# APPLICATION OF INNOVATIVE METHODOLOGY FOR RISK ASSESSMENT AND INSPECTION METHODS ON EXAMPLE OF SMALL EXPERIMENTAL BIOMASS GASIFICATION UNIT

by

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*Application of Innovative methodology for risk assessment and inspection methods is the result of a long-term work in the field of Risk-Based Inspection. As such, it was successfully applied on oil and gas facilities in the Middle East. As an example of its versatility, application will be shown on small experimental biomass gasification plant utilized for the purpose of combined heat and power generation, built in Serbia in the middle of the past decade. Throughout the analysis both active and passive damage mechanisms will be identified as well as barriers thus enabling the creation of a system that documents the dynamics of the damage mechanisms and installed barriers.*

Key words: *Risk-Based Inspection, damage mechanisms, barriers, biomass gasification*

## Introduction

Risk-Based Inspection (RBI) methodology has been developed for oil and gas industry as a risk-based, multidisciplinary, decision support process to help plant owners tackle multiple issues that span from safety, catastrophic damage prevention to inspection optimization through design of a uniquely made inspection program while in compliance with safety regulations for a specific plant/unit/piece of equipment. The RBI approach, described and postulated in document API RBI 580, has been recognized and widely accepted as good engineering practice by majority of the companies in the oil and chemical industry since its first edition in May 2002. Before the publication, document was six years in the making. Today, 20 years later, API RBI 580 [1] is in its third edition with forth edition in preparation. Even with these relatively frequent updates for an API document, RBI approach is not without deficiencies. The document itself gives a summary and describes these potential deficiencies, named therein as pitfalls, grouped by the key steps that are needed to successfully complete RBI process that can lead to less than adequate risk management results from using RBI. Furthermore, API RP 580 is not a legally binding document, nor is it imposing any legal requirements. Nevertheless, section 5.8 of API RP 580 states that legal requirements can vary form one jurisdiction another and as such mandate specific actions, in most cases inspection between intervals. Usually, jurisdictions that permit applications of API inspection codes and standards will also permit findings of the

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conducted RBI assessment. For large facilities, inspection dates will coincide with turnaround dates and thus legally required dates, for the most part. In other cases, conducting RBI reassessment will be to check and monitor previously critical points and/or points of interest, and as such those inspections will be conducted to improve safety and security of the facility and thus be overall beneficial.

Main reasons for developing the Innovative approach lie in the analysis of the pitfalls in current RBI implementations and already identified pitfalls that are listed in API RP 580 document. Understanding the relation between process conditions, barriers and damage mechanisms is key to making better assessment of the condition of the working equipment which, in turn, saves further inspection efforts and, lastly, funds. Namely, this approach reveals that both the list of damage mechanisms and their classification to active/potential are dynamic in time and will change as the equipment and barriers age or process and its parameters change. Collating thus obtained information enables the development of an inspection plan that is based not only on active damage mechanisms, but instead, includes the onset and development of other damage mechanisms in time, as well as the overall damage state of the component. Pilić *at al*. [2] describes the Innovative approach to the RBI, principles that should be applied throughout the process of damage mechanism and barrier identification. Being able to accomplish all previously stated, it is of utmost importance to successfully complete corrosion analysis, which can be done by fulfilling the following requirements:
– analysis should be based on design and operating conditions,
– applicable process upset scenarios should be stated in the documents that are usually provided by the party interested in conducting RBI/Corrosion Analysis,
– all basic modes of degradation must be considered when identifying damage mechanisms for equipment, including: internal thinning due to corrosion or erosion, external thinning due to corrosion, cracking, metallurgical changes, mechanical forces, *etc*.,
– each process unit should be broken down into Corrosion Loops (CL), and
– each CL is a practical way to describe, understand and check degradation mechanisms in a unit and consists of a group of assets (piping system and equipment) grouped together with similar process conditions, made of similar materials of construction and sharing similar corrosion/degradation threats or same active/potential damage mechanisms as per non-mandatory Appendix A of ASME PCC-3 [3] and API RP 970 [4] Annex B mainly [2].

