A Technical and Economic Study for the Application of the New Grade Thor™115 in Refinery Furnaces Pipes

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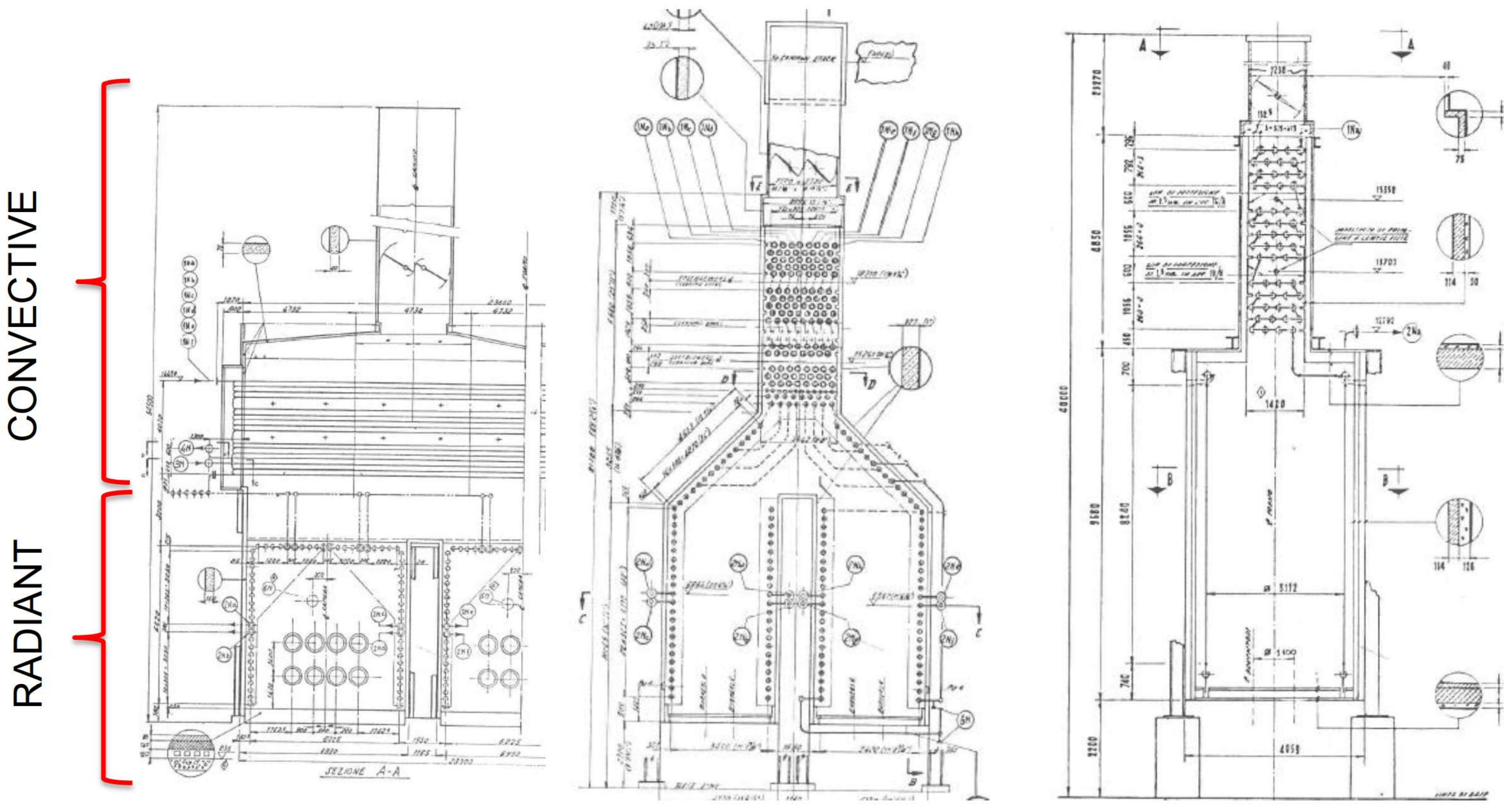
Outline

- ✓ Fired Heater Furnaces and Damage mechanisms
- ✓ Metallurgy and properties of Thor™ 115 and P9
- ✓ Life modelling
- ✓ Model Validation with real cases
- ✓ Economic evaluation and benchmark between Thor™ 115 and P9
- ✓ Conclusions

