International Journal of Advanced Science and Research
ISSN: 2455-4227, Impact Factor: RJIF 5.12
www.allsciencejournal.com
Volume 1; Issue 10; October 2016; Page No. 22-29

Latest technologies of municipal solid waste management in developed and developing countries: A review

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Abstract

Municipal Solid Waste Management plays an important role in sustainable development. Zero waste is a latest visionary concept for confounding waste problems of our society. The idea has been implemented in various sectors including municipal waste, mining and construction. The zero waste concept has been embraced by policy makers, as it is a step forwards towards sustainable development. To implement the concept Municipal solid waste department need to be efficient. Recently solid waste management practices have incorporated with updated technologies to tackle modern challenges in the field of municipal solid waste management. This article has briefly described latest municipal solid waste management technologies and parameters, which should be keep in consideration while choosing the technology for implementation. The article is very useful, as it explored the latest, efficient and environmentally sound technologies in the sector of municipal solid waste.

Keywords: Municipal solid waste management, Zero waste, latest technologies, sustainable development

1. Introduction

Municipal solid waste (MSW) production has rapidly enhanced in previous years. Since 1960, waste generation has drastically increased by a factor of 2.6 [1]. The treatment of MSW should be effectively safe and most importantly, it should be environmentally sound. Reduction, reuse, recycling, sorting, segregation, processing, and disposing are major steps of integrated waste management [2, 3, 4]. Currently many health and environmental issues are related to improper waste management in developing countries [3]. One of the most common issue regarding old methods of waste management is the emission of greenhouse and other toxic gases from treatment and disposal procedures [2, 3]. Hence, other alternative for the management of MSW are required. Excessive use of resources in the industrial sector as well in the households, generates immense quantity of solid waste, which is challenging global sustainability [4]. It has been noticed that with economic improvement in developed countries, the amount of waste generation has been drastically increased [5]. Today, MSW can be seen at every nook and corner, this is due to the poor collection and inadequate transportation in developing countries, where solid waste management is a matter of least concern. According to World Bank global review world cities generates about 1.3 billion tonnes of MSW annually, the amount is expected to reach 2.2 billion tonnes by the end of 2025 [6]. Solid waste management sector comes under the duty of local government, and reasonable portion of budget is allocated for this. In most developing countries solid waste and street sweeping is a single largest source of employment. Additionally it is among the most malignant local pollutant. Poor collection of waste leads deterioration of environmental aesthetics, local flooding, land, air, and water pollution [6, 8]. All these consequences leads to severe human health hazards, which can only be minimize by implementing cost effective technical and policy measures.

To overcome the severe consequences of poor waste management and human health risks recently many new technologies have been introduced. These are more environmentally sound and efficient. While the choice and application of such technology depends upon different factors including country's economic condition, priorities, and types of waste generated [11]. Developing countries like Italy, Japan, USA, and UK are practicing zero waste concept municipal waste management, they are introducing modern ways of waste collection and storage, methods of incineration, pyrolysis, plasma gasification, aerobic and anaerobic digestion, vertification, and deep slurry injections [15, 20, 32, 33, 42, 45, 64]. Other than advance treatment and disposing technologies they are strictly implementing the concept of 3Rs, reduce, reuse and recycle [25]. Competitively developing countries as Nigeria, Bangladesh, India and Pakistan lag behind in the race of latest technologies, while they have a scope to learn from the experiences of developed countries. Lack of expertise, financial resources and other legal framework failure are the root causes of the MSWM problems in all Asia. Along with this the main reasons for uncontrolled solid waste disposal is lack of public awareness and the basic environmental ethics. Developing countries usually focus on disposal of waste and the most common way is landfill. This cannot only cause decrease of average landfill life but also air pollution and global warming due to the release of CO_2 and CH_4 [7, 8, 9]. Latest technologies solved this issue by introducing landfill gas based micro turbines and fuel cells [59, 60]. Hence it is the need of time to implement latest, environment friendly, and less expensive MSWM technologies in order to maintain the sustainability of planet earth [10, 11, 12].

This objective of the article is to compile recently introduced technologies in the sector of MSWM. MSWM is network of activities from storage to disposal. To avoid the environmental contamination and human health risks due to the poor waste management, developing countries should shift towards latest technologies of MSWM. The researcher has briefly covered those latest and innovative technologies of waste management from storage, collection, recycling, processing, energy recovery and final disposal.