Showcasing the versatility of Innovative methodology, its application on small experimental biomass gasification plant for combined heat and power (CHP) generation will be shown.

## Facility and process description

There are unused potentials in production of both forest and agricultural biomass in Serbia. The annual amount of biomass produced is 26.4 million tonns total [5]. From this quantity of biomass, 30-40% can be utilized for heating purposes and electricity generation. The remaining balance of biomass can be used to increase soil fertility, for vegetable production, producing animal feed and*, etc.* [5, 6]. A research study was conducted within the technological project of the Ministry of Education, Science and Technological Development of the Republic of Serbia that explores the possibilities of utilizing the remaining biomass for energy purposes. It was concluded that it is both economically and environmentally feasible to produce heat and electrical energy. The review article [7] presents the concept of a gasification plant and CHP that uses biomass as fuel, more specifically corn cob. The plant, which was under construction at the time of project finalization, was located near the industrial area of Belgrade and yet close enough to the agricultural region where corn is grown. It is estimated that about 1700 tonne per year of corn cob is available for the needs of heat and electricity production [7]. According to the same paper, and based on a review of the literature, it was found that corn cob is an ideal fuel for gas production through the gasification process, since the lower heating value of corn cob is 18.6 MJ/kg with an ash content of 1.4%.

Figure 1 depicts principal scheme of biomass gasification plant and CHP generation. From the same figure it can be concluded that experimental plant consists of several systems:
1 – System for transportation and biomass dosing.
2 – System for gasification (gasifier).
3 – System for filtration of gasification products.
4 – System for gas and air transportation.
5 – System for heat recovery
6 – System for CHP production.

Systems 1 and 6 (dosing and CHP production) will not be included in analysis since risk assessment methodology functionally does not encompass beforementioned systems (proposed system for CHP is gas engine – hence it is more subject of machinery reliability analysis than conventional risk assessment of pressure vessels). Subsequently, secondary inputs and outputs shown in fig. 1 will not be included in the analysis either since both data for materials and process conditions are not available.

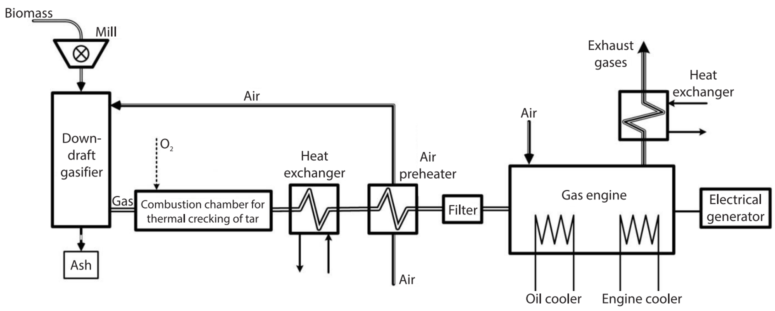


**Figure 1. Principle scheme of biomass gasification plant for CHP production, modified from [7]**

The maximum flow of biomass at the generator inlet is in the range of 140-190 kg/h while the generator is designed as a downdraft gasifier, as shown in fig. 2, as per [8]. For the purpose of this article, it will be assumed that generator is working in the continues mode. Application of this type of gasifier significantly lowers the content of tars and dust in produced syngas. The gasifier's material of construction depends on expected temperatures in individual zones of the generator [7]. According to the review article [9], for expected operating temperatures in the gasification zone of 800-900 °C, similar types of gasifiers are made from materials that withstand the required temperatures such as fireclay bricks, refractory bricks which are then addition-

