Proceedings of the
International Conference on Mechanical Engineering 2009
(ICME2009) 26- 28 December 2009, Dhaka, Bangladesh

ICME09-RT-30

A HOLISTIC APPROACH FOR DUST PREVENTION: COMBINATION OF LEV AND PREVENTION UNITS

Abdullah-Al-Mamun, F. Mahboob Nijhoom and Farzana Khurshid

Department of Industrial and Production Engineering,
Bangladesh University of Engineering and Techology, Dhaka, Bangladesh

ABSTRACT

The complex industrial process flow, magnitude of the enormous tasks carried out and the dependence upon relatively old setup leave open doors for further improvements in the industrial sectors in Bangladesh. In this paper the detergent plant of a reputed chemical company of Bangladesh is assessed and possible solutions are proposed to minimize the emanation of detergent dust from different sources. Here a Local Exhaust Ventilation (LEV) system is designed over the mixing chamber which is the main source of dust emission. A proper duct-fan combination is modeled and a new filter design is proposed. Analysis shows that, designing the ductwork considering the properties of dust particle and maintaining a steady pressure difference between inlet and outlet can increase the exhaust capability with optimum power requirement. Some prevention units are also designed to further keep the dust away from the worker. The main focus of this study is to increase the human comfort level inside the plant which can be achieved by providing the workpeople a cleaner and safer air to breath.

Keywords: Dust Minimization, LEV, Human Comfort, Ventilation.

1. INTRODUCTION

Ventilation in workplaces can include both general (fresh air) ventilation and ventilation used to control airborne contamination of the workplace. Ventilation used to control airborne contamination can be either dilution ventilation or local exhaust ventilation (LEV). Dilution ventilation provides a flow of air into and out of the working area and does not give any control at the source of the contaminant. LEV intercepts the contaminant as soon as it is generated and directs it into a system of ducting connected to an extract fan [3]. To achieve the same degree of control, far less air is extracted using a LEV system than with an equivalent dilution system, with considerable cost savings.

LEV can be defined as a system that uses extract ventilation to prevent or reduce the level of airborne hazardous substances from being breathed by people in the workplace, which draws pollutants away from a process or operation that is likely to release a hazardous substance into the air and which consists of an inlet, such as a hood, slot, booth or cabinet placed around or close to the point of release of the substance. This device is connected via ducting to the inlet of a fan or air mover. The extracted air is usually discharged to the atmosphere or returned elsewhere in the workplace, having first been cleaned to make it safe for release. The LEV system designed here is for the mixing chamber of detergent in a detergent plant. The standard calculations are made for a specific application. But the procedure can be used for other types of LEV system where the particles are fine, light, generally corrosive and hazardous for human health.

2. VENTILATION SYSTEM DESIGN

Local exhaust ventilation is needed when employees are exposed to high toxic chemicals and when large amounts of dusts or welding fumes are generated. In detergent production Soda ash and LABSA (Linear Alkyl Benzene Sulfonic acid) are the main ingredients. High exposure to the organic solvent may cause Nervous System Damage(Central and peripheral), kidney and liver damage and adverse reproductive effect [1]. American Conference of Governmental Industrial Hygienist(ACGIH) recommends Local Exhaust Ventilation system for high toxic material of threshold limit values (TVLs) less than 100 ppm (such as Toluene or Benzene) [4]. So a proper local exhaust ventilation system is necessary for the effective removal of air born contaminants that would otherwise pollute work environment resulting health hazards or nuisance or air pollution.

Local exhaust ventilation operates on the principle that air moves from an area of high pressure to an area of low pressure. The difference in low pressure is created by a fan that draws or sucks air through the ventilation system. Local exhaust systems are located as close as possible to the source of contamination to capture the contaminant before it is released into the work area. A local exhaust system operates in the same manner as a household vacuum cleaner.

A local exhaust system has five basic elements:

1. A "hood" or opening that captures the contaminant at the source,
2. Ducts that transport the airborne chemicals through the system,
3. An air cleaning device (not always required) that removes the contaminant from the moving air in the system,
4. A fan that moves the air through the system and discharges (blows) it outdoors,
5. An exhaust stack through which the contaminated air is discharged.

