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Investigation Of Environmental And Economic Effects Of Utilizing Used Transformer Oil As An Alternative Fuel In Cement Kiln

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Abstract

Cement industry is an energy intensive process and contributes about 5% to global anthropogenic carbon dioxide emissions. The demand of cement usage is rising year by year, leading to increased fuel requirements and environmental concerns. Increasing fuel requirements becomes alarming due to increase in fuel prices at international level. The primary goal of this research endeavor is to burn used transformer oil as a substitute fuel source in kiln operations and assess its impact on both fuel expenses and environmental emissions. The improper disposal of used transformer oil poses environmental hazards due to the presence of Polychlorinated Biphenyls (PCBs). Prolonged exposure to PCBs can result in adverse health effects in humans, including nervous system disorders, weakened immune function, and the development of cancers in the digestive tract, liver, and skin. Consequently, utilizing used transformer oil as an alternative kiln fuel in the cement industry would serve the dual purpose of reducing fuel costs and mitigating the release of PCBs into the environment. The study found that burning 20% used transformer oil in cement kilns reduced particulate matter and carbon monoxide by 42% and 26%, respectively, compared to imported coal. Fuel cost also reduced by 947 PKR/ton of clinker. The research highlights that using the used transformer oil as an alternative fuel could be economically viable and cleaner solution.

Keywords: Cement industry, Fuel economy, Incineration, Industrial waste, Used transformer oil.

1. Introduction:

The manufacture of cement is a complex procedure that includes numerous stages, such as crushing, grinding, and pyro processing. Cement production consumes large quantities of raw materials and energy. Thermal energy accounts for about 20-25% of cement production cost while electricity consumption is 100-120 kWh per ton of cement. Thermal energy is used mainly during clinker formation process in kiln [1]. The demand for cement is on the rise due to rapid urbanization, but this increased production has serious environmental implications. The cement industry contributes to approximately 5-10% of human-induced CO_2 emissions, and about half of these emissions result from the combustion of fuel during the formation of clinker in cement kilns [2].

The increased prices and environmental consequences associated with the use of fossil fuels have compelled cement manufacturers worldwide to explore the substitution of traditional fuels with alternative options. The incorporation of alternative fuels in the cement industry has been a practice since the mid-1980s [3, 4]. These alternatives not only offer cost-effectiveness but also result in reduced carbon dioxide emissions.

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Various categories of alternative fuels find application in the cement sector such as tire-derived fuel, refuse-derived fuel, municipal solid waste (MSW), solvents, used oil, and agricultural biomass [5]. Similarly, used transformer oil can be utilized as an alternative fuel. Disposing of the used transformer oil is hazardous to the environment because it contains Polychlorinated Biphenyls (PCBs). PCBs are a class of halogenated organic compounds consisting of molecules between 1 and 10 chlorine atoms bonded to the two rings of biphenyl, Figure 1 [6, 7]. This gives rise to 209 possible congeners but only about 130 of these are found in commercial products [8]. PCBs possess characteristics of chemical stability, low in flammability and miscibility which made them widely applied as insulators, coolants, and lubricants in transformers, capacitors, and other electrical equipment from the 1930s to the late 1970s [6].

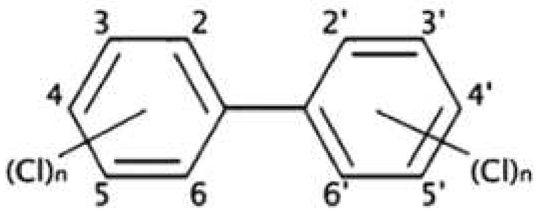


Figure 1: Molecular structure of PCBs

Global PCB production was prohibited after 1970; however, environmental contamination sustained due to unintended spills and leaks resulting from inadequate storage, transportation, and disposal practices [9]. As per UNEP, 48% of the PCBs produced found usage in transformer oil, 21% in capacitors, and 10% in other essentially closed systems. The remaining 21% was utilized in open applications [10]. PCBs have the ability to infiltrate food chains, exhibit long-lasting persistence when deposited, and consequently impacting the entire ecosystem. [11]. Humans are exposed to PCBs through diet, especially from meat, fish and dairy products [12]. As stated by Stockholm Convention on Persistent Organic Pollutants, the appropriate disposal of waste containing PCBs must be completed by 2028, contributing to the elimination of PCBs from the natural environment [13].

