Causas de falhas de equipamentos e tubulações em plantas de processo

Segue a análise realizada pela entidade HSE-Hazardous Installations Directorate, sobre as principais causas de falhas de equipamentos e tubulações.

A HSD é responsável por regulamentar e promover melhorias em saúde e segurança, contribuindo para o objetivo geral de reduzir e controlar os principais riscos de perigo presentes nas seguintes indústrias e setores de alto risco:
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HSE Health & Safety Executive — Hazardous Installations Directorate

Causes of Plant Failure

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1. CORROSION

Corrosion is caused by electro-chemical processes in which a metal reacts with its environment to form an oxide or compound by the formation of cells comprising an anode (the deteriorating metal), a cathode (adjacent metal) and a conducting solution (acid / salts). It can occur both internally and externally to pipelines, vessels, plant, machinery, structures and supports.

The materials selection philosophy aspect of the design phase of all plant and structures should take into account the anticipated conditions (pressure, temperature and atmosphere) and the contents of the system in order to either minimise corrosion or to make adequate allowances for it in the form of additional material thicknesses. Some further aspects of the use of different materials for various applications are discussed in Materials Commonly Used in Process Plant.

The initial corrosion on some metals creates an impervious coating which prevents further corrosion taking place.

Corrosion can be exacerbated by utilising different materials which then set up an electrochemical cell which in turn causes wastage of the anode.

1.1 Types

a) Oxygen pitting, bi-metallic (internal and external).

b) Water lines, low velocity/stagnant conditions, under millscale deposits, crevice-type corrosion (differential aeration), localised at areas of dissimilar metals (galvanic action).

c) Carbon dioxide uniform loss, specific through turbulence, wet gas "Mesa" type (internal). Note: Mesa type corrosion is a descriptive word emanating from the Mesa region of Spain which is noted for its table top sharp edged plateau with shallow broad valleys.

d) Hot aerated water lines, where CO_2 partial pressure is 0.2 barg, areas of turbulence (bends, tees, weld upsets), wet gas lines.

e) Hydrogen Sulphide (internal).

f) Sour service, partial pressure > 0.003 barg, bacterial attack on sulphates in low acid conditions.

g) Stress Corrosion Cracking (internal and external).

h) Chloride SCC in austenitic steels at temperatures above 60°C, combined corrosive and tensile stress, externally.

i) Can be associated with damaged / wet coverings and insulation material, inadequate or maloperating cathodic protection.

1.2 Prevention

a) Adequate design parameters.

- i) Choice of materials, taking into account all envisaged conditions and contained fluids or products.
- ii) Avoiding the use of dissimilar metals.
- iii) Suitable corrosion allowances.
- iv) Joint design and configuration.
- v) Applied coatings (internal and external).
- vi) Drainage facilities.
- vii) Inspection and monitoring facilities.
- viii) Installation considerations.

1.3 Monitoring

a) Condition Monitoring (containment system):

i) Planned inspection procedures.

ii) Planned corrosion monitoring procedures, by ultrasonic thickness measurement, probes, coupons, cathodic protection, etc.

b) Condition Monitoring. (contained fluids):

i) Continuous process and operation monitoring.

ii) Planned application of inhibitors to contained fluids.

iii) Regular checks and monitoring that the contained fluids are within the design parameters.

c) Monitoring at manufacture and installation:

i) Storage and protection of pipework and plant at fabrication stage and prior to commissioning.

ii) Correct selection and usage of fabrication methods and consumables.

iii) Satisfactory installation to avoid deadlegs, moisture traps, environmental hazards.

iv) Proper selection and application of monitoring and inspection procedures during fabrication and installation.

v) Suitable insulation and protection during installation. Equipment and installation drainage points etc.

