IAGT
Industrial Application of Gas Turbines

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IMPACT OF FUEL CONTAMINANTS ON GAS TURBINE OPERATION

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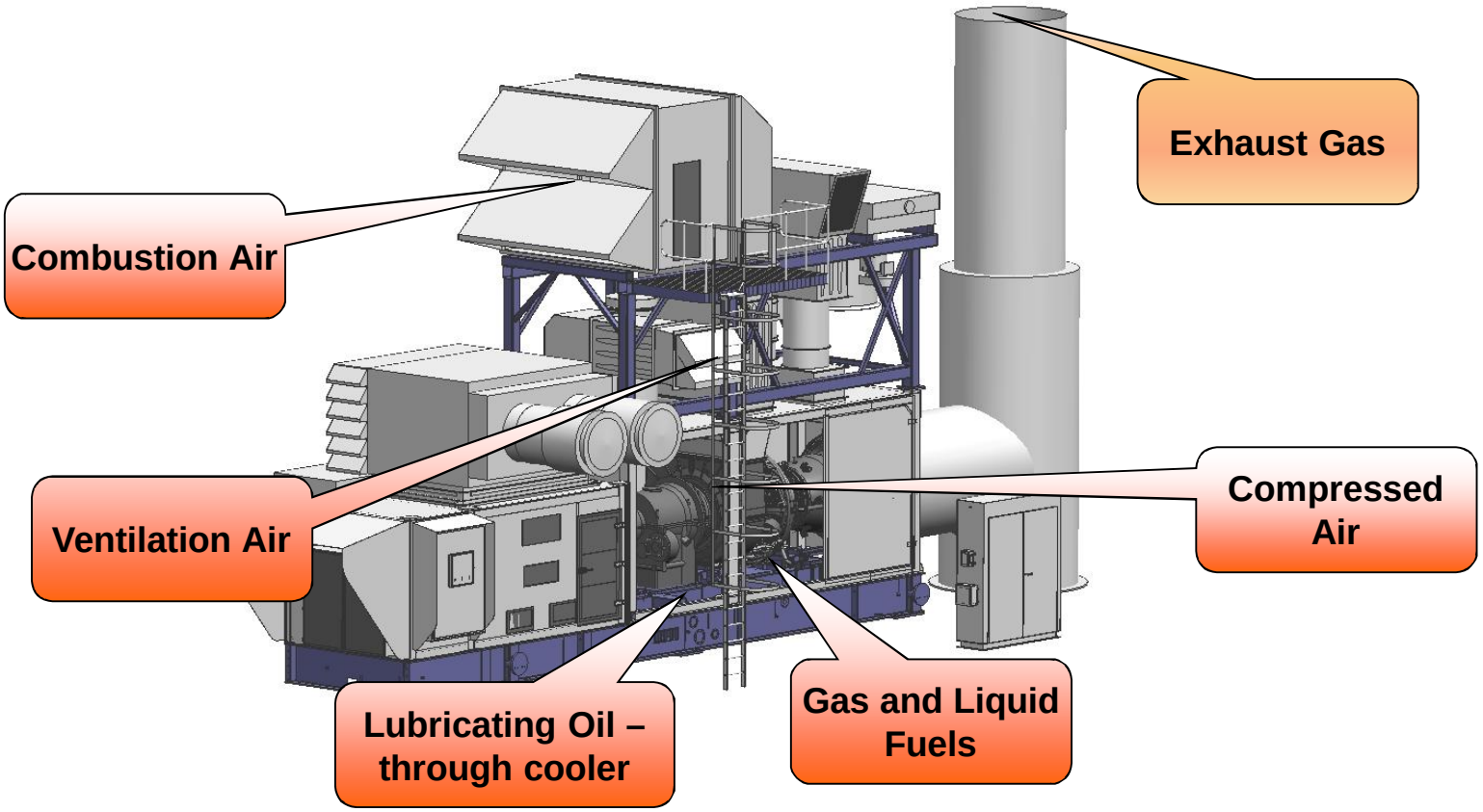
IMPACT OF FUEL CONTAMINANTS ON GAS TURBINE OPERATION

- **Agenda**
  - Introduction
  - Fuel Types & Composition
  - Fuel Contaminants
  - Impact of contaminants
    - Engine operability – eg performance
    - Engine component life

