

**ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES**

MSc THESIS

Çağrı ÜN

**PRODUCTION, PERFORMANCE AND EMISSION STUDIES OF
MUNICIPAL AND MEDICAL WASTE PLASTIC FUELS AND ITS BLENDS
WITH DIESEL**

DEPARTMENT OF AUTOMOTIVE ENGINEERING

ADANA, 2014

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ABSTRACT

MSc THESIS

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DEPARTMENT OF AUTOMOTIVE ENGINEERING**

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The basic aim of this study was to examine the usage of plastic municipal and medical waste, as an alternative source to diesel fuel. For this study; waste plastic materials, obtained from municipal and medical wastes, were used. Waste plastics were transformed to waste plastic fuel by thermal cracking. Municipal and medical waste plastic fuels were blended with diesel fuel at volumetric ratios of 10%, 20% and 50%. Fuel properties of waste plastic fuels and its blends were analyzed in accordance with the standards of American Society for Testing and Materials (ASTM) methods. In addition to fuel properties, engine performance and exhaust emission studies of waste plastic fuel-diesel blends were carried out.

Key Words: Engine Performance, Emissions, Fuel Properties, Thermal Cracking, Municipal and Medical Waste Plastic Fuel

ÖZ

YÜKSEK LİSANS TEZİ

<p>BELEDİYE VE TIBBİ ATIK PLASTİKLERİNDEN YAKIT ELDESİ VE BU YAKITIN DİZEL KARIŞIMLARININ PERFORMANS VE EMİSYON DEĞERLERİNİN ARAŞTIRILMASI</p>

Çağrı ÜN

**ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
OTOMOTİV MÜHENDİSLİĞİ ANABİLİM DALI**

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Bu çalışmanın ana hedefi; plastik belediye ve tıbbi atıklarının alternatif bir dizel yakıt kaynağı olarak kullanımının incelenmesidir. Bu çalışma için; belediye ve tıbbi atıklardan elde edilen atık plastik materyaller kullanılmıştır. Atık plastikler termal parçalanma ile atık plastik yakıtıya dönüştürülmüştür. Belediye ve tıbbi atık plastik yakıtı, dizel yakıt ile hacimsel olarak %10, %20 ve %50 oranlarında karıştırılmıştır. Atık plastik yakıtlarının ve dizel karışımlarının yakıt özellikleri Amerikan Test ve Malzeme Birliği (ASTM) yöntem standartlarına göre analiz edilmiştir. Ayrıca atık plastik yakıt-dizel karışımları için; yakıt özellikleri, motor performansı ve egzoz emisyon çalışmaları gerçekleştirilmiştir.

Anahtar Kelimeler: Motor Performansı, Emisyonlar, Yakıt Özellikleri, Termal Parçalanma, Belediye ve Tıbbi Atık Plastik Yakıtı

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CONTENTS	PAGE
ABSTRACT	I
ÖZ.....	II
ACKNOWLEDGEMENTS	III
CONTENTS	IV
LIST OF TABLES	VIII
LIST OF FIGURES	XII
LIST OF ABBREVIATIONS AND NOMENCLATURE	XIV
1. INTRODUCTION	1
2. LITERATURE REVIEW	5
3. MATERIAL AND METHOD	15
3.1. Municipal Solid Waste	18
3.1.1. Composition of Municipal Solid Waste	23
3.1.2. Future Projections for Solid Waste	26
3.1.3. Municipal Solid Waste Management	29
3.1.3.1. Reduce, Reuse and Recycle Methods	29
3.1.3.2. Treatment and Disposal Methods	30
3.1.3.3. Dumps and Landfills.....	32
3.1.3.4. Biological Waste Treatment	34
3.1.4. Municipal Solid Waste Situation in Turkey and Adana	35
3.2. Medical Waste (Health-Care Waste)	39
3.2.1. Classification of Health-Care Waste	40
3.2.2. Sources of Health-Care Waste	50
3.2.3. Characteristics of Health-Care Waste	52
3.2.3.1. Average Material Constituents of Health-Care Waste	54
3.2.3.2. Moisture Content of Health-Care Waste	55
3.2.3.3. Percent Incombustibles in Health-Care Waste	56
3.2.3.4. Heating Value of Health-Care Waste.....	56
3.2.4. Hazards of Medical Waste	58
3.2.4.1. Hazards from Infectious Waste and Sharps.....	59

3.2.4.2. Hazards from Chemical and Pharmaceutical Waste.....	59
3.2.4.3. Hazards from Genotoxic Waste	60
3.2.4.4. Hazards from Radioactive Waste.....	61
3.2.4.5. Hazards from Health-Care Waste Treatment Methods	62
3.2.5. Selection of Medical Waste Treatment Methods	63
3.2.6. Overview of Medical Waste Treatment Technologies	64
3.2.6.1. Thermal Processes	68
3.2.6.1.(1). Low Heat Thermal Processes.....	69
3.2.6.1.(2). High Heat Thermal Processes.....	73
3.2.6.2. Chemical Processes	78
3.2.6.3. Irradiation Technologies	80
3.2.6.4. Biological Processes	81
3.2.6.5. Mechanical Processes	81
3.2.7. Health-Care Waste Situation in Turkey and Adana	82
3.3. Plastics	86
3.3.1. Plastic Types.....	88
3.3.2. The SPI Resin Identification Code.....	92
3.3.3. Description of Waste Plastics	99
3.3.4. Damage of Waste Plastics.....	100
3.3.5. Converting Waste Plastics to Fuel	102
3.3.5.1. Pyrolysis/Thermal Degradation	104
3.4. Experimental	108
3.4.1. Reactor.....	110
3.4.2. Properties of Waste Plastics.....	110
3.4.3. Production of Waste Plastic Fuels.....	113
3.4.4. Preparing Municipal and Medical Waste Plastic Fuel Blends	114
3.4.5. Fuel Quality Measurement Methods	115
3.4.5.1. Density Measurement	116
3.4.5.2. Viscosity Measurement.....	116
3.4.5.3. Cetane Number Measurement.....	117
3.4.5.4. Flash Point Measurement.....	118

3.4.5.5. Pour Point Measurement.....	119
3.4.5.6. Heating Capacity Measurement.....	120
3.4.6. Diesel Engine Test Rig	121
3.4.7. Exhaust Emission Measurements	123
4. RESULTS AND DISCUSSION	125
4.1. Municipal Waste Plastic-Diesel Blended Fuels.....	125
4.1.1. Fuel Properties	125
4.1.2. Engine Performances	126
4.1.2.1. Brake Power Outputs	126
4.1.2.2. Torque Outputs	128
4.1.3. Exhaust Emissions	129
4.1.3.1. CO Emissions	129
4.1.3.2. CO ₂ Emissions.....	130
4.1.3.3. NO _x Emissions.....	132
4.2. Medical Waste Plastic-Diesel Blended Fuels.....	133
4.2.1. Fuel Properties	133
4.2.2. Engine Performances	135
4.2.2.1. Brake Power Outputs	135
4.2.2.2. Torque Outputs	136
4.2.3. Exhaust Emissions	138
4.2.3.1. CO Emissions	138
4.2.3.2. CO ₂ Emissions.....	139
4.2.3.3. NO _x Emissions.....	140
5. CONCLUSION AND RECOMMENDATIONS	143
REFERENCES.....	145
CURRICULUM VITAE	151

LIST OF TABLES	PAGE
Table 3.1. Generators and types of solid waste.....	16
Table 3.2. Comparison of solid waste characterisation worldwide (% wet wt).....	19
Table 3.3. General sources of municipal solid wastes	21
Table 3.4. Classification of materials comprising municipal solid wastes	21
Table 3.5. Types of waste and their sources	23
Table 3.6. Domestic waste composition for selected major cities in the ESCAP region (%)	25
Table 3.7. Urban waste composition in different parts of the world.....	26
Table 3.8. Waste generation projections for 2025 by region	28
Table 3.9. Seasonal variations in the composition of waste in selected cities in Turkey at 1993	37
Table 3.10. Municipal solid waste composition in major cities of Turkey, (% in weight)	39
Table 3.11. Categories of health-care waste	41
Table 3.12. Chemical waste from health-care activities	47
Table 3.13. Worldwide average material constituents of healthcare waste (excluding food waste).....	55
Table 3.14. Average material constituents of healthcare waste	55
Table 3.15. Percent moisture content of health-care waste constituents.....	56
Table 3.16. Heating values of various healthcare waste components.....	57
Table 3.17. Advantages and disadvantages of treatment options	66
Table 3.18. Typical reaction conditions and products from pyrolysis, gasification and incineration processes.....	78
Table 3.19. Average amount of medical waste per outpatient and inpatient at Turkey (2010 – 2012)	84
Table 3.20. Amount of medical waste by disposal methods at Turkey and Adana (2012) kg/year.....	85
Table 3.21. Physical and elemental composition of hospital waste in four hospitals in Sivas, Turkey	86

Table 3.22.	Table of plastic packaging resins codes	94
Table 3.23.	Polymer as feedstock for fuel production	104
Table 3.24.	Suitability of some plastics for pyrolysis and their products	106
Table 3.25.	Properties of waste plastic pyrolysis oil and diesel fuel	111
Table 3.26.	HDPE-2 plastic properties	112
Table 3.27.	LDPE-4 plastic properties	112
Table 3.28.	PP-5 plastic properties	113
Table 3.29.	PS-6 plastic properties	113
Table 3.30.	Municipal waste plastic fuel contents of prepared diesel blends	115
Table 3.31.	Medical waste plastic fuel contents of prepared diesel blends	115
Table 3.32.	Technical specifications of the test engine.....	122
Table 3.33.	Technical specifications of the dynamometer.....	122
Table 4.1.	Fuel properties of municipal waste plastic-diesel blended fuels.....	125
Table 4.2.	R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of brake power with engine speed values.....	127
Table 4.3.	R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of torque with engine speed values	129
Table 4.4.	R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of CO with engine speed values	130
Table 4.5.	R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of CO ₂ with engine speed values.....	131
Table 4.6.	R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of NO _x with engine speed values	133
Table 4.7.	Fuel properties of medical waste plastic-diesel blended fuels.....	134
Table 4.8.	R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of brake power with engine speed values	136
Table 4.9.	R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of torque with engine speed values.....	137
Table 4.10.	R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of CO with engine speed values	139

Table 4.11. R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of CO_2 with engine speed values	140
Table 4.12. R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of NO_x with engine speed values.....	141
Table 4.13. Reduction and increment ratios of CO, CO_2 and NO_x emissions	144

LIST OF FIGURES	PAGE
Figure 2.1. Design features of the assessed incinerator.....	10
Figure 3.1. Global solid waste composition (2009)	24
Figure 3.2. Composition of domestic waste in Turkey (2008).....	38
Figure 3.3. Typical waste compositions in health-care facilities	40
Figure 3.4. Simplified schematic of a pre-vacuum autoclave	73
Figure 3.5. Simplified flow scheme of the incineration process	77
Figure 3.6. Pyrolysis process of generating fuel oil from the waste plastics	107
Figure 3.7. Thermal cracking reactor	109
Figure 3.8. Technical draw of reactor system.....	109
Figure 3.9. Municipal waste plastic experiment samples.....	110
Figure 3.10 Medical waste plastic experiment samples.....	111
Figure 3.11. Distillated medical waste plastic fuel	114
Figure 3.12. Medical waste plastic fuel-diesel blends	115
Figure 3.13. Kyoto electronics DA-130 portable densimeter	116
Figure 3.14. Saybolt universal viscosimeter	117
Figure 3.15. Zeltex ZX 440.....	118
Figure 3.16. Tanaka APM-7.....	119
Figure 3.17. Tanaka MPC-102 L	120
Figure 3.18. IKA-WERKE C2000 calorimeter.....	121
Figure 3.19. Layout of experimental setup	121
Figure 4.1. Brake power outputs versus engine speed of diesel, MUNWP10, MUNWP20 and MUNWP50	127
Figure 4.2. Torque outputs versus engine speed of diesel, MUNWP10, MUNWP20 and MUNWP50	128
Figure 4.3. CO emission values of diesel, MUNWP10, MUNWP20 and MUNWP50	130
Figure 4.4. CO ₂ emission values of diesel, MUNWP10, MUNWP20 and MUNWP50	131

Figure 4.5. NO _x emission values of diesel, MUNWP10, MUNWP20 and MUNWP50	132
Figure 4.6. Brake power outputs versus engine speed for diesel, MEDWP10, MEDWP20 and MEDWP50	136
Figure 4.7. Torque outputs versus engine speed for diesel, MEDWP10, MEDWP20 and MEDWP50	137
Figure 4.8. CO emission values of diesel, MEDWP10, MEDWP20 and MEDWP50	138
Figure 4.9. CO ₂ emission values of diesel, MEDWP10, MEDWP20 and MEDWP50.....	139
Figure 4.10. NO _x emission values of diesel, MEDWP10, MEDWP20 and MEDWP50.....	141

LIST OF ABBREVIATIONS AND NOMENCULATURE

MSW	: Municipal Solid Waste
ESCAP	: United Nations Economic and Social Commission for Asia and Pasific
ASEAN	: Association of Southeast Asian Nations
MOEF	: Ministry of Environment and Forestry
SWMP	: Solid Waste Master Plan
UNEP	: United Nations Environmental Programme
WHO	: World Health Organization
AFR	: Africa Region
EAP	: East Asia and Pacific Region
ECA	: Europe and Central Asia Region
LCR	: Latin America and the Caribbean Region
MENA	: Middle East and North Africa Region
OECD	: Organisation for Economic Co-operation and Development
SAR	: South Asia Region
GHG	: Greenhouse Gas
ASTM	: American Society for Testing and Materials
MUNWP	: Municipal Waste Plastic
MEDWP	: Medical Waste Plastic
PET	: Polyethylene Terephthalate
HDPE	: High Density Polyethylene
LDPE	: Low Density Polyethylene
NO _x	: Nitrogen Oxide
CO	: Carbon Monoxide
PP	: Polypropylene
PS	: Polystyrene
PVC	: Polyvinyl Chloride
PBD	: Polybutadiene
GC/MS	: Gas Chromatography and Mass Spectrometer
FT-IR	: Furrier Transform Infrared Spectroscopy

DSC	: Differential Scanning Calorimeter
EPA	: US Environmental Protection Agency
PE	: Polyethylene
US-Y	: Zeolite Catalyst of Ultrastable Y-Type
LDO	: Light Diesel Oil
HSD	: High Speed Diesel
AV	: Acid Value
GL	: Gas Liquid
FID	: Flame Ionization Detector
Ow(t)	: Other Waste Loaded in Primary Chamber
Sw(t)	: Sharps Waste Loaded in Primary Chamber
Tc(t)	: The Incineration Cycle Time
Do(t)	: Total Diesel Oil Consumed per Cycle
WPE	: Waste Polyethylene
LP	: Light Phase
HP	: Heavy Phase
GC/MS	: Gas Chromatography/Mass Spectrometry
C&D	: Construction and Demolition Waste
ICI	: Industrial, Commercial and Institutional
HEPA	: High Efficiency Particulate Air
JICA	: Japan International Cooperation Agency
WEEE	: Waste Electrical and Electronic Equipment
DNA	: Deoxyribonucleic Acid
MSEA	: Egypt Ministry of State for Environmental Affairs
EEAA	: Egyptian Environmental Affairs Agency
USAID	: U.S. Agency for International Development
HCWH	: Health Care Without Harm

1. INTRODUCTION

Economic growth, changing consumption and production patterns are resulting into rapid increase in generation of waste plastics in the world. In Asia and the Pacific, as well as many other developing regions, plastic consumption has increased much more than the world average due to rapid urbanization and economic development.

The world's annual consumption of plastic materials has increased from around 5 million tonnes in the 1950's to nearly 100 million tonnes; thus, 20 times more plastic is produced today than 50 years ago. This implies that on the one hand, more resources are being used to meet the increased demand of plastic, and on the other hand, more plastic waste is being generated.

Due to the increase in generation, waste plastics are becoming a major stream in solid waste. After food waste and paper waste, plastic waste is the major constitute of municipal and industrial waste in cities. Even the cities with low economic growth have started producing more plastic waste due to plastic packaging, plastic shopping bags, PET bottles and other goods/appliances using plastic as the major component.

This increase has turned into a major challenge for local authorities, responsible for solid waste management and sanitation. Due to lack of integrated solid waste management, most of the plastic waste is neither collected properly nor disposed of in appropriate manner to avoid its negative impacts on environment and public health and waste plastics are causing littering and choking of sewerage system. On the other hand, plastic waste recycling can provide an opportunity to collect and dispose of plastic waste in the most environmental friendly way and it can be converted into a resource. In most of the situations, plastic waste recycling could also be economically viable, as it generates resources, which are in high demand. Plastic waste recycling also has a great potential for resource conservation and GHG emissions reduction, such as producing diesel fuel from plastic waste. This resource conservation goal is very important for most of the national and local governments, where rapid industrialization and economic development is putting a lot of pressure on natural resources. Some of the developed countries have already

established commercial level resource recovery from waste plastics. Therefore, having a “latecomer’s advantage,” developing countries can learn from these experiences and technologies available to them (UNEP, 2009a).

Healthcare waste is all the waste generated by healthcare facilities, medical laboratories and biomedical research facilities, as well as waste from minor or scattered sources. The bulk of healthcare waste is produced by hospitals. Improper treatment and disposal of healthcare waste pose serious hazards of disease transmission due to exposures to infectious agents among waste pickers, waste workers, health workers, patients, and the community in general. Open burning and incineration without adequate pollution control expose waste workers and the community to toxic contaminants in air emissions and ash (UNEP, 2012).

Health-care waste comes from many sources, including major sources such as hospitals, clinics and laboratories, as well as minor sources such as doctor’s offices, dental clinics and convalescent homes. Between 75% and 90% of the waste produced by health-care facilities is non-hazardous or general health-care waste, and only 10% to 25% of health-care waste has a hazard that requires careful management. A significant portion of non-hazardous, general waste is recyclable or compostable (WHO, 2013).

Health-care waste management, as well as posing technical problems, is strongly influenced by cultural, social, and economic circumstances. A well designed waste policy, a legislative framework, and plans for achieving local implementation are essential. Change will be gradual and should be technically and financially sustainable in the long term (WHO, 1999).

The basic aim of this study was to examine the usage of plastic municipal and medical waste, as an alternative source to diesel fuel. For this study; waste plastic materials, obtained from municipal and medical wastes, were used. Waste plastics were transformed to waste plastic fuel by thermal cracking. Municipal and medical waste plastic fuels were blended with diesel fuel at volumetric ratios of 10%, 20% and 50%. Fuel properties of waste plastic fuels and its blends were analyzed in accordance with the standards of American Society for Testing and Materials

(ASTM) methods. In addition to fuel properties, engine performance and exhaust emission studies of waste plastic fuel-diesel blends were carried out.

2. LITERATURE REVIEW

The amount of waste plastics discarded each year is constantly increasing and is causing serious pollution-related problems worldwide. Chemically recycling such waste might provide cheap and abundant sources of useful chemicals and energy. Among a number of potential approaches to recycling, chemical approaches, which convert waste plastics to useful hydrocarbons, have been recognized as being of particular promise.

The production of gasoline, kerosene and diesel from waste plastics is an emerging technological solution to the vast amount of plastics that cannot be economically recovered by conventional mechanical recycling operations.

Plastic pyrolysis involves the thermal degradation of the wastes in the absence of oxygen/air. It provides for the disposal of plastic wastes with recovery of valuable gasoline and diesel-range hydrocarbons. During pyrolysis, the polymeric materials are heated to high temperatures, such that their macromolecular structures are broken down into smaller molecules, resulting in a wide range of hydrocarbons being formed. These pyrolytic products can be divided into a noncondensable gas fraction, a liquid fraction (consisting of paraffins, olefins, naphthenes and aromatics), and solid residues (i.e. char) (Scheirs et al., 2006).

Sarker et al. (2012) performed the experiments of combination waste plastics such as High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polypropylene (PP) and Polyvinyl Chloride (PVC) were carried out in a steel reactor. The thermal cracking process was carried out in temperature range of 150 °C to 400 °C. The principle process products are gaseous and liquid hydrocarbon fractions similar to refinery cracking products. The solid carbon residue of around 8% to 9% of the total raw materials are similar to coal cokes and contains higher mineral contents than the other two products. Upon further analysis using gas chromatography and mass spectrometer (GC/MS) and furrier transform infrared spectroscopy (FT-IR) of the liquid hydrocarbon fraction showed similar chemical properties to commercial gasoline and diesel products. The similarity was in the distribution of carbon chains and alkane groups. Analysis using differential scanning

calorimeter (DSC) showed the calorific value is comparable as well. The thermal degradation process was shown to be efficient because it was able to convert PVC, which contains 56% chlorine to hydrocarbon products. Specific analysis was done for the identification of chlorine in the liquid hydrocarbon products, and results have shown that the liquid hydrocarbon products contained lower chlorine content than standard chlorine level allowed by EPA. It was found that PVC decreased the amount of liquid products and increased the residue and gases yield. The highest effect was observed for simultaneous presence of PVC in the polymer mixture. The thermal process fuel consists of benzene derivatives toluene and p-Xylene but heteroatoms are also present as organic compounds. PVC affected the amount and distribution of chlorine containing compounds in thermal degradation process liquid hydrocarbon fuel.

