Method and Techniques in Geothermal Power Plant Training

BASIC MAINTENANCE AND RELIABILITY IN GEOTHERMAL POWER PLANT

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IMPORTANCE OF MAINTENANCE AND RELIABILITY

- ☑ Failure has far reaching effects on
  - ☑ Operation
  - ☑ Reputation
  - ☑ Profitability
  - ☑ Dissatisfied customers
  - ☑ Idle employees
  - ☑ Profits becoming losses
  - ☑ Reduced value of investment in plant and equipment

EQUIPMENT MALFUNCTIONS

Equipment malfunctions have a direct impact on:

- Production capacity
- Production costs
- Product and service quality
- Employee or customer safety
- Customer satisfaction

IMPORTANCE OF MAINTENANCE AND RELIABILITY

A formal definition of maintenance is "that function of manufacturing management that is concerned with day to day problem of keeping the physical plant in good operating condition"

Objectives

- Minimize loss of productive time
- Minimize repair time & cost
- Keep productive assets in working condition
- Minimize accidents
- Minimize total maintenance cost
- Improve quality of products

IMPORTANCE OF MAINTENANCE AND RELIABILITY

- Dependability of service
- Assured quality
- Prevent equipment failure
- Cost control
- Huge investment in equipment

TYPES OF MAINTENANCE

- Breakdown maintenance or corrective maintenance
- Preventive maintenance
- Predictive maintenance
- Routine maintenance
- Planned maintenance

BREAKDOWN MAINTENANCE

- Occurs when there is a work stoppage due to machine breakdown
- Maintenance becomes repair work
- Seeks to get the equipment back into operation as quickly as possible
- To control the investment in replacement spare machines

Corrective or Breakdown Maintenance

- ➢ Corrective or Breakdown maintenance implies that repairs are made after the equipment is failed and can not perform its normal function anymore

- ➢ Quite justified in small factories where:
  - Down times are non-critical and repair costs are less than other type of maintenance
  - Financial justification for scheduling are not felt

Disadvantages of Corrective Maintenance

- Breakdown generally occurs inappropriate times leading to poor and hurried maintenance
- Excessive delay in production & reduces output
- Faster plant deterioration
- Increases chances of accidents and less safety for both workers and machines
- More spoilt materials
- Direct loss of profit
- Can not be employed for equipments regulated by statutory provisions e.g. cranes, lift and hoists etc

PREVENTIVE MAINTENANCE

It is undertaken before the need arises and aims to minimize the possibility of un -anticipated production interruption or major breakdowns

It consists of:

- Proper design and installation of equipment
- Periodic inspection of plant and other equipments
- Repetitive servicing and overhaul of equipment
- Adequate lubrication, cleaning and painting

PREVENTIVE MAINTENANCE

Advantages:

- Reduces break down and thereby down time
- Lass odd-time repair and reduces over time of crews
- Greater safety of workers
- Lower maintenance and repair costs
- Less stand-by equipments and spare parts
- Better product quality and fewer reworks and scraps
- Increases plant life
- Increases chances to get production incentive bonus

PREVENTIVE MAINTENANCE

Benefits:

- Greater Safety
- Decreased Production Down Time
- Fewer large Scale & Repetitive Repairs
- Less Cost for Simple Repairs
- Less Standby Equipment Required
- Better Spare parts Control
- Proper Identification f Items

PREDICTIVE MAINTENANCE

In this, sensitive intruments(eg.vibration analysers,amplitude meters,audio gauges,optical tooling and resistance gauges) are used to predict trouble. Conditions can be measured on a continuous basis and this enables the maintenance people to plan for an overhaul.

Predictive (Condition-based) Maintenance

- In predictive maintenance, machinery conditions are periodically monitored and this enables the maintenance crews to take timely actions, such as machine adjustment, repair or overhaul

- It makes use of human sense and other sensitive instruments, such as
  - audio gauge, vibration analyzer, amplitude meter, pressure, temperature and resistance strain gauges etc.

Predictive Maintenance (Contd.)

- Unusual sounds coming out of a rotating equipment predicts a trouble
- An excessively hot electric cable predicts a trouble
- Simple hand touch can point out many unusual equipment conditions and thus predicts a trouble

ROUTINE MAINTENANCE

- Routine maintenance: this includes activities such as periodic inspection, cleaning,lubrication and repair of production equipments after their service life.

PLANNED MAINTENANCE

- it involves the inspection of all plant and equipments, machinery, buildings according to a predetermined schedule in order to service overhaul, lubricate or repair, before actual break down or deterioration in service occurs

CONTROL OF MAINTENANCE

1. Authorized by an official
2. Maintenance schedule
3. Issue materials against proper authorization
4. Maintenance budgets
5. Equipment records

Issues:

- How much maintenance is needed?
- What size maintenance crews must be used?
- Can maintenance be sub-contracted?
- Should maintenance staff be covered by wage incentive schemes?
- Can effective use be made of computers for analyzing and scheduling activities?

MAINTENANCE SCHEDULING

Scheduling refers to timing and sequences of operations.

It is an important segment of the production planning & control activity as well as the service operations like plant maintenance with benefits:

- Facilitates optimum use of highly paid maintenance staff
- Equipments can be utilized effectively
- Eliminates undue interruptions in the production flow

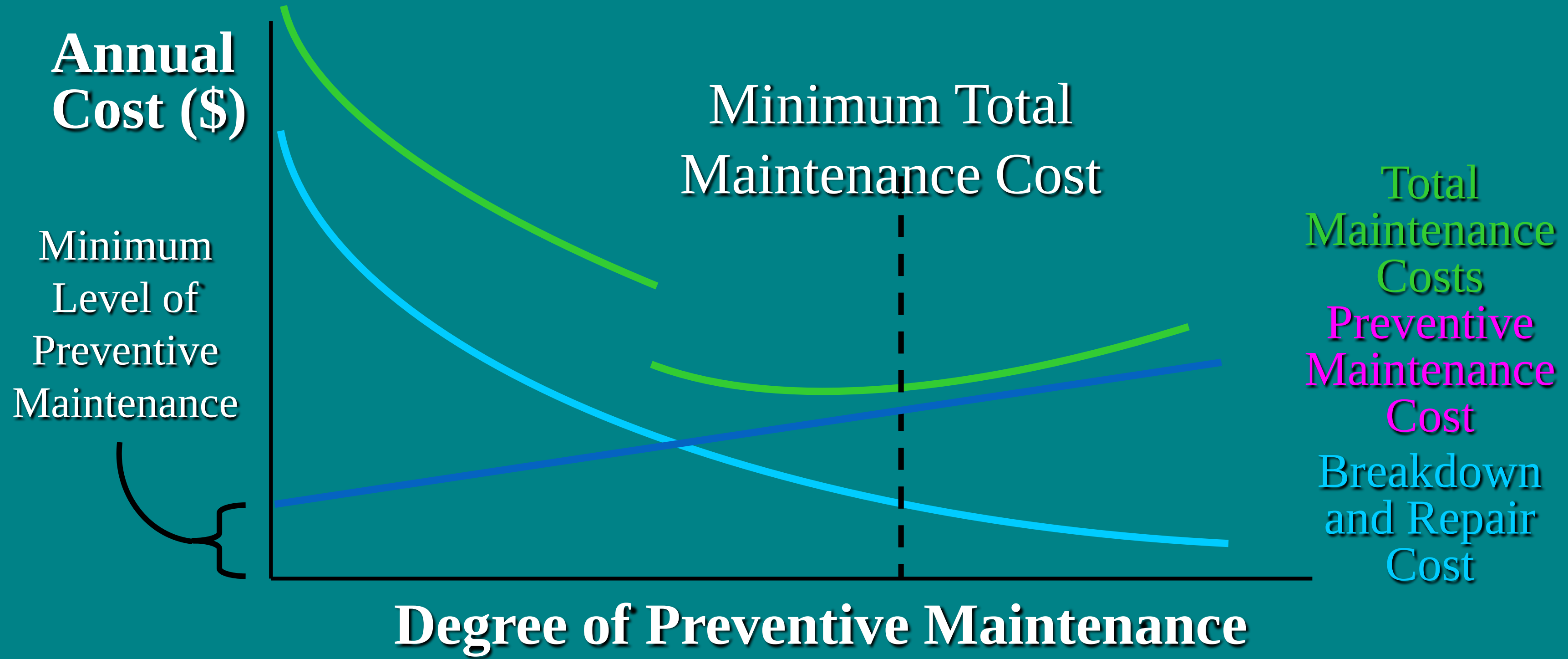
Maintenance Departments

- A maintenance manager typically is a plant engineer who reports to a plant or manufacturing manager
- Maintenance departments are usually split into two groups:
    - Buildings and Grounds
    - Equipment

TRADEOFF BETWEEN REPAIR AND PREVENTIVE MAINTENANCE

- At minimum level of PM, it is a remedial policy
  - fix machines only when they break
  - the cost of breakdowns, interruptions to production, and repairs is high
- As the PM effort is increased, breakdown and repair cost is reduced
- At some point, the total maintenance cost (PM, breakdown, and repair) reach a minimum

TRADE OFF BETWEEN REPAIR AND PREVENTIVE MAINTENANCE



TRADEOFF BETWEEN REPAIR AND PREVENTIVE MAINTENANCE

Maintenance Policy	Reduces Frequency	Reduces Severity
Emphasize preventive maintenance	X	X
Provide extra machines	X	
Replace machine parts early	X	
Involve operators in maintenance	X	X
Overdesign machines	X	
Design machines for maintainability		X
Enhance maint. dept.'s capability	X	X
Increase spare parts supply		X
Increase standby machines		X
Increase in-process inventories		X