Gas Turbine Installation

Sources of Contamination

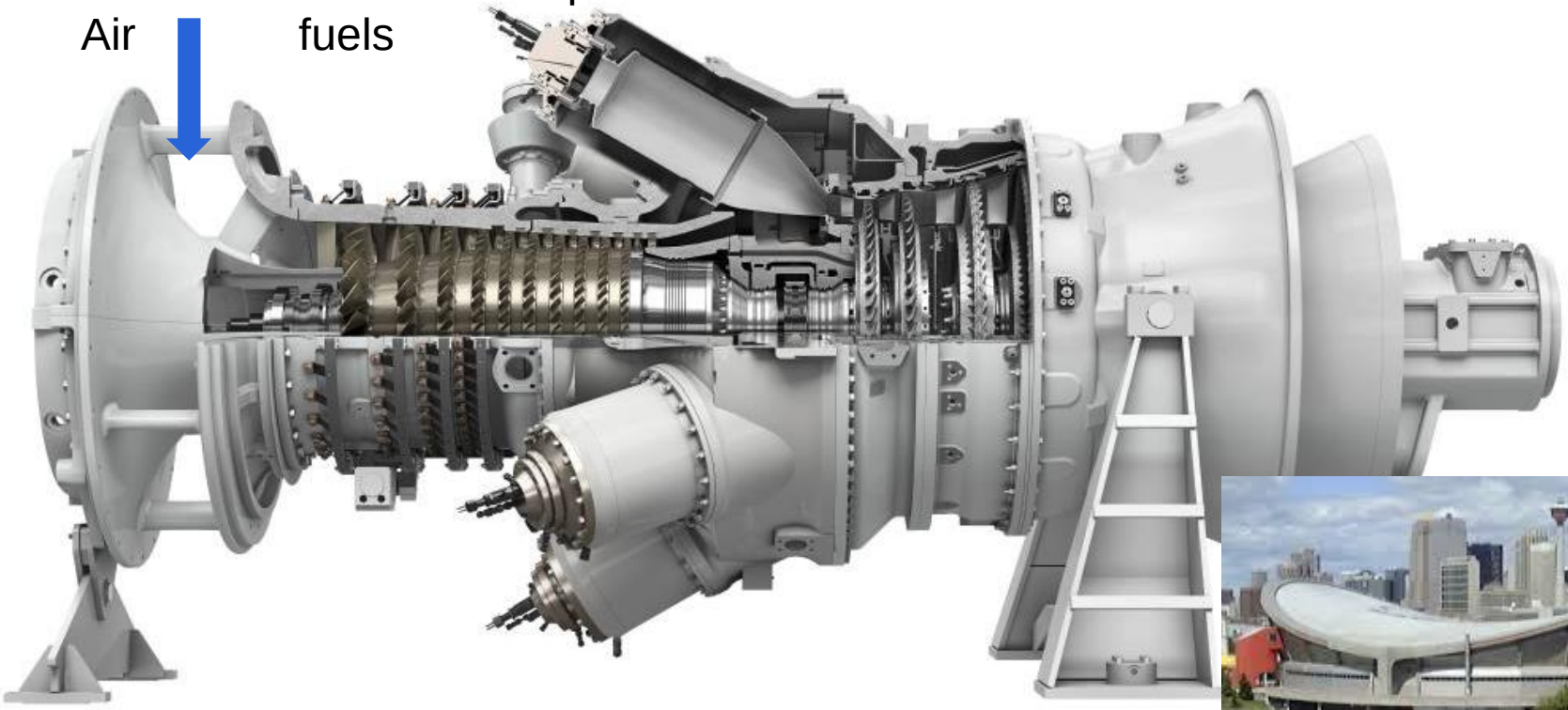


Gas Turbine Installation

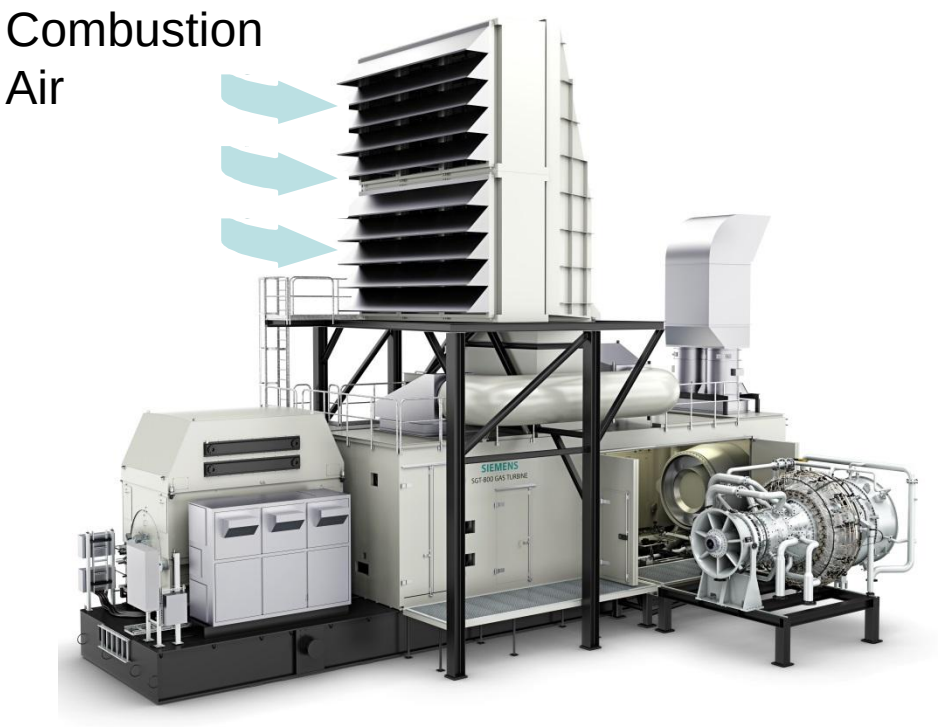
Sources of Contamination

Combustion Air

Gaseous / Liquid fuels



Air Filtration



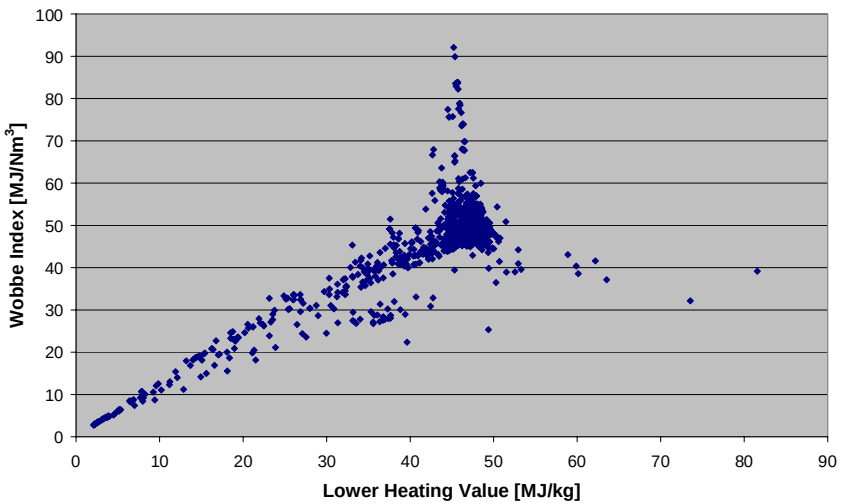
- Air filtration is a major topic in owns right
- Ensure design meets requirements for local environment
- Understand local issues
- Minimise break through of Particulate matter
- Reduces compressor degradation; pre-cursor to reduction in turbine power output