Tiwari et al. (2009) studied the process involves catalytic degradation of waste plastic into fuel range hydrocarbon i.e. petrol, diesel and kerosene etc. A catalytic cracking process in which waste plastic were melted and cracked in the absence of oxygen and at very high temperature, the resulting gases were cooled by condensation and resulting crude oil was recovered. From this crude oil various products petrol, diesel and kerosene etc. can be obtained by distillation. This process mainly consists of four units; (1) reacting vessel or reaction chamber, (2) condensation unit, (3) receiving unit, (4) distillation unit. More specifically the degradation of waste plastic except PVC and PET over two commercial grade cracking catalysts, containing 20% and 40% ultra stable Y zeolite, respectively, was studied in a semi-batch reactor. Also the effect of polymer catalyst ratio was studied on the formation of liquid hydrocarbons. The best results were obtained when polymer catalyst ratio was 4:1 and after this ratio the liquid yield decreases. Furthermore alternate method for disposal of waste plastic is also studied. And the results of this process are found to be better than other alternate methods which are used for the disposal of waste plastic.

A clear trend of liquid hydrocarbon formation was observed with the catalyst content during the catalytic degradations of polyethylene over the commercial cracking catalysts. Further more it is very clear from the above experiment that waste

plastic can be converted into liquid fuel that can directly used as fuel but it will be better to use the as LDO and HSD for furnace heating etc. the process is very cheap as the catalyst can be recovered and used again and again. Conversion of waste plastic into fuel will reduce dependence on fossil fuels as well as the one of the most critical problem can be solved. The process is 100% eco-friendly as nothing is left in the environment and getting rid of plastic waste. Sulfur content in the fuel generated is less than 0.002% (Tiwari et al., 2009).

Sárközi et al. (2011) obtained by catalytic cracking of average municipal waste sample are presented with the aim to obtain liquid fuels. The yield of such fuels is determined mainly by plastics content in the waste and in their experiments was between 35 to 50% wt. from the input waste at the temperatures of 390 – 550 °C. Municipal waste for the testing of catalytic cracking included plastics, paper, wood, textiles, metals, glass, biological wastes and water (moisture of material). Municipal wastes collection came from the city Győr, Hungary. It was adjusted to the size of 5 mm. As the catalyst, natural zeolite with particle size 1-3 mm was used. Cracking of municipal waste was taking off in the three-stage stainless steel reactor with screw mixers with a diameter of 300 mm. The capacity of the reactor was 200 - 350 kg/h of wastes. During the measurements in a continuous reactor semi-continuous mode was kept. The temperature was measured at each stage by a thermocouple and had an increasing trend from stage to stage. The reactor heating was direct by flame of natural gas. Resulting volatile products were lead into two condensers in series with different coolant temperatures. The condensers were designed for the condensation of all condensable products. Volatile and gas products, which were not condensed, were kept in storage tank and then burned in a gas engine.

Treatment of liquid condensate consisted of two distillation steps and was performed in the laboratory. The first distillation was carried out at atmospheric pressure to a temperature of 150 °C. Condensate from this operation was separated spontaneously into two liquid phases after a short time, thus forming the water phase and the upper nonpolar phase, the fraction 150 °C. The residue after the first distillation step underwent vacuum distillation at a pressure of 20 kPa and a temperature of 250 °C which corresponds to the temperature of about 330 °C at

normal pressure. Vacuum distillate, which contained components with boiling point between 150 °C to 330 °C after re-calculation, was named as a fraction 150 °C - 330 °C. The distillation residue was a dark viscous liquid like bitumen.

The fraction 150 °C is usually a clear pale yellow in color with a strong odor. Fraction 150-330 °C is again a clear orange liquid with a characteristic odor. It may contain the paraffin deposits, soluble at 40 °C. Individual fractions obtained by the treatment of the liquid condensate were evaluated by gas chromatography and the acid value (AV), density, viscosity and mass balance were determined. For analytical evaluation, the GL chromatography device Chrompack CP 9000 with a glass column packed with 10% SE 30 on Chromatone NAW-DMCS 1.8 mx 3 mm, provided with FID was used. To determine other parameters, the standardized procedures were performed. In the condensate after its distillation the components C₄ - C₇ prevailed in it, typical for gasoline, but with the higher density comparable with the fossil diesel (Sárközi et al., 2011).

Manyele and Kagonji (2012) involved assessment of the medical waste incineration which is a thermal waste treatment process that involves the combustion of organic substances contained in the waste materials at higher temperatures (850 °C – 1000 °C), a process which takes too long if the incinerator is not well designed and operated. The incineration process detoxifies medical waste by destroying most of the organic compounds contained in it and reduces the volume and weight of the waste leading to inert residual of solids, with an appreciable amount of fuel being consumed.

Their study was conducted at Temeke district hospital for 22 months consecutively covering 654 days of daily data collection on waste loading rate fuel consumption and cycle times. The composition for the medical waste incinerated varied between 15% and 35% for sharps waste and between 65% and 85% for other waste, with mean values of 25% and 75%, respectively. The results revealed poor performance of the incinerator due to higher fuel consumption (above 30 L/cycle). The incineration cycle times were observed to range between 2 and 4 hours, all of which were too high for the loading rates observed (55 - 214 kg). A strong dependency of diesel oil consumption on cycle time was observed due to lack of

temperature control leading to continuous fuel flow into the burners. The incineration capacity was very low compared to other incinerators in terms of tons per year. Their study gives an insight on the factors affecting incinerator performance assessed based on diesel oil consumption and cycle times. It can be generalized that the incinerator performance was poor due to several factors ranging from poor incinerator design, operator skills, waste management practices, waste storage practices, etc. The hospital was advised to install a new incinerator with short incineration cycle time (30 - 40 minutes) and lower fuel consumption (10 L/cycle) at a loading rate of 200 kg/cycle.

The old Temeke hospital incinerator was a simple facility comprising of a cylindrical combustion chamber with an opening for waste feeding and a chimney for smoke outlet, as shown in Figure 2.1. The secondary burner (or afterburner) is connected to the chimney, which acts as a secondary chamber. The waste is loaded on the grate and ashes are collected below the grate. Such units are not suitable in terms of combustion efficiency and environmental acceptance. The first chamber performs pyrolytic destruction of the waste and final combustion of gases takes place in the secondary chamber. This incinerator was designed mainly for destroying placentas from labor wards, but due to scarcity of incineration facilities, it was used for destroying all medical waste generated in a district hospital, which implies that the incinerator was being overloaded.

The fuel consumption was alarmingly high, about 20 - 40 L/h, which necessitated investigation. The maximum temperature was about 700 °C only in the secondary chamber, but the primary chamber temperature was only about 400 °C – 500 °C. The incinerator had the capacity to burn only about 10 placentas per day, but was usually loaded from 55 to 214 kg of mixed medical waste due to lack of incineration facilities. Lack of air pollution control device made the whole equipment less useful. The incinerator was located in densely populated area, which made the smoke problems to be a continuous nuisance to the nearby community. Other incinerator problem in relation to its design was fluid leakage (blood) from the drying placentas in the primary chamber onto the floor which caused aesthetic view and odorous environment.

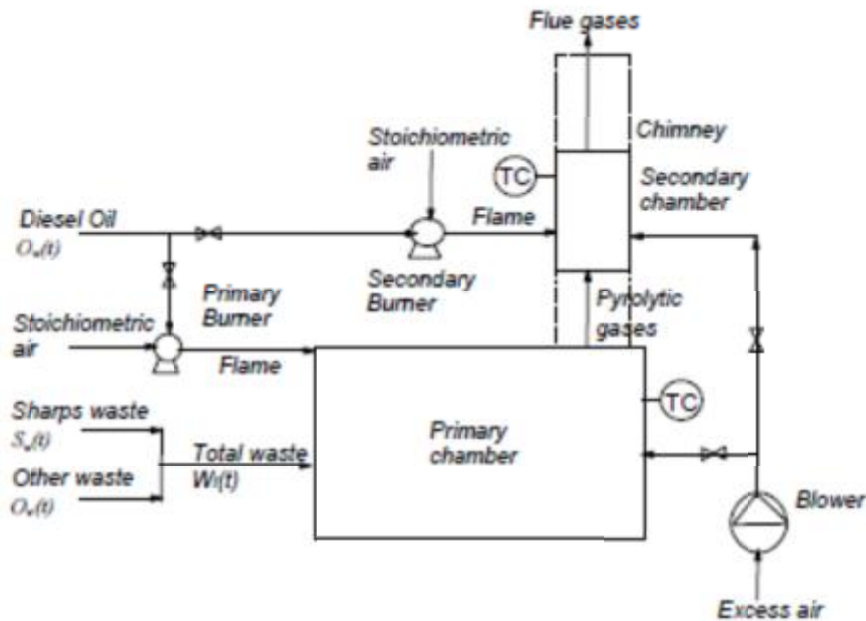


Figure 2.1. Design features of the assessed incinerator (Manyele and Kagonji, 2012).

Based on the above findings, it can be concluded that;

- 1) The sharps waste composition for the medical waste incinerated varied between 15% and 35%, while the other waste varied between 65% and 85% with mean values of 25% and 75%, respectively,
- 2) The results revealed poor performance of the incinerator due to higher fuel consumption (above 30 L/cycle),
- 3) The incineration cycle times were observed to range between 2 and 4 hours, all of which were too high for the loading rates observed (60 - 120 kg),
- 4) A strong dependency of total diesel oil consumed per cycle by the two burners, $Do(t)$, and the incineration cycle time, $Tc(t)$, was observed due to lack of temperature control leading to continuous fuel flow into the burners (at 10 L/h), caused by low temperature in the chambers below the set points of 600 °C – 700 °C in the primary chamber and 950 °C in the secondary chamber,

- 5) The incineration capacity was very low compared to other incinerators in terms of tons per year,
- 6) Manyele and Kagonji (2012) gives an insight on the factors affecting incinerator performance assessed based on diesel oil consumption and cycle times,
- 7) It can be generalized that the incinerator performance was poor due to several factors ranging from poor incinerator design, operator skills, waste management practices, waste storage practices, etc (Manyele and Kagonji, 2012).

Özcanlı (2003) evaluated the use of fuels produced from waste polyethylene (WPE) as an internal combustion engine fuel. Waste Polyethylene (WPE) was degraded thermally for conversion. The fuel collected at optimum conditions (414 °C - 480 °C range and 2 hour reaction time) was fractionated at different temperatures and fuel property of the fractions was evaluated. The volatile fractions and the residue part of WPE final product are called as light phase (LP) and heavy phase (HP), respectively. Light Phase and Heavy Phase were blended with diesel fuel (D) at the volumetric ratios of 5%, 10%, 15%, 20% and 100%. Fuel properties of plastic oils and their blends with diesel fuel were stated. On the other hand, performance and emission characteristics of 5% waste fuel-diesel fuel were evaluated. The WPE fuels were compared with the diesel fuel. Although the pour points of waste fuels have been concluded as a disadvantage, it is found that they can also be used as recycled-fuel in compression ignition engines by blending them with diesel fuel in order to reduce fossil fuel usage.

In order to decrease fossil fuel consumption, recycled fuel production and usage were evaluated in Özcanlı's study. Generally, fuel properties of blends were found comparable with those of diesel fuel within the EN standards and they can also be used as fuel in compression ignition engines. Only the pour point values were stated as disadvantages. For this reason LP5 and HP5 are determined as the suitable blends for engine usage related to cold weather conditions and they can be used in diesel engines without any constructive modification (Özcanlı, 2013).

Sarker and Rashid (2013) did waste plastics mixture and waste tire mixture to liquid fuel was recovery using ferric carbonate catalyst at temperature range 250 - 430 °C. Raw materials were low density polyethylene, high density polyethylene, polypropylene, polystyrene and waste tire. In batch process experiment was conducted under laboratory fume hood with vacuum system. 50% waste plastics and 50% tire sample was use by weight and 2% ferric carbonate was added as a catalyst. Product fuel density is 0.78 gm/ml and fuel was analysis by GC/MS and hydrocarbon chain showed C₃ - C₂₀ including aromatic group. Experimental conversion rate showed liquid fuel conversion rate was 47.4%, light gas 14.9% and left over residue was 37.7%. Product fuel can use internal combustion engine or electricity production. Tire mixed with waste plastics production percentage is decrease because waste tire has high percentage of additives. Fuel color is light yellow and fuel was analysis by GC/MS and carbon chain was detected C₃ to C₂₀. Product fuel has aromatic group compounds and compounds are benzene, toluene, ethylbenzene, p-xylene, (1-methylethyl)-benzene, propyl-benzene, 1-ethyl-3-methyl-benzene, α-methylstyrene, 4-ethenyl-1,2-dimethyl-benzene, bis-1, 1'- (1, 3 - propanediyl) benzene. Aromatic group percentage high because initial raw materials has polystyrene (PS) and tire both materials has aromatic group compounds. Fuel can use internal combustion engines and fuel can produce electricity using generator or power plant. Using present technology can convert waste plastic and tire to fuel and at a time can reduce waste plastics and waste tire problem from environment. Huge amount of waste plastics and waste tire are setting landfill or environment all of those waste plastic and waste tires can convert into valuable fuel sources. It can create lot of job sector and boost up renewable/alternative energy sector and reduce some percentage of oil dependency.

Kumar and Singh (2011) examined the thermal degradation of waste plastics in an inert atmosphere has been regarded as a productive method, because this process can convert waste plastics into hydrocarbons that can be used either as fuels or as a source of chemicals. Their work, waste high-density polyethylene (HDPE) plastic was chosen as the material for pyrolysis. A simple pyrolysis reactor system has been used to pyrolyse waste HDPE with the objective of optimizing the liquid

product yield at a temperature range of 400 °C to 550 °C. Results of pyrolysis experiments showed that, at a temperature of 450 °C and below, the major product of the pyrolysis was oily liquid which became a viscous liquid or waxy solid at temperatures above 475 °C. The yield of the liquid fraction obtained increased with the residence time for waste HDPE. The liquid fractions obtained were analyzed for composition using FT-IR and GC/MS. The physical properties of the pyrolytic oil show the presence of a mixture of different fuel fractions such as gasoline, kerosene and diesel in the oil. The liquid yield is highest at 450 °C. Highly volatile products are obtained at low temperature. The products obtained at 500 °C and 550 °C are viscous liquid and wax and the product obtained at 600 °C is only wax. Liquid yield increases as the holding time increases from 1 hr to 4 hr at temperatures from 400 °C to 450 °C, but as the holding time increases from 4 hr to 6 hr, the liquid yield decreases. Reaction time decreases with an increase in temperature. It has been shown that a simple batch pyrolysis method can convert waste HDPE to liquid hydrocarbon products with a significant yield, which varies with temperature.

Wallis et al. (2007) performed the thermal degradation of high density polyethylene was conducted in a reactive extruder at various screw speeds with reaction temperatures of 400 °C and 425 °C. The residence time of the extruder was estimated and the molecular weight distribution of the fed plastic and reaction products was analysed using gel permeation chromatography. A continuous kinetic model was used to describe the degradation of the high density polyethylene in the reactive extruder. The breakage kernel and the scission rate model parameters were estimated from the experimental data for a variety of cases. It was found that purely random breakage and a scission rate which had a power law dependence on molecular size of 0.474 best described the experimental data.

3. MATERIAL AND METHOD

Waste can be loosely defined as any material that is considered to be of no further use to the owner and is, hence, discarded. However, most discarded waste can be reused or recycled, one of the principles of most waste management philosophies. What may be of no further use to one person and regarded as waste to be dumped, may be of use to the next person, and is the basis of the rag picking trade, the sifting through of refuse at landfills for recovery and resale, a very fundamental historical waste management practice still functioning in many countries, often conducted on a highly organised commercial basis.

Waste is generated universally and is a direct consequence of all human activities. Wastes are generally classified into solid, liquid and gaseous. Gaseous waste is normally vented to the atmosphere, either with or without treatment depending on composition and the specific regulations of the country involved. Liquid wastes are commonly discharged into sewers or rivers, which in many countries is subject to legislation governing treatment before discharge. In many parts of the world such legislation either does not exist or is not sufficiently implemented, and liquid wastes are discharged into water bodies or allowed to infiltrate into the ground. Indiscriminant disposal of liquid wastes pose a major pollution threat to both surface and groundwater.

Solid waste composition, rate of generation and methods of treatment and disposal vary considerably throughout the world and largely determine the potential of waste to impair groundwater quality. The purpose of this chapter is to outline the risk that waste disposal presents to groundwater quality and the information that is required to assess this risk (Allen and Taylor, 2006).

Several categories of waste are discussed in terms of their arisings, treatment and disposal options. The wastes described in detail are municipal solid waste, hazardous waste including clinical waste, household hazardous waste and sewage sludge. Other wastes described are agricultural waste, industrial waste, construction and demolition waste, mines and quarry waste, power station ash, scrap tyres and end of life vehicles (Williams, 2005).

Differences in the wealth of communities and countries, degree of urbanisation and industrialisation, and intensity of agricultural activities account for the significant differences in waste treatment and disposal problems faced by developed and developing countries, and between urban and rural areas (ESCAP, 2000).

Table 3.1. gives the sources and types of waste generated.

Table 3.1. Generators and types of solid waste (Hoornweg and Bhada-Tata, 2012).

Source	Typical Waste Generators	Types of Solid Wastes
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g., bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes (e.g., paints, aerosols, gas tanks, waste containing mercury, motor oil, cleaning agents), e-wastes (e.g., computers, phones, TVs)
Industrial	Light and heavy manufacturing, fabrication, construction sites, power and chemical plants (excluding specific	Housekeeping wastes, packaging, food wastes, construction and demolition materials, hazardous wastes, ashes,

Table 3.1. continued

	process wastes if the municipality does not oversee their collection)	special wastes
Commercial	Stores, hotels, restaurants, markets, office buildings	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes, e-wastes
Institutional	Schools, hospitals (non-medical waste), prisons, government buildings, airports	Same as commercial
Construction and Demolition	New construction sites, road repair, renovation sites, demolition of buildings	Wood, steel, concrete, dirt, bricks, tiles
Municipal Services	Street cleaning, landscaping, parks, beaches, other recreational areas, water and wastewater treatment plants	Street sweepings; landscape and tree trimmings; general wastes from parks, beaches, and other recreational areas, sludge

All of the above should be included as municipal solid waste. Industrial, commercial, and institutional (ICI) wastes are often grouped together and usually represent more than 50% of MSW. C&D waste is often treated separately; if well managed it can be disposed separately. The items below are usually considered MSW if the municipality oversees their collection and disposal.

Table 3.1. continued

Process	Heavy and light manufacturing, refineries, chemical plants, power plants, mineral extraction and processing	Industrial process wastes, scrap materials, off-specification products, slag, tailings
Medical waste	Hospitals, nursing homes, clinics	Infectious wastes (bandages, gloves, cultures, swabs, blood and body fluids), hazardous wastes (sharps, instruments, chemicals), radioactive waste from cancer therapies, pharmaceutical waste
Agricultural	Crops, orchards, vineyards, dairies, feedlots, farms	Spoiled food wastes, agricultural wastes (e.g., rice husks, cotton stalks, coconut shells, coffee waste), hazardous wastes (e.g., pesticides)

3.1. Municipal Solid Waste

Municipal solid waste (MSW) is a term usually applied to a heterogeneous collection of wastes produced in urban areas, the nature of which varies from region to region. The characteristics and quantity of the solid waste generated in a region is not only a function of the living standard and lifestyle of the region's inhabitants, but also of the abundance and type of the region's natural resources. Urban wastes can be subdivided into two major components; organic and inorganic. In general, the organic components of urban solid waste can be classified into three broad

categories: putrescible, fermentable, and non-fermentable. Putrescible wastes tend to decompose rapidly and unless carefully controlled, decompose with the production of objectionable odours and visual unpleasantness. Fermentable wastes tend to decompose rapidly, but without the unpleasant accompaniments of putrefaction. Non-fermentable wastes tend to resist decomposition and, therefore, break down very slowly. A major source of putrescible waste is food preparation and consumption. As such, its nature varies with lifestyle, standard of living, and seasonality of foods. Fermentable wastes are typified by crop and market debris.

The primary difference between wastes generated in developing nations and those generated in industrialised countries is the higher organic content characteristic of the former. The extent of the difference is indicated by the data in Table 3.2., in which is presented information relative to the quantity and composition of municipal solid wastes generated in several countries (UNEP, 2005).

Table 3.2. Comparison of solid waste characterization worldwide (% wet wt) (UNEP, 2005).

Location	Putrescibles	Paper	Metals	Glass	Plastics, Rubber, Leather	Textiles	Ceramics, Dust, Stones	Wt (g)/cap/ day
Bangalore, India	75,2	1,5	0,1	0,2	0,9	3,1	19,0	400
Manila, Philippines	45,5	14,5	4,9	2,7	8,6	1,3	27,5	400
Asunción, Paraguay	60,8	12,2	2,3	4,6	4,4	2,5	13,2	460
Seoul, Korea	22,3	16,2	4,1	10,6	9,6	3,8	33,4a	2,000a
Vienna, Austria	23,3	33,6	3,7	10,4	7,0	3,1	18,9b	1,180
Mexico City, Mexico	59,8c	11,9	1,1	3,3	3,5	0,4	20,0	680
Paris, France	16,3	40,9	3,2	9,4	8,4	4,4	17,4	1,430
Australia	23,6	39,1	6,6	10,2	9,9	-	9,0	1,870
Sunnyvale, California, USA	39,4d	40,8	3,5	4,4	9,6	1,0	1,3	2,000
Bexar County, Texas, USA	43,8d	34,0	4,3	5,5	7,5	2,0	2,9	1,816

a Includes briquette ash (average).

b Includes "all others".

c Includes small amounts of wood, hay, and straw.

d Includes garden waste.

