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Cost savings achievable through application of risk based inspection philosophies

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ABSTRACT : The development of South African legislation concerning the inspection of boilers and pressure vessels is briefly reviewed in order to present an understanding of current prescriptive time--based inspection requirements. The alternative philosophy of Risk Based Inspection (RBI) is explained and the potential benefits in terms of increased equipment integrity and reduced cost is demonstrated.
A case study on hydrogenation reactor is presented where a saying of millions of Rands in catalysts costs was achieved by extending the shutdown frequency of the reactor based upon the results of a comprehensive RBI study. The dominant potential damage mechanisms were found to be internal corrosion by light organic acids in the catalyst dump nozzles and the outlet nozzle both of which could be monitored using non-intrusive ultrasonic "C-scan" - techniques to map accurately wall thinning.

1. INTRODUCTION

The harnessing of steam power in the 18th century was one of the major initiating events of the Industrial Revolution and whilst the resulting benefits for mankind are indisputably, there was unfortunate, also a penalty to pay in terms of the serious injuries and deaths caused by numerous steam boiler explosions. The need to address satisfactorily the safety aspects eventually led to the development of boiler and pressure vessel design codes early in the 20th century, and to the introduction of legislation to govern the manufacture, testing and maintenance of boilers and pressure vessels design codes early in the 20th century, and to the introduction of legislation to govern the manufacture, testing, inspection and maintenance of boilers and pressure vessels.

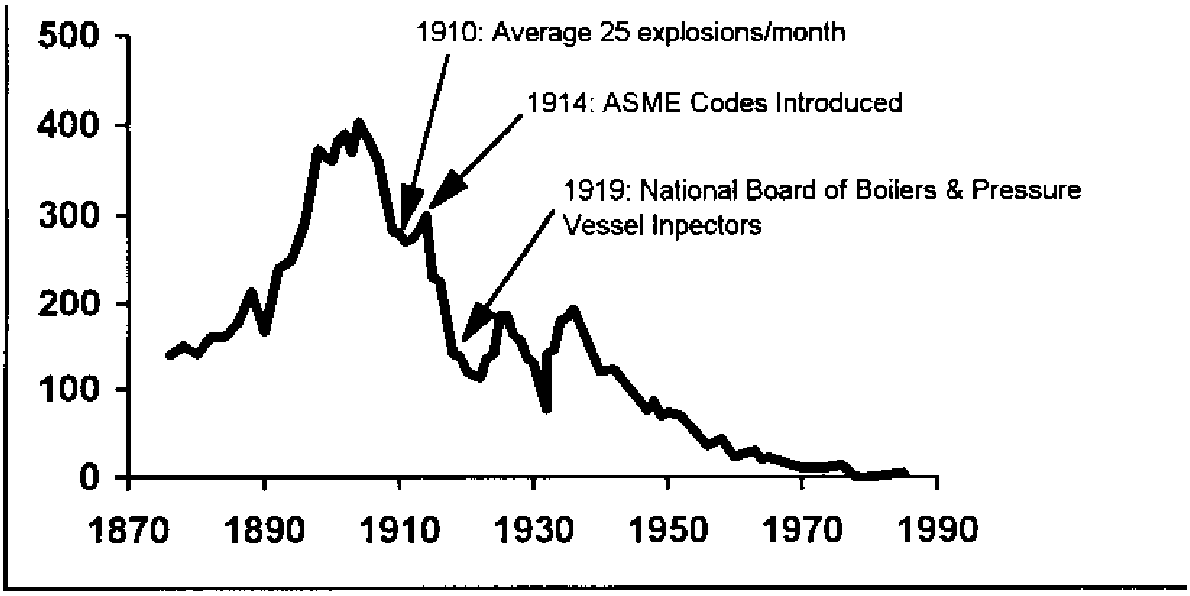

Figure 1 - Boiler explosions in the USA (Cross, 1990)

Statistical data concerning the instances of boiler explosions in the United States over the I00 year period from 1880 to 1980 dramatically illustrates the success that such measures have had in almost eliminating such incidents by the end of the century (Fig. I990).

