Oil and Gas Pipeline Design, Maintenance and Repair

Dr. Abdel-Alim Hashem
Professor of Petroleum Engineering
Mining, Petroleum & Metallurgical Eng. Dept.
Faculty of Engineering – Cairo University
aelsayed@mail.eng.cu.edu.eg
ahshem2000@yahoo.com

Part 8 : Maintenance, Reliability and Failure Analysis

Contents

Maintenance Objective

- “Ensuring that physical assets continue to do what their users want them to do” [Moubray]
- “To preserve the system function" [Smith]
- “Physical as-sets" are pipes, valves, active equipment (pumps, compressors, etc., also referred to as dynamic or rotating equipment), instrumentation, fixed equipment (vessels, heat exchangers, etc., also referred to as static equipment), in-line components (traps, strainers, etc.), insulation and supports.

Maintenance Variety of Manners

- Maintenance information is ignored. Things are fixed as they break, time and again.
- Maintenance information is recorded as data, somewhere on a server, on a shelf or in a drawer.
- Maintenance data is converted into knowledge for a few, the maintenance mechanic and possibly the system engineer.
- Maintenance knowledge is converted into wisdom, by analysis, trending, and communication (in a clear and illustrated manner) to the whole organization.

Maintenance Plan

- For each system, determine a maintenance strategy
- For each system identified for proactive maintenance, prepare a component list (pipe segments, valves, pumps, compressors, etc.).
- For each component, specify the required function, its failure mode and failure cause.
- For each component failure cause, select the proper inspection technique, The objective here is to decide what needs to be inspected, when, where and how.
- Determine the acceptance criteria that will be used to evaluate the inspection results and to determine the "fitness-for-service" of the system

Maintenance Plan

- Plan and implement maintenance inspections, either on stream (on line) or during an outage (shutdown).
- Document results, intelligently, clearly, and succinctly. Illustrate with digital photographs. Record in a retrievable and sortable maintenance database. Maintain "system health reports".
- Issue clear recommendations, for example in three categories: green (ok as-is), yellow (plan for future inspection, degradation is taking place but equipment is fit-for-service till next inspection), or red (repair or replace).

Maintenance Strategies

There are two maintenance strategies

1. A reactive approach (corrective maintenance, running equipment to failure, or near failure)
2. A proactive ap-proach (inspecting equipment and taking early steps to overhaul, repair or replace, before failure).

Maintenance Strategies

Systems of a proactive maintenance strategy include

- Facility safety basis: systems essential to prevent or mitigate credible accidents that would have unacceptable consequences to the workers, the public or the envi-ronment.
- Production loss: systems essential to maintain an acceptable level of produc-tion throughput.
- Maintenance cost: systems with equipment that would be costly to replace, or would require long lead times.

Maintenance Strategies

Systems of a proactive maintenance strategy include

- Risk of failure: systems at greater risk of failure, for example because of corrosion, operation at high pressure or temperature, operation beyond vendor recom-mendations, or based on past company or industry experience.
- Regulatory requirements: systems or components that are required, by regula-tion, to be periodically inspected or tested

Corrective Maintenance

- Is reactive maintenance: run to failure, then repair or replace
- Quite common for non-essential systems
- Maintenance managers cite limited manpower and budgets focused first on solving the day's emergencies as an impediment to predictive maintenance
- A recent survey reported corrective maintenance at 40% of the maintenance workload
- Well-implemented, corrective maintenance yields a wealth of knowledge

Corrective Maintenance Work Package

- Equipment make and model.
- As-found condition (photographs are recommended).
- Mechanics' opinion as to the likely cause of failure.
- Corrective action (and possibly recommendation to avoid recurrence).