MORE ON REPAIR PROGRAM

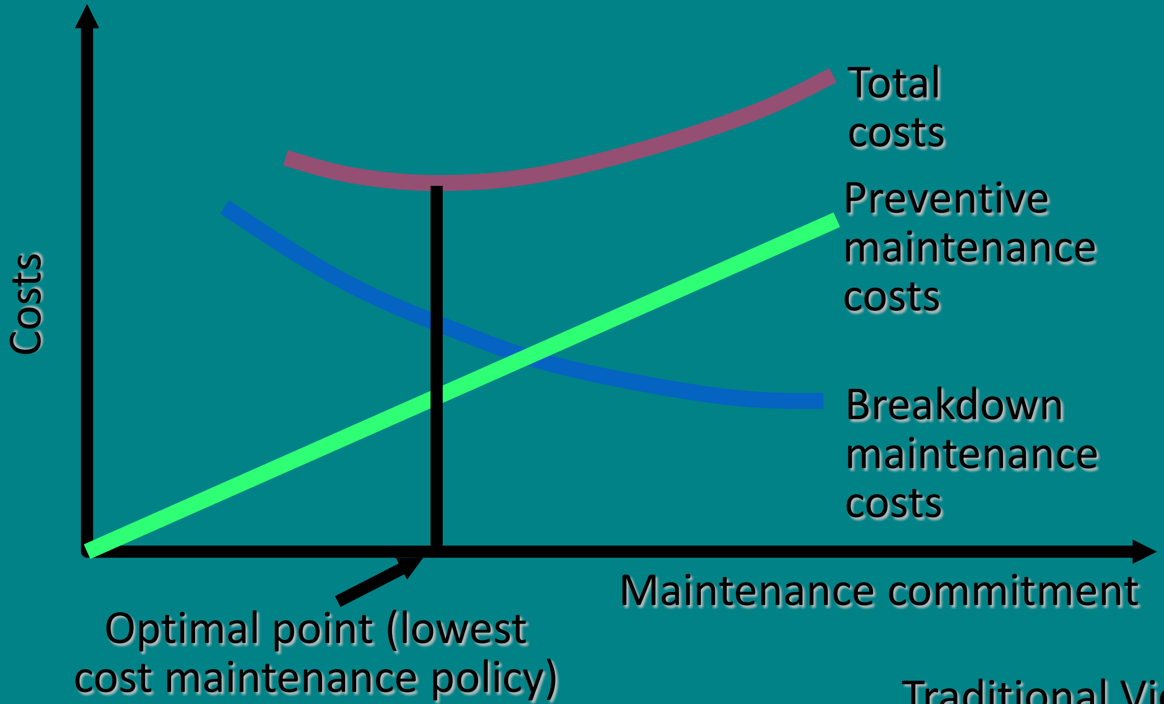
Repair Programs

- Objectives
  - Get equipment back into operation as quickly as possible.
  - Control cost of repairs crews.
  - Control cost of the operation of repair shops.
  - Control the investment in replacement spare parts.
  - Control the investment in standby or backup machines.
  - Perform the appropriate amount of repairs at each malfunction.

Repair Crews and Standby Machines

- Repairs often performed on an emergency basis to:
  - Minimize interruptions to production
  - Correct unsafe working conditions
  - Improve product/service quality
- In emergency situations:
  - Specialists may work overtime
  - Supervisor/engineers are nearby to collaborate
  - Standby machines may be quickly put in operation

Maintenance Costs



Traditional View

Figure 17.4 (a)

Maintenance Costs

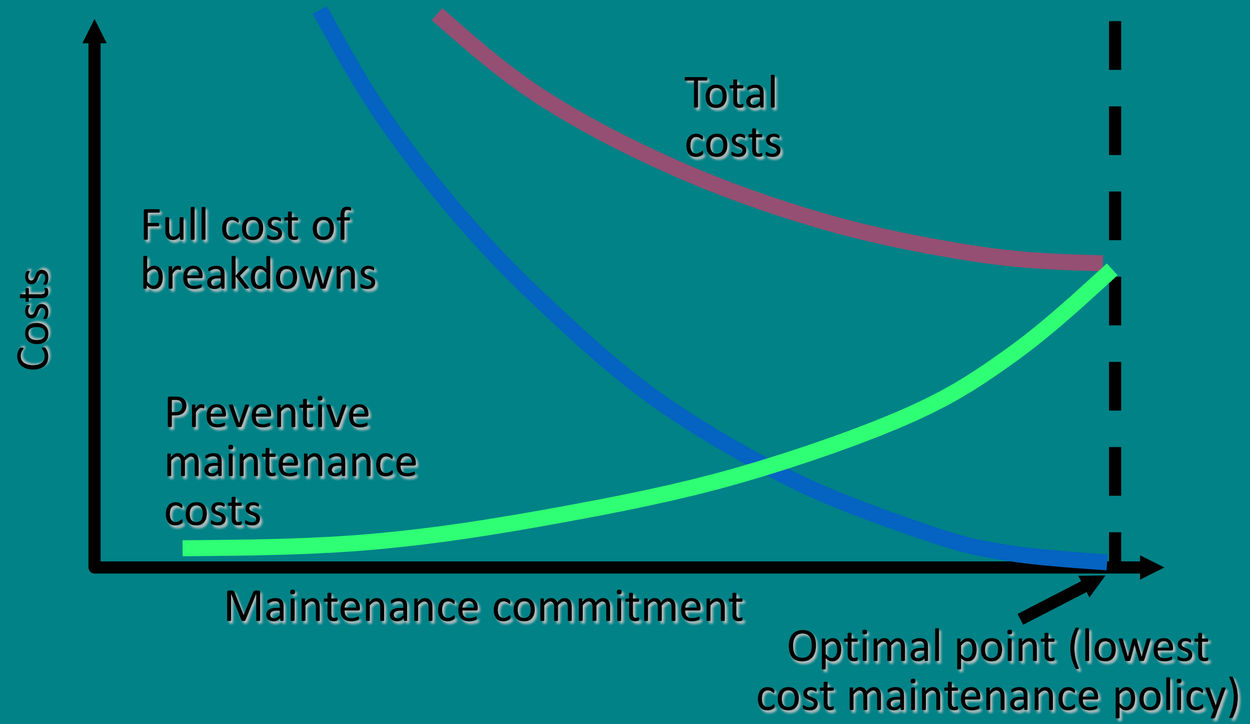


Figure 17.4 (b)
Full Cost View

Breakdowns Trigger Repairs and Corrective Actions

An equipment breakdown should trigger two actions:

- Fast repair of the malfunction equipment
- Development of a program to eliminate cause of the malfunction and need for such repairs in the future
    - Modification/redesign of malfunctioning machine
    - Modification/redesign of part or product being processed
    - Training of operators to improve machine care
    - More frequent preventive maintenance/inspection

Extent of Repairs

- Do just enough repairs to get equipment running again.
- Repair the malfunction and replace some parts that are worn.
- Perform a major overhaul of the equipment.
- Replace the old equipment with new.

Decision Analysis in Repair Programs

- Determining the size of repair crews
  - This is one repair-capacity decision
  - Queuing analysis (Chapter 9) is often used
  - Computer simulation (Chapter 9) is used when the assumptions of queuing formulas do not apply
- Determining the number of standby machines to have
  - Trade-off between cost of lost production time and cost of machine storage, handling, ….

Advantages of Letting Workers Repair Their Own Machines

- Greater variety may make job more satisfying
- May be more sensitive to potential malfunctions
- Increase flexibility
- Can make minor repairs faster
- Can avoid minor repairs by cleaning, lubricating, adjusting and servicing machines
- Operate machines more carefully

MORE ON PREVENTIVE MAINTENANCE PROGRAM

Reasons for a PM Program

- Reduce the frequency and severity of interruptions due to malfunctions
- Extend the useful life of equipment
- Reduce the total cost of maintenance by substituting PM costs for repair costs
- Provide a safe working environment
- Improve product quality by keeping equipment in proper adjustment

PM and Operations Strategies

- PM program is essential to the success of a product-focused positioning strategy
- On production lines, there are little if any in-process inventories between adjacent operations
- If a machine breaks down, all downstream operations will soon run out of parts to work on

Automation and the Prominence of PM

- Many operations are slowly moving toward workerless production
- We are seeing a shift from large to smaller production workforces
- Along with this, we are seeing a shift from small to larger PM workforces
- Production workers displaced by automation will need to be retrained to become PM workers

Scheduling PM Activities

- PM and production are increasingly viewed as being equally important
- In some plants, two 8-hour shifts are devoted to production and one 4-hour minishift is devoted to PM
- In other plants, three shifts are used for production, but time allowances are factored into production schedules for PM activities

PM Database Requirements

- Detailed records, or an ongoing history, must be maintained on each machine
  - Dates and frequency of breakdowns
  - Descriptions of malfunctions
  - Costs of repairs
- Machine specifications/checklists for PM inspection
- Computers generally used to maintain a database
- Also, data can be kept in plastic pocket on a machine

Modern Approaches to PM

- PM at the source - workers have the fundamental responsibility for preventing machine breakdowns by conducting PM on their own machines
- Workers listen for indications of potential equipment malfunction
- Maintenance-related records maintained by workers
- Use of quality circles

Decision Analysis in PM

Three decisions in particular

- Determining the number of spare parts to carry
- Determining how often to perform PM on a group of machines
- Planning and controlling a large-scale PM project

RELIABILITY

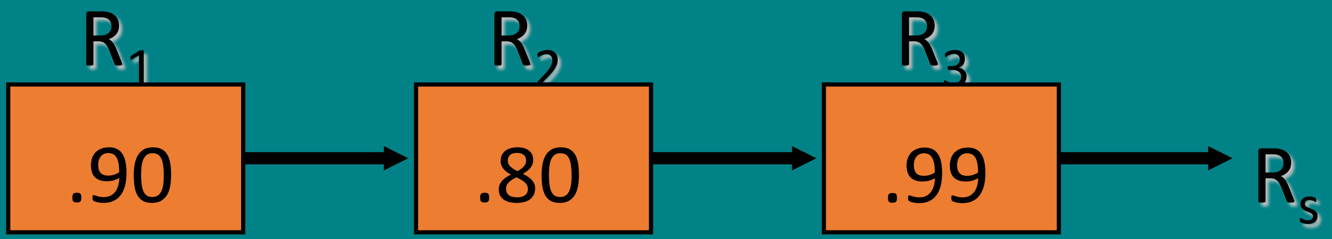
Reliability

Improving individual components

$$R_s = R_1 \times R_2 \times R_3 \times \ldots \times R_n$$

where R_1 = reliability of component 1
R_2 = reliability of component 2
and so on