Fired heater furnaces



BOX type

CABIN type

CYLINDRICAL type

Damage mechanisms

- **External oxidation**: oxide scale formation in presence of oxygen at the external piping surface. The metal loss increases with increasing temperature. Critical in areas of flame impingement, localised overheating;
- **Corrosion**: Two main corrosion mechanism:
  - Sulfidation
  - Naphthenic Acid Corrosion (NAC).
- **Coking**: crude oil thermal instability at the operating conditions. Coke deposits at inner surface cause thermal gradient increasing and metal temperature raise beyond the nominal conditions;
- **Carburization**: coke formation and chemical reaction with metal; formation of carbides. The inner layer will result in an embrittled region with increased hardness, which can bring to an unexpected and unpredictable brittle failure (reduced creep ductility, spalling);

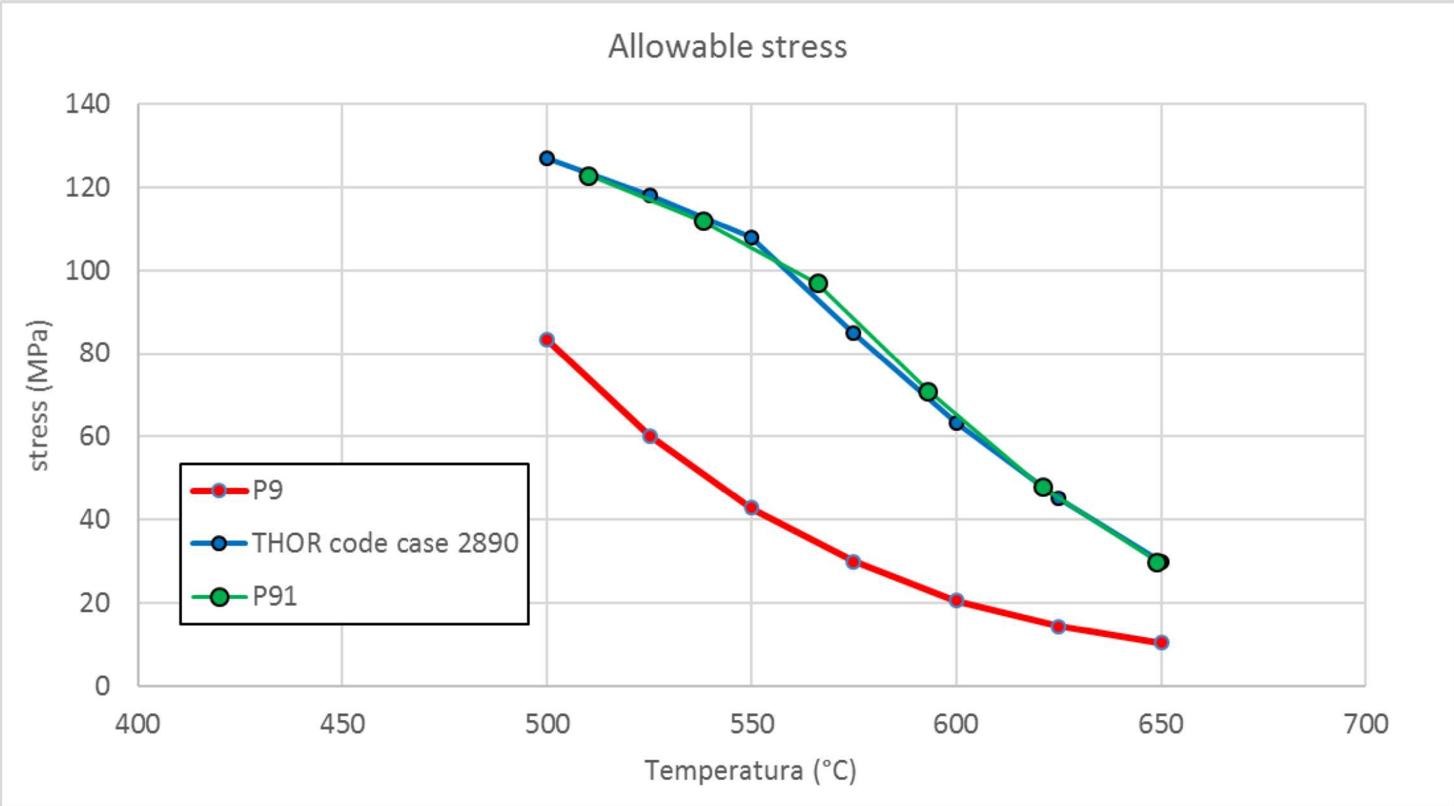
Metallurgy and properties

- ✓ P9: base grade used in pipes. Introduced in 1940-1960 to improve corrosion resistance; martensitic microstructure.

