations from the design intention that may lead to operational problems or unwanted risks and accidents in the system.(Frank Crawley 2015)

The study needs a multidisciplinary team because it is comprehensive and related to all parts of the system that includes various scientific fields such as engineering, electricity, chemistry, mechanics, etc.(Frank Crawley 2015)

This method is clear, creative and its methodological tools encourage team members to think outside the box and consider all scenarios, their causes and possible outcomes. In addition, the early identification of possible risks and operating problems will allow the identification of appropriate preventive procedures and the improvement of the system before the crisis and accidents occur.(Frank Crawley 2015)

Table (2-1): Example of HAZOP template.

Date: Line ou equipment:								
1	2	3	4	5	6	7	8	9
N°	**Guide word**	**Parameter**	**causes**	**results**	**Detection**	**Existing Security Tools**	**recommendations**	**observations**

2. Phases of HAZOP analysis:

An HAZOP study is performed in 03 phases:

1) Preparation phase:

Team members are selected from various disciplines related to the study to be conducted. After the formation of the team, the leader and the responsibilities of the members are determined and the main objectives and tools are clarified.(Tarlengco 2023)

At this phase also must collect the necessary information about the factory: upgrade of pipes and appliances, schemes (P & IDs), pipe table, safety valve classification, etc.(Signoret and Leroy 2021)

The team then divides the integrated system into homogeneous sections according to the analogy of the parameters, called parts or nodes, so that the design intention of the system can be clearly defined.(Signoret and Leroy 2021)

2) Examination Phase:

At this phase, the team begins to study the system, analyze the data and address the possible causes and consequences of deviations, according to the conduct of the study described in the figure (2-1).

3) Documentation and Follow-up Phase:

At this phase, the Hazop templates are followed up and reviewed in order to prepare the final reports of the results. Some parts of the system may be re-examined, and finally the final signature of the official documents containing details of the study and the actions to be taken and submitted to the concerned authorities.(Tarlengco 2023)

3. Conduct of HAZOP study:

The study is conducting by following the figure (2.1) and the steps described below (Debray, Chaumette et al. 2006):

1) First, choose a line or a node. It generally includes equipment and its connections, all of which perform a function in the job description process.
2) Choose an operating parameter, ex: temperature.
3) Retain a guide word, ex: more than, and study the associated deviation, ex: high temperature.
4) Verify that the deviation is credible. If so, go to 5, otherwise return to 3.
5) List and record the causes and potential consequences of this deviation.
6) List and record Safeguards or controls that may prevent the cause and for the Consequences..
7) Propose recommendations and improvements where appropriate.
8) Retain a new guide word for the same parameter and repeat the analysis in point 3.
9) When all guide words have been considered, retain a new parameter and repeat the analysis in point 2.
10) When all phases have been considered, retain a new line and repeat the analysis in point 1.

