Centrifugal Compressor Failure Analysis

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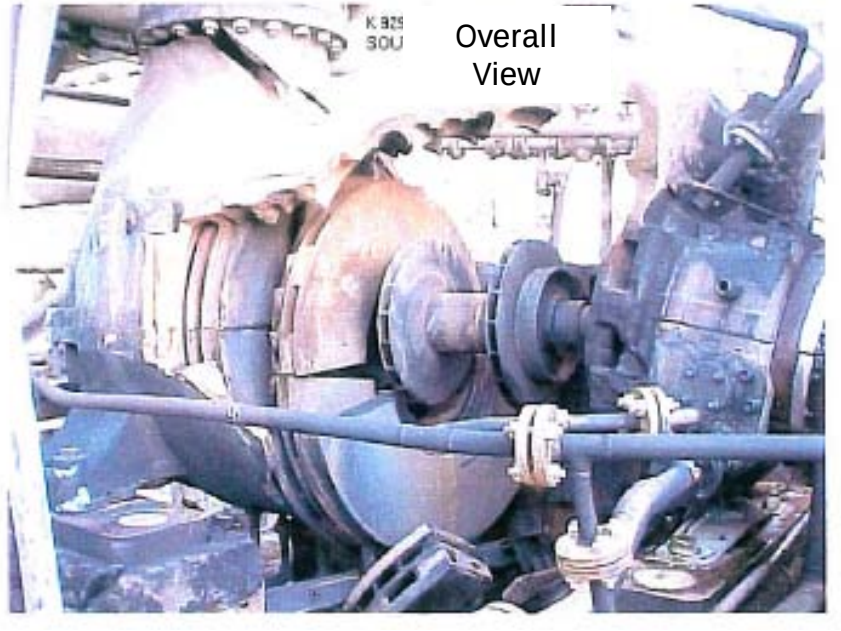
Outline

- Introduction & Background
- Site Visits
- Root Cause Failure Analysis
  - Failure Site Assessment
  - Mechanical, Metallurgical, Compressor Performance
  - Failure Scenario Assessment
- Conclusions
- Recommendations

Introduction & Background

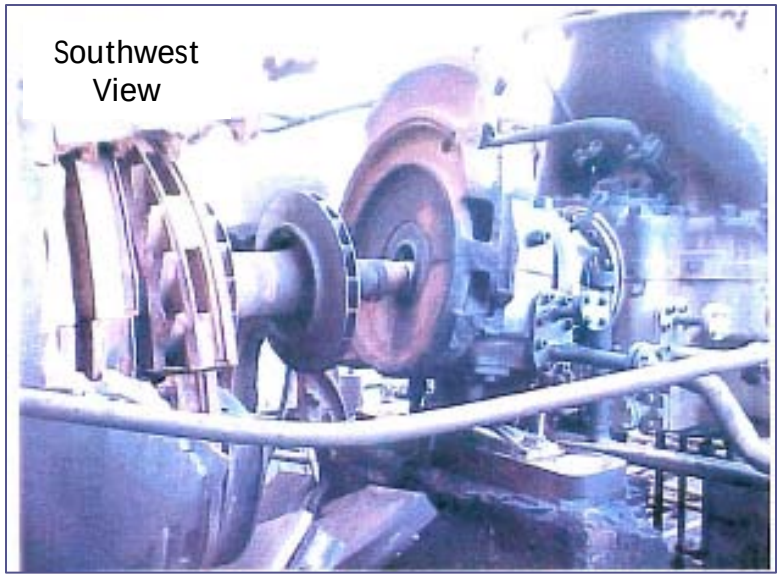
- Compressor failure at refining facility in Gulf Coast of USA
  - 6000 HP two stage process gas compressor in catalytic cracking process
  - Catastrophic failure occurred prior to shutdown for turnaround