Failure Modes

- Failure mode and failure cause should be captured in a standard format, and regularly sorted, analyzed and trended
- The objectives to understand failure cause, and take pre-emptive measures to avoid recurrence, optimize per-formance, reduce costs, and improve safety
- Company may develop its own maintenance history software
- To help in documentation and sorting, each class of equipment would have a standard list of failure modes and failure causes

Failure Mode 1 - Pumps Fails to Start

Corresponding Failure Causes:

- Loss of power.
- Internal binding.
- Failed bearing.
- Failed coupling.
- Open or shorted motor.
- Start circuit fails.

Failure Mode 2 - Pump Delivers Inadequate Flow

Corresponding Failure Causes:

- Worn or broken impeller.
- Worn wear ring.
- Discharge valve closed.
- Cavitation.
- Seal failure.
- Casing cracked.
- Gasket leak.
- Clogged strainer.
- Shaft damage.

Failure Mode 3 - Pump Exhibits Abnormal Condition

Corresponding Failure Causes:

- Excessive vibration.
- Leak of process fluid.
- Oil leaks.
- Excessive temperature.
- Unusual noise.

A Second Level of Failure Causes

- The cause of the cause
- May be necessary to diagnose and correct the failure mode.

An Example of Second Level Failure Causes

Failure Cause 1st Level - Excessive Vibration in Pump
Failure Cause 2nd Level:
Mechanical Cause:

- Unbalance.
- Eccentric rotor.
- Bent shaft.
- Axial misalignment at shaft coupling.
- Angular misalignment at shaft coupling.
- Loose foot.
- Rotor rubs against fixed part.
- Bearing wear.
- Oil instabilities.

An Example of Second Level Failure Causes

Failure Cause 1st Level - Excessive Vibration in Centrifugal Pump

Failure Cause 2nd Level:

Mechanical Cause:

- Gear worn or broken.
- Faulty motor.
- Belt drive misaligned.

Hydraulic Cause:

- Pressure pulsing from vane pass.
- Flow turbulence.
- Cavitation.
- Hydraulic resonance (Helmholtz oscillator)

Pro-active Maintenance

- Preventive or Predictive Maintenance
- Inspection Checklists

Preventive or Predictive Maintenance

- Where a system cannot be run to failure, it has to be part of the pro-active maintenance program.
- A choice must now be made between Preventive Maintenance (PM) or Predictive Maintenance (PdM).
- With PM, also referred to as Scheduled Maintenance [Patton], pre-determined maintenance activities take place at predetermined intervals; for example, replacing pump lube oil every X months, testing a relief valve every X years, etc

Preventive Maintenance (PM)

- Also, referred to as Scheduled Maintenance [Patton], pre-determined maintenance activities take place at predetermined intervals
- For example, replacing pump lube oil every X months, testing a relief valve every X years, etc
- Based on several factors:
  - Equipment failure history.
  - Vendor recommendations.
  - Industry practice, codes, standards.
  - Personnel experience.
  - Risk: likelihood and consequence of malfunction or failure.

