Fire Protection of Process Equipment

API 521 6th edition

Colin Deddis, April 2014

deeper understanding

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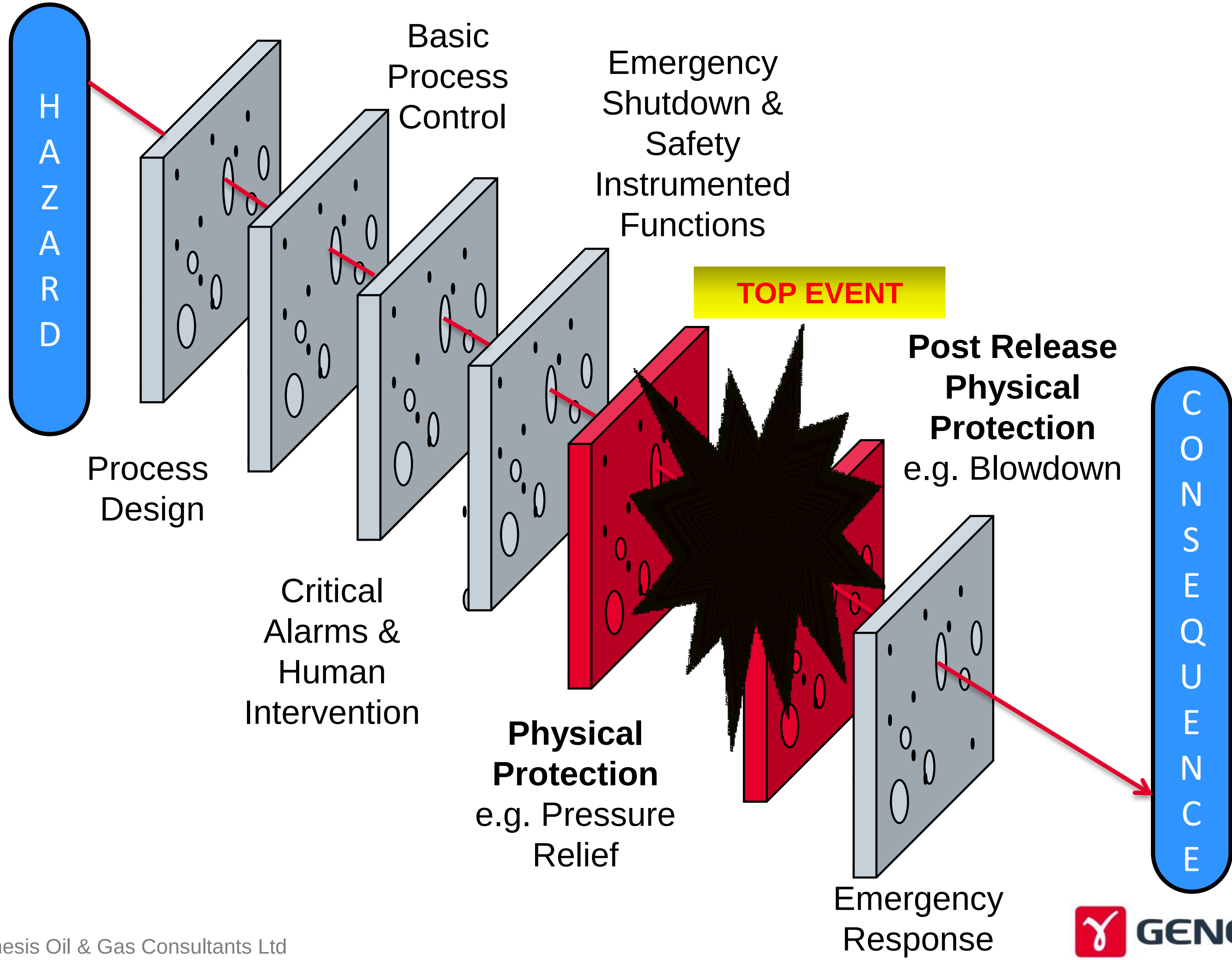
Fire Protection of Process Equipment

- Relief and depressuring systems as fire protection.
- Emergency depressurisation design – key features
- API empirical fire model & its limitations
- Introduction to analytical fire model
- Advantages of analytical model

Relief and Blowdown Systems



Emergency Depressurisation (Blowdown)