Motivation and Objective:

The research investigates the feasibility of using used transformer oil as an alternative fuel in cement kilns to achieve sustainable disposal of waste and reduce greenhouse gas emissions. The main objectives are to:

i. Study the environmental advantages, such as reductions in greenhouse gas emissions, of utilizing used transformer oil in comparison to conventional fuels.
ii. Analyse the economic viability of incorporating used transformer oil into cement kiln operations and taking into account potential cost savings.

1.1 Methods for PCB Disposal:

There are many methods for PCBs disposal. Supercritical water oxidation (SCWO) is a new growing technology to treat a wide variety of organic compounds and toxic waste. Under supercritical conditions, it convert carbon to carbon dioxide, hydrogen to water and chlorine atoms to chloride ions and nitrogen, sculpture and phosphorus to nitrates, sulphates and phosphates respectively [14]. The primary drawback of SCWO lies in its substantial capital and operational expenditures [15]. Plasma arc systems use high temperature (5000 to 15,000 °C) to produce. A large electric current is passed through an inert gas stream. Hazardous contaminants, such as PCBs, dioxins, furans, and pesticides are broken down into their atomic constituents, by infusion into the plasma, or using the plasma as heat source for combustion or pyrolysis [16]. Drawback of plasma arc technology is the significant increase in energy consumption, which subsequently leads to elevated operational costs [17]. In Base-catalysed decomposition method, PCBs are dechlorinated by using a high-boiling point hydrocarbon, base and metal catalyst. Bases act as a nucleophilic activation group, hydrocarbons as hydrogen donors and a metal catalyst as an electron transfer surface take part in the PCB dechlorination process. Further study is needed for commercial use of this method [18]. Autoclaving is a pressurized thermal process performed in a closed vessel at high temperature under high pressure [19]. This method is costly and also not suitable for all kind of

Hazardous waste [20]. A study achieved a remarkable 99.87% destruction efficiency for PCDD/Fs and an even more impressive 99.9998% for dl-PCBs using a fluidized-bed incinerator [21].

Incineration is one of the most effective methods for the treatment and disposal of hazardous waste [22]. It is one of the most widely adopted technologies for treating various material sources, including pesticides, PCBs, and explosives. While there are different incinerator designs available, most typically comprise rotary kilns, combustion chambers equipped with an afterburner, a quench tower, and an air pollution control system. These incinerators can achieve removal efficiencies of over 99.99%. When it comes to PCBs and dioxins, high-temperature incinerators can attain destruction and removal efficiencies of up to 99.99%. The U.S. EPA has sanctioned high-efficiency incinerators for the eradication of PCBs with concentrations exceeding 50 ppm. Incinerators used for liquids PCB disposal must meet specific technical requirements, such as a residence time of 2-3 seconds at 1200 °C and maintaining 3% excess oxygen levels [23]. Hence, the utilization of used transformer oil as an alternative fuel in the cement industry, where kilns operate at temperatures around 1400°C, not only presents a viable option but also contributes to the elimination of PCBs from the environment.

The purpose of this study is to utilize used transformer oil as an alternative fuel in cement kiln and determine its environmental and economic effects.

