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Study of Technical and Engineering Aspects of the Existing Venturi Scrubber System for Effectiveness in a Plant

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Abstract

Coke calcining plant generates significant amount of particulate matter and gases from exhaust streams causing respiratory health issues as well as environmental impact. In order to control its implications, proper inspection and maintenance of emission control technologies plays vital role. The present study reviews air pollution issues related to calcine pet coke industry and through analysis of indoor and outdoor air quality assessment from CPC plant and its implications over nearby housing settlements at different working capacities of the plant. Upon careful investigation the study recommended mitigation measures to be adopted such as regular maintenance of cyclone separator and bag filters as well as rearrangement of loading warehouse area, increasing green cover with strategic planning, etc.

Keywords: *Emission Control Strategies, Air Quality, Particulate Matter, Air Pollution Mitigation*

1.0 Introduction

1.1 The Plant Description

The calcining plant utilizes green pet coke, which is preheated to remove moisture. This preheated pet coke is then fed into a rotary kiln with a capacity of 200 TPD, equipped with a secondary fan and a shell-mounted tertiary air fan. The exhaust gases from the rotary kiln are directed to an incinerator to ensure complete combustion of any unburnt hydrocarbons. The plant currently consists of two spray towers and a venturi scrubber followed by a cyclone, with one of each serving as a standby unit. This setup allows the gas to be vented through a 160 ft stack after passing through these pollution control devices. The equipment nozzles have a flow rate of 38 l/min. An induced draft fan at the end of the pollution control system has a capacity of 100,000 m³/hr. additionally, the water pumps supporting the equipment operate with a capacity of 7,500 m³/hr (Figure 1).

Previously, the plant was run at 66% capacity before the arrangements are made. In this report the plant was run at 66% capacity for measurement first and then as for testing the plant was run at 100% capacity before for the subsequent pollution measurement. The data was taken after about 12 hrs of running at 100% capacity to ensure a steady state condition and also to allow the pollutants to reach the surrounding habitation. It is required to be mentioned that the pollution data, reported here is dependent on the direction of air flow, flow velocity, humidity, temperature, atmospheric stability condition, etc., that vary with time.

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Figure 1. The Venturi scrubber setup.

2.0 A Review of Calcined Pet Coke (CPC) Production-Related Pollution Potential

Inhalation is the most prevalent concern, as black dust was observed to be blown off the stock piles and stack under extreme weather conditions, and was found to accumulate on residential properties in the vicinity of stockpiled pet coke. Airborne pet coke has the potential to exacerbate pre-existing lung and skin ailments, or may have additive or synergistic effects with other environmental toxins[1]. In places where road related dust and gas sources combine with several industrial sources of pollution and major transportation networks, there are instances of higher rates of lung and bronchus morbidity compared to the rest of the city[2]. Furthermore, the incidence of adult asthma is likely to be 50% higher in such places than places largely unaffected[3,5]. Studies on human pet coke exposure have been limited to coke oven workers, but this is not indicative of a residential exposure due to such factors as differences in coking operations in different industries and in various countries, and exposure to multiple toxins contributed by different sources[4]. The most prominent threat to urban environmental health is most likely as a fine PM. Ambient PM in fine and ultrafine ranges (aerodynamic diameter < 2.5µm, $PM_{2.5}$) is strongly associated with the pathogenesis of air pollution-associated systemic diseases[6-8]. Traffic-related $PM_{2.5}$ is a complex mixture of particles and gases from gasoline and diesel engines, together with dust from wear of road surfaces, tires, and brakes.

3.0 About the Study

The IIT Kharagpur team led by Prof. Jayanta Bhattacharya of IIT Kharagpur visited the plant for two days, 26-27 September 2018 and carefully measured the ambient air quality inside and outside the plant and near the housing settlements at plants running capacity of pre suggested 66% and its full capacity of 100%. The team utilized 3M's EVM equipment to measure the concentrations of particulate matter (PM_{10}, $PM_{2.5}$) and gaseous emissions (NO_x, CO_2, SO_x, and CO), which serve as indicators of ambient air quality, at different places in and around the plant wherever needed and possible. The various operational parameters, design, and capacity data were also noted as reported and found during the visit, and many other data were provided by the KPC management. The plant was in operation at 66% and 100% during the time of the visits to measure the ambient air quality at both the capacities. The management briefed the team on the various operational parameters of the plant.