- ✓ Thor™ 115: Tenaris new martensitic steel for high temperature applications with enhanced oxidation resistance;
    - Improved steam oxidation resistance vs. 9/91Cr grade
    - Creep properties similar to grade 91
    - Friendly in manufacturing and welding

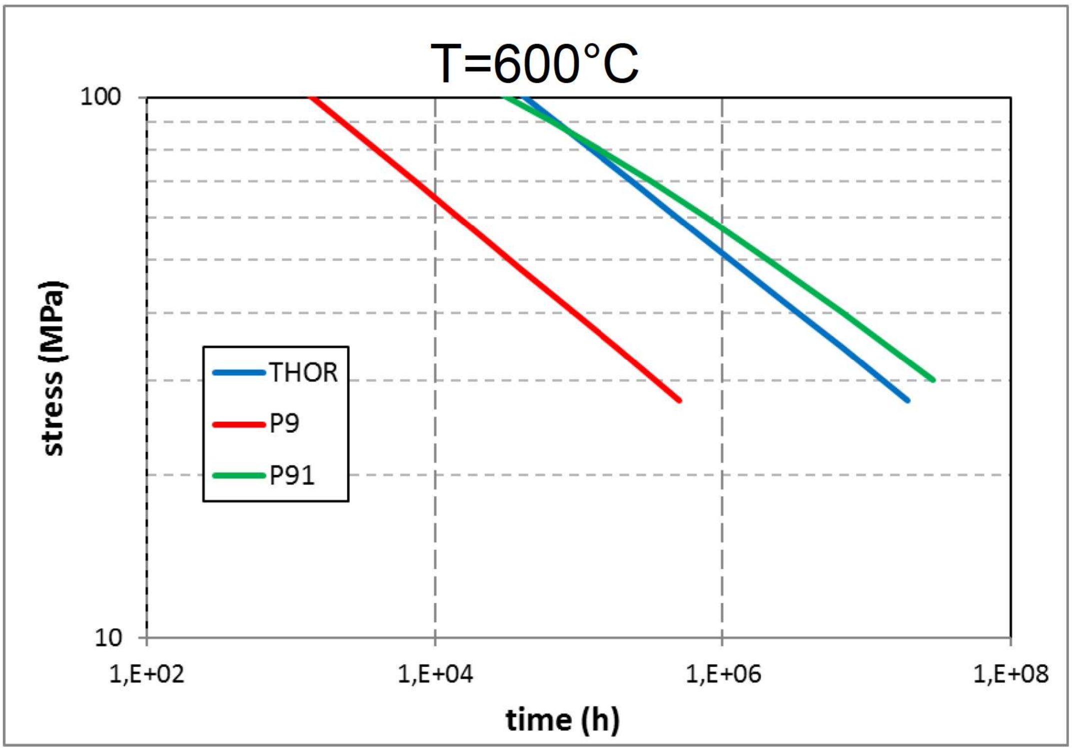
	C	Mn	Si	Cr	Mo	V	Nb	N
Gr. 9	0.1	0.4	0.6	9.0	1.0	-	-	-
Gr. 91	0.1	0.4	0.4	9.0	1.0	0.2	0.08	0.05
Thor™ 115	0.1	0.4	0.4	11.0	0.5	0.2	0.04	0.05

Allowable stress



Conventional creep initiation: T=575°C (P9: 520°C)