Regrettably, no similar statistics are available for South Africa, but the development of South African statutory legislation Governing vessels under pressure is summarised in TABLE 1.
The first recorded boiler explosion at Langlaagte in 1896 during the development of the Witwatersrand gold fields eventually led to the promulgation of the first Mines &, Works Act in 1911 in South Africa.
During the next 80 years relatively little development took place in terms of inspection and test requirements other than slight variations in the prescribed intervals between hydrostatic pressure testing and the internal and external inspections, and to min modifications to the prescribed test pressure. These inspection intervals were determined in a fairly arbitrary manner, based up what appeared to be engineering "judgement" at the time, and inevitable tend towards conservatism.

Table 1. Development of South African Legislation for Vessels under Pressure

1896	FIRST RECORDED BOILER EXPLOSION - LANGLAAGTE
1911	FIRST MINING ACT PASSED - APPOINTMENT OF COMPETENT PERSON TO CARE FOR BOILERS & PRESSURE VESSELS - HYDRAULIC TEST TO ENSURE PRESSURE RETENTION CAPABILITY - DEPT. OF MINES GIVEN AUTHORITY TO OVERSEE ALL BOILERS & PRESSURE VESSELS – INCLU FACTORIES
1926	REQUIAREMENTS INTRODUCED FOR CALCULATIONS TO PROVE VESSELS STRONG ENOUGH TO W OPERATING CONDITIONS
1939	STANDARDS DEVELOPED FOR MATERIALS CONTRUCTION, FATIGUE LOADING ETC. REQUIRED P BOILERS & PRESSURE VESSELS MANUFACTURED UNDER SUPERVISION OF INSPECTION AUTHORI
1941	SIGNATORY TO I.L.O. CONCENTION FACTORIES MACHINERY & BUILDING - BOILERS - INSPECTED & TESTED – 30 MONTHS - PRESSURE VESSEL - INSPECTED - 2 YEARS -TESTED - 4 YEARS
1956	MINES & WORKS ACT (ACT NO 27 OF 1956) - BOILERS - INSPECTED & TESTED – 15 MONTHS - PRESSURE VESSELS - - INSPECTED - 1 YEAR - TESTED - 2 YEARS
1983	MACHINERY & OCCUPATIONAL SAFETY ACT (MOSACT) (ACT NO 6 OF 1983) – BOILERS & PRESSURE VESSELS - INSPECTED & TESTED - 36 MONTHS SUPERSEDES FACTORIES ACT
1991	MINERALS ACT (ACT 50 OF 1991) - MINES & WORKS ACT REGULATIONS OF 1956 RETAINED SUPERSEDES MINES & WORKS ACT
1993	OCCUPATIONAL HEALTH AND SAFETY ACT (OHSACT) (ACT NO 85 OF 1993) (SUPERSEDES MOSACT) VESSELS UNDER PRESSURE - SIMILAR TO 1992 REGULATIONS BUT MUCH GREATER DEGREE OF "SELF REGULATION"
1996	MINE HEALTH & SAFETY ACT (ACT NO 29 OF 1996) - BOILER & PRESSURE VESSEL REGULATIONS UNCHANGED SUPPLEMENTS MINERALS ACT

The cost of conforming to the prescribed regulations can be considerable for a large integrated plant where a total shutdown of several days may be required. It is thus not uncommon to find that exemptions are granted by the relevant Regulatory Authority to extend the inspection intervals in specific cases provided that certain specified alternative measures are implemented and that personnel safety is not compromised
The modem trend world-wide is tending towards less prescriptive legislation, with a greater onus being placed on the plant operator to demonstrate satisfactory measures for ensuring plant safety. South African legislation in this respect has not yet released its hold on the prescriptive requirements, but there are encouraging signs of a greater degree of self-regulation evident in the 1996 Vessels Under Pressure Regulations of the OHS Act.