- Used to prevent incident escalation:
  - Increases survivability time and potentially mitigates failure of pressurised equipment due to high temperatures from external fire, exothermic reactions etc.
  - Minimises release of fuel from a leak (reduces likelihood and impact of a resultant fire/explosion)

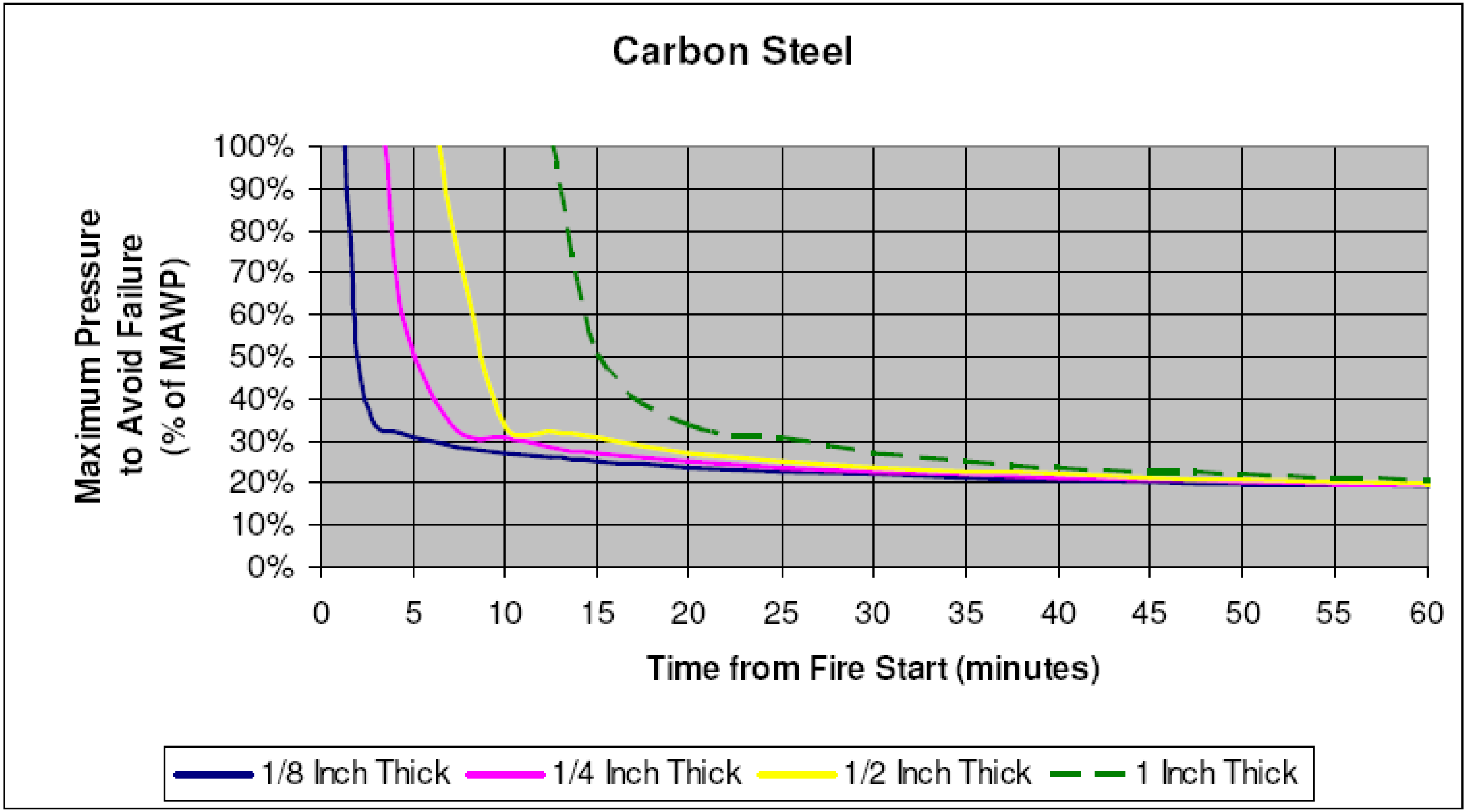
Emergency Depressurisation – Depressuring Rate

- Depressurisation targets for fire case if flare system capacity not limiting:
  - If wall thickness <25 mm – lower of 6.9 barg or 50% design pressure in 15 minutes
  - If wall thickness >25 mm – 50% of design pressure in 15 minutes