3.1 Stack Emissions

Emissions from CPC manufacture include particulate matter, carbon monoxide (CO), organics, nitrogen oxides, sulphur compounds, Polycyclic Organic Matter (POM), and trace elements. US EPA, AP-42 provides the details of the contents: Carbon Disulphide, Carbonyl Sulphide, Methane, Nonmethane VOC Acetylene, Ethane, Ethylene, Propylene, Propane, Isobutane, n-Butane, n-Pentane, POM, and trace elements. The principal source of emissions in the thermal process is the main process vent. The vent stream consists of the reactor effluent and the quench water vapor. Gaseous emissions may vary considerably according to the grade of RPC being produced. Organic and CO emissions tend to be higher for small particle production, corresponding with the lower yields obtained. Sulphur compound emissions are a function of the feed sulphur content.

3.2 Objective

Analysis of ambient air quality inside and outside the plant and near the housing settlements in the downwind direction at plants running capacity of 66% and 100%.

3.3 Materials and Methods

3.3.1 Data Made Available to the Team

During the visit, the team were supplied with the plant by the management as:

- Air pollution equipment material – Mild steel (inside brick lining is provided in wet scrubber).
- Rotary kiln and combustion chamber material – IS2002 boiler grade steel.

Figure 2. EVM 7 (3M).

Figure 3. Field visit and measurement by team.

- RPC to CPC Conversion ratio – 1.22.
- Available ID fan capacity – 1, 00,000 m^3/hr.
- Available water supply pump capacity – 7500 l/hr.
- Rated plant production capacity – 200 tonne/day.
- Temperature inside rotary kiln – 900°C.
- Height of the stack – 160 ft.

3.3.2 The Measuring Equipment

The EVM-7 is a compact device that monitors both particulate matter and air quality. By integrating the functions of three separate instruments, the EVM-7 reduces the overall cost of ownership. This robust and user-friendly model offers simultaneous monitoring of particulate mass concentrations (0.1-10 μm), specific volatile organic compounds, selected toxic gases, carbon dioxide, relative humidity, and temperature.

1.3.3 Method of Measurement

EVM 7 equipment is fitted with SOx and NOx sensors alternatively with simultaneous measurement of the particulate matter concentrations of $PM_{2.5}$ and PM_{10} at various locations in and around the plant premises wherever found feasible and needed. All the readings are taken with the equipment when placed at a nominal height of 1m from the ground surface.

Table 1. Characteristics of Calcined Petroleum Coke (CPC) and Raw Petroleum Coke (RPC)

S. No.	Characteristics	CPC	RPC
1	Moisture (%)	0.29	6.79
2	Sulphur (%)	2.30	2.35
3	Volatile Matter (%)	0.25	11.25
4	Ash (%)	0.34	0.22
5	Fixed Carbon (%)	99.12	81.74
6	Nickel (ppm)	210	194
7	Vanadium (ppm)	370	310
8	Silicon (ppm)	478	420
9	Iron (ppm)	270	220

Table 2. Spot Particulate Matter and Gaseous Emissions Compared to Standards inside the Plant Premises but not within the Plant

		66% Capacity				100% Capacity			
S. No	**Location**	**$PM_{2.5}$ (μg/m³)**	**PM_{10} (μg/m³)**	**SO_x (μg/m³)**	**NO_x (μg/m³)**	**$PM_{2.5}$ (μg/m³)**	**PM_{10} (μg/m³)**	**SO_x (μg/m³)**	**NO_x (μg/m³)**
1	GATE No. 1	20	81	11.5	12.1	30	**123**	20.3	13.6
2	Near RPC stack	20	89	14.2	16.3	34	**135**	16.2	20.8
3	Near shiv temple(inside plant)	43	80	9.6	9.3	60	57	10.1	13.6
4	Near water reservoir	25	76	13.5	15.8	32	64	15.5	17.2
5	Near HT Tower (Behind CPC silo)	15	55	14.8	10.2	31	65	15.2	11.7
6	Near cooling stack	21	50	8.3	6.2	32	76	13.1	11.2
7	Near stack attached to rotary kiln after venturi scrubber and cyclone	18	90	30	28	27	**136**	45	42
	AAQ Standard	**60**	**100**	**80**	**80**	**60**	**100**	**80**	**80**

Wind direction is southwest on both the days of measurement (26th and 27th September) and the weather condition is sunny on 26th and overcast on 27th of September.