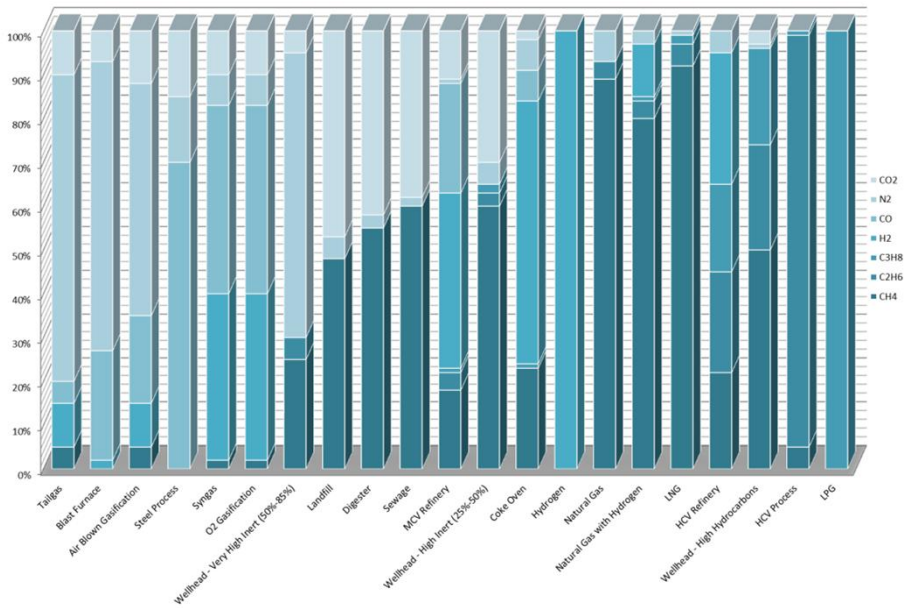
Air Filtration

Combustion Air

- Air filtration is a major topic in owns right
- Ensure design meets requirements for local environment
- Understand local issues

Fuel Type and Composition

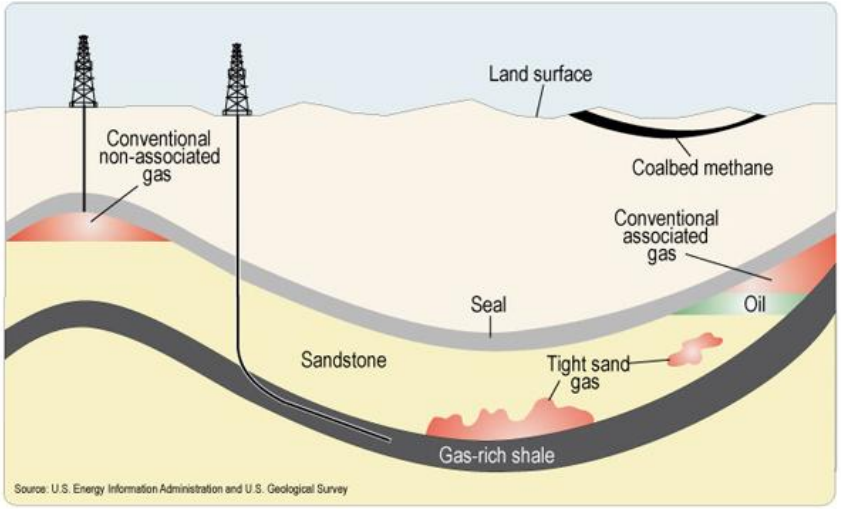




- Most applications specify good quality natural gas
- Some specify fuels with increasing inert content
- Fuels may contain higher hydrocarbons, or other burning components, eg hydrogen and carbon monoxide

