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Utilization of fiber-reinforced plastic (FRP) waste generated by a wind-turbine manufacturing company

by

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Abstract

The paper addresses the problem of disposing about 5 tonnes per day of fiber-reinforced plastic (FRP) waste generated by M/s Suzlon Energy Ltd ─ which is a company situated at Puducherry for manufacturing turbines and blades for wind-energy extraction. The waste being absolutely non-biodegradable, cannot be disposed in landfills and its incineration or open burning is a cause of serious air pollution. We have explored the use of this waste as an additive in brick-making and in cement manufacture. As demonstrated in the paper, both options are able to put the FRP waste into use. Further, both options help the cause of environmental protection directly as well as indirectly.

Keywords:

FRP waste;
wind turbines;
brick-making;
cement manufacture;
co-processing

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1. Introduction

1.1 The virtues of fiber-reinforced plastics (FRPs)

Fiber reinforced plastic (FRP) is one of the many gifts of technology that has influenced human life in numerous spheres. As the name suggests, FRP represents plastic which contains fibers of other materials that add strength, flexibility, durability and other virtues to the plastic. FRPs are distinguished by six attributes that give them an edge over other materials: longer life cycles, increased corrosion resistance, improved fire resistance, easier design (because of tailor made properties), mouldability (which enables functional integration of, complex shapes), and high strength-to-weight ratio.

FRPs were first used in making boats and bath tubs about 50 years ago. Now, they are widely used in building construction, automobiles, furniture, sports equipment, medical equipment and innumerable other areas. Due to their light weight and ease of installation FRPs are also the materials of choice in the manufacture of wind mills.

But even as FRPs are extremely pleasing, useful and comfortable during their product life, most of their virtues become great hurdles in disposing them once they have turned to waste. FRPs are non-biodegradable so can not be assimilated in nature by any means. Nor can they be reused in economically viable manner.

1.2 The Suzlon Energy Ltd episode:

M/s. Suzlon Energy Ltd. had established a unit at Puducherry in 2005 to manufacture wind mills. Even though the management of air, water and noise environments had been planned properly by the industry, the aspect of solid waste management was neglected by the industry. The process of rotor blade manufacturing used by M/s Suzlen Energy involves moulding of FRP baldes followed by trimming and assembling. The trimming activity generates around 7 tonnes per day (TPD) of FRP waste. Initially the industry passed on the waste to local vendors who then burnt the FRP waste in the open. It created air pollution and soon raised a public outcry. As a result the unit was forced to store the FRP waste within their premises.

Wind turbines being manufactured at M/s Suzlon Energy (Suzlon-Energy-LTD-Koregaon-Park/020PXX20-XX20-110420150536-R1C1_BZDET)

With time the waste material accumulated into a 6000 ton mountain. The industry took no initiative to dispose it.

On the night of the 11th December 2006, a major fire broke out in the FRP waste storage yard, It happens to be the first-ever major industrial fire in the history of Puducherry[4, 8].

The location around the accident site was enveloped with thick and malodorous smoke. It caused eye and throat irritation, vomiting and headache to the people living around the industry. Twenty six of them had to be admitted in hospitals, raising panic among the public. It took three days to dowse the fire.

Whether the fire was due to electrical short circuit or was set off intentionally (to bypass the disposal problem), is yet to be established. But it impacted the environment very badly. The Ambient air quality analysis

carried out on the day following the fire revealed that the levels of suspended particulate matter (SPM), oxides of sulphur (SOx), and oxides of nitrogen (NOx) were abnormal. SPM was 205 µg/m^3 against the prescribed standard of 100 µg/m^3. There was massive release of other hazardous air pollutants (HAP), volatile organic components (VOC) and heavy metals (HC). The Puducherry Pollution Control Committee had to close all the activities of M/s Suzlon Energy Ltd as per the provision of Section 5 of Environment (Protection) Act, 1986, rendering thousands of employees jobless.

1.3 The present work

The episode referred above reflects how serious the problem of FRP waste disposal is. At present FRP waste can only be disposed either by open burning, or incineration, or land-fill. The first two methods create air pollution and the third is economically unviable as the cost of land has increased ten folds since last five years. Moreover, since FRP is totally non-biodegradable, landfilling amounts to just accumulating the problem and postponing its solution. It was for this reason that the management of M/s Suzlon EnergyLtd had simply piled up their FRP waste on open land within their premises.

The present study was carried out with an aim to find a way by which FRP waste generated by M/s Suzlon Energy Ltd can be gainfully utilized. Two options were explored: i) use of FRP as an additive in brick-making; and ii) coprocessing FRP in a cement kiln. Unlike other attempts of utilizing FRP waste, reviewed by Ramesh (2009) [7], and Marsh (2001) [6], the use of FRP as a building material or source of energy via incineration appear to hold the most promise [5, 9]. Accordingly, ways to dispose the FRP waste generated by M/s Suzlon Energy Ltd were explored,seeking them to be economically viable and with a small ecological footprint.

2. Materials and method

2.1 Quantification and characterization of FRP waste being generated by M/s Suzlon Energy Ltd

An assessment of the FRP waste being generated in different streams by M/s Suzlon Energy Ltd was first carried out and the land area required for its disposal was calculated. The characteristics of the waste, including its physical properties and its organic and inorganic constituents, were then determined following standard methods (APHA 1995).

2.2 Use of the FRP waste in brick manufacturing

The schematic is presented in Figure 1. Different proportions, ranging from 3 to 10%, of FRP waste were explored as additive in brick-making. The ingredients used in FRP-added brick making are given in Table 1.

The FRP waste was first pulverized in a crusher equipped with stainless steel blades, then sieved, before taking it for brick-making. Bricks containing different proportions of FRP waste were made by thoroughly blending the ingredients (Figure 1) with addition of water to ensure homogeneity, and then moulding under pressure. The moulded bricks were air dried for 21 days during which curing also occurred.

The bricks were tested as per the ISI building code.

2.3 Use of FRP in cement manufacture

Cement is made by heating a mixture of calcareous and argillaceous materials to a temperature of about 1450ºC. This leads to partial fusion and nodules of clinker are formed. The cooled clinker is mixed with a certain quantity of gypsum, and sometimes other cementation materials, and ground into a fine meal-cement. The schematic diagram of the process is given in Figure 2.

2.1.1 The process used

The main components of clinker are lime (CaO), silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3). The first stage in cement manufacture is the quarrying of raw materials. To obtain proper composition of the raw mix, corrective ingredients such as bauxite and iron ore are added to compensate for deficiencies of silica, alumina and iron oxide in the raw material. After pre-blending, the chemically balanced raw mix is made to pass through the mill feed system, on to a roller mill. The mill is fed with hot gases from the kiln to dry the raw mix to less than 1%

moisture. The dried material is then conveyed to the blending silo where continuous homogenization ensures the correct raw meal composition.

The clinker production is performed in a dry suspension pre-heater cement kiln equipped with a pre-calciner. The kiln employed in the present study rotates with a speed of 2.4 rounds per minute, is 3.75 meter in diameter and in 55 meter long. It has a two string pre-heater tower (4 stages and 2 stages respectively) and produces approximately 2400 tones of the intermediate product – clinker − per day. The clinker is cooled in a grate cooler, 20.6 meter long and 2.5 meter wide. The maximum feeding capacity is 160 tons of raw meal per hour to the second stage cyclone from the top. The main burner is a Duflox, usually fired with 3 tons of coal per hour. After clinkerisation the material is sent to the cement mill where the mineral component such as fly ash and gypsum are added to produce Portland cement.

