



RE-AN International
Technology Services Ltd

Processed Fuel Oil

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1/8/2012

Report

Executive Summary

For decades waste oil was collected and processed into a low grade fuel, to be used for firing in applications where high ash content fuel would have no negative impact. Rotary kilns used in the manufacture of road surface material would be a typical application.

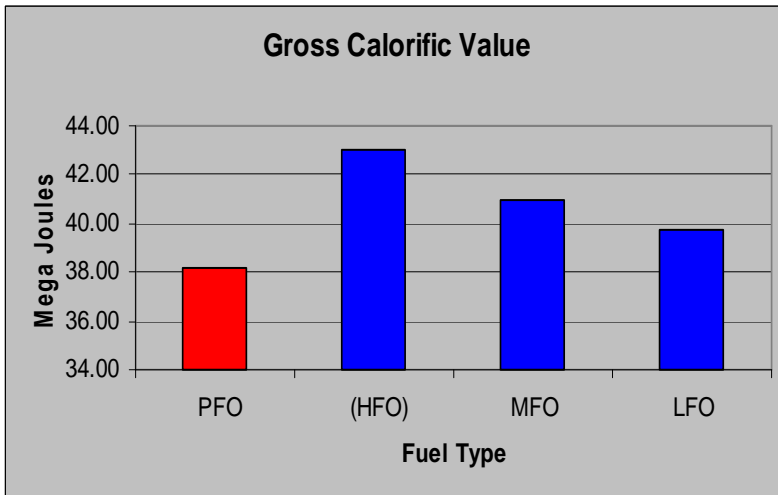
The UK Court of Appeal Judgement in the OSS Group V's The Environmental Agency, (2007) case, found that once the waste oil had undergone specific treatments to remove a significant proportion of the heavy metals and other contaminants, it should no longer be considered as waste. Following this finding, The Environmental Agency issued the Processed Fuel Quality Protocol specifying Processed Fuel as a recovered product will not be subject to The Waste Incineration Directive, provided the oil complies with the standards set out in Appendix C of this protocol. However to date the burning of PFO as a Waste Derived Fuel is subject to the Environmental Permitting Regulations and operators burning PFO will need to discuss with the Environmental Agency if they require a variation to their licence and what additional monitoring regimes are required to change from a virgin fuel oil to a waste derived fuel.

Process Fuel Oil is recovered waste oil that has undergone a process to recover this oil as a fuel. A large percentage of Processed Fuel Oil start life as lubricants and therefore contains lubricant package additives, wear metals, combustion derivatives and reformatted hydrocarbon compounds, including PCB, chlorine, heavy metals and acids. This waste oil is subjected to a process that involves the addition of acids to precipitate out a significant amount, but not all metals and other impurities. This is a skilled operation and failure to carry out this process carefully or the failure to neutralise the treated oil can lead to an out of specification product.

The UK Environmental Agency has drafted a Protocol including a specification to which this waste derived fuel oil must comply with, to be classified as Processed Fuel Oil. The Irish EPA is currently considering its position in respect of this issue and when contacted replied ***'The EPA is currently reviewing the status of PFO which has been recovered according to the UK quality protocol. The EPA will make a decision in due course. Until then, the EPA***

cannot advise that PFO can be combusted without controls in compliance with the Waste Incineration Directive.' (Irish EPA 19/7/2012)