2. Methodology:

2.1 Process Description:

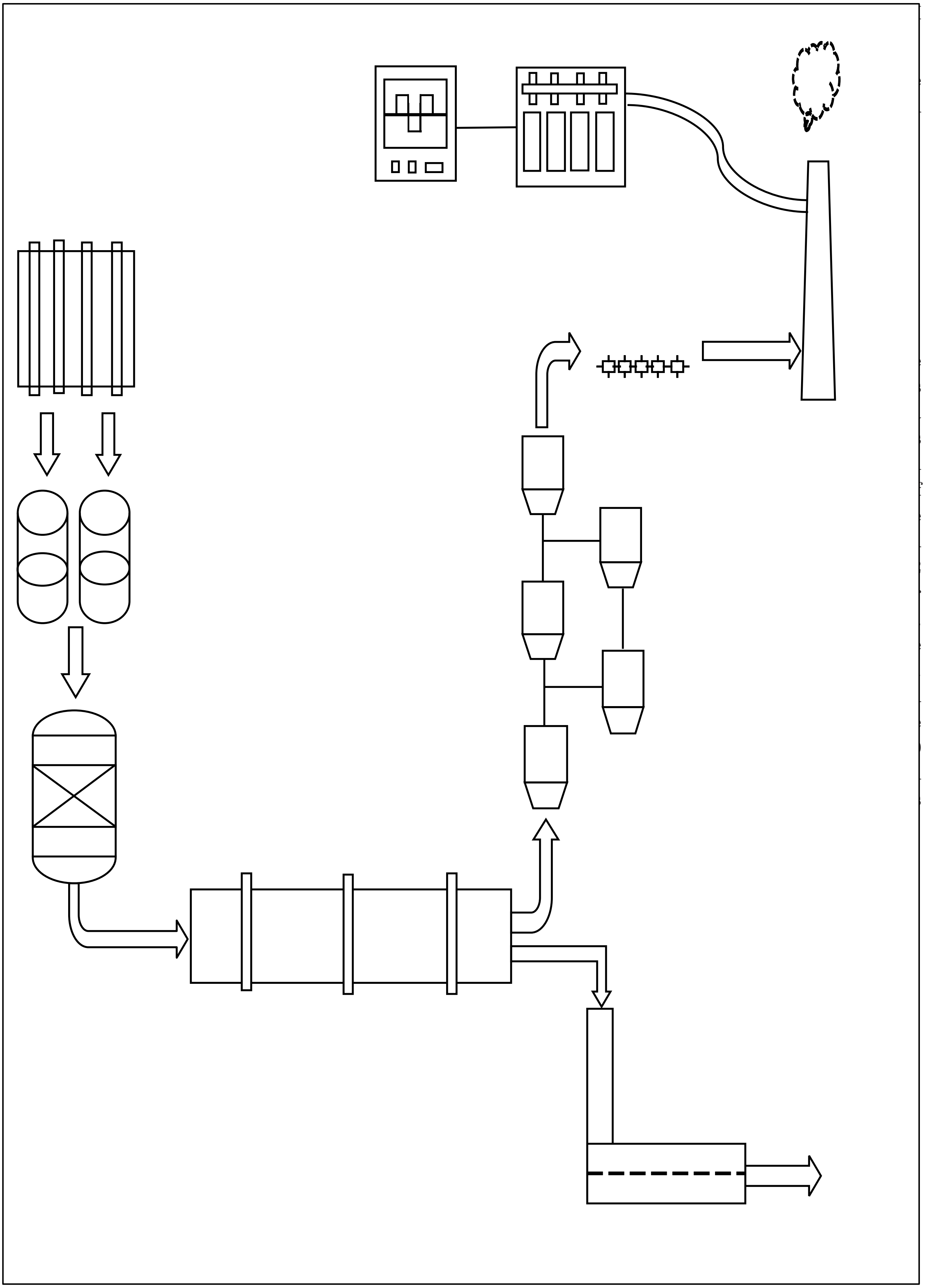
Figure 2 shows the flow diagram for burning of used transformer oil which involves several stages and instruments to ensure smooth operation and safety. Initially, the used transformer oil was collected and stored in tanks equipped with level sensors to monitor the amount of oil. The oil was then preheated using a boiler. Subsequently, the preheated oil was injected in the kiln burner. Kiln was typically a long, cylindrical structure with slight inclination so that materials could move downwards gradually from the feed end to the discharge end. Inside the kiln, combustion took place. The hot gases produced by combustion flow in the opposite direction of the feed, and provided heat required for the chemical reactions to occur. The main function of the kiln was to facilitate the chemical reaction between the raw materials, which transformed into clinker. Clinker was dropped in a cooler due to continuous rotation of kiln and slight inclination. The process of heating the raw materials in the kiln is known as calcination and it occurred at temperatures ranging from 1400°C to 1500°C. Gases from combustion flow through the kiln and passed through the preheater from where they entered an electrostatic precipitator and then moved out through a stack into the atmosphere. At the stack, gas analyzers and flow meters were used to measure emissions of PM, CO_2, NOx, and SOx. Details of stack emission monitoring is explained in section 2.4.

2.2 Used Oil Collection and Analysis:

Used oil was taken from Islamabad Electric Supply Company (IESCO) grid station. There is no such specific data present in the literature about the used transformer oil on annual disposal in Pakistan. However, IESCO provided 350 ton used transformer oil in order to carry out the research and other findings. The chemical composition of used transformer oil and imported coal is shown in Table 1. Used oil contains more carbon contents and less sulphur contents than imported coal. Due to less sulphur contents, it will not affect the process of clinker formation.

Table 1: The Chemical composition of the UTO and Imported Coal.