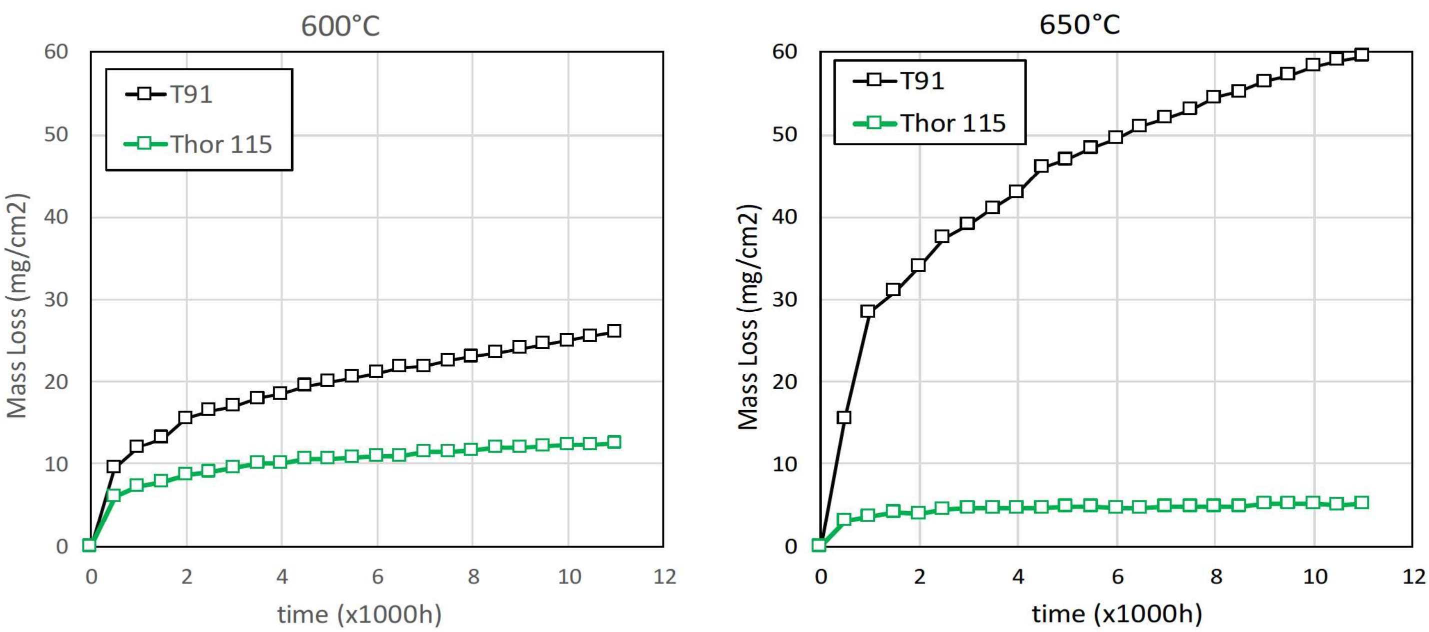
Creep strength



Conventional creep initiation: T=575°C (P9: 520°C)