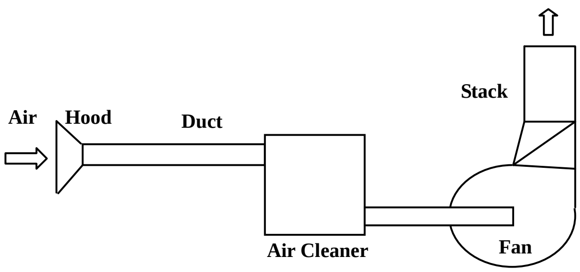

Fig 1. Components of a LEV System

3. PROBLEMS OF EXISTING LEV

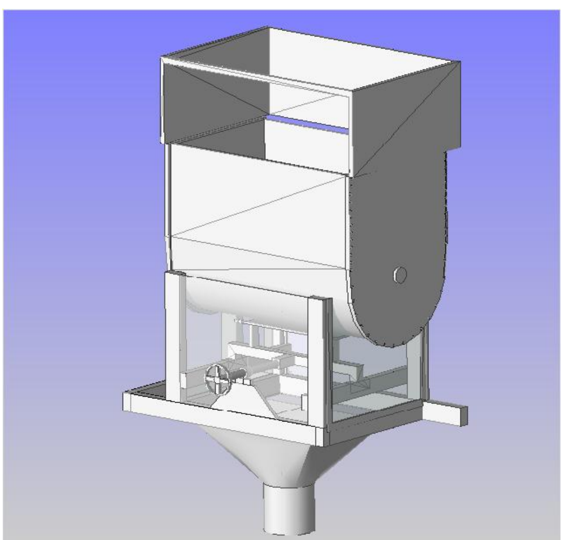

Fig 2. Schematic of the Mixing Chamber

In the mixing chamber (fig.2) different types of chemicals are mixed to form the granular detergent powder. Large powder lump remains in the chamber but the fine dust of detergent evolves and stays in the air inside the plant**.** This fine dust powder is detrimental for human health and may cause breathing problem of the worker. So it is desirable to remove the dust from the mixing chamber preventing to enter in the plant environment.

The volume of the mixing chamber

$$(81\times121.5\times45)+(70\times111.5\times59)+\left(\frac{\pi\times35^2}{2}\times111.5\right)$$

$$=1117914.145cm^3$$

$$=1.1179m^3$$

Considering the air inside the hood as well as the coming air through the opening, the total volume is assumed to be (1+1.1179) or 2.118 m^3.

The existing LEV system has following shortcomings:

- Inadequate dust removal capacity.
- Long ducting causes huge pressure drop across he pipe.
- No stack at the outlet of the exhaust system.
- No filter to purify exhaust air or separate the dust particle.
- The exhaust dust is collected in a cotton sack in the storage area which makes the area dustier.

4. NEW DESIGN OF LEV

Each component of the LEV is designed in detail to minimize the dust inside the plant area. Each components are designed so that it met the functional requirements and standards of different international occupational health and safety organization like NIOSH and.

4.1 Hood

The hood (fig.3) is used suck the fume, dust, and smoke out of the workstation or the area from where these things evolve. The existing hood over the mixing chamber is enclosure type hood.

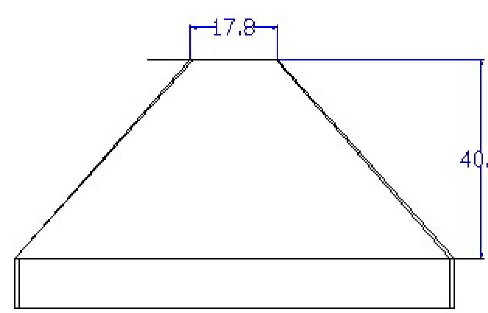

Fig 3. Side View of the Hood (cm)

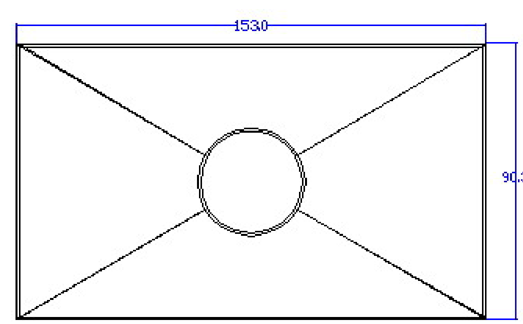

Fig 4. Top View of the Hood (cm)

The hood totally enclosed the emission source except the opening for pouring raw material. There are small opening on both side of the mixing chamber to induce the air flow through the exhaust system. The dust that evolves during mixing is taken away from the breathing zone of the worker. For above reasons the hood design is kept unchanged with small change in height.

