FUEL SELECTION

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There is a wide variety of liquid heating fuels available in South Africa. Each varies in cost, Specification and characteristics. There are an even greater variety of liquid fuel requirements in the many heating applications in use. The principle of the "Most Economical Fuel Suitable for the Application" should always apply. Arriving at what characteristics and specification is suitable for any given application requires an understanding of the fuels' properties (energy value, contaminants, density, emissivity and viscosity) and energy cost.

INTRODUCTION

Fuel selection is a critical aspect of combustion application efficiency as the cost of the energy source can be in excess of 70% of the total cost of operation. (Appendix-I)

Fuels vary greatly in their cost depending on their ease of use, qualities and availability. In general fuels of low quality and energy value cost less than fuels of high quality and energy value. Fuels also have characteristics that affect their cost and make them more or less suitable for particular applications.

The over-riding principle in fuel selection is to choose "The Most Economic Fuel Suitable for the Application". The problem is arriving at this balance, as a bias exists between the buyers and users. Operational staff, whose responsibility it is to ensure consistent and reliable operation, demand better quality fuel and argue for using higher quality fuels. On the other hand, management aims to purchase at the lowest possible cost. To arrive at the suitable choice requires some understanding of the effects and real costs.

This paper attempts to explain the characteristics of liquid heating fuels as they relate to establishing their fitness for purpose.

FUEL COSTS

Fuel costs vary significantly and it is worth reducing this to a factor based on the cost of diesel as a reference fuel to illustrate this point. A range of available fuels and their costs are shown in Table-I below.

Table-I

DESCRIPTION	COST[*]	FACTOR
Coal	R9,00/GJ	0,113
Coal Tar	R38/GJ	0,475
Heavy Oil	R39/GJ	0,488
Low Sulphur Heavy Oil	R40,00/GJ	0,500
Light Oil	R50,00/GJ	0,625
Diesel	R80,00/GJ	1,000
Paraffin	R57,00/GJ	0,713
Natural Gas	R40 – R80/GJ	0,5 – 1,0
LPG	R80 – R90/GJ	1,0 – 1,125
Electricity	R45 – R70/GJ	0,56 – 0,88

**Base date October 2003, Rand per Gross Energy excluding transport differential*

FUEL CHARACTERISTICS

The following are the main characteristics of fuels that influence their suitability or limitation for use in any given application:

Energy Value

The usefulness of a fuel in combustion is in the amount of energy it contains. Energy is measured in joules and the energy content of a fuel is given in joules per kilogram. In the process of combustion, the hydrocarbon (hydrogen and carbon) molecules are chemically converted into carbon dioxide (CO_2) and water (H_2O) releasing heat in the process. The energy value of a fuel is usually given as the Gross Energy value. However not all of the Gross Energy is usable in the heating application as the hydrogen, which is converted into water, is usually released up the stack as a vapour, carrying with it the latent heat of evaporation. The energy left is called the Net Energy value of the fuel. Thus a fuel with a greater mass of hydrogen atoms to carbon atoms will have a larger difference between the Gross and Net Energy values. Therefore the fuel with the highest Net Energy value will provide the most energy in joules per kilogram.

Some typical Gross and Net Energy values are shown in Table-II.

Table-II

DESCRIPTION	UNITS	GROSS ENERGY (MJ/kg)	NET ENERGY (MJ/kg)
LPG	MJ/kg	50	46,3
Paraffin	MJ/kg	46,5	43,3
Diesel	MJ/kg	46	43,0
Light Oil	MJ/kg	45,5	42,7
Heavy Oil	MJ/kg	43,5	41,7
Coal Tar	MJ/kg	37	37,2
Natural Gas	MJ/kg	29	
Coal –A grade	MJ/kg	28	27
Electricity	MJ/kWh	3,6	N/A

Density

The density of a fuel is usually only of interest in liquid fuels if the cost is given in cents per litre. In order to convert this cost into joules per kilogram, this property is required.