4.0 Results and Discussions

The flue gas emitted from the rotary kiln consequent to the calcination of coke process comprises particulate matter, volatile fraction, and gaseous pollutants including SO_2. The characteristics of Calcined Petroleum Coke (CPC) and Raw Petroleum Coke (RPC) as provided by the plant authorities are as follows:

Table 1 shows the loss of moisture, volatile matter and release of Sulphur which can be in the form of SO_2 along with some other oxidized gaseous emissions like NO_x, CO, and CO_2 released from volatiles. According to the mass balance diagrams obtained from plant authorities during an inspection at an inspection at full plant capacity with an RPC of 10.15 T/hr, flue gas generation from the kiln is 18665 Nm^3/hr, with a dust load of 782 kg/hr. The combustion chamber following the rotary kiln enables the burning of incompletely combusted and residual CO and other carbon particles aided by atmospheric air at 900°C, increasing the gas volume to 31,590 NM^3/hr and reducing the dust load to 38.5 kg/hr at the outlet of the combustion chamber, at the inlet of the air pollution control equipment. The reduction in dust mass is offset by a rise in gaseous emissions, indicating complete combustion of the converted particulate matter.

The air pollution control equipment comprises of a wet scrubber followed by venturi scrubber and a static cyclone in a series in the same order. The flue gas is allowed to pass through the air pollution equipment in counter current water stream to remove the particulate matter and to an extent, some gaseous emissions. The water current along with the particulate matter removal, also serves as a coolant reducing the temperature of the flue gas from 900°C, before it is released from the stack of 160ft height.

From the ambient air quality measurements inside the plant premises at 66% and 100% capacity taken at 7 different locations are as shown in the table 2. The average concentrations of particulate matter $PM_{2.5}$ and PM_{10} are in the range of 15 to 43 µg/Nm^3 and 50 to 90 µg/Nm^3 (at 66% capacity) and 27 to 60 µg/Nm^3 and 57 to 136 µg/Nm^3 (at 100% capacity). The particulate matter emissions at 66% capacity of plant operation are within the limits of prescribed standards of 60 and 100 µg/Nm^3. At 100% capacity of plant operation, at 3 out of 7 places measurement, the concentrations of PM_{10} are not

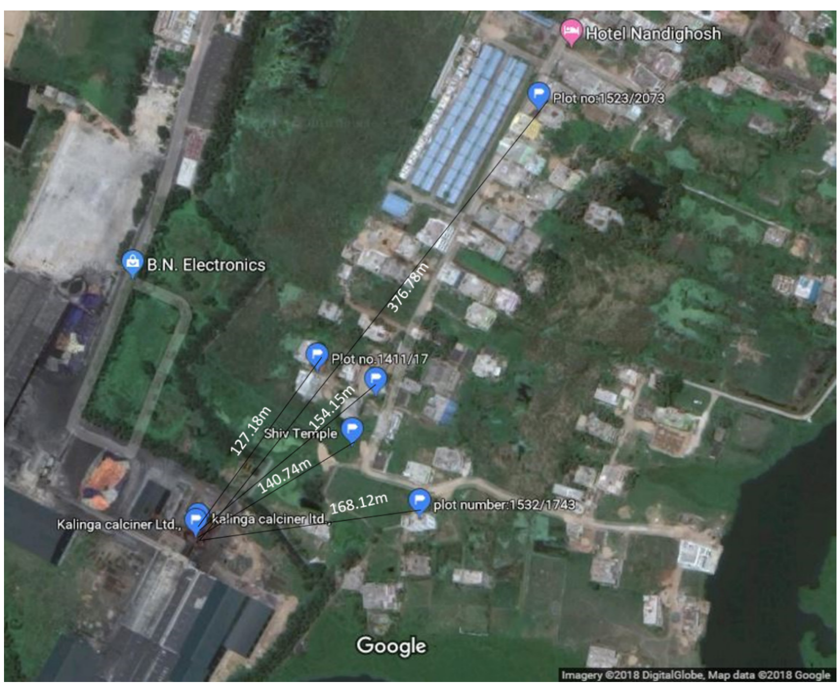

Figure 4. Places of air quality measurement downwind of the plant.