Wastes generated in countries located in humid, tropical, and semitropical areas usually are characterised by a high concentration of plant debris; whereas those generated in areas subject to seasonal changes in temperature or those in which coal or wood are used for cooking and heating may contain an abundance of ash. The concentration of ash may be substantially higher during winter. Regardless of climatic differences, the wastes usually are more or less contaminated with nightsoil. These differences prevail even in wastes generated in large metropolitan areas of a developing country.

Ideally, solid waste should not contain faecal matter or urine, and the mixing of these materials with household waste should be prohibited by law. However, enforcement difficulties, combined with variations in way of life, necessitate some tolerance in this matter. Solid waste collection in a manner satisfactory with respect to environmental health is made difficult when human excretory wastes are mixed with household wastes. Handling of pathological wastes, abattoir wastes, industrial wastes and similar materials, in association with household wastes, also should not be permitted. Nevertheless, it is important to keep in mind that despite all precautions, some pathogens and chemical residues inevitably will be present in the waste (UNEP, 2005).

Municipal wastes are composed of wastes generated by households and wastes of similar character from shops, market and offices, open areas, and treatment plant sites. Each of these sources of municipal waste are elaborated in Table 3.3. Types of solid wastes comprising municipal wastes are described in detail in Table 3.4 (ESCAP, 2000).

Table 3.3. General sources of municipal solid wastes (ESCAP, 2000).

Source	Typical facilities, activities or locations where wastes are generated	Types of solid waste
Residential	Single-family and multi-family dwellings, low medium, and high-rise apartments, etc.	Food wastes, rubbish, ashes, special wastes
Commercial and Institutional	Stores, restaurants, markets, office buildings, hotels, motels, schools, print shops, auto repair shops, medical facilities and institutions	Food wastes, rubbish, ashes, demolition and construction wastes, special wastes, occasionally hazardous wastes
Open areas	Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.	Street sweepings, roadside litter, rubbish and other special wastes
Treatment plant sites	Water, sewage and industrial waste water treatment processes	Treatment plant sludges

Table 3.4. Classification of materials comprising municipal solid wastes (ESCAP, 2000).

Component	Description
Food wastes	The animal, fruit, or vegetable residues (also called garbage) resulting from the handling, preparation, cooking and eating of foods. Because food wastes are putrescible, they will decompose rapidly, especially in warm weather.
Rubbish	Combustible and non-combustible solid wastes, excluding food wastes or putrescible materials. Typically combustible rubbish consists of materials such as paper, cardboard, plastics, textiles, rubber, leather, wood, furniture, and garden trimmings. Non-combustible rubbish consists of items such as glass, crockery, tin cans, aluminium cans, ferrous and non-ferrous metals, dirt and construction material.

Table 3.4. continued

Ashes and residues	Materials remaining from the burning wood, coal, coke, and other combustible wastes. Ashes and residues are normally composed of fine, powdery materials, cinders, clinkers, and small amounts of burned and partially burned materials.
Demolition and construction wastes	Wastes from razed buildings and other structures are classified as demolition wastes. Wastes from the construction, remodelling, and repairing of residential, commercial, and industrial buildings and similar structures are classified as construction wastes. These wastes may include dirt, stones, concrete, bricks, plaster, lumber, shingles, and plumbing, heating, and electrical parts. They are usually of an inert nature. The main exception is asbestos, where special disposal is required.
Special wastes	Wastes such as street sweepings, roadside litter, catch-basin debris, dead animals, trash like abandoned vehicles, electrical appliances are classified as special wastes.
Treatment plant wastes and dredged soil	<p>The solid and semisolid wastes from water, sewage and industrial waste water treatment facilities are included in this classification. Sewage sludge is a slurry of fine organic-rich particles with a highly variable chemical composition depending on the sources of the effluent and the type and efficiency of the treatment processes. Sewage sludges tend to concentrate heavy metals and water-soluble synthetic organic compounds, but they may also contain greases, oils and bacteria.</p> <p>Dredged materials are excavated from river estuaries, harbours and other waterways to aid navigation. It is estimated that 10% of dredged materials is contaminated by oil, heavy metals, nutrients and organochlorine compounds.</p>

3.1.1. Composition of Municipal Solid Waste

In the municipal solid waste stream, waste is broadly classified into organic and inorganic. Waste composition is categorized as organic, paper, plastic, glass, metals, and 'other'. These categories can be further refined, however, these six categories are usually sufficient for general solid waste planning purposes. Table 3.5. describes the different types of waste and their sources.

An important component that needs to be considered is 'construction and demolition waste' (C&D), such as building rubble, concrete and masonry. In some cities this can represent as much as 40% of the total waste stream (Hoornweg and Bhada-Tata, 2012).

Table 3.5. Types of waste and their sources (Hoornweg and Bhada-Tata, 2012).

TYPE	SOURCES
Organic	Food scraps, yard (leaves, grass, brush) waste, wood, process residues
Paper	Paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper, paper beverage cups. Strictly speaking paper is organic but unless it is contaminated by food residue, paper is not classified as organic
Plastic	Bottles, packaging, containers, bags, lids, cups
Glass	Bottles, broken glassware, light bulbs, colored glass
Metal	Cans, foil, tins, non-hazardous aerosol cans, appliances (white goods), railings, bicycles
Other	Textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other inert materials

Figure 3.1. shows the MSW composition for the entire world in 2009. Organic waste comprises the majority of MSW, followed by paper, metal, other wastes, plastic, and glass. These are only approximate values, given that the data sets are from various years (Hoornweg and Bhada-Tata, 2012).

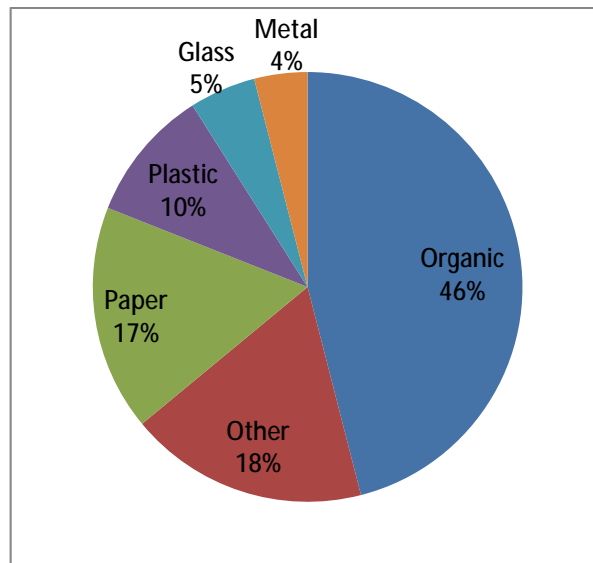


Figure 3.1. Global solid waste composition (2009) (Hoornweg and Bhada-Tata, 2012).

In order to develop frameworks within which effective waste management strategies can be planned, it is essential to know not only the amounts of waste generated and their sources, but also the type of materials in each waste stream, their properties, potential toxicity, and the hazards they pose to human health and the environment. The lack of reliable time series on solid waste streams and rapid changes in the composition of waste streams are a serious impediment to setting priorities in solid waste management in many developed as well as developing countries.

Municipal wastes in developing countries have a higher proportion of organic matter and ash, a higher moisture content and lower paper content, although refuse from the wealthier suburbs is similar in composition to West European wastes. Per capita generation of municipal wastes varies between 2.75 and 4.0 kg/day in high income countries, but is as little as 0.5 kg/day in countries with the lowest income levels. Despite the large amounts of waste produced by individuals in the wealthy industrialised nations, municipal wastes account for a small proportion of total wastes generated.

An important component of domestic wastes in industrialised countries is the "bulky" or "consumer durables" wastes, e.g. cars, refrigerators, washing machines.

The number of items discarded each year is growing as rapid changes in technology and production of new models reduces what is perceived to be their useful life. Such wastes are estimated at about 12 million tonnes/year in the European Union (ESCAP, 2000).

In Table 3.6., the composition of domestic waste for several capitals or major cities in Asia and elsewhere is shown.

Table 3.6. Domestic waste composition for selected major cities in the ESCAP region (%) (ESCAP, 2000).

Country/ area and city	Vegetable and putrescible	Paper	Textile	Rubber/ wood and leather	Plastics	Metal	Glass	Ash/earth
Australia, Sydney	33.8	37.7	3.6	0.7	2.8	8.5	12.9	-
China, Beijing	37.0	3.0	1.0	-	0.5	1.0	0.5	57.0
Egypt, Cairo	75.0	16.0	1.0	1.0	1.0	3.0	3.0	1.0
Hong Kong	14.0	30.0	21.0	1.0	18.0	4.0	3.0	10.0
India, Delhi	58.1	5.9	3.6	-	1.5	0.6	0.3	30.0
Indonesia, Jakarta	79.5	7.8	2.4	3.7	3.7	1.4	0.5	-
Japan, Tokyo	23.0	38.0	-	1.0	7.0	4.0	7.0	20.0
Jordan, Amman	71.0	16.8	1.8	-	4.8	2.6	2.2	0.8
Malaysia, Kuala Lumpur	51.8	28.3	2.0	2.8	7.7	4.9	2.3	-
Nepal, Kathmandu	68.8	5.6	6.8	-	0.4	5.3	1.4	11.7
Pakistan, Lahore	49.0	4.0	5.0	27.0	2.0	4.0	3.0	24.0
Philippines, Manila	31.8	14.4	1.3	1.1	7.5	4.9	2.7	36.3
Rep. of Korea, Seoul	10.4	6.7	0.6	1.0	2.6	0.6	0.6	76.6
Saudi Arabia, Riyadh	63.0	14.0	0.7	2.0	4.0	10.6	3.0	2.3
Singapore	36.0	32.3	3.9	2.8	6.7	7.0	4.0	7.3
Sri Lanka, Colombo	73.0	7.0	2.5	2.2	2.1	2.3	1.2	9.8
Taiwan Province of China, Taipei	39.7	20.6	12.8	2.0	4.0	2.5	7.6	10.8
Thailand, Bangkok	25.0	24.7	4.7	8.8	11.2	5.3	5.5	14.8

For comparison, data on solid wastes for several countries and regions have been brought together in Table 3.6. and 3.7. While in Asia food remains and vegetables comprise the bulk of the waste (75%), in Europe and the United States, this place is taken by paper, metals and glass (50-60%). The ASEAN countries occupy a middle position, with 45% of urban waste being accounted for by organic wastes while 30% comes from paper, metals and glass. All these data may be taken

as representative for the 1970's. The differences influence, as is explained later, the manner in which waste is collected and treated (ESCAP, 2000).

Table 3.7. Urban waste composition in different parts of the world (ESCAP, 2000).

	United States	Europe	ASEAN	Middle East	Asia	Africa
Vegetable	28.6	21.7	44.7	50.0	75.0	85.4
Paper	43.8	31.7	21.5	16.0	2.0	6.9
Metals	9.1	5.8	4.7	5.0	0.1	3.1
Glass	9.0	8.0	3.0	2.0	0.2	0.7
Textiles	2.7	-	2.9	3.0	3.0	1.2
Plastic	3.0	3.6	7.4	1.0	1.0	1.4
Other	3.7	29.2	18.7	23.0	18.7	1.3
Total	100%	100%	100%	100%	100%	100%

3.1.2. Future Projections for Solid Waste

Currently, world cities generate about 1.3 billion tonnes of solid waste per year. This volume is expected to increase to 2.2 billion tonnes by 2025. Waste generation rates will more than double over the next twenty years in lower income countries. Globally, solid waste management costs will increase from today's annual \$205.4 billion to about \$375.5 billion in 2025. Cost increases will be most severe in low income countries (more than 5-fold increases) and lower-middle income countries (more than 4-fold increases).

The global impacts of solid waste are growing fast. Solid waste is a large source of methane, a powerful GHG that is particularly impactful in the short term. The recycling industry, with more than two million informal waste pickers, is now a global business with international markets and extensive supply and transportation networks. Locally, uncollected solid waste contributes to flooding, air pollution, and public health impacts such as respiratory ailments, diarrhea and dengue fever. In

lower income country cities solid waste management is usually a city's single largest budgetary item.

As the world hurtles toward its urban future, the amount of municipal solidwaste (MSW), one of the most important by-products of an urban lifestyle, is growing even faster than the rate of urbanization. Ten years ago there were 2.9 billion urban residents who generated about 0.64 kg of MSW per person per day (0.68 billion tonnes per year). This report estimates that today these amounts have increased to about 3 billion residents generating 1.2 kg per person per day (1.3 billion tonnes per year). By 2025, this will likely increase to 4.3 billion urban residents generating about 1.42 kg/capita/day of municipal solid waste (2.2 billion tonnes per year) (Hoornweg and Bhada-Tata, 2012).

Table 3.8. shows estimates of waste generation for the year 2025 as expected according to current trends in population growth in each region.

Table 3.8. Waste generation projections for 2025 by region (Hoomweg and Bhada-Tata, 2012).

REGION	Current Available Data			Projections for 2025				
	Total Urban Population (millions)	Urban Waste Generations		Projected Population		Projected Urban Waste		Total tons/day
		Per Capital kg/capita/day	Total tons/day	Total Population (millions)	Urban Population (millions)	Per Capita kg/capita/day	Total tons/day	
AFR	260	0.65	169,119	1,152	518	0.85	441,840	
EAP	777	0.95	738,958	2,124	1,229	1.5	1,865,379	
ECA	227	1.1	254,389	339	239	1.5	354,810	
LCR	399	1.1	437,545	681	466	1.6	728,392	
MENA	162	1.1	173,545	379	257	1.43	369,320	
OECD	729	2.2	1,566,286	1,031	842	2.1	1,742,417	
SAR	426	0.45	192,410	1,938	734	0.77	567,545	
Total	2,980	1.2	3,532,252	7,644	4,285	1.4	6,069,703	

3.1.3. Municipal Solid Waste Management

Management of solid waste reduces or eliminates adverse impacts on the environment and human health and supports economic development and improved quality of life. A number of processes are involved in effectively managing waste for a municipality.

3.1.3.1. Reduce, Reuse and Recycle Methods

Methods of waste reduction, waste reuse and recycling are preferred options when managing waste. There are many environmental benefits that can be derived from the use of these methods. These methods reduce or prevent green house gas emissions, reduce the release of pollutants, conserve resources, save energy and reduce the demand for waste treatment technology and landfill space. Therefore it is advisable that these methods be adopted and incorporated as part of the waste management plan.

Waste Reduction and Reuse: Waste reduction and reuse of products are both methods of waste prevention. They eliminate the production of waste at the source of usual generation and reduce the demands for large scale treatment and disposal facilities. Methods of waste reduction include manufacturing products with less packaging, encouraging customers to bring their own reusable bags for packaging, encouraging the public to choose reusable products such as cloth napkins and reusable plastic and glass containers, backyard composting and sharing and donating any unwanted items rather than discarding them. All of the methods of waste prevention mentioned require public participation. In order to get the public onboard, training and educational programmes need to be undertaken to educate the public about their role in the process. Also the government may need to regulate the types and amount of packaging used by manufacturers and make the reuse of shopping bags mandatory.

Recycling: Recycling refers to the removal of items from the waste stream to be used as raw materials in the manufacture of new products. Thus from this definition recycling occurs in three phases. First the waste is sorted and recyclables collected, the recyclables are used to create raw materials. These raw materials are then used in the production of new products.

The sorting of recyclables may be done at the source (i.e. within the household or office) for selective collection by the municipality or to be dropped off by the waste producer at a recycling centres. The pre-sorting at the source requires public participation which may not be forthcoming if there are no benefits to be derived. Also a system of selective collection by the government can be costly. It would require more frequent circulation of trucks within a neighbourhood or the importation of more vehicles to facilitate the collection.

Another option is to mix the recyclables with the general waste stream for collection and then sorting and recovery of the recyclable materials can be performed by the municipality at a suitable site. The sorting by the municipality has the advantage of eliminating the dependence on the public and ensuring that the recycling does occur. The disadvantage however, is that the value of the recyclable materials is reduced since being mixed in and compacted with other garbage can have adverse effects on the quality of the recyclable material.

3.1.3.2. Treatment and Disposal Methods

Waste treatment techniques seek to transform the waste into a form that is more manageable, reduce the volume or reduce the toxicity of the waste thus making the waste easier to dispose of. Treatment methods are selected based on the composition, quantity, and form of the waste material. Some waste treatment methods being used today include subjecting the waste to extremely high temperatures, dumping on land or land filling and use of biological processes to treat the waste. It should be noted that treatment and disposal options are chosen as a last resort to the previously mentioned management strategies reducing, reusing and recycling of waste.

Incineration: Incineration is the most common thermal treatment process. This is the combustion of waste in the presence of oxygen. After incineration, the wastes are converted to carbon dioxide, water vapour and ash. This method may be used as a means of recovering energy to be used in heating or the supply of electricity. In addition to supplying energy incineration technologies have the advantage of reducing the volume of the waste, rendering it harmless, reducing transportation costs and reducing the production of the green house gas methane.

Pyrolysis and Gasification: Pyrolysis and gasification are similar processes they both decompose organic waste by exposing it to high temperatures and low amounts of oxygen. Gasification uses a low oxygen environment while pyrolysis allows no oxygen. These techniques use heat and an oxygen starved environment to convert biomass into other forms. A mixture of combustible and non-combustible gases as well as pyroligenous liquid is produced by these processes. All of these products have a high heat value and can be utilised. Gasification is advantageous since it allows for the incineration of waste with energy recovery and without the air pollution that is characteristic of other incineration methods.

Open Burning: Open burning is the burning of unwanted materials in a manner that causes smoke and other emissions to be released directly into the air without passing through a chimney or stack. This includes the burning of outdoor piles, burning in a burn barrel and the use of incinerators which have no pollution control devices and as such release the gaseous by products directly into the atmosphere. Open burning has been practiced by a number of urban centres because it reduces the volume of refuse received at the dump and therefore extends the life of their dumpsite. Garbage may be burnt because of the ease and convenience of the method or because of the cheapness of the method. In countries where house holders are required to pay for garbage disposal, burning of waste in the backyard allows the householder to avoid paying the costs associated with collecting, hauling and dumping the waste.

Open burning has many negative effects on both human health and the environment. This uncontrolled burning of garbage releases many pollutants into the atmosphere. These include dioxins, particulate matter, polycyclic aromatic

compounds, volatile organic compounds, carbon monoxide, hexachlorobenzene and ash. All of these chemicals pose serious risks to human health. Dioxins are capable of producing a multitude of health problems; they can have adverse effects on reproduction, development, disrupt the hormonal systems or even cause cancer. The polycyclic aromatic compounds and the hexachlorobenzene are considered to be carcinogenic. The particulate matter can be harmful to persons with respiratory problems such as asthma or bronchitis and carbon monoxide can cause neurological symptoms.

The harmful effects of open burning are also felt by the environment. This process releases acidic gases such as the halo-hydrates; it also may release the oxides of nitrogen and carbon. Nitrogen oxides contribute to acid rain, ozone depletion, smog and global warming. In addition to being a green house gas carbon monoxide reacts with sunlight to produce ozone which can be harmful. The particulate matter creates smoke and haze which contribute to air pollution.

3.1.3.3. Dumps and Landfills

Sanitary Landfills: Sanitary landfills are designed to greatly reduce or eliminate the risks that waste disposal may pose to the public health and environmental quality. They are usually placed in areas where land features act as natural buffers between the landfill and the environment. For example the area may be comprised of clay soil which is fairly impermeable due to its tightly packed particles, or the area may be characterised by a low water table and an absence of surface water bodies thus preventing the threat of water contamination.

In addition to the strategic placement of the landfill other protective measures are incorporated into its design. The bottom and sides of landfills are lined with layers of clay or plastic to keep the liquid waste, known as leachate, from escaping into the soil. The leachate is collected and pumped to the surface for treatment. Boreholes or monitoring wells are dug in the vicinity of the landfill to monitor groundwater quality.

A landfill is divided into a series of individual cells and only a few cells of the site are filled with trash at any one time. This minimizes exposure to wind and rain. The daily waste is spread and compacted to reduce the volume, a cover is then applied to reduce odours and keep out pests. When the landfill has reached its capacity it is capped with an impermeable seal which is typically composed of clay soil.

Some sanitary landfills are used to recover energy. The natural anaerobic decomposition of the waste in the landfill produces landfill gases which include carbon dioxide, methane and traces of other gases. Methane can be used as an energy source to produce heat or electricity. Thus some landfills are fitted with landfill gas collection systems to capitalise on the methane being produced. The process of generating gas is very slow, for the energy recovery system to be successful there needs to be large volumes of wastes.

These landfills present the least environmental and health risk and the records kept can be a good source of information for future use in waste management, however, the cost of establishing these sanitary landfills are high when compared to the other land disposal methods.

Controlled dumps: Controlled dumps are disposal sites which comply with most of the requirements for a sanitary landfill but usually have one deficiency. They may have a planned capacity but no cell planning, there may be partial leachate management, partial or no gas management, regular cover, compaction in some cases, basic record keeping and they are fenced or enclosed. These dumps have a reduced risk of environmental contamination, the initial costs are low and the operational costs are moderate. While there is controlled access and use, they are still accessible by scavengers and so there is some recovery of materials through this practice.

