

INTRODUCTION

Heating fuels are extensively used in industry to provide energy for the production of steam, hot air for drying and the melting or curing of products in furnaces. Liquid fuels have many advantages over electrical or solid fuels, as they are generally more cost effective and require less capital intensive plant.

This FFS fuels handbook gives explanations and helpful tips in getting the best out your combustion appliance. There are useful explanations of the principles and concepts that effect the successful use of liquid heating fuels. The handling of the fuel from the storage tank to the burner is an important part of the operation and can be better managed with a clear understanding of how it should work and where problems may arise.

With careful selection of the liquid heating fuel that is best suited for the application, attention to detail in the design of the installation of the fuel handling system, and efficient and effective operation of the system, the user should achieve the goal of adding maximum value to the process.

PURPOSE OF A FUEL OIL RETICULATION SYSTEM

- To be able to receive bulk fuel oil deliveries. (Tanker loads)
- To store an adequate quantity of fuel safely to ensure an uninterrupted supply.
- To deliver the fuel oil to the burner at a constant temperature and pressure.
- To remove any unwanted particulate that may cause blockages.
- To contain spillages and minimise leaks.

PURPOSE OF A FUEL OIL COMBUSTION SYSTEM

- To initiate and maintain combustion
- To direct the flame at the required heating area.
- To proportion the fuel oil and air in the optimal ratio.
- To atomise the fuel oil into the air stream
- To effectively mix the fuel oil and air.

FUEL SELECTION

There are many different heating fuels available in South Africa, including several special fuels by FFS Refiners. Heating fuels such as diesel or LO10 are light or thin oils of high quality that require no pre-heating for use. LSO (low sulphur oil), HFO (heavy furnace oil) or R50:50 are thick, low cost fuels with some impurities that require heated storage and reticulation systems. The relative cost of heating fuels is generally dependent on their quality with regard to the level of impurities and their viscosity. As far as impurities and viscosity is concerned, this equates to ease of use. The selection of the heating fuel best suited to the system depends on the following considerations:

- The type of burner used (size, viscosity requirement, ash content tolerance, turn-down ratio required)
- The type of fuel reticulation system installed (heated, unheated)
- The environmental sensitivity of the area (sulphur)
- The application tolerance to impurities (ash, water)
- The relative cost of the heating fuels

The principle of heating fuel selection should be **“the most economical fuel suitable for the application”**. Fuels that require heating to reduce their viscosity and contain ash that results in additional operational cleaning costs are usually a lot cheaper than low viscosity low ash easy-to-use fuels.

The Table (1) below lists most of the fuels available and their particular advantages and disadvantages:

AVAILABLE HEATING FUELS				
FUEL	SOURCE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
R50:50	FFS recycled oil	Recycled heavy oil	Very low cost	High viscosity Variable sulphur High ash Requires pre-heating
COAL TAR	Gasification of coal and coke producers	Heavy fuel	Very low cost Low sulphur High radiant heat	High viscosity Medium Ash High radiant heat Requires pre-heating Requires specialised firing tube design for boilers
HFO (FO 150) (HFO 180)	Oil refineries Residual oil	Heavy Furnace Oil is a residue remaining after distillation of petroleum	Low cost Medium to low ash content	High viscosity High sulphur Requires pre-heating
LSO	Residual and recycled oils	Recycled oil blend of low sulphur synthetic fuels	Low cost Low sulphur	High viscosity Medium ash Requires pre-heating

Table - 1

AVAILABLE HEATING FUELS				
FUEL	SOURCE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
R20:20	FFS	Recycled light oils	Medium cost Medium sulphur Low viscosity Requires no pre-heating Low ash	Low ash
LO10	FFS	Light distillate derived fuel from recycled lubrication oil	Medium cost Very low sulphur Very low ash Requires no pre-heating Low viscosity	Medium to high cost
Power Parafin	Oil refineries	Light distillate fuel	Low viscosity Low sulphur Very low ash	High cost Low lubricity - high wear Low radiant heat
Diesel	Oil refineries	Light oil	Low viscosity Very low ash	Very high cost Medium sulphur

Table - 1 (cont)

COST OF FUELS

Fuels are usually sold in Rands per ton or Cents per litre and it is not possible to compare the relative costs without first converting to units of energy. In order to compare the cost of heating fuels, the fuel price be converted to cost per Joule. This enables comparisons with gas and electricity as well. A Joule is the energy value of heating fuels and the true measure of value for money. In order to convert to a cost per Joule, the energy value of the fuel and its density must be known.

Heating fuels also have impurities such as water and ash (non-combustible materials) which should be deducted from the mass to achieve a more correct energy value, however the level of impurities are usually small enough such as to be ignored. The radiance or luminosity of the flame can also result in better or worse heat value.

Table (2) lists the density and energy values of the common heating fuels available:

ENERGY VALUES		
FUEL	ENERGY VALUE (gross) KJ/kg	DENSITY kg/litre
R50/50	44000	0.950
COAL TAR	39000	1.050
HFO	43365	0.985
LSO	44200	0.92
R20/20	45000	0.910
LO10	45500	0.840
Paraffin	46460	0.794
Diesel	46000	0.880

Table - 2

The calculation from Rands per ton to Rands per megaJoule is simply:

$$\mathbf{R/MJ = (R/ton \times 1000) / (kJ/kg)}$$

The calculation from Cents per litre to Rands per megaJoule is as follows:

$$\mathbf{R/MJ = (10\ 000 \times Cents/litre) / [(kJ/kg) \times (kg/litre)]}$$

HEATING FUEL QUALITY

All heating fuels contain some impurities that do not combust. These impurities are measured as water content in the fuel and the ash remaining after combustion. As the cost of the fuel is closely related to its ash content, it is important to determine the combustion systems sensitivity to these impurities. There are several types of impurities that occur in heating fuels, each of which result in particular problems that may be experienced in an application.