Viscosity

This property applies to liquid fuels only. Viscosity is a characteristic of a liquid that describes its resistance to flow. The relevance of this is in its ease of use as a combustion fuel. In order to effect good combustion, a liquid fuel must be sprayed into the combustion chamber mixed with air in sufficiently small droplets to achieve full combustion in the available flame residence time. This is the process of atomisation, which can only occur if the viscosity is low enough. It is generally accepted that a liquid fuel must have a viscosity below 20 centiStokes (cSt) in order to achieve adequate atomisation in most burner designs. This does not preclude the use of heavy fuel oil, as pre-heating liquid fuel reduces its viscosity. There is however a cost penalty in doing this, however it is usually very small in relation to the large differential in cost between light and heavy fuels, at about 0,5 – 0,75% of total energy cost.

Liquid fuels are usually specified as to their viscosity at set temperatures

Table-III shows the pre-heating temperatures required to reduce the viscosity below the 20 cSt level.

Table-III

DESCRIPTION	TEMPERATURE (^{O}C)
LPG	Not applicable
Paraffin	-20^{O}C
Diesel	-10^{O}C
Light Oil	0^{O}C
Medium Oil	+40^{O}C
Heavy Oil	+90^{O}C
Coal Tar	+80^{O}C
Natural Gas	Not applicable
Coal	Not applicable
Electricity	Not applicable

Contaminants

All fuels contain contaminants but in varying amounts. The most important of these contaminants are ash, water and sulphur.

ash

Ash is defined as the material remaining after complete combustion. It consists of inorganic compounds and elements. The concerns of ash in liquid heating fuels are as follows:

1. As a solid, such as silica, iron and aluminium oxide in the fuel it can cause wear of pumps and burner nozzles.
2. Certain elements, such as phosphorus, aluminium, iron and sulphur, can attack refractory
3. Ash can remain behind in the heating appliance causing blockages and loss of heat transfer. This ultimately leads to higher stack temperatures and a loss of efficiency.
4. Ash can contaminate the product in direct-fired heating applications. For example iron and sulphur in the fuel affect the colour of bricks
5. Ash can go up the stack as particulate emissions.
6. Ash has no heating value and as such does not contribute to the energy input of the fuel.

The sensitivity of any given application to ash in the fuel is thus dependent on:

1. The tolerance of the application to ash, which relates to:
    a. The ease or difficulty and cost of cleaning or removing the ash from the system, and
    b. The frequency of cleaning and the cost and consequences of cleaning downtime on the rest of the operation.

    For example lime and cement kilns are insensitive to ash, while float glass firing is highly sensitive to ash.

2. The amount of spare capacity available, which determines the cleaning cycle. If for example the boiler is running at greater than 97% of full capacity then a very small amount of ashing will necessitate a shut-down for cleaning.
3. Product contamination, where loss of product specification and value may occur due to discolouration.
4. Environmental sensitivity of the area to particulate emissions.

The savings in fuel costs from using low-cost high ash fuels are almost always greater than the cleaning and fuel reticulation equipment wear costs. It is generally only when cleaning stoppages result in costly production losses that a more expensive low-ash fuel is justified.

Water

The water content in liquid heating fuels is usually considered acceptable for all applications if it is below 1% by mass. Water of up to 10% in the fuel may be beneficial in the atomisation process in some applications provided it is evenly distributed. However, if the water settles out into pockets, it can result in flame-outs. Water does not generally add energy but in most applications consumes energy, however the presence of water vapour in the combustion gas does improve the heat transfer properties by some small amount, which may compensate for the loss.

Sulphur

The sulphur content of the fuel is important, as sulphur is the primary environmental pollutant resulting from combustion. Sulphur in the fuel combines with oxygen to form sulphur oxide gas (SO_x), of which sulphur dioxide (SO_2) is the major component, which is a noxious substance. Sulphur oxide gas combines readily with water to form a sulphuric acid, which causes acid rain and corrosion of buildings, stacks and combustion appliances. Many areas are particularly sensitive to these odorous emissions and low-sulphur fuels are mandated by environmental laws and regulations, typically for use at inner-city hospitals and bakeries.

Table IV below gives the average sulphur content by mass in a range of fuels.