S.No	Description	Unit	UTO	Imported Coal
1	Carbon	%	89.69	70.94
2	Hydrogen	%	7.98	4.22
3	Nitrogen	%	0.05	1.74
4	Sulphur	%	0.36	0.79
5	Oxygen	%	0.79	3.85
6	Ash	%	1.13	18.46



3. Results and discussion:

3.1 Economic Effects of Used Oil:

In order to assess the economic benefits of used oil utilization, an economic model proposed by Hemidat, Safwat, et al. has been used. The model proposes six different options resulting from adding RDF as a substitute fuel for the pet coke fuel currently used [24]. This model is used in cement industries for calculation of fuel cost. Method of this model for calculation of fuel cost is demonstrated in Table 4. Used transformer oil is utilized at ratios of 10%, 15% and 20%. Table 3 shows the parameters of cement plant in which experimentation took place:

Table 3: Cement Plant Parameters

S.No	Parameter	Value
1	Daily kiln production quantity	7000 tons/day (24 hours)
2	Number of total operating hours	5880 hours/year @ 67% run factor
3	Daily imported coal consumption	860 tons/day, 35.83 kg/hr
4	Total energy consumption	730 kcal/kg of clinker
5	Total energy consumption for the clinker stage	26 kWh/ton
6	Calorific value of imported coal	5,943 kcal/kg
7	Cost of 1 ton of imported coal	236 USD (41,667 PKR)
8	Calorific value of used transformer oil	9,545 kcal/kg

Below are the calculations of fuel cost determination:

Clinker Production(A)= 7000 T/day
Heat Consumption(B)= 730 Kcal/kg.cl
Total Heat Required(C) = (A) × (B) = 5,110,000,000 kcal =

Table 4: Fuel Cost Calculations

Scenarios	Fuel Name	Fuel Substitution	Unit Price		NCV	Heat Required	Quantity of Fuel	Fuel Cost	
		%	PKR/Ton	USD/T	Kcal/kg	Kcal/kg	Tons	PKR /T.cl	USD /T.cl
		(D)	(E)		(F)	$G = C \times D$	$H = G / F \times 1000$	$I = (H \times E) / B$	
Imported Coal Only	Imported Coal	100%	41,667.00	236.25	5943.00	5.11×10^9	859.84	5,118.11	29.02
Fuel Cost of Imported Coal								5,118.11	29.02
UTO + Imported Coal	UTO	20%	5000.00	28.35	9545.00	1.02×10^9	107.07	76.48	0.43
	Imported Coal	80%	41,667.00	236.25	5943.00	4.08×10^9	687.87	4,094.49	23.22
Fuel Cost of UTO + Imported Coal								4,170.97	23.65

As per above Table 4 of fuel cost calculation.
Saving of fuel cost by using 20% used oil is:

Table 5 shows the comparison of fuel cost and net savings per day while using 10%, 15 % and 20 % used oil along with imported coal. Comparison shows that using 10% used oil result in saving of 512 PKR per ton of clinker and 20% used oil result in saving of 947 PKR per ton of clinker along with 90% and 80% imported coal respectively. 20% burning of used oil in kiln will lead to saving of almost 6.6 million per day.

Table 5: Fuel Cost Comparison of UTO and Imported Coal along with Savings

Parameters	Unit	100% Imported Coal	10% Used Oil	15% Used Oil	20% Used Oil
Used oil substitution	%	0	10	15	20
Imported Coal substitution	%	100	90	85	80
Used oil consumption	T/h	0	54	80	107
Imported coal consumption	T/h	860	774	731	688
Fuel cost Used oil	USD/T.cl.	0.00	0.22	0.32	0.43
	PKR/T.cl.	0	38	57	76
Fuel cost Imported coal	USD/T.cl.	29.02	26.12	24.67	23.22
	PKR/T.cl.	5118	4606	4350	4095
Net Savings (per T.cl.)	USD/T.cl.	0	2.69	4.03	5.37
	PKR/T.cl.	0	474	710	947
Net Savings (per Day)	USD/Day	0	18,796	28,194	37,592
	PKR/Day	0	3,315,031	4,972,546	6,630,062

3.2 Environmental impacts of Used Oil:

The metallic analysis of the used oil sample and the trace elements emitted by the used oil, as well as the PCBs content during the burning of used oil in the cement kiln, are displayed in Table 6. Table 6 demonstrates that after combustion of UTO, there was a reduction of metallic contents by more than 99%. The stack emissions data suggest that minimal amounts of metals are emitted during the burning process of used oil, with the bulk of these metals being captured by the clinker.