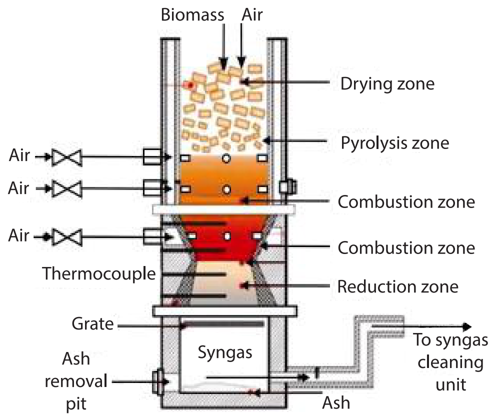


**Figure 2. Example of downdraft gasifier design [8]**

**Table 1. Gas composition (vol.% d.b.) after downdraft gasification of corncobs [7] with additional data**

| Element | vol.% | Value |
|---|---|---|
| $N_2$ | % | 48.3 |
| $CO_2$ | % | 9.5 |
| CO | % | 26.7 |
| $H_2$ | % | 13.5 |
| $CH_4$ | % | 2 |
| Additional data | Unit | Value |
| Gas production | $m^3/h$ * | 290-400 |
| Gas temperature | °C | 750 |
| Lower heating value | kJ/kg | 5500 |

* Dry raw gas at normal conditions

ally insulated with appropriate insulation material and jacketing on the outside of equipment. From the perspective of *classical* RBI analysis, a gasifier can be considered more as a civil structure then typical pressure vessel. Other parts of the generator are made of boiler steel and chrome-plated fire-resistant steel according to the expected operating temperatures [7]. Further, rest of the plant is built to meet the expected operating temperatures in individual sections of the system. Table 1 shows the composition of the syngas as well as additional data related to syngas, which are of importance for the following parts of this article.

Accordingly, any component, equipment or unit consisting of several key parts should be made of a material that can withstand high temperatures and working conditions. The groups of materials that meet process and operational requirements and are chosen by the design team are following:

– series 400 ferritic stainless steel, *i.e.*, type 446 for parts of reactor and pipelines from gasifiers to utilization boiler.
– type A106, unalloyed steel used for other parts of gasifiers and pipelines not exposed to excessive temperatures in the furnace, and
– the A179, a workhorse material for heat exchangers and parts of the pipelines in which the gas temperature is below 100 °C.

### *Material properties*

Type 446 steel is heat resistant steel that has excellent corrosion resistance in an environment with temperature higher than 550 °C and smaller loads. Due to the fact that it is also resistant to scaling at temperatures up to 1150 °C and to oxidizing sulphuric gases, it is frequently used as a construction material for fabrication of steam generators, air superheaters, fans, armature furnace, burners, gas turbines and internal combustion engines exhaust piping and other parts of thermal power plants.

The P235G1TH steel is representative steel from group A106 steels, belonging to a group of unalloyed quality steels which are resistant up to 480 °C and are suitable for use as construction material for hot water piping, steam piping, boilers and other types of pressure vessels that are operating on elevated temperatures.

The DX55D steel belongs to a group of low alloy carbon steels that are most suitable for piping construction and for construction of equipment that is not operating at higher temperatures.

Chemical compositions of previously mentioned steels are given in tab. 2.

**Table 2. Chemical composition of steels [10-12]**

| Material | C | Si | Mn | P | S | Cr | Al | Ti |
|---|---|---|---|---|---|---|---|---|
| | ≤% | ≤% | ≤% | ≤% | ≤% | ≤% | % | % |
| X10CrAlSi25 | 0.12 | 0.70-1.40 | 1.00 | 0.04 | 0.015 | 23-26 | 1.20-1.70 | – |
| P235G1TH | 0.17 | 0.10-0.35 | 0.40-0.80 | 0.04 | 0.04 | – | – | – |
| DX55D | 0.12 | 0.50 | 0.60 | 0.10 | 0.045 | – | – | 0.30 |

It should be noted that each segment of pipeline is fully insulated. Type and thickness of insulation is dependent on temperature: for the high temperature sections with gas temperature up to 800 °C ceramic and stone wool is used, for the high temperature sections with gas temperature up to 450 °C stone wool is used while for the low temperature sections with gas temperature up to 200 °C mineral wool is used. In each case jacketing is necessary.

## Damage mechanism and barrier identification

Damage mechanisms will be identified based on the parameters that influence mechanical integrity and/or reliability of the component, equipment or unit, as defined in API 584 [13], type of material used for the construction of the observed part of the system as per standard ASME PCC-3 [3], recommended practices API 571 [14] and API 970 [4]. Further, list of selected criteria per API 970's Annex B [4] and as well as defined process variables that are specific to gasification plant will also be taken into account when identifying damage mechanisms.