1.4 Examples

1. External Chlorine induced SCC of Oil/Gas HP Separator due to warm, (90°C) wet insulation attached to solid stainless steel (duplex).
2. Stress Corrosion Cracking in duplex stainless steel pipe welds due to low pH, high chloride and high hydrogen sulphide environment (Acid washing downhole safety valves).
3. Pin-point corrosion of heat exchanger tubes in fin-fan coolers on closed circuit cooling water systems due to inadequate addition of corrosion inhibitors and tested alkalinity of the medium.
4. External corrosion of pipework, vessels and storage tanks in places that usually are covered, but where insulation breaks have occurred, particularly in harsh environments. e.g. coastal locations, (gas terminals etc.)
5. External corrosion of boiler blowdown elbows and associated pipework, located in floor sumps, which become fouled with wet warm debris.
6. Cavitational corrosion caused by bubble collapse in process systems and more commonly in boiler water tubes as scab pitting.
7. Internal corrosion occurring in dead-legs on systems which do not have adequate draining facilities, or are not operated as frequently as required.
8. Floor plate and lower shell plate corrosion due to smothering with wet acidic/chlorinated waste material and debris.
9. Preferential corrosion attack in the heat affected zone (HAZ) of welds in carbon steel gas flowlines, initiated from a fairly benign gas output at start up of production to an inclusion of degrees of corrosive trace elements without proper degrees of inhibition being implemented.

1.5 Key Words

Trace elements, corrosive extraction products, oxygen bubbling, H_2S attack, damp warm conditions (under insulation), sub-surface (soil), acidic, chlorine content, preferential attack, drainage, design, monitoring.

2. EROSION

Caused by internally by excessive fluid velocity, change in phase, cavitation, change in flow direction, presence of particulates.

Caused externally by sand, salt, water (rain and sea), wind, cavitation, venturi effect round buildings etc. Pressure leaks can cause impingement and have a lancing effect at the leak itself and at areas where the leaking fluid strikes another surface.

2.1 Prevention

a) Adequate design parameters:

i) Choice of materials.

ii) Plant layout and siting.

iii) Coverings and coatings.

iv) Filtration.

v) Reduction of dissolved gases in fluids.

vi) Avoidance of abrupt changes in pipe section and short radius bends.

2.2 Monitoring

a) Routine inspection programmes (visual supported by ultrasonic thickness measurements where appropriate).

i) Non-intrusive internal inspection and monitoring at suspected system sites (bends, Tees, elbows etc.).

ii) Intrusive inspection and monitoring at areas where erosion is probable.

2.3 Examples

1. Failure of bends on 50 mmNB pipework carrying pulverised anthracite to the combustion chamber of a fluidised bed steam generator at the Grimesthorpe European power station project.
2. Thinning of swept bends of flowlines carrying first oil from offshore extraction due to the scouring effect of sand particulates.
3. Perforation of "U" bends in tubular heat exchangers.
4. Rapid perforation of adjacent boiler downcomer tubes from tubewall leak through cracking.
5. Thinning of exposed pipe through sand blasting in desert and seaside locations.
6. Turbulence effect created by incorrectly fitted / incorrectly sized flange gaskets.

3. EXTERNAL LOADING

Can be caused by the effects of snow, winds, ice, floods, support failure, system/equipment failure, environmental failures (earth movements), filling / emptying, change in contained fluids.

3.1 Prevention

a) Adequately considered design parameters.

i) Adequate consideration of environmental factors, (wind, snow, ice formations, earth tremors).

ii) Provision of spiral deflector vanes on pipework, tall vessels etc.

iii) Provision of guyed supports for tall structures.

iv) Design considerations for supports and hangers (to include perceived environmental loadings).

v) "Golfballing" of large spherical or cylindrical storage and process vessels.

vi) Adequate foundations provision.

vii) Provision of trace heating for the prevention of ice or snow build-up.

3.2 Monitoring

a) Regular, scheduled external inspection regimes with dedicated methods and reviews.
b) Regular scheduled maintenance of trace heating facilities etc.
c) Documented procedures for information sharing in the event of a change of use, including change in contained fluids.

4. IMPACT

From road and rail vehicles, failed equipment, or other sources, including aircraft, and dropped or swinging loads or objects.