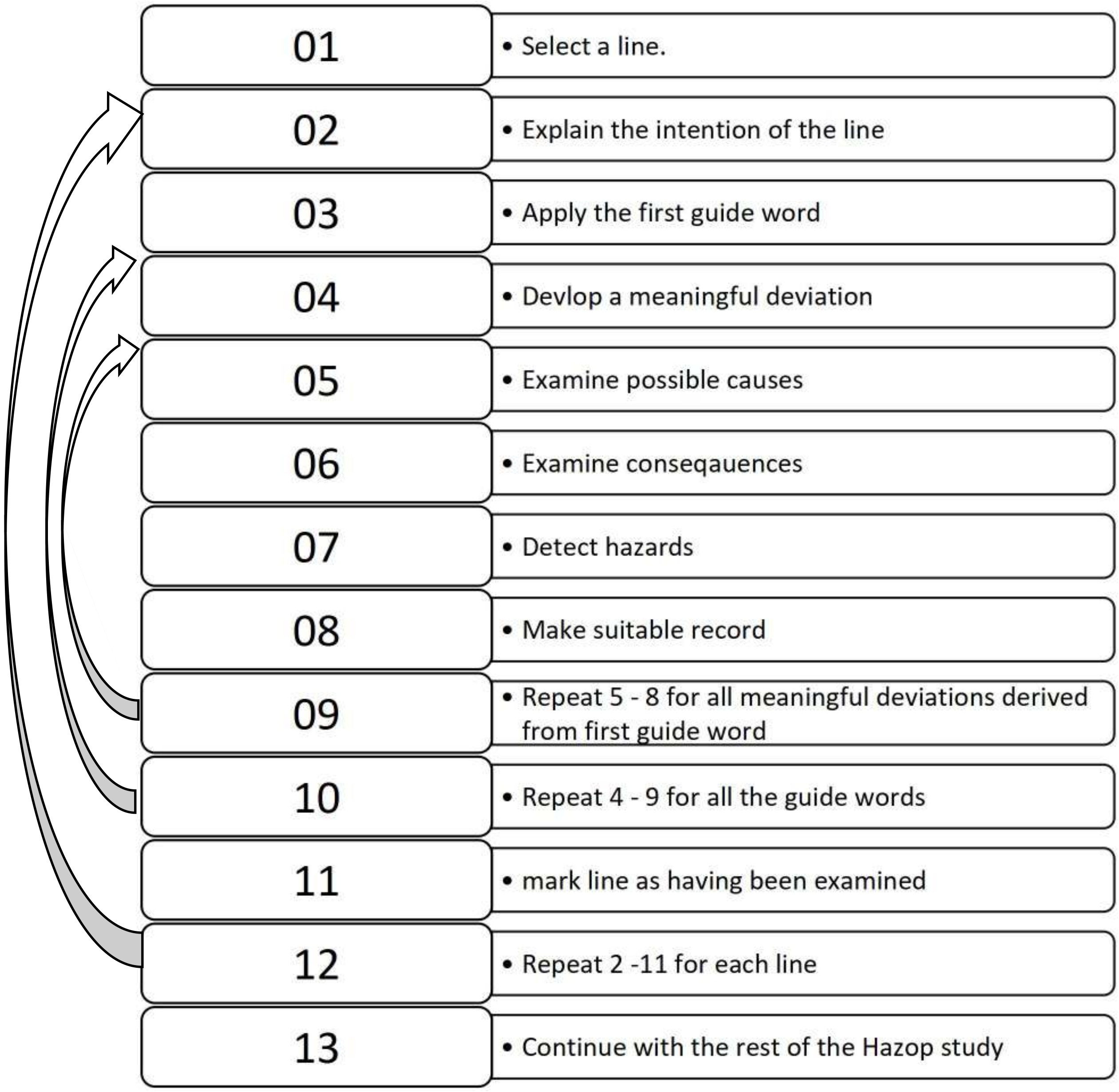

Figure (2-1): Sequence of HAZOP study.(Mannan and Lees 2005)

1) Definition of parameters and operations :

At the beginning, we must determine parameters and operations according to the study's requirements, objectives and available data.A parameter is a general term used to describe any variable, component or activity considered in the process or operation under study. Parameters can include things like flow rate, pressure, temperature, level, composition, and many others. (Frank Crawley 2015)

An operation refers to a specific task or set of tasks performed in the industrial process, Applicable operations typically include: Filling, Transferring, Purging, Emptying, Draining, Venting, Maintenance, Start-up , Shut-down..ect.(HYATT 2002)

2) Definition of guide words and deviations:

When conducting a HAZOP study, we use a set of guide words to systematically and accurately examine each parameter, where deviations from the design intention that may lead to risks and operating problems are determined by combining each parameter with the guide words that relate to them(Debray, Chaumette et al. 2006). There are many guide words and they are used according to study requirements and available data about parameters, the main purpose of which is to help the team search for all important deviations creatively and systematically(Frank Crawley 2015).

The standard set of guide words includes the following(Frank Crawley 2015):

- **No**: What if none of the parameters are under consideration?

- **More**: What if there is more teacher under consideration?

- **Less**: What if there is a little teacher under consideration?

- **Part**: What if only part of the teacher under consideration exists?

- **Vice versa**: What if the process step is reversed or sequenced?

- **Other than**: What if something else unintended happens?

- **So**: What else can happen in addition to what was intended?

The team systematically examines each parameter in combination with a set of guide words to identify potential deviations from design intent that could lead to hazards or operational problems. For example, if the parameter under consideration is temperature and the guide word is "more", the team could think about what would happen if there was more heat than expected in a certain part of the process.(Debray, Chaumette et al. 2006)

Table (2-2): Examples of deviations.(Debray, Chaumette et al. 2006)

Guide words	Parameter	Deviation
More than	Temperature	High temperature
Less than	Pressure	Low pressure
Inverse of	Flow	Return of product

3) Identifying the causes and the results of deviations:

Deviations relate to a variety of causes depending on the nature and features of the system. The team is interested in studying and examining the system profoundly to identify those direct and indirect causes. These are the most famous causes that lead to deviations and therefore to disasters and negative consequences (Frank Crawley 2015):

- Equipment failure: Such as a valve sticking open or closed.
- Human error: Such as an operator making an incorrect adjustment to a control system.
- Changes in operating conditions: Such as changes in feed-stock composition or flow rate.
- Design flaws: Such as inadequate sizing of equipment or insufficient redundancy in critical systems.
- External factors: Such as weather events or power outages.