2. RISK BASED INSPECTION

The climate in South Africa is thus Favourable for reviewing the philosophy behind the historical approach to equipment integrity and to seek a more rational means of improving plant safety in a more economical manner.
Risk Based Inspection (RBI) is a process which compromises an assessment of in-, hazards and risks involved with each piece of process equipment in a plant, leading to the development of air appropriate inspection frequency and extent', and other risk-reducing actions. Risk levels are prioritised in a systematic manner so that an inspection programme can be planned that focuses more resources on higher risk equipment while possibly saving inspection

resources that are not doing an effective job of reducing risk. The philosophy was originally developed by the U.K. Atomic Energy Authority during, the 1960's to facilitate a more precise evaluation of potential risk of failure in the nuclear industry. During the last decade RBI concepts have been increasingly applied to structure targeted inspection programmes in the oil and petrochemical industries in addition to the nuclear industry, principally in Europe, Scandinavia and the USA, but also in many, other oil-producing countries.

The detailed methodology of the process is published elsewhere (Renolds 1995, 1996, 1997), (Geenen 1996). (API 1997) but in broad terms the assessments may be carried out in a relatively, simple qualitative manner or in a highly detailed quantitative manner. Qualitative risk assessment allows for a relatively, quick overview to rank plant equipment on the basis of likelihood of failure and consequences of failure which are then presented in a risk matrix to identify clearly the priorities. The heart of such an assessment is the HAZOP study. originally developed for the Chemical Industry as a simple, systematic & comprehensive examination of plant design aimed at identifying potential HAZARD & OPERABILITY problems. A multidisciplinary team is used including Inspection, Maintenance, Production, Process, Metallurgy and Mechanical Design to consider all relevant technical data in a highly structured manner, The aim is to identify all potential failure mechanisms acting on each component or node of equipment and to assign LIKELIHOOD & SEVERITY categories. The quantitative approach involves detailed assessments of the likelihood and consequences of failure of each plant item, where failure comprises small, medium or large loss of containment, or complete rupture. Likelihood of failure is evaluated from generic equipment failure frequency data when available, modified to take account of equipment age, condition, complexity, process conditions, modes of degradation and rates of deterioration etc. The consequence of failure is determined from an estimation of potential inventor, release, hazard rating, and environmental damage and business interruptions. (Cushnaghan 1997)

Using this method, the likelihood and consequence ratings can be used to optimise the scope and frequency of inspection and the inspection technique can be determined on the basis of the predicted damage mechanism. For example, it would be inappropriate to specify, external magnetic particle testing of welds if the most credible failure mechanism is wall thinning by internal corrosion! This usually results in a reduced inspection time during shutdowns since the inspection programme can be specifically targeted at the predicted problem areas, while the interval between inspections can often safely be increased, leading to greater plant availability.

This approach also lends itself to the active consideration of non-intrusive inspection techniques to detect and monitor predicted damage mechanisms, since the probable nature and location of the damage can be defined. This can result in significant cost saving since it obviates the need for full personnel access with the attendant requirements for vessel isolation, purging, scaffolding, insulation removal and vessel entry, preparations and obviously reduces the potential safety hazard to the inspector.

The philosophy, of RBI and some of the attendant cost savings is perhaps best illustrated by reference to a case study which follows.

3. RBI CASE STUDY - HYDROGENATOR

In the hydrogenation section of the alcohol recovery unit at Mossgas, aldehydes and ketones are converted with hydrogen to the corresponding alcohols. The hydrogenation reaction is carried out in the vapour phase in a fixed bed hydrogenator with a nickel-based catalyst (Fig. 2).