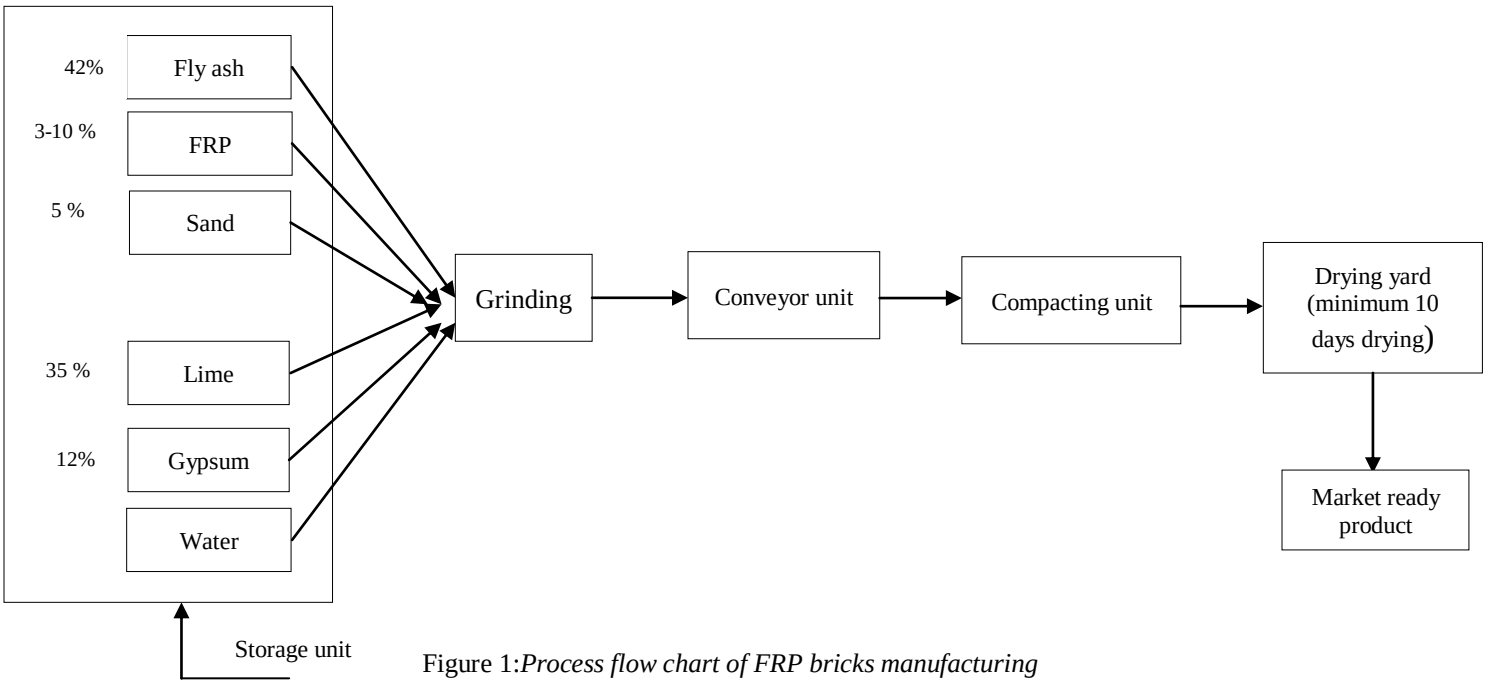

Figure 1:*Process flow chart of FRP bricks manufacturing*

The feeding system installed for the FRP waste co-processing consisted of (Figure 3) a hoist covered, with bucket, hopper, chute, double flap damper and shut off gate. The hoist lifts the waste material packed in bags from the ground level to the 2nd floor of the pre-heather tower. The capacity of the hoist is 3 tones and the volume of the hoist bucket is 0.35 m^3. The material was unloaded from the bucket on to the feeding chute. A double flap damper was used in order to avoid false air entry. A shut off gate was incorporated in the system keeping safety considerations in view. Both the double flap damper and the shut off gate were interlocked with kiln operation ensuring safety in case of back firing. In order to maintain the feed rate of the waste material, a counter was placed on the feeding chute to check the number of bags being co-processed. A hooter was provided at the platform which gave signal to the operating staff to put the waste packed in bag on the feeding chute at the pre-decided time. Fire, temperature, and pressure sensors were provided at the chute ensuring proper flow of material as well as safety.

The entire operation of FRP waste utilization was monitored using computer aided displayer starting from FRP waste feeding to flue gas disposal though stack. The feed rate for FRP waste was calculated starting 30 kg/hr at kiln inlet. It was gradually raised with strict monitoring with the help of a computerized monitoring system. The process stabilization occurred at the feed rate of 98 Kg per hour. The same rate was then maintained throughout the experiment.

2.1.2 Flue gas monitoring

In order to assess the impact of FRP waste utilization in the cement kiln on the environment, a comprehensive monitoring programme was set up (Table 2). All the parameters stipulated in the Central Pollution

Control Board (CPCB) guideline for incineration of hazardous wastes were sampled and analyzed using state-of-the art equipment. Considering that the "*as usual process"* of clinker production would release various toxic gases, and to different between this pollution and the one generated by FRP, the monitoring was carried out in three different phases: pre-co processing, co-processing and post−co processing. The variables assessed and the methodology adopted are described below:

Representative samples of coal and raw meal were analyzed for heavy metals Sb, As, Cd, Cr, Cu, Pb, Mn, Ni, Tl, V, Fe, Zn, Sn, Se and for total organic compounds (TOC) during the entire trail period. Leachability test (including heavy metals Cd, Tl, Hg, Sb, As, Pb, Cr, Co, Ni, Cu, Mn, V, Zn, Sn, Se, Fe) was conducted for representative samples of that clinker.

The TOC were determined by USEPA Method No. 25 A – which requires is continuous online measurement for 24 hours. Flue gas was sampled via a heated probe and was passed through the hydrogen flame. This caused organic compounds to get ionized and the strength of ionization was reflected as ionization peaks in the TOC analyzer screen. The peak areas gave the TOC content.

For hydrogen chloride and hydrogen fluoride, an integrated sample was extracted from the source was passed through a heated probe, and filtered into dilute sulfuric acid and dilute sodium hydroxide solutions, respectively. The filter collected particulate matter including halide salts but they were not routinely recovered and analyzed. The hydrogen halides are soluble in the acidic solution and form chloride (Cl), bromide (Br), and fluoride (F) ions. The halogens have a very low solubility in acidic solution and pass through to the alkaline solution where they get hydrolyzed to form a proton (H^+), the halide ion, and the hypo-halous acid (HClO or HBrO). Sodium thio sulfate was added in excess to the alkaline solution to assure reaction with the hypo-halous acid to form a second halide ion such that 2 halide ions were formed for each molecule of halogen gas. The halide ions were measured by ion chromatography. Hydrogen chloride and hydrogen fluoride were monitored during all the three phases of the trial.