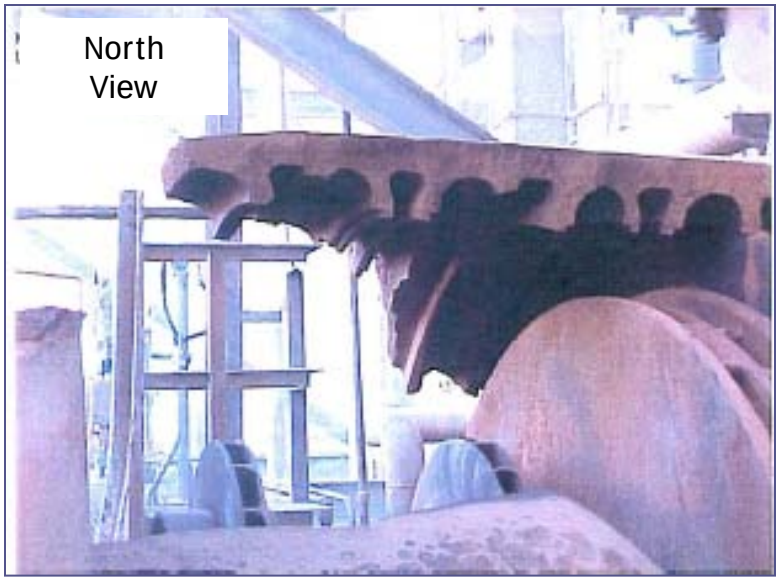


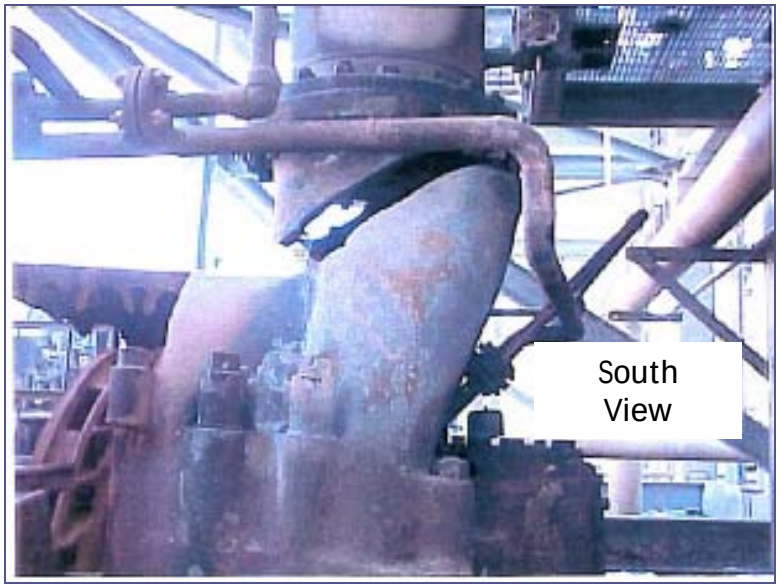
Site Visits

- KHE conducted 4 site visits
  - Observed failed compressor – *documentation*
  - Gathered relevant data – *process/mechanical*
  - Interview plant personnel – *chain of events*
  - Inspect failed components - *metallography*
  - Directed removal of compressor – *preservation of evidence*
  - Discuss analyses results conducted – *Failure scenarios*

Failure Site Assessment



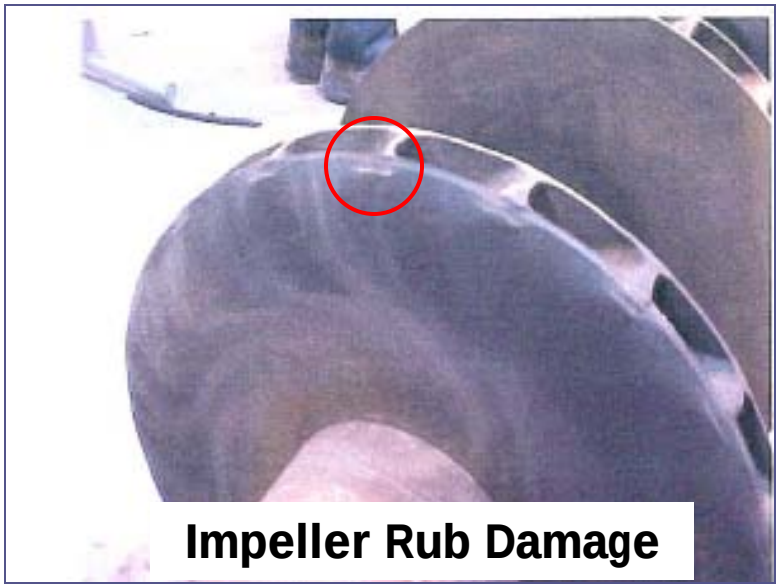




- Impellers still on rotor
- Sudden case rupture evidence

Bearing Housing Damage

Mechanical Seal Damage



Impeller Rub Damage

- Evidence of rubbing

Recreation of Failed Compressor

Damaged Compressor

Small damage parts

Root Cause Failure Analysis

Metallurgical Assessment

- Damaged casing separated by brittle fracture under sudden overload
  - Most of the case broke into large pieces
  - No sign of fatigue, corrosion or impact damage
  - Fracture origin difficult to detect due to brittle nature of cast iron
- Inlet vanes showed signs of thinning and pitting due to corrosion but had no effect on the failure
- Corrosion on pipe and cast fittings
  - Not related to failure

