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Design Of A De-Dusting System In A Cement Manufacturing Factory, A Case Study Of East Africa Portland Cement (EAPCC), Kenya

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Abstract - **East African Portland Cement (EAPCC) is located in Athi River town, a town predominated with cement and other manufacturing industries, in Kajiado County, Kenya. Much of the air pollution from this facility is that of the particulate matter (PM) that originate from most of its manufacturing processes** [1]**. Previous researches have shown that the PMs (PM2.5 and PM10) pose the greatest threat to human health as compared to any other pollutant hence the need for de-dusting systems. EAPCC as well as most cement manufacturing factories in this town employ conventional processes in their cement manufacturing processes which produce a lot of dust in the form of particulate matter (PM) to the environment posing health hazards to workers, the neighbouring community and the environment. The main uncontrolled source of the PMs in these cement facility is in its bag filling stations. To address this issue, this research designed, fabricated and tested a prototype De-dusting system. The BAM 1020 air sampler was used to measure the PM levels. The prototype, when operated with the de-dusting system ON, had a mean of 23.65 μg/m^3 for PM2 and 46.08 μg/m^3 for PM10 and when operated without had a mean of 163.73 μg/m^3 for PM2.5 and 299.05 μg/m^3 for PM10. It is, therefore, possible to contain this dust levels to within the internationally acceptable levels (World Health Organisation (WHO) and National Environment Management Authority (NEMA) air quality limits; permissible limits for PM2.5 and PM10 for 24 hour duration at Industrial areas are 75 μg/m^3 and 150 μg/m^3 respectively) and also the possibility of recovering the product through recirculation to the system. Based on the prototype results, a full scale factory de-dusting system design has been designed ready for execution, which, if implemented, will improve air Quality in Athi River and its environs. To sustain the air quality, regular environmental audit and monitoring practices by the industries and enhanced enforcement by sector regulators (NEMA and Directorate of Occupational Safety and Health Services (DOSHS)) to ensure compliance by all participants is also recommended.**

***Key words*-** **East Africa Portland Cement; Pollution; Particulate Matter; De-dusting System**

I. INTRODUCTION

Majority of cement factories in Kenya embrace conventional system of cement manufacture. The entire system is equipped with inbuilt, some efficient, de-dusting systems except at the bag loading section. In this section, rotary filling machines are used to fill cement into the bags. A bag is placed on a spout/nozzle which then fills the bag with cement by aid of vertical impellers or air type filling systems. Due to the design of the bag in a manner so as to relieve the filling pressure and insufficiency of efficient de-dusting systems at this location, a lot of dust is generated which is let free into the air. There is a lot of cement spillage at this section too. However, a Local Exhaust Ventilation System (LEVs) is placed at the discharge conveyor to help clean the already filled bags by reducing the levels of cement dust on their surfaces. The following diagram highlights the key sources of PMs in the cement manufacturing processes.