- Range of gaseous fuels starting with very weak fuels, eg blast furnace gas to very rich LPG type (ie contain high hydrocarbon species)
- Does not cover the whole story …

Fuel Sources



- Associated gas
- Non-associated gas
- Shale gas
- Besides the main gas constituent Methane, all can contain a variety of other species:
  - Higher hydrocarbons, ethane, propane, …
  - Inert species
  - Can be sour ie contain H2S and CO2
- Well head gas fuels contain contaminants

Fuel Contamination

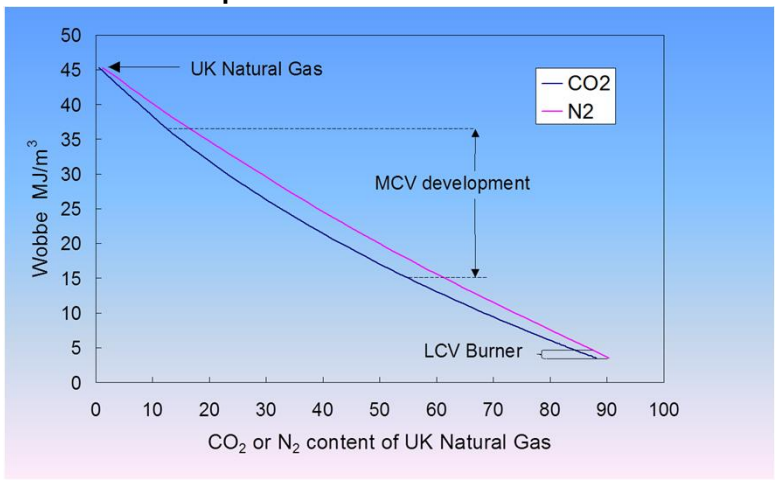
- Pipeline quality gas is clean and dry and provided to tight specifications
- For other gaseous fuels this is often not the case
- Need to understand fuel composition, with reference to:
  - non ‘burnable’ species
  - other burnable species
- “Contaminants” often seen include:
- Water
- Non combustible diluents eg nitrogen, carbon dioxide …
- Halogenated components/compounds
- Alkaline metals
- Hydrogen / Carbon monoxide
- …

Impact of contaminants 1 diluent species

Nitrogen / Carbon dioxide

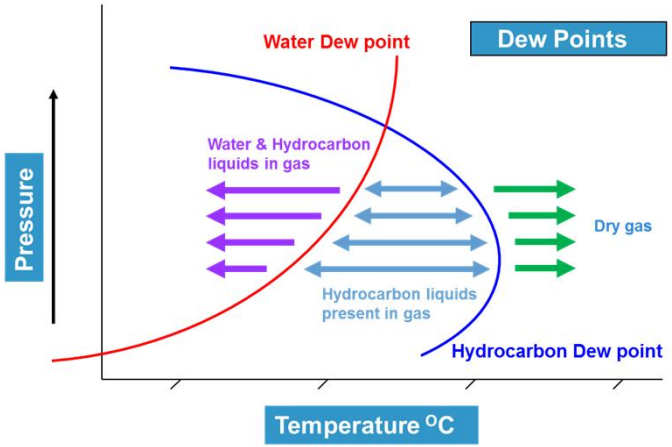
- **Often found:**
- well head gases
- Bio-gas from de-composition / fermentation of waste
  - Landfill gas
  - Anaerobic digester
  - Waste water treatment process

- For same volume flow lower energy content, hence to achieve same energy content higher flow rate necessary
- May require change to combustor geometry to accommodate increased flow rate without impacting system or combustion pressures



Impact of contaminants 2 water

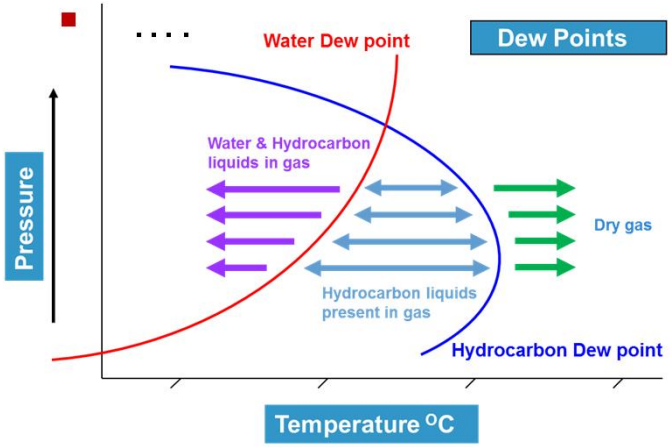
- Water can be specified as part of the gas composition
- Maybe implicit by virtue of saturated gas