Root Cause Failure Analysis

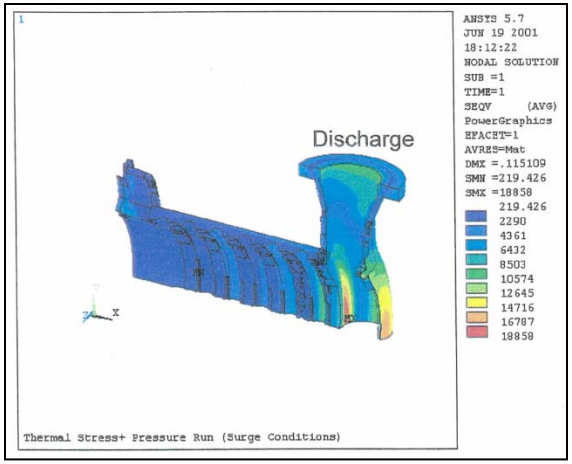
Mechanical Assessment - Vibrations, Bearings, Power

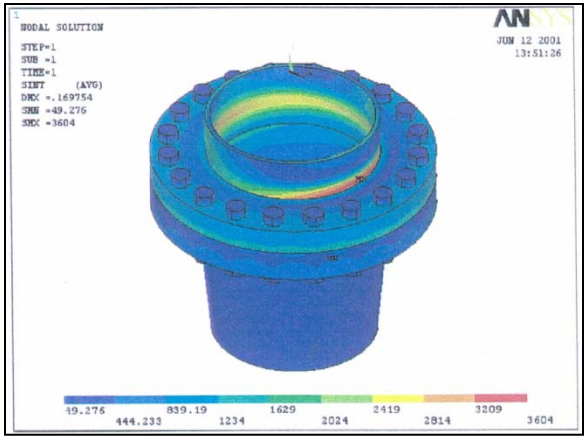
- No significant changes in measured radial and axial vibration levels before failure (maybe due to slow sampling time)
  - However, Stage 2 thrust bearing shows significant activity even though failure occurred in Stage 1
    - Maybe due to coupling of stages or clearances favor loading in Stage 2
- Lower bearing temps suggest bearings loads decreased
- Power trend shows unloading of compressor (decreasing process load) at 3:30 am
  - After 6:50 am power signals visibly unstable
- Motor and compressor power imbalance possible due to:
  - Increased flow through balance line
  - Measured pressure ratios lower than actual
  - Measurement error in flow rate at low flow
  - Recirculation through Stage 1.

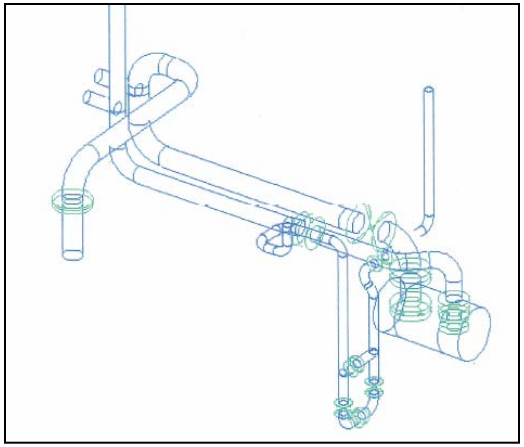
Root Cause Failure Analysis

Mechanical Assessment – Thermal, nozzle design, piping

- Case thermal stresses below case strength
- Suction and discharge pipe stresses within acceptable design stress levels
- Discharge nozzle stresses acceptable



