

## ALTERNATE FUEL OPTIONS IN THE KILN

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**Abstract** - *The sources of fossil fuels are depleting each day and thus there is a need for the search of alternative fuels for the kiln. Nowadays, paper industry faces a major problem with the increasing cost of furnace oil. Furnace oil is used in the kilns as fuel for firing for the production of lime. The objective is to substitute an alternative fuel for furnace oil. In the present work used engine oil is blended with furnace oil in the ratio of 75 to 25 (by weight) and is used as an alternative fuel for furnace oil. The paper focuses on the study of calorific value, flash point, ash content, viscosity of the furnace oil and the blended oil samples. The pollution policies of the industries are also taken into account.*

**Key Words:** *Blended oil, Used engine oil, Combustion properties, Furnace oil, Lime kiln, Pulp mill, Test results*

### 1. INTRODUCTION

The depletion of world petroleum sources and increased environmental concerns have stimulated recent interest in alternative sources for petroleum based fuels for firing. With rising energy costs and new environmental regulations in the past years, many paper industries have made it a priority to reduce their energy consumption and operation expenses. Lime reburning kiln is the biggest user of fossil fuels and only part of the mill, which needs significant purchasing of fuel. Fluctuating prices for fossil fuels and more stringent carbon taxes has made lime kiln energy consumption an important issue impacting the overall pulp mill profitability.

Lime kiln operating expenses can be decreased with increasing the thermal efficiency of the kiln and using new fuels for the combustion process. Most of lime kilns use heavy fuel oil as their energy source, but many mills have interest to replace them with alternative renewable fuels in the future. Operation of the lime kiln affects the whole pulp mill and it must stay stable to produce acceptable quality lime and to keep pulp products from the mill good-quality.

Many things have to be considered when replacing the traditional fuels used in the kiln. Availability, heating value, chemical composition and combustion behaviour of the alternative fuels are important matters when examining the effects of replacing on combustion, flue gas emissions and economy of the pulp mill.

Aim of this study is to examine the requirements of lime kiln fuel and to find the best fuel substitutes for the kiln. This study focuses on the blend of used engine oil and furnace oil. The waste engine oil can be obtained from the industry itself. The engine oil is used as lubricating oil in pumps and gears of various equipments and is removed and replaced periodically with fresh engine oil. This used engine oil is disposed of after use. Thus, this used oil can be used as a substitute.

The used oil may be considered as a hazardous waste and have to be disposed of according to Environmental Protection Agency (EPA) regulations. The used oil have the advantage of being inexpensive as compared to conventional fuels and they are readily available at garages and oil change service centers, vehicle dismantlers, machine shops and industries. This paper describes a new approach to lime kiln fuel for firing that combines furnace oil and used engine oil in the ratio of 75 to 25 (by weight).

### 2. OVERVIEW

Production of fuel from used engine oil involves chemical filtrations and blending process. It could solve some of the energy problem with increasing or decreasing the blending percentage of pre-treated used engine oil.

Used engine oils from vehicles, machinery have high heat value and can fit into many greenhouse operations. It is found that when even a small amount of used engine oil is co fired with the gaseous fuel it significantly enhances thermal radiation capabilities of the gaseous fuel flame.

### 3. DESCRIPTION OF THE KILN OPERATION

#### 3.1 Process in Kraft Pulp Mill

Efficient and closed chemical recovery is great benefit of the paper mill process. It makes recirculation of cooking

chemicals in the process possible while using only little amount of makeup chemicals. Reausticizing plant is important part of chemical recovery at pulp mill.

The kraft process, which uses sodium hydroxide (NaOH) and sodium sulphide (Na<sub>2</sub>S) to pulp wood, is the dominant pulping process in the pulp and paper industry. The high strength of kraft pulp, the ability of the process to handle almost all species of softwood and hardwood, and the favourable economics due to high chemical recovery efficiency (about 97%) give the kraft process an advantage over other pulping processes.