Table 6: Metallic contents of Used Oil

Trace Metals	Unit	EPA Standard	Used Oil Sample	@10 % UTO	@15 % UTO	@20 % UTO
Lead (Pb)	µg/Nm³	50,000	207,200	25.00	55.00	68.00
Mercury (Hg)	µg/Nm³	10,000	200,590	1.80	8.30	9.00
Cadmium (Cd)	µg/Nm³	20,000	112,410	15.20	14.00	22.00
Arsenic (As)	µg/Nm³	20,000	74,922	1.90	2.10	2.60
Copper (Cu)	µg/Nm³	50,000	63,546	27.00	29.00	37.00
Antimony (Sb)	µg/Nm³	20,000	12,175	20.00	19.00	11.00
Zinc (Zn)	µg/Nm³	200,000	65,380	62.00	68.00	71.00
PCBs	pg/Nm³	NA	3,394	1.36	1.73	1.82

Figure 3 Shows Metallic contents emissions trends from stacks. Maximum reduction takes place at 10% used oil burning although overall reduction is still more than 99%.Mercury is reduced maximum and Antimony is reduced minimum.

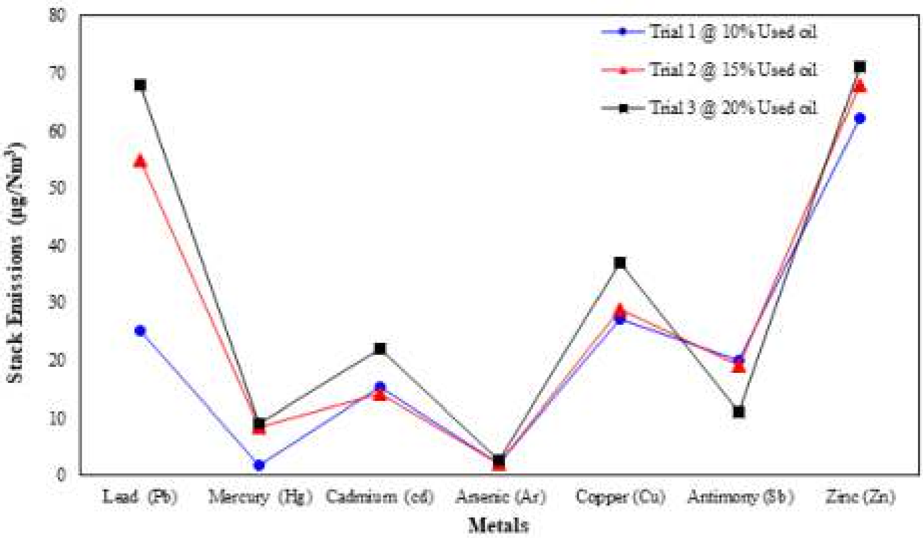


Figure 3: Metallic Contents Emissions from Stack

Figure 4 presents emissions of PCB congeners. The burning of used transformer oil (UTO) in the kiln led to a reduction in PCBs content by over 99%. Notably, PCB congener 156 exhibited the highest reduction, reaching up to 99.99%, when 10% of used oil was substituted.