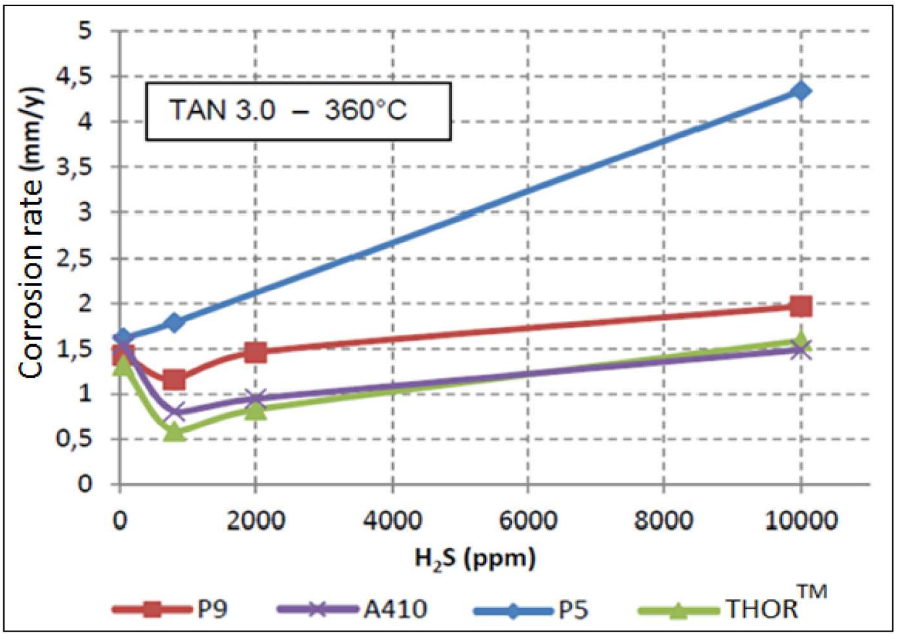
Oxidation and corrosion

Steam oxidation tests (ORNL) in the range 600-650°C
Comparison with gr. 91



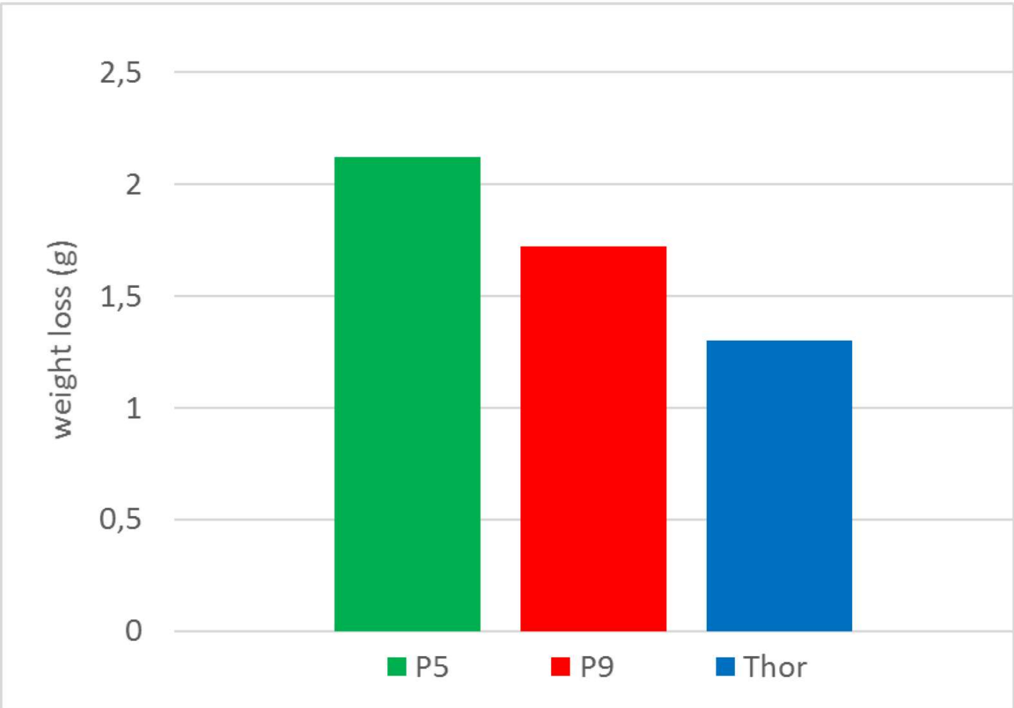
Oxidation and corrosion

Sulphidation and Naftenic Acid Corrosion
Venezia Tecnologie Pilot Plant
Comparative tests in naphtenic and sulphidic environment



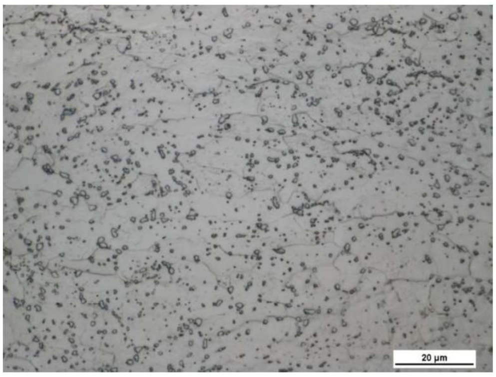
Oxidation and corrosion

Heavy Gas Oil (HGO) hydrotreating tests (sulphidation)
pilot plant in ADNOC Research Center (UAE)
2 cycles tests @ 1 month/each: T=390°C+420°C

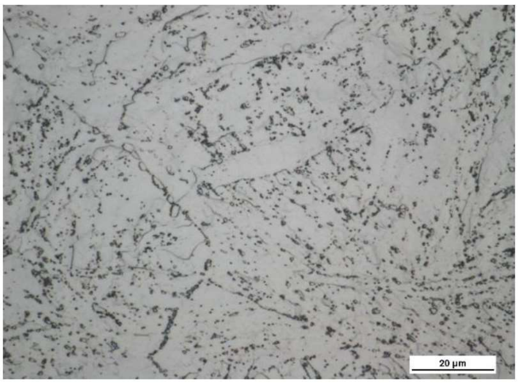


Microstructural evolution

- ✓ Crept specimens examination
- ✓ Metallographic analysis
- ✓ Hardness decay due to overtempering