It should be noted, that at this stage, damage mechanisms are merely identified and classified as active or passive. If the corrosion allowance is to be calculated for the component that is subjected to corrosive atmosphere, the following article [15] and standards [16, 17] could be consulted.

### *Damage mechanism identification*

Due to relatively simple and straightforward process, CL and subsequent damage mechanisms will be mainly identified on the basis of the used material (material selection is based on operating conditions of the process). Construction materials were chosen with process conditions, mainly temperature, as driving criteria. Following analysis depicts this reasoning.

Heat resistant steel X10CrAlSi25 (UNS mark S44600 or AISI/SAE mark 446) is ferritic chromium stainless steel with aluminum in addition and belongs to a series 400 of stainless steels defined by American standardization (AISI/SAE - American Iron and Steel Institute). In combination with the process and working conditions ($t$ = 750 °C) and working fluid, following damage mechanisms have been identified:

1 – 885 °F (475 °C) Embrittlement,
2 – Brittle Fracture,
3 – Corrosion Fatigue,
4 – Corrosion Under Insulation (CUI),
5 – Creep and Stress Rupture,
6 – Erosion/Erosion – Corrosion,
7 – Oxidation,
8 – Short Term Overheating – Stress Rupture,
9 – Sigma Phase Embrittlement, and
10 – Thermal Fatigue.

Unalloyed quality steel P235G1TH (UNS mark K02501 or AISI/SAE mark A106 Grade A) belongs to a group of boiler steels which are used for construction of vessels and pipelines that are operating at elevated temperatures. In combination with the process and working conditions ($t$ = 440 °C) and working fluid, following damage mechanisms have been identified:

1 – Brittle Fracture,
2 – Corrosion Fatigue,
3 – Corrosion Under Insulation (CUI),
4 – Erosion/Erosion – Corrosion,
5 – Creep and Stress Rupture,

6 – Oxidation,
7 – Short Term Overheating – Stress Rupture, and
8 – Thermal Fatigue.

Low alloy quality carbon steel DX55D (UNS mark K01200 or AISI/SAE mark A179) belongs to a group of steels that are suitable for construction of pipelines that are not operating at elevated temperatures and where a change in the fluid phase is expected. In combination with the process and working conditions ($t$ = 80 °C) and working fluid, following damage mechanisms have been identified:
1 – Brittle Fracture,
2 – $CO_2$ Corrosion,
3 – Corrosion Under Insulation (CUI),
4 – Erosion/Erosion – Corrosion,
5 – Thermal Fatigue, and
6 – Thermal Shock.

For the refractory materials, the following damage mechanisms have been identified:
1 – Refractory Degradation and
2 – Thermal Shock.

Overview of all identified damage mechanisms, materials and conditions considered are shown in tab. 3. Conditions under which damage mechanisms occur are given in the following text and as such are fully taken from the referenced literature with factors only relevant to gasification unit.

**Table 3. Overview table of damage mechanisms**

| Section | Material | Temperature [°C] | Fluid speed [ms$^{-1}$] | 885 °F Embrittlement | Brittle Fracture | $CO_2$ Corrosion | Corrosion Fatigue | CUI | Creep and Stress Rupture | Erosion/Erosion – Corrosion | Refractory Degradation | Oxidation | Short Term Overheating – Stress Rupture | Sigma Phase Embrittlement | Thermal Fatigue | Thermal Shock |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Section 1 | X10CrAl-Si25 | 750 | 11.4 | x* | (x)** | | x | (x) | x | x | | x | (x) | x | x | |
| Section 2 | P235G1TH | 440 | 16.6 | | (x) | | x | x | x | x | | x | (x) | | x | |
| Section 3 | DX55D | ~80 | 19 | | (x) | (x) | | x | | x | | | | | (x) | x |
| Refractory | | ~850 | – | | | | | | | | x | | | | | x |

*$x$ - active damage mechanism and **($x$) - potential damage mechanism

*885 °F (475°C) embrittlement* [13]: 885 °F (475 °C) embrittlement is a loss of ductility and fracture toughness due to a metallurgical change that can occur in stainless steels containing a ferrite phase as the result of exposure in the temperature range 600 °F to 1000 °F (315-540 °C). The embrittlement can lead to cracking failure.