Table 3. Spot Particulate Matter Concentration and Gaseous Emissions Compared to Standards Outside the Plant Premises

	66% Capacity				100% Capacity			
Location	**PM** $_{2.5\ (\mu g/m^3)}$	**PM** $_{10\ (\mu g/m^3)}$	**SO** $_{x\ (\mu g/m^3)}$	**NO** $_{x\ (\mu g/m^3)}$	**PM** $_{2.5\ (\mu g/m^3)}$	**PM** $_{10\ (\mu g/m^3)}$	**SO** $_{x\ (\mu g/m^3)}$	**NO** $_{x\ (\mu g/m^3)}$
Near Lord Shiva temple (20.30:86.62)	38	57	11.5	10.1	58	86	17.4	15.3
House of Ranjan Kumar Sahoo (Plot no.:1532/1743)								
Ground floor	34	41	12.1	9.4	51	62	18.3	14.2
First floor	34	57	10.6	9.6	51	88	16.1	14.5
2nd floor	27	48	9.4	10.8	41	73	14.2	16.4
House of Kanhu Mallik (Plot no.1421)								
Ground floor	31	51	19.5	16.8	47	77	29.5	25.5
2nd floor	22	36	17.4	13.9	33	54	26.4	21.1
House of MD Idrish (Plot no.1411/17)								
Ground floor	20	34	14.2	12.8	30	51	21.5	19.4
2nd floor	19	31	13.7	10.5	32	47	20.8	15.9
House of MD Hassan (Plot no:1523/2073)								
Ground floor	21	32	11.5	10.2	32	48	17.4	15.5
1st floor	18	31	13.1	10.7	27	47	19.8	16.2
Standard	**60**	**100**	**80**	**80**	**60**	**100**	**80**	**80**

in compliance with the standards and they are above the prescribed limits.

The concentrations of SO_x and NO_x inside the plant premises are within the prescribed national ambient air quality standards of 80 and 80 µg/Nm^3.[9]

The concentrations of particulate matter ($PM_{2.5}$ and PM_{10}) and gaseous emissions (So_x and NO_x) measured at 5 places outside the plant in the downwind direction are all within the limits of prescribed national ambient air quality standards at both 66% and 100% running capacity of the plant (table 3). But the caveat is that they are high and less but close to the standards.

5.0 Sources of Fugitive Dust Contributors other than the Calciner Plant

Main Road Dust: KCL plant at Pardeep is located just by the side of the main road leading to Pardeep from Chandikhol and it has very high traffic almost all times of the year. Around KCL plant there are banks, housing, hotels, small factories that have come after the plant has come up. The growth is unregulated, and will be unsustainable in the long run. The Paradeep-Chandikhol Road has huge traffic and by an estimation produces Fugitive Road Dust (FRD) between 11,000-25000 kg day^{-1} km^{-1} of particulate matter in various times of the year. The fugitive road dust comprises of road silt dust and tailpipe emissions, of sizes between PM 1-10 micron and more. It is found that fugitive road dust emissions accounts for 20–35% of vehicle tailpipe emissions that are likely to be similar the dusts from calcination of CPC. Predicted atmospheric concentrations and deposition rates can therefore be either over- or under-estimated by several orders of magnitude. Inadequate consideration is often given to temporal and spatial variation in factors that govern the release of dust sized particles; as for example, bulk pore water and humidity, texture, mineralogy and cohesion. At most industrial sites, heavy vehicle movement and material handling also can cause intermittent releases of significant quantities of dust. The wind directions and velocity also undergo changes, sending the dust around and contributing to dust accumulations in the surrounding habitats, including the houses near the KCL plant. Moreover, it was observed that other plants, notably the plant by Carbon plant which is at a distance of 1-1.5 Km, can also contribute to the CPC dust in the habitations and the localities around the KCL plant. In nutshell, it can be said that the significant contributors to dust in the locality around are from the Chandikhol- Paradeep Road, KCL plant, numerous small utilities as well as the other Carbon Plant. There can be numerous other minor contributors like burning wood and coal, tyres, etc. at various times that increase pollutant levels.