Reliability Example



Reliability of the process is

$R_s = R_1 \times R_2 \times R_3 = .90 \times .80 \times .99 = .713$ or 71.3%

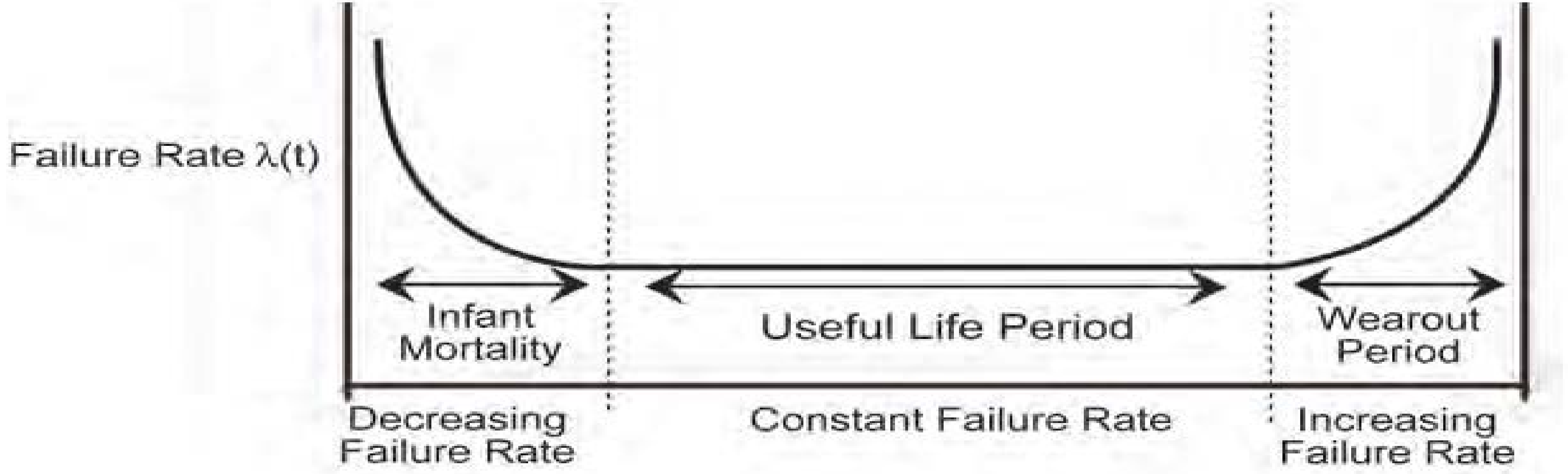
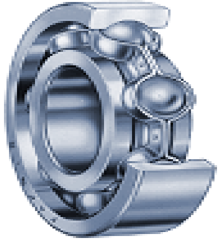
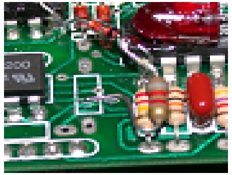
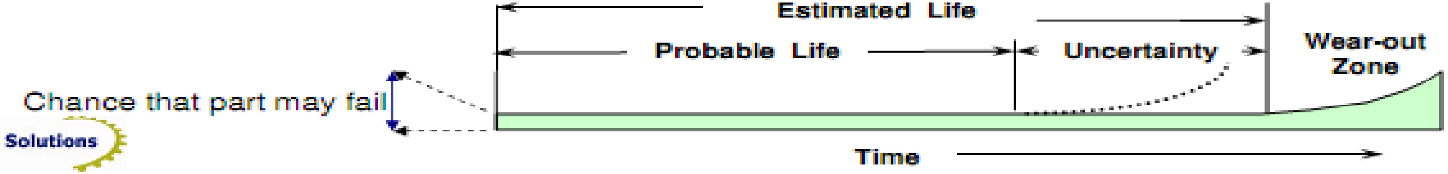


Figure 5.1.1. Component failure rate over time for component population

What is the Reliability of These Parts and Systems?







Lifetime Reliability · Solutions

Failure Prediction Mathematics – Weibull Reliability of Parts and Components

A decreasing failure rate < 1 would suggest 'infant mortality'. That is, defective items fail early and the failure rate decreases over time as they fall out of the population.

Hence need high quality control and accuracy in manufacture and assembly or 'burn-in' on purpose.

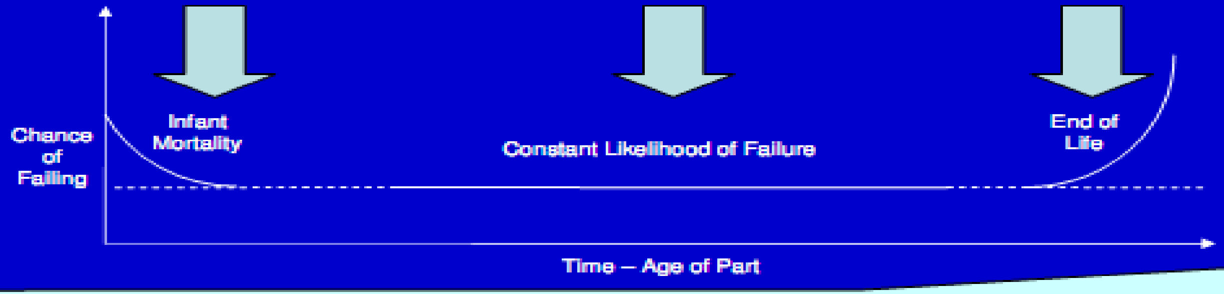
A constant failure rate ~ 1 suggests that items are failing from random events.

Hence cannot predict when a particular part will fail so use condition monitoring to check for failure mechanism.

An increasing failure rate >1 suggests "wear out" - parts are more likely to fail as time goes on.

Hence change parts as part of a PM on a time basis.

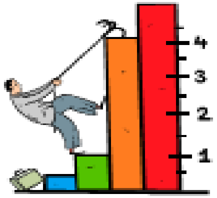
The Maintenance Zones of Component Life

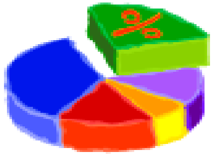


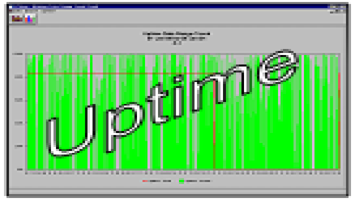
Mr Weibull (say Vaybull) discovered the mathematics to model the life of parts. It uses historic failure data from your CMMS to estimate what life a part has in your operation.

Equipment Performance Trending

- 'Bad Actors' Monitoring
- Mean Time Between Failure (MTBF)
- Mean Time to Repair (MTTR)
- Repeat Failures
- Uptime / Downtime
- Improvement/Change over a Time Period







Overall System Reliability

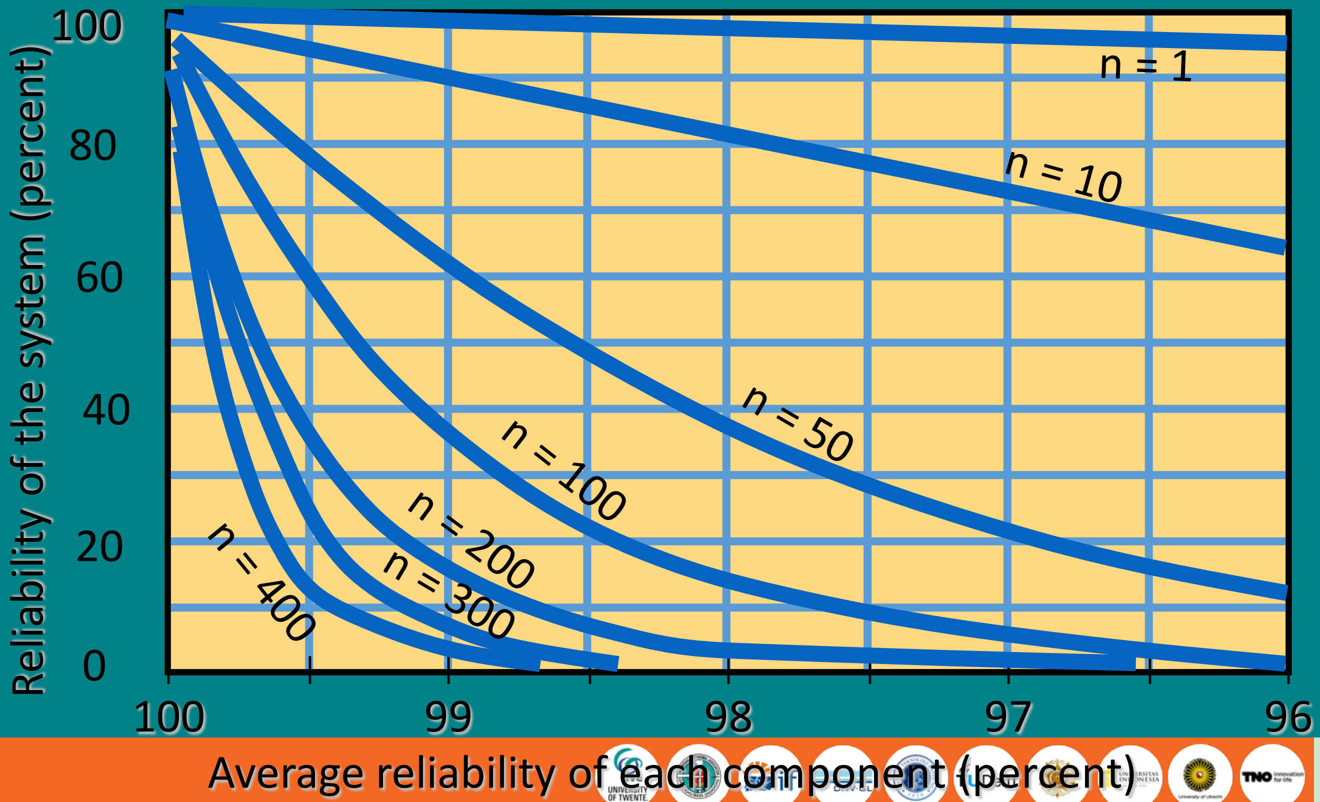


Figure 17.2

Approaches to Improving Machine Reliability

- Overdesign - enhancing the machine design to avoid a particular type of failure
- Design simplification - reducing the number of interacting parts in a machine
- Redundant components - building backup components right into the machine so that if one part fails, it's automatically substituted