2. Collection and transport

Modern collection and transportation of municipal solid waste involve many technical steps and emerging technologies in integrated waste management system [13]. The overlapping of information technology with waste management system give raise to many innovative technologies in the way of sustainable development. Latest technologies including underground collection system, Web based GIS technology, Waste bin monitoring system using GSM, and Waste compactors are being discussed further.

2.1 Underground collection system

New technologies for waste storage are underground and semi underground storing systems. In these technologies waste bins or containers are being replaced by underground collection points. This includes the placement of plastic container in excavation of 2-3m with only inlet in environment [14]. The collection and transportation of waste is carried out using special types of trucks. These types of containers are being used worldwide since years. They have quite extensive range of application from recyclables, to organic waste and oils. The technology is beneficial for the regions with extremely hot climatic conditions as the waste would be stored underground in relatively low temperature. On the other hand the technology require less maintenance and is more aesthetically acceptable [15].

2.2 Web based GIS (Geographic information system) technology

Over the last few years the GIS technology has gained popularity in almost every field of life. Coupling the GIS technology along with waste collecting became popular over the past few years in developed countries like Italy. Through this municipalities can manage the entire waste cycle from production point to disposal areas, by optimizing and automating every step of cycle [16].

The evolution of Information and Communication technology (ICTs) has allowed the creation of efficient integrated systems which also capable to meet the requirements of the waste cycle. This solution of coupling the waste collection and the Web- GIS oriented systems has become increasingly used over the last years in Italy [17]. It is a structured and integrated application, dedicated, generally to, individual Municipalities or to Municipalities and Multi-utilities Associations, for managing the entire cycle of waste, from the point of production to the landfill or to the recycling/ treatment plants, by automating and optimizing each step of the chain. The full traceability and certification of the various. According to the Italian and European case studies the implementation of web based GIS technology optimized the waste collection and source separation for recycling had become efficient up to 80% [17].

As GIS can model the world landmarks and streets, it can play an important role in waste collection sector. GIS in combination of other software can give information regarding the most reliable routs, number of residents, number of contracts, their validation, and potential frauds [17].

2.3 Waste bin monitoring technology using Global System of Mobile (GSM)

Combination of Zigbee technology and GSM is a latest trend in the field of waste collection. In this technology sensors are placed in public garbage bins to detect a certain optimum level of waste. As the garbage reaches the threshold level, indication will be transferred to the controller which will further give indication to driver of collection truck for emptying the bin urgently. The indication will be send to the driver through SMS using GSM [18].

2.4 Compact garbage collection trucks

In many developing countries, because of narrow and congested roads small garbage collection trucks are used. Latest technologies introduced garbage compactors in collector trucks in order to increase the collection capacity of vehicle. With continuous modification currently these trucks have achieved high compression rate as they can carry 1.5 times more waste as compare to flat pile trucks [19]. The technology does not only increase collection capacity, but also increases the fuel efficiency which is more environmentally and economically feasible. Researchers are been working to introduce electric motor drive and hybrid type collection trucks to overcome problems like greenhouse gas emissions and air pollution [19].

3. Segregation and sorting

After collection the second step involved in MSW management system is sorting or segregation of different types of wastes for further processing [20]. Among all the steps sorting is the determining step for reuse and recycling. Latest technologies for municipal waste sorting includes optical sorting, Eddy current sorting, multi compartment bins, and optical sensor based sorting technologies [22, 23, 24].

3.1 Multi-compartment bins

Recently, developed countries including Sweden are using multi compartment bins for source segregation of waste. These types of waste bins have separate compartments for different types of waste. Through this organic, paper waste and recyclables can be segregated on the spot of generation, while recyclable can be recycled or reused, as through this method contamination can be avoided [23].

3.2 Optical sorting

The technology has been emerged rapidly since the last few years. Different types of plastic, composites, and other wastes are being sorted with the help of color sensitive cameras, UV sensors and infrared spectroscopy. With the help of sensors the position of different waste components are identified. This type of sorting is most commonly used for glass waste. Latest technology included optical sorting with laser which is relatively expensive [21]. According to studies this technology can reach a purity of 99.7% for flint glass [22].