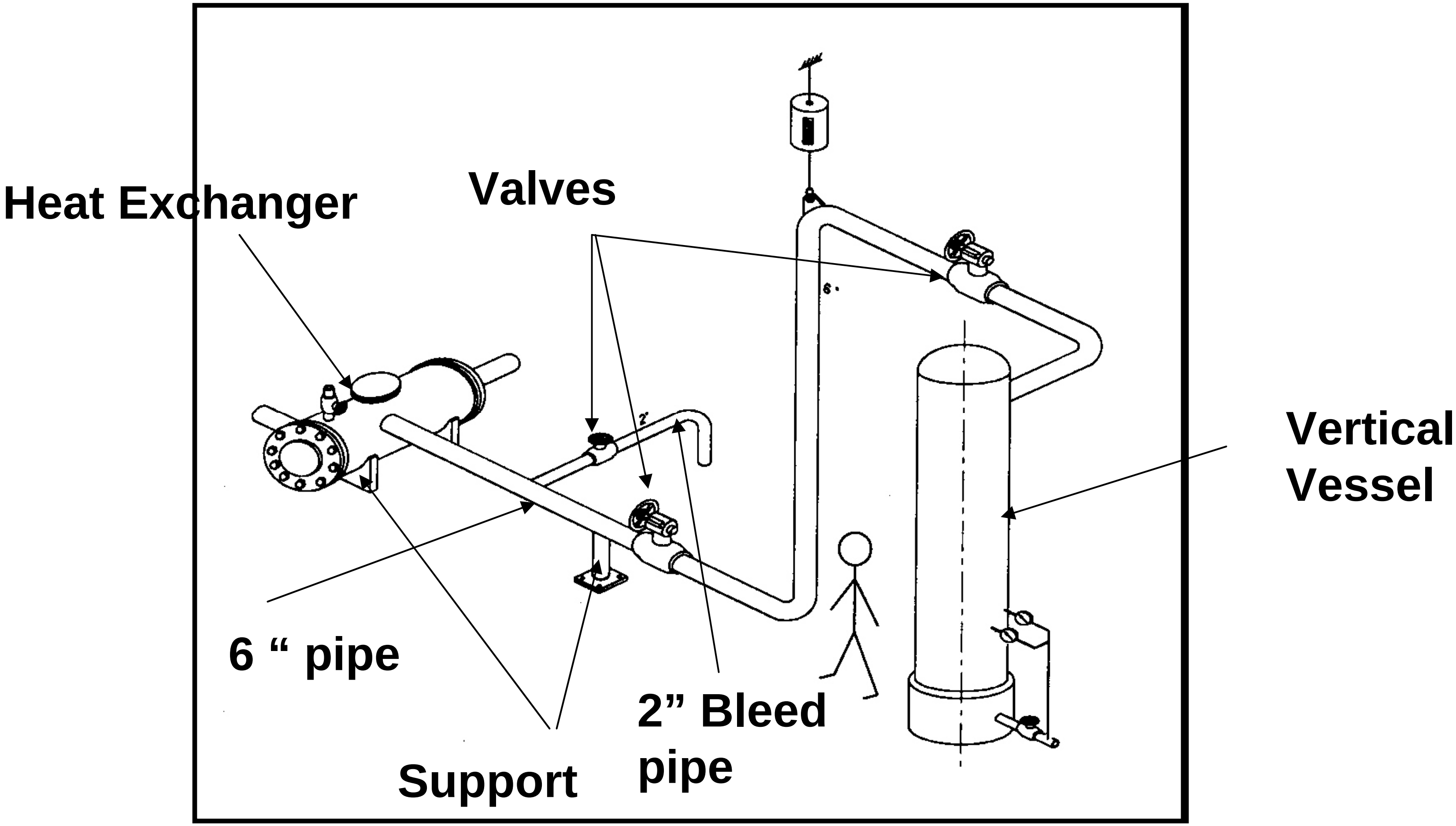
Predictive Maintenance (PdM)

- Given to the combina-tion of three activities: vibration analysis, thermography, and oil analysis
- Viewed in a much broader sense
- Based on the expert inspection and analysis - as quantitative as possible
- Involves more upfront effort and more expertise than PM

Inspection Checklists

- Use inspection checklists to guide and document the inspection
- Visual inspections supplemented by periodic surface inspections:
  - (typically liquid penetrant testing (PT) or magnetic particle testing (MT) or volumetric inspections
  - (typically ultrasonic testing (UT) or radiographic testing (RT)
- Based on the system's or component's risk
- Degradation of piping and equipment supports (steel or concrete structures) must be determined case by case, applying the rules of the construction codes and standards

Illustrative Example for PdM



PdM Techniques

- The system consists of 6" pipe, from a vertical vessel to horizontal heat exchanger, with two welded manual valves, a support and a spring hanger (line hot in service); and a 2" branch line with a threaded manual valve
- The maintenance plan follows the outline of section
- Maintenance strategy: predictive because the system is essential to operations

Component List, Function, Failure Mode and Failure Cause

Piping 6" and 2", needs to remain leak tight

- Failure mode would be loss of pressure boundary
- Failure causes: corrosion or fatigue cracking Manual valves, normally open, must be able to close for isolation

Manual valves, normally open, be able to close for isolation

- Failure mode would be loss of operability (hand wheel cannot be turned), loss of leak tightness if closed, loss of pressure boundary through body, bonnet, packing, joints
- Failure causes: corrosion buildup, corrosion of wall, packing wear, debris at valve seat, wear of valve disk or plug.