WATER CONTENT

The water content of heating fuels is usually considered acceptable for all applications if it is below 0,3% by mass. Water in the fuel up to 10% by mass can be beneficial in the atomisation of the oil in some applications provided that it is evenly distributed. However problems can arise when the water settles into pockets or layers causing erratic burning or even flame outs. Water contents of up to 2% are often tolerable. Water does not generally add energy to the fuel.

ASH CONTENT

Ash may consist of any inorganic or non-combustible material that remains after combustion. In a heating fuel application, the sensitivity to ash will depend on several factors, such as:

- The ease or difficulty of de-ashing or cleaning the furnace or boiler (time, frequency, availability,)
- Product contamination (deposits, discoloration etc.)
- Dust emission levels
- Abrasive wear (pumps, burner etc.)

The savings in fuel costs from using low cost high ash fuels is generally much greater than the replacement cost of worn pumps and nozzles.

Ash as silicate, iron oxides and aluminium oxides may cause increased wear to certain types of pumps and burner nozzles.

Ash as oxides can cause product discoloration. However, this can be an advantage in some applications such as brick making.

The place and type of ash deposit may be of concern. Some ashes are hard deposits whilst others are easily cleanable dusts. Some dusts settle and some result in air emissions .

SULPHUR CONTENT

The sulphur content of a heating fuel is important, as sulphur is the primary environmental pollutant resulting from combustion. The sulphur in the fuel combines with oxygen during combustion to form sulphur oxide compounds (SOx's) that are noxious. Sulphur oxide fumes also combine readily with water vapour to form acid, which causes acid rain, corrosion of flues, boilers, stacks and surrounding buildings. Many areas are particularly sensitive to these odorous emissions and low sulphur fuels are mandated by environmental laws and regulations.

The Table (3) shows the typical contaminant levels (by mass) in the available fuels.

CONTAMINANT CONTENT			
FUEL	ASH CONTENT (%)	WATER CONTENT (%)	SULPHUR CONTENT (%)
R50/50	0,6 – 1,0	0,2 – 0,5	1,0 - 1,5
COAL TAR	< 0,5	0,25 - 0,3	0,4 - 0,6
HFO	< 0,2	< 0,1	2,2 - 4,0
LSO	0,2 – 0,3	0,2 –0,75	1,0 - 2,0
R20/20	< 0,1	< 0,2	0,5 – 1,5
LO10	< 0,01	< 0,1	< 0,2
Power Paraffin	< 0,01	< 0,01	< 0,01
Diesel	< 0,01	< 0,025	0,4 - 0,55

Table - 3

PHYSICAL PROPERTIES

In order to fully understand the behaviour of liquid heating fuels, an understanding of some of the physical properties of the liquid is necessary. The physical properties that most affect combustion are viscosity, pour point and flash point.

VISCOSITY

The viscosity of a fluid is a measure of its internal resistance to flow. Viscosity is the opposite of fluidity. All liquid heating fuels decrease in viscosity with increasing temperature. The importance of viscosity is not only in its resistance to flow through pipelines (pump selection and pipe sizing) but more importantly in the burner's ability to atomise the fuel for efficient burning. Viscosity is most commonly expressed in centiStokes or centipoise. Viscosity is measured in several ways. Some instruments measure the time for the fluid to flow through a small hole at a predetermined temperature. The time in seconds can then be converted to centiStokes from a table, and is then expressed as the viscosity at that particular temperature.

The viscosity of the fuel is thus very important in determining the correct temperature that the fuel should be kept at in various parts of the reticulation system.

$$\text{Centistokes} = \text{Centipoise} / \text{Specific Gravity}$$

Table (4) gives typical viscosities and temperatures:

VISCOSITY & TEMPERATURES			
FUEL	VISCOSITY (cSt)	ATOMISING TEMPERATURE	OUTFLOW TEMPERATURE
R50/50	10 - 20 @ 100°C	85°C – 95°C	65°C – 75°C
COAL TAR	12 -18 @ 100°C	80°C – 90°C	60°C – 70°C
HFO	20 @ 90°C	95°C – 105°C	65°C – 75°C
LSO	16 - 20 @ 90°C	85°C – 95°C	65°C – 75°C
R20/20	20 @ 50°C	Ambient	Ambient
LO10	4 @ 50°C	Ambient	Ambient
Power Paraffin	1 - 2 @ 25°C	Ambient	Ambient
Diesel	2,2 – 5,3 @ 40°C	Ambient	Ambient

Table - 4

POUR POINT

Some fuels have a wax content and become solid or un-pourable below a critical temperature. Others just become so thick at low temperatures that they effectively become un-flowable. The significance of this property is in the design of the fuel reticulation and storage system. Fuels that have a pour point temperature above the minimum ambient temperature for the site require a heated reticulation system to ensure that the fuel is kept liquid and flowable at all times. This includes a tank out-flow heater, line-heaters, pipeline heat tracing and insulation.

FLASH POINT

The presence of volatile liquids, known as light-ends for their short carbon chain lengths in the fuels, will produce flammable or explosive gasses when heated above a certain temperature. The critical temperature at which this occurs is known as the flash point of the fuel. This property gives an indication as to the relative hazard that exists in using and storing this material at a given temperature.

It should be noted that enclosed spaces such as the empty spaces in tanks should be treated as hazardous areas and all flames or sources of ignition should be kept well away, regardless of the temperature.

The method most commonly used to determine the flash point is called the "closed-cup flash point".