Hourly samples of all raw materials (lime stone, bauxite, and iron ore), raw meal, kiln coal, clinker coal, clinker and green mesh with resin were collected and one composite sample per day was made.

Carbon monoxide (CO) and nitrogen oxides (NOx), were measured by the USEPA Method No. 7 E-using portable digital flue gas analyzer of Quintox make. Orsat Apparatus was used to determine O_2 and CO_2. Flue gas was collected in the bladder and allowed to pass through KOH solution so that CO_2 present in the flue gas got absorbed. The flue gas was again passed though pyrogalol solution to absorb the O_2. CO was analyzed through flue gas analyzer.

SOx was measured by the USEPA Method No. 6 A/B, in which the gas sample is extracted from a sampling point in the stack. The SO_2 in the flue gas was absorbed in 50 ml of 6% H_2O_2. The SO_2 and the sulfur trioxide, including fractions in any sulfur acid mist, were separated. The SO_2 fraction was measured by the barium-thorium titration method.

For particulate matter (PM), the USEPA Method No. 17 was used in which the PM is withdrawn iso-kinetically from the source and collected on a glass fiber filter maintained at stack temperature. A 1000 liters of flue gas is collected and made to pass through the thimble of which dry weight is known. After sampling, the thimble is dried and weighted to find the fraction.

For heavy metals, a stack sample was withdrawn iso-kinetically from the source. Particulate emissions were collected in the probe and on a heated filter, and gaseous emissions were collected in an aqueous acidic solution of hydrogen peroxide (analyzed for all metals including Hg) and an aqueous acidic solution of potassium permanganate (analyzed only for Hg). The recovered samples were digested, and appropriate fractions were analyzed for Hg by cold vapor atomic absorption spectroscopy (CVAAS) and for Sb, As, Cd, Cr, Co, Cu, Pb, Mn, Ni, Ti, by inductively coupled argon plasma emission spectroscopy (ICAP) and Atomic absorption spectroscopy (AAS). Graphite furnace atomic absorption spectroscopy (GFAAS) was used to analyses Sb, As, Cd, Co, Pb, Se, and Ti. The number, frequency, and codes of the analysis methods are summarized in Table 2.