P9 80000h@600°C

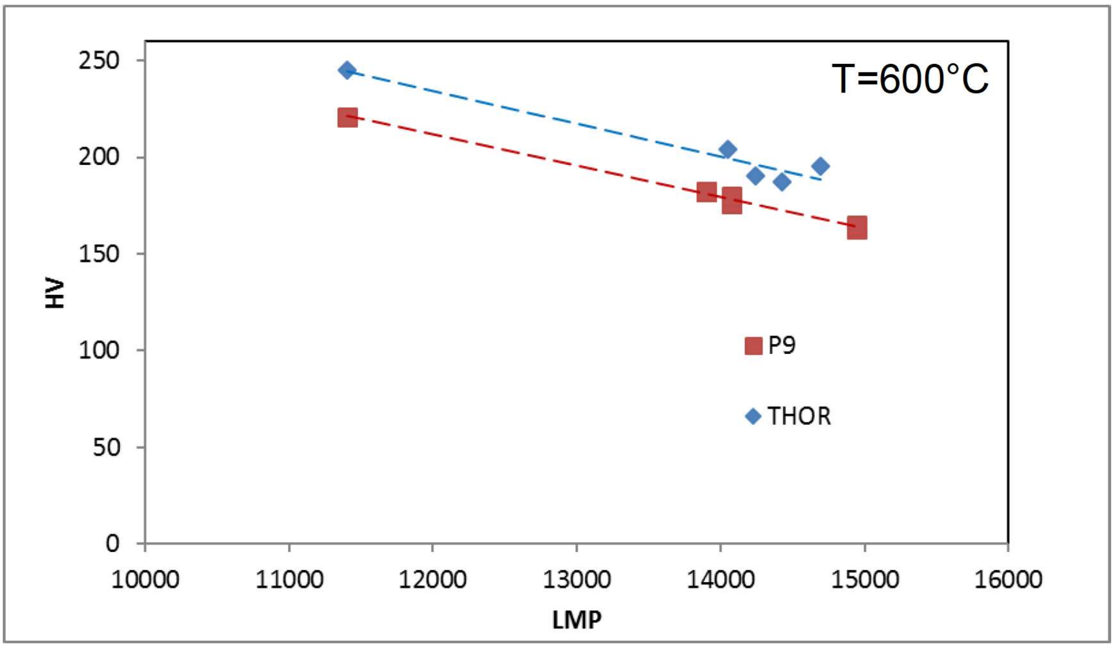


THOR 22000h@650°C

$M_{23}C_6$ carbides evolution in both alloys

Hardness evolution

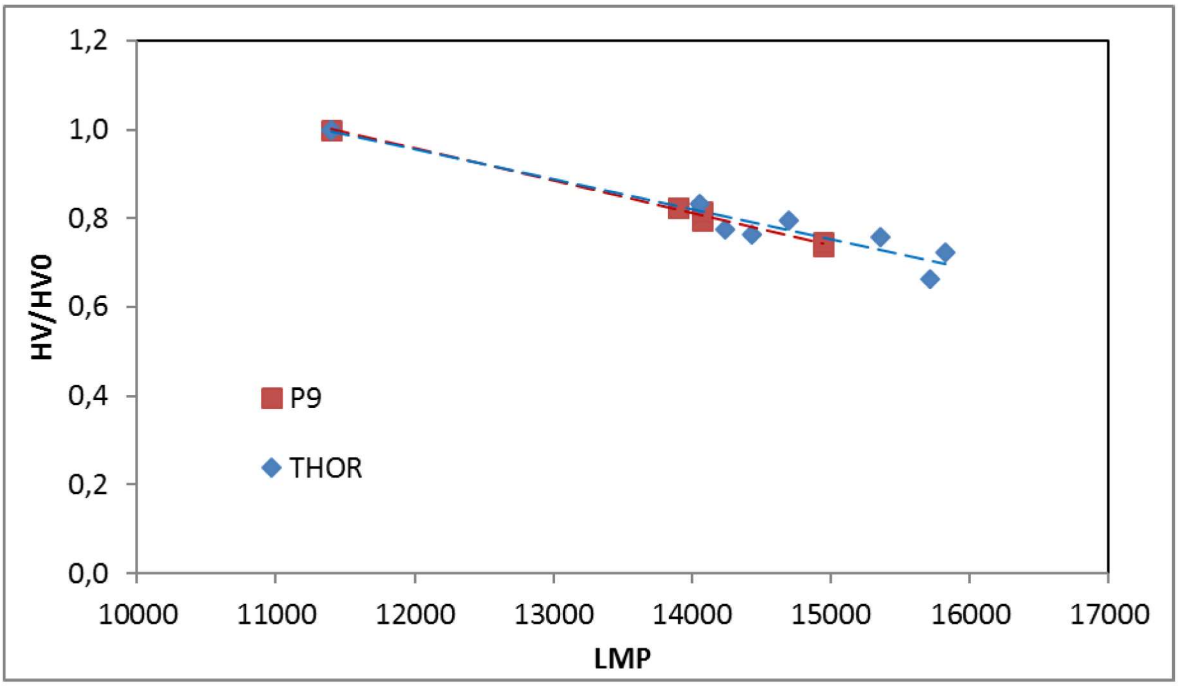
✓ Hardness decay due to martensite overtempering



$$HV = 405 - 0.016\,LMP$$ for P9

$$HV = 439 - 0.017\,LMP$$ for Thor™ 115

Hardness evolution



Life estimation model

The applied stress is balanced by the allowable stress
Applied stress increases in time due to wt reduction (oxydation or corrosion)
Allowable stress decreases in time due to HV reduction