4.1 Prevention

a) Adequate provision to ensure surrounding equipment, building attachments, are safe and secure.
b) Avoid siting plant within the arc of cranes, winches, gantries, etc.
c) Avoid crossing roads with pipelines, and ensure sufficient clearance for all foreseeable vehicle travel (including JCBs with elevated buckets).
d) Employ rigid guarding where necessary (likelihood, possibility).
e) Adequate distance between plant and road, railways, rivers and canals etc.
f) Careful siting of small bore pipework in relation to walkways and access points.

4.2 Monitoring

a) Surveillance of plant, surroundings and adjacent equipment.

4.3 Examples

Distorted and ruptured pipelines on overhead pipetrack resulting from impact by JCB raised bucket during travel (illegal).

Indented pipelines from equipment miss-handling during removal/replacement for refurbishment or inspection during refinery downtimes (numerous).

Sheet steel cladding of crane structures becoming detached and impacting on pipework during fall.

Distortion and severance of unprotected small bore pipework in way of regular human access.

5. PRESSURE

Failure due to over-pressure caused by control failure, external fire, internal explosion, excessive reaction rate, liquid expansion, exothermic reaction, or collapse caused by vacuum.

5.1 Prevention

a) Design parameters to include suitable process pressure controllers for systems, particularly where multi-system inter-action is required.

b) Installation of suitable additional pressure controlled shutdown or warning devices where operational environments deem this a necessity (Gas terminals, chemical plant etc.).

c) Design parameters should ensure conditions where there may be a potential for internal explosion (e.g. through mixture of gasses) are fully considered.

d) Design and operating procedures should take account of the possibility of excessive reaction rates and limit the resulting rises in pressure and / or temperature to acceptable limits.

e) Design and operating procedures should take account of the possibility of liquid expansion to limit the resulting rises in pressure and / or temperature to acceptable limits.

f) Design and operating procedures should take account of the possibility of exothermic reaction and limit the resulting rises in pressure and / or temperature to acceptable limits.

g) Design parameters should include suitable prevention devices (vacuum breakers) and structural strength where vacuum generation is possible unless the plant has been designed to safely withstand vacuum conditions.

h) Fitting of suitable relieving devices to the systems and vessels (pressure safety valves, bursting discs, fusible plugs) which have adequate margin between system operating pressure and actuation pressure and which prevent design parameters being exceeded.

i) System dump facilities in case of over-pressure.

5.2 Monitoring

a) Regular programmed and audited testing and calibration of pressure control, relieving, indicating and warning devices.

b) Regular review of design codes and guidance for pressure systems.

c) Regular review of safety notices regarding incidents to pressure systems.

d) Regular review of the operators awareness and skills

e) A formal procedure to review operating procedures in the event of change of use or contents of a pressure system

f) Regular and formal testing and maintenance of vent and flare headers.

6. TEMPERATURE

Excessive excursions of high and low temperatures due to process upsets, fire, adverse weather conditions, fouling, blockages or phase changes can lead to failure due to rapid or large temperature variations. Rapid temperature changes or low temperatures can lead to cracking. High temperatures can lead to failure due to loss of structural strength without the design pressure being exceeded.

6.1 Prevention (internal)

a) Adequate thermostatic control of the system contents
b) Design parameters adequate for predictable temperature variations
c) Provision of insulation where required

6.2 Prevention (external)

a) Temperature sensors, gas sensors
b) The provision of blast and fire walls where required
c) Deluge systems provision
d) Insulation to the system's vessels and pipework

6.3 Monitoring

a) Implement regular inspection and testing of all alarm, control and shut down devices
b) Regular surveillance and monitoring of insulation, fireproofing etc.

7. VIBRATION

Vibration can be generated through changes in phase, water hammer, liquid slugs in gas systems, gas bubbles or pockets in liquid systems, high pressure drop, cavitation, incorrect siting of rotating machinery, incorrect pipe supports, loss of buffer gas in damper vessels, damaged supports and hangers, all of which can give rise to fatigue failure.