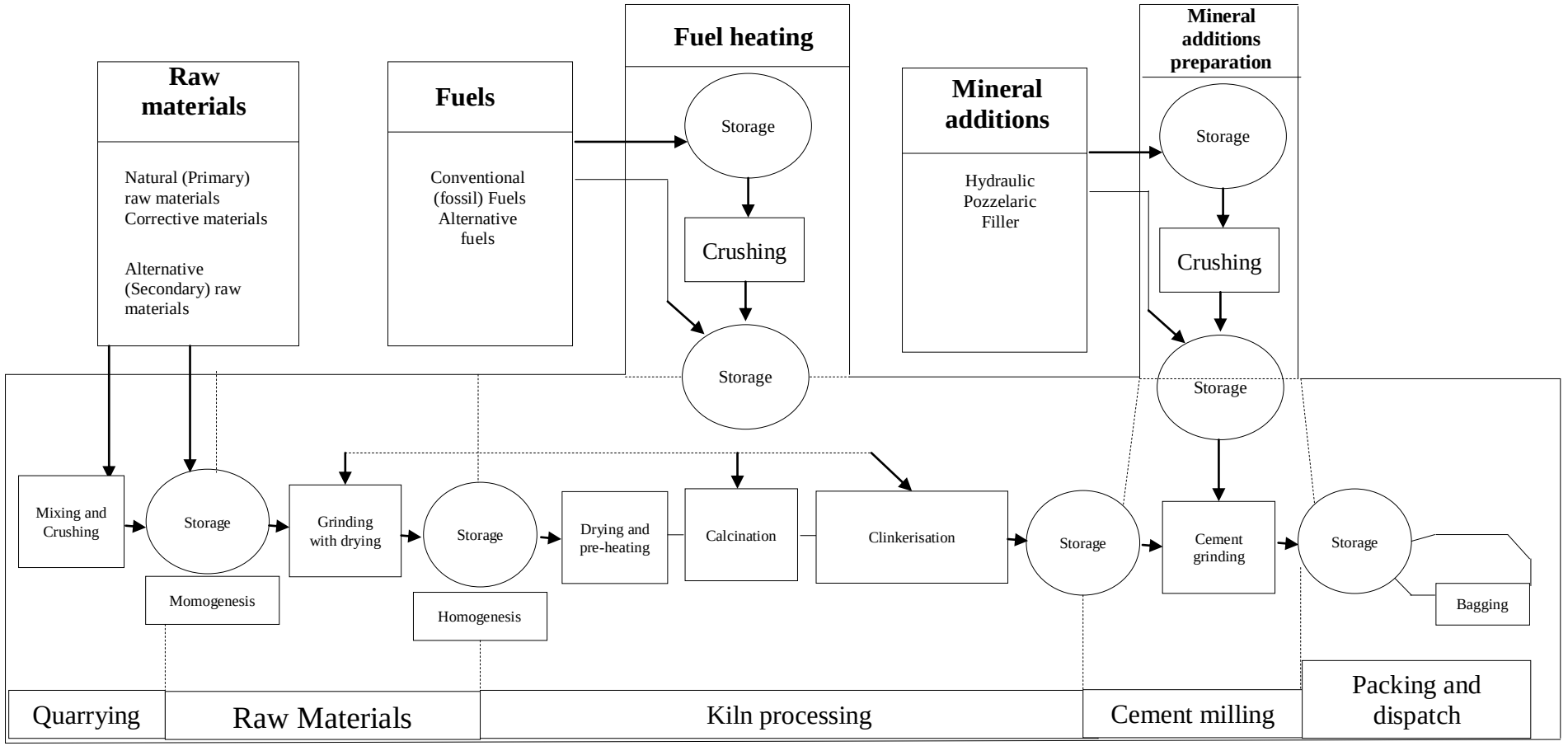

Figure 2:*Schematic of the cement production process*

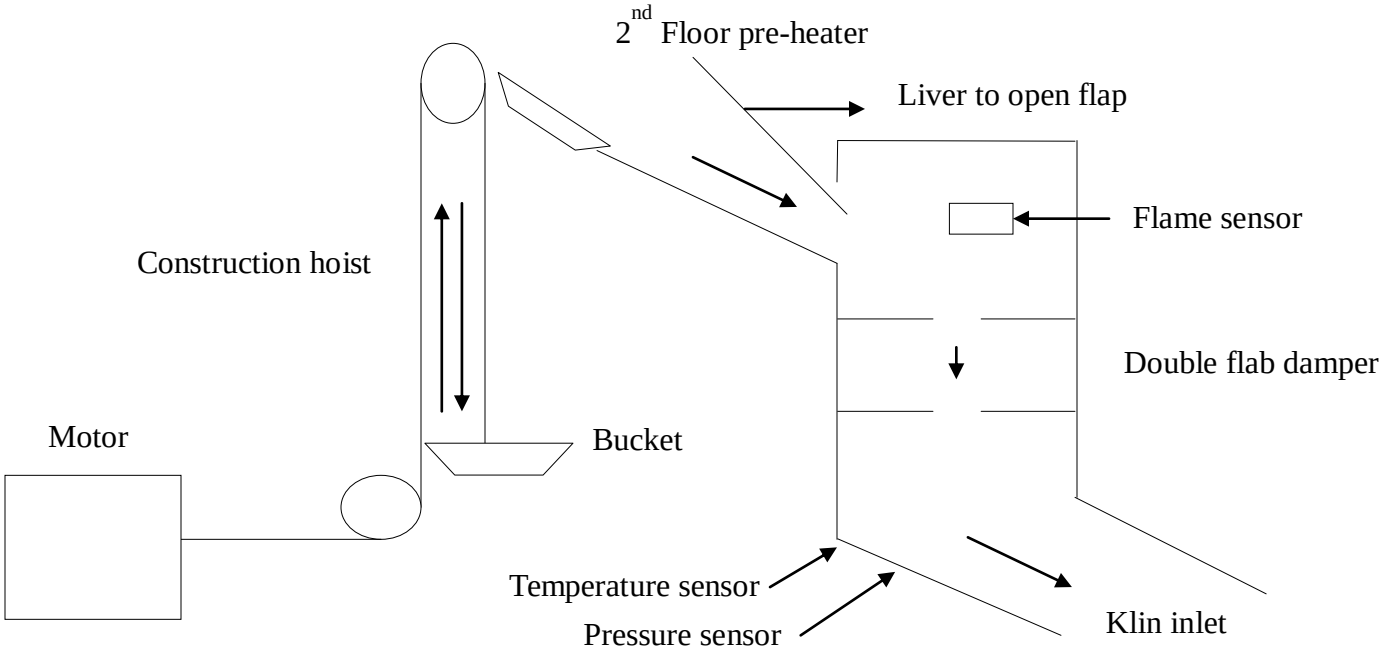

Figure 3:*The FRP waste feeding system*

3. Results and discussion

3.1. Quantification of the FRP waste

The quantities of the FRP waste being generated by the different units of M/s Suzlon Energy Ltd are given in Table 3. As may be seen, over 5 tonnes of waste is generated per day and each of the units generates significant quantities of the waste. The characteristics of this waste are given in Table 4.

It was seen experimentally that each ton of FRP waste occupies an area of 2 x 2 x 1.25 m. In a pile 20 m high, 16 such FRP heaps can be accommodated. Proceedings in this manner it is seen that 300 m^2 of land area will be required for piling up 1000 tons of FRP. It will have a volume of 5000 m^3. To accommodate each year of FRP waste 675 m^2 of land will be needed. Finding so much land is nether economically nor environmentally feasible.

3.2 Use of FRP waste in brick-making

The results of the compressive strengths and water absorption characteristics of the FRP-mixed bricks are presented in Table 5. The corresponding BIS values are collected in Table 6. It is seen that the bricks made of 10% FRP waste do not meet the BIS standards in respect of water absorption and compressive strength even for third class bricks. But the bricks made of 5 and 7.5% of FRP waste powder complied with the BIS standard for third class bricks in respect of compressive strength and second class bricks in respect of water absorption. The bricks made of 3% of FRP powder meet the BIS specification of First class bricks in respect of water abosroption and compressive strength in respect of second class bricks. Based on these findings it is recommended that 3 % FRP bricks can be used for low-quality constructions such as of a compound wall or low cost housing where, otherwise, mud bricks are used.

3.3 Use of FRP waste as fuel in cement manufacture

For such mud bricks soil, has been used in the construction of shelters for thousands of year and approximately 30% of the world's present population still lives in earthen structures. As much as 10 billion tones of common burnt clay is consumed annually in making such shelters. Approximately 34 billion tones of clay from 5000 acres of top layer of soil is dug out for brick manufacturing. Soil erosion and pollution due to emissions from

coal or fire-wood burning, which is needed in making these bricks, are the serious problems posed by brick industry. Replacing top soil by FRP waste in brick making would help in replenishing of top soil which is an invaluable natural resource.

It is seen that waste has a calorific value of 8207 Kcal, with an ash content of < 3%; these are considered ideal for co-processing.

The gaseous emissions arising from the cement manufacture in the ACC cement, Coimbatore, where the co-processing tests were done, are disposed through a 100 meter tall stack. The stack dimensions and the characteristics of its flue gases are given in Table 7. The pollutant emissions with and without FRP use are given in Tables 8-21. The impacts are summarized in Table 22. It is also seen (Table 23) that the use of FRP waste does not adversely effectthe crucial properties of the cement. The coal feed rate (average net calorific value of 5540 Kcal/Kg) in kiln during the trial burn was 15.43 tonnes per hour. The useful heat value of the waste was 8134 Kcal/Kg; hence the thermal substitution rate (TSR) was 0.924%.

Co-processing is an engineered process that employs thermal oxidation at high temperature (normally 1100 ºC or higher) to destroy the organic fraction of waste. Combustion gas temperatures and residence times in cement kilns exceed those of commercial hazardous waste incinerators. These high combustion temperatures and long residence times, along with the strong turbulence encountered in cement kilns, ensure complete destruction of even the most stable of organic compounds. Burning of cement clinker requires a material temperature of 1400 – 1500 ºC; consequently the flame temperature must be even higher in order to obtain heat transmission from flame to material. In the cause of preheated kilns and pre calciner kilns the gas temperature in the burning zone is about 2000ºC. In mid-kiln it is about 1700 ºC and at the kiln exit it is about 1100 ºC. The gas retention time is about 5 seconds.

The large size of the kilns and the large quantity of the material present in them result in a high degree of thermal stability. In other words, temperature within the kiln changes very slowly. Thus even if a cement kiln is forced into an emergency shut-down resulting from a loss of primary fuel or a severe malfunction, all hazardous waste in the kiln will still be completely destroyed. Further, the cement kilns are operated under alkaline conditions. Therefore virtually all hydrogen chloride entering a kiln is neutralized to form sodium chloride, potassium chloride or calcium chloride, which are non-toxic substances. Consequently, emission of hydrogen chloride, a strongly acidic compound during the FRP-aided cement manufacture is significantly lower than emission from commercial hazardous waste incinerators.

Moreover unlike incineration and landfill, the use of FRP in cement co-processing did not leave behind any residue that might have adversely impacted the environment. Thus, this co-processing appears an ecologically sustainable solution for FRP waste management.

4. Summary and conclusion

The paper presents an illustrative case study of M/s Suzlon Energy Ltd ─ an industry which manufactures fiber-reinforced plastic (FRP) turbines at Puducherry for wind energy generation. We have shown how the >5 tonnes per day of FRP waste generated by the industry posed a major disposal problem and eventually led to a highly polluting fire ─ the first of its kind in the industrial history of Puducherry. In this backdrop the paper presents our attempts to find environmentally compatible ways of utilizing the FRP waste being generated by M/s Suzlon Energy Ltd. Two options were explored: FRP as an additive in brick making, and in cement manufacture. The former option was seen to yield bricks which comply with BIS standards and can substitute mud bricks. Towards the second option very extensive monitoring of the flue gases was carried out before FRP-addition, during FRP use, and after the FRP use. CO, NOx, SOx, organic pollutants, hydrogen halides, and metals/metalloids were all meticulously monitored. It was seen that the use of FRP neither increases pollutant emissions beyond acceptable levels nor does adversely effect the cement quality.