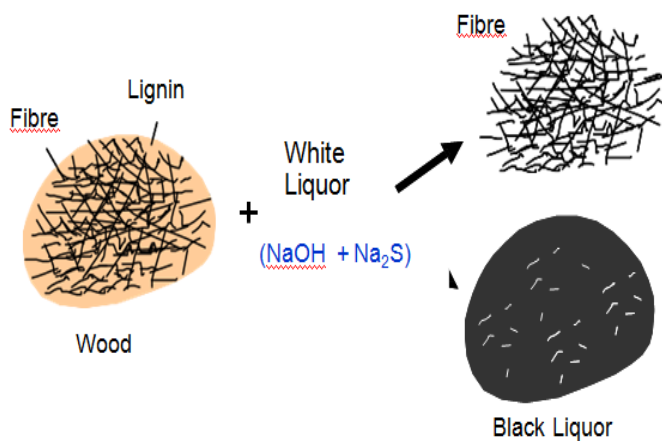


Fig -1: Kraft pulping process

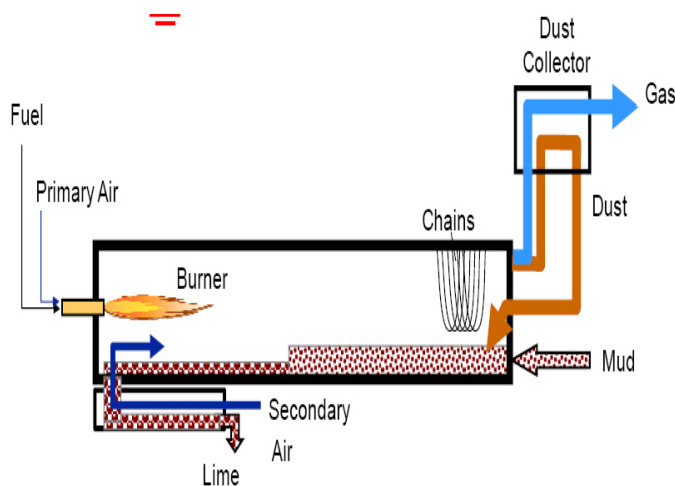


Fig -2: Lime kiln installation

In the kraft process, about half of the wood is dissolved, and together with the spent pulping chemicals, forms a liquid stream called weak black liquor as in Fig-1. The weak black liquor is separated from the pulp by washing, and is sent to the kraft recovery system, where the inorganic pulping chemicals are recovered for reuse, while the dissolved organics are used as a fuel to make steam and power.

A typical kiln installation is shown in Fig-2. It uses green liquor from recovery boiler as raw material and consumes lime, calcium oxide (CaO) to produce white liquor, which is an important chemical used in pulping.

Fig-3 shows a simple flowsheet of the kraft chemical recovery process. The process has three main functions: i) minimizing the environmental impact of waste material (black liquor) from the pulping process; ii) recycling pulping chemicals (NaOH and Na<sub>2</sub>S) and iii) co-generating steam and power.

Sodium hydroxide, which is mixed with the wood chips and cooked in the digester to get weak black liquor and is recovered in the recovery boiler and regenerated in the reausticizing plant. As shown in Fig-3, weak black liquor from brown stock washers is concentrated in multi-effect evaporators and concentrators to a point where it can be effectively burned in a recovery boiler, usually at 65% solids or higher. Concentrated black liquor is sprayed into the lower part of the recovery boiler where it is burned in an oxygen deficient environment so that Na<sub>2</sub>S is formed. The extent of sulphide formation is measured by the reduction efficiency, typically over 90%. The inorganic sodium and sulphur are recovered as a molten smelt which consists mostly of Na<sub>2</sub>S and sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>). The molten smelt enters a dissolving tank where it is dissolved in water to form green liquor. The green liquor is then sent to the causticizing plant, where it is reacted with lime (CaO) to convert the Na<sub>2</sub>CO<sub>3</sub> to NaOH. Conversion is measured by causticizing efficiency, typically 80 to 83%. The Na<sub>2</sub>S passes through the causticizing step unchanged. The causticized green liquor is known as "white liquor" which contains mostly NaOH and Na<sub>2</sub>S. It is returned to the digester for reuse in pulping. The precipitated CaCO<sub>3</sub> (lime mud) from the causticizing reaction is washed, and sent to a lime kiln where it is heated to a high temperature to regenerate CaO for reuse.