The team identifies the expected consequences of these deviations, if these results are unacceptable and will disrupt the system, the team will determine appropriate preventive measures, recommendations and improvements for the system. These are some of the common results (Frank Crawley 2015):

- Safety hazards: Such as fires, explosions, or toxic releases.
- Environmental hazards: Such as spills or emissions.
- Quality issues: Such as off-spec products or reduced yields.
- Equipment damage: Deviations can also lead to equipment damage or failure, which can result in downtime and lost production.
- Increased costs: Deviations can also lead to increased costs due to repairs, cleanup.

4) Examination of safe-guards:

After determining the causes and consequences of deviations, the team examines and tests existing prevention measures and safeguards aimed at preventing or mitigating results and disasters resulting from these deviations, Safeguards can include things like alarms, trips, interlocks, relief valves, or emergency shutdown systems. (Frank Crawley 2015)

There are several methods to examine safeguards. One of these methods is to analyze the results while ignoring the presence of protective equipment or safe guards, with a view to identifying the worst possible results, i.e. the team has been alerted about the worst that may happen. The team then identifies security solutions and recommendations in which existing safeguards are observed and adjusted as needed. (Frank Crawley 2015)

5) Estimation of the risk:

Risk probability is estimated based on many factors such as frequency of occurrence, likelihood of failure or level of human error that may lead to deviation, Risk severity is assessed based on factors such as potential impact on safety, environment, production or quality, Through the risk matrix, high, medium and low risk is determined, This helps to prioritize safety or correction actions. (Frank Crawley 2015)

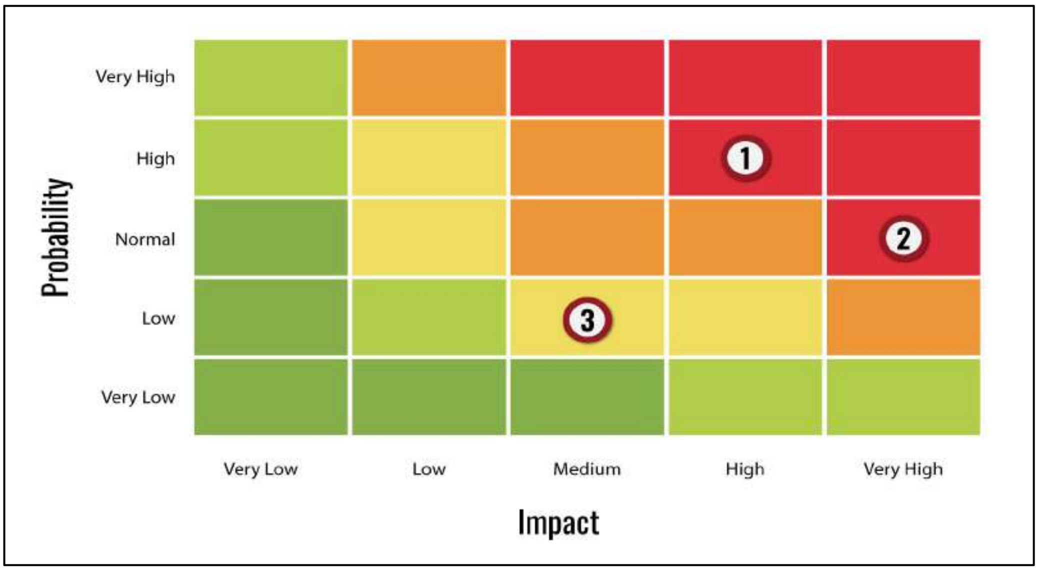

Figure (2-2): Risk matrix.

When applying risk matrix to consequences. It is recommended to evaluate the severity of the lack of safeguards so as to determine the worst that may happen, and the probability should be assessed taking into account the existence of existing safeguards.(HYATT 2002)

HAZOP basically relies on a qualitative risk study, but the team can conduct a half-quantitative study by estimating the likelihood of deviation or the severity of its consequences, which is necessary in the area of major risks, and depends on the availability of sufficient data about the system.Basically HAZOP relies on qualitative risk study, but the team can do a half-quantitative study by estimating the likelihood of deviation or the severity of its consequences, which is necessary in the field of major risks, and depends on the availability of sufficient data about the system.(Debray, Chaumette et al. 2006)

6) Recommendations for improving the system:

At the end of the study it is necessary to identify the necessary recommendations and improvements, it varies during the HAZOP study depending on the specific process being studied, but may include: changes in system design or some equipment, adjustments to operating procedures, installation of additional safeguards or protection measures, or changes in emergency response plans.(Frank Crawley 2015)

SECTION 03: HAZOP advantages and limitations

After explaining the principles and fundamentals of applying the HAZOP Study, in this section we will clarify the advantages and limitations of this method and its future, where these details must be considered and taken into account when conducting studies.