Component List, Function, Failure Mode and Failure Cause

Vertical vessel must remain leak tight. No overpressure.

- Failure mode would be loss of pressure boundary (leak) or rupture by overpressure.
- Failure causes: corrosion, failure of pressure relief valve to open and discharge at set pressure

Heat exchanger must operate at nominal and full flow, need to maintain heat transfer. No overpressure.

- Failure mode: tube leak, shell and heads leak, head flange leak, overpressure.
- Failure causes: corrosion (thinning, cracking or plugging), inadequate flange gasket, bolts or assembly torque, tube vibration in cross flow, failure of pressure relief valve to open and discharge at set pressure

Component List, Function, Failure Mode and Failure Cause

Supports, must maintain pipe in position, variable spring needs to remain within travel range.

- Failure mode: support fails, pipe dislodges, and spring motion exceeds travel allowance.
- Failure causes: corrosion, impact (such as water hammer) or vibration, wear of support parts, external damage

Inspection locations and techniques

- Piping and vessels: visual inspection of equipment and supports

Component List, Function, Failure Mode and Failure Cause

Inspection locations and techniques

- Valves: many facilities overhaul valves on a rotating schedule (preventive maintenance PM)
- Supports: on critical systems, support members and anchor bolts visually inspected, for evidence of damage
- Acceptance criteria for the integrity of the pressure boundary of piping, ves-sels, heat exchangers and valve bodies are based on fitness-for-service procedures,

Reliability

- There are basically three methods to gain knowledge from maintenance ac-tivities.
- The first method is to investigate a failure or malfunction in the field, as it happens.
- The advantage of this approach is that a lot of first hand information can be gathered regarding failure mode and failure cause.
- The shortcoming is the diffi-culty to generalize the findings.
- The second method is to qualitatively review his-torical maintenance records, particularly corrective maintenance, for a class of equipment over a period of time

Some Examples of Mean Failure Rates

Tanks and Vessels

- Tank leakage IE-7/hour
- Vessel ruptures 5E-9/hour
- Heat exchanger tube leak 1 E-6/hour
- 1/4" leak in vessel or storage tank 4E-5/year
- 4" leak in vessel or storage tank IE-5/year
- Rupture of vessel 6E-6/year
- Rupture of storage tank 2E-5/year

Some Examples of Mean Failure Rates

Pipe and Fittings:

- Leak of metallic straight pipe 0.0268E-6/hour
- Leak of metallic fittings 0.57E-6/hour
- Flange gasket leak 1 E-7/hour
- Plugged strainer 3E-6/hour
- 1/4" leak in 3/4" pipe IE-5/year-ft
- 1/4" leak in 6" pipe 4E-7/year-ft
- 1/4" leak in pipe larger than 16" 6E-8/year-ft
- Rupture of %" pipe 3 E- 7/year - ft
- Rupture 6" pipe 8E-8/year-ft
- Rupture pipe larger than 16" E-8/year-ft

Some Examples of Mean Failure Rates

Valves:

- Solenoid valve fails open 3E-6/hour
- Solenoid valve fails closed 3E-6/hour
- Solenoid fails to respond 2.83E-3/demand
- Motor operator fails to respond 5.58E-3/demand
- Air operator fails to respond 2.2E-3/demand
- Safety relief fails to open 3E-3/day
- Safety relief fails to reclose 3E-3/day
- Check valve leaks through E-6/hour
- Check valve leaks through 3.18E-6/hour