3.3 Automatic Bottle Sorting System

This technology is widely used in Japan in recent years. It is comprised on sizing, aligning and clearing machine, along with color identification sensors [22]. The role of sizing machine is to divide the bottles according to the size, after which bottles will send to color sensing machine and then conveyer belt. The bottles of each color are shredded and cullet is prepared. Through this volume of waste is reduced and cullet can be further used in different fields [22].

3.4 Automated Sorting
Modern sorting plants are converting to sensor based sorting systems to improve sorting efficiency. This technology had exempted the low technology or manual sorting options. This technology is beneficial because it has high recovery rate, low operation cost and high reorganization capability. This process can convert and useless garbage to highly useful product output, which can reduce carbon footprint and emissions [24].

3.5 Mechanical Biological Treatment (MBT)
The term MBT is used for the combination of biological and mechanical processes for thr transportation and segregation of waste into various outputs. MBT is be considered as pretreatment. The main aim of MBT is the energy recovery from the waste. The biological processes are designed to minimize the content of water and the mechanical process aims to separate metals and glass from the waste. The quality of the digestate and the compost which has produced by the MBT plant can be challenging for the application on soils, due to the presence of chemical contaminants, which sometimes exceed the standard values [54].

4. Recycling
The best management practice is the implementation of 3Rs concept, developed countries had shifted to this concept decades back, while developing countries are still working on it [25]. Municipal solid waste is a combination of components such as paper, plastic, glass and metal, which can be recycle and reuse certain times. Studies revealed that 28 to 48% of Thailand's MSW is comprised on such components [25]. Further discussed are some latest recycling and reusing technologies.

4.1 Deinking Technology for paper recycling
In developed countries deinking technology was introduced years ago. It is still latest in some developing countries. Through this process paper ink is removed from recycled paper slurry. In Europe the annual production of de-inked pulp has be increased up to 15%. Frequent recycling of newspaper and printed white paper can challenge the quality of paper [22]. According to studies newspaper can be recycled up to 5 times [26].

4.2 Biodegradable and degradable plastic
Arise of new technology plastic which is able to degrade 90% of itself in 90 days has resolved many issues regarding plastic disposal. Biodegradable plastic can be introduce to composting or anaerobic digestion along with organic waste in order to give productive output [22]. Many starch based plastics have been reported as biodegradable [22].
Degradable plastics does not contain stabilizing chemicals to prevent degradation due to UV light and oxygen, as compare to traditional fossil based plastic [27]. Degradable plastic have additives which help in slow and self-degradation due to the sunlight and oxygen. In this process the product slowly loose its shape and then disintegrate completely. This is known as physical disintegration [22].

4.3 Cullet remanufacturing
Mostly glass bottles are reused by refilling after returning to the shops and companies. Latest technologies have been introduced for the remanufacturing of broken glass pieces called cullet. The cullet undergoes melting and remanufacturing of glass bottles or containers. Cullet is also used as substitute in building material and as raw material in insulation [22].

5. Processing
The next step in integrated waste management is processing of collected waste. Processing can helpful in decreasing the waste volume, and recovering many productive outputs including compost, steam, and electricity [28]. The main function of processing is to prolong landfill life. Further will be discussing some latest technologies for waste processing and energy recovery.

5.1 Autoclaving
The technology involve treating the waste with steam at 140-160 ^{O}C for 30-40 minutes [22]. This sterilize the waste and the residue is subjected to screening. Where waste is separated on the basis of weight, organic fiber is segregated from glass and girt. Metals and plastics will send for recycling. The organic fiber has many uses including land applications and as fiber in construction industry or in the making of Refused Derived Fuel (RDFs). The residue of the process is then sent for disposal to the landfill site [29].

5.2 Fluffing
Recently a processing method has been evolved in which the solid waste is separated, sterilize and the organic portion is processed to form pulp like material known as fluff. Many processing facilities have shredders which reduce the size of paper, metal, glass, and organic waste up to 2-5cm. Batteries, carpet and other type waste is separated manually. The reduced size product is then transferred to conveyer stream where metallic portion separates out. High temperature steam is then introduce for further breaking of molecular bonds which destroys pathogens. The product is further grind, dewatered, and separated from other types of waste. The remaining is fine cellulosic material emerges as sanitized, sand like, granular fluff [30].
The fluff by product can be used as soil amendment because of its organic base and high nitrogen content. If not utilized so, the fluff can enter the landfill with 30-75% reduced volume as compare to original content. This technology is currently adopted by western countries where 95% recycling rate has been achieved [30].