- Depressurisation targets if flare system capacity is limiting:
  - Detailed analyses
  - Passive fire protection requirements

- Depressuring rate = rate of vapour formation (liquid containing systems) + rate required to reduce pressure

Emergency Depressurisation – Fire Case



Typical Carbon Steel (SA-515, Grade 70) Internal Pressure
Versus Pool Fire Exposure Time to Minimize Potential for Vessel Rupture

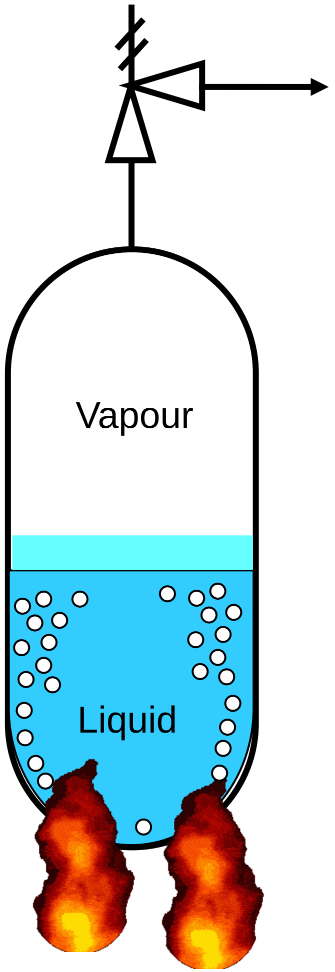
API 521 – Empirical Fire Model

Relief device sizing

$$Q = C_1 F A_{ws}^{0.82}$$

Where:

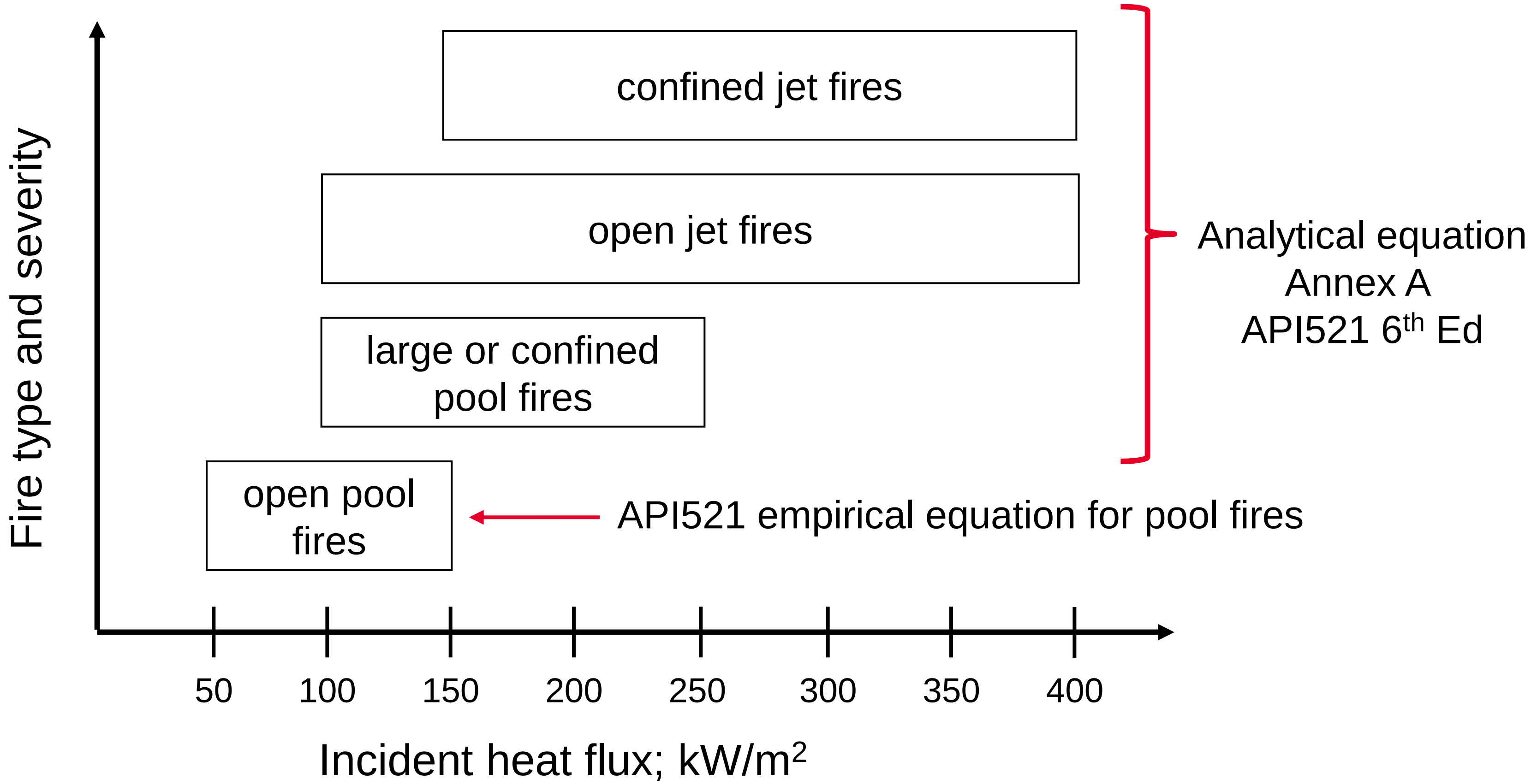
Q is the total heat absorption (input) to the wetted surface, expressed in W
C_1 is a constant
F is an environment factor
A_{ws} is the total wetted surface, expressed in m^2