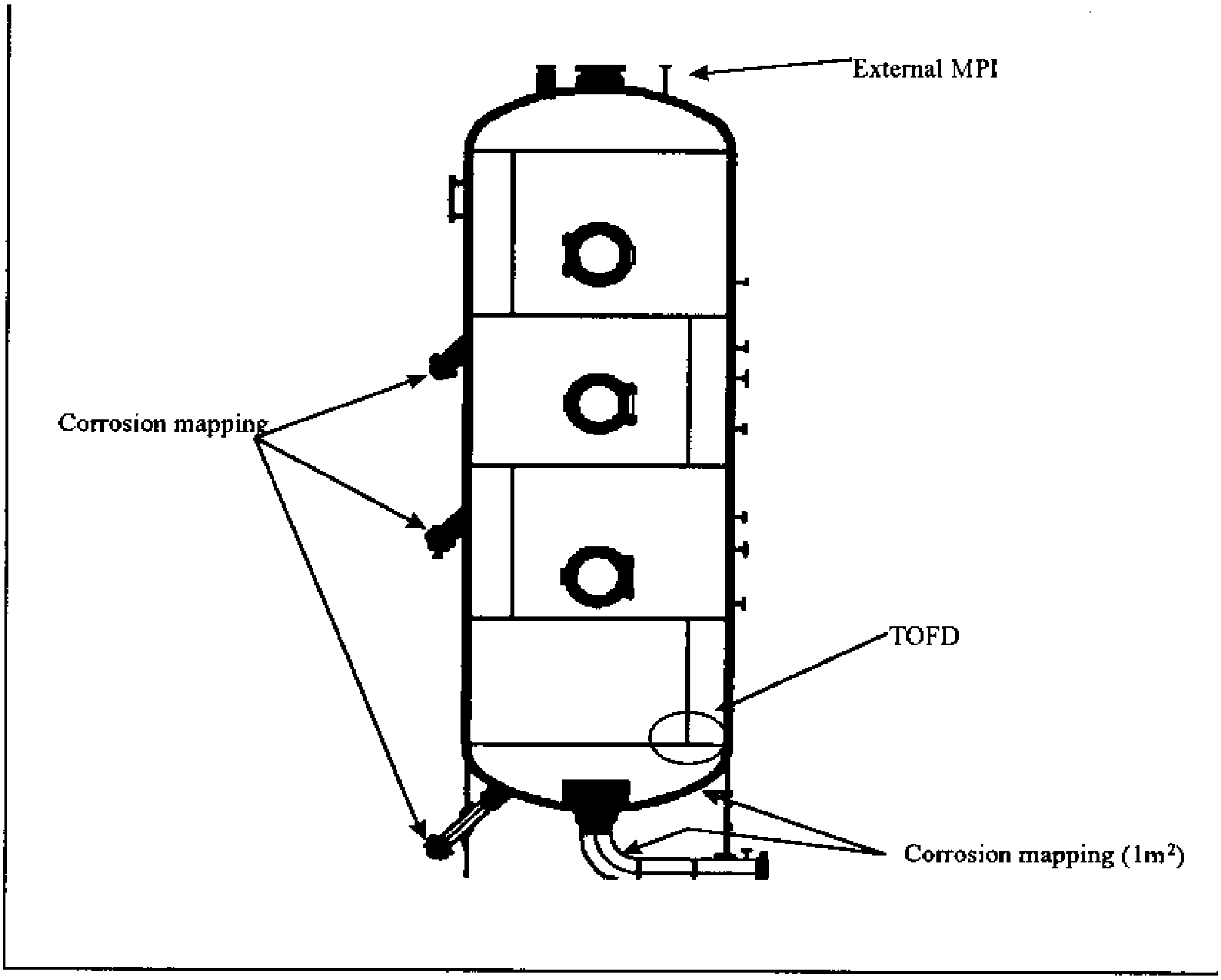

Figure 2 - Corrosion survey on hydrogenator 16-VR101.

The hydrogenator had been granted exemption in terms of regulation 3.15.1 of the Mines & Works Act from the provisions of regulations 23.12. 1.(b) (inspection) and 23.12.3.(c) (testing). The exemption was due to expire in October 1996 which would have meant opening up the vessel for internal inspection and testing with the consequential loss of millions of Rands worth of perfectly, good catalyst.

A comprehensive RBI study was therefore undertaken in order to present a responsible arid defensible justification for continued exemption.
The damage mechanisms arid structural features considered in the HA-ZOP studs, are shown in TABLE?