1. HAZOP advantages:

There are several advantages to risk assessment in general and using the Hazop method in particular, we find: (Dunjó, Fthenakis et al. 2010; Frank Crawley 2015)

- Early identification of potential hazards by examining each element or parameter of a process, and identifying deviations from the intended design that could lead to hazardous situations.
- Improved safety in industrial processes by recommending appropriate measures to prevent or mitigate potential hazards, reducing the risk of accidents or incidents.
- Cost-effective method for identifying potential hazards and operability problems compared to other techniques.
- Improved efficiency by recommending changes that reduce downtime or increase productivity.
- Creative and imaginative examination by innovating solutions for potential hazards or operability problems.
- Using a risk-based approach to prioritize which potential hazards or operability problems should be addressed first.

- Documentation ofthe study findings through a report detailing all the risks in the system and the recommendations for eliminating or mitigating them.

2. HAZOP Limitations:

After we have identified the most important advantages, there are limits to be considered for the HAZOP procedure to ensure the effectiveness and accuracy of the study, including: (Dunjó, Fthenakis et al. 2010)

- Limited scope: HAZOP analysis focuses on operational problems and potential risks and does not care about other aspects of human, environmental and security factors.
- Subjectivity: The study depends on the team's experience and the views of its members, i.e. the other team may detect other risks and take other actions.
- Time consumption: the study takes longer in case the system is complex and includes many equipment and production lines.
- Expensive: It's an effective method but it requires resources such as time, personnel and equipment.
- Limited effectiveness of new processes: This is because of a lack of sufficient data and information, as opposed to the old processes around which previous studies are available.

3. HAZOP future:

This method is likely to be further developed and improved by integrating with modern technology while preserving its basic principles. Some potential areas for future development include:(Frank Crawley 2015)

- Integration with digital technologies such as virtual reality, artificial intelligence and machine learning will enhance their effectiveness and facilitate their achievement in complex systems
- Expansion of new industries where safety and operability are critical concerns.
- Integration with other risk assessment methods to ensure a more comprehensive understanding of risks
- Focus on sustainability which can lead to the integration of environmental and social factors into HAZOP studies.
- Focus on human factors which may lead to a greater focus on analysis of the impact of human error or behaviour during HAZOP studies.

Conclusion:

In this chapter, we learned about the basic and theoretical principles of the HAZOP method, and we have identified its comprehensive methodology that will allow us to apply efficiently and effectively. It depends on identifying deviations from the design intention by combining the parameters of the system with the appropriate guide words, then identifying the causes, results and existing safety equipment, and finally proposing solutions and recommendations while recording and documenting all the details of the study.

It is a very effective method in assessing the risks in tirmo-hydraulic systems that involves transferring or storing fluids or treating them according to specific parameters. Its main purpose is to ensure continuity, efficiency and productivity in various industrial systems by identifying deviations, removing their causes and preventing their recurrence. This is in accordance with the approved occupational health and safety regulations.

CHAPTER 03:

Case study

based on a real system.

Introduction:

Through the theoretical part we learned about the check valve, its definition, its mechanism, its types, and other details that clarify the general importance of this equipment in a compressor system, as it protects the station, workers and the environment from disasters resulting from the risk of reverse flow.

In this part we will address the problem of the study that relates to the risks of the failure of the check valve, by conducting a HAZOP analysis and determining the causes and results of the perceived deviations, according to the specific study conditions.

<u>SECTION 01:</u> Description of study system

1. Identification of the system:

Through the incarnation scheme of the gas compressor station at the Southern Center in Hassi Messaud, we have identified the study system according to the study problem, which is the importance of the check valve in the case of reverse flow of gas.

The study will include the application of the HAZOP method of risk analysis at the system specified.

The system that we will study includes the line between the outlet of the high pressure compressor (GB 803)to the high pressure manifold.