4.2 Filter

The proper filtration system for a LEV system depends on the characteristics of air stream and nature and quantity of the contaminants. Here a low cost filter (fig.5) is designed which is efficient to separate the detergent dust particles from the environment.

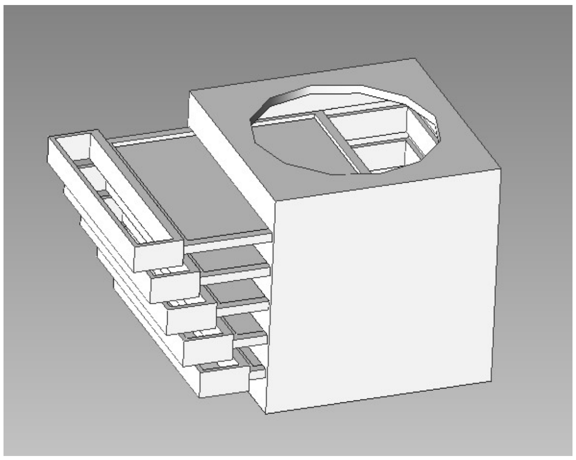

Fig 5. Schematic View of Cubic Filtration Device

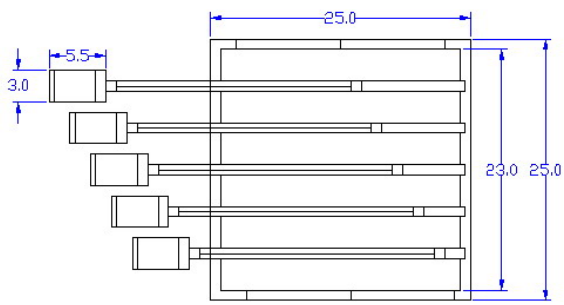

Fig 6. Dimensions of the Filtration Device (cm)

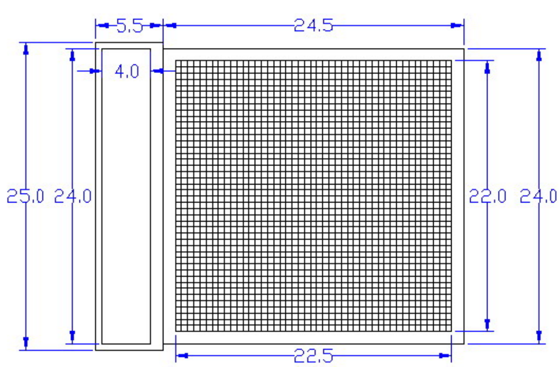

Fig 7. Top View of a Filter (cm)

The filter is placed prior to the fan to avoid degradation and corrosion of blades. They are designed in the form of trays that can be inserted into a cubic hollow box. The filter trays can be pulled out for cleaning purpose. It consists of five filters of consecutively larger mesh size.

Mesh size increases from bottom to top to capture large particles first and smaller particles successively. Very small particles are left to discharge with air through the exhaust system. The filter is made from thin metal wire. Different offset distances are used to put up different mesh size. Sequential perforations of filters from bottom to top are selected to be 50, 70, 90, 100 and 120 meshes. The fine dust particles which are usually smaller than 120 meshes are carried with the air flow out to the environment.

4.3 Duct

Ductwork provides a channel for flow of the contaminated air exhausted from the hood to the point of discharge. If the air contains dust, the air velocity in the duct must be high enough to prevent the dust from settling out and plugging the ductwork. The location and construction of the ductwork must provide sufficient protection against external damage and corrosion, but be accessible for servicing and maintenance.

Air in motion encounters resistance along any surface confining the flowing air volume, and some of the energy of the air is lost by conversion to heat in overcoming this resistance. Friction losses increase with:

- Increasing roughness of the surface walls
- Increasing length of ducting
- Increasing air velocity
- Decreasing diameter of ducting

Energy is also lost from air flowing turbulently - these are termed dynamic losses. Turbulence is caused by changes in direction in a duct like Elbows and angles. The pressure drop in a duct system due to dynamic losses increases with the number of elbows or angles.