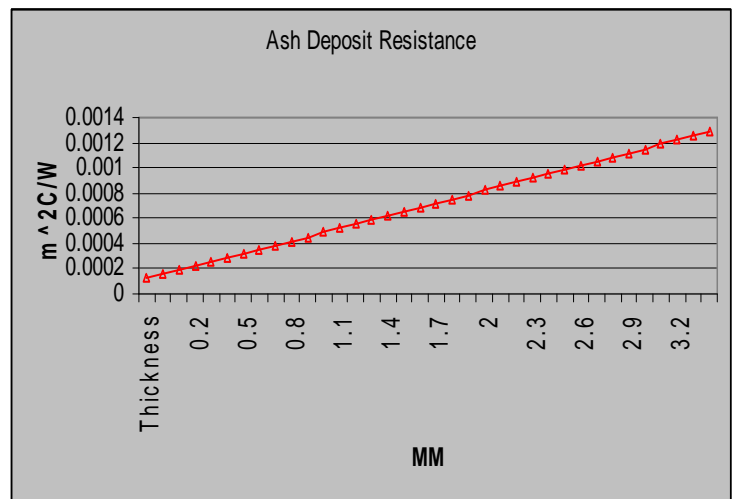
Processed Fuel Oil is sold to industry under suppliers own trade names and has recently been offered widely to the boiler sector as an alternative to virgin fuel oil. This product is generally sold at a price that is significantly cheaper than its virgin fuel oil equivalent. The un-



suspecting purchaser of Processed Fuel Oil may feel that they are getting a very competitively priced alternative fuel and thus be able to reduce their operating costs. However Processed Fuel Oil has a significantly lower calorific value, up to 14% less than its

virgin fuel equivalent. The lower calorific value of Processed Fuel Oil and its potential to contain high ash that interferes with efficient heat transfer may eliminate any perceived cost benefit from the cheaper fuel price.

The potentially significant high ash and high sediment content of Processed Fuel Oil compared to that of the virgin fuel may impact on the smooth operation of common steam boilers. In addition, end users must consider the potential for a halogen content expressed as chlorine. The burning of processed fuel containing halogens, particularly chlorine, may result



in the formation of highly corrosive hydrochloric acid that will attack the boiler heat transfer surfaces and boiler shell walls. Studies carried out on boilers have testified to the negative and damaging impact that chlorine attack has on heat transfer surfaces. Further expense may be incurred by operators in respect of the increased cleaning schedule associated with high ash fuel, the requirement for specialised contractors to carry out this operation, the cost of the disposal of what may be classified as a hazardous substance and down time. In addition, if the

fuel processing operation is not carried out correctly, residue acids may lead to a strong acid number in the fuel resulting in severe corrosion of the boiler and burner equipment. Plant operators who decide to burn Processed Fuel Oil should consider requesting a certificate of analysis for each load of oil purchased and refuse to be satisfied with the issuing of a general specification. As per Appendix E of the Processed Fuel Oil Quality Protocol 2011. Purchasers of Process Fuel should pay particular attention to the sulphated ash content and the strong acid number reported on the certificate of analysis and give thought to possible impacts of these parameters.

In addition, the operator must concern himself with environmental concerns that may arise from the potential of emitting heavy metals into the atmosphere and their impact on the ambient air quality standards as set out in The Air Quality Standard Regulations 2010 for heavy metals, PCB and other contaminants.

Processed Fuel Oil

Report

History

For a considerable number of years, waste oil derived from various sources, such as spent automotive and industrial lubricants, ship separator residues and other contaminated or spoiled lubricants and fuel have been collected and subjected to a recovery process which consisted of dewatering and the removal of abrasive solids by centrifuging or filtering. The recovered oil was then blended to a consistent viscosity and sold under various trade names as a low cost fuel. This fuel was particularly popular with the road making material industry for use in rotary kilns. High ash content was of no concern in this application, because the flame and thus the combustion contaminants were in direct contact with the stone and bitumen for road making, and were absorbed harmlessly into the finished road making product.