Table (5) lists the average flash points:

FLASH POINT	
FUEL	TEMPERATURE (°C)
R50/50	> 60°C
Coal tar	> 90°C
HFO	> 90°C
LSO	> 70°C
R20/20	> 50°C
LO10	> 50°C
Power Paraffin	> 45°C
Diesel	> 65°C

Table - 5

LABORATORY ANALYSES

The quality control of heating fuels requires that the various physical properties be measured against the standard specifications. This requires laboratory analyses to be carried out to determine the physical properties of the fuels. FFS has a laboratory at every factory that routinely carries out these analyses. FFS ensures that every tanker load of fuel that leaves the factories is within specification. The following laboratory analyses are performed:

- Ash content (expressed as a percentage mass)
- Water content (expressed as a percentage mass)

- Flash point (expressed as a temperature)
- Pour point* (expressed as a temperature)
- Viscosity (expressed as centiStokes at a given temperature)
 - * measured on some heavy fuels only.

Other laboratory results are carried out on a non-routine basis (some by outside laboratories):

- Energy content (expressed as kiloJoules per kilogram)
- Sulphur content (expressed at a mass percentage of total sulphur)
- Elemental ash analysis (expressed as mass percentages of the major elements)

FFS supply very comprehensive Material Safety Data sheets with all our products. This information is necessary in case of fire, contact, ingestion etc.

TRANSPORTATION

Industrial heating fuels are usually delivered in bulk by road tanker. All FFS drivers are "HAZCHEM" trained and the fuel is transported under the '3YE' hazardous chemical symbol. Bulk delivery requires the user to have adequate storage facilities to receive a minimum size load and maintain easy access for large articulated vehicles. The fuel is off-loaded from the road tanker by means of the user's pump via a flexible hose. Ownership and responsibility of the fuel passes from the supplier to the user at the coupling of the flexible hose and the road tanker. Although FFS road tanker drivers will carry out the task of off-loading the fuel, the responsibility always lies with the user. It is also the user's responsibility to ensure that there is sufficient space in the storage tank to receive the full load. Customers, when ordering, should allow at least 48 hours for the delivery of a load of fuel.

RETICULATION SYSTEMS

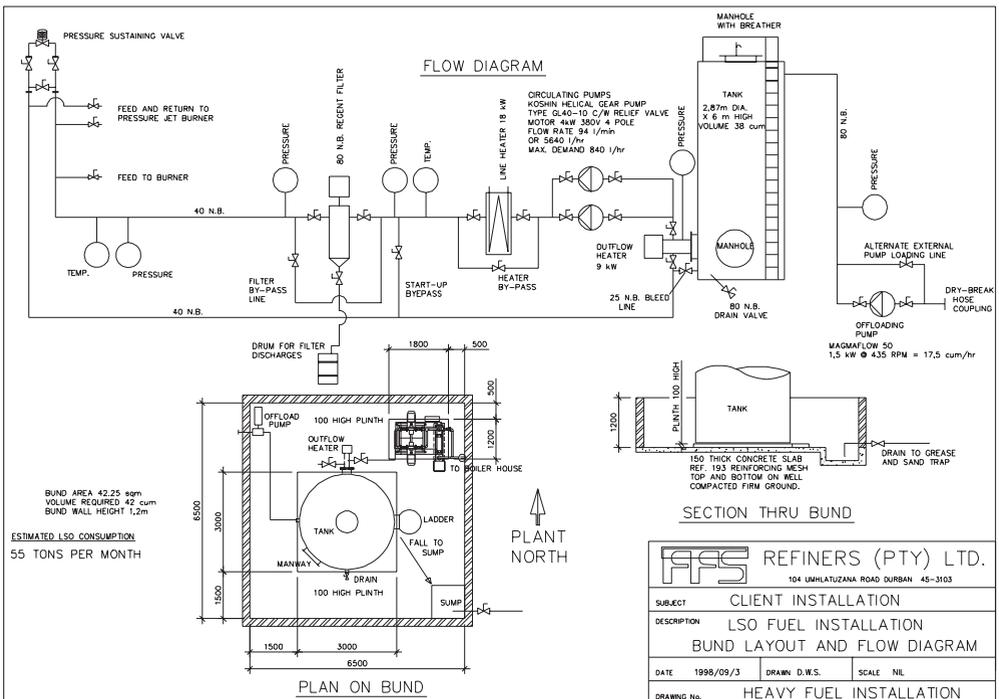
The design and construction of the fuel reticulation system is critical to the successful operation of the heating system. By following a few simple design rules a much improved operability can be achieved and so ensure a trouble free system.

HAZARDOUS AREA CLASSIFICATION

Due to the flammable and explosive gas potential of heating fuels, all installations should be built to the SABS 0108 electrical equipment for hazardous installations in the category of Zone 2. This requires that non-sparking electrical (ExN) motors are used and all electrical instruments in the hazardous zones are intrinsically safe (IS). Tanks (internal) and around tank vents should be considered Zone 1.