The reausticizing process has two targets, to produce clean, hot white liquor containing minimum amount of unreactive chemicals for the cooking process, and prepare clean and dry lime mud to burn in the lime kiln for reuse as lime with minimum energy usage. Two important reactions of reausticizing are slaking and causticizing. When green liquor is mixed with lime (CaO) it slakes with water and forms calcium hydroxide (Ca(OH)<sub>2</sub>). Calcium hydroxide continues to react with sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>) in green liquor forming sodium hydroxide (NaOH), main compound in white liquor and also calcium carbonate (CaCO<sub>3</sub>), called lime mud as by-product. Fig. 2 shows causticizing process as a part of the kraft pulp mill chemical recovery circuit.

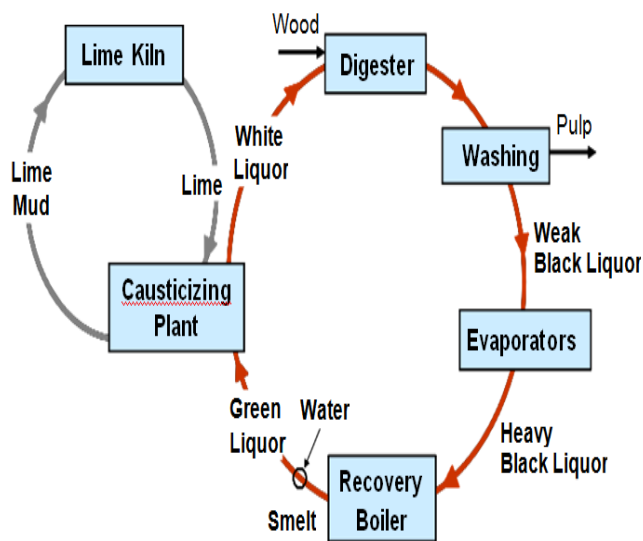
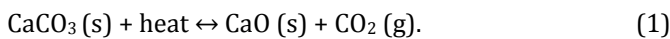


Fig -3: Causticizing process of the pulp mill recovery plant

### 3.2 Function and Construction of Lime Kiln

Lime reburning is a part of chemical circuit called lime cycle. Lime regeneration is called reburning because it involves treating lime mud in high temperatures in a lime kiln. The function of the lime kiln is to convert lime mud back to lime for reuse in the causticizing process. Equation 1 shows the conversion from lime mud to lime.



Lime kiln is a rotary combustion kiln where heat transfers from combustion gas to lime particles. Lime kilns are typically 2-4 m in diameter and 50-120 m in length with typical rotational speed of 0.5-1.5 rpm. Lime mud is fed to the kiln from cold end and the kiln slopes slightly, about 1-4 per cent toward the firing end. Lime mud moves slowly through the bottom of the kiln towards the firing end as result of inclination and rotation. Flue gases and lime dust exits the kiln from the cold end. Flue gases pass through electrostatic precipitator and wet scrubber and lime dust captured in the precipitator is fed back to the kiln. Lime retention time in the kiln is approximately 2.5-4 hours depending on kiln dimensions, rotational speed and lime mud properties.

Lime kiln can be divided to four process zones according to the temperature profile of solids and fuel gases:

1. Thermal drying: moisture in the lime mud evaporates.
2. Heating: lime mud gets heated to the reaction temperature.
3. Calcination: calcium carbonate dissociates into calcium oxide and carbon dioxide.

4. Sintering and cooling: formed fine powder agglomerates into nodules and then cools before leaving the kiln.

Fig. 4 shows the lime kiln heating zones. Red line in the figure is fuel oil. Calcination reaction occurs in the actual burning zone where gas temperature increases to 1100°C. The endothermic calcination occurs spontaneously when lime mud reaches 800°C and sufficient reaction rate is reached approximately at 1100°C. The flue gas temperature needs to be significantly higher because of the poor heat transfer in the kiln.