Limitations:

- Open pool fire (global average heat flux)
- Liquid filled systems only
- Underestimates local peak heat flux
- <u>Relief device sizing only</u>

Emergency Depressurisation – Fire Case



Guidelines for design and protection of pressure systems to withstand severe fires, Institute of Petroleum, 2003

Analytical method - Heat absorbed
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$$q_{absorbed} = \underbrace{\sigma \cdot \alpha_{surfrace} \varepsilon_{fire} T_{fire}^{4}}_{\text{Radiative heat flux to equipment}} - \underbrace{\sigma \cdot \varepsilon_{surface} T_{surface}^{4}}_{\text{Radiative heat flux from equipment}} + \underbrace{h\left(T_{gas} - T_{surface}\right)}_{\text{Convective heat transfer between combustion gases and equipment surface}}$$

where:

$q_{absorbed}$ is the absorbed heat flux from the fire (W/m^2)

σ is the Stephan-Boltzmann's constant

$\alpha_{surfrace}$ is the equipment absorptivity

ε_{fire} is the fire emissivity

$\varepsilon_{surface}$ is the equipment emissivity

T_{fire} is the fire temperature (K)

$T_{surface}$ is the equipment temperature (K)

T_{gas} is the equipment temperature of air/fire in contact with the equipment (K)

h is the convection heat transfer coefficient of air/fire in contact with equipment (W/m^{2}K)

Analytical method
Recommended range of parameter values – pool fire

Parameter	Description	Pool Fire	
		Surface Average Heat Flux	Local Peak Heat Flux
ε_{fire}	Hydrocarbon flame emissivity	0.6 to 1.0	0.6 to 1.0
$\varepsilon_{surface}$	Equipment emissivity	0.3 to 0.8	
$\alpha_{surface}$	Equipment absorptivity		
h	Convective heat transfer coefficient between equipment and surrounding air	10 $W/m^2 \cdot K$ to 30 $W/m^2 \cdot K$ (1.76 $Btu/h \cdot ft^2 \cdot °R$ to 5.28 $Btu/h \cdot ft^2 \cdot °R$)	
T_{gas}	Temperature of combustion gases flowing over the surface	773 K to 1173 K (500 °C to 900 °C) 1392 °R to 2112 °R (932 °F to 1652 °F)	1173 K to 1423 K (900 °C to 1150 °C) 2112 °R to 2562 °R (1652 °F to 2102 °F)
T_{fire}	Fire temperature	873 K to 1273 K (600 °C to 1000 °C) 1572 °R to 2292 °R (1112 °F to 1832 °F)	
$T_{surface}$	Equipment temperature	Note 3	
σ	Stefan-Boltzmann constant	5.67×10^{-8} $W/m^2 \cdot K^4$ (0.1713×10^{-8} $Btu/h \cdot ft^2 \cdot °R^4$)	
q_{fire}	Note 1	30 kW/m^2 to 100 kW/m^2 (9510 $Btu/h \cdot ft^2$ to 31,700 $Btu/h \cdot ft^2$)	60 kW/m^2 to 200 kW/m^2 (19,020 $Btu/h \cdot ft^2$ to 63,400 $Btu/h \cdot ft^2$)
$q_{absorbed}$	Note 2	25 kW/m^2 to 75 kW/m^2 (7925 $Btu/h \cdot ft^2$ to 23,775 $Btu/h \cdot ft^2$)	45 kW/m^2 to 150 kW/m^2 (14,265 $Btu/h \cdot ft^2$ to 47,750 $Btu/h \cdot ft^2$)