Affected materials: 400 series SS (*e.g.*, 405, 409, 410, 410S, 430, and 446).

Critical factors:

– The high er chromium ferritic stainless steels [*e.g.*, 430 (16-18% Cr) and 446 (23-27% Cr)] and duplex stainless steels (22-25% Cr) are much more susceptible.

– High temperature exposure is required for embrittlement. A primary consideration is operating time at temperature within the critical temperature range. Damage is cumulative and results from the formation of an embrittling ordered metallic phase that occurs most readily at approximately 885 °F (475 °C).

*Brittle Fracture* [13]: Brittle fracture is the sudden rapid fracture under stress (residual or applied) where the material exhibits little or no evidence of ductility or plastic deformation. Although rare in refining operations, in-service brittle fracture of a pressure vessel or other pressurized equipment can have serious consequences.

Affected materials: Carbon steels and low alloy steels are of prime concern, particularly older steels. 400 series SS are also susceptible even if not embrittled.

Critical factors:

– Susceptibility of a material to brittle fracture may be increased by the presence of embrittling phases.
– The heat treatment condition of the material can affect its fracture toughness.
– Thicker material sections have an inherently lower resistance to brittle fracture due to the nature of the stress state within a thick section of metal.

*$CO_2$ Corrosion* [13]*:* $CO_2$ corrosion results when $CO_2$ dissolves in water to form carbonic acid ($H_2CO_3$). The acid may lower the pH, and sufficient quantities may promote general corrosion and/or pitting corrosion of carbon steel.

Affected materials: Carbon steel and low alloy steels are affected. Increasing the level of chromium in steels offers no major improvement in resistance until a minimum of 12% Cr is reached,

Critical factors:

– Liquid water must be present for $CO_2$ corrosion occur. Beyond that, the partial pressure of $CO_2$, pH, temperature, oxygen contamination, and velocity are critical factors.
– Corrosion occurs in the liquid water phase, often at locations where $CO_2$ condenses from the vapor phase.
– Oxygen can accelerate corrosion rates.

*Corrosion Fatigue* [13]*:* A form of fatigue cracking in which cracks develop under the combined effects of cyclic loading and corrosion. The number of fatigue stress cycles to failure is reduced in a corrosive environment as compared to the number of cycles to failure in the absence of a corrosive environment. Cracking often initiates at a stress concentration such as a pit in the surface. Cracking can initiate at multiple sites.

Affected materials: All metals and alloys.

Critical factors:

– The critical factors are the same as those associated with mechanical fatigue, *i.e.*, cyclic stress level, number and frequency of stress cycles, stress concentration, and material properties, along with the addition of the nature of the corrosive environment.
– Although corrosion fatigue can occur in the absence of visible or obvious corrosion on the metal surface, in practice, cracking is more likely to occur in environments that promote pitting or localized corrosion.
– Corrosion fatigue cracking can result from either mechanically induced cyclic stresses or thermally induced cyclic stresses.

*Corrosion Under Insulation (CUI)* [13]*:* Corrosion of piping, pressure vessels, and structural components resulting from water trapped under insulation or fireproofing.

Affected materials: Carbon steel, low alloy steels, 300 series SS, 400 series SS, and duplex stainless steels

Critical factors:
– Temperature, duration of wetting, design of the insulation system, insulation type, and environment are critical factors.
– The extent of CUI attack depends on the total amount of time the equipment remains wet from exposure to wet insulation.
– Cyclic thermal operation or intermittent service can increase corrosion.
– Plants located in areas with high annual rainfall or warmer marine locations are more prone to CUI than plants located in cool and dry or warm and dry locations.