Lime mud from lime mud silo is mechanically dried in filter plant before feeding it to the kiln. This is called lime mud dewatering and its purpose is to increase the dry solids in the mud. The moisture in lime mud has a significant effect on the energy consumption of the kiln. It consists of a mud filter where the moisture content is reduced to about 30 to 35%, a rotary kiln and dust collector. In LMD dryer the lime mud is fed to a flue gas stream where the heat of the gases dries the mud. Then a cyclone separates dry mud and feeds it to the kiln. Lime mud has also to be sintered in the kiln to make usable product for further processing.

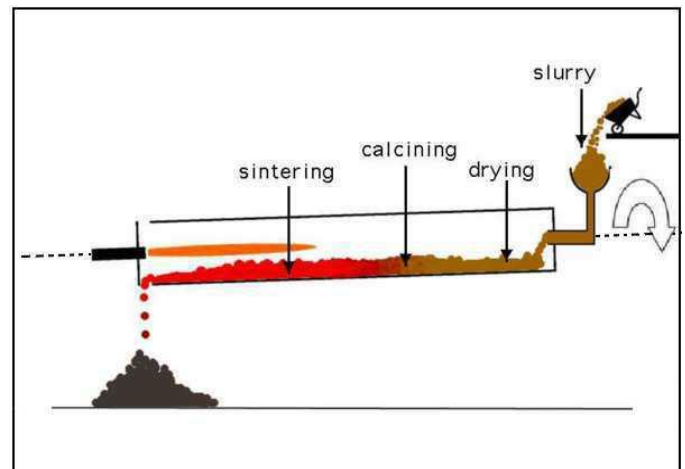


Fig -4: Lime kiln heating zones

The kiln generally consists of three sections. The first section is a preheater or chain section where the calcium carbonate mud is dried and nodulised. In the final zone, lime powder agglomerates into lime nodules with diameter of 10-50 mm. The second section is a calcining zone where the feed is heated to about 1150°C and converted to calcium oxide. Most kilns have a third section where the quick lime is cooled before leaving the kiln and the secondary combustion air is preheated. The cooler consists of a number of tubes arranged around the circumference of the kiln at the firing end of the kiln where lime heat is recovered to combustion air. Production lime move through the product cooler and the temperature at the outlet is (70-90)°C.

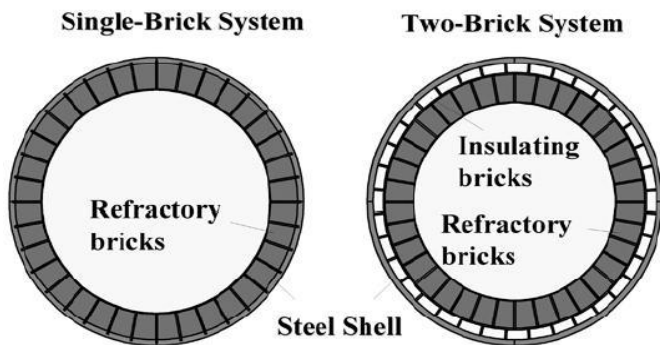


Fig -5: Brick lining in lime kiln

The burned lime from the kiln has a wide particle size distribution. Oversized particles are crushed by a lump crusher or hammer mill after leaving the kiln.

Atmospheric air is used as coolant. The lime before stabilization is not pure and contains certain lime sludge thus the drainer portion at the product end drains the impure lime and lime mud. Secondary air is used in normal and parallel to the kiln to achieve maximum purity and proper burning. All lime kilns have a refractory lining that protects kiln shell from overheating and limits heat losses. Refractory system consists of bricks that are composed of special heat-resistant and chemical-attack resistant materials, such as alumina or silica components. Each kiln zone has a lining of a certain material and thickness.

Treatment of lime mud in the lime kiln requires external heat and this requires high fuel combustion temperature. Higher flame temperatures mean higher production capacity and efficiency, but too high temperatures cause refractory damage and over-burned, slow-reacting lime product. Therefore stability and control of the combustion temperature are also important to make good quality lime and to maintain stable operation of the kiln.