The high silt content over the paved roads in Paradeep is partially caused by the poorly designed or maintained road drainage systems, which are inefficient at collecting rain water, thus causing water to pool on the road surface. When the rain water evaporates, a considerable amount of mineral dust is left on the road surface. Therefore, improving the drainage systems for paved roads is of great importance for lowering dust content on road surfaces. To estimate these amounts of emission using a relatively simple equation such as that provided in AP 42 (US EPA, 1995 US Environmental Protection Agency, AP-42, fifth ed. Compilation of Air Pollutant Emission Factors, Volume I, Stationary Point and Area Sources. Published online at http://www.epa.gov/ttn/chief/ap42/index.html.):

$$E = A \times EF \times (1 - ER / 100)$$

Where *A* is the activity rate, *EF* is an emission factor quantifying the amount of dust released during a given event or activity, and *ER* is the efficiency (%) of any control measures in effect. For industrial sites affected by wind erosion, *A* can be taken as the number of emission events/activities occurring within a given period of time. In the stock pile area(s) the dust generated will be governed by either the frequency of disturbance of the material (loading and unloading), or the number of heat and wind cumulative events in a given time period that exceed the threshold for particle entrainment. For supply-limited materials it is often assumed that all erodible particles are removed in a single wind event, so that no subsequent dust emission occurs until the surface is disturbed again.

6.0 Inferences and Recommendations

6.1 Inferences

1. The major contributors to dust inside the plant is obviously the plant but outside the plants, the major contributors are KCL plant, Road silt dust and tailpipe emissions and the other Carbon Plant and

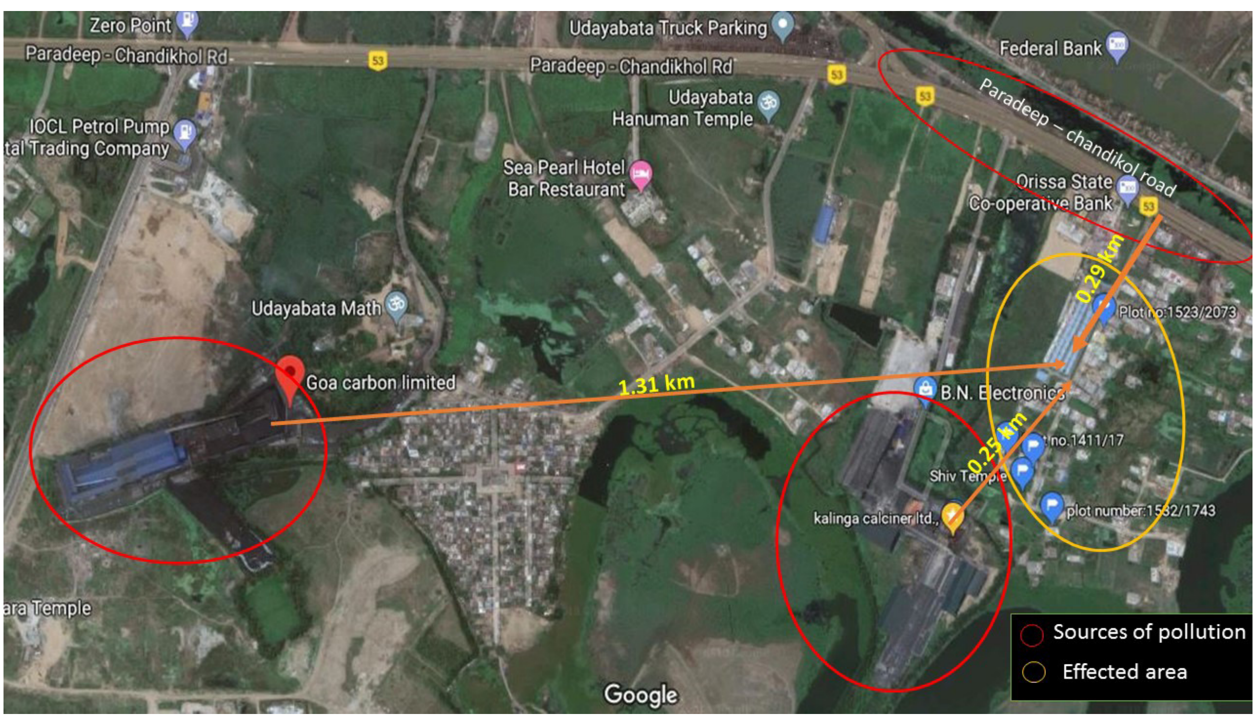

Figure 5. Major Fugitive Dust sources to the locality studied from the RPC Stockpile Go down and open areas.

other contributors. Finding out the contributions of each was beyond the scope of the study.