Table-IV

FUEL	**ASH CONTENT**$^{\#}$ **(%mass)**	**SULPHUR CONTENT**$^{\#}$ **(%mass)**
R50/50	1,5%	2,5%
COAL TAR	0,3%	0,6%
FO 150	0,05%	3,5%
LSO	0,1%	1,75%
R20/20	1,0%	1,0%
LO10	0,07%	0,7%
PARAFFIN	<0,01%	<0,01%
DIESEL	<0,01%	<0,35%
COAL	12% - 22%	1,0%
GAS	0	0
ELECTRICITY	N/A	N/A

$^{\#}$*Typical values*

Pour Point

The pour point of a liquid fuel is the temperature at which the fuel will start to flow. Some oils contain waxes that become solid below a certain temperature and other oils just become too thick at low temperatures, so that they effectively become non-flowable. In unheated fuel reticulation systems, the choice of fuel must be suitable for the minimum temperature of the area. Once a heated fuel reticulation system is installed this is of less concern.

Flash Point

Liquid fuels contain volatile components that produce flammable explosive gases. The propensity of a fuel oil to produce flammable explosive gases is related to the amount of volatile components in the fuel and the temperature of the fuel. The flash point of the fuel represents the temperature at which the fuel oil will produce sufficient vapour as to cause combustion in the presence of a naked flame. This property gives an indication as to the relative hazard that exists in using and storing this fuel oil at a given temperature. The most common method is called the closed-cup flash point. It should be noted that enclosed spaces such as the void space of fuel storage tanks should be treated as hazardous flammable areas and all flames and sources of ignition must be kept well away regardless of the temperature or flash point of the fuel. Only intrinsically safe instrumentation should be used in these Zone-1[2] areas. The fuel oil's flash point should not be confused with the auto-ignition point, which is a much higher temperature.

Emissivity

Fuel oils burn with different amounts of radiant heat. Some fuels such as paraffin and gas burn with a low radiance flame and others such as coal tar burn with a very high radiance flame. The difference is in the amount of radiant heat the flame produces. The higher the carbon-to-hydrogen ratio in the fuel, the more radiant the flame. Direct fired heating applications, such as glass melting require a radiant flame to get the heat into the charge quickly with a minimum of heating area. Glass furnaces fired with gas can have a significant efficiency loss of between 12% – 25%. Steam boiler efficiency is generally not sensitive to fuel emissivity. However, conventional steam boilers are generally intolerant of the high-radiance flame from fuels such as coal tar, as the firing tubes do not offer enough heat transfer area to remove the heat quickly enough to prevent localised overheating and damage to the firing tube. Burner design and settings can also affect the flame's radiance.

SUITABLE FUELS SELECTION

The selection of suitable fuels is dependent on:

1. The relative cost of the available heating fuels
2. The applications tolerance to impurities (ash, water, metals etc)
3. The design of the appliance (radiance/convection, size/shape)
4. The environmental sensitivity of the area (sulphur, particulates, smutting)
5. Existing installations:
    a. The type of burner installed (wear, viscosity, turn-down, temperature limitations)
    b. The type of fuel reticulation system installed.

As can be seen in the cost evaluation sheets in Appendix-I, the capital cost of boilers, burners and reticulation systems is relatively small as a percentage of the total cost of energy at 10 – 20%. Thus the constraint of an existing system should be compared to the capital cost of alternatives before discarding the option of a change.

QUALITY COST

Estimating the cost of quality is usually a relatively simple calculation in most applications. The process is as follows:

1. Determine what the base maintenance cost is disregarding wear and tear from the fuel. For example a pump may have on average a 9 months life running on a high quality ash-free fuel, and a minimum amount of monthly maintenance. Knowing the pump cost, the average monthly minimum maintenance cost and the fuel consumption, the cost per ton of fuel can be calculated.
2. Then determine the maximum level of contaminant usable and the worst-case cost running on this lowest fuel quality.
3. A logarithmic function will give a rational estimate of the relationship between fuel quality and ash content, allowing costs between these limits to be determined, on the premise that the wear will increase disproportionately with higher solids (ash) contaminates.
4. Add the cost of cleaning and the cleaning cycle as a fuel cost per ton.
5. Include the cost of downtime, if any.