TOTAL PRODUCTIVE MAINTENANCE

TPM

- ☑ Designing machines that are reliable, easy to operate, and easy to maintain
- ☑ Emphasizing total cost of ownership when purchasing machines, so that service and maintenance are included in the cost
- ☑ Developing preventive maintenance plans that utilize the best practices of operators, maintenance departments, and depot service
- ☑ Training workers to operate and maintain their own machines

Principle Objectives in Maintenance

- To achieve product quality and customer satisfaction through adjusted and serviced equipment
- Maximize useful life of equipment
- Keep equipment safe and prevent safety hazards
- Minimize frequency and severity of interruptions
- Maximize production capacity – through high utilization of facility

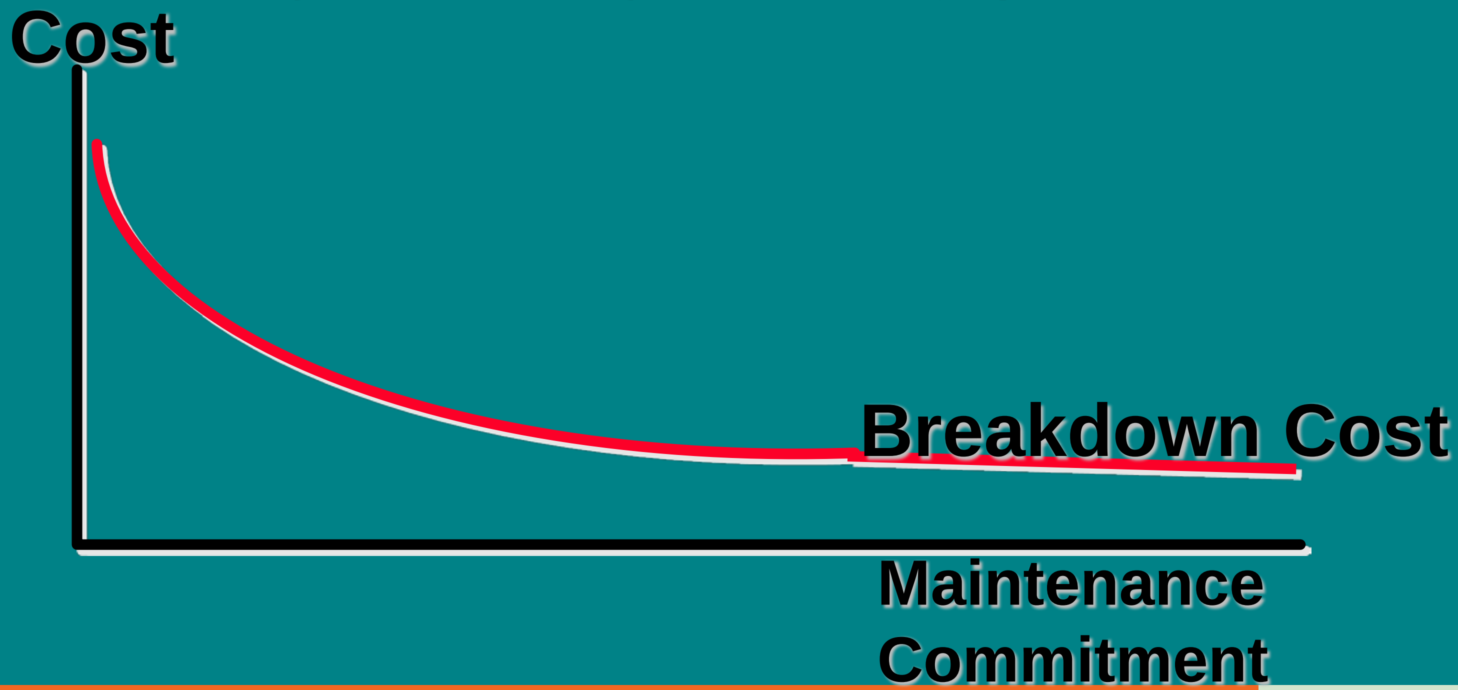
Problems in Maintenance

- Lack of management attention to maintenance
- Little participation by accounting in analyzing and reporting costs
- Difficulties in applying quantitative analysis
- Difficulties in obtaining time and cost estimates for maintenance works
- Difficulties in measuring performance

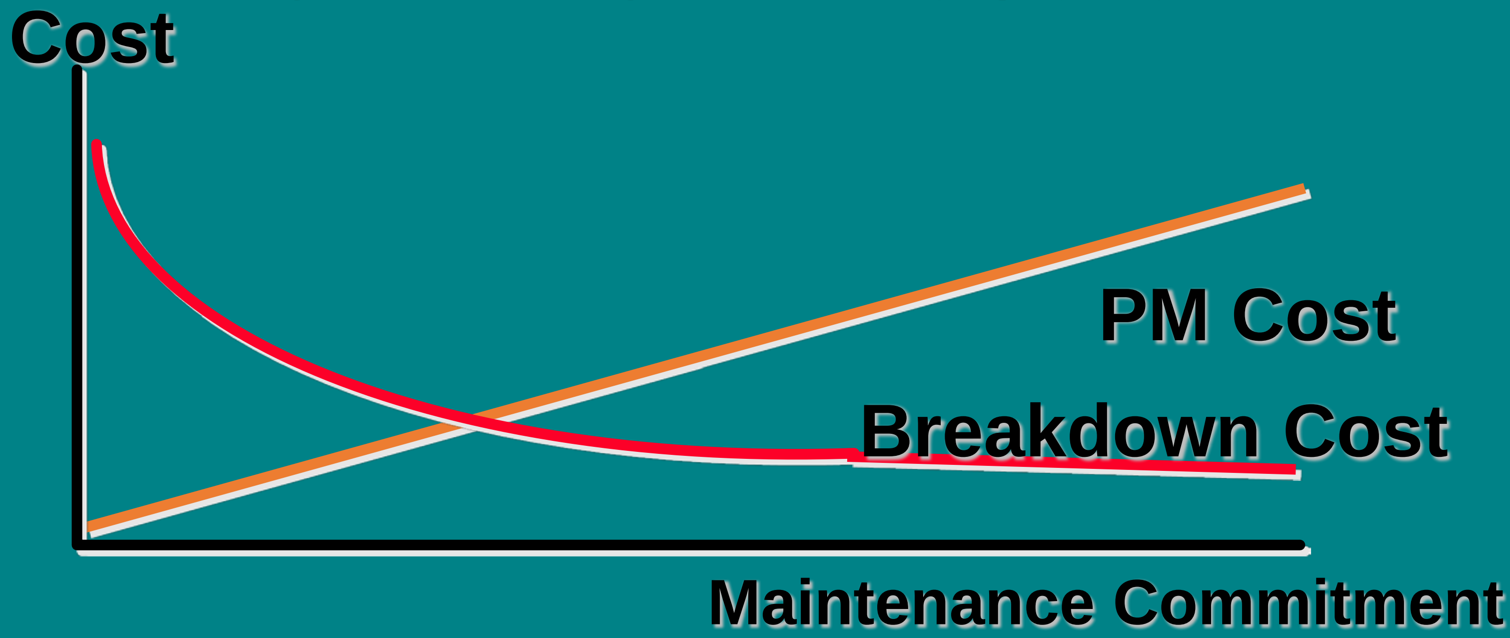
Problems Exist Due To:

- Failure to develop written objectives and policy
- Inadequate budgetary control
- Inadequate control procedures for work order, service requests etc.
- Infrequent use of standards
- To control maintenance work
- Absence of cost reports to aid maintenance planning and control system