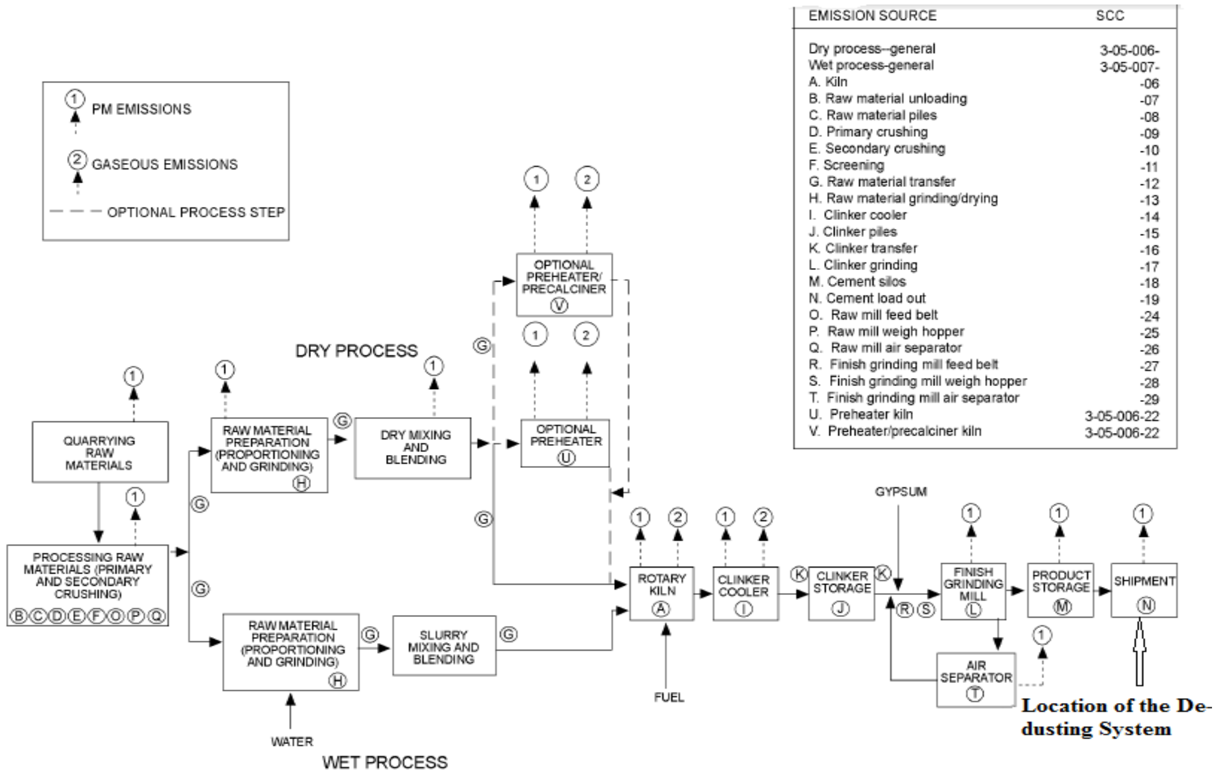

Fig. 1 Potential points of dust emission [2].

Cement dust particle sizes are within the respirable range and therefore exposure to them can cause numerous health hazards such as the onset of acute or chronic respiratory diseases, lung function impairment and respiratory function deficits [3]. Cement dust also causes allergies (such as mild rash, occupational asthma and severe skin ulcers which last for a life time) resulting from the hexavalent chromium in it. Other effects are such as eye irritation (redness, chemical burns or subsequent blindness), nose and throat irritation, choking, silicosis (lung disease), lung cancer and breathing difficulties.

Cement can cause ill health by skin contact, eye contact, or inhalation. Risk of injury depends on duration and level of exposure and individual sensitivity [4].

Occupational cement dust exposure increases the chances of developing pulmonary disorders, carcinogenesis, and liver abnormalities. It also causes tooth surface loss and increased intensity of periodontal disease that leads to destruction of tooth supporting tissues (periodontal ligament and alveolar bone), eventual exfoliation of teeth and gingival inflammation [5]. Other effects of cement dust are soiling of surfaces caused by falling dust, reduced visibility caused by suspended dust particles, interference of CO_2 exchange in plants and leaf injury [6].

The fly ash contains toxic substances, such as dibenzofuran and bibenzo-p-dioxane mixtures which interfere with the normal physiological development of agricultural crops [7].It also contains heavy metals like lead, nickel, chromium cobalt, and pollutants hazardous to the biotic environment, with impact on human, vegetation, ecosystems and animal health [8].

Loses of cement in a cement plant occur mainly through two ways:

i. Through leakages in the conveying ducts and
ii. As dust through bag filling and loading of trucks, ship, barge and rail cars.

Whereas leakages can be repaired through either welding or replacement of the associated ducts, losses through dust require specialized equipment to remove and recycle the dust as this reduces cement loss and the adverse effects of cement dust to the environment. Loading processes, however, have equipment like dustless loading spouts which fully address the problem.

Following are the commercially available de-dusting systems used with the bag filling machines (they are all tailored to suit specific design versions of filling machines).

i. Rotary Packer with Central De-dusting System (rotary filling machine) [9]
ii. Exhaust Hood Placed Around Bag Loading Nozzles (in-line filling machine) [10]
iii. Exhaust Hoppers below Entire Filling Station (in-line filling machine) [10]
iv. Dual-Nozzle Bagging System (rotary filling machine) [10]

This research, however, differs with the other systems in the following ways

i. The systems presented above are not compatible with the existing old generation rotary bag filling machines.

ii. Very expensive to modify them in order to suit into the older versions

iii. OASIS system is incapable of recycling the cement dust

II. MATERIALS AND METHODS

A. Prototype Design

Design calculations for single-hood prototype system are as follows (diagram and calculation sheet)