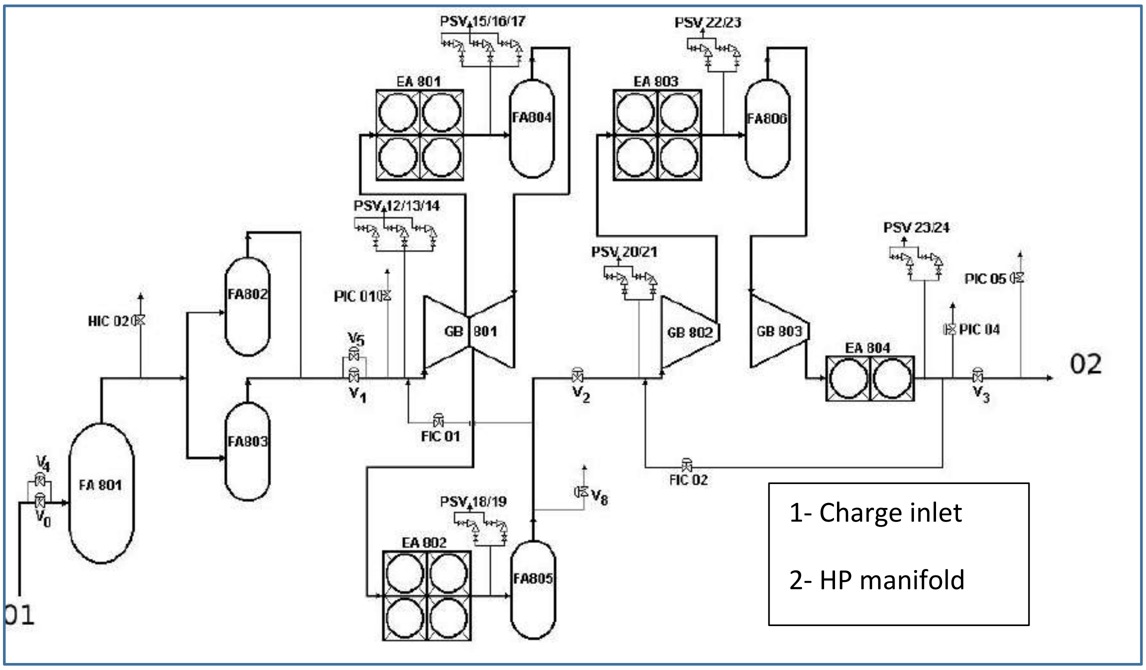

Figure (3-1): P&ID of compression station CS 04 in SIC.

2. Overview of study system process:

Our study system is the last pipe the gas passes in the station, The compressor (GB 803) increases the gas pressure to 400 bar and then the compressed gas passes through the pipe to the cooling fans (Air Cooler EA 804), Where compressed gas is cooled after warming to 95 ° C as a result of compression, After cooling passes directly to HP Manifold, this line includes a lot of automatic safety systems that monitor pressure, temperature and flow changes to ensure the stability of the system's operational values, It also includes an check valve that prevents reverse flow from the Manifold side.

Due to the high pressure value in this line, the error results will be very severe especially if the error is related to the check valve.

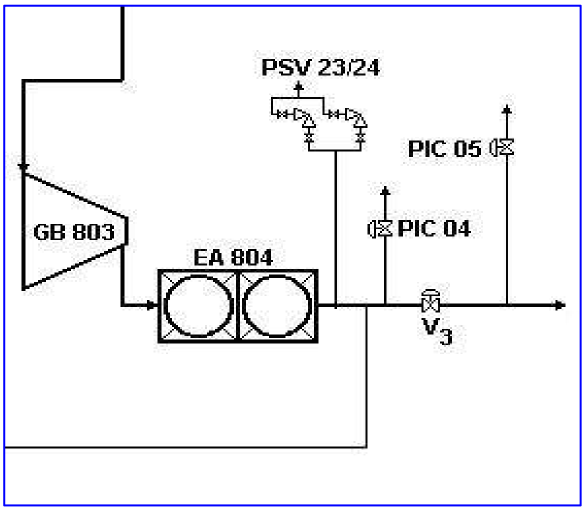

Figure (3-2): P&ID of the main study system.

3. Equipment functions:

It is necessary to determine the primary role of equipment and control system within the scope of the study, According to our internship outputs and according to the P&ID of compression station CS 04, note the first annex (Annex 01), we found this table :

Table (3-1): Table of equipment functions in study system.