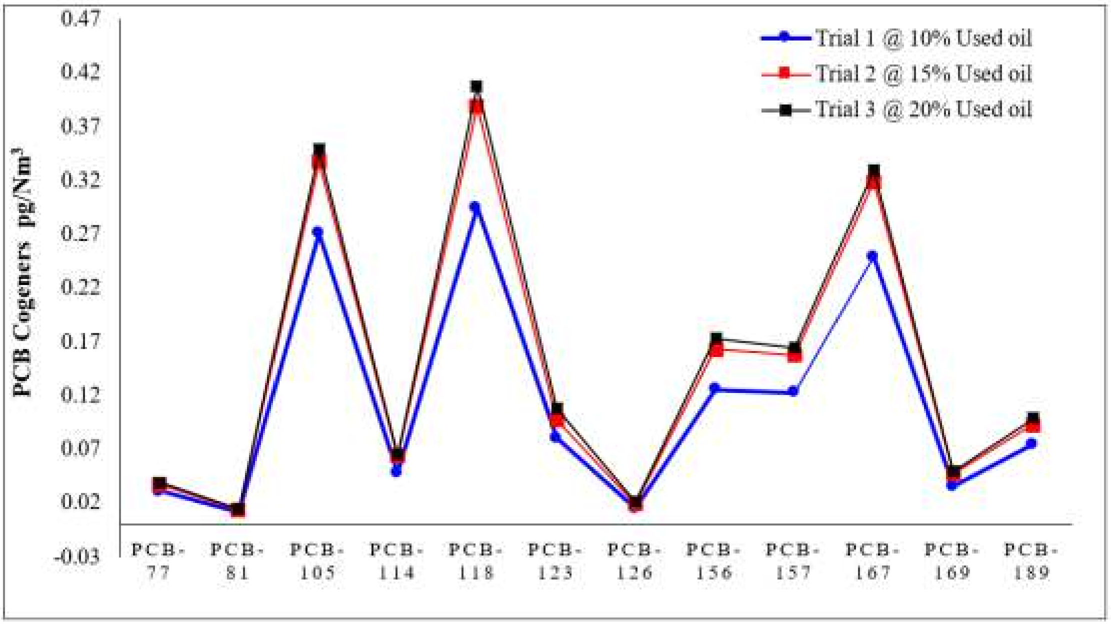


Figure 4: PCB congeners Emissions from Stack

According to Punjab Environmental Quality Standards for Industrial Gaseous Emissions by Environmental Protection department in Pakistan, particulate matter (PM), carbon monoxide, sulphur oxides were monitored during combustion of used oil and their results are shown in Table 7. Table shows the results of PM, CO, SO_x and NO_x during 100% imported coal consumption and also during burning of UTO with 10%, 15% and 20% substitution along with imported coal.

Table 7: Particulate Matter, Carbon Monoxide, NO_x and SO_x Emissions

Parameters	Unit	PEQS Limits	Imported Coal @ 100%	Trial 1 @ 10% Used oil	Trial 2 @ 15% Used oil	Trial 3 @ 20% Used oil
Particulate matter (PM)	mg/Nm³	300	38	34	28	22
Carbon Monoxide (CO)	mg/Nm³	800	480	420	380	356
Oxides of Nitrogen (NO_x)	mg/Nm³	1,200	540	430	396	362
Sulphur Oxides (SO_x)	mg/Nm³	1,700	180	146	138	119

Figure 5 is explaining the results that during used oil utilization all the stack emissions are reduced as compared to 100 % imported coal. Particulate matter emissions reduced from 38 in case of 100 % imported coal to 22 with the 20% used oil substitution. Similarly, carbon monoxide (CO) reduced gradually with increasing used oil substitution. Carbon monoxide is reduced less as compared to reduction percentage of PM, SO_x and NO_x due to more carbon contents in UTO. Nitrogen oxides and sulphur oxides also reduces with increasing used oil substitution. SO_x are reduced maximum as compared to reduction percentage of PM, CO and NO_x due to less sulphur contents in UTO as compared to imported coal.

