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Estimation of the healthcare waste generation during COVID-19 pandemic in Bangladesh

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HIGHLIGHTS

• COVID-19 healthcare waste generation in Bangladesh is estimated.
• Daily face masks and hand gloves usage in Bangladesh is determined.
• Medical waste increased from 658.08 tons in March 2020 to 16,164.74 tons in April 2021.
• Infected and isolated patients are responsible for major waste generation.
• Special attention is needed both in MSW and medical waste management.

ABSTRACT

COVID-19 pandemic-borne wastes imposed a severe threat to human lives as well as the total environment. Improper handling of these wastes increases the possibility of future transmission. Therefore, immediate actions are required from both local and international authorities to mitigate the amount of waste generation and ensure proper disposal of these wastes, especially for low-income and developing countries where solid waste management is challenging. In this study, an attempt is made to estimate healthcare waste generated during the COVID-19 pandemic in Bangladesh. This study includes infected, ICU, deceased, isolated and quarantined patients as the primary sources of medical waste. Results showed that COVID-19 medical waste from these patients was 658.08 tons in March 2020 and increased to 16,164.74 tons in April 2021. A top portion of these wastes was generated from infected and quarantined patients. Based on survey data, approximate daily usage of face masks and hand gloves is also determined. Probable waste generation from COVID-19 confirmatory tests and vaccination has been simulated. Finally, several guidelines are provided to ensure the country’s proper disposal and management of COVID-related wastes.

ARTICLE INFO

Article history:
Received 19 September 2021
Received in revised form 21 November 2021
Accepted 6 December 2021
Available online 9 December 2021

Editor: Damià Barceló

Keywords:
Biomedical waste management
Environmental and public health
Face masks
Solid waste management

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1. Introduction

Currently, the world is facing a serious concern due to the emergence of the pandemic COVID-19. Every country globally has undertaken different preventive measures such as social distancing, imposing lockdown, border closure, face masks, gloves, aprons, and face shields to prevent the virus from spreading. However, local and international authorities’ attempts remain unsuccessful in most countries as the number of infected patients and death rates increase day by day. Approximately 240 million people have been infected, and 4.90 million have suffered tragic death till October 15, 2021 (Worldometers, 2020). General people and medical personnel use PPE, such as face masks, hand gloves, and face shields to prevent transmission, ultimately increasing medical and healthcare waste at an alarming rate. Biomedical waste poses a severe threat to lower-income countries like Bangladesh. Owing to diseases caused by unmanaged medical waste, at least 5.2 million people, including 4 million children, die each year around the world (WHO, 2020). Several studies have shown the severity of healthcare waste generation due to this pandemic. According to Peng et al. (2020), daily medical waste generation in China was around 469 tons. After the first case was detected in Indonesia, 12,740 tons of medical waste were generated in 60 days (Mihai, 2020). The disposal of these infectious wastes requires special attention as these can serve as a medium of transmission. Waste produced due to this pandemic has caused many environmental and health concerns in many countries (Yu et al., 2020). Plastic pollution from the used PPE has gained global attention and will contribute to ongoing microplastic pollution. In many developing and emerging countries, recycling workers collect material without using proper PPE, and these collected materials are reused; hence there is a greater chance of transmission (Nzediegwu and Chang, 2020). Improper management of this solid waste will exacerbate the disease transmission even in the ongoing and after the pandemic period. Therefore, the need for biomedical waste management, especially for low and developing countries, is a must for preventing the widespread of this pandemic.