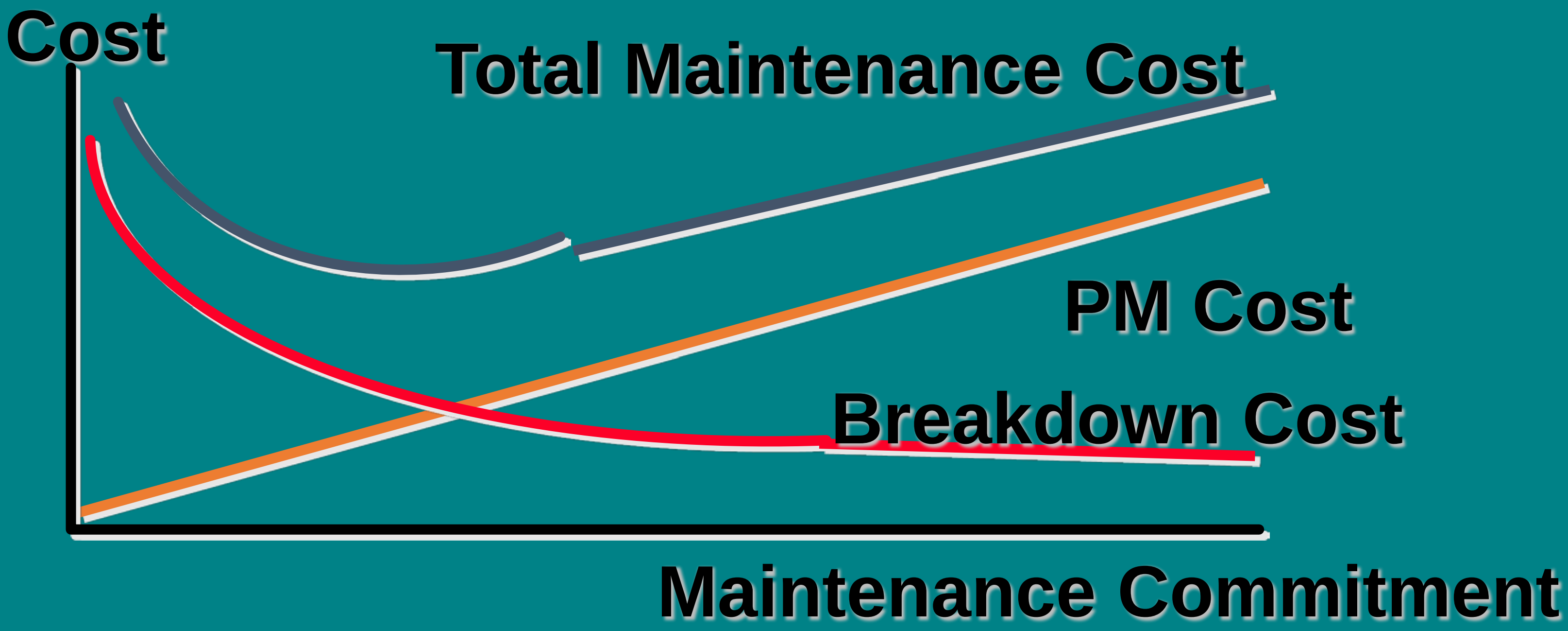
Maintenance Costs



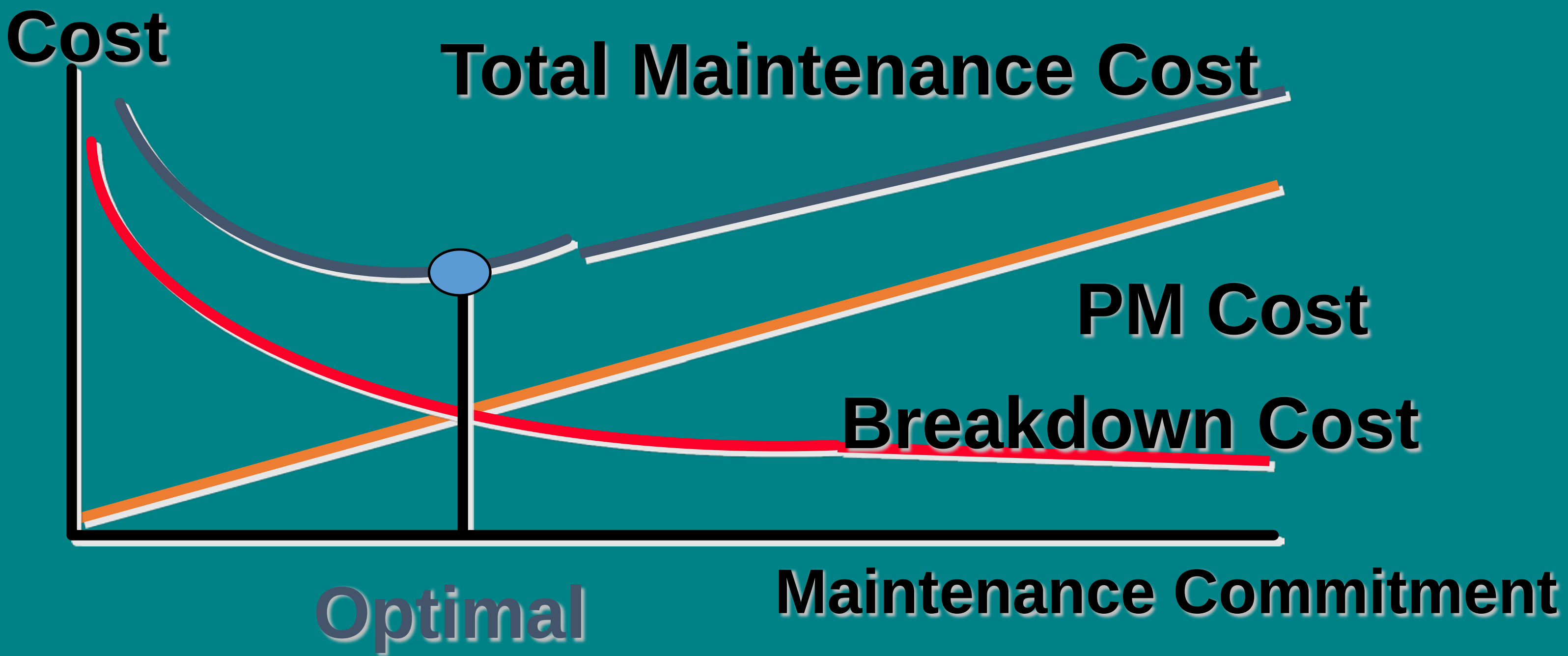
Maintenance Costs



Maintenance Costs

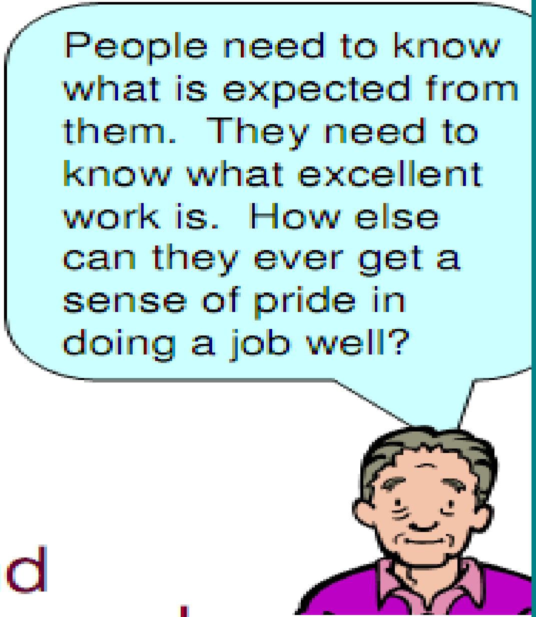


Maintenance Costs



Specifying Workmanship Standards

- Standardised Work
- Setting the Standards for a Job
- Identifying Necessary Skills for a Job
- Failure Preventing Job Procedures



We must protect the plant and equipment from good intentioned people who don't know what they are doing.

Power Plant Performance

Identification of the Relationship between Availability, Reliability and Productivity

DEFINITION

- Availability and Reliability Indices

“Availability is the probability of a device or system being in the operating or up state at a given period t in the future”. (Billinton, P.67)

“Reliability is the probability of a device or system performing the purpose adequately for the period of time intended under the operating conditions encountered”. (Billinton,

P.59)

POWER PLANT CONDITIONS

It is necessary to mention that a power plant would be in one of the four following modes:

- Service mode: producing electrical energy at full load.
- Failure mode: forced out, because of a random failure.
- Maintenance mode: undergoing programmed maintenance.
- Idle mode: neither failure nor programmed maintenance, but there is not enough demand

POWER PLANT CONDITIONS

The above can be mathematically represented by:

$$A = \frac{ST + IT}{T} \times 100 \qquad R = \frac{ST}{ST + FT} \times 100$$

A: availability
R: reliability
ST: total time in service mode during a defined period
FT: total time in failure mode during a defined period
MT: total time in maintenance mode during a defined period
IT: total time in idle mode during a defined period
T: defined period

BUILDING POWER PLANT KPI

Appendix 1: Summary of Maintenance Key Performance Indicators

	Type of Measure	Measuring	Key Performance Indicator	World Class Target Level
1	Result Lagging	Cost	Maintenance Cost	Context specific
2	Result Lagging	Cost	Maintenance Cost / Replacement Asset Value of Plant and Equipment	2 - 3%
3	Result Lagging	Cost	Maintenance Cost / Manufacturing Cost	< 10 – 15%
4	Result Lagging	Cost	Maintenance Cost / Unit Output	Context specific
5	Result Lagging	Cost	Maintenance Cost / Total Sales	6 - 8%
6	Result Lagging	Failures	Mean Time Between Failure (MTBF)	Context specific
7	Result Lagging	Failures	Failure Frequency	Context specific
8	Result Lagging	Downtime	Unscheduled Maintenance Related Downtime (hours)	Context specific
9	Result Lagging	Downtime	Scheduled Maintenance Related Downtime (hours)	Context specific
10	Result Lagging	Downtime	Maintenance Related Shutdown Overrun (hours)	Context specific

BUILDING POWER PLANT KPI

11	Process Leading	Work Identification	Percentage of work requests remaining in "Request" status for less than 5 days, over the specified time period.	80% of all work requests should be processed in 5 days or less. Some work requests will require more time to review but attention must be paid to 'late finish date' or required by date.
12	Process Leading	Work Identification	Percentage of available man-hours used for proactive work (AMP + AMP initiated corrective work) over a specified time period.	Target for proactive work is 75 to 80%. Recognizing 5 -10% of available man-hours attributed to redesign or modification (improvement work) this would leave approximately 10% - 15% reactive.
13	Process Leading	Work Identification	Percentage of available man-hours used on modifications over the specified time period.	Expect a level of 5 to 10% of man-hours spent on modification work.
14	Process Leading	Work Planning	Percentage of work orders with man-hour estimates within 10% of actual over the specified time period.	Estimating accuracy of greater than 90% would be the expected level of performance.
15	Process Leading	Work Planning	Percentage of work orders, over the specified time period, with all planning fields completed.	95% + should be expected. Expect a high level of compliance for these fields to enable the scheduling function to work.
			Percentage of Work Orders assigned	

BUILDING POWER PLANT KPI

16	Process, Leading	Work Planning	Percentage of Work Orders assigned "Rework" status (Due to a need for additional Planning) over the last month.	This level should not exceed 2 to 3%.
17	Process, Leading	Work Planning	Percentage of Work Orders in "New" or "Planning" status less than 5 days, over the last month.	80% of all work orders should be possible to process in 5 days or less. Some work orders will require more time to plan but attention must be paid to 'late finish date'.
18	Process, Leading	Work Scheduling	Percentage of work orders, over the specified time period, having a scheduled date earlier or equal to the late finish or required by date.	95%+ should be expected in order to ensure the majority of the work orders are completed before their 'late finish date.'
19	Process, Leading	Work Scheduling	Percentage of scheduled available man-hours to total available man-hours over the specified time period.	Target 80% of man-hours applied to scheduled work.
20	Process, Leading	Work Scheduling	Percentage of Work Orders assigned "Delay" status due to unavailability of manpower, equipment, space or services over the specified time period.	This number should not exceed 3 to 5%.