7.1 Prevention

a) Ensure that system operation and contained fluid flow characteristics are constantly monitored for prevention of mechanical shocking caused by fluctuations.
b) Ensuring that provision is made for liquid systems to be vented to prevent gas entrainment.
c) Accurately determined siting of mechanical and rotating machinery.
d) Pipelines and pipework layout is are such that the effect of vibration is minimised.
e) All pipelines and pipework is properly supported, and such supports and hangers are suitable for the purpose.
f) All equipment and piping holding down devices are adequate and secure.
g) Adequate shock / vibration mountings are fitted to plant and machinery.
h) There is adequate provision of damper vessels at pump/compressor discharges, (especially reciprocating type).

7.2 Monitoring

a) Adequate, programmed, audited surveillance by visual and electromechanical means.
b) Machinery vibration analysis exercises carried out, results reported and acted on.
c) Monitoring and recording of damper vessel precharge pressure.

8. WRONG EQUIPMENT

Wrong equipment can be fitted at installation or be supplied as a replacement during the life of the plant or at a modification. The equipment may be wrong because it has been incorrectly specified, or because the supplier has not supplied in accordance with the specification.

Wrongly supplied equipment can lead to failure due to incompatible materials, wrong design, or it may have a rating or duty other than that which it is intended to fulfil.

8.1 Prevention

a) Formal system for ensuring that only equipment specified under the design approval process is supplied and fitted.
b) Adequate system design parameters from inception to first fabrication.
c) Audited and auditable "TIPS" (Technical Integrity Procurement System) in place for new and replacement items, including pipework, steelwork, fixtures and fittings.
d) Auditable obedience to design procedures during build, to include formal design change procedures and engineering query routes to fulfilment.
e) Manufacturer, supplier, installer, operator and maintainer knowledge assessment and awareness systems are in place and audited.
f) Auditable maintenance procedures, check lists, equipment lists in place.
g) Permit to work systems in place.

9. DEFECTIVE EQUIPMENT

Defective equipment can be supplied when the plant is initially installed or subsequently as a replacement or during a modification.

This category covers circumstances where the equipment was correctly specified, but was defective in some way, such as the materials, the duty, or it may have been wrongly assembled. It may not work in accordance with the specification, in terms of performance, or the trips, interlocks, protective devices etc. may not function as required.

The materials of construction may not be as per the specification, or it may be intended for a duty other than that which was specified.

Such defects can lead to the system failing or at least not perform as required.

9.1 Prevention

a) Formal system for ensuring that only equipment specified under the design approval process is supplied and fitted.

b) Plant and equipment purchased from approved suppliers only.

c) Audited and auditable "TIPS" (Technical Integrity Procurement System) in place for new and replacement items, including pipework, steelwork, fixtures and fittings

d) Recorded vendor inspections at the supplier's or manufacturer's works on all major plant and equipment.

e) Adequate and recorded commissioning tests on all new and repaired equipment.

f) Manufacturer, supplier, installer, operator and maintainer knowledge assessment and awareness systems are in place and audited.

g) Auditable maintenance procedures, check lists, equipment lists in place.

h) Permit to work systems in place.

10. HUMAN ERROR

Many of the causes of plant failure already discussed have elements of human error built in to them, from the design stage through to operation and maintenance. The types of failure directly covered here are those associated with the operation of the plant, where errors of judgement or ignorance form a major hazard.

Human error can cause overfilling, overloading through lack of or mis-placed judgement and/or information giving rise to incorrect decisions by operators. Lack of knowledge or training of operations staff giving can also give rise to failure due to operational errors.

10.1 Prevention

a) Formal written training schemes are in place with performance tests and assessments where required.

b) Formal written operating procedures manuals are available covering normal and emergency operations.

c) Formal written operating instructions with check lists as required are on hand / displayed and signed up.

d) Regular auditing of procedures to account for changes in operating parameters etc.

e) Formal permit to work systems in place.

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Page last updated: 1st May 2001