In the designed exhaust system the duct length is reduced from **8m to 3.32m** to reduce the pressure drop. Vertical duct is designed to discharge dust outside the plant area rather than in the storage. The duct of LEV system is classified as **class-2**[2] according to concentration and abrasiveness of dust particle. For duct diameter ranging from 100-200mm the steel sheet thickness should be **22-18 mm** [2]. The design duct velocity for "fine and light dust" should be between **10-12.5 m/s** [2] to avoid settling of particles. The appropriate duct diameter and associated pressure drops are calculated in following section for efficient and optimum air removal.

4.4 Fan

Air is moved through the ductwork by a motor-driven fan. There are two major types of fans used in industrial ventilation:

- Axial flow types where the airflow is parallel to the fan shaft.

- Centrifugal flow types, where the airflow is perpendicular to the fan shaft.

Though centrifugal fan is quieter and can operate in higher static pressure, axial fan is more efficient in moving large volume of air. In the new LEV system an axial fan is proposed because the static pressure requirement is low. The appropriate duct-fan arrangement is determined in the following section for an available standard axial exhaust fan. The calculations may vary according to the data provided by the fan manufacturer regarding different fan model.

4.5 Stack

Exhaust stacks also need to be designed and located properly for the most efficient operation of a local exhaust system. The proposed stack design(fig.8) is following:

- In the design 'Discharge cap' is used instead of 'weather cap' because it tends to force the contaminant back down to the building.
- The stack is designed to be horizontal to avoid rain fall into the duct. Another advantage of discharge cap is that, it creates an induced air flow at the exhaust terminal.
- The exhaust stack should not be too close to fresh air intake. According to WISHA (Washington Industrial Safety and Health Act) they should be located no closer than 50 feet to prevent re-circulation of contaminants. In the proposed design the distance between this two is nearly 26m (86ft) which meets the requirement.

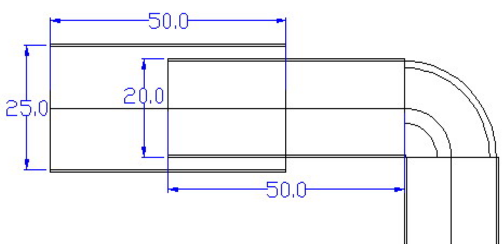

Fig 8. Dimension of the Stack (cm)

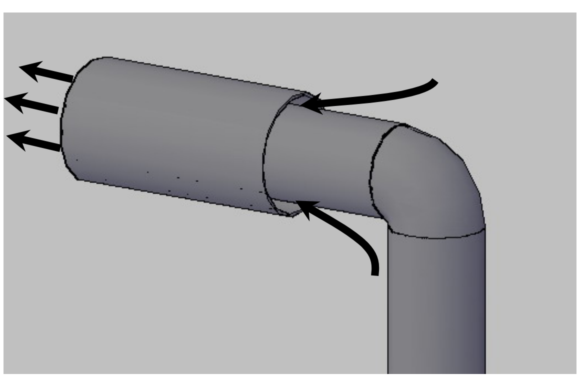

Fig 9. Induced Air Flow through the Stack

In addition to that, the exhaust end is directed opposite to the fresh air intake terminal. As a result, the air flow is boosted away from the air intake. It ensures that, no dust particle is circulated back into the plant area.

5. CAPACITY OF THE EXHAUST SYSTEM

If the total air inside the chamber is to be changed 4 times per minute then the required capacity

$$= 2.118 \times 60 \times 4$$
$$= 508.32 m^3 / h$$

In order to force air to flow through a duct, it has to be blown or sucked .There must be a difference (p) between the pressures at opposite ends of the duct. For straight ducts, the magnitude of the difference is proportional both to the square of the required volumetric flow V and to the length L of the duct.

$$p(V, L) = kLV^2$$

Any change in the cross-section of the duct, or its direction (e.g. inlet or exhaust terminals, bends, etc.) requires an additional pressure difference to maintain the air flow. This is again proportional to the square of the flow(fig.10).

$$p(V) = cV^2$$

Fans for use in ducted ventilation systems can be characterised by the air flow $V_f(p)$ that they will produce against a given pressure difference p. The performance of a particular combination of fan and duct system will be determined by finding the values of pressure p and flow V that simultaneously satisfy the following two conditions:

P = Total pressure difference required for duct and terminals to deliver a flow V

V = Flow delivered by fan working against a pressure difference p

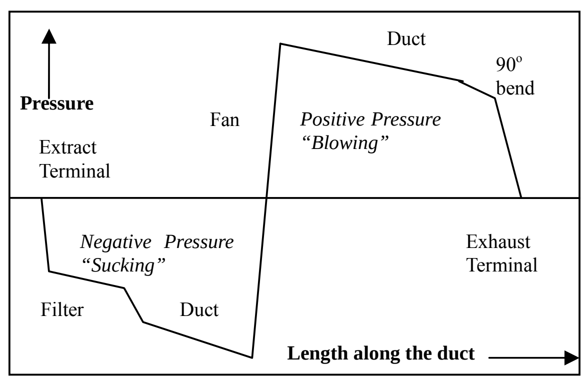

Fig 10. Pressure Variation along the length of the duct

For dry detergent dust classified as "very fine and light dust", the inside duct velocity should be between 10-12.5 m/s [2]. As the powder itself is the product, we have considered maintaining the minimum value of that range. To keep the mean air velocity (preferred) in the duct m/s, the duct diameter d must satisfy:

Flow / area = Velocity

$$508.32/(3600 \times \pi d^2/4) = 10$$

$$d = \left((4 \times 508.32)/(10 \times 3600 \times \pi)\right)^{\frac{1}{2}} = 0.13408\text{ m} = 134.08\text{mm}$$

No pressure data is available for 134.08 cm duct diameter. So the next standard diameter 200mm can be considered for duct. Though velocity will be decreased slightly due to increased diameter it will not affect much the capacity of the LEV system. Pressure drop along the proposed ducting arrangement for 1000 m^3/h flow rate is calculated as follows for a particular fan model.

Table 1: Pressure drop in ductwork
(Data obtained from manufacturer of ACM200 Fan)

Component	Pressure drop (Pa)
Extract terminal	624
2.82 m straight duct (10 Pa/m)	28.2
Filter	20*
90º bend	21
0.5 m straight duct (10 Pa/m)	5
Exhaust terminal	66
Total	764.2

So, for a flow of 508.32 m^3/h, the total pressure drop is 764.2 × $(508.32/1000)^2$ = 197.46 Pa. The performance chart below shows that the point (508.32, 197.46) is inside the performance envelope of the recommended ACM200 fan (fig.11). It therefore can deliver the target flow.

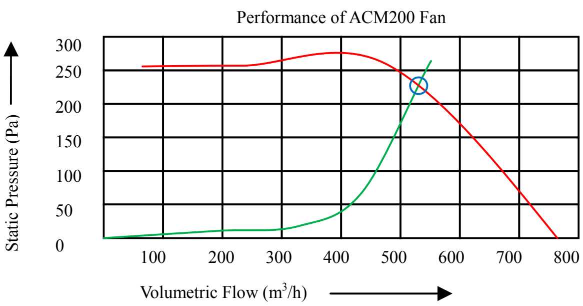

Fig 11. Performance curve of ACM 200 Fan

To determine what actual ventilation can be achieved, write v for the normalised flow $V/1000$, so that $p = 764.2\,v^2$ .This relationship is the ***system operating curve*** for flow in the duct, and is shown in green on the above chart. As the flow increases, the pressure will increase until, at the point where the curves intersect, the fan reaches its performance limit. To determine the intersection for static pressures between 0 and 220 Pa, the flow rate for the fan (in m^3/h) is given approximately by

$$V = 778 - 1.14p$$

Or, equivalently,

$$v = 0.778 - 0.00114p$$

Substituting for p gives a quadratic equation for v

$$v = 0.778 - .00114\left(764.2v^2\right)$$

That is, $.871188v^2 + v - .778 = 0$

With positive solution, $v = .53171$

This corresponds to a flow rate 531.71 m^3/h

$$= \frac{531.71 - 508.32}{508.32} \times 100\%$$
$$= 4.6\%$$

So, our obtained flow from the specified fan-duct combination is 4.6**%** better than the target.