Table 2 Damage mechanisms and structural features considered in the Hazop study

DAMAGE MECHANISMS	STRUCTURAL FEATURES
Internal corrosion	Vessel plate
External corrosion	Vessel welds
Cavitation	Catalyst support grid
Fatique (thermal, mechanical, etc.)	Inlet nozzle (CI)
Embrittlement	Outlet Nozzle (C2)
Hydrogen damage (embrittlement, HIC, SOHIC, etc)	Vapour quench nozzles (C3,C4)
Fluid hammer	Catalyst dump nozzles (C5, C6,C7)
Ductile failure	Manhole nozzle (E1,E2,E3)
Brittle fracture	Thermocouple nozzles (E1,E2,E3)
Mechanical damage	Impingement plate
Erosion	Support rings
	Skirt-to-vessel weld

The risk profile derived during the HAZOP study shown in figs. 3 & 4

	Minor (4)	Marginal (3)	Critical (2)	Catastrophic (1)
High (1)	Int Cor IP/n			
Medium (2)	Int Cor VP/n Int Cor VW/n Int Cor CSG/n Int Cor ONO/n Int Cor VQN/n Int Cor CDN/n Int Cor MHN/n Int Cor TCN/n			
Low (3)	Int Cor CSG/n Int Cor INO/n Int Cor SR/n	Int Cor VP/l Int Cor VW/l Int Cor VQN/l Int Cor MHN/l Int Cor TCN/l		
Negligible (4)	Int Cor VP/n Int Cor VW/n Int Cor CDN/n Int Cor MHN/n	Int Cor INO/l		

Figure 3 - Hydrogenator 16-VR101 HAZOP results for internal corrosion.

The dominant damage mechanism was found to be internal corrosion by light organic acids, with the greatest risks being leaks due to internal corrosion of the catalyst dump nozzles and the outlet nozzle at the bottom of the vessel. The catalyst dump nozzles are not lagged, and could thus lead to localized internal corrosion through condensation and accumulation of organic acids and water/CO2 at the low point of these nozzles. Ale severity of a leak in this region would be critical

	Minor (4)	Marginal (3)	Critical (2)	Catastrophic (1)
High (1)				
Medium (2)	Fat INO/n FAT IP/n Ext Cor SVW/n			
Low (3)	Ext Cor VP/n Ext Cor SVW/n Ext Cor INO/n Ext Cor VQN/n Ext Cor TCN/n Ext Cor MHN/n Fl Ham VP/n Fl Ham VW/n Fl Ham IP/n Fat IP/n	Fat INO/l		
Negligible (4)	H Dam VP/n H Dam VW/n H Dam CSG/n H Dam INO/n H Dam ONO/n H Dam VQN/n H Dam CDN/n H Dam SR/n H Dam IP/n H Dam MHN/n H Dam TCN/n Erosion CDN/n Fatigue SR/n Du Fail SR/n	H Dam VP/l H Dam VW/l H Dam INO/l H Dam ONO/l H Dam VQN/l H Dam CDN/l H Dam MHN/l H Dam TCN/l Du Fail VP/l Du Fail VW/l Du Fail MHN/l		

Figure 4 - Hydrogenator 16-VR101 HAZOP results for other damage mechanisms.

TABLE 3. Non-intrusive Test Programme for Hydrogenator 16-VR1O1

1. Corrosion mapping of low points of catalysts dump nozzles, using C-Scan
2. Corrosion mapping of outlet pipe elbow between the outlet nozzle and the blanking flange, using C-Scan
3. Magnetic particle inspection of external surface of inlet nozzle-to-shell weld for possible fatigue cracking
4. Ultrasonic inspection of bottom head-to-shell circ weld and long weld, using TOFD for possible internal weld corrosion
5. Corrosion mapping of 1m2 are of bottom head using C-Scan
6. Wall thickness readings at all existing gauge points ultrasonic wall thickness monitor

since a jet of hydrogen, catalyst and volatile chemicals would be directed to the ground.
Over the temperature range in the hydrogenator the higher temperature at the bottom of the vessel represents a worst case in relation to organic acid corrosion. Organic acid corrosion is also increased by high velocities and in this respect the outlet nozzle region is a potential worst case location. 'ac elbow in the pipe between the outlet nozzle and the blanking flange is considered to be a particularly susceptible location, and a leak in this region would lead to a fire in the skirt area with critical safety severity.