Bangladesh has the second most COVID-infected patients in South Asia. Bangladesh first identified COVID infected patient on March 8, 2020. To prevent the widespread of this virus, the Government of Bangladesh first imposed a nationwide lockdown from March 26 to May 30 (Shammi and Tareq, 2020). Since then, many partial and complete lockdowns have been imposed to control the widespread virus. However, the infection rate slowly increased, and currently, more than 1.46 million are infected, while more than 25,000 (as of August 23, 2021) people lost their lives due to COVID (Worldometers, 2020). The country’s health sector experienced massive pressure due to an alarming rise in infected patients. In Bangladesh, the number of Government and private hospitals is 654 and 5055 (Rahman et al., 2020). Approximately 9061 diagnostics centers are also located nationwide. All of these hospitals and centers produce a vast amount of medical waste. Due to COVID, many makeshift isolations and quarantine centers are also set up, contributing to biomedical waste generation. The history of medical waste management in Bangladesh is not satisfactory, and this country has been facing overwhelming challenges in ensuring the safe disposal of COVID waste. According to Rahman et al. (2020), in April, more than 14,500 tons of biomedical waste were produced throughout the country due to COVID. In its capital city (Dhaka), the daily waste was 206 tons (Rahman et al., 2020). This situation is alarming throughout the country, as many hospitals do not follow proper disposal methods (Shammi and Tareq, 2020). Incineration is the best way to dispose of medical waste, and many hospitals in Bangladesh do not possess such a facility. Many burn wastes in the backyard, which further increases the possibility of air pollution (Shammi and Tareq, 2020). Due to the large volume of COVID waste and regular waste, solid waste management, and plastic waste management have faced enormous challenges throughout the country.

According to a survey, more than 49% of people use the same container to dispose of household waste and COVID waste, which may increase infection (Shammi et al., 2021). Besides, for ensuring the safety of medical personnel, the Government supplies PPE throughout the country, and improper handling of these used PPE also contributes to plastic pollution. Table 1 shows the number of supplied PPE.

The primary objective of this study is to estimate COVID-19 related medical waste and urban generation in Bangladesh from March 2020 to May 2021 to highlight the importance of solid waste and medical waste management to meet international standards. Besides, a detailed literature review has found that limited studies have addressed waste generation due to the vaccination process and conducted tests. So, probable waste generation due to the vaccination process and COVID confirmatory tests have been outlined in this study. Estimating the COVID-19 related wastes will help policymakers to manage them properly, ultimately preventing disease transmission. Moreover, this analysis can serve as a helpful guideline for many developing and low-income country decision-makers to estimate the waste generated due to this pandemic. It is believed that this analysis will draw the attention of scientific communities to frame appropriate policies for the safe handling of COVID-19 waste.

2. Materials and methods

2.1. Data collection

Data regarding infected and deceased patients is collected from Worldometer (Worldometers, 2020). The number of isolated and quarantined persons is collected from the daily COVID-19 press release of the Directorate General of Health Services of Bangladesh (DGHS, 2020). Data regarding vaccination programs and conducted tests are collected from the COVID-19 vaccination dashboard of DGHS (https://dghs.gov.bd.).

2.2. Medical waste generation

Total COVID medical waste generation in a hospital is the product of inpatient waste and the waste generated per patient. (Minoglou et al., 2017)

### Table 1

| PPE products               | Supplied till August 23, 2021 |
|----------------------------|--------------------------------|
| Apron and Gowns            | 0.086                          |
| Gloves for examination     | 0.823                          |
| Gloves surgical            | 0.841                          |
| Hand /face/ eye shields    | 0.823                          |
| Masks                      | 7.50                           |
| PPE kits                   | 0.794                          |
| Sanitizer                  | 0.274                          |
| Shoe protector             | 0.044                          |
| Others                     | 6.19                           |

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determined that the amount of medical waste production in Jordan was 2.69 kg/bed/day. Korkut (2018) determined the increase in daily medical waste generation from 0.43 kg/bed/day in 2000 to 1.68 kg/bed/day in 2017 in Istanbul, Turkey. Table 2 shows the daily waste generation in different countries (Minoglou et al., 2017). Waste reported in Table 2 includes both infectious and non-infectious waste. According to WHO, “High-income countries generate hazardous waste 0.5 kg per hospital bed daily, whereas, for low-income countries, it is 0.2 kg per bed” (WHO, 2020). WHO also reported that 80% of health care waste is non-hazardous. Due to the increase in COVID-infected patients, the amount of waste generation has also increased. For example, in the study of (Abu-Qdais et al., 2020), the average waste generated from a COVID-infected patient was 3.95 kg/bed/day. So, the amount of waste generated by an infected person can be calculated via Eq. (1) (Mihai, 2020; Sangkham, 2020).

\[
W_M = N_{Patient} \times WMGR
\]  (1)

Where, \(W_M\) is the total waste generated per day in kg, \(N_{Patient}\) is the number of the patient, and \(WMGR\) is the waste produced by an individual patient per bed in kg.