*Creep and Stress Rupture* [13]: At high temperatures metal components can continuously deform under load, even below their elastic yield stress. Exposure to stress at high temperatures initially promotes void formation at grain boundary triple points, which with time grow to form fissures and, later, cracks. As fissures and cracks coalesce, failure can occur, although the gross deformation associated with tensile overloading is not observed.

Affected materials: All metals and alloys.

Critical factors:
– The rate of creep deformation (creep rate or strain rate) is a function of the material, applied stress, and temperature.
– Creep cracking, once initiated, can progress rapidly.
– Increased stress due to loss in thickness from corrosion will reduce time to creep failure.

*Erosion/Erosion – Corrosion* [13]: This subject covers a wide range of situations of material loss, from flowing solid particles alone or in a liquid or vapor stream physically abrading the material to material loss accelerated by the flow of corrosive liquid or vapor possibly combined with the velocity-assisted removal of a protective film or scale.

Erosion-corrosion is a description for the damage that occurs when particle erosion and/or high flow velocity contributes to corrosion by removing protective films or scales or otherwise accelerating the corrosion rate. This is also called velocity-assisted corrosion.

Affected materials: All metals, but mostly carbon steel and copper alloys in refining. Refractories are also affected. Most commonly affected are materials without true passivity, where the corrosion rate is limited by a protective corrosion layer or inhibitive film.

Critical factors:
– With solid particle mechanical erosion, metal loss rates will depend on the velocity and number of impacting particles, as well as the size, shape, hardness, and density of the impacting particles, the hardness of the material subject to erosion, and the angle of impact.
– For corrosive liquid droplets entrained in a vapor, metal loss rates will depend on the velocity and number or rate of impacting droplets and the corrosivity of the liquid.

*Refractory Degradation* [13]: Both thermally insulating and erosion-resistant refractories are susceptible to various forms of mechanical damage (cracking, spalling, and erosion) as well as corrosion due to oxidation, sulfidation, and other high temperature mechanisms. High skin temperatures on the base metal being protected may result from refractory damage.

Affected materials: Refractory materials include insulating ceramic fibers, castables, refractory brick, and plastic refractories. All 300 series SS, 400 series SS, and nickel-based alloys also oxidize to varying degrees, depending on composition and temperature.

Critical factors:
– Refractory lined equipment should be designed to handle the erosion, thermal shock, and thermal expansion be encountered in service.
– Refractory type and density need to be selected to resist abrasion and erosion based on service requirements.

– Coke deposits may develop behind refractory and promote cracking and deterioration.
– Refractories can suffer vibration damage.
– Refractories can be damaged by exposure to moisture.

*Oxidation* [13]: Oxygen, most often present as a component of air (approximately 21%), reacts with carbon steel and other alloys at high temperature, converting the metal to oxide scale and thereby reducing the metal wall thickness.

Affected materials: All iron-based materials including carbon steel and low alloy steels, both cast and wrought, are affected. All 300 series SS, 400 series SS, and nickel-based alloys also oxidize to varying degrees, depending on composition and temperature.

Critical factors:
– The primary factors affecting high temperature oxidation are metal temperature and alloy composition.

*Short Term Overheating – Stress Rupture* [13]: Permanent deformation occurring at very high temperatures and typically relatively low stress levels as a result of localized overheating. It typically will result in bulging and eventual failure by stress rupture. If the temperature is high enough, failure will occur very quickly by tensile overload, since tensile strengths drop off dramatically at very high temperatures. At less severe temperatures, short-term creep failure will occur.

Affected materials: All fired heater tube and boiler tube materials and common materials of construction.

Critical factors:
– Temperature, time, and stress are the critical factors.
– The local overheating is well above the design temperature.
– Previous loss in thickness due to corrosion will reduce time to failure due to the increased stress on the remaining thickness.

*Sigma Phase Embrittlement* [13]: Formation of a metallurgical phase known as sigma phase in some stainless steels when they are heated above about 540 °C can result in a loss of ductility and fracture toughness. The embrittlement can lead to cracking failure.

Affected materials: The 400 series SS and other ferritic and martensitic stainless steel with >17% Cr are also susceptible (*e.g.*, Types 430 and 440).