Bioreactor Landfills: Recent technological advances have lead to the introduction of the bioreactor landfill. The bioreactor landfills use enhanced microbiological processes to accelerate the decomposition of waste. The main controlling factor is the constant addition of liquid to maintain optimum moisture for microbial digestion. This liquid is usually added by re-circulating the landfill

leachate. In cases where leachate is not enough, water or other liquid waste such as sewage sludge can be used. The landfill may use either anaerobic or aerobic microbial digestion or it may be designed to combine the two. These enhanced microbial processes have the advantage of rapidly reducing the volume of the waste creating more space for additional waste, they also maximise the production and capture of methane for energy recovery systems and they reduce the costs associated with leachate management. For bioreactor landfills to be successful the waste should be comprised predominantly of organic matter and should be produced in large volumes.

3.1.3.4. Biological Waste Treatment

Composting: Composting is the controlled aerobic decomposition of organic matter by the action of micro organisms and small invertebrates. There are a number of composting techniques being used today. These include: in vessel composting, windrow composting, vermicomposting and static pile composting. The process is controlled by making the environmental conditions optimum for the waste decomposers to thrive. The rate of compost formation is controlled by the composition and constituents of the materials i.e. their carbon/nitrogen (C/N) ratio, the temperature, the moisture content and the amount of air.

The C/N ratio is very important for the process to be efficient. The micro organisms require carbon as an energy source and nitrogen for the synthesis of some proteins. If the correct C/N ratio is not achieved, then application of the compost with either a high or low C/N ratio can have adverse effects on both the soil and the plants. A high C/N ratio can be corrected by dehydrated mud and a low ratio corrected by adding cellulose.

Moisture content greatly influences the composting process. The microbes need the moisture to perform their metabolic functions. If the waste becomes too dry the composting is not favoured. If however there is too much moisture then it is possible that it may displace the air in the compost heap depriving the organisms of oxygen and drowning them.

A high temperature is desirable for the elimination of pathogenic organisms. However, if temperatures are too high, above 75 °C then the organisms necessary to complete the composting process are destroyed. Optimum temperatures for the process are in the range of 50 °C - 60 °C with the ideal being 60 °C.

Aeration is a very important and the quantity of air needs to be properly controlled when composting. If there is insufficient oxygen the aerobes will begin to die and will be replaced by anaerobes. The anaerobes are undesirable since they will slow the process, produce odours and also produce the highly flammable methane gas. Air can be incorporated by churning the compost.

Anaerobic Digestion: Anaerobic digestion like composting uses biological processes to decompose organic waste. However, where composting can use a variety of microbes and must have air, anaerobic digestion uses bacteria and an oxygen free environment to decompose the waste. Aerobic respiration, typical of composting, results in the formation of carbon dioxide and water. While the anaerobic respiration results in the formation of carbon dioxide and methane. In addition to generating the humus which is used as a soil enhancer, anaerobic digestion is also used as a method of producing biogas which can be used to generate electricity.

Optimal conditions for the process require nutrients such as nitrogen, phosphorous and potassium, it requires that the pH be maintained around 7 and the alkalinity be appropriate to buffer pH changes, temperature should also be controlled (Anonymous, 2013a).

3.1.4. Municipal Solid Waste Situation in Turkey and Adana

In accordance with Law on Environment, Solid Waste Management Regulation, Metropolitan Municipalities Law and Municipal Law; metropolitan municipalities and municipalities out of adjacent zones and the highest civilian authority out of these zones are responsible for ensuring the disposal of domestic and domestic type industrial solid waste while avoiding environmental damage, waste while avoiding environmental damage, ensuring the maximal use of the landfills and

ensuring the classification and separation of recyclable solid waste to contribute to the economy and taking relevant measures to ensure these.

Municipalities, while fulfilling their duties in collecting and transporting the solid waste to a great extent, can not show the required level of activity and attention in disposal within solid waste management. The great majority of the solid waste in the country are still not being disposed in accordance with the legislation. There exist many administrative, financial and technical reasons contributing to this existing situation. Especially unsanitary disposal, errors in selection of the disposal sites and the drawbacks in administration are causing ever increasing problems.

In solid waste production, primarily the amount of waste produced should be reduced. Moreover, the need for awareness raising in households for separation of waste at the source, to make it ready for collection, is ongoing.

Existence of many local administrative units in the same region makes it compulsory to have cooperation and coordination in solid waste services like in other infrastructural services. Local administrative union model applications, as promoted by the new legislation, come up as a facilitating bodies for realization of local-level environmental services.

Solid waste in Turkey is generally discharged to unsanitary landfill sites in an uncontrolled manner (UN, 2010).

Turkey's first municipal waste composition studies is made by State Institute of Statistics Turkey at 1993. And the results is shown at Table 3.9. ;

Table 3.9. Seasonal variations in the composition of waste in selected cities in Turkey at 1993 (ESCAP, 2000).

Cities	Household solid waste per capita (g/day)		Food wastes (%)		Rubbish (%)		Ash, slag, etc. (%)	
	July	December	July	December	July	December	July	December
Adana	865	473	75.42	70.56	22.91	12.48	1.66	6.96
Ankara	615	635	80.50	46.29	16.77	4.25	2.74	49.46
Bursa	613	793	77.16	33.75	19.51	8.28	3.33	57.96
Diyarbakır	365	250	85.99	48.36	9.64	3.76	4.37	47.88
Gaziantep	221	175	83.30	40.28	16.53	10.81	0.17	48.91
İskenderun	597	443	78.86	72.36	20.94	14.96	0.19	12.68
İstanbul	554	514	80.53	43.70	18.18	8.66	1.29	47.64
İzmir	723	484	84.02	51.89	14.85	10.80	1.13	37.31
Kayseri	752	374	76.87	49.37	11.52	3.63	11.61	47.00
Konya	683	539	76.85	37.75	8.42	4.09.00	14.73	58.16
Samsun	542	450	83.32	63.04	15.00	9.20	1.68	27.76

Studies on establishment of a nation-wide effective solid waste management system have been initiated. In this regard, Solid Waste Master Plan for the domestic-type waste is completed and further studies are ongoing for development of the National and Regional Waste Management Plan for other waste types.

“Solid Waste Master Plan Project”, implemented under coordination of Ministry of Environment and Forestry (MOEF) and Undersecretariat of State Planning Organization in 2006, has aimed at establishment of unions between municipalities for solid waste disposal across Turkey, development of economically sustainable Regional Solid Waste Facilities and ensuring the implementation of the projects within a plan. As foreseen by the relevant legislation, plans are developed for the establishment of sanitary landfill sites, reduction of amount of produced solid waste, ensuring recycling, reduction of solid waste transport costs and use of transport sites equipped with appropriate technologies where deemed necessary; 16

type of projects are developed in this regard so as to provide guidance to municipalities.

MOEF's estimation of domestic solid waste production in 2008, calculated through per capita waste estimates, is 26,8 million tons. 13,3 million tons of these wastes are disposed in sanitary landfills while 0,3 million tons are processed in compost facilities. The number of sanitary landfill sites in operation have risen to 41 by 2009.

MOEF have carried out various regional fieldwork in 2006 in order to determine the domestic waste composition of households in Turkey in addition to solid waste surveys sent to cities that are representative of Turkey, including 16 metropolitan municipalities. In the light of the fieldwork and declared information on composition, solid waste projections are calculated for the use of all municipalities (UN, 2010).

The outcome of these studies as 2008 municipal waste composition in Turkey is shown in Figure 3.2.

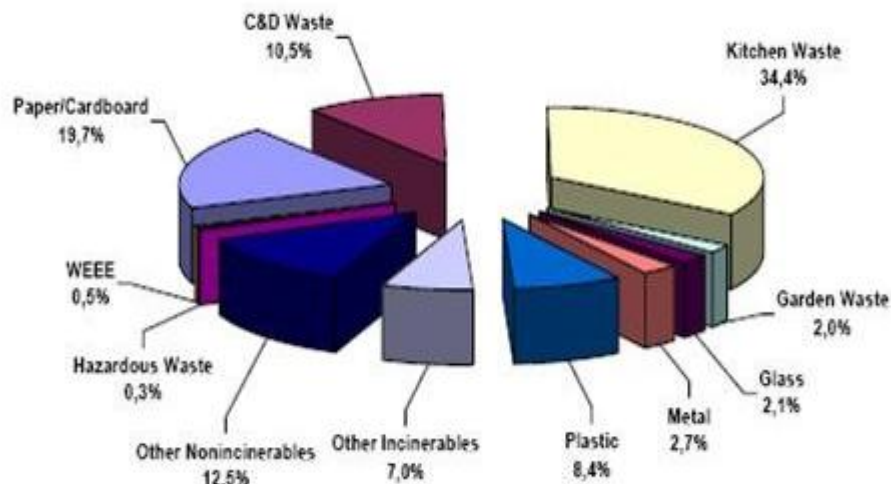


Figure 3.2. Composition of domestic waste in Turkey (2008) (Anonymous, 2013b).

Average of 1500 tons municipal waste is transported from city center to the Sofulu Garbage Landfill Area per day by Adana Metropolitan Municipality. Municipal waste is collected from the houses and institutions (MEU, 2012).

Table 3.10. shows that major constituents of the municipal solid waste (MSW) are organic, whereas recyclable materials constitute almost 1/3 of total MSW in big cities (Metin et al., 2003).

Table 3.10. Municipal solid waste composition in major cities of Turkey, (% , in weight) (Metin et al., 2003).

	BURSA (Bursa Greatercity Municipality, 2000)	İSTANBUL (İstanbul Greatercity Municipality, 2000)	İZMİR (İzmir Greatercity Municipality, 2000)	ADANA (JICA, 2000)	MERSİN (JICA, 2000)
Population (1997)	1,958,529	9,198,809	3,114,859	1,682,483	1,508,232
Organic	53,1	43	46	64,4	63
Recyclable	36,4	33,9	31	25,2	29,4
Paper/board	18,4	7,8	12	14,8	18,42
Plastics	11,6	14,2	12	5,92	6,69
Metal	3	5,8	3	1,4	1,25
Glass	3,4	6,2	4	3,08	3,08
Others	10,5	23,1	23	11,4	7,6

3.2. Medical Waste (Health-Care Waste)

The term health-care waste includes all the waste generated within health-care facilities, research centres and laboratories related to medical procedures. In addition, it includes the same types of waste originating from minor and scattered sources, including waste produced in the course of health care undertaken in the home (e.g. home dialysis, self-administration of insulin, recuperative care). Between 75% and 90% of the waste produced by health-care providers is comparable to domestic waste and usually called “non-hazardous” or “general health-care waste”. It comes mostly from the administrative, kitchen and housekeeping functions at health-care facilities and may also include packaging waste and waste generated during

maintenance of health-care buildings are shown at Figure 3.3. The remaining 10 – 25% of health-care waste is regarded as “hazardous” and may pose a variety of environmental and health risks (WHO, 2013).

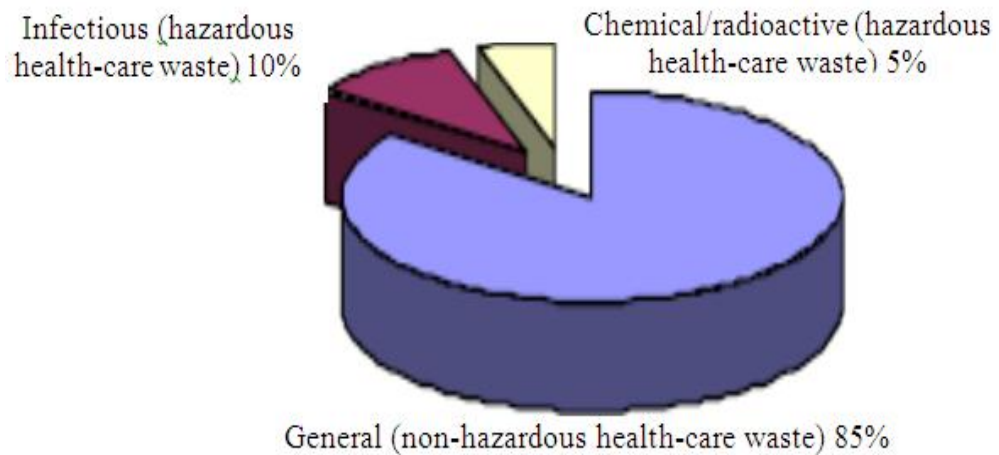


Figure 3.3. Typical waste compositions in health-care facilities (WHO, 2013).

3.2.1. Classification of Health-Care Waste

A classification of health-care waste is summarized in Table 3.11.;

Table 3.11. Categories of health-care waste (WHO, 2013).

<u>WASTE CATEGORY</u>	<u>DESCRIPTION AND EXAMPLES</u>
Hazardous health-care waste	
Sharps waste	Used or unused sharps (e.g. hypodermic, intravenous or other needles; auto-disable syringes; syringes with attached needles; infusion sets; scalpels; pipettes; knives; blades; broken glass).
Infectious waste	Waste suspected to contain pathogens and that poses a risk of disease transmission (e.g. waste contaminated with blood and other body fluids; laboratory cultures and microbiological stocks; waste including excreta and other materials that have been in contact with patients infected with highly infectious diseases in isolation wards).
Pathological waste	Human tissues, organs or fluids; body parts; fetuses; unused blood products.
Pharmaceutical waste, cytotoxic waste	Pharmaceuticals that are expired or no longer needed; items contaminated by or containing pharmaceuticals. Cytotoxic waste containing substances with genotoxic properties (e.g. waste containing cytostatic drugs – often used in cancer therapy; genotoxic chemicals).
Chemical waste	Waste containing chemical substances (e.g. laboratory reagents; film developer; disinfectants that are expired or no longer needed; solvents; waste with high content of heavy metals, e.g. batteries; broken thermometers and blood-pressure gauges).
Radioactive waste	Waste containing radioactive substances (e.g. unused liquids from radiotherapy or laboratory research; contaminated glassware, packages or absorbent paper; urine and excreta from patients treated or tested with unsealed radionuclides; sealed sources).
Non-hazardous or general health-care waste	Waste that does not pose any particular biological, chemical, radioactive or physical hazard.

Sharps Waste: Sharps are items that could cause cuts or puncture wounds, including needles, hypodermic needles, scalpels and other blades, knives, infusion sets, saws, broken glass and pipettes. Whether or not they are infected, such items are usually considered highly hazardous health-care waste and should be treated as if they were potentially infected.

Infectious Waste: Infectious waste is material suspected to contain pathogens (bacteria, viruses, parasites or fungi) in sufficient concentration or quantity to cause disease in susceptible hosts. This category includes;

- ü waste contaminated with blood or other body fluids,
- ü cultures and stocks of infectious agents from laboratory work,
- ü waste from infected patients in isolation wards.

Waste contaminated with blood or other body fluids include free-flowing blood, blood components and other body fluids; dressings, bandages, swabs, gloves, masks, gowns, drapes and other material contaminated with blood or other body fluids; and waste that has been in contact with the blood of patients undergoing haemodialysis (e.g. dialysis equipment such as tubing and filters, disposable towels, gowns, aprons, gloves and laboratory coats).

Waste from infected patients in isolation wards includes excreta, dressings from infected or surgical wounds, and clothes heavily soiled with human blood or other body fluids. Waste from non-infective patients and that is not contaminated with blood or body fluids may be considered non-infectious. In low-resource settings, the infection control or medical personnel should determine whether waste from non-isolation ward patients should be classified as infectious waste. They should apply the principles of the chain of infection to assess the risk of disease transmission from local practices used in the collection, handling, transport, treatment and disposal of waste.

Pathological waste: Pathological waste could be considered a subcategory of infectious waste, but is often classified separately, especially when special methods of handling, treatment and disposal are used. Pathological waste consists of tissues,

organs, body parts, blood, body fluids and other waste from surgery and autopsies on patients with infectious diseases. It also includes human fetuses and infected animal carcasses. Recognizable human or animal body parts are sometimes called anatomical waste. Pathological waste may include healthy body parts that have been removed during a medical procedure or produced during medical research.

Pharmaceutical waste (including genotoxic waste): Pharmaceutical waste includes expired, unused, spilt and contaminated pharmaceutical products, prescribed and proprietary drugs, vaccines and sera that are no longer required, and, due to their chemical or biological nature, need to be disposed of carefully. The category also includes discarded items heavily contaminated during the handling of pharmaceuticals, such as bottles, vials and boxes containing pharmaceutical residues, gloves, masks and connecting tubing.

Genotoxic waste is highly hazardous and may have mutagenic (capable of inducing a genetic mutation), teratogenic (capable of causing defects in an embryo or fetus) or carcinogenic (cancer-causing) properties. The disposal of genotoxic waste raises serious safety problems, both inside hospitals and after disposal, and should be given special attention. Genotoxic waste may include certain cytostatic drugs (see below), vomit, urine or faeces from patients treated with cytostatic drugs, chemicals and radioactive material.

Technically, genotoxic means toxic to the deoxyribonucleic acid (DNA); cytotoxic means toxic to the cell; cytostatic means suppressing the growth and multiplication of the cell; antineoplastic means inhibiting the development of abnormal tissue growth; and chemotherapeutic means the use of chemicals for treatment, including cancer therapy.

Cytotoxic (chemotherapeutic or antineoplastic) drugs, the principal substances in this category, have the ability to kill or stop the growth of certain living cells and are used in chemotherapy of cancer. They play an important role in the therapy of various neoplastic conditions, but are also finding wider application as immunosuppressive agents in organ transplantation and in treating various diseases with an immunological basis. Cytotoxic drugs are most often used in specialized departments, such as oncology and radiotherapy units, whose main role is cancer

treatment. Their use in other hospital departments and outside the hospital in clinics and elsewhere is also increasing.

Cytostatic drugs can be categorized as follows;

- alkylating agents: cause alkylation of DNA nucleotides, which leads to cross,
- linking and miscoding of the genetic stock,
- antimetabolites: inhibit the biosynthesis of nucleic acids in the cell,
- mitotic inhibitors: prevent cell replication.

Cytotoxic wastes are generated from several sources and can include the following;

- contaminated materials from drug preparation and administration, such as syringes,
- needles, gauzes, vials, packaging,
- outdated drugs, excess (leftover) solutions, drugs returned from the wards,
- urine, faeces and vomit from patients, which may contain potentially hazardous,
- amounts of the administered cytostatic drugs or of their metabolites, and which should be considered genotoxic for at least 48 hours and sometimes up to 1 week after drug administration.

In specialized oncological hospitals, genotoxic waste (containing cytostatic or radioactive substances) may constitute as much as 1% of the total health-care wastes.

Chemical waste: Chemical waste consists of discarded solid, liquid and gaseous chemicals; for example, from diagnostic and experimental work and from cleaning and disinfecting procedures. Chemical waste from health care is considered to be hazardous if it has at least one of the following properties;

- Ü toxic (harmful),
- Ü corrosive (e.g. acids of pH < 2 and bases of pH >12),
- Ü flammable,
- Ü reactive (explosive, water reactive, shock sensitive),
- Ü oxidizing.

Non-hazardous chemical waste consists of chemicals with none of the above properties; for example, sugars, aminoacids and certain organic and inorganic salts, which are widely used in transfusion liquids.

The most common types of hazardous chemicals used in health-care centres and hospitals, and the most likely to be found in waste, are described in the following paragraphs.

Formaldehyde is a significant source of chemical waste in hospitals. It is used to clean and disinfect equipment (e.g. haemodialysis or surgical equipment); to preserve specimens; to disinfect liquid infectious waste; and in pathology, autopsy, dialysis, embalming and nursing units.

Photographic fixing and developing solutions are used in X-ray departments where photographic film continues to be used. The fixer usually contains 5–10% hydroquinone, 15% potassium hydroxide and less than 1% silver. The developer contains approximately 45% glutaraldehyde. Acetic acid is used in both “stop” baths and fixer solutions.

Wastes containing solvents are generated in various departments of a hospital, including pathology and histology laboratories and engineering departments. Solvents include halogenated and non-halogenated compounds. Waste organic chemicals generated in health-care facilities include disinfecting and cleaning solutions, vacuum-pump and engine oils, insecticides and rodenticides. Waste inorganic chemicals consist mainly of acids and alkalis, oxidants and reducing agents.

Wastes from materials with high heavy-metal contents represent a subcategory of hazardous chemical waste and are usually highly toxic. Mercury is an example of a highly toxic yet common substance in health-care facilities. Mercury

wastes are typically generated by spillage from broken clinical equipment, but their volume is decreasing in many countries with the substitution of mercury-free instruments (e.g. digital thermometers, aneroid bloodpressure gauges). Whenever possible, spilt drops of mercury should be recovered. Residues from dentistry also have high mercury contents. Cadmium waste comes mainly from discarded batteries. Reinforced wood panels containing lead are still used in radiation proofing in X-ray and diagnostic departments.

Many types of gas are used in health care and are often stored in portable pressurized cylinders, cartridges and aerosol cans. Many of these are reusable, once empty or of no further use (although they may still contain residues). However, certain types – notably aerosol cans – are single-use containers that require disposal. Whether inert or potentially harmful, gases in pressurized containers should always be handled with care; containers may explode if incinerated or accidentally punctured (WHO, 2013).

We can see the lists the general classes of chemical waste found in health-care facilities in below;

Table 3.12. Chemical waste from health-care activities (WHO, 2013).