In an earlier study, the Asian Development Bank (ADB) estimated that daily waste generation from a COVID infected patient is 3.40 kg (ADB, 2020; Haque et al., 2021). This study assumes daily waste generation from a COVID infected, deceased, and ICU patient is 3.40 kg. According to WHO, quarantined patients do not exhibit any symptoms but have been in contact with infected patients or have traveled to areas affected by the pandemic, and isolated patients are those who are generally infected. The general quarantine period is 14 days, and the waste produced by these patients requires special attention (Mihai, 2020). To estimate waste generated from quarantined patients, this study has considered the municipal waste generated by quarantined households (Mihai, 2020). In Bangladesh, the daily municipal waste generation rate is 0.49 kg per person in urban areas and 0.33 kg per person in rural areas. The latter was considered a conservative option to determine waste flow in quarantined households (Huda et al., 2014). Eq. (2) (waste generation rate 3.40) is used to estimate waste generation from isolated patients. Eq. (2) can further be modified to estimate waste generation from quarantined patients.

\[
W_{Quarantined\ waste} = N_{No\ of\ quarantined\ person} \times 0.33\ kg
\]  (2)

2.3. Estimation of daily used face mask and hand gloves

Daily usage of face masks can be determined by the Eq. (3) (Mihai, 2020; Nzediegwu and Chang, 2020):

\[
P_{Face\ mask} = N_{population} \times UP \times FM_{acceptance} \times \left( \frac{FM_{usage}}{10000} \right)
\]  (3)

Where, \(P_{Face\ mask}\) = Daily Face mask generation, \(N_{population}\) = Population, \(UP\) = Percentage of the urban population, \(FM_{acceptance}\) = Acceptance of face masks in the population (63%) (Chowdhury et al., 2021), \(FM_{usage}\) = general assumption that a person in the total population utilizes one mask every day.

Similarly, daily usage of face masks and hand gloves can be determined by Eq. (4).

\[
P_{Hand\ gloves} = N_{population} \times UP \times HG_{acceptance} \times \left( \frac{HG_{usage}}{10000} \right)
\]  (4)

Where, \(HG_{acceptance}\) = Hand gloves acceptance rate among the general population (30%) (Islam et al., 2020). \(HG_{usage}\) = general assumption that a person in the total population utilizes one pair every day.

2.4. Estimation of medical waste generated from COVID vaccination and conducted tests

The onset of 2021 has seen a global vaccination drive against COVID-19. Global authorities have taken initiatives to vaccinate a significant portion of the population to protect human health and prevent the widespread of this virus. To achieve the desired level of immunization among people, the production of vaccines has risen significantly. With this increasing demand for vaccines, a massive rise in materials such as rubber, plastic, and glass is also expected (Phadke et al., 2021). These wastes will negatively impact the environment, especially in developing countries where insufficient waste management infrastructure is developed (Omran et al., 2021). Vaccination and test kits contain chemical bottles, swabs, and syringes which can act as a potential source of infectious medical waste. Thus, proper disposal of these potential infectious wastes is necessary to avoid future transmission. To estimate the waste from vaccination kits and COVID-19 test kits, the total weight of these kits is determined, shown in Table 3. Data regarding conducted tests and vaccination are collected from the Directorate General of Health Services (https://dghs.gov.bd.). Eqs. 5 and 6 can be used to estimate waste from Vaccination programs and COVID-19 tests:

\[
W_{Vaccination\ set} = W_{Vaccination\ kit} \times N_{no\ of\ vaccinated\ people}
\]  (5)

\[
W_{COVID-19\ test} = W_{Test\ kit} \times N_{no\ of\ test\ conducted}
\]  (6)

2.5. Limitations of this analysis

This analysis aims to introduce a method for the rapid estimation of COVID-19 related medical waste in Bangladesh. However, this study is subjected to several uncertainties. The accuracy of the results largely depends on the transparency of COVID-19 related data (number of infected, quarantined, ICU, and isolated patients) taken from several local and international databases. Medical and municipal waste generated due to COVID was not available for Bangladesh. So, estimation was made based on data from supportive literature. Researches should be undertaken in health care facilities and affected areas to determine the waste generation rate. Also, careful consideration is needed to determine waste generated in ICU and general units. These analyses are essential to improve hospitals and households’ baseline scenarios and upgrade the current model.