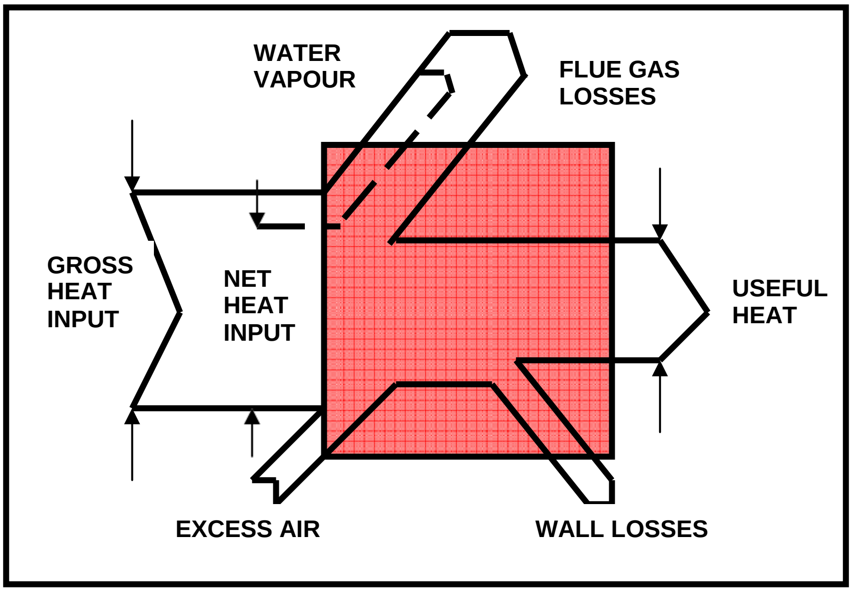
USEFUL ENERGY

The Net Energy input into the heating application is not the full amount of useful energy. The Sankey Diagram below shows where energy is lost.

The Net Energy input is further depleted by:

1. Loss of heat up the stack or flue. The products of combustion gases exit the heating appliance at elevated temperature and carry with them sensible heat.
2. To practically achieve complete combustion an amount of excess oxygen/air is required. This excess air takes up heat that is then lost as usable heat.
3. There are then also heat losses out of the system through the walls, conveyors etc.

What remains is the useful heat input.



Sankey Diagram

EVALUATION

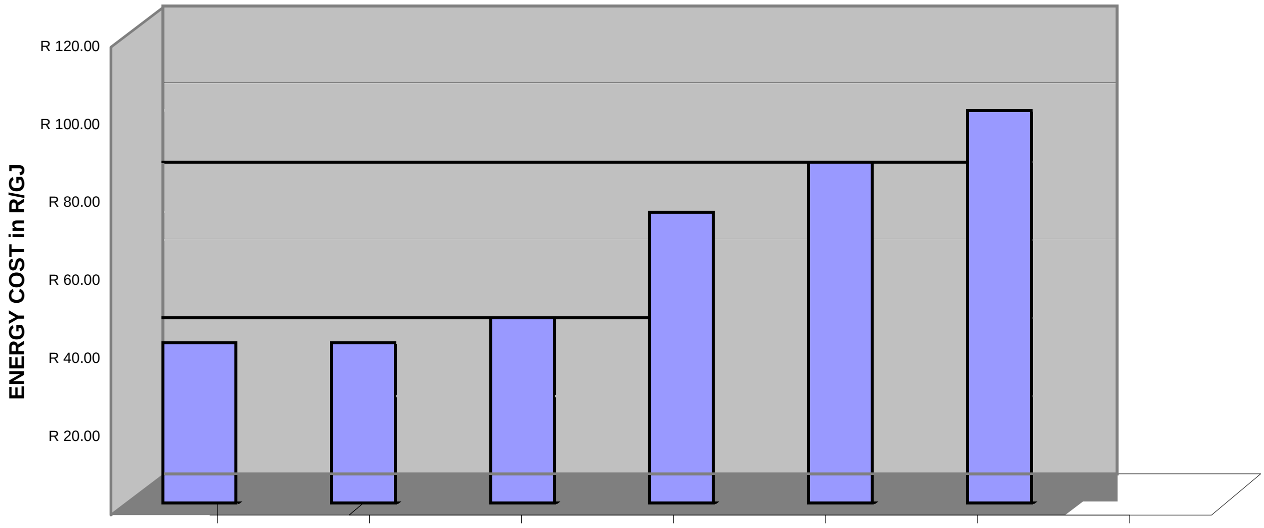
Once the range of suitable (usable) fuels has been identified and their costs determined, an evaluation could be carried out.