Legislative History

The waste oil industry first became regulated with the introduction of EC Directive 75/439/EEC in 1975 and amended by directive 87/101/EEC in 1987 which resulted in the introduction of European Communities (Waste Oil) Regulation 1992 in Ireland. This legislation introduced technical limitations on the emissions resulting from the burning of Recovered Waste Oil in plants with a thermal output of 3MW or more. (Scannell, Y 1995) Agreement in the various jurisdictions permitted these emission limits to be monitored by the proxy of a fuel analysis and occasional stack monitoring. The more serious pollutants such as Poly Chlorinated Biphenyl's (PCB), heavy metals and halogens among others were given threshold limits. Following a UK High Court decision in 2001 affecting the waste solvent industry, the UK EPA refocused their attention on the final disposal of Waste Oil, concluding that the heretofore controls on the burning of recycled fuel oil were inadequate and that further restrictions as set out in the Waste Incineration Directive were appropriate. This decision impacted negatively on the waste oil industry and in effect closed off all avenues of burning, and thus final disposal. Following the UK Court of Appeal Judgement in the OSS Group Vs The UK Environmental Agency 2007 case (Environment Agency Quality Protocol) which found that once the waste oil had undergone specific treatments to remove a significant

proportion of the heavy metals and other contaminants it should no longer be considered as waste. The UK Environmental Agency issued the “Processed Fuel Quality Protocol End of Waste Criteria” thus removing the obligation to comply with the Waste Incineration Directive. However, those wishing to use Processed Fuel Oils in the Boilers will be regulated under Section 1.1 of Part 2 of Schedule 1 of the Environmental Permitting (England and Wales Regulations 2007) and the equivalent regulations for Scotland and Northern Ireland. The Westminster Government has proposed amendment to the above Regulations that would remove this requirement. However, the European Parliament has not as yet accepted that the UK Protocol meets the legal requirements of Article 6 of the Directive 2008/98/EC.

Thus Process Fuel is classified as a fuel manufactured from waste and is therefore subject to Section 1.1 of Part 2 of Schedule 1 of the Environmental Permitting (England and Wales Regulations 2007) and the equivalent regulations for Scotland and Northern Ireland. In the Republic of Ireland, the EPA is currently reviewing the status of PFO which has been recovered according to the UK quality protocol and they replied that *‘The EPA will make a decision in due course. Until then, the EPA cannot advise that PFO can be combusted without controls in compliance with the Waste Incineration Directive.’* (Irish EPA 19/7/2012)

Current Market Position

Waste oil recovery companies have adopted the UK Process Fuel Oil Protocol enthusiastically both in the UK and the Republic of Ireland and introduced a process that uses Phosphorus Acid among other acid treatments, followed by neutralising, to significantly reduce the heavy metal and ash content of the processed oil. The “Processed Fuel Oil” is sold under various trade names throughout both jurisdictions. Producers of Processed Fuel Oil are now offering this product for all industrial applications, including combustion in Industrial Boiler Plants to produce steam. Heretofore, they avoided boiler plant applications because the high ash content very quickly filled the boiler tubes with ash and thus significantly reduced the heat transfer from the hot gases into the water/steam side of the boiler, giving rise to operational and safety concerns.

Specifications and Product Quality

For reclaimed waste oil to be marketed as Processed Fuel Oil (PFO), the finished processed product must comply with the specifications set out in Table 1 Appendix C for distillates and Table 2 Appendix C for residue fuel oil as per the Processed Fuel Oil Quality Protocol published by the UK Environmental Agency 2011. This specification, in effect, imposes parameters on process fuel that are similar to the requirements of British Standards BS 2869 Class D for Gas Oil and BS 2869 class E, F, and G for residue fuel oil, but with additional specifications for PCB, Chlorine, Ash and Heavy Metals not found in the virgin fuel oils. Operators burning Processed Fuel should enter into discussion with the Environmental Agency to establish if a variation in their licence is required to substitute a virgin fuel for what is a waste derived fuel.

Quality of Processed Fuel Oil

Purchasers of PFO may find comfort in the belief that the quality of any purchased PFO is comparable to virgin fuel oil complying as it does to BS 2869 Class E, F, and G. However herein is the difficulty for end users. BS 2869 specification is so broad that maximum limits set out in the standards greatly exceed the typical parameters of purchased virgin fuel oil. As the end user is purchasing energy for the generation of steam, the purchaser should be aware of the typical parameters of PFO versus virgin fuel oil and how this may impact negatively on the performance of their steam production.