All-in-all the study leads to two viable options for large-scale use of FRP waste generated by M/s Suzlon Energy Ltd in particular and wind turbine manufacturing units in general. Utilization of these options may contribute substantially to the control of FRP-related pollution and the resultant eco-degradation [1-3].

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Table 1: Ingredients used in FRP−added bricks

The ingredient	*Proportion, %*	*Quantity used, Kg*
Fly ash	40	300
Sand	15	112
FRP waste	3 to 10	20-75
Gypsum	5	35

Table 2: The sampling protocol and the methods of analysis

Variable	*Analytical method code*	*Number of samples*	*Frequency*
Particulate matter	USEPA (5/17)	3	Once in each shift
SO_2	USEPA (6A/B)	3	Once in each shift
HCl, HF	USEPA 26 (ion chromatography)	3	Once in each shift
HBr	USEPA 26 (ion chromatography)	3	Once in each shift
NOx	Instrumental (electrochemical sensor)	3	Once in each shift
Hg (particulate and gaseous)	USEPA 101 A (cold vapour AAS)	3	Once in each shift
Antimony, Arsenic , Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Nickel, Thallium, Vanadium, Zinc, Tin, Selenium, Aluminum	USEPA 29 (I-MS)	3	Once in each shift
Dioxins and furans (I-TEF)	USEPA 23A	1	Once in each phase
TOC/total hydrocarbon	USEPA Method 25 A	1	Once over a period of 24 hours
Benzene	NIOSH 1503	3	Once in each shift
PAH (particulate and gaseous)	TO 13	1	Once in each phase
NH_3	Indo phenol	3	Once in each shift

Table 3: Quantity of FRP solid waste needing disposal, generated by M/s Suzlon Energy Ltd, Kg/day

tage name	*Type of solid waste*	*Rotor blade*				*Nacelle cover*			*Total Kg/day*
		AE-26	AE-31	AE-32	AE-40	600 KW	1.25 KW	1.5 KW	
MPRP	PVC & PS foam	10	10	10	15	10	10	10	75
	Resin & hardener	59	87	87	100	25	35	39	432
	Subtotal (A)	69	97	97	115	35	45	49	507
Pre-fabrication	Green mesh with resin	77	90	95	120	50	60	77	569
	Subtotal (B)	77	90	95	120	50	60	77	569
Molding	Helping material with resin	173	200	210	260	140	190	237	1410
	Subtotal (C)	173	200	210	260	140	190	237	1410
Dry finishing	Flash cutting of finishing	75	90	92	140	60	80	100	367
	Sawing ring	25	30	30	38	0	0	0	123
	Painting rollers	13	15	15	20	13	20	20	116
	Sanding paper	13	16	16	20	13	32	32	142
	Put can & paint can	8	13	13	16	6	8	8	72
	Subtotal (D)	134	164	166	234	92	140	160	1090
Total solid waste (A+B+C+D)		453	551	568	729	317	435	523	
Number of pieces manufacturing per day		2	1	2	2	1	1	1	
Total solid waste (A+B+C+D), kg/day		906	551	113	1458	317	435	523	5326

Table 4: Characteristics of the FRP waste generated by M/S Suzlon Energy Ltd

Parameter	*Method of assessment*	*Value*
Physical state	SW-846	Solid
Color	SW-846	Green
Texture	SW-846	Dry soild
Specific gravity, g/cc	ASTM D-5057-900	0.49
Moisture, %	-	1.3
Calorific value, Cal/g	IS: 1350 Part-II	8778
Melting point, ºC	SW846-1020 A	1100C
Loss on drying at 105ºC	APHA2540	1
Loss on ignition at 550, %	APHA2540	95
Ash content, %	APHA2540	3
Sulphate as SO_4, mg/Kg	APHA4500E	3194
Chloride as Cl, mg/Kg	APHA 4500 Cl-A	1566
pH	SW-846-9045 C	6.2
Organic halogen, mg/Kg	SW-846-505	20287
Carbon, %	CHNS-Analyzer	75
Hydrogen, %	CHNS-Analyzer	10.9
Nitrogen, %	CHNS-Analyzer	1.5
Sulphur, %	CHNS-Analyzer	BDL*
Chromium, mg/Kg	AAS	22
Nickel mg/Kg	AAS	1
Cadmium, mg/Kg	AAS	BDL*
Lead, mg/Kg	AAS	92
Mercury, mg/Kg	AAS	BDL*
Antimony, mg/Kg	AAS	<5
Arsenic, mg/Kg	AAS	<1
Cadmium, mg/Kg	AAS	<1
Chromium, mg/Kg	AAS	29.85
Cobalt, mg/Kg	AAS	<1
Copper, mg/Kg	AAS	8.51
Lead, mg/Kg	AAS	94.74
Manganese, mg/Kg	AAS	8.87
Nickel, mg/Kg	AAS	6.98
Mercury, mg/Kg	AAS	<1
Thallium, mg/Kg	AAS	<1
Vanadium, mg/Kg	AAS	<1
Zinc, mg/Kg	AAS	9.20
TPH, mg/kg	AAS	<150
Tin, mg/Kg	AAS	<5
Selenium mg/Kg	AAS	<1
Iron, %	AAS	0.026
PCB mg/Kg	AAS	<1
PCP, mg/Kg	AAS	<0.5
Calorific value, kcal/Kg	AAS	8207
Moisture, %	AAS	1.25
Ash, %	AAS	1.81
Volatile matter, %	AAS	91.7
Fixed carbon, %	AAS	5.24
Carbon, %	AAS	69.36
Sulphur, %	AAS	0.04
Nitrogen, %	AAS	0.83
Oxygen, %	AAS	18.87
Hydrogen, %	AAS	9.10
TOC, %	AAS	16.7

* Below detectable limit

Table 5: Compressive strength and waste absorption characteristics of FRP mixed bricks

Batch number	*FRP proportion, %*	*Compressive strength, MPa*	*Water absorption, %*
FRP1	10	1.8	23.3
FRP2	10	2.3	21.8
FRP3	10	1.9	22.2
AVG	0	2	22.4
FRP4	7.5	5.04	15.4
FRP5	7.5	4.26	14.4
FRP6	7.5	4.80	14.6
AVG	0	4.7	14.8
FRP7	5	5.9	9.5
FRP8	5	6.1	9.9
FRP9	5	6.2	10.5
AVG	0	6	9.9
FRP10	3	8.1	14.2
FRP11	3	8.6	15.5
FRP12	3	8.5	15.2
AVG	0	8.4	14.9

Table 6: BIS standards for bricks

Classification	*Compressive strength, MPa*	*Water absorption, %*
First class	10.5	<15
Second class	7	<22
Third class	3.5	20-25

Table7: Stack dimensions and flue gases of M/s ACC Cement, Coimbatore

Aspect	*Unit*	*Average value*
Stack diameter	m	2.65
Cross section area	m^2	5.52
Pressure	mmHg	720
Gas temperature	^oC	133
Moisture	vol, %	15.44
Oxygen content	vol, %	10.4
Carbon dioxide	vol, %	14.8
Carbon monoxide	mg/Nm^3	258.5
Exhaust gas velocity	m/s	26.1
Exhaust gas volume (Stack conditions)	m^3/h	518465
Exhaust gas volume (Stack conditions)	m^3n, wet/h	359262
Exhaust gas volume (normal, dry)	m^3 n, dry/h	303792