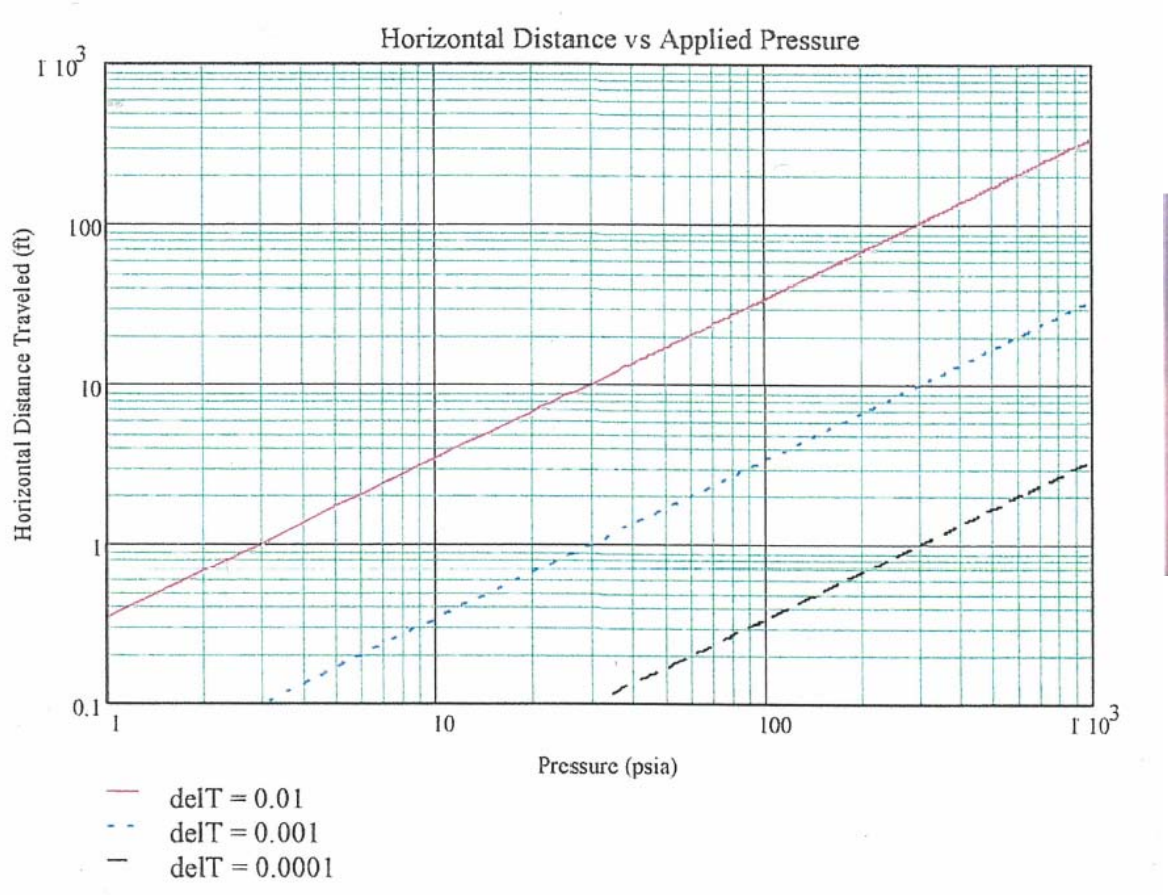




Root Cause Failure Analysis