NOTE 1 Typical range in fire heat flux. A wider range of heat fluxes is possible. The fire heat flux is found by ignoring the reradiation (by setting $\varepsilon_{surface} = 0$), setting $\alpha_{surface} = 1$, and setting the equipment temperature < 323 K (582 °R).

NOTE 2 Typical range in absorbed heat flux at start of fire [i.e. at wall temperatures of < 323 K (582 °R)]. A wider range of heat fluxes is possible.

NOTE 3 The equipment temperature is a variable that increases as the surface heats up.

API 521 6th Ed, Table A2

Analytical method
Recommended range of parameter values – jet fire

Parameter	Description	Jet fire			
		Surface Average Heat Flux		Local Peak Heat Flux	
Leak rates Note 5		>2 kg/s (>4.41 lb/s) (large jet)	≤2 kg/s (≤4.41 lb/s) (small jet)	>2 kg/s (>4.41 lb/s) (large jet)	≤2 kg/s (≤4.41 lb/s) (small jet)
ε_{fire}	Hydrocarbon flame emissivity	0.6 to 1.0	NA	0.6 to 1.0	0.6 to 1.0
$\varepsilon_{surface}$	Equipment emissivity	0.3 to 0.8	NA	0.3 to 0.8	0.3 to 0.8
$\alpha_{surface}$	Equipment absorptivity		NA		
h	Convective heat transfer coefficient between equipment and surrounding air	10 W/m²·K to 100 W/m²·K (1.76 Btu/h·ft²·°R to 17.6 Btu/h·ft²·°R)	NA	50 W/m²·K to 150 W/m²·K (8.8 Btu/h·ft²·°R to 26.4 Btu/h·ft²·°R)	50 W/m²·K to 150 W/m²·K (8.8 Btu/h·ft²·°R to 26.4 Btu/h·ft²·°R)
T_{gas}	Temperature of combustion gases flowing over the surface	573 K to 1173 K (300 °C to 900 °C) 1032 °R to 2112 °R (572 °F to 1652 °F)	NA	1173 K to 1523 K (900 °C to 1250 °C) 2112 °R to 2742 °R (1652 °F to 2282 °F)	1123 K to 1473 K (850 °C to 1200 °C) 2022 °R to 2652 °R (1562 °F to 2192 °F)
T_{fire}	Fire temperature	773 K to 1273 K (500 °C to 1000 °C) 1392 °R to 2292 °R (932 °F to 1832 °F)	NA		
$T_{surface}$	Equipment temperature	Note 3			
σ	Stefan-Boltzmann constant	5.67×10^{-8} W/m²·K⁴ (0.1713×10^{-8} Btu/h·ft²·°R⁴)			
q_{fire}	Note 1	40 kW/m² to 150 kW/m² (12,680 Btu/h·ft² to 47,550 Btu/h·ft²)	NA	150 kW/m² to 400 kW/m² (47,550 Btu/h·ft² to 126,800 Btu/h·ft²)	150 kW/m² to 300 kW/m² (47,550 Btu/h·ft² to 95,100 Btu/h·ft²)
$q_{absorbed}$	Note 2	30 kW/m² to 120 kW/m² (9510 Btu/h·ft² to 38,040 Btu/h·ft²)	NA	120 kW/m² to 320 kW/m² (38,040 Btu/h·ft² to 101,440 Btu/h·ft²)	120 kW/m² to 250 kW/m² (38,040 Btu/h·ft² to 79,250 Btu/h·ft²)