The parameters that are of most concern are as follows:

- Ash content/Sulphated Ash Content
- Total Sediment Content
- Strong Acid Number

Typical comparisons actual versus standards

Table 2 Specification for PFO & Residual oil equivalents						
Property Typical	Units	PFO	HFO	MFO	LFO	IP Method
Kinematics Viscosity	mm ² /sec	8	20	15	8	BS 2000-71 Section 1
Carbon Residue	%(m/m)					
Sulphated Ash (Max)	%(m/m)	0.2	0.04	0.04	0.02	
Flash Point (min)	C	66	66	66	66	
Water Content Max	%(V/V)	2	0.5	0.5	0.5	
Sediment by Extraction (Max)	%(m/m)		0.04	0.04	0.02	BS 2000-375
Sulphur (Max)	%(m/m)	1	0.9	0.8	0.7	BS 2000-336
Strong Acid Number		Zero	Zero	Zero	Zero	BS 2000-139
Total halogens (as Chlorine)	mg/kg	150	0	0	0	
PCB's (Max)	mg/kg	5	0	0	0	IP 462
Metals (Max)	mg/kg		-	-	-	
Mercury	mg/kg	5	0.02	0.02	0.02	
Lead	mg/kg	25	20	18	14	
Nickel	mg/kg	5	8	7	5	
Chromium	mg/kg	5	3	2.8	2	
Copper	mg/kg	40	9	8	6	
Zinc	mg/kg	300	14	13	12	
Arsenic	mg/kg	5	10	8	6	
Cadmium	mg/kg	5	2	1.5	1	
Thallium	mg/kg	5	0	0	0	
Antimony	mg/kg	5	0	0	0	
Cobalt	mg/kg	5	3	3	2.6	
Manganese	mg/kg	5	16	14	12	
Vanadium	mg/kg	5	40	35	30	

Ash and Total Sediment Content of Processed Fuel Oil

The boiler operator would be most concerned with the ash content of the fuel expressed in terms of Total Ash or Sulphated Ash content by the fuel supplier.

The Ash contained in fuel oils will be deposited in layers in the boiler tubes during combustion. Oil ash is deposited in a solid phase in the boiler tubes and thus enhances the thermal resistance of the heat transfer between the hot gas side and the water/steam side of the boiler. Continuous build up of ash and sediment within the boiler tubes may significantly reduce the heat recovery efficiency. This will manifest itself in elevated stack temperatures as the energy is lost through the boiler stack. Zbogar et al references Wall et al in arriving at a thermal conductivity value for boiler ash deposits of $K_s=3\text{W/M K}$. This is comparable to the thermal conductivity of silica containing material at high temperature (Zbogar et al 2005, 403).

An industrial boiler will burn approximately 53 Kgs of oil per 1,000 Kg of steam generated depending on the boiler efficiency, steam pressure, burner type, heat loss and other factors. The boiler industries use an empirical figure of 26 litres of oil per 460 Kg (1,000 lbs) of steam produced. Fuel Oil of grades E, F, G will produce approximately 9 grams of ash per thousand pounds of steam produced. Process Fuel used in the same application has the potential to produce up to 52 grams of ash for the same fuel usage and steam production. This is a factor of almost six times the potential ash production of virgin fuel oil, with a significant potential for energy loss to the end user. Heat transfer in tube boilers takes place by convection and radiation from the combustion gas to the tube wall. Conduction occurs through the tube wall and convection from the tubes to the water (Gutiérrez Ortiz, 2011 3465). However, this process does not take place uniformly as the velocity of the gas decreases as it travels down and back along the boiler tube passes (usually 3). As a result, ash deposits will not occur uniformly along the fire tubes. A point occurs where gas velocity is not high enough to continue to carry the ash and it deposits in layers at a certain point along the tube length. Ash capture can be enhanced by mechanisms occurring within the boiler tubes. Zbogar et al discusses the increased thermal resistance that takes place as ash deposits become molten and enhances the capturing effect of molten ash along the tube path. (Zbogar et al 2005, 2258) It is accepted that the greatest ash deposits occurs where the fire tubes reverse by 180 degrees, entering the second pass and most ash deposit occurs before the fire tube turns again for the third pass. Ash build up at these points can lead to hot spots where heat transfer from the hot gases to the water phase is so poor that tube distortion can occur in extreme cases.