A non -intrusive testing programme was devised to target specific locations which pose the highest safety, risk, and specified inspection techniques with a very high reliability, in detecting the anticipated forms of damage at those locations. In addition, other marginal areas of concern identified by the HAZOP were also addressed, such as possible fatigue cracking at the inlet nozzle and preferential internal weld corrosion (Table 3).
Critical crack size estimates for any cracks in the circumferential and longitudinal welds of the hydrogenator shell were also derived using fracture mechanics to support the proposed inspection programme
It should be noted that the conventional statutory, inspection and testing stipulated by, the Mines & Works Act Regulations requires- "an examination of the internal and external surfaces of the vessel and all the fittings and appurtenances" and... " a pressure test by water or. where the use of water is impractical, by any other suitable liquid, to a pressure of 1.3 times the maximum safe working gauge pressure of the vessel." Such an inspection and test plan would not determine accurately, the corrosion state at the bottom of the catalyst dump nozzles, nor the state of corrosion on the elbow of the pipe front the outlet nozzle to the blanking flange due to access problems.
The exemption application was made conditional upon successful implementation of the non-intrusive testing programme and that no critical defects were revealed. It was also pointed out that the proposed programme was considered to be at least as safe as the Inspections and tests stipulated in the regulations.
An extension to the existing exemption was granted by the authorities to the extent that the prescribed statutory inspections and tests may be carried out when replacing the catalysts.
The RBI exercise conducted on the hydrogenator was thus instrumental in saving millions of Rands worth of catalysts. Perhaps more importantly, however, it identified the dominant failure mechanism and the most susceptible high-risk areas which would probably not have been detected by the conventional inspection and test plan. It has thus been possible to target specific areas and manage pro-actively any deterioration which may occur.

4 CONCLUDING REMARKS

In this paper an attempt has been made to summarize the development of South African statutory, legislation as it applies to the inspection of boilers and pressure vessels and to contrast the somewhat draconian regulations of yesteryear, with the increasing levels of self-regulation anticipated in the future. Attention has been drawn to the opportunity, thus presented for Optimising inspection programmes, and the concept of RBI has been introduced as representing the most rational and responsible means of determining what to inspect, where to inspect and when to inspect.
The methodology of an RBI study has been outlined briefly and illustrated by reference to a South African case study where not only was a substantial catalyst cost saving achieved, but a much clearer understanding of the potential degradation mechanism emerged, thus enabling a specifically targeted and appropriate inspection programme to be irnplemented to pro-actively manage any deterioration.

REFERENCES

A.ller, J.E., Horowsitz, N.C., Reynolds, J.T. & Weber, B.J., "Risk Based Inspection for the Petrochemical Industry." Proc. ASME Pressure Vessel and Piping Conference, July 1995.

API 581(1997) Preliminary Draft Base Resource Document, Risk-Based Inspections

Cross, W,, '-The Code: An Authorised History of the ASME Boiler &, Pressure vessel Code ASME. 1990,

Cushnaghan, S. K. Harvey, A., "The application of Risk Based Inspection to an onshore gas terminal." Paper Presented at TAGSI one day Symposium, January 1997.

Geencn, F.M. & Maeseele, M.M., "The SAPREF approach to mechanical integrity management: Plant Degradation Management PDM." Proc. 2nd International Symposium on Risk, Economy & Safety, Failure Minimisation & Analysis -Failure' 96, South Africa, July, 1996. Mines & Works Act (Act No 27 of 1956).

Occupational Health & Safety, Act (Act No 86 of 1993), Vessels Under Pressure Regulations. October 1996.

Renolds, J.T., "The application of risk-based inspection methodology. in the petroleum and petrochemical industry?." NPRA Maintenance Conference. Paper MC-96-81, (USA) 1996.

Renolds, J.T.. "API Risk-Based Inspection Project Update." NPRA Maintenance Conference. Paper NIC-97-82,

New Orleans, USA. May 1997,

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