Code	**Name**	**functions**
GB 803	HP compressor	It compresses the gas up to 400 bar
EA 804	Air Cooler (figure 3-3)	Decrease gas temperature to the appropriate value
TE 1-830 + TI 1-830	Temperature element + Temperature indicator	Determining the gas temperature value in the control room
PI 12 PI 113	Pressure indicator	Determining the gas pressure value in the control room
PSV 1-824 PSV 1-825	Pressure safety valve	Discharge of excess pressure exceeding safe value
PCV 1-804	Pressure control valve	Maintain pressure balance between compressor suction and discharge
ROV 1-803	Remote operated valve	Gas discharge when pressure exceeds safe values

4. Risk factors:

The worker at the pressure station is exposed to many different risks, as they must be dealt with in accordance with occupational health and safety regulations in the field:

First, gas is considered to be the most dangerous element of the plant, given the possibility of an explosive atmosphere forming in any place, and the occurrence of any leak will inevitably lead to catastrophic disasters.

Secondly, the risk of temperature that increases when compressed in the compressor and especially is very high in the aspects of the heat exchanger and torch.

Third, the noise generated by the compression process and the passage of gas is high values leading to damage in exposed workers, so it is necessary to wear the appropriate protective equipment for this condition.

In addition to the risks of fall and chemical, physical and electrical hazards that require the application of all procedures in accordance with occupational health and safety regulations to ensure the safety and security of the plant and workers.

SECTION 02: Results of HAZOP Procedure

1. Purpose of the study:

The primary purpose of applying the HAZOP method in the specified compressor system is to determine the primary role of the check valve in preventing reverse flow resulting from several different factors illustrated in the table...; and identifying the problems expected to occur if the check valve fails or the severity of the results at the entire system level.

2. The main parameter and its deviation:

The appropriate parameter for problematic study is flow, because it is the only parameter directly related to the function of the check valve, where we studied the system in case of reverse flow with the identification of direct and root causes, expected results and effects of the check valve in this case in terms of security and safety.

The HAZOP study is about processing different parameters according to the system, and the study line includes many parameters: pressure, temperature, flow.., but in order to achieve the purpose of the study and focus on the fundamental problem we processed one parameter, it’s flow.

We will study the deviation : reverse flow, monitor the behavior of the check valve in this case and the problems that will occur while identifying the direct and indirect causes of this deviation and the expected negative consequences that will include the entire station.

3. The causes of reverse flow :

Reverse flow from high pressure manifold (HP) to HP compressor can occur at the re-injection station due to several reasons. there are some possible reasons:

a) Pressure imbalance:

Large pressure imbalance between HP manifold and HP compressor leads to reverse flow. If the pressure on the manifold side exceeds the side of the compressor due to the discontinuation of the compressor operation due to maintenance, repairs or faulty monitoring systems that maintain the balance of pressure and flow.

b) Back pressure of downstream systems:

If there is a sudden or unexpected increase in pressure downstream of HP, it can create a back pressure and force the flow to reverse towards the compressor. This can be caused by malfunction or failure in downstream equipment or systems.

c) Failure of control system:

Failure or error in control system responsible for regulating flow direction can lead to reverse flow. This may be caused by a programming error, failure to sense or inappropriate configuration of control logic.

4. The action of check valve:

The check valve is the first barrier in the face of reverse flow and its prevention according to two cases:

a) First case (desired):

When the reverse flow occurs, the chack valve is closed directly, immediately and completely, which prevents the passage of gas to the compressor. The pressure increases and has a maximum value, the gas is directed towards the torch after opening the ROV 1 - 805 valve as a result of the captor's sensitivity to the high pressure value in this line.

b) Second case:

The check valve fails in the face of reverse flow, resulting in gas flow towards cooler fans and HP compressor. Finally, results are very catastrophic.

Causes of check valve failure and results explained in section II

5. The severity of results:

The severity of reverse flow results from high pressure manifold (HP) at the pressure station can vary depending on several factors. Here are some possible consequences that can occur due to reverse flow:

a) Equipment damage:

Reverse flow causes damage to equipment in the pressure station. When the flow direction is reversed, the equipment, such as compressors, can be exposed to abnormal operating conditions and increased stress. This can lead to mechanical failures, increased wear and tear, and potential damage to internal components.

b) Efficiency loss:

Reverse flow disrupts the normal flow pattern within the pressure station. This results in reduced efficiency because the equipment does not work perfectly. Inefficient operation can lead to reduced production capacity, increased power consumption, and reduced overall performance of the pressure station.

c) Safety hazards:

backflow can pose safety risks for staff working in and around the pressure station. It can lead to unexpected pressure differences, which can lead to sudden release of high-pressure liquids. Such releases can cause damage or damage to the surrounding infrastructure if appropriate safety measures are not taken.

d) Operation disorders:

Reverse flow affects the overall process served by the pressure station. It can disrupt the natural flow of fluids within the system, affecting the processes or operations of the downstream. This can reduce process efficiency, gas quality problems produced or even close the entire process if the reverse flow is severe and cannot be resolved quickly.