BUILDING POWER PLANT KPI

	Type of Measure	Measuring	Key Performance Indicator	World Class Target Level
21	Process, Leading	Work Execution	Percentage of Work Orders completed during the schedule period before the late finish or required by date.	Schedule compliance of 90%+ should be achieved.
22	Process, Leading	Work Execution	Percentage of maintenance work orders requiring rework.	Rework should be less than 3%.
23	Process, Leading	Work Execution	Percentage of work orders with all data fields completed over the specified time period.	Should achieve 95%+. Expectation is that work orders are completed properly.
24	Process, Leading	Work Follow-up	Percentage of work orders closed within 3 days, over the specified time period.	Should achieve 95%+. Expectation is that work orders are reviewed and closed promptly.
25	Process, Leading	Performance Analysis	Number of asset reliability improvement actions initiated by the performance analysis function, over the specified time period.	No number is correct but level of relative activity is important. No actions being initiated when lots of performance gaps exist is inappropriate.
26	Process, Leading	Performance Analysis	Number of equipment reliability improvement actions resolved, over the specified time period. (Did we achieve performance gap closure)	This is a measure of project success.

Operational Challenges in Geothermal Power Generation

CHALLENGES

- Operational challenges
- Redesign and replace
- Proprietary equipment
- Deposition & scaling
- Sampling and analysis

Areas of Maintenance:

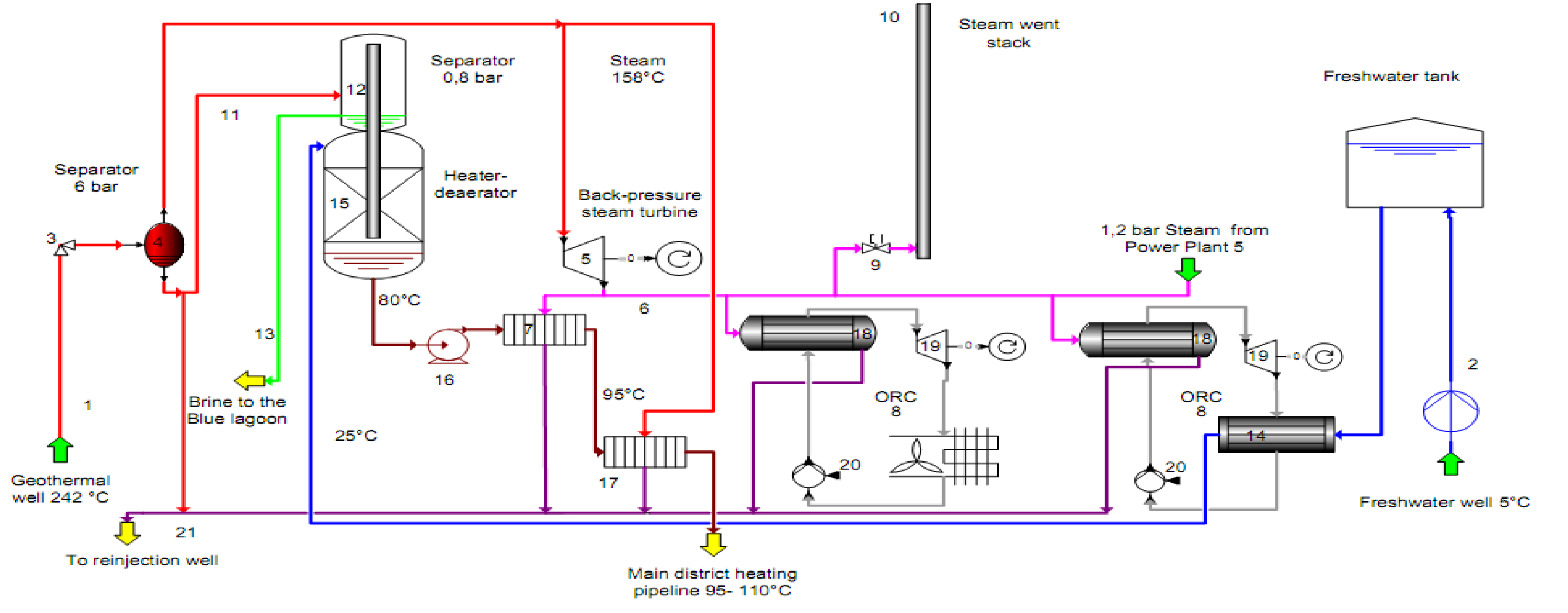
1. Civil maintenance- Building construction and maintenance, maintaining service facilities
2. Mechanical Maintenance- Maintaining machines and equipments, transport vehicles, compressors and furnaces.
3. Electrical Maintenance- Maintaining electrical equipments such as generators, transformer, motors, telephone systems, lighting, fans, etc.

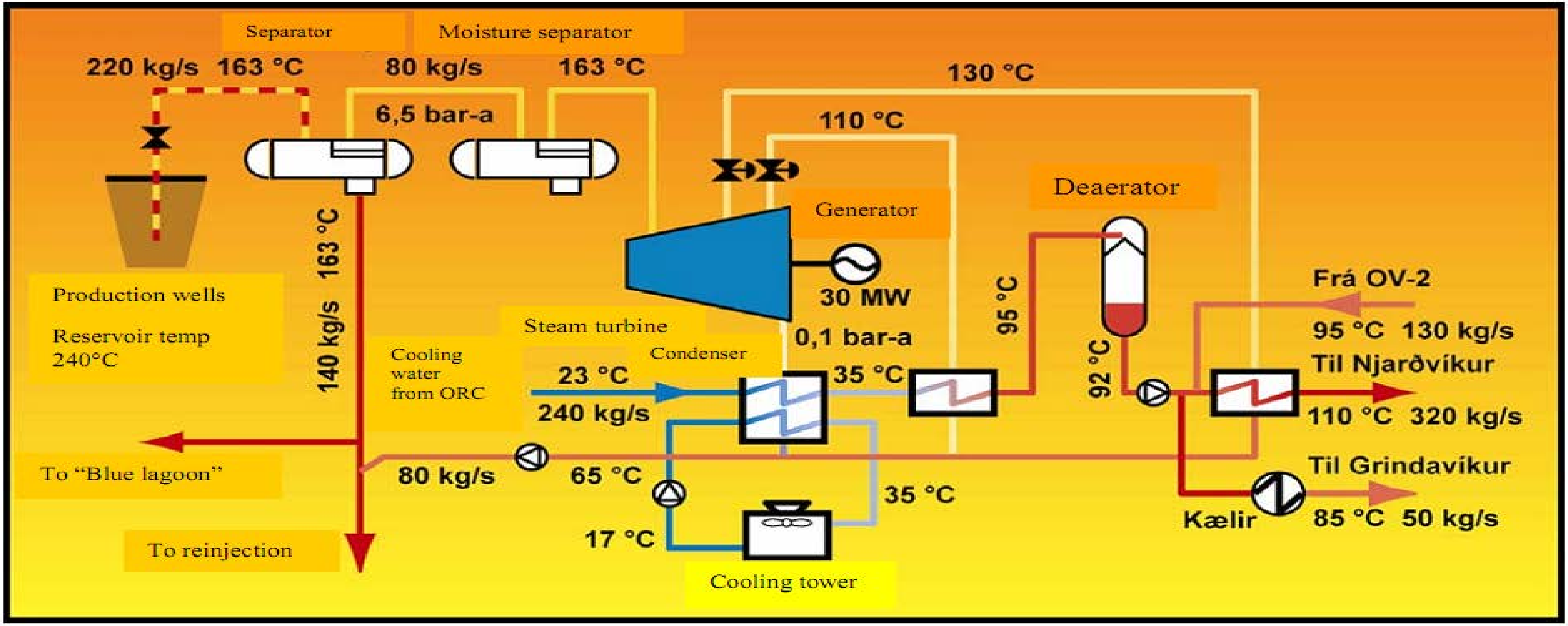
OPERATION CHALLENGES

DESIGN OF PLANTS

Key challenges:

- Matching above ground equipment to below ground performance
- New field testing is a snapshot in time that determines plant design
- Decisions for plant are made before a bulk of the wells are drilled – you don’t really know how the field will perform until the plant is running
- Designing a plant to match current and future performance – difficult
- Allow flexibility in the plant to operate within a range of pressure, temperature and enthalpy.
- One thing is for certain the field will change over the life of the plant
- Incremental process and efficiency improvements with operating plants
- Significant production losses for unplanned or forced outages
- Finding the balance between efficiency, scaling, corrosion and cost


Separator 0,8 bar
Steam 158°C
10
Steam went stack
Freshwater tank
12
11
Separator 6 bar
15
Heater-deaerator
Back-pressure steam turbine
3
4
5
9
1,2 bar Steam from Power Plant 5
80°C
6
7
18
19
13
16
95°C
ORC 8
2
1
Brine to the Blue lagoon
25°C
14
20
17
Geothermal well 242 °C
Freshwater well 5°C
21
To reinjection well
Main district heating pipeline 95- 110°C


Separator
Moisture separator
220 kg/s
163 °C
80 kg/s
163 °C
130 °C
6,5 bar-a
110 °C
Deaerator
Generator
163 °C
140 kg/s
30 MW
95 °C
Frá OV-2
Production wells
Reservoir temp
240°C
Steam turbine
0,1 bar-a
95 °C 130 kg/s
Til Njarðvíkur
Cooling
water
from ORC
Condenser
23 °C
35 °C
92 °C
240 kg/s
110 °C 320 kg/s
To "Blue lagoon"
80 kg/s
65 °C
35 °C
Til Grindavíkur
Kælir
85 °C 50 kg/s
17 °C
To reinjection
Cooling tower