$$applied\ stress \quad \sigma = \frac{pD}{2wt}$$

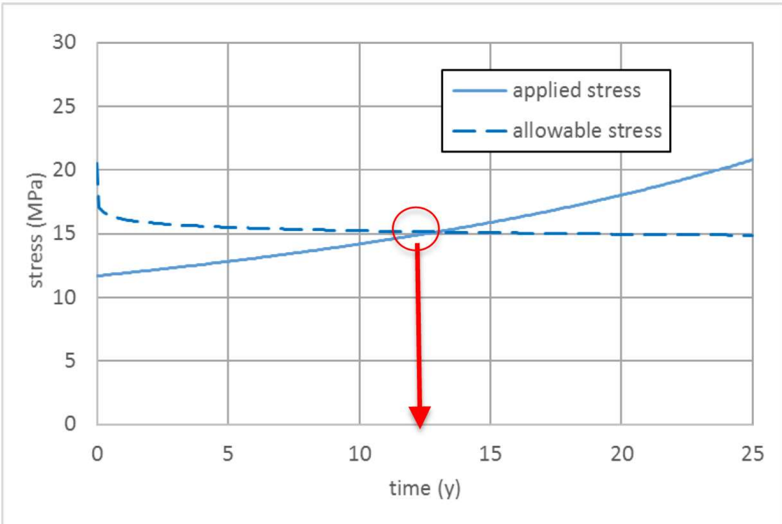
$$wt = wt_0 - (OR + CR)t$$

$$allowable\ stress\ S = S_0\, f(LMP)$$

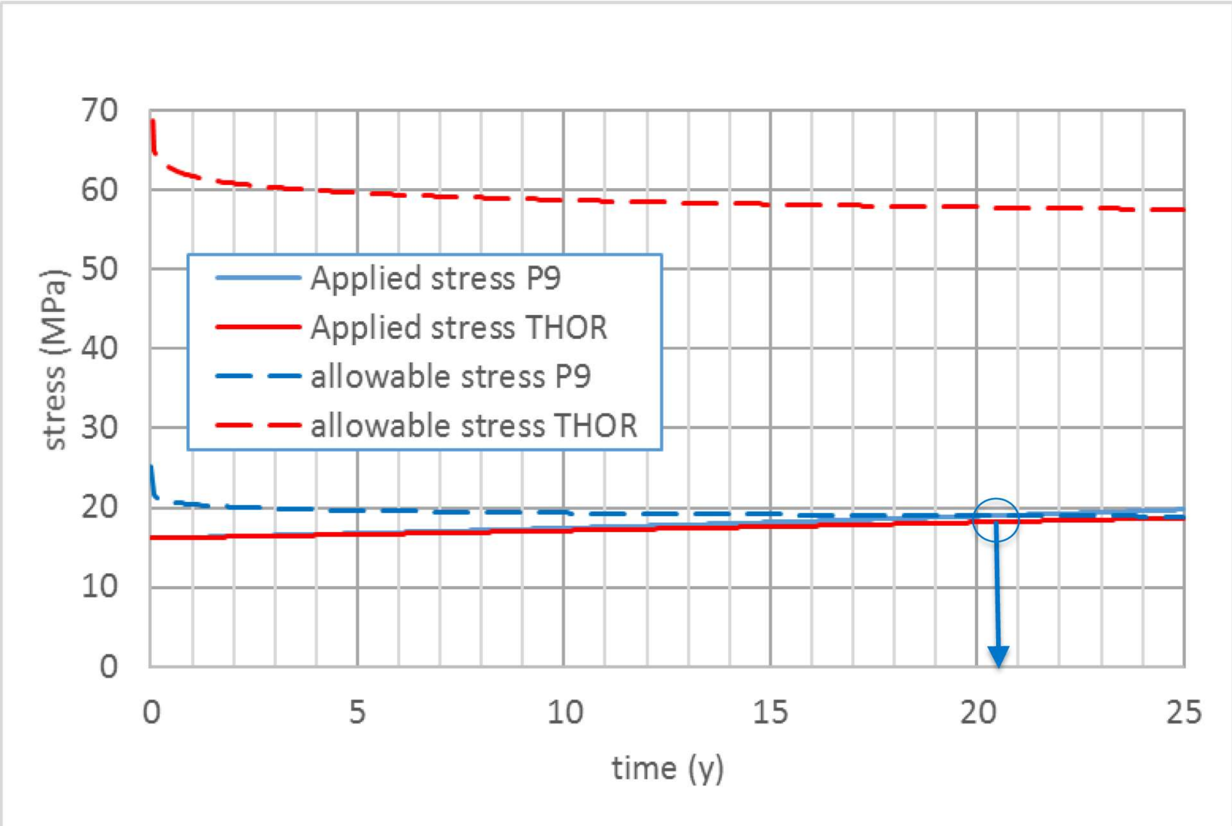
$$S_0\ is\ the\ reference\ all.\ stress$$