Table 8: Emission characteristics in terms of CO, PM, SOx, NOx

Phases	*Measuring period (hrs)*	*Oxygen, %*	*Moisture, %*	*Carbon, %*	*CO at actual O_2 ref. (mg/m3 n, dry)*	*CO at 10% O_2restorage units, mg/m^3*	PM at actual O_2 ref. ($mg/m_{3n,dry}$)	PM at 10% O_2 ref. ($mg/m_{3n,dry}$)	SO_x at actual O_2 ref. ($mg_{3n,dry}$)	SO_x at 10% O_2 ref. ($mg/m_{3n,dry}$)	NO_x at actual O_2 ref. ($mg/m_{3n,dry}$)	NO_x at 10% O_2 ref. ($mg/m_{3n,dry}$)
Pre coprocessing	20:30 – 22:00	11.0	13.6	15.6	202	222.4	1.92	2.11	148	16295	1564	1722
	06.:30 – 08.00	10.2	14.8	15.8	338	344.3	3.35	3.41	107	109	1608	1638.1
	15:00 – 16:30	10.0	13.9	15.8	267	267.0	1.95	1.95	106	106	1419	1419.5
Coprocessing	08:00 – 09.30	10.2	15.5	17.2	258	262.8	1.88	1.92	94	95.8	1472	1499.5
	17:30 19:00	10.4	14.2	18.2	202	209.7	2.45	2.54	80	83.1	1414	1467.9
	00:30 – 02:00	10.4	14.4	14.2	331	343.6	1.49	1.55	107	111.1	1543	1601.8
Post coprocessing	17:00 – 18:30	10.8	16.1	13.2	300	323.8	2.24	2.42	81	87.4	1508	1627.5
	08:00 – 09.30	10.2	15.2	14.4	222	226.2	1.42	1.45	105	107	1608	1638.1
	13:30 – 15:00	10.2	15.8	14.6	206	209.9	3.39	3.45	84	85.6	1564	1593.2

Table 9: Emission levels of hydrogen halides

Phase	*Time, hrs*	*HCL at actual O_2 ref. ($mg/m^3_{n,dry}$)*	*HCL at 10% O_2 ref. ($mg/m^3_{n,dry}$)*	*HF at actual O_2 ref. ($mg/m^3_{n,dry}$)*	*HF at 10% O_2 ref. ($mg/m^3_{n,dry}$)*	*HBr at actual O_2 ref. ($mg/m^3_{n,dry}$)*	*HBr at 10% O_2 ref. ($mg/m^3_{n,dry}$)*
Pre co-processing	20:30 – 22:00	ND	ND	ND	ND	ND	ND
	06:30 – 80:00	ND	ND	ND	ND	ND	ND
	15:00 – 16:30	ND	ND	ND	ND	ND	ND
Co-processing	08:00 – 09.30	1.70	1.73	ND	ND	ND	ND
	17:30 – 19:00	ND	ND	ND	ND	ND	ND
	00:30 – 02:00	ND	ND	ND	ND	ND	ND
Post co-processing	17:00 – 18:30	ND	ND	ND	ND	ND	ND
	08:00 – 09:30	ND	ND	5.46	5.56	ND	ND
	13:30 – 15:00	ND	ND	ND	ND	ND	ND

Table 10: Emission levels of ammonia, mercury and benzene

Phase	*Time, hrs*	*NH3 at actual O_2 ref. ($mg/m^3_{n,dry}$)*	*NH3 10% O_2 ref. ($mg/m^3_{n,dry}$)*	*Hg at actual O_2 ref. ($\mu g/m^3_{n,dry}$)*	*Hg at 10% O_2 ref. ($\mu g/m^3_{n,dry}$)*	*C_6H_6 at actual O_2 ref. ($mg/m^3_{n,dry}$)*	*C_6H_6 at 10% O_2 ref. ($mg/m^3_{n,dry}$)*
Pre Co-processing	20:30 – 22:00	ND	ND	2.16	2.38	ND	ND
	06:30 – 08:00	ND	ND	ND	ND	ND	ND
	15:00 – 16:30	ND	ND	5.07	5.07	ND	ND
Co-processing	08:00 – 09:30	ND	ND	10.63	10.83	ND	ND
	17:30 – 19:00	ND	ND	3.31	3.44	ND	ND
	0:30 – 02:00	ND	ND	4.12	4.28	ND	ND
Post co-processing	17:00 – 18:30	ND	ND	4.18	4.51	ND	ND
	08:00 – 09:30	ND	ND	ND	ND	ND	ND
	13:30 – 15:00	ND	ND	3.13	3.19	ND	ND

Table 11: Emission level of total organic carbon

Phase	*Time, hrs*	*NH3 at actual O_2 ref. ($mg/m^3_{n,dry}$)*	*NH3 10% O_2 ref. ($mg/m^3_{n,dry}$)*	*Hg at actual O_2 ref. ($\mu g/m^3_{n,dry}$)*
Pre Co-processing	24 hrs	10.4	3.11	3.23
Co-processing	24 hrs	10.2	3.42	3.48
Post co-processing	24 hrs	10.4	2.86	2.97

Table 12: Metals and metalloids in the emissions prior to FRP co-processing

Metals	*Non-filterable (gaseous) ($\mu g/m^3_{n,dry}$)*	*Particule-bound (particles $\mu g/m^3_{n,dry}$)*	*Total ($\mu g/m^3_{n,dry}$)*	*Total @ 10, % O_2 ($\mu g/m^3_{n,dry}$)*
Antimony	ND	5.7	5.7	6.15
Arsenic	ND	ND	ND	ND
Cadmium	ND	ND	ND	ND
Chromium	ND	ND	ND	ND
Cobalt	ND	ND	ND	ND
Copper	ND	ND	ND	ND
Lead	ND	ND	ND	ND
Manganese	8.33	ND	8.33	8.99
Nickel	ND	ND	ND	ND
Vanadium	ND	ND	ND	ND
Zinc	ND	ND	ND	ND
Tin	204.74	25.85	230.59	248.85
Selenium	ND	ND	ND	ND
Aluminum	5.61	178.36	183.97	198.54
Thallium	ND	ND	ND	ND

Table 13: Metals and metalloids in the emissions during FRP co-processing

Metals	*Non-filterable (gaseous) ($\mu g/m^3_{n,dry}$)*	*Particule-bound (particles $\mu g/m^3_{n,dry}$)*	*Total ($\mu g/m^3_{n,dry}$)*	*Total @ 10, % O_2 ($\mu g/m^3_{n,dry}$)*
Antimony	ND	ND	ND	ND
Arsenic	ND	ND	ND	ND
Cadmium	ND	ND	ND	ND
Chromium	ND	ND	ND	ND
Cobalt	ND	ND	ND	ND
Copper	6.83	ND	6.83	6.96
Lead	ND	ND	ND	ND
Manganese	3.50	ND	3.50	3.57
Nickel	3.22	ND	3.22	3.28
Vanadium	ND	ND	ND	ND
Zinc	10.97	ND	10.97	11.18
Tin	179.0	10.11	189.11	192.64
Selenium	ND	ND	ND	ND
Aluminum	23.48	15.44	38.92	39.65
Thallium	ND	ND	ND	ND