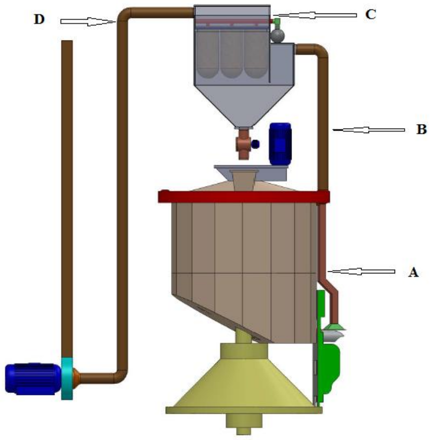

Fig 2 De-dusting system prototype

TABLE I: VELOCITY PRESSURE METHOD CALCULATION SHEET [11]

1.				**Identification of Duct section**			**A**	**B**	**C**	**D**	**E**
2.	T			Dry-bulb temperature							
3.	Q			Standard volumetric flow rate		m^3/s	0.086	0.086	0.086	0.086	0.086
4.	V_1			Minimum transport velocity		m/s	20	20		17	20
5.	m_{H2O}			Kg of water per min.		H_20/min					
6.	m_{da}			Kg of dry air per min.		Da/min					
7.	df			Density factor							
8.	Q_{act}			Actual volumetric flow rate		m^3/s					
9.	A_1			Target duct area	3 ÷ 4	m^2	0.0043	0.0043		0.0051	0.0043
10.	d			Selected duct diameter		m	0.08×0.045	0.065		0.065	0.08×0.045
11.	A			Selected duct area		m^2	0.0036	0.0033		0.0033	0.0036
12.	V_d			Duct velocity	3 ÷ 11	m/s	23.9	26.1		26.1	23.9
13.	VP_d			Duct velocity pressure		Pa	342.7	408.7		408.7	342.7
14.	h			Total heat	Branch balance						
15.	A_s	HOOD LOSSES	SLOT	Slot area		m^2					
16.	F_s	HOOD LOSSES	SLOT	Slot loss coefficient							
17.		HOOD LOSSES	SLOT	Acceleration factor							
18.	V_s	HOOD LOSSES	SLOT	Slot velocity	8 ÷ 15	m/s					
19.	VP_s	HOOD LOSSES	SLOT	Slot velocity pressure		Pa					
20.		HOOD LOSSES	SLOT	Slot loss in VP	16 + 17						
21.		HOOD LOSSES	SLOT	Slot static pressure	20 × 19	Pa					
22.	F_h	HOOD LOSSES		Duct entry coefficient			0.15				
23.		HOOD LOSSES		Acceleration factor		0 or 1	1.00				
24.		HOOD LOSSES		Duct entry loss in VP	22 + 23		1.15				
25.		HOOD LOSSES		Duct entry loss	24 × 13	Pa	394.11				
26.		HOOD LOSSES		Other losses		Pa					
27.	SP_h	HOOD LOSSES		Hood static pressure	21 + 25 + 26	Pa	394.11				
28.	L	DUCT LO		Straight duct length		m	0.888	1.185		3.334	1.838
29.	H_f	DUCT LO		Duct friction factor			0.906	0.944		0.944	0.906
30.		DUCT LO		Number of 90° elbows			1	1		2	
31.	F_{el}	DUCT LO		Elbow loss coefficient			0.13	0.13		0.13	
32.	F_{en}	DUCT LO		Branch entry coefficient							
33.		DUCT LO		Special fitting							

		S	coefficient							
34.	h_f	S	Duct friction loss in VP	28 × 29		0.805	1.119		3.147	1.665
35.		E	Elbow loss in VP	30 × 31		0.13	0.13		0.26	
36.		S	Branch entry loss in VP	32						
37.			Duct loss in VP	33 + 34 + 35 + 36		0.935	1.249		3.407	1.665
38.			Duct loss	37 × 13	Pa	320.42	510.47		1392.44	570.6
39.			Other losses		Pa			497.68		
40.	VP_r		Resultant velocity pressure		Pa					
41.			Loss from velocity increase	13 – 40 (if >0)	Pa					
42.			Duct pressure loss	27 + 38 + 39 + 41	Pa	714.53	510.47	497.68	1392.44	570.6
43.	SP_{gov}		Governing static pressure		Pa	714.53	714.53	1392.44	1392.44	714.53
44.	SP_{cum}		Cumulative static pressure		Pa	714.53	1225	1722.68	3115.12	3685.72
45.	Q_{corr}		Corrected volumetric flow rate		m^3/s	0	0	0	0	
46.	V_{corr}		Corrected velocity	45 ÷ 11	m/s	0	0	0	0	
47.	VP_{corr}		Corrected velocity pressure		Pa					