SECTION 03: Check valve failure description and Recommendations

In this section we will explain how to discover the failure of the check valve in the system while identifying the causes and consequences of this failure and conclude by providing appropriate recommendations for this problem.

Figure (3-3): Maintenance of the check valve in SIC plant.

1. check valves failure discovery:

In the work site inspection process, we can identify the visual signs of failure or damage in the check valve by:

First, visual inspection, and may include leaks, cracks, corrosion or visible abnormalities in the valve's body or components, so that they can be seen in the eye during the examination.

Second, Flow control, continuous monitoring of the flow through pipes will provide indications of the failure of the check valve, and sudden changes in flow and pressure will be shown through which the fault in the check valve is known.

Third, Diagnostic testing of the check valve such as ultrasonic or magnetic particle examination to detect incisions or other failures not seen by the eye, and analysis of historical data on the performance to detect technical problems that affected its quality.

Figure (3-4): Check valve failure discovery.

2. check valves failure mode:

We make sure there is a failure in the check valve and the possibility of unwanted risks and results through the following modes :

- There is cracking in the valve's body or internal components or damage.
- Spring failure or mechanism that controls the movement of the valve disc.

- Blockage or contamination of the valve.
- Leakage problem caused by erroneous installation.

3. check valves failure cause:

There are several factors leading to the failure of the check valve, including:

- Improper selection of the check valve type for the specific application and operating conditions.
- Inadequate maintenance or improper installation.
- Corrosion, erosion or chemical attack of the valve body or internal components.
- Fatigue failure.
- Blockage of the valve due to debris, foreign objectsor sediment in the process fluid.
- Excessive pressure or compressor surges.

4. check valves failure results:

The failure of the check valve will result in negative consequences, the severity of which depends on different factors related to the valve type, its mechanism, system size and operating condition, possible outcomes include:

- Equipment over-pressure in excess of 300% MAWP, which can lead to system damage or failure.
- Excessive flare loading conditions, which can result in safety hazards and environmental impacts.

- Compressor/turbine reverse rotation that can result in major mechanical damage as well as a gas release and fire.
- Loss of production due to system downtime for repairs or replacement.

5. Recommendations:

When dealing with check valve failure hazards in a compression system, it's important to consider potential risks and take appropriate measures to mitigate them. Here are some recommendations:

a) Regular Maintenance:

Implement a routine maintenance schedule to inspect, test, and replace check valves as needed. This helps identify any signs of wear, damage, or malfunctioning components before they cause hazardous situations.

b) Backup Check Valves:

Install redundant check valves in critical sections of the compression system. This provides a backup mechanism in case one check valve fails, reducing the risk of system failure and potential hazards.

c) Pressure Relief Devices:

Incorporate pressure relief devices, such as relief valves or rupture discs, to safeguard against excessive pressure buildup. These devices can activate and release pressure if a check valve fails or if there's a sudden surge in pressure, preventing catastrophic failures.

d) System Monitoring:

Utilize comprehensive monitoring systems to continuously track pressure levels, valve performance, and other relevant parameters. An automated monitoring system can detect anomalies, triggering alerts or shutdown procedures if abnormalities are detected.

e) Redundant Safety Systems:

Implement additional safety measures, such as emergency shutdown systems or interlocks, which can activate in response to check valve failures. These systems can isolate the affected section, stop the compression process, or initiate safety protocols to minimize risks.

f) Training and Awareness:

Ensure that personnel involved in operating, maintaining, and troubleshooting the compression system receive proper training on check valve functionality, hazard awareness, and emergency response procedures. Knowledgeable and vigilant operators can respond effectively to potential hazards.

g) Contingency Plans:

Develop contingency plans and emergency response protocols specific to check valve failures. These plans should include steps to mitigate hazards, isolate affected areas, and ensure the safety of personnel and the environment. Regular drills and simulations can help validate and improve these plans.

h) Compliance with Standards:

Follow relevant industry standards, codes, and regulations pertaining to compression systems and check valve installations. These standards provide guidelines for design, installation, maintenance, and safety practices to minimize hazards.

Conclusion:

At the conclusion of the check valve failure study, we stress that it is very necessary to take into account the specific recommendations to ensure that catastrophic results do not occur, as the check valve is an important component of the system and must be installed at all critical points where the reverse flow occurs.

The safety of workers and the safety of equipment in the pressure station depends on the efficiency of automatic and physical safety equipment, and the check valve is the most important of these barriers.