2. Since the plant came before the habitation around, a green buffer zone around would have been ideal. Sparse green cover exists but that is not sufficient.
3. The pollution level is high inside the premises of the plant at 100% running capacity.
4. The concentrations of SO_x and NO_x inside the plant, at the time of the study premises are within the prescribed national ambient air quality standards of 80 and 80 µg/Nm^3.
5. On outside of the plant, at the housing areas concentration of particulate matter is close but less than the upper limit of AAQ standard.
6. At 104.74m from the stack of the KCL plant concentration of particulate matter was higher but gradually reduced with distance. Though this is a temporal data, it can be said that airborne fugitive dust has been contributed from material handling areas like stockpiles, truck transport as well as laden dust on the surface.

A. Recommendations for the Plant from the Study

1. All pollution control equipment must be operated continuously and periodic maintenance of the equipment should be done. Bag filters, cyclones, and similar devices should be cleaned routinely, and maintenance records must be maintained. If any pollution control equipment is malfunctioning or under repair, the plant should not be operated.
2. During the visit, with all pollution control equipment in operation and the plant running at full capacity, the concentration of pollutants was observed to be within the permissible limits.
3. The people residing on the outskirts of the plant have a common complaint that the plant does not run the pollution control equipment regularly and particularly during night time they are stopped. The plant must keep its records clear about running the plant and pollution control equipment at all times of operation.
4. Concrete floors should be routinely cleaned using mobile vacuum cleaners, and water sprinklers should be activated at regular intervals within the plant premises during dry periods to minimize fugitive emissions.
5. RPC material is fine and combustible, and the stock shed is fully open on one side. To minimize fugitive dust, RPC and CPC should be stored in a closed area with doors that can be opened when necessary. The handling process generates significant dust. Fugitive dust emissions can be controlled through various strategies, including chemical stabilization with surfactants, planting vegetation, constructing windbreaks, and watering. While chemical treatments offer longer-lasting dust suppression, they can be expensive, harmful to plants and animals, and may contaminate the material. Watering remains the most common and cost-effective method.
6. The loading area shed/warehouse should be enclosed on all sides during regular operations and only opened during stockpile preparation. This approach will significantly reduce fugitive dust emissions from the stockpile area. Once covered, the space should be well-lit and properly ventilated.
7. Rooftop ventilators, such as wind-driven ventilators, should be utilized.
8. All stationary equipment areas for CPC and RPC loading or transferring should remain covered during material transfer at all times. Moving material handling equipment, such as motors and belt sections, must be properly fenced. Workers in this area should receive regular training on safe operating practices.
9. There should be a continuous tree plantation with a minimum width of 6 meters around the entire truck loading, waiting, and queuing areas.
10. Water sprinkling and floor dust cleaning should also be done in the truck bays.
11. Personal Protective Equipment (PPE) must be provided to workers in any area where airborne dust or other hazards are present.
12. The plant must implement an emergency management and disaster response plan to ensure safety.
13. The plant must adopt a zero effluent water discharge strategy across all operational areas and conduct regular audits of water sources and their structural integrity for optimal benefit.
14. All personnel road and passage areas there should be a minimum of 3m wide green barrier between the people and the dusty areas in all places, as much as possible.
15. Workers must be provided with Personal Protective Equipment (PPE) and required to use it consistently.

Failure to adhere to this requirement may result in a reduction of attendance records as a penalty.

It was seen during the visit that the for both ordinary men and women doing routine and casual works, contract workers possibly, were sleeping and resting on the floor; there is no rest room as well as no wash room. There should be separate rest and wash rooms with drinking water facilities for the men and women (Factories Act 1948 provisions).

16. Proper rest with wash room must be provided to the workers both for female and male workers separately.
17. An audit must be done by the management to see the extent of large tree vegetation in the total plant area. This should be mandatorily not less than 33% and this green cover should not include soft green areas like gardening and shubbing, Vegetation cover

Figure 6. (a) Women workers resting in the Open, exposed to dust. (b) Thin green barrier between the resting place and the road and truck waiting bay. This area can be selectively greened to reduce the exposure to the workers and passers-by.

has to be increased around the KCL owned land (also please see figure in the text).

18. Vegetative cover protects surface soils from erosion and reduces ground-level wind velocity, thus reducing the potential for dust to become airborne. Therefore, increasing the vegetation cover on the KCL owned area will also help to reduce dust concentrations as well as be useful as some heat sink[12-15].