The design drawings for a single hood de-dusting system were as shown below:

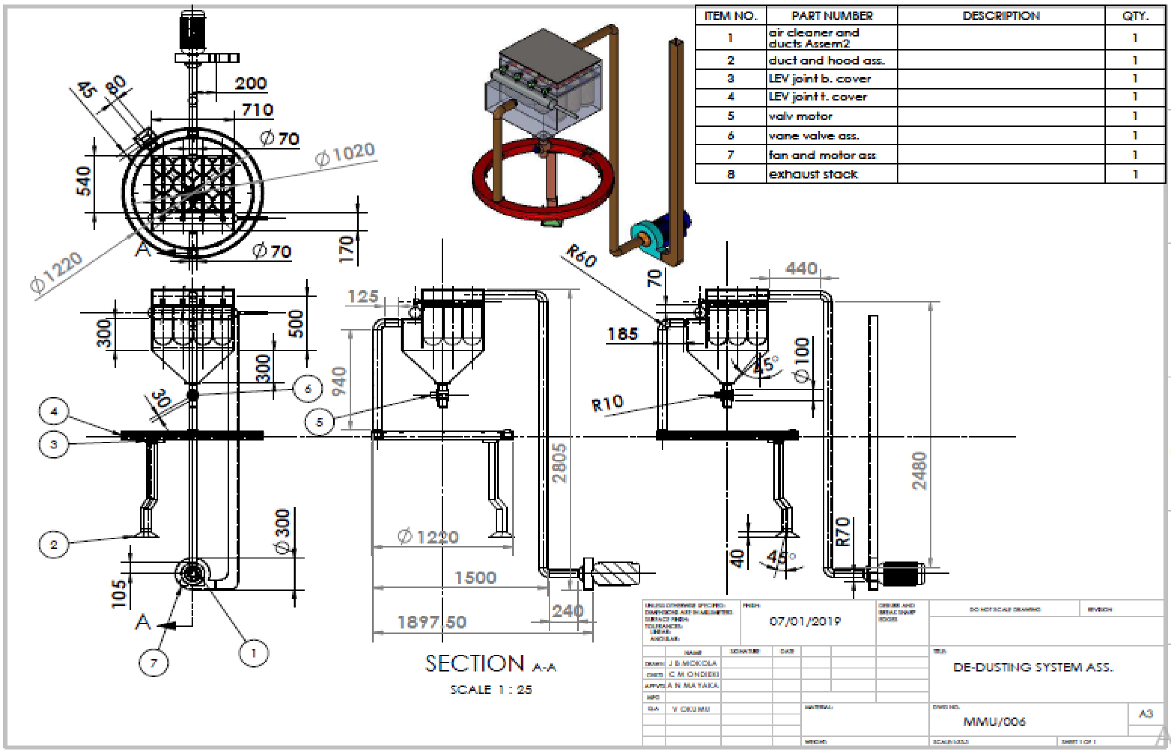

Fig 3. De-dusting System Assembly

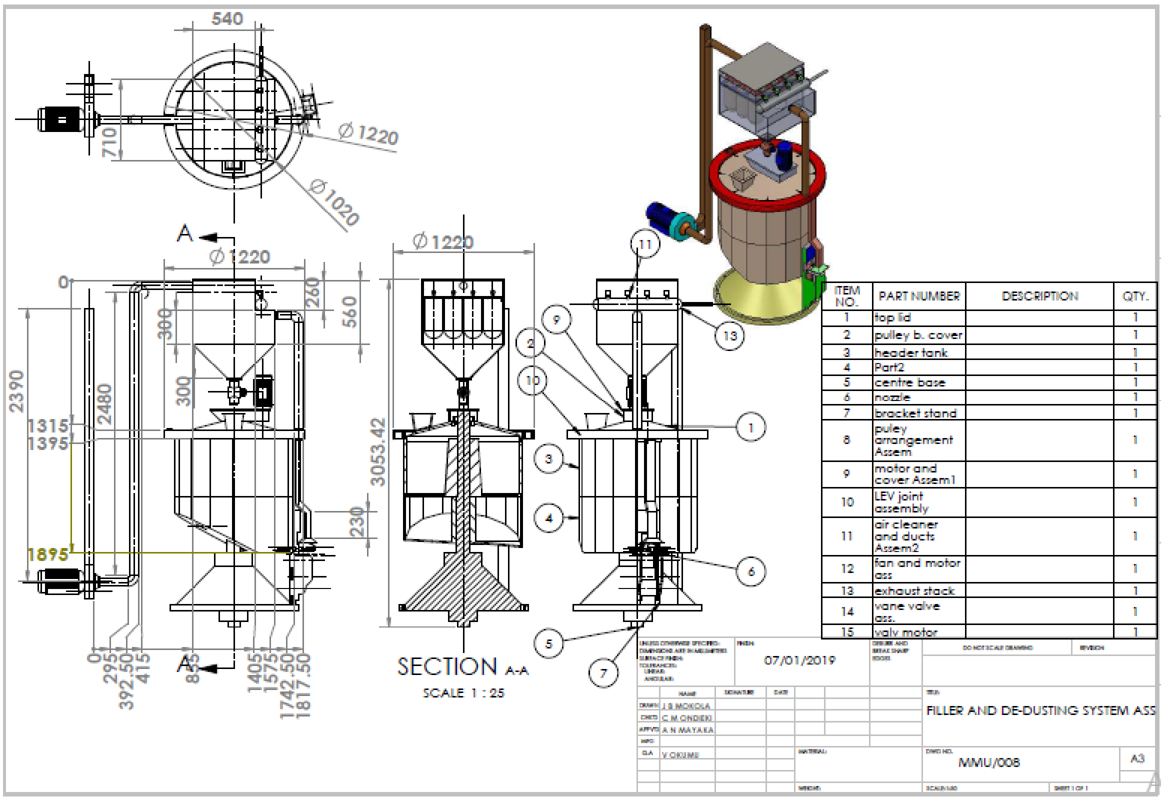

Fig 4. Filler and De-dusting System Assembly

B. Factory scale design

Design calculations for multi-hood system (for EAPCC factory scale) are as follows (diagram and calculation sheet)

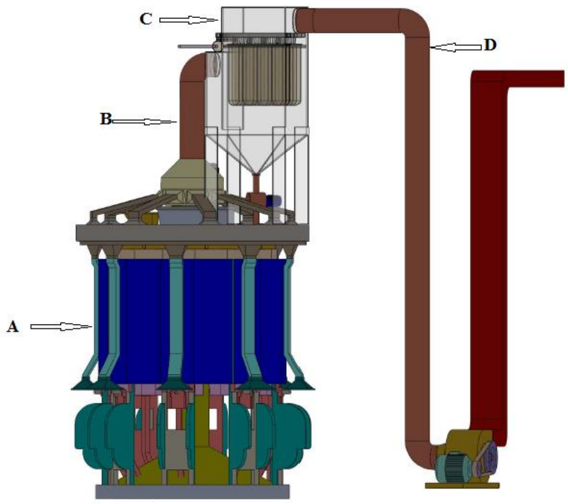

Fig 5. Full scale model of the De-dusting System

TABLE II: VELOCITY PRESSURE METHOD CALCULATION SHEET [11]

1.		**Duct segment identification**			A	B	C	D
2.	*T*	Dry-bulb temperature						
3.	*Q*	Standard volumetric flow rate		m^3/s	0.5742	4.5936	4.5936	4.5936
4.	V_1	Minimum transport velocity		m/s	20	20		17
5.	m_{H2O}	Kg of water per min.		H_20/min				
6.	m_{da}	Kg of dry air per min.		Da/min				
7.	*df*	Density factor						
8.	Q_{act}	Actual volumetric flow rate		m^3/s				
9.	A_1	Target duct area	3 ÷ 4	m^2	0.2871	0.2297		0.2297
10.	*d*	Selected duct diameter		m	0.25×0.1	0.425		0.425
11.	*A*	Selected duct area		m^2	0.025	0.1416		0.1416
12.	V_d	Duct velocity	3 ÷ 11	m/s	22.968	32.441		32.441