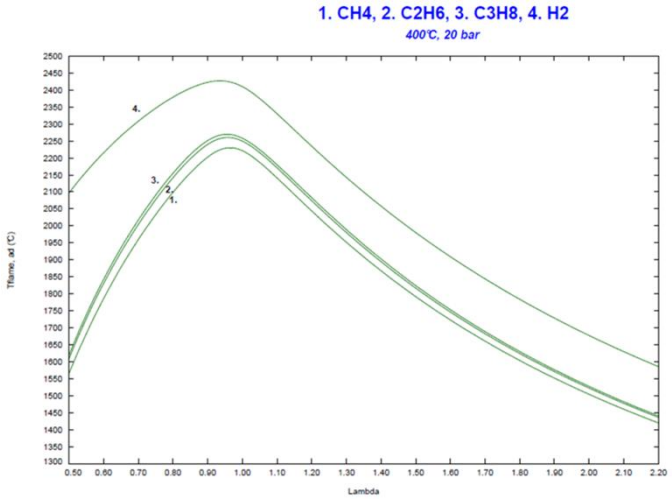
- Impact of water on dew point, hence supply temperature
- Necessary to provide gas at a suitable margin above dew point – minimum supply temperature
- Increased supply temperature reduces heating value
- Hydrate formation
- Corrosion impact
- May contain water soluble contaminants

Impact of contaminants 3.1 higher hydrocarbons

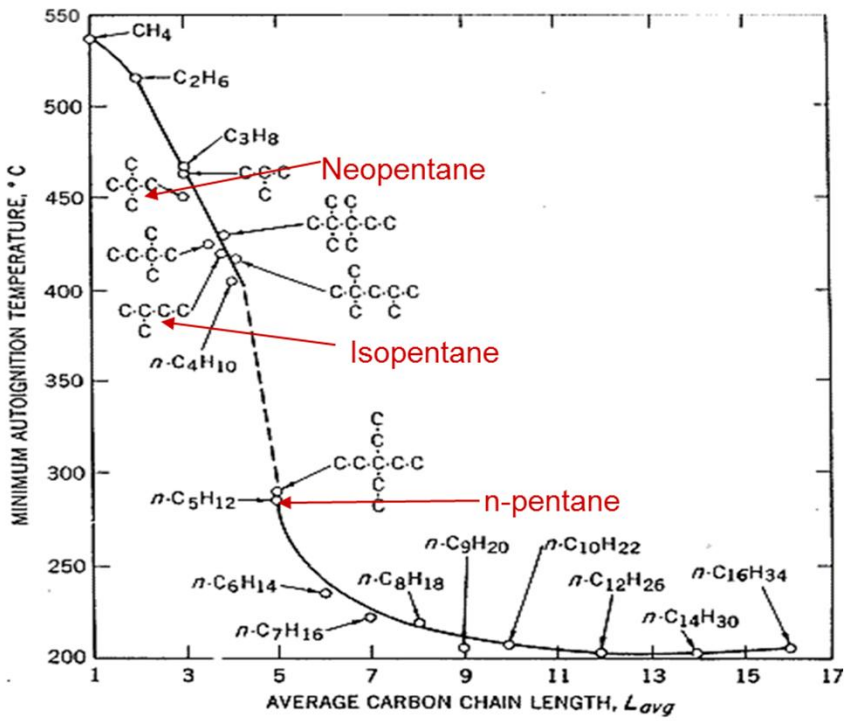
- Hydrocarbons other than methane
  - Ethane
  - Propane
  - Butane
  - Pentane
  - ….



- Have an impact on hydrocarbon dew point, hence supply temperature
- Flame velocity increase
- Potential for ‘auto-ignition’



Impact of contaminants 3.2 higher hydrocarbons



- Auto ignition Temperature
- Lowest temperature where a hydrocarbon can spontaneously ignite
- Generally faster and more intense combustion affecting:
  - flame stability and combustion dynamics
  - flame position and the risk for flashback, temperature distribution in the combustion system
  - emissions of NOx and CO
  - behaviour of the engine control system

Impact of contaminants 4.1 other burnable species

- Hydrogen
- carbon monoxide

Flame speed vs fuel type

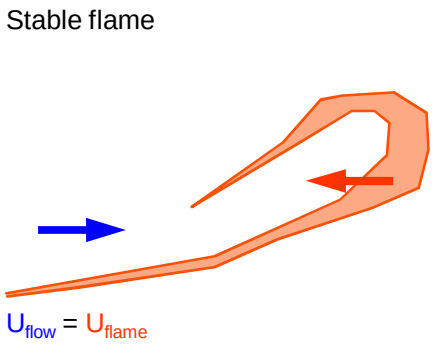
	Max flame speed (cm/s)
Methane, CH4	37.3
Ethane, C2H6	44.2
Propane, C3H8	42.7
Hydrogen, H2	**291.2**
Carbon Monoxide, CO	42.9

- Highly reactive
- Impact on flame velocity
- Permitted levels differ with combustion types (less permitted in, for example, lean pre-mix combustor)
- Flame speed determined by the combustion reaction rates and depend on:
  - Equivalence ratio φ
  - Fuel type
  - Flow regime (laminar or turbulent)

Impact of contaminants 4.2 other burnable species

Flashback and Blow-off

- If the flame speed does not match the flow speed of the reactants, the flame front will move
- If the flame speed is too high, you can get flashback (flame moving upstream towards the fuel injection)
- If the flame speed s too low, you can get blow-off (flame pushed downstream).