5.3 Melting technology
Many developing and developed nations now-a-days are looking for melting technology. In which the waste is melted through electricity or fuel combustion at approximately 1400 ^{o}C [22]. This technology reduces the waste volume up to certain degree and the stable stag is obtained as a byproduct. The solidified residue has many application in construction industry and in land reclamation. The technology has many advantages over incineration. Firstly, it overcome the problem of fly ash, and secondly the melted solidified slag

has stabilized metal portion, hence it can avoid water contamination by leaching as in case of incineration [22].

5.4 Incineration
A thermal waste treatment process in which the unprocessed waste is burn at high temperature is commonly known as Incineration. Sufficient quantity of air is needed in order to oxidize the feedstock or the fuel. For combustion, waste has exposed to 850 ºC [31], and then it is converted to H_2O, CO_2, and the non-combustible material which is known as incinerator bottom ash (IBA) [32]. Recently Japanese researchers are introducing pollution free incineration by recycling incinerated ash, and removal of acidic gases through control technology [33]. Conventional stroke furnace is efficient and environment friendly incinerator reactor [34].

In the United Kingdom the most commonly used combustion reactor is moving grate [35]. The combustion system gradually propels the waste into the combustion chamber by a mechanical actuated grate. The waste is continuously entering from one end of the furnace and the residual ash is being discharged from the other end. The processing conditions needs to be fully controlled in order to optimize the combustion, and also ensuring complete combustion of the feed [35].

Fixed grate reactor is a brick-lined cell which has a fixed metal grate above the ash pit, having two openings, one is at the top or on side for loading and the other one is on the parallel side for removing incombustible solids [36].

5.5 Vermicomposting
The latest technology which is being used in many developing countries as Japan and UK [37]. In this process animal waste, pharmaceutical waste, food and sewage waste is processed through earthworms to give output known as vermiwash which is very rich in Nitrogen, Phosphate and Potassium. In this process specific species of earthworms have been fed on waste which give rise to new generations to feed on waste pile. The processing period ranges from 28-120 days [37]. The temperature ranges between 18-67 ºC with pH between 5.9 and 8.3 where the moisture content 80%. The vermiwash is used as bio fertilizer for crops of maize, soy bean, marigold and cow pea [37].

6. Energy recovery
The last step before disposal is energy recovery. All the waste residue after sorting, reuse, recycle and processing, is further inaugurated for energy recovery. In 2009-2010 UK generates 32millions of waste from which 48% was returned to landfills, 39% was recycled, and energy was produced from 13% of MSW [38]. Studies reviled that energy from waste could account for 17% of UK's electriciy by 2020 [38]. Latest energy conversion technologies are categorize into two broad categories, including bioconversion and thermal conversion technologies. Waste to Energy (WTE) provides a renewable alternative of energy in the world, where we have limited fossil reservoirs.

6.1 Thermal Conversion
This is a technology utilize water, heat or pressure to convert organic and inorganic waste to useful chemicals and compounds. Raw materials like plastics, computer cases, tires and crop residue are subjected to thermal processing system which convert them to useful molecules of fuel gas, oil, and other beneficial products [39]. Through these methods, even heavy metals are converted to harmless oxides [40]. Thermal technologies like incineration and combustion have been used since decades for the conversion of WTE. With the advance in technology in previous years many latest thermal treatment technologies have been introduced some of them are discussed further.

6.1.1 Advance Thermal Treatment Technologies
Advance thermal treatment technologies have been introduced in recent years for efficient and pollution free WTE conversion. These technologies included pyrolysis, gasification and excluded incineration. Now-a-days incineration is used as a processing technology rather as energy generating technology. Because in such a mass burn system the organic content of municipal waste is converted to heat, with the emission of CO_2 and H_2O, which has no fuel value and emission of greenhouse gas is a real problem. Pyrolysis and gasification are not are not very new concepts they have been using since decade for the production charcoal, coke and producer gas. Recently these concepts are extensively been utilized for WTE conversion of solid waste [41].