When **σ = S**
the pipe becomes critical: end of life

Example:
P9, T=600°C
OD=88.9 mm; wt=5.7 mm
P=15 bar
OR=0.05 mm/y
CR=0.05 mm/y



Case study: Crude Heater Radiant coil



T=587°C
P=20 bar

OD=88.9 mm
wt=5.5 mm

OR=**0.04** mm/y
CR=0.0 mm/y

Coil fully replaced after 190.000h (**22 y**)

Predicted: **20.5 y**

Shutdown in refinery: intervals

- For creep controls:
  - after 100.000h ± 10% (**10-12 years**)
  - every 50.000h ± 10% (**4-5 years**)
  - Reduced schedule for defects (**1,5 years**)

- General refinery turnaround for maintenance: every **4-5 years**
- Additional shutdowns for furnaces (clean up): every **2-2,5 years**

- Genaral turnaround duration: 45-60 dd
- Limited shutdowns for controls: 20 dd

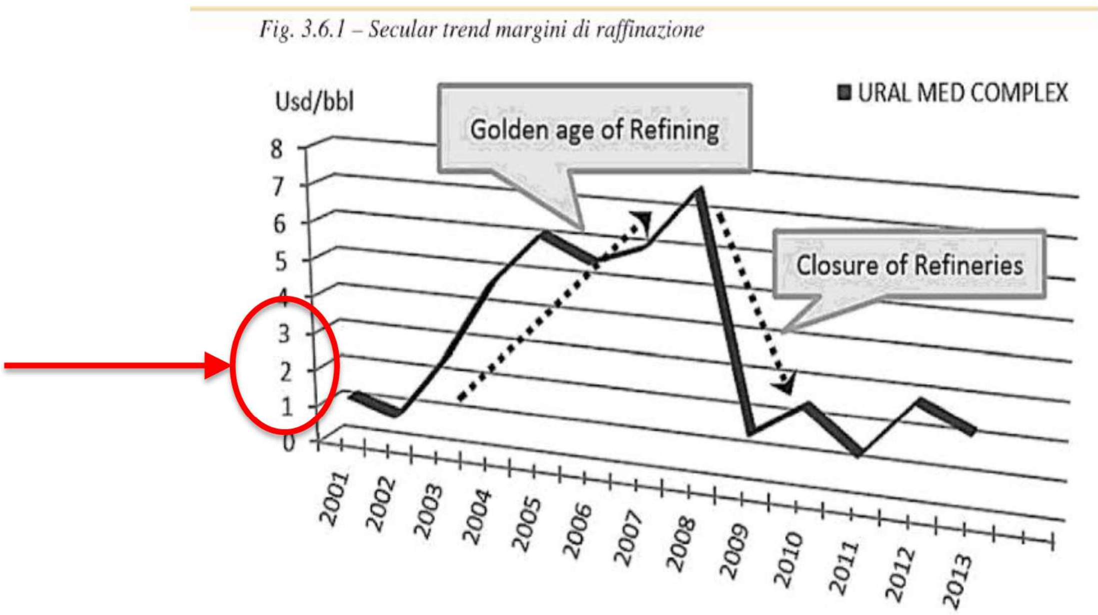
- Not planned shutdowns: 20 dd

Shutdown costs

- Basic cost: loss of production
- Refining Net margin = $\frac{\text{Total refinery sale}}{\text{Crude cost + operational costs}}$

Refinery margin:

1 – 3 USD/barrel



Shutdown costs

Loss of production = Refining Net margin x furnace ouput

- Typical furnace output = 200 t/h
- Refinery margin = 1 – 3 USD/barrel
- 1 production day = 30-100 K€
- 20 days shutdown = **600 – 2000 K€** (if 100% furnace production lost)

Recoil costs:
- 20-50 t of pipes = **100 – 200 K€** (material costs)
- Additional costs: dismantling, rebuilding, manpower, scaffolding, safety, recommissioning

Inspection costs:
- 1 furnace NDT cost = **10 - 20 K€**

Thor™115 cost ≈ 1.1 P9 cost **only 10-20 K€ difference!**

Conclusions

- ✓ Crudes have increased S content and TAN, turning corrosion more critical
- ✓ Thor™115 steel grade has better performance with respect to P9 in terms of:
  - *Static and creep resistance*
  - *Oxidation resistance*
  - *High Temperature Sulphidation resistance*
- ✓ The technical comparison has shown that higher safety margins/corrosion allowances are possible;
- ✓ The economical comparison has shown that the initial cost difference is low, easily recoverable in the furnace life;
- ✓ Remarkable savings are also possible in production furnace availability (lost production)

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