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Thermal Stress and Fracture Risk Analysis During Emergency Blowdown of High-Pressure Gas Pipelines

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Introduction :

Emergency blowdown operations in high-pressure natural gas pipelines induce rapid depressurization, causing significant temperature drops due to Joule-Thomson expansion. These transient thermal effects can lead to severe thermal gradients across the pipe wall, generating critical thermo-mechanical stresses. This study investigates the magnitude of thermal and hoop stresses in a 25-km, 24-inch carbon steel pipeline during a simulated blowdown scenario. Using a steady-state segmentation approach in Aspen HYSYS 3.2 and analytical stress equations, we calculate stress development as a function of temperature and pressure drop. Results show that thermal stresses may exceed 130 MPa for cooling rates of 55 °C, and combined stresses approach or exceed the yield strength of ASTM A106 Grade B. When minimum wall temperatures fall below the material's ductile-to-brittle transition temperature (DBTT), the risk of brittle fracture becomes substantial. The study highlights the need for thermal stress mitigation strategies and contributes to safer blowdown system design in compliance with API 521 and ASME B31.3 standards.

- Importance of emergency depressurization (blowdown) in gas transmission networks
- Common failure modes: overpressure, thermal shock, material embrittlement
- Review of previous accidents (e.g., Ghislenghien, Texas City)
- Knowledge gap: limited integration between process simulation and mechanical stress prediction
- Objective: simulate a blowdown scenario and assess thermal stress and fracture risks

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Results: 3.1 HYSYS Results

- Temperature dropped from 35 °C to –20 °C within minutes
- Mass flowrate started at ~26 kg/s, decreased with pressure
- Rapid cooling identified in first 3–5 minutes of blowdown

3.2 Stress Analysis

- Thermal stress ≈ 130 MPa for ΔT = 55 °C
- Hoop stress ≈ 203 MPa at 80 bar
- Combined stress > 330 MPa → close to or exceeds yield strength

3.3 Fracture Risk Assessment

- Wall temperatures < DBTT → brittle behavior likely
- Risk of crack initiation at inner wall, especially in long rigid segments
- Need for design mitigation: staged blowdown, insulation, material selection

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4. Safety Implications

- Risk of unpredicted pipe failure during emergency depressurization
- API 521 does not cover thermal stresses in depth → needs mechanical integration
- Importance of coupling process simulations with structural checks

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5. Conclusion

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- Emergency blowdown can create severe thermal gradients and stresses
- Simulation shows potential for plastic or brittle failure in unmitigated systems
- Suggests practical mitigation:
    - Blowdown rate control
    - Minimum design metal temperature (MDMT) verification
    - Insulation or preheating in cold environments

References

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