Maximum air change per hour achievable,

$$= \frac{531.71m^3/h}{2.118m^3}$$
$$= 251.04 \text{ times / hr}$$
$$= 4.2 \text{ times / min}$$

6. COMPLETE VENTILATION ARRANGEMENT

All the components together along with appropriate fan-duct arrangement form the proper ventilation system that will minimize the toxic detergent dust to stay inside the plant. The cubic filtration device is placed at a height so that a person of average height can reach it without any physical strain. Five trays can be removed, washed and placed back to the filter in minimum time without hampering the production.

The complete arrangement should look like the following:

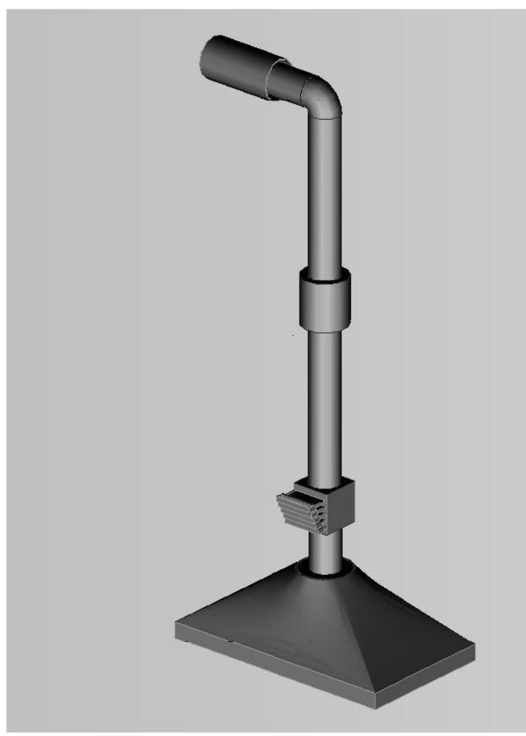

Fig 12. The complete LEV System

7. DUST PREVENTION UNITS

In a manufacturing facility where workers have to work in a toxic material, dust prevention unit adds to the process for creating a better workplace. In addition to the top of the mixing chamber, other openings from where dust is evolved can be covered with suitably designed case. It will be appropriate to use transparent plastic sheet to make the inside visible. A slide type opening can be used to clean the inside without extensive physical effort.

8. CONCLUSION

The designed LEV system here is suitable for any type of dust particle that evolve from a small area or workstation. The ducting material, thickness of metal, Capture velocity, and type of filter to be used depend on the particle diameter, nature of contaminant and condition of dispersion. So the system can be modified for above conditions to expel any type of dust that is harmful for human health and detrimental to the workplace equipments.

In a detergent plant where the overall ventilation is satisfactory, a good material handling system carries the product from place to place, storage of toxic organic chemicals are secured and dust emission spots are well covered, the new LEV system will work great. But if those factors are not maintained with care, even a sophisticated, well designed LEV system has little to contribute in health and environmental issue. So to maintain a safe and hazard free working environment and smooth operation the above factors also need necessary attention.

9. REFERENCES

1. M. J. Jafari, Ali Karimi, M.R. Azari, 2008,"The role of exhaust ventilation system in reducing occupational exposure to organic solvents in a paint manufacturing factory", Indian Journal of Occupational and Environmental Medicine Vol-12:22.
2. "Guidelines on Design, Operation and Maintenance of Local Exhaust Ventilation System" 2003, Occupation, Safety and Health Division, Ministry of Manpower, Singapore.
3. "Workplace (Health, Safety and Welfare) Regulations" Nuneaton and Bedworth Borough Council, Environmental Health Services, Council House, Coton Road, Nuneaton, Sep 2003, Issue 3.
4. ACGIH, Industrial Ventilation a manual of recommended Practice, 22 ed ACGIH, 1995.
5. ASHRAE Handbook of Fundamentals, Chapter 26 by American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). Atlanta, GA: 2001.
6. D. Jeff Burton, 1997, "Industrial Ventilation: A Self-Directed Learning Workbook (4th Edition)"

10. NOMENCLATURE

Symbol	Meaning	Unit
V	Velocity	(m/s)
d	Diameter	(m)
P	Pressure	(Pa)
V	Volumetric Flow	(m^3/h)
L	Length	(m)

11. MAILING ADDRESS

Abdullah-Al-Mamun
Lecturer,
Department of Industrial and Production Engineering,
Bangladesh University of Engineering and Technology, Dhaka-1000
E-mail: abdullah-al-mamun@ipe.buet.ac.bd