Pipeline Erosion/Corrosion

Pipeline Erosion/Corrosion

Pipeline Erosion/Corrosion

Pipeline Erosion/Corrosion

- Pipeline erosion/corrosion
  - ➢Redesign
  - ➢Select improved materials
  - ➢Reconfigure layout
  - ➢Operate
  - ➢Life improvement from less than 6 months to 3 years and counting
  - ➢Adjust design

- Never under estimate the resources operations and technical to resolve issues
- Geothermal chemistry is different at each field

REDESIGN AND REPLACE

Pipeline erosion/corrosion

Pipeline Erosion/Corrosion

PUMPS

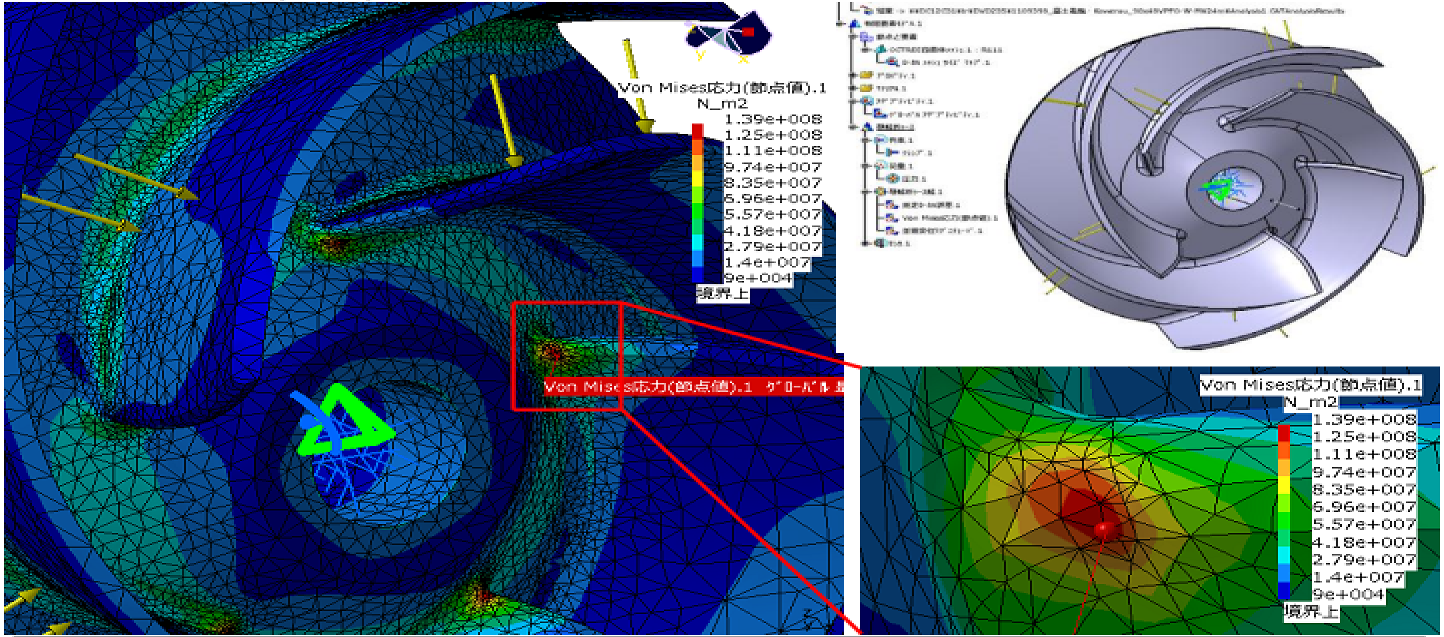
PROPRIETARY EQUIPMENT

Hot well Pump Impellers

PUMPS

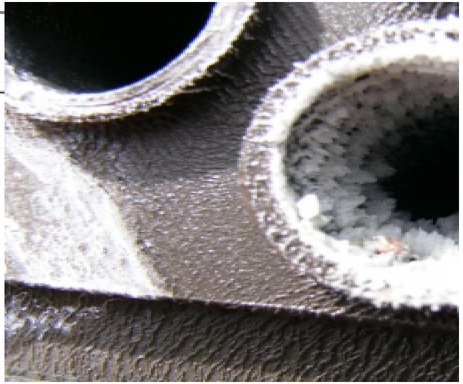
PROPRIETARY EQUIPMENT

Hot well Pump Impellers



DEPOSITION AND SCALING

Heat Exchanger Deposition & Scaling

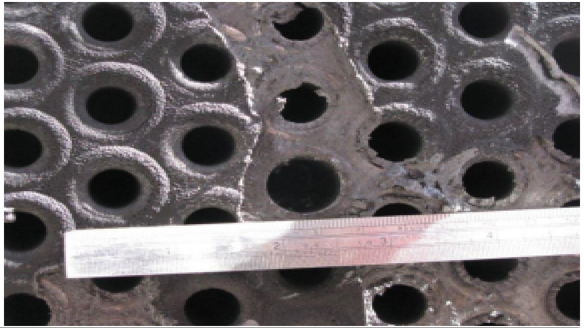


Heat exchangers in binary cycle geothermal power plants are prone to deposition and scaling from minerals in the geothermal brine.

Common deposits in heat exchangers include:

- Antimony and arsenic sulphides
- Silica

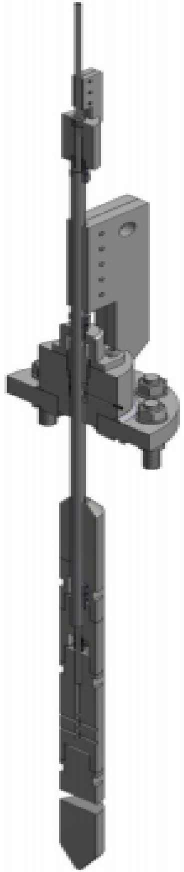
Heat exchanger deposition is often managed through process design and periodic heat exchanger cleaning (either mechanical or chemical)



DEPOSITION AND SCALING

Production Well Scaling

- Production wells are prone to scaling from calcium carbonate (calcite) where boiling occurs in the well
- Chemical dosing below boiling point
- On-going testing and well assessment required



DEPOSITION AND SCALING

Production Well Scaling

SCALING

DEPOSITION AND SCALING

Reinjection well scaling

> Different from field to field
> Don't really know until the station is operational
> Modify brine by injecting sulphuric acid to keep the silica in solution
> Managed by acid injection into HP brine before the first flash stage

DEPOSITION AND SCALING

Brine handling systems

The use of acid dosing systems for silica control can result in severe corrosion issues and material selection challenges.

Sulphuric acid service with high chloride brine at elevated temperatures can create problems

Acid dosing quills before and after brine service at elevated temperatures

DEPOSITION AND SCALING

Brine handling systems

Brine handling systems are typically constructed from carbon steel and normally form a corrosion product layer of ferrous sulphides and magnetite

- Corrosion risk is heightened
- Corrosion typically worse in areas of two phase flow
- typically worse in locations with flow disturbances
- Corrosion resistant alloys can be used – although these have there own issues
- Antimony deposition sets-up galvanic corrosion

DEPOSITION AND SCALING

Steam system

Geothermal power plants typically operate with saturated steam and steam piping is typically fabricated from carbon steel.

> Ferrous sulphide and magnetite corrosion product layer
> Corrosion product layer is not particularly stable
> Introduction of oxygen can result in rapid and severe corrosion

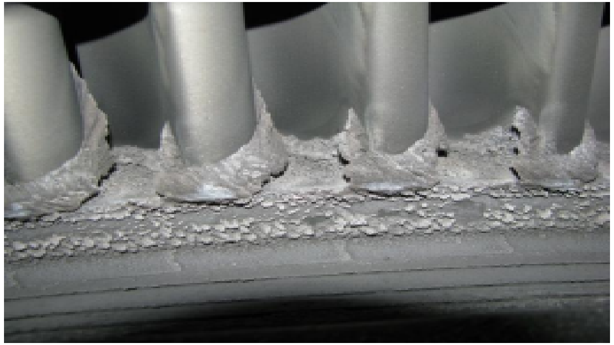
Steam Turbine

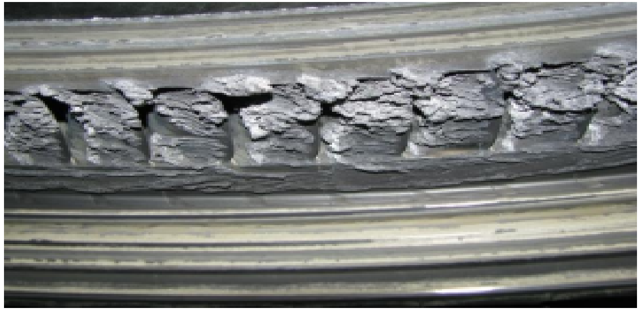
Scaling of geothermal steam turbines is not uncommon

Turbine scaling is a result of poor steam purity
> Brine carry-over
> Volatile transport
> Corrosion product transport (ferrous sulphides)

Silica is the most common deposit on geothermal steam turbines and is subject to both mechanical and volatile transport.

Turbine scaling can be exacerbated by dry steam conditions





DEPOSITION AND SCALING

Steam Turbine

SAMPLING AND ANALYSIS

Power Plant Sampling

The low pressures, saturated steam and large pipe diameters can make representative sampling in geothermal power plants difficult.

- In a multi-flash plant low pressure steam systems may operate at less than 3bar(a)
- Pipe diameters can be up to 1200mm
- Steam can contain a high non-condensable gas content
- Steam chemistry determines deposition and erosion/corrosion rates

- Currently investing significant resources to achieve online purity which we believe will be essential in providing long term trouble free turbine operation.
- Challenge – online steam purity is not done anywhere else in the geothermal environment

Production and Re-injection Well Casings

Geothermal well casing are subject to corrosion on both the inside and outside of the casing. External casing corrosion can be particularly problematic.