Chemical waste	Examples
Halogenated solvents	Chloroform, methylene chloride, perchloroethylene, refrigerants, trichloroethylene
Non-halogenated solvents	Acetone, acetonitrile, ethanol, ethyl acetate, formaldehyde, isopropanol, methanol, toluene, xylenes
Halogenated disinfectants	Calcium hypochlorite, chlorine dioxide, iodine solutions, iodophors, sodium dichloroisocyanurate, sodium hypochlorite (bleach)
Aldehydes	Formaldehyde, glutaraldehydes, ortho-phthalaldehyde
Alcohols	Ethanol, isopropanol, phenols
Other disinfectants	Hydrogen peroxide, peroxyacetic acid, quarternary amines
Metals	Arsenic, cadmium, chromium, lead, mercury, silver
Acids	Acetic, chromic, hydrochloric, nitric, sulfuric
Bases	Ammonium hydroxide, potassium hydroxide, sodium hydroxide
Oxidizers	Bleach, hydrogen peroxide, potassium dichromate, potassium permanganate
Reducers	Sodium bisulfite, sodium sulfite
Miscellaneous	Anaesthetic gases, asbestos, ethylene oxide, herbicides, paints, pesticides, waste oils

Radioactive waste: Radioactive wastes are materials contaminated with radionuclides. They are produced as a result of procedures such as in vitro analysis of body tissue and fluid, in vivo organ imaging and tumour localization, and various investigative and therapeutic practices.

Radionuclides used in health care are in either unsealed (or open) sources or sealed sources. Unsealed sources are usually liquids that are applied directly, while sealed sources are radioactive substances contained in parts of equipment or encapsulated in unbreakable or impervious objects, such as pins, “seeds” or needles.

Radioactive health-care waste often contains radionuclides with short half-lives (i.e. half of the radionuclide content decays in hours or a few days); consequently, the waste loses its radioactivity relatively quickly. However, certain specialized therapeutic procedures use radionuclides with longer half-lives; these are usually in the form of small objects placed on or in the body and may be reused on other patients after sterilization. Waste in the form of sealed sources may have a relatively high radioactivity, but is only generated in low volumes from larger medical and research laboratories. Sealed sources are generally returned to the supplier and should not enter the waste stream.

The waste produced by health-care and research activities involving radionuclides and related equipment maintenance and storage can be classified as follows;

- sealed sources,
- spent radionuclide generators,
- low-level solid waste (e.g. absorbent paper, swabs, glassware, syringes, vials),
- residues from shipments of radioactive material and unwanted solutions of radionuclides intended for diagnostic or therapeutic use,
- liquid immiscible with water, such as liquid scintillation counting,
- residues used in radioimmunoassay, and contaminated pump oil,
- waste from spills and from decontamination of radioactive spills,

- Ü excreta from patients treated or tested with unsealed radionuclides,
- Ü low-level liquid waste (e.g. from washing apparatus),
- Ü gases and exhausts from stores and fume cupboards.

Non-hazardous general waste: Non-hazardous or general waste is waste that has not been in contact with infectious agents, hazardous chemicals or radioactive substances and does not pose a sharps hazard. A significant proportion (about 85%) of all waste from health-care facilities is non-hazardous waste and is usually similar in characteristics to municipal solid waste. More than half of all non-hazardous waste from hospitals is paper, cardboard and plastics, while the rest comprises discarded food, metal, glass, textiles, plastics and wood.

In many places, community or regulatory requirements encourage materials recycling. In the past, all or most nonhazardous and municipal waste was discarded in dumps or landfills or burnt in municipal incinerators. Greater awareness of the environmental impacts of waste and the recognition that most of the non-hazardous waste from health-care facilities is potentially recyclable or compostable have changed the approaches to managing general waste.

Lists examples of common recyclable materials found in health-care facilities are below;

- Ü Corrugated cardboard boxes,
- Ü Newspapers and magazines,
- Ü Polyethylene terephthalate (PET or PETE) (e.g. plastic water bottles, soft- drink bottles),
- Ü Polystyrene packaging,
- Ü Wood (e.g. shipping pallets),
- Ü Paper (e.g. white office paper, computer printer paper, coloured ledger paper),
- Ü Metals (e.g. aluminium beverage cans and containers, food tin cans, other metalcontainers),

- ü High-density polyethylene (HDPE) (e.g. plastic milk containers, containers for food, plastic bottles for saline solutions or sterile irrigation fluids),
- ü Clear, coloured or mixed glass,
- ü Construction and demolition debris.

In addition, durable goods such as used furniture, bed frames, carpets, curtains and dishware, as well as computer equipment, printer cartridges and photocopying toners, are also potentially reusable. Flowers, food waste from kitchen services and plant waste from grounds maintenance are examples of compostable waste (WHO, 2013).

3.2.2. Sources of Health-Care Waste

Different types of health-care facilities can be viewed as major or minor sources of health-care waste, according to the quantities produced (WHO, 2013).

The major sources are listed in below;

- **Hospitals**

- ü University hospital,
- ü General hospital,
- ü District hospital.

- **Other health-care facilities**

- ü Emergency medical care services,
- ü Health-care centres and dispensaries,
- ü Obstetric and maternity clinics,
- ü Outpatient clinics,
- ü Dialysis centres,

- ü Long-term health-care establishments and hospices,
 - ü Transfusion centres,
 - ü Military medical services,
 - ü Prison hospitals or clinics.
- **Related laboratories and research centres**
- ü Medical and biomedical laboratories,
 - ü Biotechnology laboratories and institutions,
 - ü Medical research centres.
- **Mortuary and autopsy centres**
- **Animal research and testing**
- **Blood banks and blood collection services**
- **Nursing homes for the elderly**

Minor and scattered sources produce some health-care waste, but their quantities and composition will vary. These sources typically have some common features;

- ü They rarely produce radioactive or cytostatic waste,
- ü Human body parts are not normally produced,
- ü Sharps consist mainly of hypodermic needles.

Lists of some minor sources of health-care waste are below. However, it should be recognized that the quantities of waste from the home treatment of medical conditions and long-term home-based care are rising significantly in many countries (WHO, 2013).

- **Small health-care establishments**
 - Ü First-aid posts and sick bays,
 - Ü Physicians offices,
 - Ü Dental clinics,
 - Ü Acupuncturists,
 - Ü Chiropractors.

- **Specialized health-care establishments and institutions with low waste generation**
 - Ü Convalescent nursing homes,
 - Ü Psychiatric hospitals,
 - Ü Disabled persons' institutions.

- **Activities involving intravenous or subcutaneous interventions**
 - Ü Cosmetic ear-piercing and tattoo parlours,
 - Ü Illicit drug users and needle exchanges.

- **Funeral services**
- **Ambulance services**
- **Home treatment**

3.2.3. Characteristics of Health-Care Waste

Knowing the types and quantities of waste produced in a health-care facility is an important first step in safe disposal. Waste generation data are used in estimating the required capacities for containers, storage areas, transportation and treatment technologies. Waste generation data can be used to establish baseline data on rates of production in different medical areas and for procurement specifications,

planning, budgeting, calculating revenues from recycling, optimization of waste-management systems, and environmental impact assessments.

Health care waste generation data are best obtained from quantitative waste assessments. An assessment entails defining goals, planning, enlisting the cooperation of staff, procurement of equipment (e.g. weighing scales, personal protective equipment), data collection, analysis and recommendations. The process of waste assessment provides an opportunity to improve current practices, sensitize health workers about waste, and determine the potential for waste minimization. Implementing rigorous segregation can avoid over-sizing of equipment and result in cost savings.

The design of a waste-assessment programme can vary. Generally, data are collected regularly (typically daily) from each area of a facility, waste items are segregated into separate containers, each container is weighed and the weights produced are compared against the number of patients or beds in use. Data collection for a period of a few days provides limited information and may not accurately reflect weekly or seasonal variations. Data collection for a month or longer and repeated at different times in the year provides a more accurate picture and a better understanding of the quantities of waste generated in individual parts of a facility. For waste minimization, a breakdown of the amounts of recyclable materials is needed. In addition to calculating average rates, information regarding the spread of the data (data range or standard deviation) is important (WHO, 2013).

Globally, the most easily recyclable plastics are polyethylene, polypropylene and polyethylene terephthalate (PET). Conversely, polyvinyl chloride (PVC) is the most difficult, partly because its products come in a variety of forms containing different additives. Packaging of mixed materials, such as paper or card covered in plastic or aluminum foil, is rarely recyclable.

PVC is also of concern because of the toxicity of some of its additives and should be avoided wherever possible. Similarly, polycarbonate is made from bisphenol A, which is an endocrine disruptor. Latex or nitrile gloves are the most common replacements for PVC gloves. Latex or silicone tubing can replace PVC tubing, polyethylene IV bags can replace PVC bags, and ethylene vinyl acetate bags

can replace PVC bags for saline and blood. Ethylene oxide is used to sterilize medical devices, but it is carcinogenic and so should be avoided where alternatives exist (WHO, 2013).

An international classification system to identify different types of plastic is available. Common types in healthcare settings are;

- low-density polyethylene – LDPE, 4,
- high-density polyethylene – HDPE, 2,
- polypropylene – PP, 5,
- polyethylene terephthalate – PET or PETE, 1,
- polycarbonate – PC, which has no designated number but may be labeled 7 (a miscellaneous category for low-volume plastics).

Where items are not labelled, procurement staff should contact the manufacturer for further information or change to a product that is clearly labelled as being made from a material known to be recyclable (WHO, 2013).

3.2.3.1. Average Material Constituents of Health-Care Waste

The material constituents of healthcare waste are mainly paper and other cellulosic materials, plastics, glass, metal, and food waste with a small percentage of pathological waste (anatomical or body parts, tissues, organs, etc.) and placenta from child birth. Table 3.13. shows the worldwide average material constituents of healthcare waste. Table 3.14. compares average material constituents of healthcare waste in six countries. Note however that the data came from different studies that used different methodologies. About 85% of healthcare waste is non-risk (non-hazardous) general waste. In general, more than half of general waste from hospitals is paper, cardboard, and plastics, and the rest is food, metal, glass, cloth, wood, and other types of solid waste. Some have estimated that plastics could be as high as 60% especially in developed countries (Brunner, 1996). If properly segregated, most general waste from healthcare facilities is recyclable or compostable. Determining

the material constituents of general waste is important when setting up recycling programs (UNEP, 2012).

Table 3.13. Worldwide average material constituents of healthcare waste (excluding food waste) (UNEP, 2012).

Material Constituents	Composition Range (weight %)
Paper/Carton	15 - 40
Plastics	10 - 60
Glass	5 - 15
Metal	1 - 10
Cloth/Cotton/Gauze	10 - 25
Other	5 - 25

Table 3.14. Average material constituents of healthcare waste (UNEP, 2012).

Jordan*		Peru		Turkey		Taiwan		Kuwait		Italy	
Constituent	%	Constituent	%	Constituent	%	Constituent	%	Constituent	%	Constituent	%
Paper	38	Mixed paper	22	Paper	16	Paper	34	Paper	24	Paper	34
Plastic	27	Cardboard	5	Carton	5	Plastic	26	Cardboard	8	Plastics	46
Glass	10	Plastic	12	Plastic	41	Glass	7	Plastic	18	Glass	8
Metals	5	Glass	8	Glass	7	Metals	4	Glass	10	Metals	0.4
Textiles	11	Cotton/gauze	18	Metals	2	Food	15	Metals	9	Anatomical	0.1
Garbage	9	Placenta	8	Food	17	Textiles	9	Food	12	Liquids	12
				Textiles	10			Textiles	11		
		Other	27	Other	3	Other	3	Other	8		

* excluding kitchen waste

3.2.3.2. Moisture Content of Healthcare Waste

The moisture content varies considerably depending on the composition of the waste. Health-care waste from a 1900-bed hospital in Italy had an average moisture level of 26.76%, with a standard deviation of 8.48 based on 409 samples (Liberti et al., 1994). Some departments, such as obstetrics, paediatrics and dialysis, had moisture levels as high as 50%. The waste from four hospitals in Turkey had an average moisture content of 14.15% (Altin et al., 2003). The moisture content of different components of overall health-care waste and infectious waste is shown in Table 3.15.

Table 3.15. Percent moisture content of health-care waste constituents (WHO, 2013).

Overall healthcare waste (%)			Infectious waste (%)			
Component	Ecuador	Component	Jordan	Turkey	Component	Canada
Paper/Cardboard	16	Paper	22-57	4,5	Human anatomical	70-90
Food	45	Food		63	Plastics	0-1
Textile	30	Textile	37-68	8,8	Swabs, Absorbents	0-30
Plastic/Rubber	15	Plastic	11-54	2,8	Alcohol, Disinfectants	0-0,2
Kitchen Waste	47	Garbage	37-57		Animal infected anatomical	60-90
Garden Wastes	40	Carton		5	Glass	0
Medicines	64	Metal		2,25	Bedding, Shavings, Paper, Fecal matter	10-50
		Glass		2,05	Gauze, Pads, Swabs, Garments, Paper, Cellulose	0-30
		Others		8	Plastics, PVC, Syringes	0-1
					Sharps, Needles	0-1
					Fluid, Residuals	80-100

3.2.3.3. Percent Incombustibles in Healthcare Waste

The average percentage of incombustibles was found to be about 8% at four hospitals in Turkey (Altin et al., 2003). Others have estimated the incombustibles as 20.4% by weight of hospital waste. (Campbell, 1988). The percentages of ash and other residues from infectious hospital waste, based on 409 samples from a large hospital in Italy, were 66% at 100 °C, 15% at 550 °C, and 14% at 1000 °C (Liberti et al., 1994).

3.2.3.4. Heating Value of Healthcare Waste

The percentages of residues from infectious hospital waste, based on 409 samples from a hospital in Italy, were 66% at 110 °C, 15% at 550 °C, and 14% at 1000 °C. A low heating value of wet hazardous health-care waste was measured at 3500 kcal/kg (14.65 MJ/kg). The ranges of heating values for different components of health-care waste are provided in Table 3.16 (WHO, 2013).

Table 3.16. Heating values of various healthcare waste components (WHO, 2013).

Component	Heating Value (as fired)	
	MJ/kg	Kcal/kg
Human anatomical	2 - 8.4	400 -2000
Plastics	32 - 46	7700 - 11000
Swabs, Absorbents	13 - 28	3100 - 6700
Alcohol, Disinfectants	25 - 32	6100 - 7800
Animal infected anatomical	2 - 15	500 - 3600
Glass	0	0
Bedding, Shavings, Paper, Fecal matter	9 - 19	2200 - 4500
Gauze, Pads, Swabs, Garments, Paper, Cellulose	13 -28	3100 - 6700
Sharps, Needles	0 – 0.1	0 - 30
Fluid, Residuals	0 - 5	0 - 1100

The approximate chemical composition of hospital waste is 37% carbon, 18% oxygen and 4.6% hydrogen, as well as numerous other elements (Liberti et al.,1994). The toxic metals that are found in health-care waste and that are readily emitted during combustion include lead, mercury, cadmium, arsenic, chromium and zinc. In the past, elemental compositions were used to estimate the products of combustion, but this can be misleading since health-care waste varies widely. Moreover, persistent organic pollutants such as polychlorinated dioxins and furans cannot be predicted reliably from basic elemental compositions. These dioxins and furans are toxic at extremely low concentrations. However, decreasing the percentage of halogenated plastics (such as polyvinyl chloride) reduces the amounts of hydrogen chloride and other halogenated pollutants. As much as 40% of plastic waste in modern hospitals is chlorinated plastics. To facilitate recycling, common plastics are now frequently labelled with internationally recognized symbols and numbers; 1 – polyethylene terephthalate, 2 – high-density polyethylene, 3 – polyvinyl chloride, 4 – low-density polyethylene, 5 – polypropylene, 6 – polystyrene and 7 – other. Unfortunately, many polyvinyl chloride products in health care, such as blood bags, gloves, enteral feeding sets and film wraps, are not labelled (WHO, 2013).

3.2.4. Hazards of Medical Waste

The large component of non-hazardous health-care waste is similar to municipal waste and should not pose any higher risk than waste produced in households. It is the smaller hazardous health-care waste component that needs to be properly managed so that the health risks from exposure to known hazards can be minimized. Protection of the health of staff, patients and the general public is the fundamental reason for implementing a system of health-care waste management.

All individuals coming into close proximity with hazardous health-care waste are potentially at risk from exposure to a hazard, including those working within health-care facilities who generate hazardous waste, and those who either handle such waste or are exposed to it as a consequence of careless actions.

The main groups of people at risk are;

- ü medical doctors, nurses, health-care auxiliaries and hospital maintenance personnel patients in health-care facilities or receiving home care,
- ü visitors to health-care facilities,
- ü workers in support services, such as cleaners, people who work in laundries, porters,
- ü workers transporting waste to a treatment or disposal facility,
- ü workers in waste-management facilities (such as landfills or treatment plants), as well as informal recyclers (scavengers).

The general public could also be at risk whenever hazardous health-care waste is abandoned or disposed of improperly. The hazards associated with scattered, small sources of health-care waste should not be overlooked. These sources include pharmaceutical and infectious waste generated by home-based health care, and contaminated disposable materials such as from home dialysis and used needles from insulin injection, or even illicit intravenous drug use. The hazardous nature of health-care waste is due to one or more of the following characteristics;

- ü presence of infectious agents,
- ü a genotoxic or cytotoxic chemical composition,
- ü presence of toxic or hazardous chemicals or biologically aggressive,
- ü pharmaceuticals,
- ü presence of radioactivity,
- ü presence of used sharps (WHO, 2013).

3.2.4.1. Hazards from Infectious Waste and Sharps

Infectious waste should always be assumed to potentially contain a variety of pathogenic microorganisms. This is because the presence or absence of pathogens cannot be determined at the time a waste item is produced and discarded into a container. Pathogens in infectious waste that is not well managed may enter the human body through several routes;

- ü through a puncture, abrasion or cut in the skin,
- ü through mucous membranes,
- ü by inhalation,
- ü by ingestion (WHO, 2013).

3.2.4.2. Hazards from Chemical and Pharmaceutical Waste

Many of the chemicals and pharmaceuticals used in health care are hazardous. They are commonly present in small quantities in health-care waste, whereas larger quantities may be found when unwanted or outdated chemicals and pharmaceuticals are sent for disposal. Chemical wastes may cause intoxication, either by acute or chronic exposure, or physical injuries, the most common being chemical burns. Intoxication can result from absorption of a chemical or pharmaceutical through the skin or the mucous membranes, or from inhalation or ingestion. Injuries to the skin, the eyes or the mucous membranes of the airways can

occur by contact with flammable, corrosive or reactive chemicals (e.g. formaldehyde and other volatile substances).

Laboratory staff are regularly exposed to dozens of chemicals during the course of their work, especially in specialist and research hospitals. The hazardous properties most relevant to wastes from health care are as follows;

Toxic: Most chemicals are toxic at some level of exposure. Fumes, dusts and vapours from toxic materials can be especially harmful because they can be inhaled and pass quickly from the lungs into the blood, permitting rapid circulation throughout the body.

Corrosive: Strong acids and alkali bases can corrode completely through other substances, including clothing. If splashed on the skin or eyes, they can cause serious chemical burns and permanent injury. Some of these also break down into poisonous gases, which further increase their hazardousness.

Explosive: Some materials can explode when exposed to heat or flame, notably flammable liquids when ignited in confined spaces, and the uncontrolled release of compressed gases.

Flammable: Compounds with this property catch fire easily, burn rapidly, spread quickly and give off intense heat. Many materials used and stored in medical areas, laboratories and maintenance workshops are flammable, including solvents, fuels and lubricants.

Chemically reactive: These materials should be used with extreme caution and stored in special containers. Some can burn when exposed to air or water, some when mixed with other substances. It is important to note that reactive materials do not have to be near heat or flames to burn. They may burn spontaneously in the presence of air and also give off vapours that may be harmful if inhaled (WHO, 2013).

3.2.4.3. Hazards from Genotoxic Waste

Special care in handling genotoxic waste is essential. The severity of the hazards for health-care workers responsible for the handling or disposal of genotoxic

waste is governed by a combination of the substance toxicity itself and the extent and duration of exposure. Exposure to genotoxic substances in health care may also occur during the preparation of, or treatment with, particular drugs or chemicals. The main pathways of exposure are inhalation of dust or aerosols, absorption through the skin, ingestion of food accidentally contaminated with cytotoxic drugs, ingestion as a result of bad practice, such as mouth pipetting, or from waste items. Exposure may also occur through contact with body fluids and secretions of patients undergoing chemotherapy.

The cytotoxicity of many antineoplastic drugs is cell-cycle specific, targeted on specific intracellular processes such as DNA synthesis and mitosis. Other antineoplastics, such as alkylating agents, are not phase specific but are cytotoxic at any point in the cell cycle. Experimental studies have shown that many antineoplastic drugs are carcinogenic and mutagenic; secondary neoplasia (occurring after the original cancer has been eradicated) is known to be associated with some forms of chemotherapy (WHO, 2013).

3.2.4.4. Hazards from Radioactive Waste

The nature of illness caused by radioactive waste is determined by the type and extent of exposure. It can range from headache, dizziness and vomiting to much more serious problems. Radioactive waste is genotoxic, and a sufficiently high radiation dose may also affect genetic material. Handling highly active sources, such as those used in diagnostic instruments (e.g. gallium sealed sources) may cause much more severe injuries, including tissue destruction, necessitating the amputation of body parts. Extreme cases can be fatal.

The hazards of low-activity radioactive waste may arise from contamination of external surfaces of containers or improper mode or duration of waste storage. Health-care workers, and waste-handling and cleaning personnel exposed to radioactivity are most at risk (WHO, 2013).