Critical factors:
– Alloy composition, temperature, and time at temperature are the critical factors.
– Sigma phase forms in ferritic (Fe-Cr), martensitic (Fe-Cr), austenitic (Fe-Cr-Ni), and duplex stainless steels when exposed to temperatures in the range of 540-925 °C. Embrittlement can result by holding within or cooling through the transformation temperature range.

*Thermal Fatigue* [13]: Thermal fatigue is the result of cyclic stresses caused by variations in temperature. Damage is in the form of cracking that may occur anywhere in a metallic component where relative movement or differential expansion is constrained during repeated thermal cycling

Affected materials: All materials of construction.

Critical factors:
– Key factors affecting thermal fatigue are the magnitude of the temperature swing and the frequency [number of thermal cycles per second (or minute or day, *etc.*)].
– Since there are many variables that can affect where and whether thermal fatigue cracking will occur, it is not possible to define a specific, universal limit on allowable temperature swings. For example, rigid attachments may only require a relatively small temperature differential to promote cracking. However, as a reasonable rule of thumb, cracking may be suspected if the temperature swings exceed about 110-165°C.

*Thermal Shock* [13]*:* Thermal shock cracking can occur when high and non-uniform thermal stresses develop in a single event over a short time in a piece of equipment due to differential expansion or contraction. If the thermal expansion/contraction is restrained, stresses above the yield strength of the material can result. Thermal shock cracking usually occurs when a much colder liquid contacts a much warmer metal surface. In refining, the concern generally arises after a large equipment fire is extinguished using fire water.

Affected materials: All metal and alloys.

Critical factors:

– The magnitude of the temperature differential and the coefficient of thermal expansion of the material determine the magnitude of the stress.
– Stainless steels have higher coefficients of thermal expansion than carbon and alloy steels or nickel-based alloys and are more likely to see higher stresses.
– It is more prevalent in thick sections that can develop high thermal gradients.

### *Barrier identification*

During the analysis, a few critical observations have been made:

– Selection of 446 ferritic steel is questionable in regards to recommendations made to avoid its use in pressurized equipment due to embrittlement issues, as mentioned in [18, 19].
– Due to process requirements dictated by operating temperature needed for dry particle filtration, there is possibility, however slight, for the condensation to form. This, coupled with presence of $CO_2$ and oxygen in the gas can led to accelerated and localized corrosion.
– It is uncertain whether the insulated equipment and piping have been coated under insulation. Application of *e. g.*, TSA (thermally sprayed aluminum) can restrict or significantly reduce impact of Corrosion Under Insulation (CUI) [20, 21]. Table 2 in [22] lists protective coating systems typically used for carbon steel equipment.

Barriers are identified, per [2], as a measure, either introduced subsequently or as integral part of the design, that restricts, reduces or preferably eliminates damage mechanism. Table 4 shows proposed barriers.

**Table 4. Proposed barriers**

| Section | Material | Barriers |
|---|---|---|
| Section 1 | X10CrAlSi25 | Design, material selection, corrosion allowance, temperature control, pressure control |
| Section 2 | P235G1TH | Material selection, corrosion allowance, temperature control, pressure control |
| Section 3 | DX55D | Material selection, corrosion allowance, temperature control, pressure control |
| Refractory | | Temperature control, flow control, inspection |

## Conclusion

In a currently well established and accepted RBI approach, reassessment and re-evaluation of the process is required periodically in the full extent. Innovative approach to an RBI analysis categorizes component/equipment/unit in such a way that damage mechanisms identified as active, and supposedly negated and/or mitigated by introduction of a suitable barriers, are not overlooked, which offers more consistent approach to reassessment and re-evaluation. Additionally, by identifying and documenting passive/potential damage mechanisms, it is achieved that they are also not overlooked. Passive/potential damage mechanisms identification in same cases can be crucial factor in keeping and ensuring that system is running in a safe way by taking into account the degradation or failure of the barriers thus enabling the creation of a system that documents the dynamics of the damage mechanisms and installed barriers.

Presented analysis and observations could be used as guidelines for further considerations regarding the materials selection and barrier introduction, which can be the subject of further research.

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