API 521 6th Ed, Table A4

Analytical method
Stress calculations

$$\sigma_{hoop}(t) = \frac{P(t) \cdot OD}{2 \cdot wt}$$

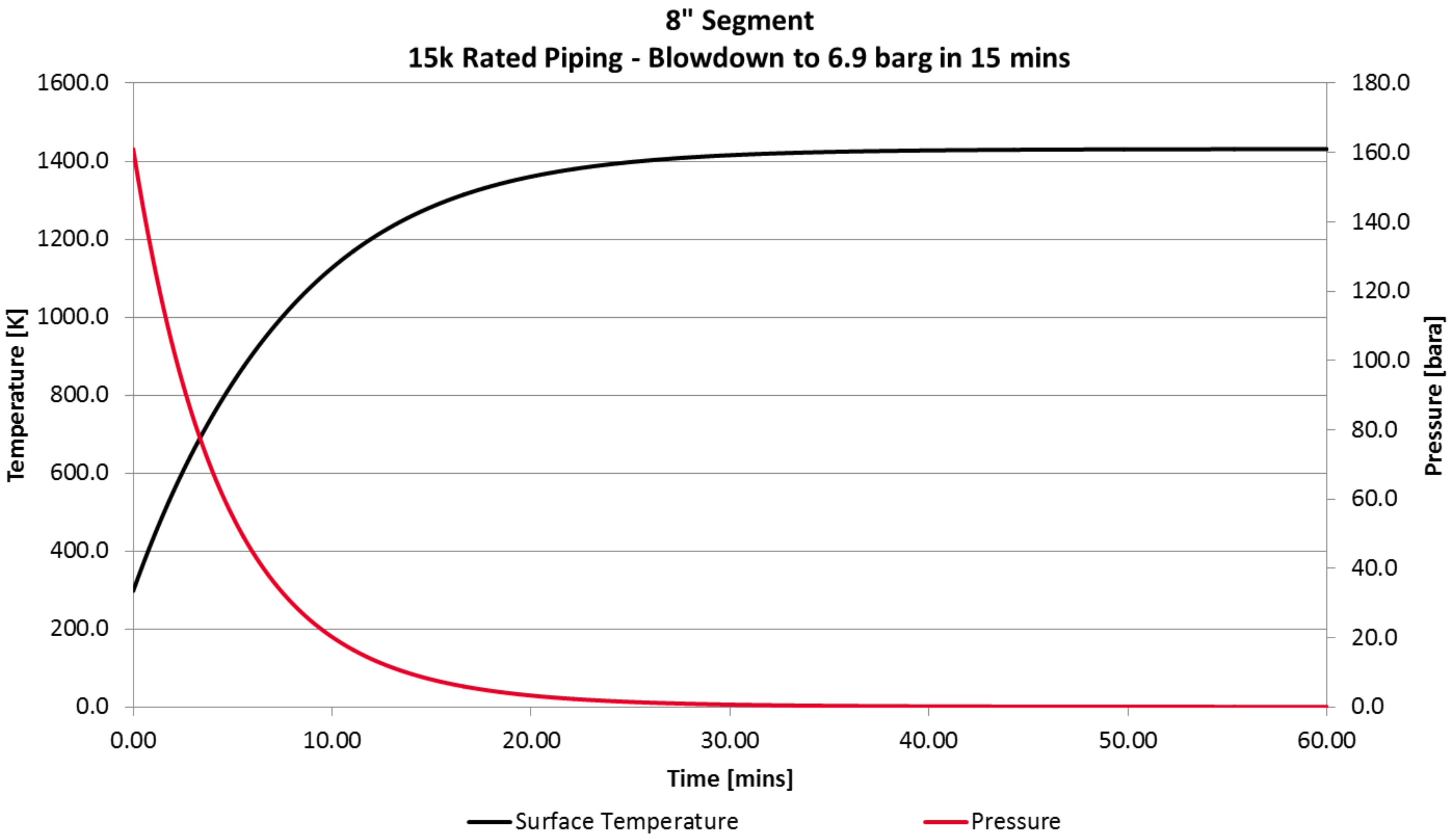
$$\sigma_{axial}(t) = \frac{P(t) \cdot OD}{4 \cdot wt}$$

$$\sigma_{von\_Mises} = \sqrt{\sigma_{hoop}^2 + \sigma_{axial}^2 - \sigma_{hoop} \cdot \sigma_{axial}}$$