The overall heat transfer coefficient (\dot{U}) takes account of the conductive and convective resistance between two fluids separated by a solid wall. For the purpose of considering heat transfer in a tube boiler, the hot gasses on the one side and the water on the steam/water side can be considered to act as fluids. The tube wall and any ash deposits are considered to be the solid wall. The total resistance to heat transfer can be calculated as an aggregate of the individual material thickness, divided by the thermal conductivity of the material. (Spirax/Sarco 2007, 2.5.12). As discussed above, thermal conductivity of ash can be taken as $3 \text{ Wm}^\circ/\text{K(C)}$ and boiler fire tubes thickness can be assumed to be 6MM, with a Thermal Conductivity of $50 \text{ W/m}^\circ\text{C}$ (Spirax/Sarco 2007, 2.5.14).

It is therefore possible to graph the \dot{U} value of a boiler tube with different thickness of ash deposits lying in the tubes to obtain an overall heat transfer coefficient. The lower the \dot{U} , the better the insulation effect of the barrier.

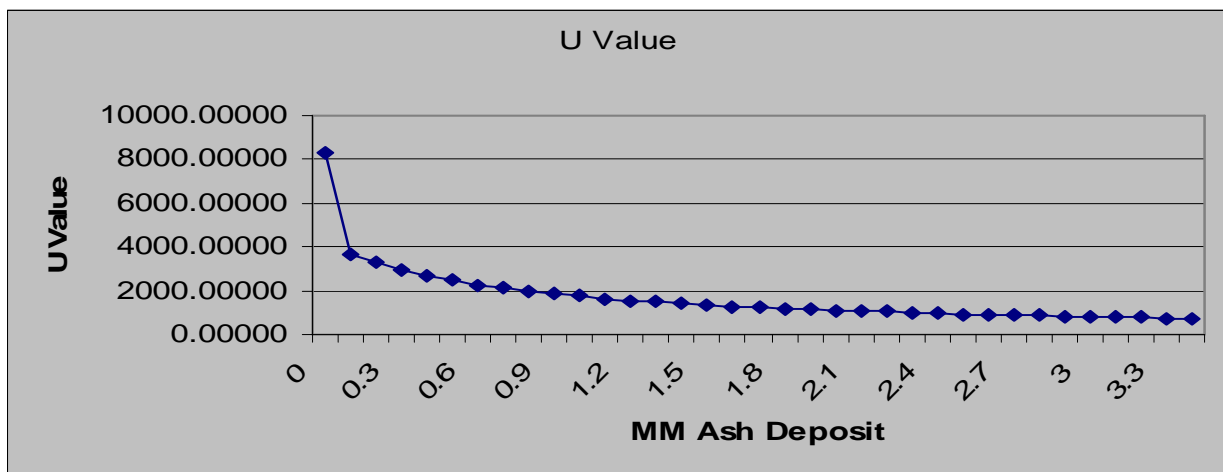


Fig.1

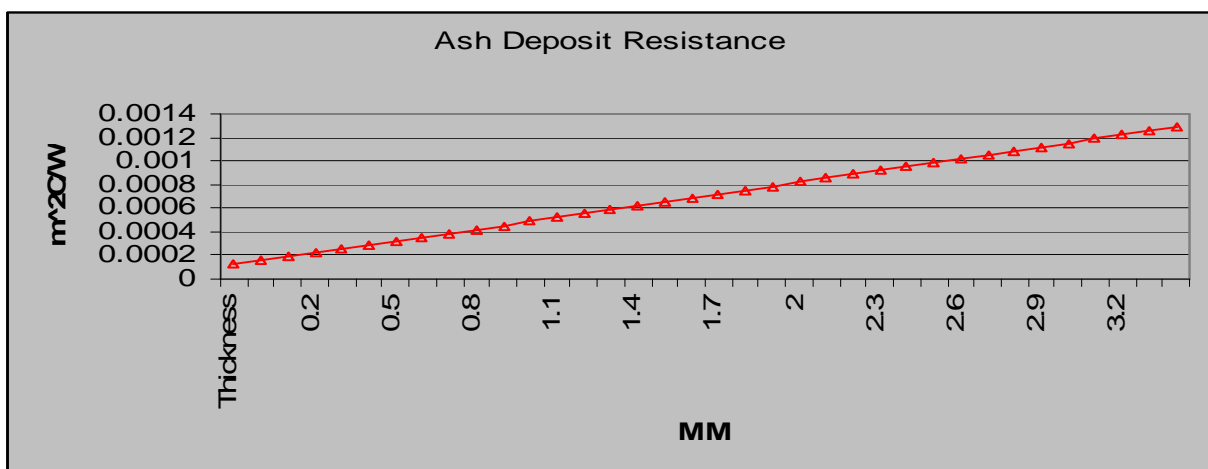


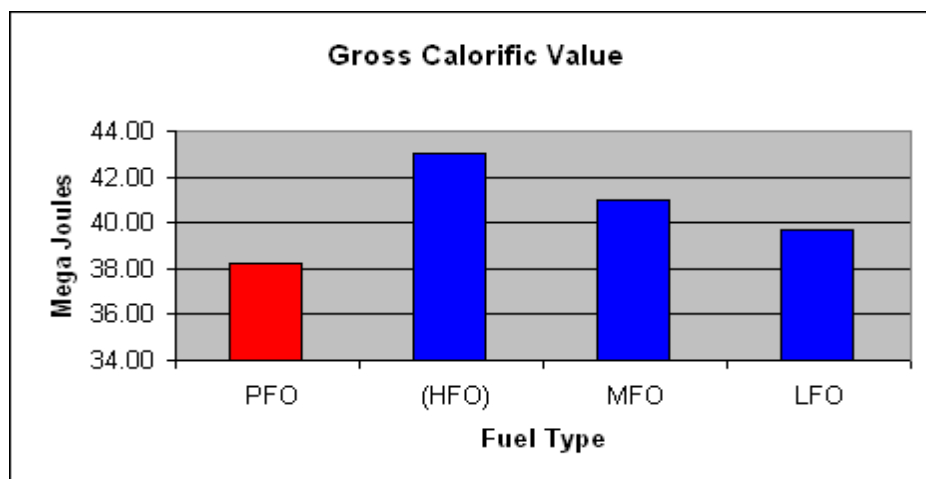
Fig 2

Energy Content

Calculating the energy content of process fuel as per the BS 2869 C.5 method, indicates that PFO has a comparable energy content per kilo to virgin fuel oil. However, fuel oil is purchased by the litre and not by the kilo and therefore purchasers of fuel must be concerned with the energy content per litre. Carrying out this calculation demonstrates that PFO is at a disadvantage when directly compared to virgin fuels, because of its low density, as demonstrated by the calculation and graph set out below.