### 3.3 Fuels Used and their Emissions

Main fuels used in lime kilns are heavy fuel oil or natural gas. Lime kiln is the biggest user of fossil fuels in production process and the only part of the paper mill that needs substantial purchasing of fuel. Carbon dioxide (CO<sub>2</sub>) emission from the kiln is directly proportional to the carbon (C) in the kiln gas. This comes from two sources: lime mud conversion and combustion of fuel. Two thirds of the carbon emissions come from the lime mud conversion and one third from the fuel combustion. Carbon in lime mud originates from wood and can be considered as carbon neutral. Carbon dioxide from fuel combustion has positive carbon footprint and if fossil fuels are used for combustion, they are counted as greenhouse gas (GHG) emissions.

Lime kiln always need some amount of makeup lime to cover lime losses and lime containing impurities and thus sea shells are fed to the kiln, after washing, through the cold end. Although losses of calcium from recovery system are usually made up using fresh lime, some amounts of make-up CaCO<sub>3</sub> are used in the kiln. Carbon contained in CaCO<sub>3</sub> is usually fossil origin and escapes as CO<sub>2</sub> from the kiln. This is also counted as fossil CO<sub>2</sub> emission.

Rising and unstable price of fuel oil has increased production costs in paper mills. Therefore, there is a need for paper mills to find more economical, carbon neutral alternative fuels that have minimal impact on lime kiln operation and chemical recovery process.

## 4. EXPERIMENTAL DETAILS

Before testing the oil, the used engine oil sample is filtered using centrifugation process at ambient temperature and humidity. The used oil sample is taken in different test tubes and is placed inside the centrifuge. The centrifuge is allowed to rotate for a certain period. Due to this rotation action of the centrifuge, the test tubes will also rotate at high speed and thus the clean engine oil can be filtered out since the impurities gets settled down at the bottom of the test tubes.

Table -1: Engine Oil Filtration

Sl. No.	Activity	Time (min)	Speed (rpm)	Observation
1)	Centrifuge process	10	3,300	No sediments separated
		20	3,300	Sediments separated- lesser volume
		20	4,000	Sediments separated- higher volume
		20	4,000	
		20	4,000	
		20	4,000	
		20	4,000	
		20	4,000	
2)	Centrifuge after filtration	30	4,000	Moisture (mist) separated
		40	4,000	Moisture (droplets) separated



## 5. RESULTS

The calorific value of the furnace oil and filtered engine oil is then tested separately using bomb calorimeter after filtration and the test results are shown in Table II. From the results we could infer that the filtered engine oil have more calorific value than furnace oil. But the engine oil cannot be used directly inside the kiln, as the flash point of engine oil is very high, thus the furnace oil and filtered engine oil is blended in two different ratios by weight for further testing. The ratios are

1. 75: 25
2. 60: 40

**Table -2:** Test Results

Sl. No.	Results	
	Sample	Calorific value in KJ/ Kg
1)	Furnace oil	46,938.215
2)	Filtered engine oil	49,676.382

The 75 :25(by weight) ratio consists of 0.375L of furnace oil and 0.125L of filtered engine oil and the 60: 40 ratio(by weight) consists of 0.3L of furnace oil and 0.2L of filtered engine oil.

The blended oils are tested for calorific value to select the desired blend of oil to be used as an alternate fuel in the kiln. The blended oils of two different ratios shows nearly the same calorific value as that of the furnace oil. The blended oil with less filtered engine oil concentration is selected for further testing as the flash point of the blended oil increases with the increase in concentration of the filtered engine oil. Thus, the blended oil in the ratio of 75: 25(by weight) is taken for testing the combustion properties.

**Table -3:** Blending of Oils

Sl. No.	Results			Observation
	Activity	Furnace oil in L	Filtered engine oil in L	
1)	Blending	0.375	0.125	Not much difference by visual
		0.3	0.2	

**Table -4:** Test Results

Sl. No.	Results	
	Sample	Calorific value in KJ/ Kg
1)	Furnace oil and filtered engine mix in the ratio (75:25)	46,645.139
2)	Furnace oil and filtered engine oil mix in the ratio (60:40)	46,929.841

This blended oil is tested for relative density, kinematic viscosity, flash point, calorific value, ash content, acidity, sulphur and moisture content.