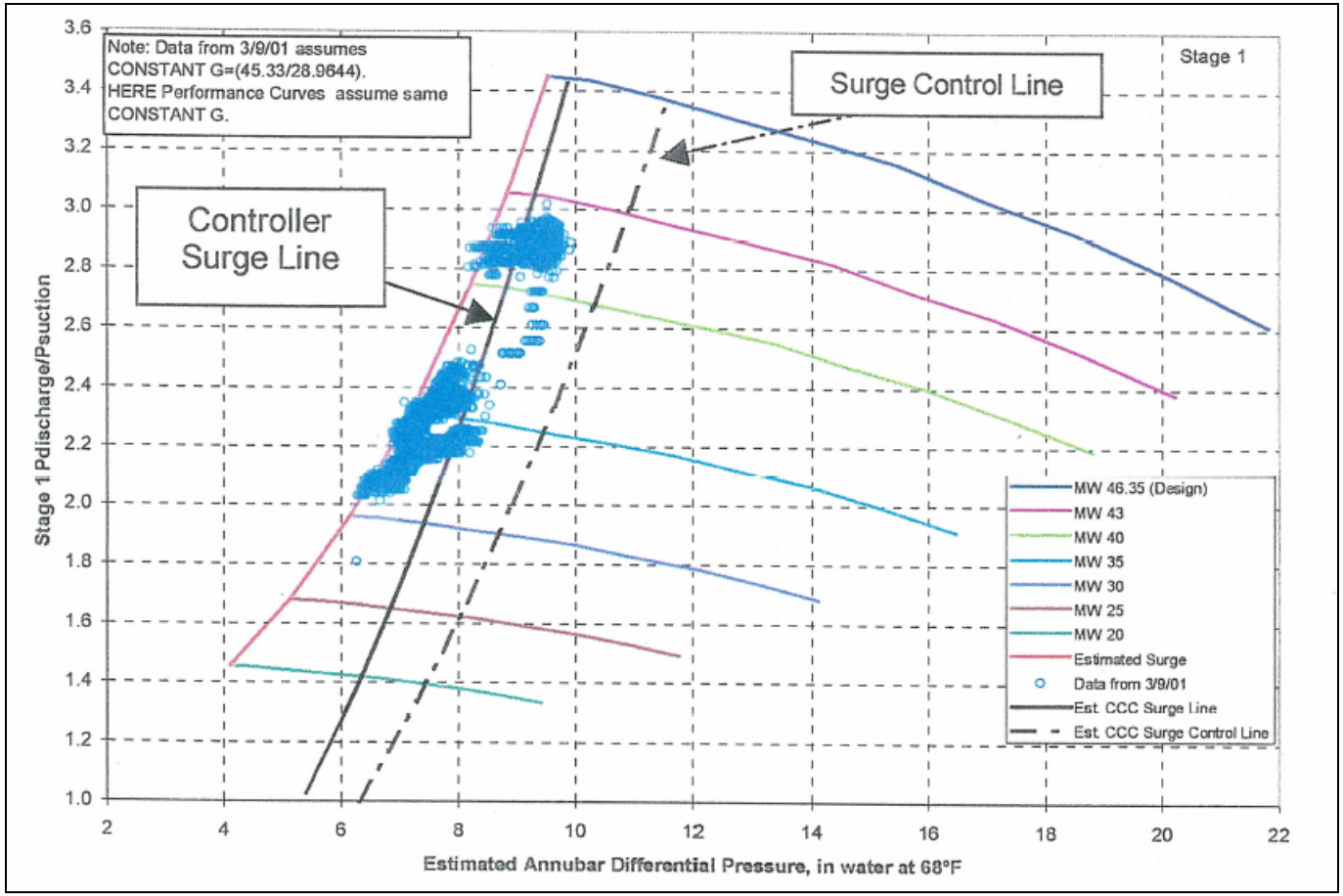
Mechanical Assessment – Projectile Analysis