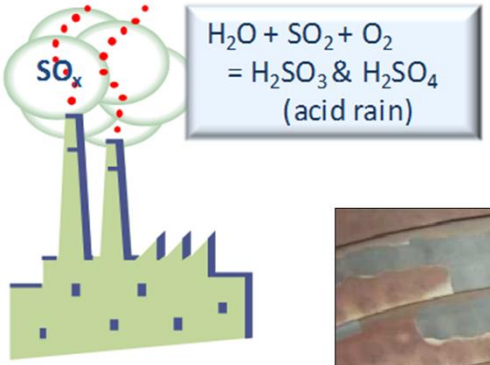


CAN FLAME FAILURE

ENGINE STOP

Impact of contaminants 5.1 other contaminants

- Hydrogen Sulphide, H_2S (Sour Gas)



Inside of the combustion chamber

- Gaseous fuels typically as H_2S or mercaptans
- Liquid fuel elemental sulphur or mercaptans

- General observations
  - poisonous even in small quantities
  - relatively benign to a turbine combustion system
  - 'what goes in comes out': Fuel treatment may be required
    - SO_x is regulated around the World
  - with water can result in the formation of acids
  - $H_2S + O_2 + H_2O = H_2SO_3$ &/or H_2SO_4 (Acid Rain)
  - presence of Na + K = sulphates; highly corrosive to nickel based turbine materials; high chromium content material better
  - Presence of Va = complex corrosive vanates
  - Sulphur may also be present in air !

Impact of contaminants 5.2
Sulphidation

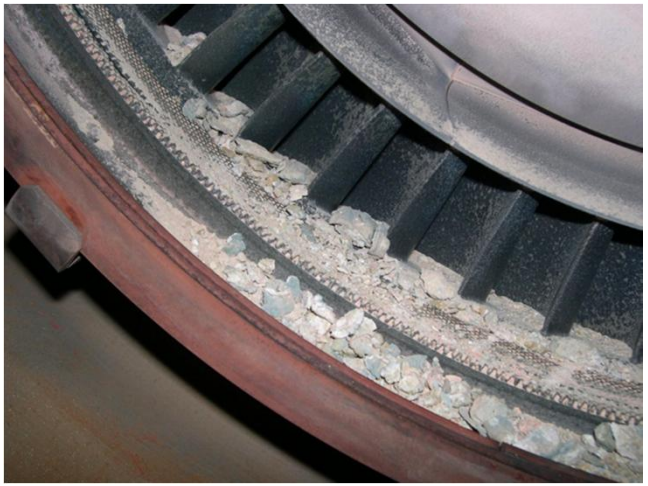
- Where Fuels contain sulphur such as Hydrogen Sulphide
- Can result in accelerated corrosion (and oxidation) damage to critical turbine components
- Local fuel treatment may be necessary to achieve defined component life