HEAVY FUEL SYSTEMS

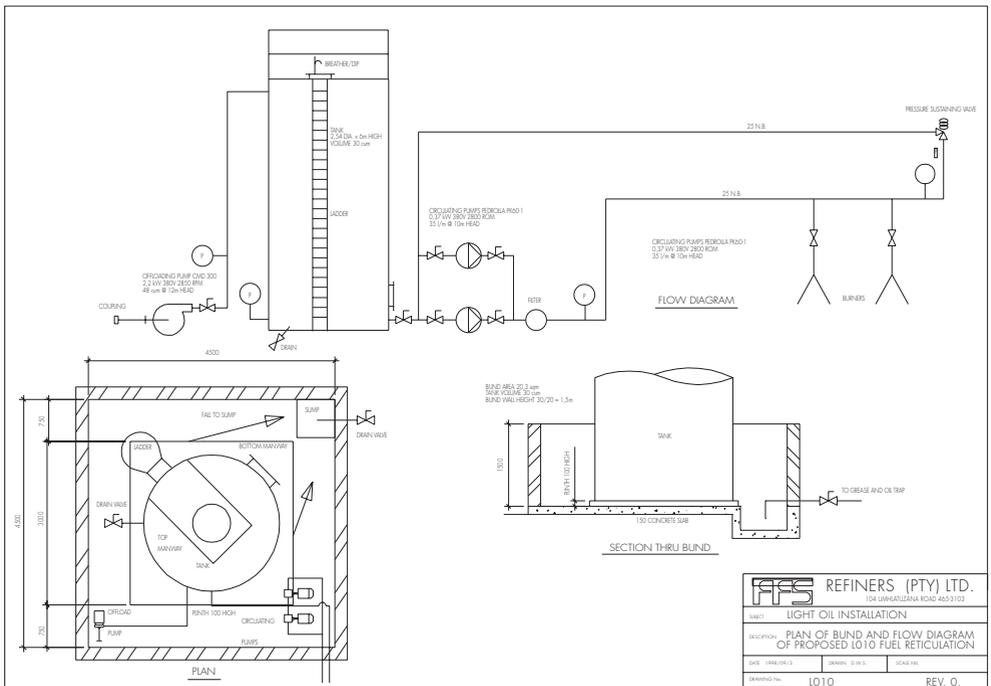
A heavy fuel installation should be as per the figure below. The storage tank does not require internal heating or insulation. An outflow heater in the tank is adequate to ensure a free flow of fuel out of the storage tank. The fuel should then be circulated past the burner/s back to the storage tank. The amount of re-circulation should be at least 4 – 6 times the quantity consumed by the burner/s. This will ensure stable burner operation with no discernable pressure fluctuation and maintain the fuel at the correct temperature. A back-pressure valve maintains the correct



pressure at the burner. The system is heated by means of a line-heater controlled by a thermocouple to maintain the correct temperature and thus viscosity. A line-filter removes any solids that may inadvertently find its way into the system. The fuels lines should be insulated and in cold areas heat traced.

LIGHT FUEL SYSTEMS.

Light fuel systems are simpler than heavy fuel systems as they do not require heating . The figure below shows the process flow diagram of a typical light fuel installation.



EQUIPMENT

A detailed description of the individual items of equipment used in a reticulation system is given below.

STORAGE TANKS

The sizing of the storage tank facility is very important. A very useful sizing estimate is to provide at least 10 days of normal consumption. There are other considerations such as practical size of tank for road tanker loads, fabrication, available space and cost. Industrial heating fuel storage tanks are generally vertical mild steel tanks mounted above ground. The South African Code of Practice (SABS 0131) does not require users to have the tank or tanks contained in a bunded area. However, it is prudent for safety and environmental reasons to build bund walls around tanks to contain accidental spillages. This is occasionally mandated by local fire departments. Where a spillage may lead to pollution of adjacent property, a full bund wall is required. Guidelines for the sizing of bunding around petroleum product storage tanks is given in the South African Bureau of Standards SABS 089 code of practice. Heating fuel storage tanks are constructed from mild steel and have two manholes, one top and one bottom. This allows for easy ventilation and access for cleaning.

As a certain amount of settlement of solids and sludge will occur in tanks over time, cleaning should be carried out at regular intervals - annually for heavy fuels and every two years for light fuels. Storage tanks should be founded on a reinforced concrete slab as designed by a structural engineer. The outsides of tanks require corrosion protection in the form of a suitable paint system, but the inside of the tank is left untreated. If the tank has been standing for some time in a corrosive environment it may require wire brushing before being put into service. Once in service the fuel will provide the corrosion protection. Standard size tanks are shown in the table below:

TANK SIZE (m ³)	DIAMETER (m)	HEIGHT (m)
23	2,31	5,5
38	2,87	6
53	2,87	8,4
64	2,87	10
83	2,87	13,2

Table - 4

PUMPS

Heavy fuels are best pumped using positive displacement pumps, as they are able to get the fuel moving when it is cold. A circulation gear pump running on LSO should give between 7000 – 10000 hours of service. Diaphragm pumps have a shorter service life, but are easier and less expensive to repair.

Light fuels are best pumped with centrifugal or turbine pumps. When high pressures are required, piston or diaphragm pumps should be used. Gear pumps are not recommended for use with LO10 as they separate out the heavy fractions of fuel that then gum up the pump.

The unloading pump should have a capacity of 30~50 m³/hour. This will allow the road tankers to offload in between 30-45 minutes.

Mechanical seals can be used to seal the pump drive shaft. Packed gland seals are adequate if properly maintained and are more economical.

It is very important that pumps have an unrestricted suction flow into the pump. This greatly reduces the wear on the pump and is the reason filters should be located after the pump.

PIPE LINES

Pipelines should be sized to ensure a flow rate of 2 – 3 m/s. This will ensure that no scaling occurs. Piping should be seamless and suitable for the pressures used.

LINE HEATERS

Heaters for heavy fuel (>150 cSt @ 50°C) installations should be of the indirect type with a maximum heat release rate of 1,2 Watts/cm² or 12 kW/m². This implies heating elements that are not in direct contact with the fuel. The reason for this is firstly for safety and secondly to prevent excessive heat causing the formation of coke particles. Coke particles may cause blockages of filters and burner nozzles. A typical size installation will contain one line heater of 9 or 18 kW. This size heater will contain 3 - 6 elements of 3 kW each. Should some of these elements fail, the specific heat input will rise and may result in coking. Once coking starts there is a reduced flow around the element pocket, which makes the problem worse. Coke particles blocking the filter will further reduce the flow rate past the heater, further exacerbating the problem.

The electrical elements should not exceed 2,4 W/cm². An element of this Watt density will heat up to approximately 600°C in still air. These electrical elements should be made of Incolloy 800 or 309S stainless steel, which will withstand temperatures of up to 750°C. The termination ends should be sealed with a ceramic bead to prevent the ingress of moisture or vapour, which can result in the breakdown of the insulation and cause a dead short.

If frequent circulation pump stops are made, resulting in no-flow situations in the heaters, then provision should be made to switch the heaters off some 15 – 20 minutes before stopping the pump. This allows the large heat store in the heater to be removed.