3. Result and discussion

3.1. Medical waste generation

Table 4 shows that the number of infected, isolated, and quarantined patients has increased significantly from March 2020 to May 2021. All of these patients generated a massive amount of biomedical waste within the analyzed months. Table 5 shows the monthly estimated COVID-19 medical waste generated in the country.

Table 5 shows that waste generation was low in March 2020 compared to other months as fewer persons were infected. It can also be noticed that the amount of waste generation increased rapidly from June 2020. The
Government of Bangladesh imposed a nationwide lockdown from March 26 to May 30, 2020. Due to lockdown, people’s movements were restricted, and hence the number of fatality and infection rates was lower. Lockdown was lifted in June, and people traveled across the country to celebrate the holy festival Eid-Al-Fitr. Due to people’s carelessness in traveling and not following proper safety protocols, the infection rate and death rate doubled. The amount of waste generation also increased tremendously in June and July 2020.

In April 2021, the second wave of transmission peaked, and the number of infected patients also increased rapidly, contributing to the highest waste generation. Infected patients generated about 81% of waste, whereas the quarantined patients generated 16% of waste. Isolated waste can also be regarded as potentially infectious waste, and the treatment of this waste needs special attention. The number of infected, quarantined, and isolated patients also increased rapidly, contributing to the highest waste generation. Infected patients generated about 81% of waste, whereas the quarantined patients generated 16% of waste. Isolated waste can also be regarded as potentially infectious waste, and the treatment of this waste needs special attention.

### Table 4

| Year | Month | Infection | ICU | Deceased | Isolation | Quarantine |
|------|-------|-----------|-----|-----------|-----------|------------|
| 2020 | March | 51        | NA  | 5         | 359       | 60,052     |
|      | April | 7618      | NA  | 163       | 1420      | 71,482     |
|      | May   | 39,486    | NA  | 482       | 5794      | 60,181     |
|      | June  | 98,330    | NA  | 1133      | 7862      | 64,667     |
|      | July  | 96,048    | 331 | 1800      | 18,310    | 56,824     |
|      | August| 75,933    | 301 | 1165      | 19,942    | 52,217     |
|      | September | 51,221 | 293 | 971       | 15,057    | 43,177     |
|      | October| 44,205    | 87  | 672       | 4676      | 20,852     |
|      | November| 56,548   | 117 | 721       | 5122      | 25,241     |
|      | December| 48,578   | 130 | 915       | 5084      | 24,606     |
| 2021 | January| 21,629    | 160 | 568       | 2920      | 14,500     |
|      | February| 11,077   | 66  | 281       | 1686      | 9720       |
|      | March  | 65,079    | 253 | 638       | 4347      | 21,853     |
|      | April  | 147,837   | 464 | 2404      | 18,005    | 62,079     |
|      | May    | 41,408    | 122 | 1169      | 12,140    | 35,007     |

### Table 6

| Country       | Population | UP % | FMacceptance % | HGacceptance % | FMusage | HGusage |
|---------------|------------|------|----------------|---------------|---------|---------|
| Bangladesh    | 164,820,045| 40   | 63             | 30            | 1 piece | 1 pair  |

Like other countries in the world, the vaccination program is currently in full swing in Bangladesh. The country administered the first dose of vaccine on January 27, 2021, and since then, 16.4 million first doses and 6.32 million second doses of vaccines have been administered (as of August 2021) (https://dghs.gov.bd). With the Government’s continuous efforts, only 4.4% of the total population have been vaccinated as of August. The Government plans to vaccinate 80% of the total population and provide 117.9 million vaccination doses throughout the country. However, with this growth in vaccination demand, waste generated from these kits has created significant concerns among environmentalists. It is estimated that about 135.90 tons and 52.10 tons have been generated throughout the country from the first and second doses of vaccination. It will rise to 973.13 tons if the target population is vaccinated. Another source of waste that is creating primary concern is COVID-19 test kits. According to Celis et al. (2021), 37.27 g of plastic waste is generated from a single real-time PCR (polymeric chain reaction) test, and these plastics are fully disposable (Tang et al., 2020). A sample is collected from the nose, mouth, or lungs via a swab and preserved in chemical preservatives during this test. In Bangladesh, PCR test is conducted, and as of August 23, 2021, about 8.65 million tests have been conducted, which will create 108.40 tons of waste. This amount will surely increase as the pandemic progresses. This waste management is challenging for a developing country like Bangladesh as waste management facilities are not fully developed. Most of these wastes need to be incinerated, and Bangladesh does not possess adequate incineration facilities. About 97% of wastes are mismanaged in Bangladesh, and the countries waste management infrastructures are already struggling against COVID wastes.
4. Environmental concern and public health