- Possible Sulphur corrosion attack

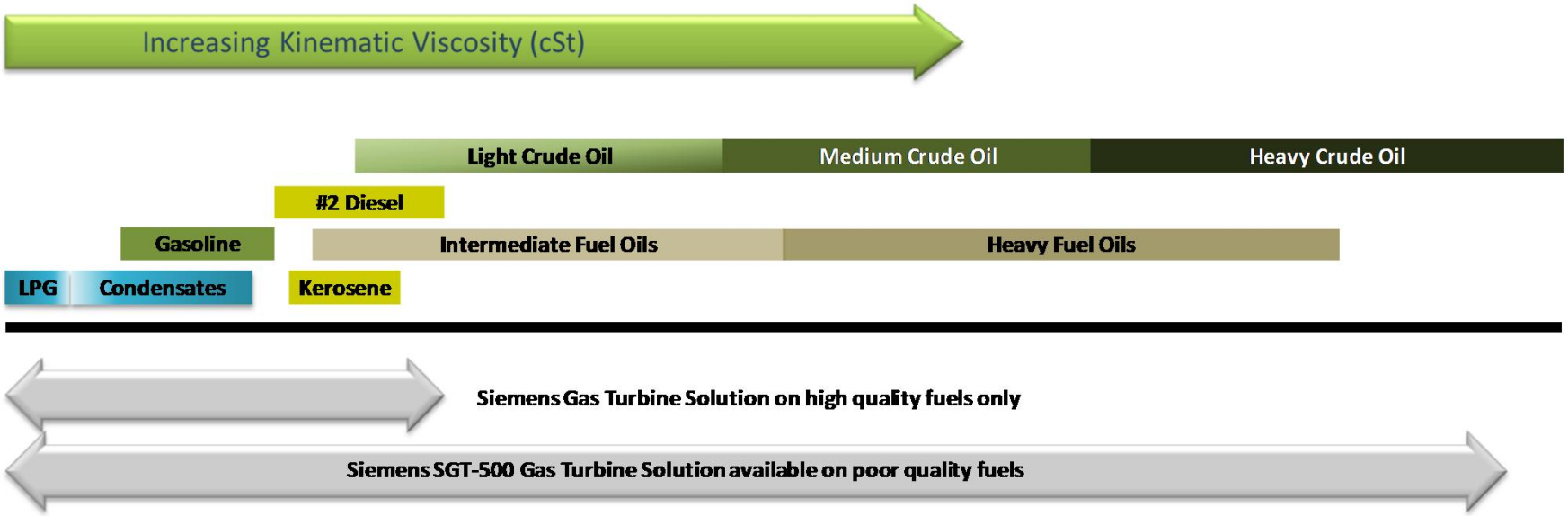
Impact of contaminants 6
Other sources

- Biogas
- de-composition / fermentation of waste
  - Landfill gas
  - Anaerobic digester
  - Waste water treatment process
- Inert Species (slide 9)
- Can also contain H2S (slides 16, 17)
- May contain silica type compounds, generally referred to as Siloxanes

- Siloxane:
  - Converts to Silica Oxides in combustion process
  - Sublimes onto turbine blades
  - Results in performance degradation



Liquid Fuels



- **All models able to operate on high quality liquid fuels such as diesel and kerosene**
  - Emissions abatement available either from “dry” (DLE) or “wet” (WLE) depending on gas turbine model
- **SGT-500 able to operate on poor quality liquid fuels such as HFO and crude oil**
  - Up to kinematic viscosities of around 1000cSt @ 50°C

Liquid fuel Challenges

- **Carbon Residue**
- Carbon Residue is the percentage of coked material remaining after a sample of fuel has been exposed to high temperatures
  - Indicates:
    - The tendency of fuel to form carbon deposits during combustion
    - Complexity of hydrocarbon constituents in the fuel
    - Difficulty in combusting the fuel and time for complete combustion
    - Affects ability to operate at low loads
    - Causes Incomplete combustion
    - Difficult to ignite
- High CR content may require start-up on a more conventional fuel

- **Alkali metals**
  - Dissolved in water present in the fuel
  - Create corrosive constituents during combustion; deposit on hot components
  - Remove by water washing / centrifuging
- **Heavy metals (Vanadium etc)**
  - Dissolved in the oil itself
  - Create corrosive constituents during combustion; deposit on hot components
  - Corrosive effect reduced by chemical dosing (magnesium-based inhibitors)
- **Water**
  - Free water leads to corrosion and fuel degradation; encourages microbial growth that produces a corrosive slime
  - Employ correct fuel storage and handling system design

- **House keeping / storage**
- **Quality control procedure**
  - Fuel specification
  - Cleanliness
  - Monitoring / recording
- **Delivery**
  - Tankers used for same fuel
  - No cross contamination
- **Storage**
  - Receiving and settling tanks
  - Centrifuge, filter, coalescer fitted to minimise impact of water and particulate matter
- **Forwarding**
  - Day tanks
  - Fine filtration (polishing) applied to each tank