When designing the reticulation system the flow rate through the heater body should be greater than ~0,05 m/s.

Routine cleaning of the heater and checking on the elements cannot be over emphasised.

FILTERS

There are several types of filters available for use as in-line fuel filters. For heavy fuel oils a wedge wire self cleaning filter is preferred with a gap width of ~100 microns. This may be hand operated or motorised. These filters provide more than adequate protection against wear and blockages. They are also very easy to clean and require very little maintenance.

For light fuels a bag filter is preferred, which will screen out to ~25 microns. This will provide the very high degree of screening necessary for extremely demanding applications.

The position of the filter is important and should be placed after the circulating pumps and the line heater. Filters before the pumps only serve to increase the back-pressure on the pump causing cavitation and starvation, which will accelerate wear and lead to early pump failure.

BACK-PRESSURE VALVES

The back-pressure valve or pressure sustaining valve is not a pressure relief valve. The seat design is different as a pressure sustaining valve is made for continuous pressure control where as a pressure relief valve

operates fully open then poor control will result.

The available back-pressure valve are:

- For heavy fuel oil: Cash-Acme, Zwicky, Regent, Birket-Bailey
- For light fuel oils: Birket-Bailey, Cash-Acme, Regent
- High pressure burner pumps: Hawk Red-top, Spaying Systems 6810.

VALVES

Valves should be of the cast steel, fire safe, ball or plug valve type, according to petroleum industry standard. All equipment should have isolating valves before and after to allow for safe servicing with minimum spillage. The valves may be of the screwed, flanged or block type. The main criterion is that the system does not leak.

COMBUSTION

The science of combustion is complex. However, by understanding and applying a few simple concepts, the efficient and effective use of fuels is easily achieved.

Simplistically, the fuel, which consists of hydrocarbons (hydrogen and carbon atoms) is converted to carbon dioxide and water ($\text{CO}_2 + \text{H}_2\text{O}$) in complete combustion and in the process releases energy in the form of heat.

Combustion can occur when the heating fuel is mixed with an adequate amount of air containing oxygen. This range of flammable fuel/oxygen ratios varies between fuels. The theoretically exact ratio is known as the stoichiometric ratio.

For combustion to be complete and rapid enough, the fuel should have intimate contact with the oxygen in the air. This is achieved when the fuel is in sufficiently small enough droplets so as to expose sufficient surface area to allow combustion to occur in the time available in the flame area. This is termed 'atomisation' of the fuel. When a fuel is not properly atomised the droplets will not be completely combusted in the flame.

If there is insufficient oxygen available (sub-stoichiometric), incomplete combustion will occur. In this situation the carbon is converted to carbon monoxide (CO) and not all the potential energy is released. In an ideal system the correct amount of oxygen and thus air required can be calculated, however, in practice, more air is required due to the loss of efficiency in mixing and making intimate contact. The amount of excess oxygen required is currently 3 – 5%, which equates to excess air required for full combustion of generally around 15 - 25% by mass. The introduction of more air than this will result in a loss of efficiency as some of the heat will be lost in heating up the additional air.

In reality, combustion is far more complex than described above as many compounds are formed and converted during the combustion process, however this has no practical use in every day burner operation.

To achieve the best efficiency the following must occur:

- The fuel must be adequately atomised (generally <50 microns droplet size)
- Adequate air must be available (3%-5% excess oxygen)
- Intimate contact of fuel and oxygen must occur (flame shape, spray pattern)
- Maximum carbon dioxide produced ($\text{CO}_2 > 12\%$)
- Minimum carbon monoxide produced ($\text{CO} < 1\%$)
- Minimum stack temperature (wasted heat)

To achieve the most effective use of the energy, the flue temperature and the excess air should be kept as low as possible, as heat going up the flue is energy lost. From the above it can be seen that the most efficient combustion can only be achieved if the oxygen, carbon dioxide contents and temperature of the flue gas are measured and optimised. There are instruments available to measure these three parameters.

The more accurate instrument is the 'Combustion Optimiser' which will measure stack temperature, oxygen, carbon dioxide and carbon monoxide levels and calculate a percentage efficiency. These instruments are costly but will quickly be paid for in fuel bill savings.

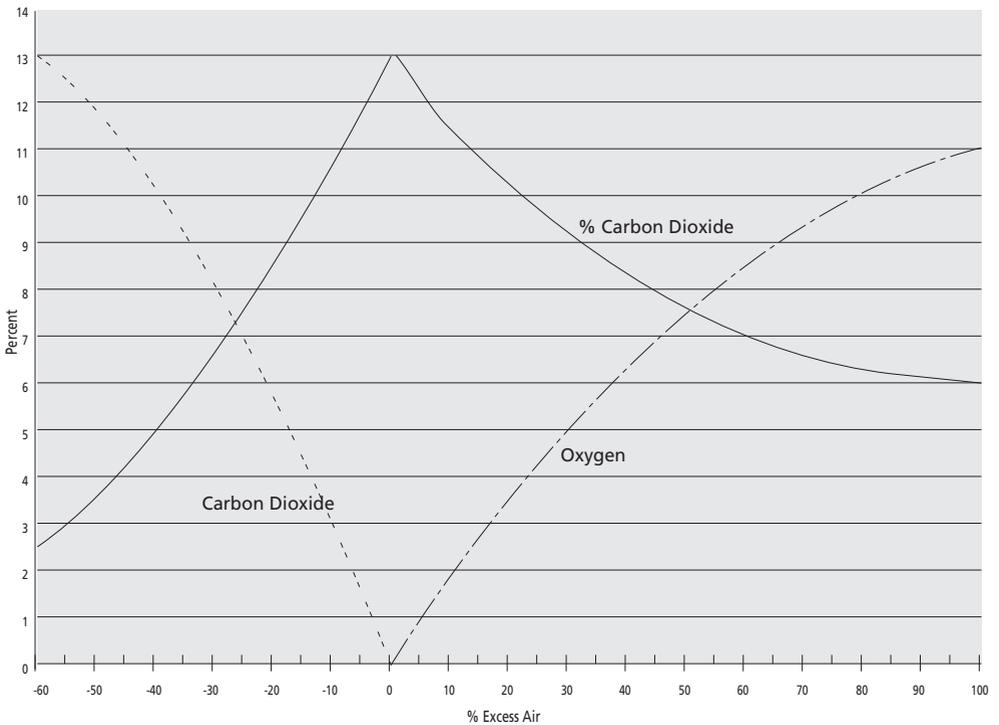
A cheaper but less practical instrument is the 'Fire Rite' system. This

simple, easy-to-use system measures the oxygen and carbon dioxide by dissolving the flue gas into a chemical solution, which changes in volume in the tubes. Results should be recorded on a daily or per shift basis and reviewed monthly.