Worldwide lockdowns were imposed in various countries to prevent the widespread of this virus. During lockdowns, a significant increment in both municipal and medical waste has been observed. Besides, during this period, online food services and online shopping have also increased. As a result, organic and inorganic waste generated from the residential sector has also increased. These organic and inorganic wastes are indirectly responsible for air, water pollution, and soil erosion (Zambrano-Monserrate et al., 2020). Besides, the waste recycling rate is also reduced in some countries, such as in some USA cities. Due to the fear of spreading the virus, these cities or states stopped recycling during lockdown (Liu et al., 2020). In Bangladesh, approximately 40,000 waste collectors work without proper PPE, and these wastes can cause future transmission of this virus (Shammi and Tareq, 2020). The number of workers was declined by half due to the fear of transmission, thus posing a severe challenge to dispose of these enormous amounts of wastes. Only one landfill facility in Matuail is available for disposing of hospital waste in Dhaka city. Still, collecting and transporting such a massive amount of waste poses a severe threat to public health and the environment.

Among various types of waste, plastic wastes severely increased due to the increment use of personal protective equipment. During eight weeks of lockdown in Singapore, an additional 1400 tons of plastic is generated. This lockdown has put extra pressure on waste management facilities. ESDO surveyed Bangladesh from March 26 to April 25 and found that about 5887 tons of waste were generated from hand gloves. About 3039 tons were plastic gloves, and the rest were surgical gloves. The amount of plastic waste also increased significantly. Polythene bags contributed to 5796 tons of waste, while face masks and hand sanitizer bottles contributed to 1592 tons and increased significantly. Polythene bags contributed to 5796 tons of waste, while face masks and hand sanitizer bottles contributed to 1592 tons and increased significantly. Polythene bags contributed to 5796 tons of waste, while face masks and hand sanitizer bottles contributed to 1592 tons and increased significantly. Polythene bags contributed to 5796 tons of waste, while face masks and hand sanitizer bottles contributed to 1592 tons and increased significantly. Polythene bags contributed to 5796 tons of waste, while face masks and hand sanitizer bottles contributed to 1592 tons and increased significantly. Polythene bags contributed to 5796 tons of waste, while face masks and hand sanitizer bottles contributed to 1592 tons and increased significantly. Polythene bags contributed to 5796 tons of waste, while face masks and hand sanitizer bottles contributed to 1592 tons and increased. As a result, organic and inorganic waste generated from the residential sector has also increased. These organic and inorganic wastes are indirectly responsible for air, water pollution, and soil erosion (Zambrano-Monserrate et al., 2020). Besides, the waste recycling rate is also reduced in some countries, such as in some USA cities. Due to the fear of spreading the virus, these cities or states stopped recycling during lockdown (Liu et al., 2020). In Bangladesh, approximately 40,000 waste collectors work without proper PPE, and these wastes can cause future transmission of this virus (Shammi and Tareq, 2020). The number of workers was declined by half due to the fear of transmission, thus posing a severe challenge to dispose of these enormous amounts of wastes. Only one landfill facility in Matuail is available for disposing of hospital waste in Dhaka city. Still, collecting and transporting such a massive amount of waste poses a severe threat to public health and the environment.

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5. Formulation of waste management policies for disposing of COVID-19 related waste

Along with controlling the propagation of the COVID-19, managing vast amounts of solid, plastic, and medical waste is more than challenging, especially in developing countries like Bangladesh, where the number of populations living in the area is not small. Besides, solid waste management in Bangladesh is not fully dynamic and potential, and along with the existing solid waste, additional COVID waste creates an extra burden to handle. Ineffective disposal of solid waste may increase the health risk of the municipal worker, health worker, rag-pickers, and others directly or indirectly involved with the COVID-19 war. In this situation, implementing a fair and efficient COVID waste management policy is the only way to handle and manage this enormous amount of waste. Here we proposed some potential approaches that can make it possible to manage COVID waste more efficiently (Fan et al., 2021; Shammi et al., 2021; Singh et al., 2020; Barua and Hossain, 2021).