3.2.4.5. Hazards from Health-Care Waste Treatment Methods

In addition to the specific hazards posed by different types of health-care waste, there are occupational hazards associated with waste-treatment processes. Some are similar to those common in industries using machinery.

Flue gases from waste incinerators may have an impact on people living and working close to a treatment site. The health risk is most serious where an incinerator is improperly operated or poorly maintained. If poorly controlled, emissions from waste incinerators may cause health concern from particulates (associated with increased cardiovascular and respiratory mortality and morbidity); volatile metals, such as mercury and cadmium (associated with damage to the immune system, neurological system, lungs and kidneys); and dioxins, furans and polycyclic aromatic hydrocarbons (which are known carcinogens but may also cause other serious health effects).

Ash from the incineration of hazardous health-care waste may continue to pose a risk. Burnt-out needles and glass may have been disinfected but can still cause physical injury. Furthermore, incinerator ash may contain elevated concentrations of heavy metals and other toxic items, and the ash provides ideal conditions for the synthesis of dioxins and furans, because it is often exposed for a long time to a temperature range of 200 °C – 450 °C.

Autoclave and steam disinfection treatment methods can also pose potential hazards that need to be managed. In particular, good maintenance and operation should be undertaken to avoid physical injuries from high operating temperatures and steam generation. Post-waste treatment water contains organic and inorganic contaminants. The concentrations should be monitored to ensure that discharges to sewerage systems are within regulated limits.

Health-care waste treatment mechanical equipment, such as shredding devices and waste compactors, can cause physical injury when improperly operated or inadequately maintained.

Burial of health-care waste in landfill sites may pose hazards to workers and public. The risks are often difficult to quantify, and the most likely injury comes

from direct physical contact with waste items. Chemical contaminants or pathogens in landfill leachate may be released into surface streams or groundwater. On poorly controlled land-disposal sites, the presence of fires and subsurface burning waste poses the further hazard of airborne smoke. The smoke may contain heavy metals and other chemical contaminants that over time may affect the health of site workers and the general public (WHO, 2013).

3.2.5. Selection of Medical Waste Treatment Methods

The choice of treatment system (incineration, sterilization, landfilling etc.) involves consideration of waste characteristics, technology capabilities and requirements, environmental and safety factors, and costs, many of which depend on local conditions. Factors to consider include;

- waste characteristics,
- quantity of wastes for treatment and disposal,
- capability of the health-care facility to handle the quantity of waste,
- types of waste for treatment and disposal,
- technology capabilities and requirements,
- local availability of treatment options and technologies,
- capacity of the system,
- treatment efficiency,
- volume and mass reduction,
- installation requirements,
- available space for equipment,
- infrastructure requirements,
- operation and maintenance requirements,
- skills needed for operating the technology,
- environmental and safety factors,
- environmental releases,

- ü location and surroundings of the treatment site and disposal facility,
- ü occupational health and safety considerations,
- ü public acceptability,
- ü options available for final disposal,
- ü regulatory requirements,
- ü cost considerations,
- ü equipment purchase cost,
- ü shipping fees and customs duties,
- ü installation and commissioning costs,
- ü annual operating costs, including preventive maintenance and testing,
- ü cost of transport and disposal of treated waste,
- ü decommissioning costs (WHO, 2013).

3.2.6. Overview of Medical Waste Treatment Technologies

Medical waste treatment is a function of the type of medical waste to be processed and the ultimate disposal of the waste after treatment. If there is any possibility of human contact after treatment, then the medical waste should be completely disinfected so that waste workers or scavengers who may come into contact with the material are not exposed to potentially infectious properties (MSEA, EEAA and USAID, 2003).

The most preferable approach, if locally achievable, is to avoid producing waste as far as possible and thus minimize the quantity entering the waste stream. Where practicable, recovering waste items for secondary use is the next most preferable method. Waste that cannot be recovered must then be dealt with by the least preferable options, such as treatment or land disposal, to reduce its health and environmental impacts (WHO, 2013).

As laws or regulations regarding the management of medical waste have evolved, there are a number of approaches that health care facilities have used to treat medical waste. These approaches include;

- ü The development of on-site treatment systems at individual health care facilities,
- ü The development of regional or cooperative treatment facilities often supplemented by,
- ü Individual systems for outlying hospitals,
- ü The treatment of medical waste in existing industrial or municipal treatment facilities,
- ü Such as municipal incinerators if they are available.

The general advantages of on-site medical waste treatment include the following;

- ü Convenience,
- ü Minimization of risk to public health by confining the waste to the health care premises.

However, there are also some disadvantages of this individualized approach including;

- ü High costs,
- ü More technical staff may be required at each health care facility to operate and maintain their treatment system,
- ü It may be difficult for government agencies to monitor the performance of many small,
- ü Facilities resulting in poor compliance with operating standards and increased,
- ü Environmental pollution.

In some cases, regional medical waste treatment facilities have been developed which provide a number of advantages;

- ü Greater cost-effectiveness through an increased economy of scale,
- ü More economical spare or expanded capacity,
- ü Better opportunity for privatization,
- ü Increased ability to monitor performance,
- ü Increased efficiency of operations as a result of a centralized, skilled staff,
- ü Decreased air pollution as a result of more effective monitoring and control.

Table 3.17. Advantages and disadvantages of treatment options (MSEA, EEAA and USAID, 2003).

TREATMENT METHOD	Advantages	Disadvantages
ROTARY KILN INCINERATION	-Adequate for all infectious waste, most chemical waste, and pharmaceutical waste. -Significant reduction of weight and volume of waste.	-High investment and operating costs. -Concern about air emissions.
CONTROLLED AIR INCINERATION	-Very high disinfection efficiency. -Adequate for all infectious waste and most pharmaceutical and chemical waste.	-Incomplete destruction of cytotoxics. -Relatively high investment and operating costs. -Concern about air emissions.

Table 3.17. continued

MULTIPLE HEARTH INCINERATION	<ul style="list-style-type: none"> -Good disinfection efficiency. -Significant reduction of weight and volume of waste. -The residues may be disposed of in landfills. -No need for highly trained operators. Relatively low investment and operating costs. 	<ul style="list-style-type: none"> -Significant emissions of atmospheric pollutants. -Need for periodic removal of slag and soot. -Inefficiency in destroying thermally resistant chemicals, and drugs such as cytotoxics.
CHEMICAL DISINFECTION	<ul style="list-style-type: none"> -Highly efficient disinfection under good operating conditions. -Some chemical disinfectants are relatively inexpensive. -Reduction in waste volume. 	<ul style="list-style-type: none"> -Requires highly qualified technicians for operation of the process. -Uses hazardous substances that require comprehensive safety measures and safe disposal. -Inadequate for pharmaceutical, chemical, and some types of infectious waste.
WET THERMAL TREATMENT	<ul style="list-style-type: none"> -Environmentally sound. -Drastic reduction in waste volume. -Relatively low investment and operating costs. 	<ul style="list-style-type: none"> -Shredders are subject to frequent breakdowns and poor functioning. -Operation requires qualified technicians. -Inadequate for anatomical, pharmaceutical, chemical waste and waste that is not readily steam-permeable.
MICROWAVE IRRADIATION	<ul style="list-style-type: none"> -Good disinfection efficiency under appropriate operating conditions. -Drastic reduction in waste volume. -Environmentally sound. 	<ul style="list-style-type: none"> -Relatively high investment and operating costs. -Potential operation and maintenance problems.

There are four basic processes for the treatment of hazardous components in health-care waste. These are;

- Thermal,
 - Low-Heat Thermal
 - High-Heat Thermal
- Chemical,
- Irradiative,
- Biological.

A fifth process “mechanical” is used as a supplement to the four main processes used in the treatment of healthcare waste (UNEP, 2012).

3.2.6.1. Thermal Processes

These processes rely on heat (thermal energy) to destroy pathogens in the waste. They represent most treatment facilities in use across the world. This category can be further subdivided into low-heat and high-heat designs. This subclassification is useful because of the marked differences in the thermochemical reactions and physical changes taking place in the wastes during their treatment in the different types of equipment. These differences produce very different atmospheric emissions characteristics (WHO, 2013).

Thermal processes are those that rely on heat (thermal energy) to destroy pathogens in the waste. This category is further subdivided into low-heat, medium-heat, and high-heat thermal processes. This further subclassification is necessary because physical and chemical mechanisms that take place in thermal processes change markedly at medium and high temperatures (HCWH, 2001).

3.2.6.1.(1). Low Heat Thermal Processes

Low-heat thermal processes are those that use thermal energy at elevated temperatures high enough to destroy microorganisms but not sufficient to cause combustion or pyrolysis of the waste.

In general, low-heat thermal technologies operate between 100 °C and 180 °C. The low-heat processes take place in either moist or dry-heat environments. Moist (or wet) thermal treatment involves the use of steam to disinfect waste and is commonly performed in an autoclave or steam-based treatment system. Microwave treatment is essentially a moist thermal process, because disinfection occurs through the action of moist heat (hot water and steam) generated by the microwave energy. Dry-heat processes use hot air without the addition of water or steam. In dry-heat systems, the waste is heated by conduction, convection and/or thermal radiation using infrared or resistance heaters (WHO, 2013).

There are a number of commercially available technologies that utilize wet or dry thermal processing for low heat disinfection. These processes will be effective in killing most types of microorganisms as long as the temperature and contact time is sufficient. Sufficiency is usually determined by the reaction of the most resistant microorganisms that may be found in the medical waste. For example, the inactivation of bacterial spores requires a minimum temperature of 121 °C (MSEA, EEAA and USAID, 2003).

Autoclaves: Autoclaves are capable of treating a range of infectious waste, including cultures and stocks, sharps, materials contaminated with blood and limited amounts of fluids, isolation and surgery waste, laboratory waste (excluding chemical waste) and “soft” waste (including gauze, bandages, drapes, gowns and bedding) from patient care. With sufficient time and temperature, it is technically possible to treat small quantities of human tissue, but ethical, legal, cultural, religious and other considerations may preclude their treatment. Autoclaves are generally not used for large anatomical remains (body parts), because it is difficult to determine beforehand the time and temperature parameters needed to allow full penetration of heat to the centre of the body part.

Autoclaves have been used for more than a century to sterilize medical instruments, and for several years they have been adapted for the treatment of infectious waste. An autoclave consists of a metal vessel designed to withstand high pressures, with a sealed door and an arrangement of pipes and valves through which steam is introduced into, and removed from, the vessel. Some autoclaves are designed with a steam jacket surrounding the vessel; steam is introduced into both the outside jacket and the inside chamber. Heating the outside jacket reduces condensation on the inside chamber wall and allows the use of steam at lower temperatures. An autoclave without a steam jacket, sometimes called a “retort”, is commonly found in large-scale applications and is cheaper to construct.

Air is an effective insulator and a principal factor in determining the efficiency of steam treatment. Removal of air from the autoclave is essential to ensure penetration of heat into the waste. Unlike instrument sterilization autoclaves, waste-treatment autoclaves must treat the air that is removed at the start of the process to prevent the release of pathogenic aerosols. This is usually done by treating the air with steam or passing it through a high-efficiency particulate air (HEPA) filter before it is released (WHO, 2013).

Autoclaving is a wet thermal disinfection process. Autoclaves use steam sterilization as a low heat thermal process. This technology has the advantage that there is considerable experience in most health care facilities with the use of smaller scale autoclaves for the sterilization of reusable medical equipment. Autoclaves are the most commonly used medical waste treatment alternative in the United States and are growing in popularity in other countries.

For this technology to be effective, the medical waste must be exposed to sufficient contact time and temperature for disinfection. The minimum contact time and temperature will depend on several factors such as the moisture content of the waste and the ease of penetration of the steam into the solid forms within the waste. Research has shown that for an autoclave to be effective, it should provide a minimum retention time of 60 minutes at 121°C (minimum) at 1 bar pressure. This will normally allow full penetration of the steam into the waste material.

A typical operating cycle for an autoclave or retort involves the following;

Waste collection: A cart or bin is lined with special plastic liners or large autoclavable bags to prevent waste from sticking to the container. Red bags are then placed in the lined container.

Pre-heating (for autoclaves): Steam is introduced into the outside jacket of the autoclave.

Waste loading: Waste containers are loaded into the autoclave or retort chamber. Periodically, chemical or biological indicators are placed in the middle of the waste load to monitor disinfection. The charging door is closed, sealing the chamber.

Air evacuation: Air is removed through gravity displacement or pre-vacuuming as explained above.

Steam treatment: Steam is introduced into the chamber until the required temperature is reached. Additional steam is automatically fed into the chamber to maintain the temperature for a set time period.

Steam discharge: Steam is vented from the chamber, usually through a condenser, to reduce the pressure and temperature. In some systems, a post-vacuum cycle is used to remove residual steam.

Unloading: Usually, additional time is provided to allow the waste to cool down further, after which the treated waste is removed and the indicator strips, if any, are removed and evaluated.

Mechanical treatment: Generally, the treated waste is fed into a shredder or compactor prior to disposal in a sanitary landfill.

Advantages and disadvantages of autoclave systems are shown below;

Ü Advantages

- Tested and proven technology with extensive use,
- On-site or regional treatment of various sizes,
- Low capital operating cost,
- No hazardous emissions since combustion is not involved,
- Complies with current rules in most industrialized countries,
- Quality control procedures are well established through extensive use,

- Less manpower required,
- No pre - or post - treatment required,

Ü Disadvantages

- Shredding may be required to make treated waste unrecognizable,
- Only 30 to 35% volume reduction,
- If autoclave does not have proper drying mechanism, foul odors can be emitted,
- Requires plastic liners or bags,
- Cannot treat all types of medical waste,
- Disposal areas may have a concern about disinfection quality control (MSEA, EEAA and USAID, 2003).

Consequently, autoclaves can be subcategorized according to the method of air removal. The three common types are;

- Ü gravity-displacement autoclaves,
- Ü pre-vacuum or high-vacuum autoclaves,
- Ü pressure pulse autoclaves.

A gravity-displacement autoclave takes advantage of the fact that steam is lighter than air. Hence, steam is introduced under pressure into the chamber, forcing the air downwards into an outlet port of the chamber.

A more effective but costlier method is the use of a vacuum pump and/or a steam ejector to evacuate air before introducing steam, as is done in pre-vacuum (also called high-vacuum) autoclaves. Pre-vacuum autoclaves need less time for disinfection due to their greater efficiency in removing air and disinfecting waste. Figure 3.4. shows a simple schematic of a pre-vacuum autoclave (WHO, 2013).

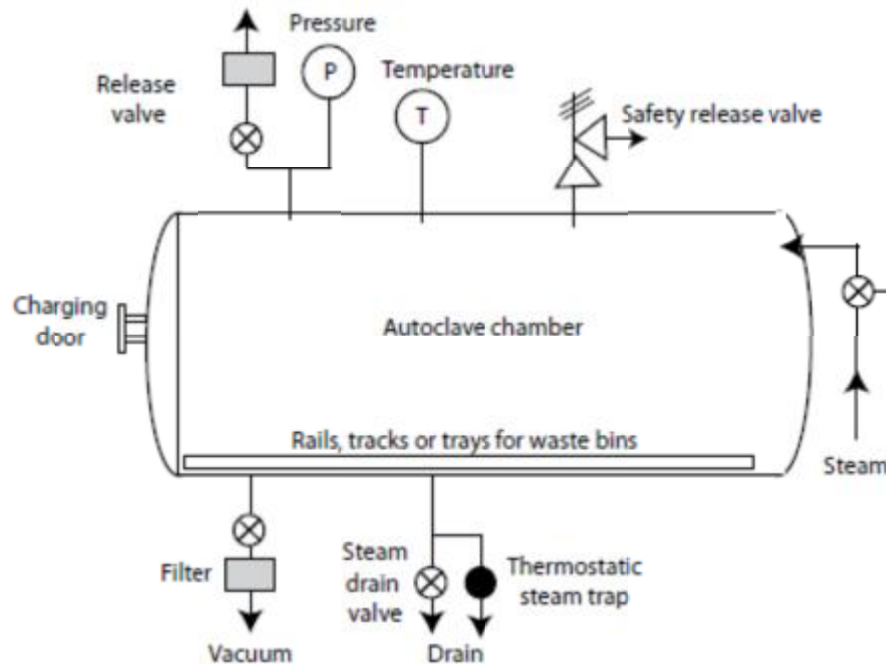


Figure 3.4. Simplified schematic of a pre-vacuum autoclave (WHO, 2013).

Dry heat technologies: These technologies use hot air, with no addition of water or steam, and operate below combustion temperatures. In dry heat systems, the waste is heated by conduction, convection, and/or thermal radiation using infrared or resistance heaters. Another technology uses frictional heating as the source of heat. As of this writing, commercial dry heat technologies are small-scale units. One dry heat technology does not reduce volume but another can achieve 75 - 80% reduction (UNEP, 2012).

3.2.6.1.(2). High Heat Thermal Processes

High heat systems operate at temperatures sufficient to cause chemical and physical changes leading to the destruction of the medical waste. These systems use combustion, pyrolysis, and/or high-temperature plasma to decontaminate and destroy the waste and operate at temperatures ranging from as low as 600 °C to more than 5,500 °C (MSEA, EEAA and USAID, 2003).

High-heat thermal processes begin to take place around 180 °C and higher, temperatures that result in chemical and physical changes in the waste through

combustion, pyrolysis, or gasification. Most high heat thermal processes operate at temperatures above 850 °C (UNEP, 2012).

High-heat thermal processes generally operate at temperatures ranging from around 1,000 °F to 15,000 °F (540 °C - 8,300 °C) or higher. Electrical resistance, induction, natural gas, and/or plasma energy provide the intense heat. High-heat processes involve chemical and physical changes to both organic and inorganic material resulting in total destruction of the waste. A significant change in the mass and volume of the waste also occurs. For example, low-heat thermal technologies that rely on shredders or grinders to reduce size decrease waste volume by about 60 to 70%, compared to 90 or 95% with high-heat thermal processes (HCWH, 2001).

Incineration: Incineration is a high-temperature combustion process that reduces organic and combustible waste to inorganic, incombustible solid residues and gaseous combustion by-products. Pyrolysis is the thermal degradation of materials through the application of heat in the absence of oxygen. In actual practice, it is difficult to have a completely oxygen-free atmosphere so some oxidation takes place. Gasification involves the addition of small, controlled amounts of oxygen or steam. Well designed and operated incinerators can reduce volume by 80-90% and mass by about 75%.

Incineration is an example of a high heat thermal system. Incineration uses high temperature combustion under controlled conditions to convert wastes containing infectious and pathological material to inert mineral residues and gases. The process of incineration results in a significant reduction in the weight and the volume of the waste combusted. Historically, incineration has been used for all forms of solid waste including municipal and hazardous wastes in addition to medical waste. Incineration technologies have evolved through the years as both a means of waste treatment and as a way to recover the energy value of solid wastes prior to its disposal. In systems where energy is recovered, steam is often produced using the energy content of the combusted solid waste. This steam can either be directly used by industry as process steam or used in more general applications for heating and cooling. In many of the large waste to energy facilities located around the world, the

produced steam is used to generate electricity either for sale or for internal use. There are three types of incinerators typically used for medical waste treatment;

1. Multiple-hearth,
2. Rotary kiln,
3. Controlled-air design.

Medical waste is normally suitable for incineration since the heating value (the organic energy content that burns and sustains a combustion process) of the waste exceeds that which is required to support the combustion process. For example, incineration only becomes practical if the heating value of a waste material is at least 2,000 kcal/kg. The heating value of medical waste is typically twice that amount. In state of the art incineration systems, supplemental fuels are only used during startup and shutdown of the system. During normal operations, the heating value of the waste placed into the incineration units should be sufficient to maintain combustion without the assistance of supplemental fuels. As a result, the heating value of any waste to be combusted is an extremely important element since the need for supplemental fuel has a significant effect on the overall costs of incineration.

Based on our current knowledge about incineration, the use of this treatment technology should be carefully considered, weighing its benefits and risks. Incineration has become controversial in many areas of the world because of concerns about air emissions resulting from the combustion process. In addition, there are a number of medical waste components that should not be incinerated including;

- ü Pressurized gas containers,
- ü Large amounts of reactive chemical waste,
- ü Photographic or radiographic wastes,
- ü Halogenated plastics such as polyvinyl chloride (PVC),
- ü Waste with high mercury or cadmium content such as broken thermometers and used batteries,

ü Sealed ampoules or ampoules containing heavy metals.

The advantages and disadvantages of incineration as a form of medical waste treatment are shown below;

Advantages:

- Can accept the greatest variety of waste,
- Treated waste is unrecognizable and exists as ash,
- Significant volume reduction (80 to 90%),
- Waste totally sterilized,
- Energy recovery potential in larger systems.

Disadvantages:

- Incinerators convert biological problem into potential air quality emission problems,
- Acid gases and heavy metals in air emissions,
- Heavy metals found in ash residues,
- Identified as a major source of dioxin and furan emissions (MSEA, EEAA and USAID, 2003).