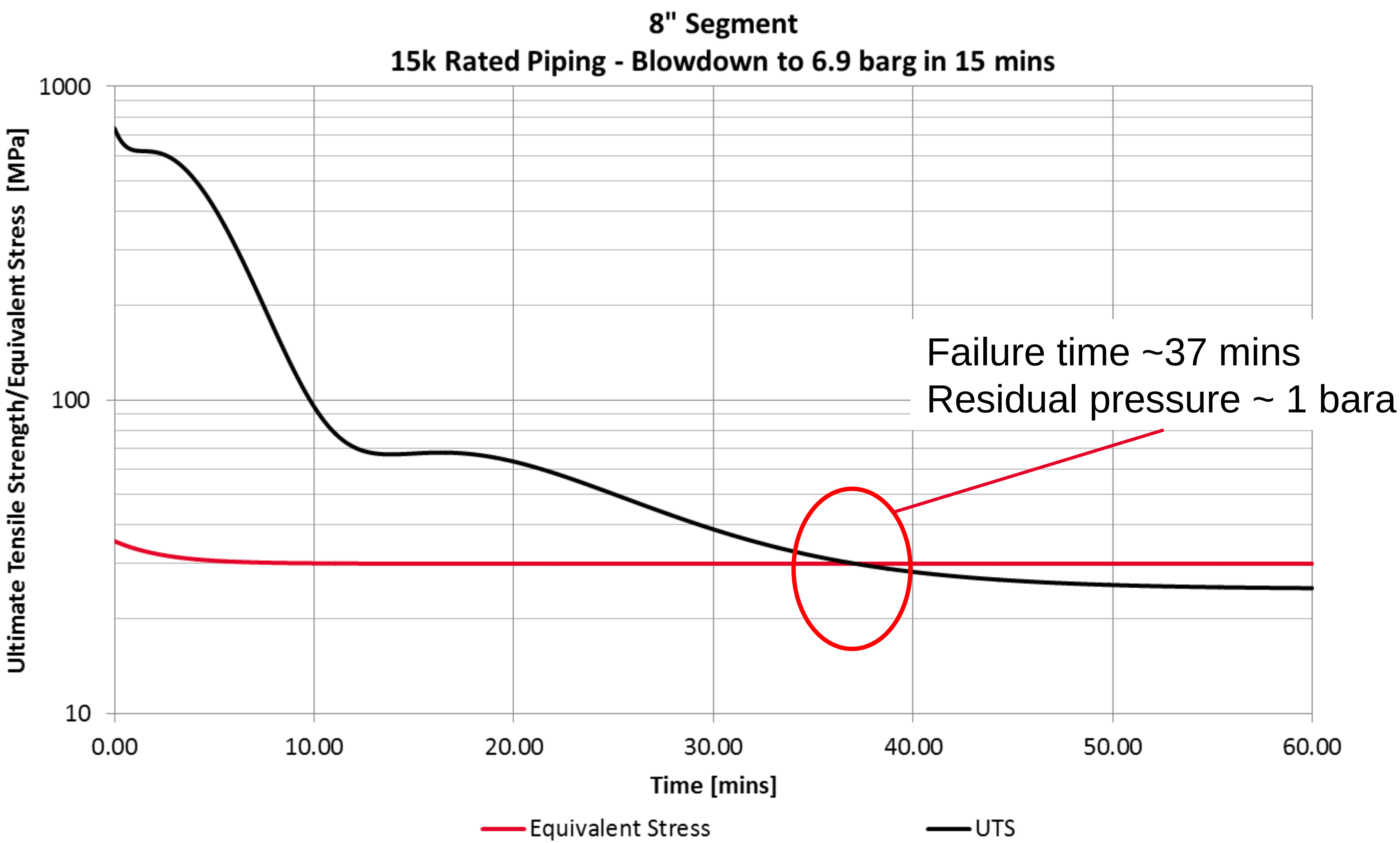
where:

σ_{hoop}	is the hoop stress
σ_{axial}	is the axial (longitudinal) stress
σ_{von_Mises}	is the equivalent (total) stress
P	is the system pressure
OD	is the outer diameter
wt	is the wall thickness

Example of Analytical Method



Example of Analytical Method



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Advantages of Analytical Model

- Applicable for all types of fires
- Time dependent properties of flame can be incorporated in the analysis
- Handles vapour/dense phase systems
- Allows optimisation of depressuring targets during design

Thank-you

Any questions?