This can best be calculated in a spreadsheet program, as shown in Appendix-II, and the results of the comparison between options may look for example like the graph below.

When carrying out fuel cost comparisons, both tangible and intangible costs can be considered. Intangible costs refer to service costs such as reliability of supply, technical support, stock holding, capacity etc.

An evaluation in this way will expose some long held myths with regard to the real cost of alternatives, especially the high cost of reducing the work load on operational staff.

TOTAL FUEL COST COMPARISON



CONCLUSION

1. Fuel selection does not have to be a subjective decision as most considerations can be reduced to a cost and the alternatives then objectively compared.
2. Very significant cost savings can be achieved by selecting the most suitable fuel for the application.
3. The first step in establishing the suitability of the available fuels is to determine the constraints on the application and the available fuels' properties and characteristics.
4. It is possible to put a cost to all of the factors that affect the combustion application and arrive at the most cost effective fuel to use.
5. By objective analysis, a balance can be achieved between financial and operational demands.

REFERENCES

1. North American Combustion Handbook by North American Mfg. Co. 1986
2. South African Bureau of Standards code of practice 089 Part II of 2001.
3. Technical Data on Fuel, by J.W.Rose and J.R.Cooper, published by The British National Committee World Energy Conference 1977

APPENDIX-I

COMPANY-A

COST OF STEAM ESTIMATE LAST UP-DATED: **January-03** PREPARED BY: **Don Hunter**

ITEM	DESCRIPTION	
1	Steam Quantity Produced	
	Tons per Hour:	16
	Hours per Month:	729
	Tons per Month:	11664

ITEM		
2	**Capital Investment**	**R 4,038,275**
	Interest rate p.a.:	25%
	Life of boiler (years):	10
	Monthly Cost:	R 91,868
	Cost per Ton of Steam:	**R 7.88**

ITEM	**Fuel Costs**	**Cost**	**Units**	**Percentage of steam produced**	**Gross CV (MJ/kg)**	**% Contaminants**	**Efficiency %**	**Tons of Fuel/ton of Steam**	**Tons/month**
3	R50:50	R 1,337	R/ton	35%	42	1.00%	82%	0.066	269
	Oil - 2	R -	R/ton	0%				0.000	0
	Oil - 3	R -	R/ton	0%				0.000	0
	Coal - 1	R 188	R/ton	65%	27.5	19.00%	80%	0.126	957
	Coal - 2	R -	R/ton	0%				0.000	0
	Average	**440**	**R/ton**	**100%**					**1227**
	Cost per Ton of Steam:	**R 46.31**							

ITEM					
4	**Electricity Costs**			**kWh/month**	**R/kWh**
	Cost per Ton of Steam:	**R 3.69**		134,500	R 0.32

ITEM					
5	**Water Costs**			**% condensate return**	**R/m^3**
	Cost per Ton of Steam:	**R 1.88**		50%	R 3.75

ITEM				
6	**Chemical Costs**			**Cost per month**
	Cost per Ton of Steam:	**R 0.43**	R/month	R 5,000

ITEM				
7	**Laboratory costs**			**R/month**
	Cost per Ton of Steam:	**R 0.43**		R 5,000

ITEM				
8	**Maintenance Costs**			**R/month**
	Spares:			R 30,000
	Outside services:			R 5,000
	Total:			R 35,000
	Cost per Ton of Steam:	**R 3.00**		

ITEM					
9	**Direct Labour Costs**		**R/hr**	**Hours/month**	**Cost/month**
	Operators:		R 31.25	330	R 10,313
	Maintenance artesans:		R 68.75	30	R 2,063
	Electrical & instrumentation:		R 81.25	10	R 813
			R 35.64	370	**R 13,188**
	Cost per Ton of Steam:	**R 1.13**			