13.	VP_d			Duct velocity pressure		Pa	317.01	632.425		632.425
14.	h			Total heat	Branch balance					
15.	A_s	HOOD LOSSES	SLOT	Slot area		m^2				
16.	F_s			Slot loss coefficient						
17.				Acceleration factor						
18.	V_s			Slot velocity	8 ÷ 15	m/s				
19.	VP_s			Slot velocity pressure		Pa				
20.				Slot loss in VP	16 + 17					
21.				Slot static pressure	20 × 19	Pa				
22.	F_h			Duct entry coefficient			0.15			
23.				Acceleration factor		0 or 1	1.00			
24.				Duct entry loss in VP	22 + 23		1.15			
25.				Duct entry loss	24 × 13	Pa	364.562			
26.				Other losses		Pa				
27.	SP_h			Hood static pressure	21 + 25 + 26	Pa	364.562			
28.	L	DUCT LOSSES		Straight duct length		m	28.896	2.1		10.5
29.	H_f			Duct friction factor			0.255	0.086		0.086
30.				Number of 90° elbows			24	1		2
31.	F_{el}			Elbow loss coefficient			0.13	0.13		0.13
32.	F_{en}			Branch entry coefficient						
33.				Special fitting coefficient						
34.	h_f			Duct friction loss in VP	28 × 29		7.368	0.181		0.903
35.				Elbow loss in VP	30 × 31		3.12	0.13		0.26
36.				Branch entry loss in VP	32					
37.				Duct loss in VP	33 + 34 + 35 + 36		10.488	0.311		1.163
38.				Duct loss	37 × 13	Pa	3324.95	196.692		735.539
39.				Other losses		Pa			497.68	
40.	VP_r			Resultant velocity pressure		Pa				
41.				Loss from velocity increase	13 – 40 (if >0)	Pa				
42.				Duct pressure loss	27 + 38 + 39 + 41	Pa	3689.52	196.692	497.68	735.539
43.	SP_{gov}			Governing static pressure		Pa	3689.52	3689.52	3689.52	3689.52
44.	SP_{cum}			Cumulative static pressure		Pa	3689.52	3886.21	4383.89	5119.43
45.	Q_{corr}			Corrected volumetric flow rate		m^3/s	0	0	0	0
46.	V_{corr}			Corrected velocity	45 ÷ 11	m/s	0	0	0	0
47.	VP_{corr}			Corrected velocity pressure		Pa				

The design drawings for multi hood De-dusting system are as shown below:

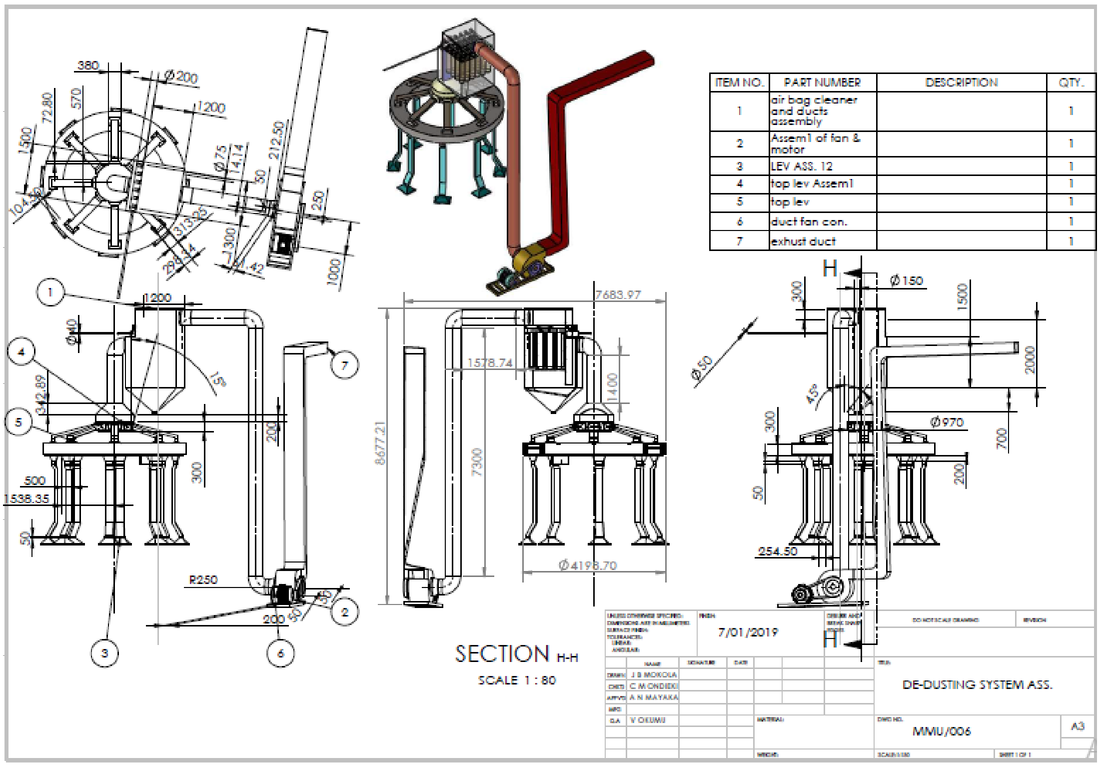

Fig. 6. De-dusting System Assembly

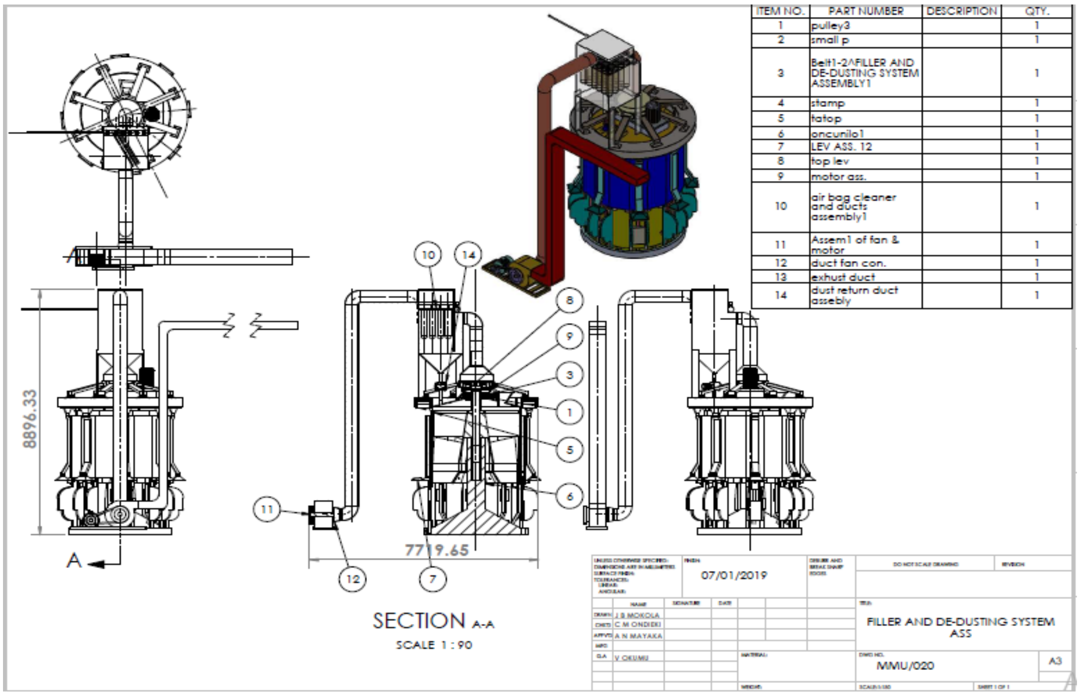

Fig.7. Filler and De-dusting System Assembly

III. RESULTS AND DISCUSSION

A. Dust Levels Generated by the Prototype with the De-dusting System OFF

The graph below fig. 8 shows the levels of dust generated with respect to the various bag filling pressures when the de-dusting machine is operated with *De-dusting System* turned OFF. Levels are above the internationally accepted limits with a mean of 163.73 µg/m^3 for PM2.5 and 299.05 µg/m^3 for PM10, World Health Organisation (WHO) and National Environment Management Authority (NEMA) air quality limits; permissible limits for PM2.5 and PM10 for 24 hour duration at Industrial areas are 75 µg/m^3 and 150 µg/m^3 respectively .