Without some means of measuring the combustion efficiency, the appliance will be run blindly and the best results are unlikely to be achieved resulting in fuel wastage.

The following graph shows the theoretical change in CO, CO₂ and O₂ with differing amounts of excess air for a typical heavy fuel oil. In practice the maximum CO₂ and minimum CO would occur with around 3% - 5% free oxygen. This correlates with approximately 15% to 25% excess air, as there is approximately 21% oxygen in air.

Theoretical Flue Gas Analysis



FLAME SHAPE

The shape of the flame is important for several reasons. A very long flame may take the heat past the appliance heat transferring area and reduce efficiency. A short flame may reduce the residence time of the fuel mixture in the flame zone and may result in unburned fuel. A wide flame may impinge on the surface of the firing chamber and will lead to failure of the refractory or blistering of the firing tube. The best flame shape is dependent on the type of burner and the shape of the qual (entry combustion chamber). Flame shape also determines the air fuel mixing success, which leads to good combustion. An incorrectly set up flame can also result in pressure oscillations or flame pulsation.

FLAME SPEED

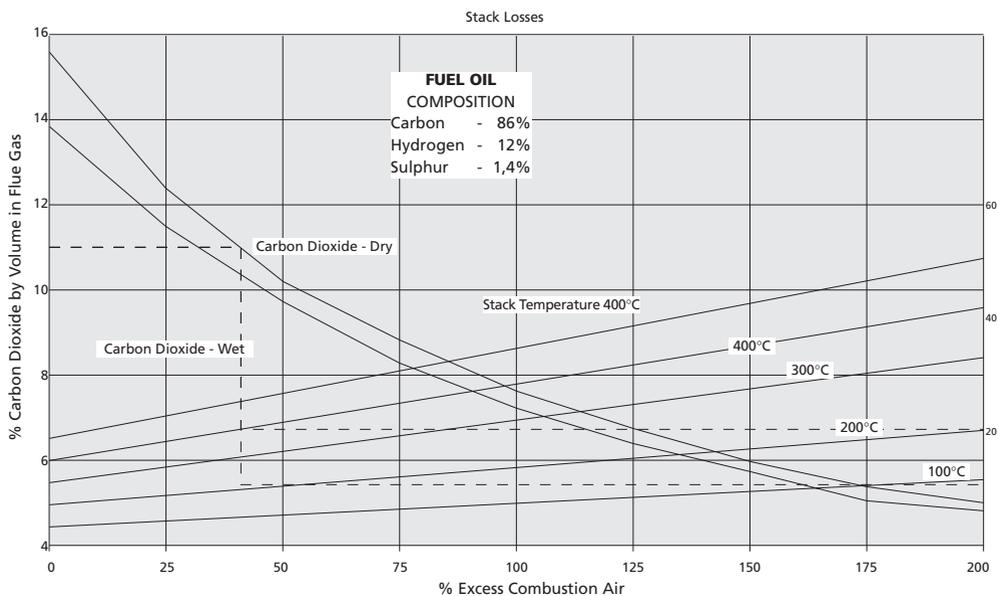
The flame is the zone of combustion within which visible radiation is produced. A stable flame is merely a flame that is moving towards the burner at the same speed that the gas mixture is coming out of the burner. The flame propagation speed is a function of the volatility of the fuel and the droplet size, and varies between fuels, burners and appliances. If the gas flow is lower than the flame propagation speed then the flame may flash back. If the gas flow is higher than the flame propagation speed then the flame will be blown away. Varying flame speeds may result in an unstable flame and pressure oscillation.

STACK LOSSES

The graph below shows the effect of the measured carbon dioxide (CO₂) and temperature of the stack waste gas on the stack losses.

For this particular fuel, with a measured CO₂ (dry) of 11% and a change in stack temperature from 220°C to 420°C, there is a ~10% loss of energy.

If the measured CO₂ (dry) was measured at an inefficient 8% and the stack temperature moved from 220°C to 420°C then the stack losses would be ~15%.



If the CO₂ (dry) content of the flue waste gas decreased from 11% to 8% with a stack temperature of 300°C, this would result in an energy loss up the stack of ~8%

A loss of efficiency equates directly to a loss of energy or an increase in the fuel bill.

ATOMISATION OF FUEL

As mentioned above the atomisation of the fuel is critical to the successful combustion of the fuel in the flame. Large droplets take longer to combust and so tend to emerge from the flame as sparklers. These sparklers tend to form hard deposits of carbonised fuel when they come into contact with the furnace surfaces. This is undesirable, as there is a loss of efficiency in the system, the potential for loss of flame shape and impingement and excessive cleaning required.

Poor atomisation can result from too high viscosity of the fuel (heavy oils) or lack of fuel pressure. Incorrectly set up burners or worn nozzles can also result in poor atomisation.

Atomisation is thus a function of:

- Fuel viscosity
- Fuel pressure
- Air pressure
- Nozzle shape and size (worn or incorrect size)
- Burner design

It should be noted that heating the fuel too much, in order to reduce the viscosity, will lead to fuel vaporisation and failure of the flame due to in-stability.