Table 14: Metals and metalloids in the emissions after FRP co-processing

Metals	*Non-filterable (gaseous) ($\mu g/m^3_{n,dry}$)*	*Particulate-bound (particles $\mu g/m^3_{n,dry}$)*	*Total ($\mu g/m^3_{n,dry}$)*	*Total @ 10, % O_2 ($\mu g/m^3_{n,dry}$)*
Antimony	ND	ND	ND	ND
Arsenic	ND	ND	ND	ND
Cadmium	ND	ND	ND	ND
Chromium	ND	ND	ND	ND
Cobalt	ND	ND	ND	ND
Copper	ND	ND	ND	ND
Lead	ND	ND	ND	ND
Manganese	ND	ND	ND	ND
Nickel	ND	ND	ND	ND
Vanadium	ND	ND	ND	ND
Zinc	ND	ND	ND	ND
Tin	6.66	133.48	140.14	151.24
Selenium	ND	ND	ND	ND
Aluminum	ND	8.92	8.92	9.63
Thallium	ND	ND	ND	ND

Table 15: Polyaromatichydrocordons (PAHs) in the emissions proior to the FRP coproessing

PAH	*Non-filtrable (gaseous) ($\mu g/m^3_{n,\,dry}$)*	*Particule-bound (particles) ($\mu g/m^3_{n,\,dry}$) ,,,,,*	*Total ($\mu g/m^3_{n,\,dry}$)*
Acenaphthylene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Acenaphthylene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Anthracene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Benzo (alpha) Anthrancene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Benzo (alpha) pyrene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Benzo (b) Fluoranthene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Benzo (g,h,i) perylene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Benzo (k) Fluoranthene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Chrysene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Dibenzo (a,h) anthracene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Fluoranthene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Fluorene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Indeno (1,2,3-cd) pyrene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Napthalene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Phenanthrene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND
Pyrene	ND (DL 5.0 µg/Nm^3)	ND (DL 5.0 µg/Nm^3)	ND

Table 16: Polyaromatichydrocordons (PAHs) in the emissions during the FRP coproessing

PAH	*Non-filtrable (gaseous) ($\mu g/m^3_{n,\,dry}$)*	*Particule-bound (particles) ($\mu g/m^3_{n,\,dry}$)*	*Total ($\mu g/m^3_{n,\,dry}$)*
Acenaphthylene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Acenaphthylene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Anthracene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (alpha) Anthrancene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (alpha) pyrene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (b) Fluoranthene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (g,h,i) perylene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (k) Fluoranthene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Chrysene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Dibenzo (a,h) anthracene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Fluoranthene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Fluorene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Indeno (1,2,3-cd) pyrene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Napthalene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Phenanthrene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Pyrene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND

Table 17: Polyaromatichydrocordons (PAHs) in the emissions after the FRP coproessing

PAH	*Non-filtrable (gaseous) ($\mu g/m_{3n,\ dry}$)*	*Particule-bound (particles) ($\mu g/m_{3n,\ dry}$)*	*Total ($\mu g/m_{3n,\ dry}$)*
Acenaphthylene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Acenaphthylene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Anthracene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (alpha) Anthrancene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (alpha) pyrene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (b) Fluoranthene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (g,h,i) perylene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Benzo (k) Fluoranthene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Chrysene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Dibenzo (a,h) anthracene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Fluoranthene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Fluorene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Indeno (1,2,3-cd) pyrene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Napthalene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Phenanthrene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND
Pyrene	ND (DL 5.0 µg/ Nm^3)	ND (DL 5.0 µg/ Nm^3)	ND

Table 18: Emission of dioxins/furans in the emissions prior to the FRP coprocessing

Congener	*Amount*	*I-TEF*	*I-TEQ (ng)*
2, 3, 7, 8-TCDF	0.013	0.1	0.0013
2, 3, 7, 8-TCDD	<0.0025	1	<0.0025
1,2,3,7,8-PeCDF	<0.0050	0.05	<0.00025
2,3,4,7,8-PeCDF	<0.0050	0.5	<0.0025
1,2,3,4,7,8-PeCDD	<0.0050	0.5	<0.0025
1,2,3,4,7,8-HxCDF	<0.0063	0.1	<0.00063
1,2,3,6,7,8-HxCDF	<0.0063	0.1	<0.00063
2,3,4,6,7,8-HxCDF	<0.0063	0.1	<0.00063
1,2,3,7,8,9-HxCDF	<0.0063	0.1	<0.00063
1,2,3,4,7,8-HxCDD	<0.0063	0.1	<0.00063
1,2,3,6,7,8-HxCDD	<0.0063	0.1	<0.00063
1,2,3,7,8,9-HxCDD	<0.0063	0.1	<0.00063
1,2,3,4,6,7,8-HpCDF	<0.025	0.01	<0.00025
1,2,3,4,6,7,8-HpCDF	<0.025	0.01	<0.00025
1,2,3,4,6,7,8-HpCDD	<0.025	0.01	<0.00025
OCDF	<0.13	0.001	<0.00013
OCDD	<0.13	0.001	<0.00013
TOTAL PCDD/PCDF			0.0013 – 0.014
TOTAL PCDD/PCDF (ng TEQ/Nm3)			0.003
TOTAL PCDD/PCDF (ng TEQ/Nm3)	At 10% O_2 Ref.		0.003

Table 19: Emission of dioxins/furans in the emissions during the FRP coprocessing

Congener	*Amount*	*I-TEF*	*I-TEQ (ng)*
2, 3, 7, 8-TCDF	0.023	0.1	0.0023
2, 3, 7, 8-TCDD	0.0069	1	0.0069
1,2,3,7,8-PeCDF	0.019	0.05	0.00095
2,3,4,7,8-PeCDF	0.024	0.5	0.012
1,2,3,4,7,8-PeCDD	<0.010	0.5	<0.0051
1,2,3,4,7,8-HxCDF	0.022	0.1	0.0022
1,2,3,6,7,8-HxCDF	0.013	0.1	0.0013
2,3,4,6,7,8-HxCDF	0.017	0.1	0.0017
1,2,3,7,8,9-HxCDF	<0.013	0.1	<0.0013
1,2,3,4,7,8-HxCDD	<0.013	0.1	0.0013
1,2,3,6,7,8-HxCDD	0.020	0.1	0.0020
1,2,3,7,8,9-HxCDD	<0.013	0.1	<0.0013
1,2,3,4,6,7,8-HpCDF	<0.051	0.01	<0.0051
1,2,3,4,6,7,8-HpCDF	<0.051	0.01	<0.0051
1,2,3,4,6,7,8-HpCDD	0.29	0.01	0.0029
OCDF	<0.25	0.001	<0.00025
OCDD	0.71	0.001	0.00071
TOTAL PCDD/PCDF			0.033 – 0.043
TOTAL PCDD/PCDF (ng TEQ/Nm3)			0.009
TOTAL PCDD/PCDF (ng TEQ/Nm3)	At 10% O_2 Ref.		0.009