19. It is reported that the shape of leaves of Mango (*Mangifera indica*), Gulmohar (*Delonix regia*), Ashoka (*Polyalthea longifolia*), Pongamia (*Derris indica*) and Umbrella (*Thespepsia populnea*) trees capture higher amounts of dust as compared to other neighbouring plants[10]. It is reported that the leaves with complex shapes and large circumference area reported to be collecting particles more efficiently[11]. Many trees like Neem (*Azadirchta indica*), Silk cotton (*Bombax ceiba*), Indian laburnum (*Cassia fistula* and *C. siamea*), Gulmohar (*Delonix regia*), Pipal (*Ficus religiosa*), Jacaranda (*Jacaranda mimosifolia*), Indian lilac (*Lagerstroemia indica*), Temple or Pagoda tree

Figure 7. Existing vegetation area around the Plant during the September visit.

Figure 8. A 25 ft (8m) width green cover of large and long plants having 1 tree in every 6 m^2 is proposed to arrest the fugitive dust from the plant to spread out to the surrounding (please see the green belt around).

(Plumeria rubra and P. alba), Java plum (*Syzygium cumini*) and several other roadside and street trees have been found to be more efficient in industrial air pollution control.

20. The RPC material when airborne in a certain minimum concentration can be explosive. The RPC storage area should have safety precautions like non-smoking environment, no transformer/substation inside and major switches should be outside the four walls. The danger is pronounced during hot dry spell days. The RPC and CPC should be fully under cover and the floors by the sides should be continuously cleaned. There must have to be fire hydrant and other proper types of fire extinguishers in proper accessible place to control fire, if takes place at any time.
21. Though not reported to the team, globally imported RPC is having increasing concentration of sulphur as the days go by; so KCL may consider a scrubber unit depending on its experience of sulphur in the pet coke.

7.0 Acknowledgement

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8.0 References

1. National ambient air quality standards, CPCB report, 2009.
2. Joseph A. Caruso, et al Petroleum Coke in the Urban Environment: A Review of Potential Health EffectsInt J Environ Res Public Health. 2015 Jun; 12(6): 6218–31.
3. Gupta R.S., Zhang X., Sharp L.K., Shannon J.J., Weiss K.B. The protective effect of community factors on childhood asthma. J. Allergy Clin. Immunol. 2009
4. Cohen A.J., Ross Anderson H., Ostro B., Pandey K.D., Krzyzanowski M., Künzli N., Gutschmidt K., Pope A., Romieu I., Samet J.M., et al. The global burden of disease due to outdoor air pollution. J. Toxicol. Environ. Health Pt. A. 2005; 68:1301–1307.
5. Raaschou-Nielsen O., Andersen Z.J., Beelen R., Samoli E., Stafoggia M., Weinmayr G., Hoffmann B., Fischer P., Nieuwenhuijsen M.J., Brunekreef B., et al. Air pollution and lung cancer incidence in 17 European cohorts: Prospective analyses from the European study of cohorts for air pollution effects (ESCAPE) Lancet Oncol. 2013; 14:813–22.
6. Brook R.D., Jerrett M., Brook J.R., Bard R.L., Finkelstein M.M. The relationship between diabetes mellitus and traffic-related air pollution. J. Occup. Environ. Med. 2008; 50:32–8.
7. Brunekreef B., Holgate S.T. Air pollution and health. Lancet. 2002; 360:1233–42.
8. Chen J.C., Schwartz J. Metabolic syndrome and inflammatory responses to long-term particulate air pollutants. Environ. Health Perspect. 2008; 116:612–7.
9. Pope C.A., Burnett R.T., Thurston G.D., Thun M.J., Calle E.E., Krewski D., Godleski J.J. Cardiovascular mortality and long-term exposure to particulate air pollution: Epidemiological evidence of general pathophysiological pathways of disease. Circulation. 2004; 109: 71–7.
10. Shetye, R. P., and S. B. Chaphekar. 1989. Some estimation on dust fall in the city of Bombay, using plants. Vol. 4: pp. 61-70. In: Progress in Ecology
11. Ingold, C. T. 1971. Fungal Spores. Clarendon Press, Oxford.
12. Maheshwari, J. K: The Flora of Delhi. Council of Scientific and Industrial Research, New Delhi (1963).
13. Oommanchan, M. The Flora of Bhopal (Angiosperms). J. K. Jain Brothers, Bhopal (1977).
14. Pokhriyal, T.C. and Subba Rao, B. K., Role of forests in mitigating air pollution. Indian For. 1986; 112: 573-582.
15. Chee, T. Y. and Ridwan, S.: Fast-growing species of trees suitable for urban roadside and shade planting. Malaysian For, 198; 47: 263-284.