Some Examples of Mean Failure Rates

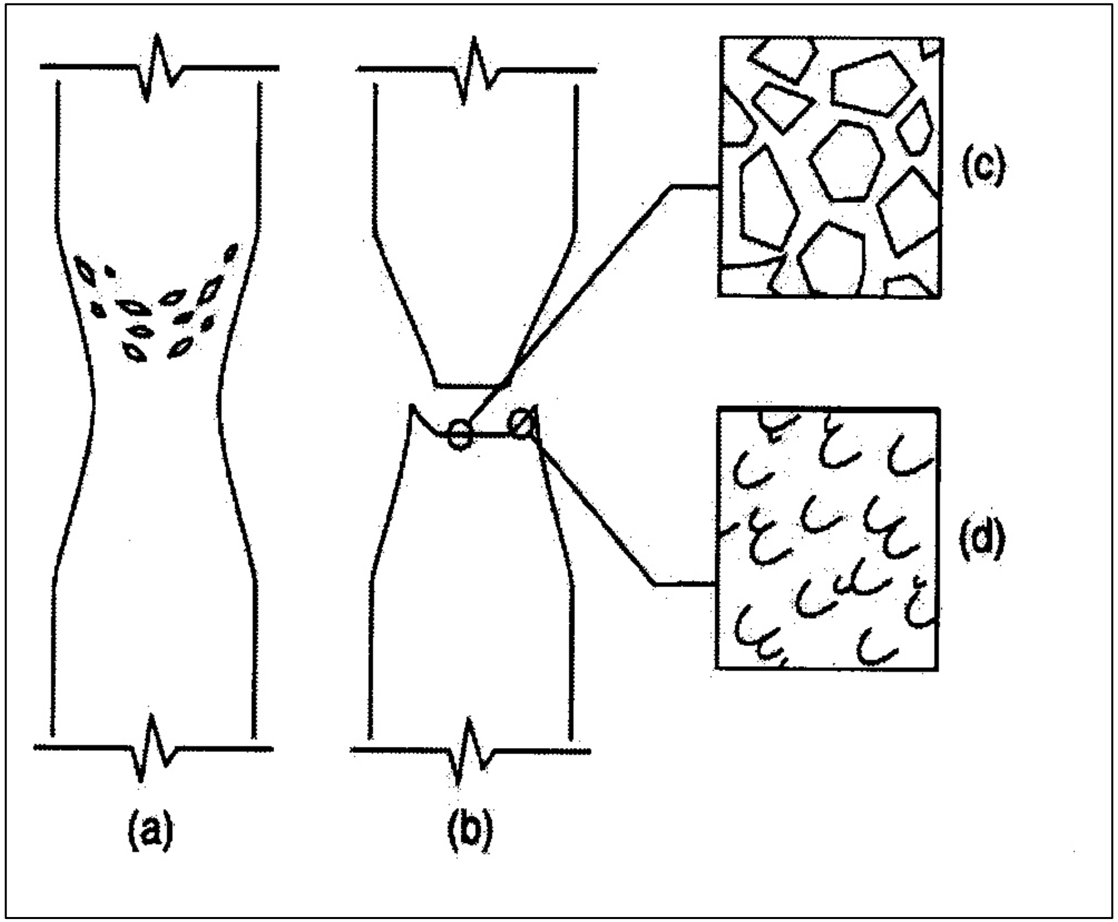
Pumps and Compressors:

- Compressor fails 1430E-6/hour
- Pump motor fails to start IE-2/demand
- Centrifugal pump motor fails to start 18.6E-3/demand
- Centrifugal pump motor fails to furl at rated speed 920E-6/hour
- Centrifugal pump motor fails while running 292E-6/hour
- Pump overspeed 3E-5/hour
- Pipe leak 3E-9/hour-foot
- Pipe rupture IE-I0/hour-foot