CV	Q	Units	Processed fuel Oil (PFO)	Heavy Fuel Oil (HFO)	Medium Fuel Oil (MFO)	Light Fuel Oil (LFO)
Density	P	g/cm ³	0.8978	1.005	0.96	0.93
Water	x	%	0.54	0.1	0.25	0.25
Ash	y	%	0.08	0.02	0.04	0.04
Sulphur	s	%	1	1.00	1.00	1.00
	Gross	M.J	52.19	52.19	52.19	52.19
	Qv	M.J.	43.30	43.30	43.30	43.30
	Qv adjusted	M.J	42.60	42.82	42.74	42.74
	Mega Joules	M.J.	42.60	42.82	42.74	42.74
	Litres/Tonne	Litres	1.12	1.00	1.04	1.08
			PFO	(HFO)	MFO	LFO
	MJ/ Litre	M.J.	38.20	42.98	40.99	39.71

Table 2



The above calculation demonstrates just how disadvantaged PFO is when compared to virgin fuels and these calculations assume that process fuel oil contains a similar ash content (0.08%) to that of virgin fuels. However as discussed earlier in the report, this assumption is by no means certain. The specification for processed fuel provides for a maximum ash content of 0.2%. Fuel containing this percentage of ash will have a lower specific energy than the figure of 38.2 MJ/L calculated above. Purchasers of process fuel should factor this reduced energy content into their price calculations and take note of the significant resistance to heat transfer outlined above caused by high potential ash deposits in the boiler.

When the reduced calorific value of PFO per litre and the potential loss of energy resulting from ash deposits are added to the down time and the cost of boiler ash deposit cleaning and disposal, end users may find that what appears to be a very cost effective energy supply is not as economical as first appears

Processing Technique

Producers of Processed Fuel Oil use acid to precipitate out the spent additives from waste lubricant oil together with other metal salts that are in solution. This process is very effective in reducing the ash content of the processed fuel. However, the operation is a skilled operation, requiring neutralisation of the acid content of the processed fuel. Failure to carry out this operation skilfully will result in an out of specification strong acid number. Should this occur, not only will the Processed Fuel Oil fail to meet the specification of Table 1 or Table 2 of the Processed Fuel Oil Quality Protocol, but corrosion of the boiler tubes and fittings in direct contact with the oil and hot gasses may occur. In addition we have received reports of very highly acidic and corrosive tars leaking from boilers where poor quality Processed Fuel Oil was supplied.

Boiler Operations & Corrosion Concerns

The potentially significant high ash and high sediment content of PFO compared to that of virgin fuel can have an impact on the smooth operation of common steam boilers. In addition, end users must consider the potential for a halogen content, expressed as chlorine. Halogens and particularly chlorine can be added to lubricants by design for their high thermal

properties for use where lubricants without halogen additives may breakdown. However most chlorine and other halogens find their way into waste oil from cleaning fluids such as breaking cleaning fluids and chlorinate cleaning solvents used extensively in maintenance and repair workshops and disposed of in the waste oil. The Process Fuel Oil Protocol permits a total halogens content of 150mg/kg which will not be found in virgin fuel oil. Traditionally waste oils, recycled oils and processed fuels were burnt in road stone tarmac plants, where the flame was in direct contact with the stone material. In this type of application, the stone absorbed the chlorine content, particularly so in limestone regions. The burning of processed fuel containing halogens, particularly chlorine, may result in corrosion on boiler heat transfer surfaces and the furnace walls because chlorine will combine with water vapour which results from the combustion of hydrocarbon and form very corrosive hydrochloric acid. Studies carried out on biomass boilers and coal boilers have testified to the negative and damaging impact of a chlorine attack has on heat transfer surfaces (Guskoter et al 1964, 2). Lee and Castaldi in their 2008 study 'The effects of varied hydrogen chloride gas concentrations on corrosion rates of commercial tube alloys under simulated environment of WTE facilities' demonstrated that while hydrogen chloride (HCL) in flue gasses increased the corrosion rate, the impact was not linear and high temperatures exasperated the problem of chlorine and halogen corrosion (Lee and Castaldi). Nielsen et al. reported that when steel is exposed to an oxidizing environment at high temperatures, the metal gradually oxidizes to a thermodynamically stable oxide which forms a protective layer that protects the metal from further corrosion. However, chlorine has the ability to penetrate this protective surface and attack the metal alloys (Nielsen et al 2000, 286). Much research has been conducted on the negative impact of chlorine and other halogens impurities in coal and biomass fuels, however literature is silent on the impact of halogens on oil boiler applications thus reflecting the typical absence of chlorine contaminants in fuel oil.