Pyrolysis

Pyrolysis is the thermal degradation of substance in the absence of oxygen. As compare to incineration, pyrolysis is a conversion of waste to liquid or gaseous fuels along with residue char, which is a mixture of non-combustible material and carbon [42]. The temperature require for the process ranges between 300-800 ºC [42]. The product gas is known as syngas which is the combination of VOCs, CO, H_2, and CH_4. The volatilize gases and volatilize liquids are efficiently used to run a steam engine. Cooled syngas is widely used as liquid fuel [42].

Gasification

Gasification involves partial oxidation of a substance, it lies between combustion and pyrolysis. The temperature required in above 750 ºC. The products are almost the same as pyrolysis; syngas and low C ash. Gasification is a reliable option as it meets the present emission standards and is helpful in maintaining the sustainability of landfill [43]. The feedstock is fed into gasifiers along with limited amount of air. Many downstream gasification processes require syngas to be cleaned from trace level of impurities. The most common impurity is mercury. Carbon bed technology has been utilized for cleanup in recent years [44]. The products of gasification are steam, chemicals, electricity, hydrogen, fertilizers, and natural gas [44].

Different types of waste gasification methods are characterized on the basis of oxygen medium, two of them are steam gasification and plasma gasification. Recently many new technologies have been developed as plasma melting gasification [44].

6.1.2 Plasma Gasification and plasma pyrolysis
A new concept of WTE is plasma gasification and provide a number of advantages [45]. Plasma technologies are further divided into three different categories plasma gasification, plasma pyrolysis and vetrification [45]. Waste like plastic, and

halogens require very high temperature treatments, in order to reduce toxic emissions and to control product composition. This also cause compound to produce syngas. The most important processes in waste management are gasification and vertification. The second step after gasification is plasma pyrolysis [45].

6.1.3 Refuse Derived Fuel (RDF)

The commercialization of waste using RDF has been utilized to make wastes useful. RDF generally refers to the processed MSW, which is basically the fraction of segregated high calorific waste. For the segregation of the waste, it is classified in a mechanical and Mechanical Biological Treatment and then they are labeled as RDF. Solid recovered fuel is a new term which is becoming famous in Europe [46].

MSW hat reaches to the plant goes through several steps of treatments and processes. Firstly the waste is collected in the shredder that break waste bags, in order to reduce their sizes. Then this shredded material is moved to a digestion tower where this waste is preserved for (almost 6 to 8) days. The first four days, the waste is kept in temperature between 60 and 65 ◦C, which is than increased to 70 ◦C for another two days [46]. Resultantly the organic part of the waste is stabilized, thus even the smallest traces of biological compounds are gone. Removal of steel cans and magnetic things from the main stream is done through a magnetic separator. The waste is further separated into three different sizes that is smaller than 8mm, then between 8 to16 mm and lastly greater than 16 mm [47].

6.1.4 Fluidized Bed Technology

For the gasification of finely classified waste fluidized bed reactors are being used. For decades it has been used for incineration, for the combustion process of uniform fuels including raw lignite, coal, and sewage sludge etc. The fluidized bed incinerator is in the form of vertical cylinder. The lower section of fluidized bed is inert materials are fluidized with the air. From the top the waste is fed into the fluidized sand bed. The bed plate has holes which allows the preheated air to enter in the combustion chamber. Range of temperature lies between 850 and 950 °C [48]. Thus the temperature in the bed is not as higher and is around 650 °C or can be a bit higher. Recently Bubbling Fluidized bed systems are commonly used for sludge treatment [49]. Circulating Fluidized bed is used for incineration of rough and dried sewage sludge, this system is highly recommended in developing countries. Rotating Fluidized bed allow a wider ranges of calorific value of the fuels [50, 51].

6.2 Bio-conversion

According to Food and Agriculture Organization (FAO), One third of the total produced food for the consumption of the human was lost along the supply chain food globally [52]. For possible energy recovery, currently food waste and other combustible waste are collectively incinerated and landfilled. However, the upper two techniques are facing more environmental and economic issues. Food waste can be used to produce biofuel through different fermentation processes. Currently, valorization is being used for the production of hydrogen, ethanol, biodiesel and biogas [53].

6.2.2 Dry Anaerobic Composting

This process is a thermophilic process in which no biogas recirculation is required. The time period of hydraulic retention time (HRT) in vertical digester is 20 days. The plant capacity lies between 10,000-35,000 Mg/year [55]. For the treatment of of MSW, this purely dry process is applied. No doubt for optimal performance in the presence of high total solid content in the reactor [55].