TOXIC EMISSIONS

The four main harmful pollutants found in the products of combustion are nitric oxide (NO), nitrogen dioxide (NO₂), carbon monoxide (CO) and sulfur dioxide (SO₂). There are other minor harmful compounds formed of which many contain sulphur. It is common to talk about NOx's and SOx's to include all of the possible nitrogen and sulphur products that occur.

NOx's

Nitrogen oxides are products of combustion formed within locally high temperature regions where nitrogen and oxygen are present. These NOx products of combustion emissions pose a significant health hazard in ambient air. They are also responsible for photochemical smog and contribute to acid rain. In the lower atmosphere, NO reacts with oxygen in the air to form NO₂ and ozone (O₃). Ground level ozone is a health hazard as it blocks air passages and impairs respiratory performance.

NOx production can be limited by:

- Limiting peak flame temperatures
- Limiting localised in-flame oxygen concentrations
- Reducing residence time at peak temperatures.

SOx's

Sulphur dioxide and sulphur trioxide are products of combustion that will be present when using any fuel containing sulphur or sulphur compounds. The final production of SOx cannot be altered by the combustion process.

SOx's are a health hazard as they affect the respiratory system. They are also of concern as they cause acid rain and general industrial corrosion. They cause leaching in soils, which can lead to plant growth problems. Serious corrosion can occur in combustion appliances if condensation occurs. This occurs easier when sulphur is present as sulphur increases the dew point temperature of the flue gas. Sulphur compounds, such as hydrogen sulphide (H_2SO_3), are offensive for their pungent odour.

PARTICULATE EMISSIONS

Particulate emissions are particles of carbon or soot from incomplete combustion. Soot is mostly as a result of too rich a mixture (too much fuel or too little air) or combustion equipment that does not mix properly. Some fuels have a tendency to smut (emit soot) even at their optimal fuel/air ratio. Particulate emission is limited by law as it constitutes a health hazard both to plant and animal (human) life.

WHITE SMOKE

White smoke emissions from the stack may be caused by the following:

- Too much excess air (measurable in excess oxygen)
- Flame impingement on refractory
- From the products melted
- From certain types of refractory

BLACK SMOKE

Black smoke emissions from the stack may be caused by the following:

- Too little excess air (measurable in excess oxygen)
- Poor atomisation (high viscosity, worn nozzles, worn pumps)
- Certain HFO's have smutting or sooting properties.

CLEANING OF BOILERS/FURNACES

The ash in the fuels will either settle in the firing tubes of boilers, be caught in dust collectors, enter the product, or emerge as emissions from the stack. As there are strict environmental restrictions regarding emissions, it is in everyone's interests to prevent ash from going up the chimney. The cleaning period required to keep your heating appliance running at peak efficiency will vary from installation to installation and on the ash content of the fuel. High ash fuels may require cleaning appliances every second or third week while low ash fuels may require appliances to be cleaned only every six weeks.

The low cost of heavy furnace oils would normally result in a large energy cost saving, regardless of the appliance cleaning period.

BURNERS

There are many different propriety brands of burners available, which fall into four basic burner types.

PRESSURE JET BURNERS

Weishaupt, Elco, Riello, Nuway, Wanson.

Pressure jet burners rely on a reasonably high fuel pressure to atomise the fuel through a spray nozzle. These burners are generally used on light fuels such as FFS's LO10, paraffin or diesel. The pressure required in the fuel supply to pressure jet burners is generally in the order of 1000 kPa (10 bar) but can be as much as 3000 kPa. The pumps used to supply these high pressures to the burner are usually positive displacement pumps such as piston pumps or gear pumps, but diaphragm pumps such as the Wanner Diaphragm pump are also suitable. Gear pumps are not suitable for use with LO10 as the centrifugal effect of these pumps tends to separate out the otherwise stable heavy fractions and result in pump failure. FFS supply a piston pump system, which gives excellent service and has the added advantage of being inexpensive and exceptionally easy to maintain.

STEAM ATOMISING BURNERS

Steam atomising burners use low (400 – 800 kPa), and occasionally high, pressure steam to atomise the fuel in a special nozzle. This two-part nozzle introduces the fuel at relatively low pressures (200 – 400 kPa) through the centre nozzle and the steam through peripheral nozzles into an atomising outer cone and nozzle. This system achieves excellent atomisation of heavy fuels. They are generally easy to start and the nozzles stay clean due to the good purging ability of steam. The disadvantage of this burner is that steam is required to run the burner although some types will allow start-up on air.

AIR ATOMISING BURNERS

Nuway, Hauck, Maxxon

Similar to steam atomising but uses air to atomise.

ROTARY CUP BURNERS

Hamworthy, Saacke

These burners are suitable for heavy fuels such as LSO and HFO. They have a rotating cup that atomises the fuel into the air steam. These are complicated burners with many expensive wearing parts and require expert servicing. Frequent cleaning of the cups is essential (once per shift or day) to ensure that they do not go out of balance. This is however easily carried out in a matter of minutes.

PROBLEM SOLVING

In order for the fuel to burn correctly, assuming that the combustion chamber and quarl shape has been correctly designed and built, in the most economical manner there are two major criteria that must be met, namely:

- (a) The fuel must arrive at the burner at the correct temperature and pressure, and
- (b) The burner must be set up correctly to burn the fuel.

The following is a trouble shooting guide that may help solve burning problems. Although this table cannot cover all types of burners with their own peculiarities and also the different types of fuels used i.e. heavy fuels which require heating and light fuels which do not require heating, it does give the general or typical faults that may be encountered.