BRITISH STANDARD

BS EN 590:2009 +A1:2010

Automotive fuels — Diesel — Requirements and test methods

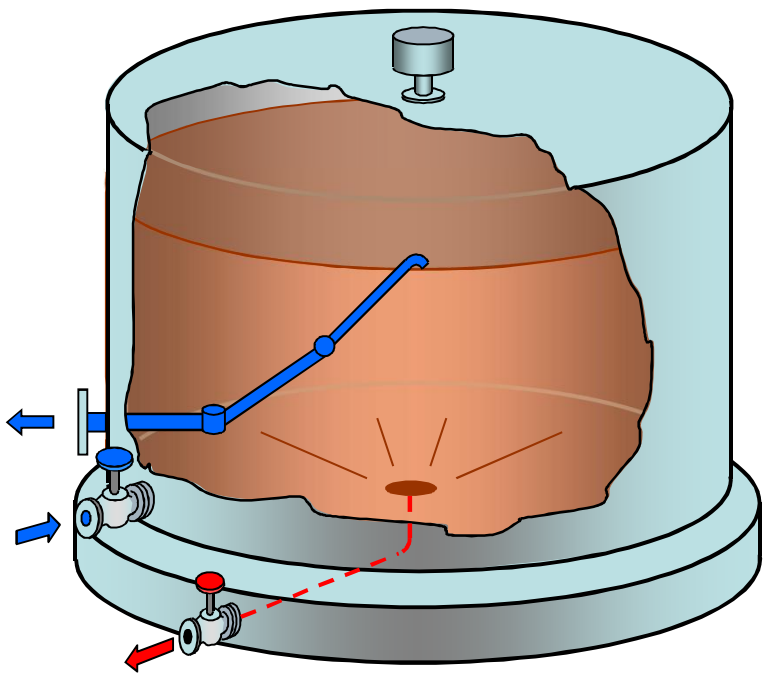
Property	Unit	Specification		Test
		Min	Max	
Cetane Number		52	54	ISO 5165
Density @15°C	kg/m3	833	837	ISO 3675
Distillation (vol. % recovered)	°C			ISO 3405
- 50% point		245	-	
- 95% point		345	350	
- final boiling point		-	370	
Flash point	°C	55	-	EN 22719
CFPP	°C	-	-5	EN 116
Viscosity @40°C	mm2/s	2.5	3.5	ISO 3104
Polycyclic aromatic hydrocarbons	% wt.	3	6	IP 391, EN 12916
Sulfur contenta	mg/kg	-	300*	ISO/DIS 14596
Copper corrosion		-	Class 1	ISO 2160
Conradson carbon residue (10% DR)	% wt.	-	0.2	ISO 10370
Ash content	% wt.	-	0.01	ISO 6245
Water content	% wt.	-	0.05	ISO 12937
Neutralization (strong acid) number	mg KOH/g	-	0.02	ASTM D974-95
Oxidation stability	mg/ml	-	0.025	ISO 12205

* sulfur limit of 50 mg/kg effective 2005 (Euro 4)
a - the actual sulfur content must be reported

ASTM INTERNATIONAL

Designation: D2880 – 03 (Reapproved 2010)

Standard Specification for Gas Turbine Fuel Oils[1]



- **Receiving and settling tanks**
  - Floating Suction
  - Sloping bottom
  - Water / Sediment take off-point / drain
  - Centrifuge, filter, coalescer fitted to minimise impact of water and particulate matter

- **Settling / Day Tank (if used)**
  - Design as for main tank, including all best practice features
  - “Polishing” system comprising aspects such as centrifuge, filter
  - Polishing applied regularly to ensure water/particulate kept to minimum acceptable level

Fuel Contamination Issues

Operational concern	Effect
Solids in gas fuel ➢ Scale, rust, sand, dirt, weld splatter, grit blast ➢ From old poorly maintained pipe system ➢ From new or modified fuel system	➢ Wear of fuel system component ➢ Valve failure to seat increased leakage ➢ Corrosion and wear of fuel injector ➢ Erosion of fuel/combustion components ➢ Build up of debris in gas passageways - impaired operation
Heavy Hydrocarbons as liquids ➢ Incorrect process control ➢ Not present in pipeline quality gases ➢ Incorrect temperature for fuel dew point ➢ Over fuelling (uncontrolled)	➢ Can drop out in fuel system, resulting in poor fuel control ➢ Carried in combustion resulting in uncontrolled combustion - explosions, flashback ➢ Abnormal distribution and localised hot gas path component damage ➢ Coking of fuel burner passages and mal distribution ➢ Abnormal temperature spread, as seen in exhaust / interduct thermocouples ➢ Adverse impact on performance and emission targets
Water in gas fuel ➢ Affinity of other contaminant - eg sodium, calcium etc ➢ Acid formation ➢ Formation of Hydrates ➢ At low temperature can freeze resulting in pipe blockage and reduced gas flow ➢ ingestion of liquids into combustion with consequential damage	➢ Ice & Hydrates can cause valve failure ➢ Corrosion of pipe system and valve ➢ Corrosion of hot turbine components ➢ Poor combustion operation, including loss of flame ➢ Unstable operation

Operational concern	Effect
Gas Fuels containing Hydrogen Sulphide H2S ➢ Poisonous even in small quantities ➢ Flammable ➢ Acidic when water present ➢ Corrosive	➢ Harmful to personnel ➢ Can result in hot gas component erosion ➢ Sulphidation attack on some materials ➢ Increased component attack in the presence of other contaminants, such as Sodium
Gas Fuels containing Carbon Dioxide, CO2 ➢ Acidic when water present ➢ Lowers effective heating value of fuel	➢ Reduced output for same volume input (lower heating value) ➢ Increased supply pressure ➢ Combustor passage size increase
Gas fuels containing Hydrogen, H2 ➢ Increased flammability ➢ Explosive	➢ Leakage of pipe work - consider regulations - eg Group 2C approval ➢ Explosive ➢ System design - flange joints and seals - embrittlement
Gas fuels containing Carbon Monoxide, CO ➢ Poisonous ➢ Exacerbates flame velocity, especially if H2 present ➢ Flash back	➢ Harmful to personnel ➢ Flashback results in damage to combustion components

Summary / Key Take Aways

- Take a holistic view when understanding the use of gas turbines
- Understand all sources likely to influence GT operation
- Maximise reliability and availability by working closely with customers
- Understand customers need
- Provide help and advice as early as possible

Gas Turbine OEM's are there to help