7. Disposal

The common and old methods of municipal solid waste disposal were open dumping, burning and incineration [56]. The process of open dumping leads to water and air pollution in the form of land litter, particulates and toxic gases. Methane gas and solid residues are also produced from burning process. American and European countries were famous for the incineration of waste with instant energy recovery, the technology became less common due to high operational cost. Disposal is the last step of MSWM, where the remaining trash after recycling, processing, and WTE is disposed of [56]. Disposal is the most technical step of waste management. Experts are encouraged to introduce technologies to lessen the amounts disposed of annually. In developing countries even today most of the disposal sites are open dumps, they have no proper leachate treatment and landfill gas utilization system [61]. Methods like open dumping were responsible for causing many aesthetic and other environmental issue [57]. Two most common ways of disposing MSW are landfills and deep well injection slurry [63, 64]. Following are modern landfill technologies through which the experts can avoid issues regarding leachate leaking, water contamination, and landfill gas explosion.

7.1 Sanitary Landfill

Landfill is a professionally engineered depression in low population area, for the final disposal of left over after all the previous steps of integrated waste management [63]. Waste is buried in that depression in order to avoid any hydraulic connection between trash and environment including air and water. Landfill is mostly preferred because it has the widest range of capabilities and is least expensive method of waste disposal. In Malaysia 80% of the waste is disposed of in landfill, this could cause serious issue in near future because the present landfill sites are left with very less capacity while the new sites are still under construction [66]. While comparatively in developing countries landfill is the least desirable option while most desirable option is WTE.

7.1 Bioreactor Technology

The latest technology to process disposed of waste rapidly is bioreactor technology. The basic aims of this technology are to enhance the rate of decomposition, circulation of leachate and increase in the growth of microbes, which decompose municipal waste. The waste is then dried by Conventional landfill technology [58].

7.2 Landfill gas recovery technologies

The landfill gas emissions are greatly varied due to geological, hydrological and geotechnical properties which have environmental impacts. The biotic and abiotic factors lead to generation of gas at landfill which is the combination of CH_4 and CO_2. Which is known as biogas. Chemical oxidation produces abiotic gas in the presence of water and metals like Aluminum. Al produces leachate which further undergoes redox reaction to produce of hydrogen gas. Metallic aluminum hydration and bottom ash results in gas production [59]. If mismanaged this gas can cause explosion of landfill or gradual leaking can cause global warming as both the gases (CH_4 and CO_2) are greenhouse gases [59].

The voluntary program landfill methane outreach program is developed to reduce greenhouse gases which are causing climate change. This organization aware the public, stakeholders and local communities about the benefits and technologies of landfill gas recovery [63].

Microturbine Technology

Modern landfills have microturbines for generation of electricity from landfill gas. This technology is used to supply electricity to the small scale nearby projects. This technology is helpful in resolving the issue of air pollution and global warming due to the emission of landfill gas air [59].

Fuel cell Technology

Energy from fuel is converted into electrical energy in an electrochemical cell is called fuel cell. Fuel supply and oxidizing agent react to generate electricity. Carbon dioxide, water vapors, heat and electricity are the end products of fuel reactions. Generation of transportation fuel for cars and buses without combustion is the application of fuel cell [60].

8. Conclusion

Serious environmental degradation occurs due to open, uncontrolled and poorly managed waste dumping in many metropolitan cities of developing countries. Where approximately 90% of the waste is disposed of in open dumping areas. Recently developed countries have implemented the visionary concept of zero waste which is encouraging latest technologies of MSWM. While on the other hand in most developing countries waste management is a matter of least concern, which is causing severe environmental and health issues in those countries.

The sustainable management of municipal solid waste can reduces the short and long term environmental and human health hazards. The article concluded that proper implementation of latest technologies in the sector of MSW management can play a very important role in providing pollution free and sustainable environment.

9. Acknowledgment

Authors are thankful to the faculty members of the Department of Environmental Science of Kinnaird College for Women, Lahore, Pakistan for guiding us and going with us all along during the entire course of the project. Especially, we would like to thank Ma'am Almas Hamid, without whose guidance the project could not have been completed.

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