- 50 lbs projectile piece due to explosion not discharge pressure



Root Cause Failure Analysis

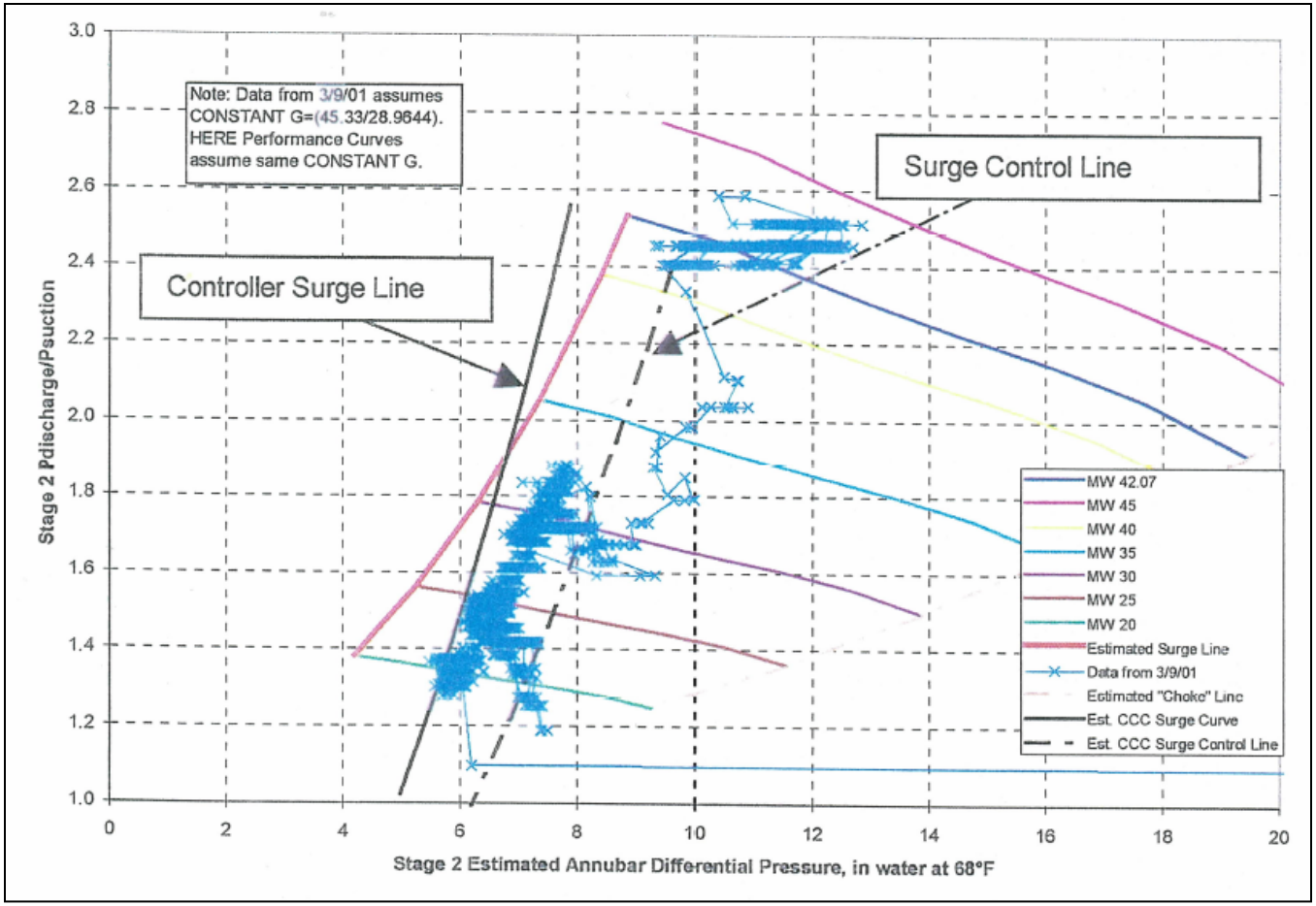
Compressor Performance Review – Stage I



- Surging evidence
  - Data from 3:00 AM until failure around 7 PM

Root Cause Failure Analysis

Compressor Performance Review – Stage II



- Evidence of surging evidence
  - Data from 3:00 AM until failure around 7 PM

Root Cause Failure Analysis

Surge Control Evaluation

- Surge control with spillback valve for both stages
  - Inadequate, response time too slow
  - Separate surge control systems with short response time needed for each stage

Root Cause Failure Analysis

Failure Scenario Assessment

- At 3:30 am periodic surges started; before 4:00 am a more significant surge took place
  - Compressor more unstable
    - Flow readings, amps readings of motor drive and thrust bearing temps (no protection)
- After initial surging, erratic DSC trend data
- Another major surge at ~ 6:50 am after reactor shutoff
  - Possible damage to balance piston or labyrinth seals of 1 Stage
  - Compressor became highly inefficient
  - 1 stage discharge temp increase while suction temp decreased
    - Probably due to recirculation via internal leak from component damage, incipient surge, full surge or gas through balance line

Root Cause Failure Analysis

Failure Scenario Assessment

- At 7:14 pm another possible significant surge might have cause the following failure scenario:
  - Thrust rotor towards discharge end (no protection)
  - Impeller contact with stationary components
    - Rub damage on backside of third impeller possibly caused upper and lower sections compressor failure, allowing air to enter compressor
    - Ignition source as well
- **Analysis of all data provided strongly suggested the root cause of the failure is the surging of the compressor without adequate surge protection.**
- Without surging , failure would not have occurred.

Conclusions

- Analysis of all data suggest that surging of the compressor without adequate surge and thrust bearing (axial displacement and temperature) protection were main causal factors.

Recommendations

- Modification of compressor surge control
  - Provide appropriate surge protection for both stages
  - Surge control with only Stage 2 spillback should be reviewed
- Verify material imbalance around shutdown
  - Review up and downstream process flows
- Use performance curves during operation
- Install polytrophic/measured discharge temp alarm
- Install surge alarm
- Install thrust movement and vibration protection systems

Recommendations

- Install on-line gas analyzer
  - Account molecular weight variations for suction flow measurements
  - Improved compressor control
- Install leak detection monitors

Recommendations were implemented and the replacement compressor ran well for several years until the plant was shut down and dismantled