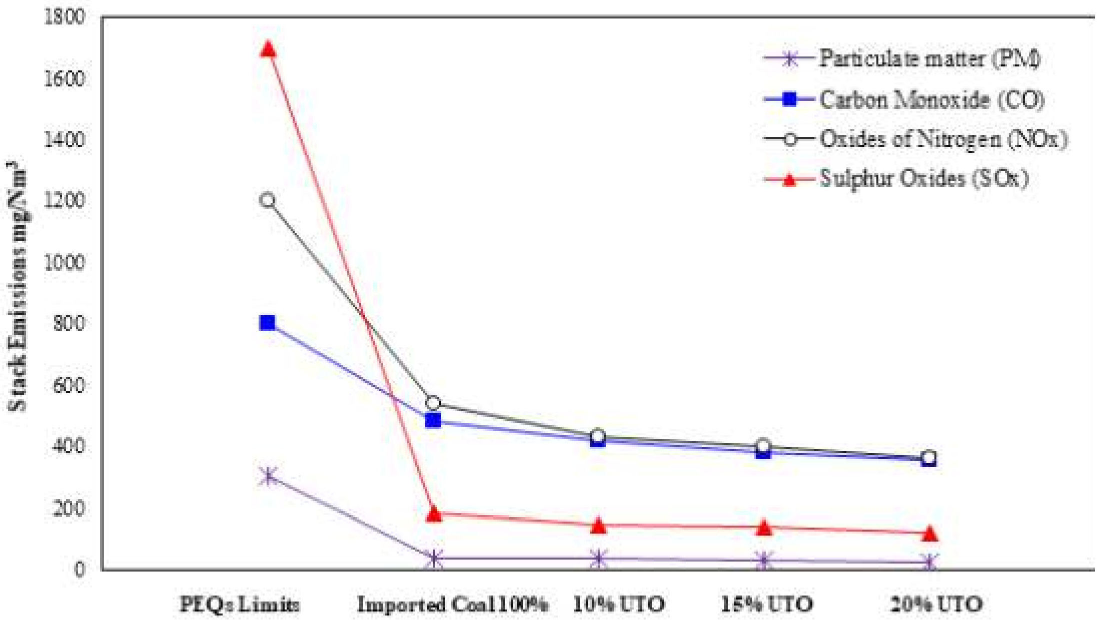


Figure 5: Stack Emissions of PM, CO, NOx, Sox

3.2.1 Carbon Dioxide Emissions:

The Environmental Protection Department in Pakistan has not established a specific standard for carbon dioxide emissions. To calculate carbon dioxide emissions, the method outlined by reference [25] is employed.

The emission factors for fuel combustion are taken from IPCC 2006 Guidelines, where the default emission factors of CO_2 for coal and used oil are 94,600 and 73,300 kg/TJ respectively. To calculate emission factor for utilized fuel, given emission factor for fuel type is multiplied by actual lower heating value of fuel as per given formula

Corrected CO_2 = Default EF_{CO2} of fuel (kg Co_2/TJ) x Average heat value of fuel (KJ/Kg)

I. Corrected CO_2 for Coal:

$= 94{,}600 \text{ kg } CO_2/\text{TJ Coal} \times 24{,}866 \text{ kJ/kg Coal} \times 10^{-9}$

$= 2.35 \text{ kg } CO_2/\text{kg Coal}$

II. Corrected CO_2 for Used Oil:

$= 73{,}300 \text{ kg } CO_2/\text{TJ used oil} \times 40{,}355 \text{ kJ/kg used oil} \times 10^{-9}$

$= 2.96 \text{ kg } CO_2/\text{kg used oil}$

Carbon dioxide emission is slightly more in case of used transformer oil due to high carbon content as compared to imported coal.

4. Conclusions:

From the above experiment it can be concluded that used oil can be incinerated in cement kiln with saving in fuel cost and minimum environmental effects. Clinker trapped maximum amount of hazardous metals. PCBs emissions are also reduced more than 99% from the original PCB contents. However, carbon dioxide emissions are slightly more than that of imported coal while utilizing UTO. UTO is a cost-effective fuel which is economical as well as its incineration will save the environment from hazardous PCBs contents. The carbon dioxide (CO_2) emissions due to used transformer oil was calculated, which gave 2.96 kg of CO_2/per kg used oil as compared to 2.35 kg of CO_2/per kg of coal. This shows that CO_2 emission was slightly higher than the case when imported coal was used. However, in this research, the focus was on reducing polychlorinated biphenyls (PCBs) emissions by mixing used transformer oil with imported coal as PCBs are toxic chemicals that can have harmful effects on human health and the environment. In the later stage, CO_2 emission reduction could be carried out using absorption columns or other CO_2 emission controlling methods.

5. List of Acronyms:

CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cl	Chlorine
dI-PCB	Dioxin-like Polychlorinated Biphenyl
EPA	Environment Protection Agency
IPCC	The Intergovernmental Panel on Climate Change
IESCO	Islamabad Electric Supply Company
Kcal/Kg.cl	Kilocalories per Kilogram Clinker
kJ/kg	Kilojoules per kilogram
kWh	Kilowatt hour
MSW	Municipal Solid Waste
MPKR	Million Pakistani Rupee
NCV	Net Calorific Value
Nm^3	Normal Cubic Meter
NOx	Nitrogen Oxides
PCBs	Polychlorinated Biphenyls
PCDD/f	Polychlorinated dibenzo-p-furans'
PKR	Pakistani Rupees
PPM	Parts Per Million
PM	Particulate Matter
pg	Pico gram
SCWO	Supercritical water oxidation
SOx	Sulphur Oxides
TJ	Tera joules
T	Ton
T.cl	Ton Clinker
µg	Microgram
UNEP	United Nations Environment Program
USEPA	United States Environment Protection Agency
UNEP	United Nations Environment Programme
USD	United States Dollar
UTO	Used Transformer Oil

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