ITEM					
10	**Over Heads**		**R/hr**	**Hours/month**	**Cost/month**
	Supervision:		R 156.25	30	R 4,688
	Head Office Over Heads:				R 10,000
					R 14,688
	Cost per Ton of Steam:	**R 1.26**			

ITEM				
11	**TOTAL COST OF STEAM**	**R 66.00**	**STANDING COSTS:**	**R 10.27**

APPENDIX-II

FUEL COST EVALUATION

SUPPLIER: **SUPPLIER-A**
Fuel Name: **HFO**
Fuel Description: **HEAVY FUEL OIL**

FUEL PROPERTIES:	**UNITS**	**VALUE**
Gross Calorific Value:	MJ/kg	44.0
Density;	litres/kg	0.95
Ash Content:	mass %	1.0%
Sulphur Content:	mass %	1.5%
Water Content:	mass %	0.5%

PRICING:			TOTALS	REMARKS
Price of Fuel:	R/ton	R 1,350.00	R 1,350.00	This price is a Rand based price per ton
Price of Fuel:	C/ltr		142.1	
Price of Fuel:	US$/ton		$193	
Price of Fuel:	R/GJ			
Basic Fuel Price:	R/GJ	R 30.68		
Cost of Contaminants:	R/GJ	R 0.46		
Basic Fuel Cost:	**R/GJ**	**R 31.14**		

APPLIANCE EFFICIENCY:	**UNITS**	**VALUE**	**UNITS**	**VALUE**
Efficiency of Fuel in Application:			**%**	**82%**
Efficiency Loss:	**R/GJ**	**R 5.61**		

TRANSPORT:			**UNITS**	**VALUE**	**UNITS**	**VALUE**
Cost of fuel delivery:	**R/GJ**	**R 3.18**	**R/ton**	**R 140.00**	**C/ltr**	

DIRECT VALUE ADDITION:	**UNITS**	**VALUE**	**UNITS**	**VALUE**	**RESIDUAL**
Equipment supply:	R/GJ	R -0.23	R	R 250,000	40%
Maintenance:	R/GJ	R 0.00	R/month	R -	
Spares:	R/GJ	R 0.00	R/month	R -	
Waste Removal:	R/GJ	R -0.05	R/month	R 1,000	
Consignment stock:	R/GJ	R 0.00	R/month	R -	0%
Fuel heating required:	R/GJ	R 0.07	R/month	R 1,491	
TOTAL VALUE ADDITION:	**R/GJ**	**R -0.21**			

QUALITY COST:	**UNITS**	**VALUE**	**UNITS**	**VALUE**		
Estimated minimum wear cost:			R/month	R 3,500		
Estimated maximum monthly wear cost:			R/month	R 25,000		
Estimated cost of cleaning:			R/month	R 5,000		
Estimated cleaning down time:			Hours/month	R 8		
Estimated cost of down time:			R/hour	R -		
Estimated total monthly cost:			R/month	R 30,000	exponential function	
Lower ash limit:				0.10%	b=	239
Upper ash limit:				1.00%	a=	2757
Estimated quality cost:	**R/GJ**	**R 1.36**	**R/month**	**R 30,000**		

PRICE ESCALATION:	**UNITS**	**VALUE**	**UNITS**	**VALUE**	**npv factors**	
Fuel Price Escalation:	R/GJ	R 0.00	p.a.%		29.67891685	R 0.00
Transport Price Escalation:	R/GJ	R 0.00	p.a.%		29.67891685	R 0.00

SUB-TOTAL OF TANGIBLE COSTS:	**R/GJ**	**R 41.09**

SUBJECTIVE VALUE ADDITION:		**VALUE**	**SCORE**	**Maximum:**	**0.25%**
Capacity:	R/GJ	R -0.08	4		
Reliability:	R/GJ	R -0.10	5		
Technical Depth and Support:	R/GJ	R -0.10	5		
Stock Control:	R/GJ	R -0.10	5		
Reactive:	R/GJ	R -0.10	5		

SUB-TOTAL INTANGIBLE VALUE:	**R/GJ**	**R -0.49**	**PERCENTAGE**	**-1.2%**

TOTAL COST OF FUEL SUPPLY:	**R/GJ**	**R 40.59**