Incineration is a high-temperature, dry oxidation process that reduces organic and combustible waste to inorganic, incombustible matter and results in a significant reduction of waste volume and weight. High-heat thermal processes take place at temperatures from about 200 °C to more than 1000 °C. They involve the chemical and physical breakdown of organic material through the processes of combustion, pyrolysis or gasification. A disadvantage of these technologies is the release of combustion by-products into the atmosphere and the generation of residual ash. The combustion of health-care waste produces mainly gaseous emissions, including steam, carbon dioxide, nitrogen oxides, a range of volatile substances (e.g. metals,

halogenic acids, products of incomplete combustion) and particulate matter, plus solid residues in the form of ashes. Figure 3.5. shows a simple schematic of the incineration process;

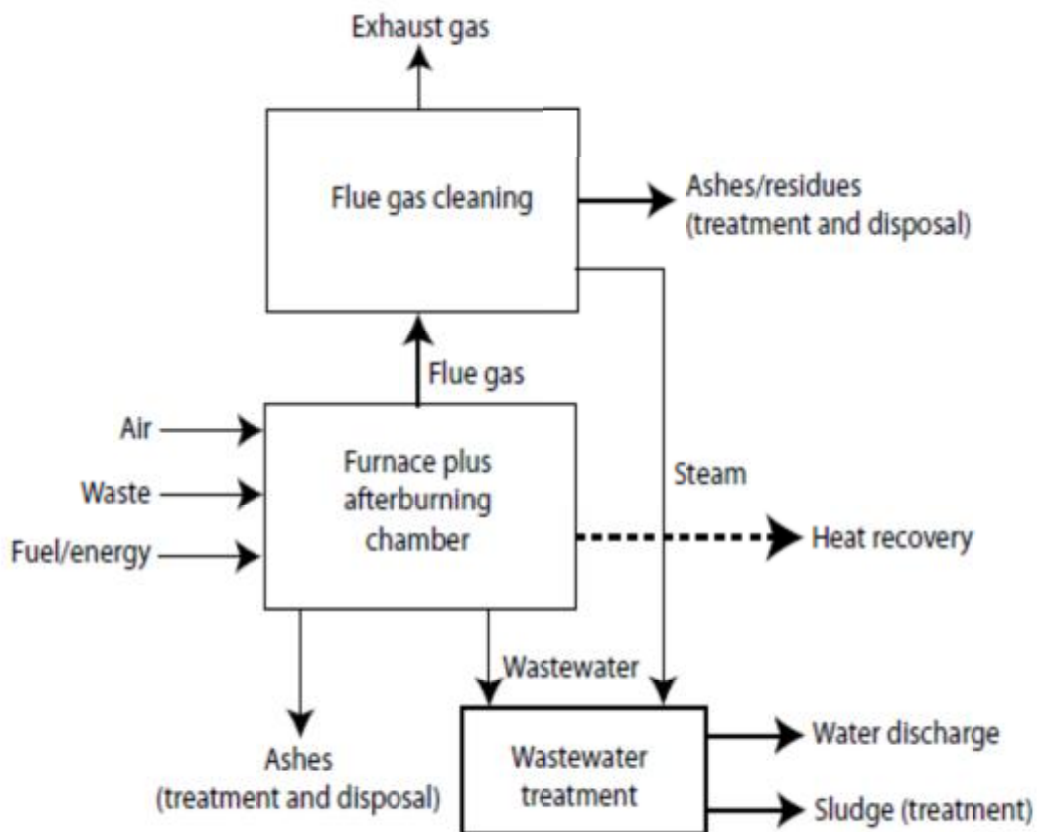


Figure 3.5. Simplified flow scheme of the incineration process (WHO, 2013).

Pyrolysis and gasification: Pyrolysis is the thermal degradation of a substance through the application of heat in the absence of oxygen. Pyrolysis is a special case of thermolysis and is most commonly used for organic materials. It occurs at high temperatures but does not involve reactions with oxygen. In practice, it is difficult to have a completely oxygen-free atmosphere, so some oxidation takes place (WHO, 2013).

Pyrolysis and plasma systems are other forms of high heat thermal processing. Pyrolysis systems attempt to process the waste materials through an oxidative process similar to combustion but with little or no oxygen. Plasma units

use extremely high temperatures to breakdown the processed waste into its basis elements. However, these systems are not yet commercially available and generally applied to medical waste treatment (MSEA, EEAA and USAID, 2003).

Pyrolysis and gasification processes operate with substoichiometric air levels. The difference between pyrolysis, gasification and incineration is clarified in Table 3.18.

Table 3.18. Typical reaction conditions and products from pyrolysis, gasification and incineration processes (MSEA, EEAA and USAID, 2003).

	Pyrolysis	Gasification	Incineration
Reaction temperature (°C)	250–700	500–1600	800–1450
Pressure (bar)	1	1-45	1
Atmosphere	Inert/nitrogen	Gasification agent: O ₂ , H ₂ O	Air
Stoichiometric ratio	0	<1	>1
Products from the process: Gas phase	H ₂ , CO, C _x H _y , H ₂ O, N ₂	H ₂ , CO, CO ₂ , CH ₄	CO ₂ , H ₂ O, O ₂
Solid phase	Ash, coke	H ₂ O, N ₂	NO ₂
Liquid phase	Pyrolysis oil, water	Slag, ash	Slag, ash

3.2.6.2. Chemical Processes

Chemical treatment methods use disinfectants such as dissolved chlorine dioxide, bleach (sodium hypochlorite), peracetic acid, lime solution, ozone gas or dry inorganic chemicals (e.g. calcium oxide powder). Chemical processes often involve shredding, grinding or mixing to increase exposure of the waste to the chemical agent. In liquid systems, the waste may go through a dewatering section to remove and recycle the disinfectant. Besides chemical disinfectants, there are also encapsulating compounds that can solidify sharps, blood or other body fluids within a solid matrix before disposal. Another example of a chemical process is a system that uses heated alkali to digest tissues, pathological waste, anatomical parts and animal carcasses in heated stainless-steel tanks (WHO, 2013).

Chemical disinfection is commonly used to kill microorganisms on medical equipment and on floors and walls in health care facilities. In addition, technologies have been developed that utilize chemical disinfection as a means of treating medical waste. The intent of these systems is to simply provide a means by which a chemical disinfectant is placed in contact with the infectious waste to kill or inactivate contained pathogens. Generally, chemical disinfection is most suitable for treating liquid waste such as blood and urine. However, solid medical waste can also be treated with chemical disinfection subject to the following limitations;

1. Shredding of the waste is usually necessary to increase the surface area contact between the disinfectant and the material to be treated,
2. Powerful disinfectants are required which can be hazardous themselves and should only be used by well-trained and adequately protected personnel,
3. The use of chemical disinfection must also consider the ultimate disposal of the liquid that will result from the disinfection process,
4. Human body parts and animal carcasses should not normally be disinfected chemically since it is difficult for the disinfectant to penetrate into their solid structure,
5. Some microorganisms are resistant to disinfectants. For example, some bacterial spores and viruses may be difficult to treat with chemical disinfection.

Chemical treatment involves the direct use of chemicals for disinfection. Common disinfectant chemicals include chlorine compounds, phenol compounds, iodine, alcohol, hexachlorophene, formaldehyde/alcohol combinations. Most chemicals are used as aqueous solutions. Water is needed to bring chemicals and microorganisms together to achieve the elimination of infectious properties. Most chemical processing systems start with shredding in order to provide better contact between the waste material and the chemical. Shredding also helps to make the waste

unrecognizable when it gets to the disposal site. Advantages and disadvantages associated with chemical treatment are as follows;

ü Advantages

- Economical with low capital investment.

ü Disadvantages

- Only for surface contaminated or penetrable waste,
- Not suited for pathological waste,
- Shredding required for most medical waste,
- Environmental risk to air and water associated with the chemical use (MSEA, EEAA and USAID, 2003).

Chemical processes employ disinfectants such as dissolved chlorine dioxide, bleach (sodium hypochlorite), peracetic acid or dry inorganic chemicals. To enhance exposure of the waste to the chemical agent, chemical processes often involve shredding, grinding, or mixing. In liquid systems, the waste may go through a dewatering section to remove and recycle the disinfectant. Besides chemical disinfectants, there are also encapsulating compounds that can solidify sharps, blood, or other body fluids within a solid matrix prior to disposal. One developing technology uses ozone to treat medical waste, and others utilize catalytic oxidation. A novel system uses alkali to hydrolyze tissues in heated stainless steel tanks (HCWH, 2001).

3.2.6.3. Irradiation Technologies

Irradiation treatment encompasses designs using irradiation from electron beams, cobalt-60 or ultraviolet sources. These technologies require shielding to prevent elevated occupational exposures to electromagnetic radiation. The pathogen destruction efficacy depends on the dose absorbed by the mass of waste. Electron beams are powerful enough to penetrate waste bags and containers. Germicidal ultraviolet radiation has been used to destroy airborne microorganisms as a

supplement to other treatment technologies, but is not able to penetrate closed waste bags (WHO, 2013).

3.2.6.4. Biological Processes

These processes are found in natural living organisms but refer specifically to the degradation of organic matter when applied to health-care waste treatment. Some biological treatment systems use enzymes to speed up the destruction of organic waste containing pathogens. Composting and vermiculture (digestion of organic wastes through the action of worms) are biological processes and have been used successfully to decompose hospital kitchen waste, as well as other organic digestible waste and placenta waste. The natural decomposition of pathological waste through burial is another example of a biological process (WHO, 2013).

3.2.6.5. Mechanical Processes

Mechanical treatment processes include several shredding, grinding, mixing and compaction technologies that reduce waste volume, although they cannot destroy pathogens. In most instances, mechanical processes are not stand-alone health-care waste-treatment processes, but supplement other treatment methods. Mechanical destruction can render a waste unrecognizable and can be used to destroy needles and syringes (depending on the type of shredding). In the case of thermal or chemical treatment processes, mechanical devices such as shredders and mixers can also improve the rate of heat transfer or expose more surface area of waste to waste treatment.

Mechanical devices used to prepare wastes before other forms of waste destruction add significantly to the level of management and maintenance required to treat health-care waste safely and efficiently.

Unless shredders, mixers and other mechanical devices are an integral part of a closed treatment system, they should not be used before the incoming health-care waste is disinfected. If they are used, workers are at an increased risk of being

exposed to pathogens in aerosols released into the environment by mechanical destruction of untreated waste bags. If mechanical processes are part of a closed system, the technology should be designed in such a way that the air in and from the mechanical process is disinfected before being released to the surroundings (WHO, 2013).

3.2.7. Health-Care Waste Situation in Turkey and Adana

The management of the health-care wastes in Turkey is one of the environmental subjects to be considered. The amount of waste from health-care facilities in Turkey is a significant portion of the total waste generated and therefore requires efficient management and control systems by a specific regulation.

Turkish legislators have approached the control of the health-care wastes by publishing a single regulation that deals with the subject in an integrated approach. With this purpose, “Turkish Medical Wastes Control Regulation (TMWCR)” was adopted in May 20th, 1993. This Regulation was the basis for improving the healthcare waste practices in the country. It establishes the legal controls and permits concerning the management of these wastes.

Although “Turkish Medical Waste Control Regulation” had been published more than ten years ago, it was not applied regularly. When the existing Regulation was evaluated, it was found out that Turkish Medical Waste Control Regulation had insufficient content for an efficient health-care waste management both at the institutional and administrative level and it needed a significant revision.

The control of the health-care waste management is also one of the most significant environmental problems in Turkey that should be solved. The management of the health-care wastes in Turkey is conducted according to Turkish Medical Wastes Control Regulation that was adapted in 1993. In the Regulation, the procedures about the classification of the wastes, collection, transportation, and temporary storage of the wastes within the institutions and the transportation of the wastes to the final disposal area are explained. In the last part of the Regulation, the method of the disposal of the wastes is mentioned. According to the Regulation, the

incineration of the health-care wastes is taken as the basis for the final disposal method.

Turkish Medical Wastes Control Regulation (TMWCR) consists of eight sections. The First Section of the Regulation defines the sources and characteristics of the solid wastes originated from the health-care institutions and related sectors. Following the definitions and other specifications the Second Section of the Regulation indicates the principles of the separate collection, temporary storage, documentation and the transportation of the infected wastes to the final disposal site.

The principles of the separate collection and handling of infected medical wastes, sharps and hazardous chemical wastes are explained in the Third Section of the Regulation while the location and the technical specifications of the temporary storage room and its cleaning principles are explained in the Fourth Section. Rules about the transportation of the infected wastes to the final disposal area, specifications of the trucks and the required training of the personnel working in this field are explained in the Fifth Section.

The Sixth Section gives the technical specifications of the incinerators, the allowable emission standards, procedures for the license of the location and the operation of the incinerators. The control methods and cancellation of the license are also explained in the same section.

The location of the site, technical specification of the preparation of the landfill areas, the drainage systems, operational rules and after care principles are given in the Seventh Section of the Regulation. In the Eight Section the follow up and the control mechanisms of the infected wastes, responsibilities of different institutions such as the municipalities and ministries are explained.

Health-care wastes are potential sources of risk to public health mostly in the middle and lower-income countries. Although central governments in these middle and low income countries are often keen to legislate against environmental pollution, they can not implement the published legislation because of the lack of financial resources (Alagöz et al., 2006).

Wastes collected in medical institutions must be stored in temporary waste storage or containers until they are collected by the municipality.

Transportation of medical wastes from temporary storage sites and containers as well as small sources to disposal sites are being carried out by entities and enterprises as authorized by the municipalities.

Medical Waste Control Regulation paved the path for implementation of alternative disposal technologies for the disposal of medical waste in Turkey. MOEF has instructed the municipalities to handle domestic solid waste and medical waste disposal in an integrated manner, to consider the medical waste disposal as a component and to prioritize sterilization as the best means of intermediate processing method as per country's circumstances.

Medical institutions are paying due attention on separation of medical waste from other solid waste at its source, transportation and temporary storage. Equally, municipalities as well have made progress in proper disposal of the medical waste. (UN, 2010).

Table 3.19. shows average amount of medical waste per outpatient and inpatient in the year 2010 and 2012 at Turkey.

Table 3.19. Average amount of medical waste per outpatient and inpatient at Turkey (2010 – 2012) (TurkStat, 2013).

	Number of health institutions collecting medical waste separately		Amount of medical waste (kg/year)		Amount of medical waste per outpatient (kg/person) ⁽²⁾		Amount of medical waste per inpatient (kg/person) ⁽³⁾	
	2010	2012	2010	2012	2010	2012	2010	2012
Total	1 398	1 449	59 966 481	68 928 799	0,20	0,20	5,32	5,79
Hospitals owned by Ministry of Health⁽¹⁾	866	869	33 322 581	37 303 772	0,14	0,14	4,91	5,36
Private hospitals	470	515	11 806 847	16 542 342	0,25	0,27	4,05	4,96
University hospitals	62	65	14 837 053	15 082 685	0,72	0,56	9,52	9,42

(1) Hospitals owned by Ministry of Defense and local administrations are also included,

(2) Outpatient is a patient who is not hospitalized overnight but who visits a hospital, clinic, or associated facility for diagnosis or treatment,

(3) Inpatient is a patient whose treatment requires a stay in the hospital.

As it can be seen from Table 3.20. medical wastes which are collected in 2012 at Turkey; 46% was sterilized and disposed at controlled landfill site. 28% wasn't sterilized and was disposed at controlled landfill site. 16% was sterilized and disposed at municipal dumping site. 1% wasn't sterilized and was disposed at municipal dumping site. 8% was disposed with the incinerator.

Table 3.20. Amount of medical waste by disposal methods at Turkey and Adana (2012) (kg/year) (TurkStat, 2013).

	Number of health institutions	Number of health institutions collecting medical waste separately	Amount of medical waste	Municipal dumping site		Controlled landfill site		Incinerated	Other ⁽¹⁾
				After sterilization	Without sterilization	After sterilization	Without sterilization		
Turkey	1 449	1 449	68 928 799	11 217 756	979 909	31 697 453	19 284 061	5 744 736	4 884
Adana	26	26	2 959 837	-	(*)	2 947 644	-	(*)	-

(-) Denotes magnitude null,

(*) Data pertaining to units which has less than three statistical units are not given by law no: 5429 which is indicated,

(1) Includes burning in an open area, furnace, burial, etc.

Table 3.21. shows that the physical and elemental composition of hospital waste in four hospitals in Sivas, Turkey. The four hospital wastes consist of 92% combustible wastes and 8% noncombustible wastes by mass. The combustible wastes constitute paper (16%), textiles (10.2%), cardboard (4%), plastics (41.2%) and food waste (17%) (Altin et al., 2003).

Table 3.21. Physical and elemental composition of hospital waste in four hospitals in Sivas, Turkey (Altin et al., 2003).

Kind of waste	Weight in the waste (%)	Average moisture content of kind of waste (%)	Moisture content in the unit waste (%)
Paper	16.1	4.5	0.72
Food	17.1	63	10.77
Textile	10.2	8.6	0.87
Cartoon	4.6	5	0.23
Plastic	41	2.8	1.15
Etc.	3	8	0.24
Combustible (%)	92		
Metal	0.8	2.25	0.02
Glass	7.2	2.05	0.15
Non-combustible (%)	8.0		
		Average	14.15

Moisture content (rightmost column) = (% by weight) x (average moisture content for the type of waste)

3.3. Plastics

Plastics were first invented in 1860, but have only been widely used in the last 30 years. Plastics are light, durable, modifiable and hygienic. Plastics are made up of long chain of molecules called polymers. Polymers are made when naturally occurring substances such as crude oil or petroleum are transformed into other substances with completely different properties. These polymers can then be made into granules, powders and liquids, becoming raw materials for plastic products (Sarker, 2011).

Plastics are a generic group of synthetic or natural materials, composed of high molecular chains whose sole or major element is carbon. In common usage the terms plastics, polymers and resins are roughly equivalent.

Plastics are manufactured from monomers, i.e. a repeatable molecular unit and building block, by means of various chemical processes, such as;

- a catalytic or peroxide-initiated polymerization of monomer(s), e.g. ethylene, propylene, or butadiene + styrene (copolymers),

- a polycondensation of dissimilar monomers (e.g. bifunctional organic acids and alcohols or amines),
- polyaddition of reactive monomer molecules,
- Especially the first group forms an attractive feedstock for pyrolysis processes.

Important monomers are polymerization grade (i.e. very high purity) ethylene, propylene, butadiene, three products obtained by thermal cracking or pyrolysis of e.g. naphtha, light gas-oil, or liquefied petroleum gases (LPG = propane or butane) and purified by low-temperature, high-pressure distillation, up to polymerization grade chemicals. Adding hetero-atoms to the monomer, such as chlorine, in vinyl chloride monomer, creates additional difficulties in pyrolysis processes and methods for separating waste plastics at the source or by mechanical means, e.g. sink/float, froth flotation, separation after identification on the basis of absorption or reflection spectra, or electrostatic sorting after tribo-electric charging, is an important practical consideration.

Before its conversion into plastic products the resulting resin is almost always compounded with various additives of different nature and constitution, meant to improve processing, stability, or mechanical specifications as a function of a given application (outdoors, i.e. UV-light exposed, oxidation, high-temperature processing). Such additives are regularly used as (maximum amount encountered, in weight percent);

- antioxidants (1%),
- heat and light stabilizers (5%),
- plasticizers (40%),
- impact resistance enhancers (10%),
- pigments, colorants and dyestuffs (5%),
- flame retardants (15%),
- mould-release agents,
- foaming agents (2%),

ü fillers (40%).

Other additives are used as antiblocker, anti-fogging and anti-static agents, bio-stabilizers, chemical blowing agents, cross-linking agents, high polymeric impact strength additives and processing aids, lubricants, metal deactivators, optical brighteners, property modifiers, reinforcements, smoke and afterglow suppressants, wetting agents, etc. Their presence, as well as chemicals used in initiating or terminating polymerization, is a complicating factor in feedstock recycling, also termed chemical recycling, in a more restricted sense, pyrolysis or thermal cracking of waste plastics, since their nature, amount, and behaviour during pyrolysis (thermal volatilization or breakdown) and eventual influence upon reaction products and mechanism are somewhat unpredictable, especially for waste plastics of unknown origin and formulation. PVC absorbs more additive volume than any other resin (Scheirs et al., 2006).

3.3.1. Plastic Types

Plastics can be classified on the basis of numerous criteria, e.g;

- ü *chemical composition*: directly connected with the nature of the monomer(s) and the method of polymerization. Plastics are thus subdivided into classes, e.g. polyolefins, vinyl polymers, styrenics, polyamides, polyesters, epoxy resins, polycarbonates, polyurethanes, etc,
- ü *chemical structure*: e.g. linear (high-density polyethylene), branched (low-density polyethylene), cross-linked and three-dimensionally networked (thermosets, rubbers),
- ü *stiffness*: elastic, flexible, or rigid,
- ü *type of application*: commodity vs engineering, general purpose vs specialty plastics,

Ü *processing method*: used (injecting moulding, extrusion, film blowing, blow (moulding, thermoforming, casting, calendaring, and many other techniques) (Scheirs et al., 2006).

Thermoplastics still soften when heated and harden again when cooled, because there is little or no bonding between individual molecular chains. All commodity plastics are thermoplastic (Scheirs et al., 2006). Thermoplastics are plastics that can be repeatedly soften and melt when heat is applied and they solidify into new shapes or new plastics products when cooled. Thermoplastics include Polyethylene Terephthalate (PET), Low Density Poly Ethylene (LDPE), Poly Vinyl Chloride (PVC), High Density Poly Ethylene (HDPE), Polypropylene (PP) and Polystyrene (PS) among others (UNEP, 2009b).