Table 20: Emission of dioxins/furans in the emissions after the FRP coprocessing

Congener	*Amount*	*I-TEF*	*I-TEQ (ng)*
2, 3, 7, 8-TCDF	0.014	0.1	0.0014
2, 3, 7, 8-TCDD	<0.0036	1	<0.0036
1,2,3,7,8-PeCDF	<0.0050	0.05	<0.00025
2,3,4,7,8-PeCDF	<0.0050	0.5	<0.0025
1,2,3,4,7,8-PeCDD	<0.0050	0.5	<0.0025
1,2,3,4,7,8-HxCDF	<0.0063	0.1	<0.00063
1,2,3,6,7,8-HxCDF	<0.0063	0.1	<0.00063
2,3,4,6,7,8-HxCDF	<0.0063	0.1	<0.00063
1,2,3,7,8,9-HxCDF	<0.0063	0.1	<0.00063
1,2,3,4,7,8-HxCDD	<0.0063	0.1	<0.00063
1,2,3,6,7,8-HxCDD	<0.0063	0.1	<0.00063
1,2,3,7,8,9-HxCDD	<0.0063	0.1	<0.00063
1,2,3,4,6,7,8-HpCDF	<0.025	0.01	<0.00025
1,2,3,4,6,7,8-HpCDF	<0.025	0.01	<0.00025
1,2,3,4,6,7,8-HpCDD	<0.025	0.01	<0.00025
OCDF	<0.13	0.001	<0.00013
OCDD	<0.13	0.001	<0.00013
TOTAL PCDD/PCDF			0.0050 – 0.016
TOTAL PCDD/PCDF (ng TEQ/Nm3)			0.003
TOTAL PCDD/PCDF (ng TEQ/Nm3)	At 10% O_2 Ref.		0.003

Table 21: Metals and metalloids in the clinker before, during, and after FRP coprocessing

Element	*Pre-coprocessing of green mesh with resin*	*Coprocessing of green mesh with resin*	*Post coprocessing of green mesh with resin*
Antimony (mg/kg)	<5	<5	<5
Aresenic (mg/kg)	<1	<1	<1
Cadmium (mg/kg)	<1	<1	<1
Chromium (mg/kg)	<1	<1	<1
Cobalt (mg/kg)	16.48	17.85	15.53
Copper (mg/kg)	20.56	20.66	15.74
Lead (mg/kg)	21.43	11.77	11.59
Manganese (mg/kg)	707.21	665.64	577.94
Nickel (mg/kg)	38.22	46.63	42.30
Mercury (mg/kg)	<1	<1	<1
Thallium (mg/kg)	<1	<1	<1
Vanadium (mg/kg)	56.17	63.28	63.83
Zinc (mg/kg)	58.17	47.97	37.47
Tin (mg/kg)	<5	<5	<5
Selenium (mg/kg)	<1	<1	<1
Iron (%)	2.60	2.76	3.29

Table 22: Summary of the impact of FRP waste on emissions

Parameter	*Units*	*Limits as prescribed by CPCB*	*Measured stack emission during the trial*	*Change in emissions during co-processing with FRP waste*		
			Pre-coprocessing	*Sample 1*	*Sample 2*	*Sample 3*
Dioxin and furan	Ng TEQ/Nm^3	0.1	0.003	0.009	0.003	0.006
TOC	mgC/ Nm^3	20	3.23	3.48	2.97	0.25
HCl	mg/ Nm^3	50	-	0.58	-	0.58
HF	mg/ Nm^3	4	-		1.85	-
SO_2	mg/ Nm^3	200	125.98	96.63	93.32	(29.35)
PM	mg/ Nm^3	50	2.49	2.00	2.44	(0.49)
CO	mg/ Nm^3	100	277.91	272.04	253.25	(5.86)
Zn	mg/ Nm^3	N.A.	0.02	0.02	0.00	0.002
Sn	mg/ Nm^3	N.A.	0.22	0.18	0.16	(0.044)
Se	mg/ Nm^3	N.A.	-		0.00	-
Al	mg/ Nm^3	N.A.	0.11	0.03	0.03	(0.085)
HBr	mg/ Nm^3	N.A.	-	-	-	-
NH_3	mg/ Nm^3	N.A.	-	-	-	-
C_6H_6	mg/ Nm^3	N.A.	-	-	-	-
PAH	mg/ Nm^3	N.A.	-	-	-	-
NO_X	mg/ Nm^3	400	1,593	1,523	1,620	(69.96)
Mercury	mg/ Nm^3	0.05	0.002	0.006	0.003	0.004
Heavy Metals						
(Sb+As+Cr+Co+Cu +Pb+Mn+Ni+	mg/ Nm^3	0.5	0.019	0.015	0.007	(0.004)
Tl+V						
Cd and Tl	mg/ Nm^3	0.05	-	-	-	-

Table 23: Characteristics of the cement

Characteristics	*Unit*	*The BIS standard 8112: 1989*	*Phase*		
			Pre coprocessing	*Coprocessing*	*Post coprocessing*
CaO	%	-	46.7	47.6	47.4
SO_3	%	3 (max)	2.5	2.5	2.55
Fineness	M2/Kg	225 (min)	390.5	390.5	388.5
Soundness	LC (mm)	10 (max)	1	2	1.5
	A.C.(%)	0.8 (max)	0.02	0.02	0.015
Setting Time	Initial	30 (min)	122.5	135	135
	Final	600 (max)	212.5	215	217.5
Residue in	90 m	-	1.3	1.6	1.6
	45 m	-	11.4	11.6	11.8
Compressive strength in	1-Day	-	16	15.5	15.1
	3-Days	23 (min)	27.6	25.7	25.75
MPa	7-Days	33 (min)	38.05	34.9	34.6

References:

[1] Abbasi, T., and Abbasi, S.A., (2010), *Pollution Control, Climate Change and Industrial Disasters*, Discovery Publishing House, New Delhi viii+301 pages.

[2] Abbasi, T., and Abbasi, S.A., (2018). PerspectiveinPollutionControl and Sustainable Development, Discovering publishing house, press.

[3] Abbasi, T., Ramasamy, E.V., Khan, F.I., and Abbasi, S. A., (2013). *Regional EIA and Risk Assessment in a Fast Developing Country*, Nova Science, New York, x+433 pages; ISBN 978-1-61942-234-6.

[4] Khan F. I., and Abbasi S.A., (1998), *Techniques and methodologies for risk analysis in chemical process industries.* Discovery Publishing House New Delhi; ix + 364 Pages.

[5] Laskar, T., Berger, E., Zauderer, B.A., Margutti, R., Soderberg, A.M., Chakraborti, S., Lunnan, R., Chornock, R., Chandra, P. and Ray, A., (2013). A reverse shock in GRB 130427A. *The Astrophysical Journal*, *776*(2), p.119.

[6] Marsh, G. (2001). Facing up to the recycling challenge, *Reinforced Plastics*, 45, (6), 22-26.

[7] Ramesh, N., (2009). Studies towards environmentally compatible disposal of fiber reinforced plastic waste, MTech thesis, Pondicherry University, 93 pages.

[8] Sarkar, C., and Abbasi, S.A., (2006). *QUALIDEX:* a virtual instrument for continuous monitoring of water quality indices, *Environmental Monitoring and Assessment (Kluwer),119,* 201-231.

[9] Subramaniaprasad, C.K., dkk, (2015). Influence of Embedded Waste-Plastic Fiber on the Improvement of the Tensile Sterength of Stabilized Mud Masonry Block, *Journal of Material in Civil Engineering ASCE*, Vol. 27, No. 7.