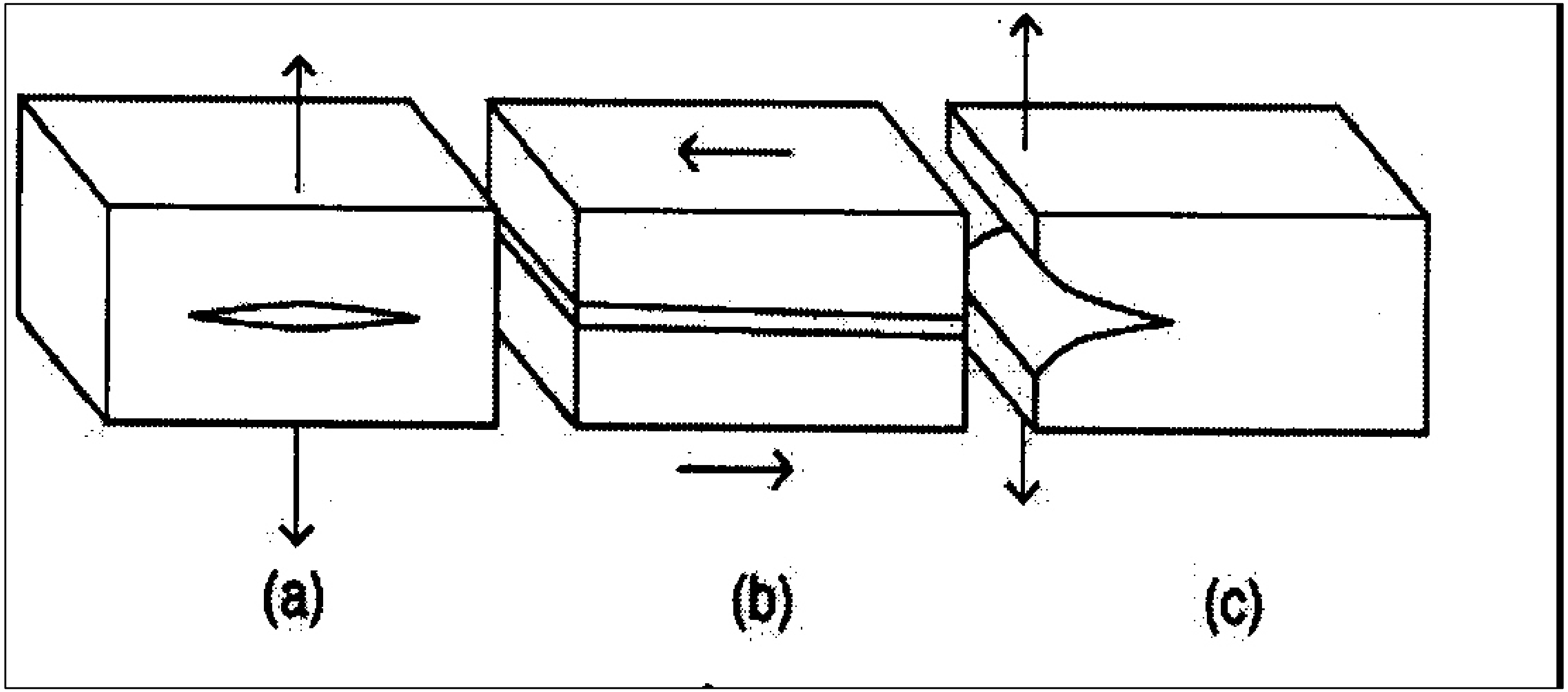
Elements of Failure Analysis

- Data Collection
- Visual Examination, Macrofractography and NDE
- Metallography and Microfractography
- Chemical Analysis
- Mechanical Tests
- Stress and Fracture Analysis
- Improvements

Shear and Tension Overload



Tension, Shear and Tearing Failures



Failure Analysis Logic