- All the solid, plastic, and medical waste products during the COVID-19 patient care home quarantine must be collected safely in a secure sharp box. Distinguish color containers should be installed in localities or supplied to residents to differentiate among MSW, medical waste. All the collected waste must be disinfected first and placed in the standard waste disposal bags.
- Biowaste management policy needs to be followed stringently, i.e., red label bag should be used for the collection of the PPE; non-chlorinated red bag needs to be used for the collection of the oxygen mask, urine bags, tubing, bottles, catheters; non-chlorinated yellow bags must be used for the collection of meters contaminated with human body blood or fluid. Leakproof and puncture-proof bags need to be used to collect scissors, syringes, needles, blades, and other sharp objects. The contaminated and broken glass needs to be collected in a puncture-proof blue-colored container. Before the collection and final disposal, all this waste material should be disinfected with 1% sodium hypochlorite (NaOCl). For disinfestation of reusable non-medical components, 70% alcoholic solution should be used (Nzediegwu and Chang, 2020).
- After collecting the COVID waste as discussed in 1 and 2, separating the waste from the non-infectious waste like cardboard, paper, and food scraps is necessary. After the separation, all the waste should be in their respective bags. All the bags must not be stored for more than 24 h, and after the waste delivery, it is necessary to disinfect the place with 1% chlorine solution.
- After the storage, it is necessary to transport the COVID waste bags to the Common Biomedical waste treatment plant. It is required to use suitable routes (strongly recommend avoiding the busy area and rush hour), dedicated and trained driver, and the particular vehicle to transport the waste. The vehicle and trolley used in waste carrying need to be disinfected with 1% sodium hypochlorite.
- It is strongly suggested to use autoclaving, chemical processes, and incineration to treat the COVID waste. It is not recommended to store the waste for more than 12 h in the transportation area. Particular caution needs to avoid contamination with any river, drinking water sources, park, residential, school, and other public places.
- Better waste management practices to treat or dispose of these medical wastes should be shorted out. Disinfection technologies such as ultraviolet germicidal irradiation, chemical heat, and thermal treatment processes should be applied to reuse the PPE (Derraik et al., 2020). In case of large waste volumes, installation of mobile incineration facilities and utilization of existing industrial furnaces and kilns ban be approved to dispose of these wastes. The infected wastes can be burned using the plasma method with very high temperatures, not presenting any environmental air pollution problem. Kumar et al. studied the best disposal options of plastic bags via a life-cycle assessment approach, and for this, this study compared to landfill, decentralized and centralized incineration (Kumar et al., 2020). This study found that the most environmentally friendly approach is decentralized incineration while the least is landfill.
- Introducing a recycling program will help handle the COVID waste and make medium- and long-term benefits in converting the wastes to green energy and resource recovery.
- It is necessary to keep a record of waste collected for effective management. Surveys should be conducted across the country to determine the amount of waste. Also, it will be helpful in future research and development.

| Items                                      | Number of amounts used during 30 days lockdown (ton) | Total waste produced (ton) | Estimated daily waste production rate (ton/day) | Waste produced in 3 months (ton) |
|--------------------------------------------|------------------------------------------------------|----------------------------|--------------------------------------------|---------------------------------|
| Hand Sanitizer bottles                      | 49 million                                           | 900.0                      | 30.0                                       | 2700.0                         |
| Single use surgical face masks              | 455 million                                          | 1592                       | 53.07                                      | 4776.30                        |
| Polyethylene (PE) bags                      | 1449 million                                         | 5796                       | 193.20                                     | 17,388.0                       |
| Non-infectious plastic waste from healthcare units | –                                                    | 251.10                     | 8.37                                       | 753.30                         |
| Polyethylene made hand gloves               | 1216 million                                         | 3039                       | 101.30                                     | 9117.0                         |
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors would like to thank the Department of Mechanical Engineering and Department of Electrical & Electronic Engineering, Chittagong University of Engineering & Technology, for their support in preparing this manuscript.

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