Other Concerns

Empirical knowledge from boiler engineers suggests a negative impact on pump seals and hoses from coming in contact with the halogen content of Processed Fuel Oil.

In addition, those burning Processed Fuel should give consideration to Café Directive (Directive on Ambient Air Quality and Clean Air for Europe 2008/50/EC) that set out

stringent limits for ambient air pollutants, including Lead, Arsenic, Cadmium and Nickel. This directive was transposed in to UK law by The Environmental Protection Air Quality Standards Regulations 2010 and into Irish Law by the Air Quality Standard Regulations S.I. 180 of 2011. The above regulations set ambient air quality standards in the Nanogram per Cubic meter range for ambient air (a million nanograms equals one milligram). Burning Processed Fuel containing heavy metals will lay down these metals and other contaminants in the boiler ash and emit them in the stack plume. How these emissions impact on ambient air quality or the immediate environment can only be determined by ambient air quality monitoring or by stack emission testing followed by air dispersion modelling. Both are very expensive programmes.

Conclusion and Recommendations

While Processed Fuel Oil may initially appear to have a significant cost advantage over that of virgin fuel oil, there may be hidden costs that arise from the burning of Processed Fuel including:-

- A reduced fuel energy content. The energy content of PFO is up to 14% less than that Heavy Fuel Oil per litre.
- A high ash content can considerably reduce heat transfer. The net effect is that the operator loses energy up the boiler stack and out into the environment.
- A build up of ash in the boiler tubes will give rise to increased boiler cleaning cost and costs associated with ash disposal.
- Boiler down time due to increased cleaning and maintenance.

Plant operators who decide to pursue the burning of Processed Fuel Oil should request a certificate of analysis for each load of oil purchased as set out in Appendix E of the Processed Fuel Oil Quality Protocol 2011 and refuse to be satisfied with the issuing of a general specification. This certificate of analysis must come from a laboratory accredited by UKCAS and whose test methods are also accredited by UKCAS.

If the producer of Processed Fuel Oil has failed to recover the supplied fuel oil in compliance with the requirements of the Process Fuel Oil Quality Protocol '*the fuel oils they produce will normally be considered to be waste and waste management controls will apply to their handling, transport and use*' (Environmental Agency Processed Fuel Oil Quality Protocol 2011: 1,1,3)

In addition, The Processed Fuel Oil Quality Protocol states explicitly that where an end user is unable to demonstrate that the fuel meets the requirement of the Quality Protocol that those burning this material may be committing an offence. '*Where this Quality Protocol is not complied with, for example the PFO does not meet an approved standard, or the producer or supplier or user cannot demonstrate evidence of compliance, the PFO will normally be considered to be waste. In such circumstances, the holder or user must comply with the appropriate Waste Management and Waste Incineration Directive controls for the transportation, storage and use as fuel of the PFO and may be committing an offence if they do not do so.*' (Environmental Agency Processed Fuel Oil Quality Protocol (2011: 1,5.1)

.The operator should pay particular attention to the sulphated ash content on this certificate of analysis For reference purposes Class E,F,G of BS 2869 2010 virgin fuel are unlikely to have an ash content exceeding 0.05% . In addition Appendix E of the UK Environmental Protection Agency in the Processed Fuel Oil Quality contains a specimen certificate of conformity to be issued by suppliers with every load of Process Fuel Oil or fuel oil blended with process fuel oil. Purchasers of Process Fuel Oil or Process Fuel Blends should obtain this certificate with every purchase.

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