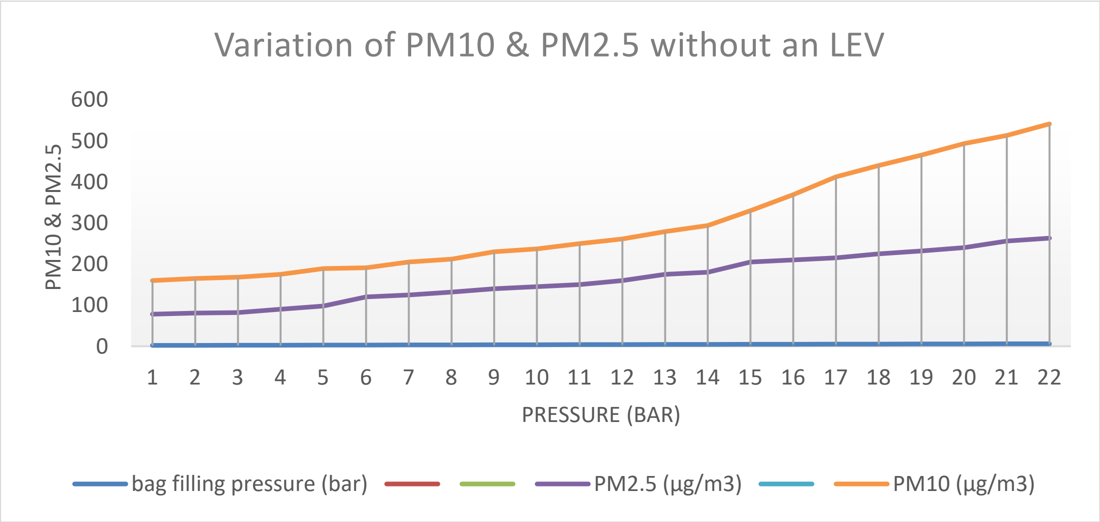

Fig 8. General data of dust level as measured when the machine is run with the de-dusting system deactivated.

B. Dust Levels Generated by the Prototype with the De-dusting System ON

The graph below fig. 9 shows the levels of dust generated with respect to the various bag filling pressures when the de-dusting machine is operated with the LEVs turned ON. Levels are all within the internationally acceptable limits with a mean of 23.65 μg/m^3 for PM2 and 46.08 μg/m^3 for PM10

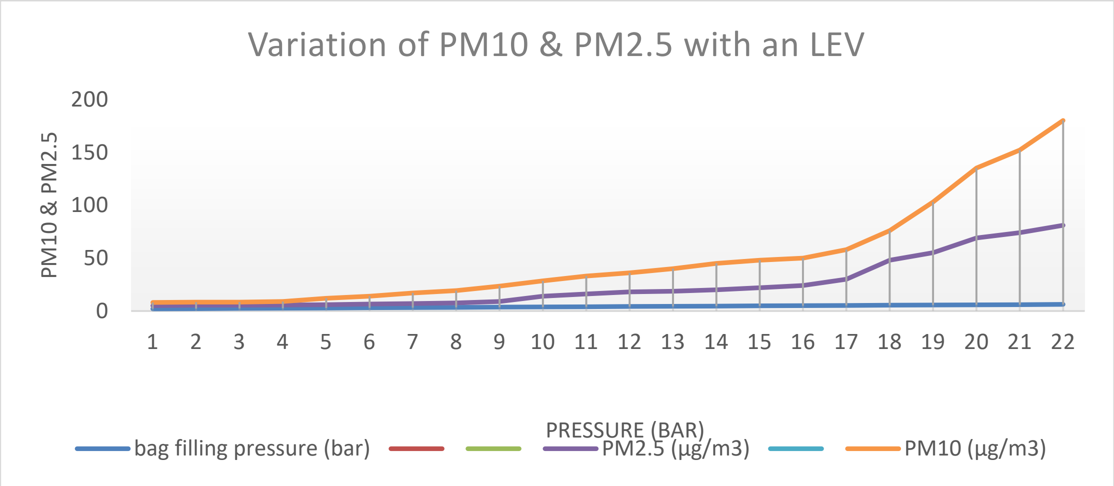

Fig. 9 General data of dust level as measured when the machine is run with the De-dusting system ON

IV. CONCLUSION AND RECOMMENDATION

A. Conclusion

i. The designed de-dusting system reduces dust levels to within the recommended limits of WHO Air Quality Guideline (AQG) and National Environment Management Authority (NEMA) permissible limits for Industrial areas.

ii. A larger percentage of cement escaping with dust is recoverable by recirculation to the mainstream using the designed de-dusting system.

B. Recommendations

The full scale factory design, if implemented, will improve air Quality within EAPCC and its environs as well as minimizing cement losses through dust. To sustain the air quality, regular environmental audit and monitoring practices by the industries and enhanced enforcement by sector regulators (NEMA and Directorate of Occupational Safety and Health Services (DOSHS)) to ensure compliance by all participants is recommended.

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