### 5.1 Density

Density is the ratio of the mass of the fuel to the volume of the fuel at a reference temperature of 15°C and is measured using a hydrometer.

### 5.2 Kinematic Viscosity

Viscosity plays a key role in handling and storing the fuels. Viscosity is an internal property of fluid that offer resistance to flow. Viscosity depends on temperature and decreases as the temperature increases. Any numerical value for viscosity has no meaning unless the temperature is also specified. Lower the viscosity , better the liquid flows and it is usually measured using the instrument called saybolt viscometer. It influences the degree of pre-heat required for handling, storage and satisfactory atomization. If the oil is too viscous, it may become difficult to pump, hard to light the burner, and tough to operate. Poor atomization may result in the formation of carbon deposits on the burner tips or on the walls. Therefore pre-heating is necessary for proper atomization.

### 5.3 Flash Point

The flash point of a fuel is the lowest temperature at which the fuel can be heated so that the vapour gives off flashes momentarily when an open flame is passed over it. The instrument used in measuring the flash point is Pensky Martens closed apparatus.

### 5.4 Calorific Value

The calorific value is the measurement of heat or energy produced, and is measured either as gross calorific value or net calorific value. The difference being the latent heat of condensation of the water vapour produced during the

combustion process. Gross calorific value (GCV) assumes all vapour produced during the combustion process is fully condensed. Net calorific value (NCV) assumes the water leaves with the combustion products without fully being condensed. Fuels should be compared based on the net calorific value and it determines the amount of fuel needed for heat transfer in the kiln. The calorific value of coal varies considerably depending on the ash and moisture content of the fuel and is measured using bomb calorimeter.

**Table -5:** Combustion Properties of the Blended Oil

Sl. No.	Comparison		
	Properties	Requirements	Blended oil in the ratio of 75: 25(by weight)
1)	Relative density at 15 °C in kg/m <sup>3</sup>	850-990	960
2)	Kinematic viscosity in μm <sup>2</sup> / s at 50 °C	85-125	105.41
3)	Flash point, °C	66	132
4)	Gross calorific value in KJ/Kg	43,961.4	46,733.062
5)	Ash (% by mass)	0.1	0.01
6)	Water content (% by mass)	1	Nil
7)	Sulphur content (% by mass)	2-4.5	1.7
8)	Acidity inorganic	Nil	Nil

### 5.5 Ash Content

The ash value is related to the inorganic material in the fuel oil. The ash levels of distillate fuels are negligible. Residual fuels have more of the ash-forming constituents.

These salts may be compounds of sodium, vanadium, calcium, magnesium, silicon, iron, aluminium, nickel, etc. Typically, the ash value is in the range 0.03–0.07%. Excessive ash in liquid fuels can cause fouling deposits in the combustion equipment. Ash has erosive effect on the burner tips, causes damage to the refractory at high temperatures and gives rise to high temperature corrosion and fouling of equipments.

### 5.6 Water Content

Water content in the oil may be present in free or emulsified form and can cause damage to the inside furnace surfaces during combustion especially if it contains dissolved salts. It can also cause spluttering of the flame at the burner tip, possibly extinguishing the flame and reducing the flame temperature or lengthening the flame.

### 5.7 Sulphur Content

The amount of sulphur in the fuel oil depends mainly on the source of the crude oil and to a lesser extent on the refining process. The main disadvantage of sulphur is the risk of corrosion by sulphuric acid formed during and after combustion, and condensing in cool parts of the chimney or stack, air preheater and economiser.

All the required parameters are tested and the blended oil from the test results conformed to the required IS specifications of the furnace oil and thus can be used in the lime kilns for firing as an alternate fuel.

The disadvantage is that the flash point of the blended oil is very high. For decreasing the flash point of the blended oil, the concentration of the filtered engine oil in the blend was decreased and the blended oil with blend ratio of 95:5 (95percent of furnace oil and 5percent of filtered engine oil by weight) is chosen to do a trial in the kiln. The blended oil in this ratio is directly fired in the kiln and the results thus obtained are satisfactory.