Well casing corrosion:

> Carbon steel casing material commonly used

> Hydrochloric acid present in some geothermal reservoirs

> Sulphuric acid present in some heated aquifers

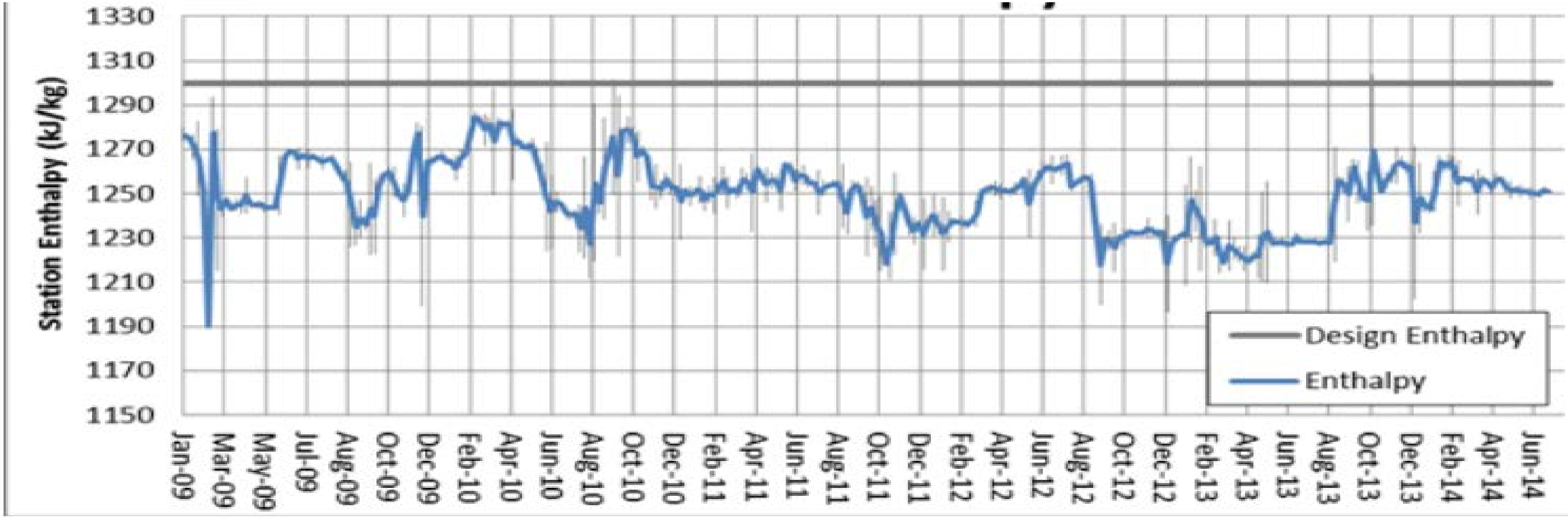
> Bicarbonate waters can corrode well casings when cement is damaged

Where well casing corrosion is problematic corrosion resistant cements may be used and in in some cases well casings may be fabricated from corrosion resistant alloys.

GEOTHERMAL RESERVOIR

Enthalpy

> Guaranteed the field will change in pressure, enthalpy and output.



Below Ground

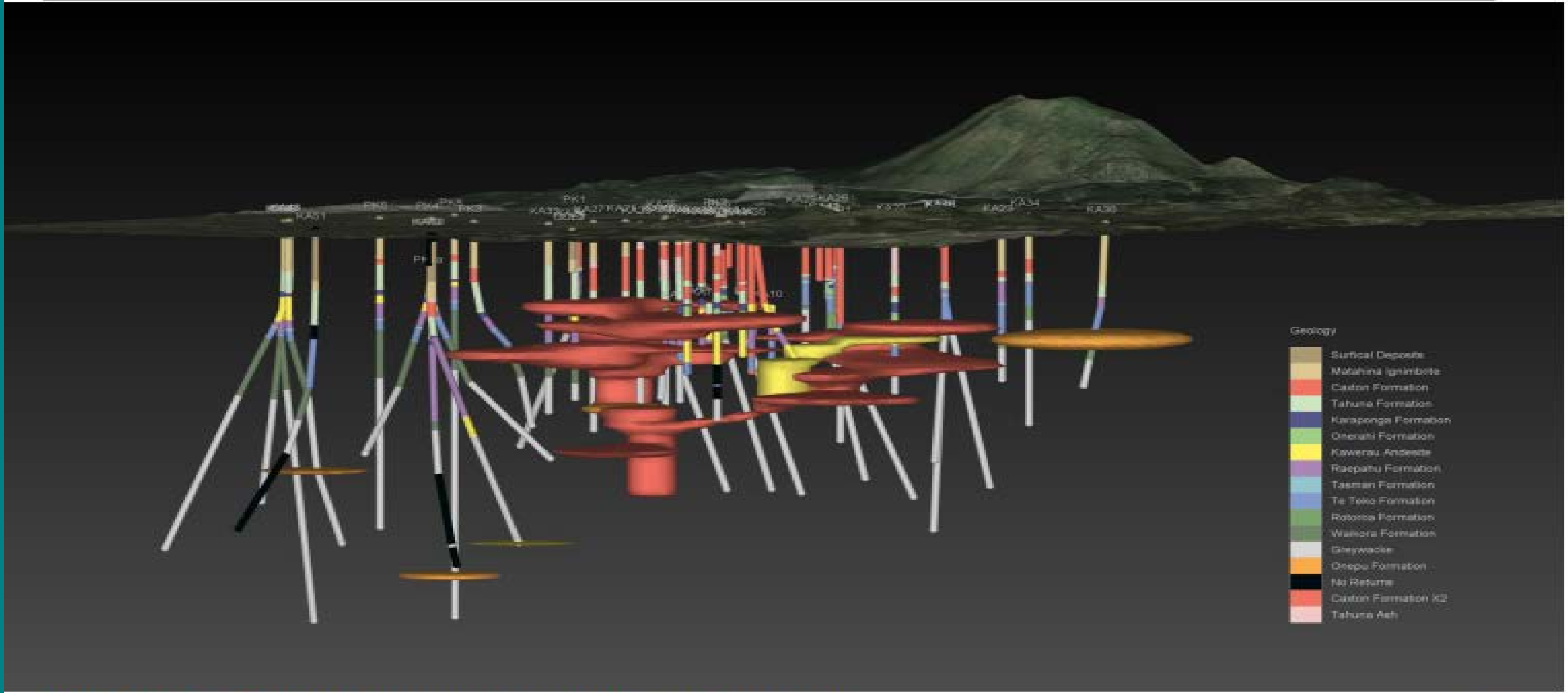


Figure 7: Slug flow knocked the pipe off its supports.

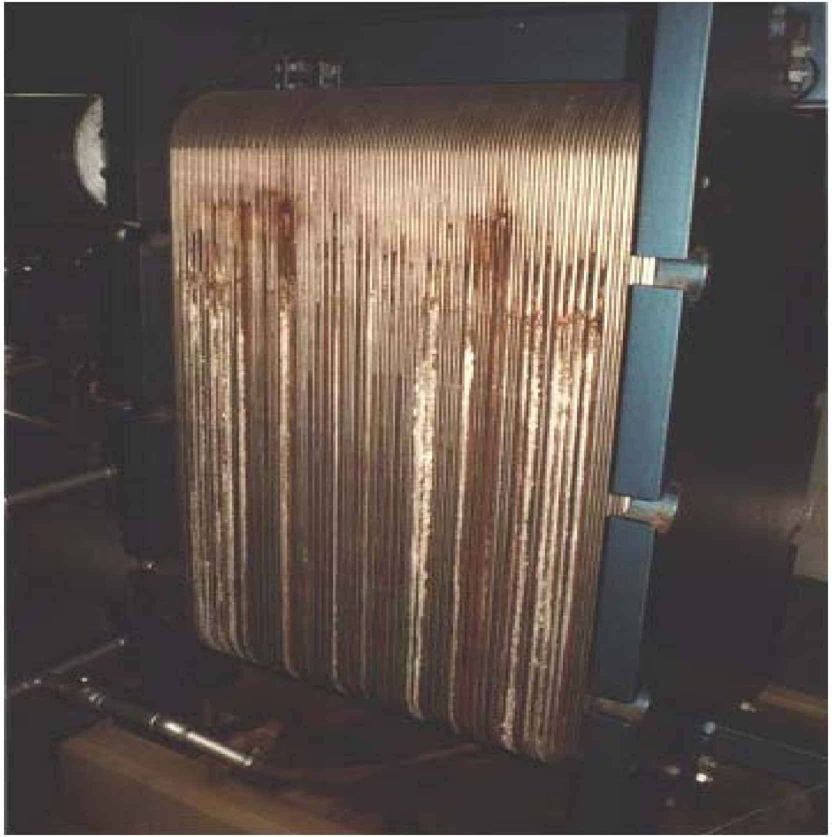


Figure 8: A plate heat exchanger with leaks.

Figure 9: Silica scaling in a 500 mm brine pipe.

Figure 10: Silencer after cleaning. Inlet pipe can be seen on the bottom.

5.10 Steam turbines

Steam turbines have to be dismantled every year to clean the scaling from the first-stage steam nozzles. The scale in the nozzles is usually silica or calcite. This nozzle scaling problem has not yet been solved adequately but some methods of steam scrubbing are being tested.

Figure 11: Steam turbine inlet nozzles with intensive scaling.

Figure 13: ORC cooling fan with gear motor.

The fan belts on the air cooled condensers used to snap at an alarming rate. The fan belts hardened because of hydrogen sulphide in the atmosphere and high humidity. This problem was solved by installing geared electrical motors for the fans.

Before an effective air cleaning system was installed (see section 5.5), the control system hardware used to suffer