(a) FUEL SUPPLY TO BURNER

SYMPTOM TABLE		
PROBLEM	SYMPTOM	CAUSE
No fuel at the burner	Pressure and temperature gauges at burner do not register. Pressure gauge at burner reading incorrect. Temperature indicator at burner reading incorrect	(i) No fuel delivery to burner (ii) Fuel pressure incorrect (iii) Fuel temp./pressure incorrect

ACTION TABLE		
PROBLEM	CAUSE	CORRECTIVE ACTION
(i) No fuel delivery to burner	Fuel level in tank too low No fuel in day tank Outflow heater faulty Filter blocked – particulate Filter blocked – carbon Filter blocked -- wax crystals	Top up fuel Check transfer pump signal, power and pump operation Check and repair Clean tank and replace fuel Check line heater as below Check line temperature
(ii) Fuel pressure incorrect	Back pressure valve faulty Filter blocked – particulate Filter blocked – carbon Filter blocked - wax Circulation pump faulty Line heater carbonised	Reset or repair Clean filter Replace blown heater elements and clean filter and heater. Raise line temperature Repair/ replace pump Clean or replace line heater
(iii) Fuel temperature incorrect	Line heater faulty Low fuel flow	Check carbonising, elements, fuses, breakers, thermostats, switches. Check as for fuel pressure

(b) BURNER RELATED PROBLEMS

SYMPTOM TABLE		
PROBLEM	SYMPTOM	CAUSE
Burner ignition failure	Burner will not start	(i) No gas flame (ii) No fuel ignition (iii) No ignition spark
Incorrect burner operation	Black smoke High back end temperature White smoke Low heat output Sparklers and klinker buildup	(iv) Incorrect burning (v) Refractory problems (vi) Blocked tubes (vii) Lean mixture (viii) Non burner related (ix) Small flame (x) Excessive air (xi) Poor atomisation (xii) Flame impingement

SYMPTOM TABLE		
PROBLEM	CAUSE	CORRECTIVE ACTION
(i) No gas flame (Gas ignition burners)	No gas Faulty gas valve No spark Air/gas ratio incorrect Faulty controller Faulty sensor	Change gas bottle Repair/replace Check as (iii) below Check settings Repair/replace Repair/replace

SYMPTOM TABLE		
PROBLEM	SYMPTON	CAUSE
(ii) No fuel ignition	Incorrect gas flame Spark ignition failure Inadequate atomisation Incorrect air/fuel ratio Blocked nozzle Worn nozzle Fuel temperature wrong Fuel pressure wrong Wrong burner settings Burner damage	Check size and position Check transformer, power, points See (xi) Check settings Clean/replace Replace Check settings Check settings Check settings Check settings
(iii) No spark	Power failure Faulty ignition transformer Faulty flame sensor Point settings incorrect	Check Repair/replace Repair/replace Set correctly
(iv) Incorrect burning	Excessive fuel/air (rich mix) Poor atomisation Klinker buildup Blocked boiler tubes Low air supply High burner pump pressure Oversize burner nozzle Modulation failure Poor refractory design/condition	Adjust mixture – more air See item (xi) See items (xi) and (xii) See item (vi) Check air damper, fan intake blockage, fan failure Set to correct pressure Fit correct nozzle Check modulation mechanism See item (v)
(v) Refractory Problem	Poor design or damage	Rectify
(vi) Blocked tubes	Ash build up	Clean regularly

ACTION TABLE		
PROBLEM	CAUSE	CORRECTIVE ACTION
(vii) Lean mixture	Incorrect air settings Fuel starvation	Rectify Check fuel pressure, dirty nozzles, faulty modulator
(viii) Non burner related	Loss of insulation Faulty circulation fans or baffles	Repair Check air circulation correct
(ix) Small flame	Dirty nozzles Nozzle too small Too much excess air Fuel starvation	Clean nozzles Fit larger nozzle Adjust air supply and check damper Check fuel supply pressure and temp, dirty nozzle, modulator.
(x) Excessive air	Too much excess air introduced to combat black smoke	Adjust air supply and look for other reasons for black smoke.
(xi) Poor atomisation	Worn burner nozzle Incorrect fuel temperature Incorrect fuel pressure Klinker buildup on nozzle	Replace nozzle Rectify Rectify Clean nozzle and check for dribbling - diffuser plate dirty or incorrectly placed
(xii) Flame impingement	Poor atomisation Burner misalignment Incorrect quarl shape or condition. Flame too large (overfiring) Flame shape	See (xi) Check and rectify Rectify Reduce flame size Reduce bushy flame

For more in-depth information on combustion physics see the
 "North America COMBUSTION HANDBOOK" VOLUMES I & II. 4455
 East 71st Street, Cleveland, Ohio 44105-5600 USA. Tel (216) 271-600
 Fax (216) 641-7852.

CONVERSION TABLE

1 Imperial gallon	= 4,546 litres (dm ³)
1 US gallon	= 3,785 litres (dm ³)
1 long ton (2240 lbs)	= 1016 kg
1 short ton (2000 lbs)	= 907,2 kg
1 BTU/ft ³ = 9,547 kcal/m ³	= 39,964 kJ/m ³
1 BTU/lb = 0,556 kcal/kg	= 2,327 kJ/kg
1 lb	= 0,4531 kg
1 lb/ft ² = 4,882 kgf/m ²	= 47,8924 N/m ²
1 lb/in ² (psi)	= 0,0703 kgf/cm ² = 6,896 N/mm ² (mPa)
1 in	= 2,54 cm
1 in ²	= 6,452 cm ²
1 in ³	= 16,39 cm ³
1 ft	= 30,48 cm
1 yd	= 91,44 cm
1 mile	= 1,609 km
1 nautical mile	= 1,8532 km
1 barrel	= 0,159 m ³
°F	= (9/5)(°C) + 32
°C	= (5/9)(°C - 32)
1 hp	= 745,7 J/s = 0,7457 kW
1 kW	= 1,341 hp
1 J	= 0,278x10 ⁻⁶ kWh
1 kWh	= 3,6x10 ⁶ J
1 bar	= 105 N/m ² (Pa)