## 6. CONCLUSION

Due to rising price of heavy fuel oil and natural gas and increasingly stringent environmental regulations in recent years, the interest in replacing these conventional fuels used in pulp mill lime kilns with alternative fuels has become a worldwide issue. Pulp manufacturers are looking both for money savings and nowadays increasingly important environmental reputation.

Fuels used for lime kilns have a lot of requirements compared to conventional combustion in heating boilers. As the operation of lime kiln requires lot of energy and affects to the whole chemical circuit of the pulping

process, the used fuel should have high heating value, good availability, constant combustion properties and should not contain much of nitrogen, sulphur and impurities. The test results of blended mix of furnace oil and filtered engine oil in the ratio of 75: 25(by weight) suggest that the blended oil have values in the permissible limit. The advantage is that the blended oil have less ash, sulphur and water content and high calorific value to that of furnace oil and thus reduces the consumption of the fuel and increases the efficiency of the kiln. The pollution policies are also satisfied. By knowing these requirements, replacing heavy fuel oil or natural gas with the blended oil is much easier and the operation of the kiln is predictable. Thus, the blended fuel can be used as alternative fuel in the lime kiln for firing.

The firing with blended oil can be done by starting with five percentage filtered engine oil and 95 percentage of furnace oil concentration and then slowly increasing the concentration of the filtered engine oil to the desired level by considering the bearable flash point of the kiln. Thus, by this way we can control the flash point of the blend but the filtered engine oil will always contain some amount of carbon in it. Even though the carbon would not affect the kiln efficiency, the ash content obtained will have carbon in it. Thus, the used engine oil should be filtered properly to eliminate the carbon content.

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#### REFERENCES

- [1] Miyamoto N, Ogawa H, Nabi MN, "Approaches to extremely low emissions and efficient diesel combustion with oxygenated fuels", *International Journal of Engine Research*, pp. 71-85, 2000.
- [2] John W. Bartok, "Approximate heating value of common fuels", Storrs, December 2004.
- [3] Luka Zajec, "Slow pyrolysis in a rotary kiln reactor: optimization and experiments", A Master's Thesis done at the School for Renewable Energy Science, Akureyri, February 2009.
- [4] Martin Bajus, Natalia Olahova Slovak, "Thermal conversion of scrap tyres", *Petroleum and Coal*, Vol. 53(2), pp. 98-105, 2011.
- [5] Moses P.M. Chinyama, "Alternative fuels in cement manufacturing", *Alternative fuel*, InTech, 2011.
- [6] Professor Paul T. Williams, "Fuels, chemicals and materials from waste", Energy Research Institute University of Leeds, March 2012.
- [7] Ossi Ikonen, "Alternative liquid biofuels for lime kilns", Bachelor's Thesis, Lappeenranta University of Technology, Lappeenranta, April 2012.
- [8] Anders Kallenberg, "Liquid bio fuels for gas turbines", Master Thesis in Engineering Physics, Sweden, February 2013.
- [9] K. Naima and A. Liazid, "Waste oils as alternative fuel for diesel engine ", *Journal of Petroleum Technology and Alternative Fuels*, Vol. 4(3), pp. 30-43, March 2013.
- [10] K. Arumugam, S. Veeraraja and P. Esakkimuthu, "Combustion of waste/ used oil by using specialized burner", *International Journal of Applied Engineering Research*, Vol. 8(15), pp. 1839-1846, November 2013.
- [11] K. Srinivas, N. Ramakrishna, Dr. B. Balu Naik, Dr. K. Kalyani Radha, "Performance and emission analysis of waste vegetable oil and it's blends with diesel and additive", *International Journal of Engineering Research and Applications*, Vol. 3, Issue 6, pp. 473-478, Nov-Dec 2013.
- [12] Stephen W. Hagemoen, "An expert system application for lime kiln automation", in paper and pulp industry technical conference, Hyannis, MA, USA, June, 1993, pp. 91-97.