General conclusion

Respecting and applying occupational health and safety principles is the main strength of most successful industrial companies. These principles include the observance of all conditions that ensure the continuity of the system's functioning as required without deviations, problems and dangers.

In our case, we found that the compressor station includes several safety systems that prevent problems and ensure the safety of workers and equipment. The check valve is one of the important barriers against reverse flow that occurs as a result of pressure and flow disruption.

It is necessary to try to detect the failure of the check valve by taking specific measures such as periodic diagnosis, taking into account the causes and consequences of this failure and adhering to the recommendations, in order to ensure the quality of the check valve during the production process and prevent the negative effects of the reverse flow in case of the failure of the check valve and secure the station in general

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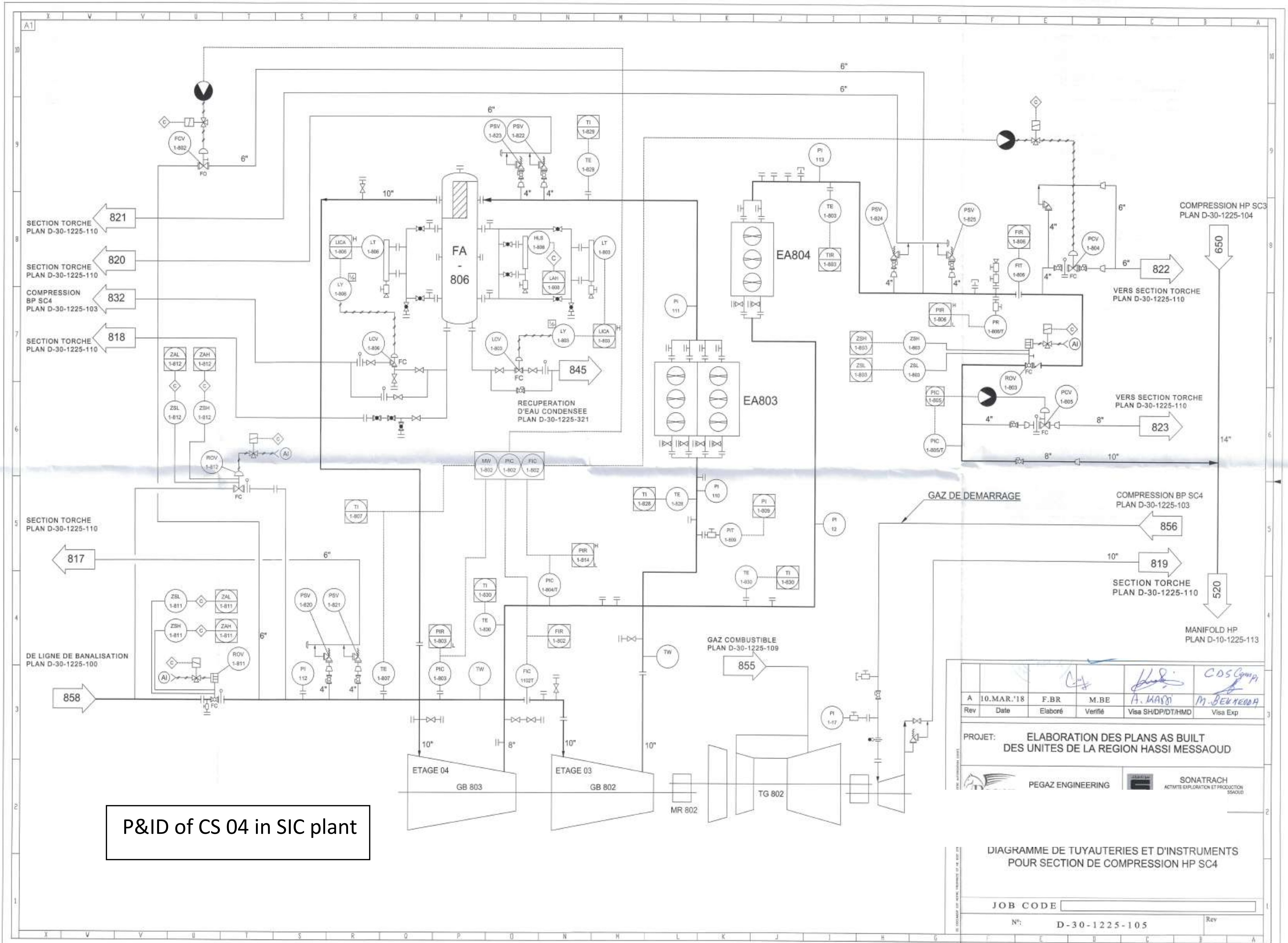
Annexes



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