Thermosets show threedimensional structures and rather than softening, thermally decompose while heating (Scheirs et al., 2006). Thermosets or thermosettings are plastics that can soften and melt but take shape only once. They are not suitable for repeated heat treatments; therefore if heat is reapplied they will not soften again but they stay permanently in the shape that they solidified into. Thermosets are widely used in electronics and automotive products. Thermoset plastics contain alkyd, epoxy, ester, melamine formaldehyde, phenolic formaldehyde, silicon, urea formaldehyde, polyurethane, metalised and multilayer plastics etc. Of the total post-consumer plastics waste in India, thermoplastics constitute 80% and the remaining 20% correspond to thermosets. Similar percentages are also representative in the rest of the world (UNEP, 2009b).

Rubber has a structure intermediate between thermosets and thermoplastics, with molecular chains linked by sulphur bridges during vulcanization. In pyrolysis, the main material is tyre rubber, a compound of styrene, butadiene and isoprene based rubber (SBR), of carbon black, sulphur, vulcanization aids and zinc oxide.

The world production of plastics keeps rising, and so does waste generation, albeit with a time lag, dictated by lifetime. This lifetime spans from weeks (packaging), over months (agricultural film) and years (cars, household appliances, furniture), even to the order of a century (in some building applications). In

numerous building applications (water distribution ducts, flooring, roofing, window frames) such lifetimes are not known with certainty. Still, take-back schemes more and more affect important markets, such as packaging, automobile, or electrical and electronic equipment. Such schemes are still developing, confronted with the immense variety in applications, resins, additives, and with the difficulty in identification and light weight of plastics.

Plastics waste arises at the levels of production, conversion, and consumption. In the first two categories source separation, identification, and recycling, is straightforward. Such simple source separation concepts no longer hold for post-consumer recycling, where entropy is immense: plastic products both geographically and functionally are widely spread, more often than not compounded with unknown additives, or mixed, soiled, composite, and difficult to collect at a reasonable cost.

Mechanical recycling, i.e. reusing as a plastic material in similar applications (closedloop recycling, e.g. film-to-film) provides the highest value to waste plastics. Loss in mechanical properties restricts recycling to simpler applications and geomembranes, sometimes simply replacing low-grade wood, as in urban furniture, such as park benches.

Feedstock recycling converts plastics into monomer, mixes of chemicals, or into synthesis gas or reducing gas. Thermal recycling (combustion) merely recovers the heat of combustion (Scheirs et al., 2006).

Plastics are classified on the basis of the polymer from which they are made, therefore the variety of plastics it is very extensive. The types of plastics that are most commonly reprocessed are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET) and polyvinyl chloride (PVC).

Polyethylene (PE) – The two main types of polyethylene are low-density polyethylene (LDPE) and high density polyethylene (HDPE). LDPE is soft, flexible and easy to cut, with the feel of candle wax. When it is very thin it is transparent; when thick it is milky white, unless a pigment is added. LDPE is used in the manufacture of film bags, sacks and sheeting, blow moulded bottles, food boxes, flexible piping and hosepipes, household articles such as buckets and bowls, toys, telephone cable sheaths, etc. HDPE is tougher and stiffer than LDPE, and is always

milky white in color, even when very thin. It is used for bags and industrial wrappings, soft drinks bottles, detergents and cosmetics containers, toys, crates, jerry cans, dustbins and other household articles.

Polypropylene (PP) – Polypropylene is more rigid than PE, and can be bent sharply without breaking. It is used for stools and chairs, high-quality home ware, strong moldings such as car battery housings and other parts, domestic appliances, suitcases, wine barrels, crates, pipes, fittings, rope, woven sacking, carpet backing, netting, surgical instruments, nursing bottles, food containers, etc.

Polystyrene (PS) – In its unprocessed form, polystyrene is brittle and usually transparent. It is often blended (copolymerized) with other materials to obtain the desired properties. High impact polystyrene (HIPS) is made by adding rubber. Polystyrene foam is often produced by incorporating a blowing agent during the polymerization process. PS is used for cheap, transparent kitchen ware, light fittings, bottles, toys, food containers, etc.

Polyethylene Terephthalate (PET) – PET exists as an amorphous (transparent) and as a semi-crystalline (opaque and white) thermoplastic material. Generally, it has good resistance to mineral oils, solvents and acids but not to bases. The semi-crystalline PET has good strength, ductility, stiffness and hardness while the amorphous type has better ductility but less stiffness and hardness. PET has good barrier properties against oxygen and carbon dioxide. Therefore, it is utilized in bottles for mineral water. Other applications include foodtrays for oven use, roasting bags, audio/video tapes as well as mechanical components and synthetic fibers.

Polyvinyl chloride (PVC) – Polyvinyl chloride is a hard, rigid material, unless plasticizers are added. Common applications for PVC include bottles, thin sheeting, transparent packaging materials, water and irrigation pipes, gutters, window frames, building panels, etc. If plasticizers are added, the product is known as plasticized polyvinyl chloride (PPVC), which is soft, flexible and rather weak, and is used to make inflatable articles such as foot balls, as well as hosepipes and cable coverings, shoes, flooring, raincoats, shower curtains, furniture coverings, automobile linings, bottles, etc.

Other plastics extensively used in our daily lives are as follow;

- *High Impact Polystyrene (HIPS)* – used in fridge liners, food packaging, vending cups,
- *Acrylonitrile Butadiene Styrene (ABS)* – used in electronic equipment cases (e.g., computer monitors, printers, keyboards), drainage pipe,
- *Polyester (PES)* – used in fibers, textiles,
- *Polyamides (PA) (Nylons)* – used in fibers, toothbrush bristles, fishing line, under-the-hood car engine mouldings,
- *Polyurethanes (PU)* – used in cushioning foams, thermal insulation foams, surface coatings, printing rollers,
- *Polycarbonates (PC)* – used in CDs, eyeglasses, riot shields, security windows, traffic lights, lenses,
- *Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS)* – A blend of PC and ABS that creates a stronger plastic. Used in car interior and exterior parts and mobile phone bodies (UNEP, 2009b).

3.3.2. The SPI Resin Identification Code

The SPI resin identification coding system is a set of symbols placed on plastics to identify the polymer type. It was developed by the Society of the Plastics Industry (SPI) in 1988, and is used internationally. The primary purpose of the codes is to allow efficient separation of different polymer types for recycling. Separation must be efficient because the plastics must be recycled separately. Even one item of the wrong type of resin can ruin a mix.

The symbols used in the code consist of arrows that cycle clockwise to form a rounded triangle and enclosing a number, often with an acronym representing the plastic below the triangle. When the number is omitted, the symbol is known as the universal Recycling Symbol, indicating generic recyclable materials. In this case,

other text and labels are used to indicate the material(s) used. Previously recycled resins are coded with an "R" prefix (for example, a *PETE* bottle made of recycled resin could be marked as *RPETE* using same numbering).

The number does not indicate how hard the item is to recycle, nor how often the plastic was recycled. It is an arbitrarily assigned number that has no other meaning aside from identifying the specific plastic (Anonymous, 2013c).

The main category of plastics include;

- *Recyclable Plastics (Thermoplastics):* PET, HDPE, LDPE, PP, PVC, PS, etc.,
- *Non-Recyclable Plastics (Thermoset & Others):* Multilayer & Laminated Plastics, PUF, Bakelite, Polycarbonate, Melamine, Nylon etc.

As per BIS Classification, there are seven categories of plastics (CPCB, 2012).

Table 3.22. shows the plastic packaging resins codes, descriptions, properties, product application and products made with recycled contents;

Table 3.22. Table of plastic packaging resins codes (Anonymous, 2013d).



RESIN CODES	DESCRIPTIONS	PROPERTIES	PRODUCT APPLICATION	PRODUCTS MADE WITH RECYCLED CONTENT*
	<p>Polyethylene Terephthalate (PET, PETE). -PET is clear, tough, and has good gas and moisture barrier properties. This resin is commonly used in beverage bottles and many injection molded consumer product containers. Cleaned, recycled PET flakes and pellets are in great demand for spinning fiber for carpet yarns, producing fiberfill and geo-textiles. Nickname: Polyester.</p>	<ul style="list-style-type: none"> -Clear and optically smooth surfaces for oriented films and bottles. -Excellent barrier to oxygen, water, and carbon dioxide. -High impact capability and shatter resistance, -Excellent resistance to most solvents. -Capability for hot-filling. 	<ul style="list-style-type: none"> -Plastic bottles for soft drinks, water, juice, sports drinks, beer, mouthwash, catsup and salad dressing. -Food jars for peanut butter, jelly, jam and pickles. -Ovenable film and microwavable food trays. -In addition to packaging, PET's major uses are textiles, monofilament, carpet, strapping, films, and engineering moldings. 	<ul style="list-style-type: none"> -Fiber for carpet, fleece jackets, comforter fill, and tote bags. -Containers for food, beverages (bottles), and non-food items. -Film and sheet. -Strapping.
	<p>High Density Polyethylene (HDPE). -HDPE is used to make many types of bottles. Unpigmented bottles are</p>	<ul style="list-style-type: none"> -Excellent resistance to most solvents. -Higher tensile strength compared to other 	<ul style="list-style-type: none"> -Bottles for milk, water, juice, cosmetics, shampoo, dish and laundry detergents, and household 	

Table 3.22. continued


<p>Table 3.22. continued</p>	<p>ent, good barrier properties and stiffness, and are well suited to packaging products with a short shelf life such as milk. Because HDPE has good chemical resistance, it is used for packaging many household and industrial chemicals such as detergents and bleach. Pigmented HDPE bottles have better stress crack resistance than unpigmented HDPE.</p>	<p>forms of polyethylene.</p> <p>-Relatively stiff material with useful temperature capabilities.</p>	<p>cleaners,</p> <p>-Bags for groceries and retail purchases.</p> <p>-Cereal box liners.</p> <p>-Reusable shipping containers.</p> <p>-In addition to packaging, HDPE's major uses are in injection molding applications, extruded pipe and conduit, plastic wood composites, and wire and cable covering.</p>	
	<p>Polyvinyl Chloride (PVC, Vinyl).</p> <p>-In addition to its stable physical properties, PVC has good chemical resistance, weatherability, flow characteristics and stable electrical properties. The diverse slate of vinyl products can be broadly divided into rigid and flexible materials.</p>	<p>-High impact strength, brilliant clarity, excellent processing performance.</p> <p>-Resistance to grease, oil and chemicals.</p>	<p>-Rigid packaging applications include blister packs and clamshells.</p> <p>-Flexible packaging uses include bags for bedding and medical, shrink wrap, deli and meat wrap and tamper resistance.</p> <p>-In addition to packaging, PVC's</p>	<p>-Pipe, decking, fencing, paneling, gutters, carpet backing, floor tiles and mats, resilient flooring, mud flaps, cassette trays, electrical boxes, cables, traffic cones, garden hose, and mobile home skirting.</p>

Table 3.22. continued


			major uses are rigid applications such as pipe, siding, window frames, fencing, decking and railing. Flexible applications include medical products such as blood bags and medical tubing, wire and cable insulation, carpet backing, and flooring.	-Packaging, film and sheet, and loose-leaf binders.
	<p>Low Density Polyethylene (LDPE).</p> <p>-LDPE is used predominately in film applications due to its toughness, flexibility and relative transparency, making it popular for use in applications where heat sealing is necessary. LDPE also is used to manufacture some flexible lids and bottles as well as in wire and cable applications.</p> <p>-Includes Linear Low</p>	<p>-Excellent resistance to acids, bases and vegetable oils.</p> <p>-Toughness, flexibility and relative transparency (good combination of properties for packaging applications requiring heat-sealing).</p>	<p>-Bags for dry cleaning, newspapers, bread, frozen foods, fresh produce, and household garbage.</p> <p>-Shrink wrap and stretch film.</p> <p>-Coatings for paper milk cartons and hot and cold beverage cups.</p> <p>-Container lids.</p> <p>-Toys.</p> <p>-Squeezable</p>	<p>-Shipping envelopes, garbage can liners, floor tile, paneling, furniture, film and sheet, compost bins, trash cans, landscape timber, and outdoor lumber.</p>

Table 3.22. continued


	Density Polyethylene (LLDPE).		bottles (e.g., honey and mustard). -In addition to packaging, LDPE's major uses are in injection molding applications, adhesives and sealants, and wire and cable coverings.	
	Polypropylene (PP). -PP has good chemical resistance, is strong, and has a high melting point making it good for hot- fill liquids. This resin is found in flexible and rigid packaging, fibers, and large molded parts for automotive and consumer products.	-Excellent optical clarity in biaxially oriented films and stretch blow molded containers. -Low moisture vapor transmission. -Inertness toward acids, alkalis and most solvents.	-Containers for yogurt, margarine, takeout meals, and deli foods. -Medicine bottles. -Bottle caps and closures. -Bottles for catsup and syrup. -In addition to packaging, PP's major uses are in fibers, appliances and consumer products, including durable applications such as automotive and carpeting.	-Automobile applications, such as battery cases, signal lights, battery cables, brooms and brushes, ice scrapers, oil funnels, and bicycle racks. -Garden rakes, storage bins, shipping pallets, sheeting, trays.

Table 3.22. continued



	<p>Polystyrene (PS).</p> <p>-PS is a versatile plastic that can be rigid or foamed. General purpose polystyrene is clear, hard and brittle. It has a relatively low melting point. Typical applications include protective packaging, foodservice packaging, bottles and food containers.</p> <p>-PS is often combined with rubber to make high impact polystyrene (HIPS) which is used for packaging and durable applications requiring toughness, but not clarity.</p>	<p>-Excellent moisture barrier for short shelf life products.</p> <p>-Excellent optical clarity in general purpose form.</p> <p>-Significant stiffness in both foamed and rigid forms.</p> <p>-Low density and high stiffness in foamed applications.</p> <p>-Low thermal conductivity and excellent insulation properties in foamed form.</p>	<p>-Food service items, such as cups, plates, bowls, cutlery, hinged takeout containers (clamshells), meat and poultry trays, and rigid food containers (e.g., yogurt). These items may be made with foamed or non-foamed PS.</p> <p>-Protective foam packaging for furniture, electronics and other delicate items.</p> <p>-Packing peanuts, known as "loose fill."</p> <p>-Compact disc cases and aspirin bottles.</p> <p>-In addition to packaging, PS's major uses are in agricultural trays, electronic housings,</p>	<p>-Thermal insulation, thermometers, light switch plates, vents, desk trays, rulers, and license plate frames.</p> <p>-Cameras or video cassette casings.</p> <p>-Foamed foodservice applications, such as egg shell cartons.</p> <p>-Plastic mouldings (i.e., wood replacement products).</p> <p>-Expandable polystyrene (EPS) foam protective packaging.</p>
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Table 3.22. continued

			cable spools, building insulation, video cassette cartridges, coat hangers, and medical products and toys.	
	Other: Use of this code indicates that a package is made with a resin other than the six listed above, or is made of more than one resin and used in a multi-layer combination.	-Dependent on resin or combination of resins.	-Three and five gallon reusable water bottles, some citrus juice and catsup bottles. -Ovenbaking bags, barrier layers, and custom packaging.	-Bottles and plastic lumber applications.

*Recycling may not be available in all areas. Check to see if plastics recycling is available in your community.

3.3.3. Description of Waste Plastics

The growth in plastics use is due to their beneficial characteristics; 21st. century economic growth making them even more suitable for a wide variety of applications, such as: food and product packaging, car manufacturing, agricultural use, housing products and etc. Because of good safety and hygiene properties for food packaging, excellent thermal and electrical insulation properties, plastics are more desirable among consumers. Low production cost, lower energy consumption and CO₂ emissions during production of plastics are relatively lower than making alternative materials, such as glass, metals and etc. Yet for all their advantages, plastics have a considerable downside in terms of their environmental impact. Plastic production requires large amounts of resources, primarily fossil fuels and 8% of the

world's annual oil production is used in the production of plastics. Potentially harmful chemicals are added as stabilizers or colorants. Many of these have not undergone environmental risk assessment and their impact on human health and environment is currently uncertain. Worldwide municipal sites like shops or malls had the largest proportion of plastic rubbish items (Sarker, 2011).

As European society has grown wealthier it has created more and more rubbish. Each year in the European Union, 3 billion tonnes of waste is thrown away (some of 90 million tonnes are hazardous). This amounts (about 6 tonnes of solid waste) for every man, woman and child. It is clear that treating and disposing of all this material (without harming the environment) becomes a major problem. The amount of waste generated in Europe increased by 10% in between 1990 and 1995. Most of what we throw away is either burnt in incinerators, or dumped into landfill sites (67%). By 2020, the OECD estimates, we could be generating 45% more waste than we did in 1995. Obviously we must reverse this trend if we are to avoid being submerged in rubbish (Sárközi et al., 2011).

3.3.4. Damage of Waste Plastics

The environmental hazards due to mismanagement of plastics waste include the followings;

- ü Littered plastics spoils beauty of the city and choke drains and make important public places filthy,
- ü Garbage containing plastics, when burnt may cause air pollution by emitting polluting gases,
- ü Garbage mixed with plastics interferes in waste processing facilities and may also cause problems in landfill operations,
- ü Plastics waste littered at various places other than the bins set up by the local authorities, remains uncollected,

- Ü Local vendors (vegetable, fruits and groceries) are using plastics carry bags not meeting with the prescribed specifications and such bags are not even collected by ragpickers,
- Ü Recycling industries operating in non-conforming areas are posing unhygienic problems to the environment (Anonymous, 2013e).

Indiscriminate littering of unskilled recycling/reprocessing and non-biodegradability of plastic waste raises the following environmental issues;

- Ü During polymerization process fugitive emissions are released,
- Ü During product manufacturing various types of gases are released,
- Ü Indiscriminate plastic waste disposal on land makes the land infertile due to its impervious nature,
- Ü Burning of plastics generates toxic emissions such as Carbon Monoxide, Chlorine, Hydrochloric Acid, Dioxin, Furans, Amines, Nitrides, Styrene, Benzene, 1, 3- butadiene, CCl₄, and Acetaldehyde,
- Ü Lead and Cadmium pigments, commonly used in LDPE, HDPE and PP as additives are toxic and are known to leach out,
- Ü Non-recyclable plastic wastes such as multilayer, metalised pouches and other thermoset plastic poses disposal problems,
- Ü Sub-standard plastic bags, films etc. pose problem in collection and recycling,
- Ü Littered plastics give unaesthetic look and choke the drain,
- Ü Garbage mixed with plastics interferes in waste processing facilities and also cause problems in landfill operations,
- Ü Recycling industries operating in non-conforming areas are posing environment problems due to unsound recycling practices (CPCB, 2012).

3.3.5. Converting Waste Plastics to Fuel

Waste plastics are one of the most promising resources for fuel production because of its high heat of combustion and due to the increasing availability in local communities. Unlike paper and wood, plastics do not absorb much moisture and the water content of plastics is far lower than the water content of biomass such as crops and kitchen wastes.

The conversion methods of waste plastics into fuel depend on the types of plastics to be targeted and the properties of other wastes that might be used in the process. Additionally the effective conversion requires appropriate technologies to be selected according to local economic, environmental, social and technical characteristics.

In general, the conversion of waste plastic into fuel requires feedstock's which are non-hazardous and combustible. In particular each type of waste plastic conversion method has its own suitable feedstock. The composition of the plastics used as feedstock may be very different and some plastic articles might contain undesirable substances (e.g. additives such as flame-retardants containing bromine and antimony compounds or plastics containing nitrogen, halogens, sulphur or any other hazardous substances) which pose potential risks to humans and to the environment.

The types of plastics and their composition will condition the conversion process and will determine the pretreatment requirements, the combustion temperature for the conversion and therefore the energy consumption required, the fuel quality output, the flue gas composition (e.g. formation of hazardous flue gases such as NO_x and HCl), the fly ash and bottom ash composition, and the potential of chemical corrosion of the equipment (UNEP, 2009a).

Therefore the major quality concerns when converting waste plastics into fuel resources are as follows;

1) Smooth feeding to conversion equipment: Prior to their conversion into fuel resources, waste plastics are subject to various methods of pretreatment to facilitate the smooth and efficient treatment during the subsequent conversion

process. Depending on their structures (e.g. rigid, films, sheets or expanded (foamed) material) the pretreatment equipment used for each type of plastic (crushing or shredding) is often different.

2) *Effective conversion into fuel products:* In solid fuel production, thermoplastics act as binders which form pellets or briquettes by melting and adhering to other non-melting substances such as paper, wood and thermosetting plastics. Although wooden materials are formed into pellets using a pelletizer, mixing plastics with wood or paper complicates the pellet preparation process. Suitable heating is required to produce pellets from thermoplastics and other combustible waste. In liquid fuel production, thermoplastics containing liquid hydrocarbon can be used as feedstock. The type of plastic being used determines the processing rate as well as the product yield. Contamination by undesirable substances and the presence of moisture increases energy consumption and promotes the formation of byproducts in the fuel production process.

3) *Well-controlled combustion and clean flue gas in fuel user facilities:* It is important to match the fuel type and its quality to the burner in order to improve heat recovery efficiency. Contamination by nitrogen, chlorine, and inorganic species, for instance, can affect the flue gas composition and the amount of ash produced. When using fuel prepared from waste plastics, it must be assured that the flue gas composition complies with local air pollution regulations. In the same way, ash quality must also be in compliance with local regulations when disposed at the landfill. If there aren't any relevant regulations, both the producers and consumers of the recycled fuel should control the fuel quality and the emissions at combustion in order to minimize their environmental impact (UNEP, 2009a).

Table 3.23. classifies various plastics according to the types of fuel they can produce. It can be observed that thermoplastics consisting of carbon and hydrogen are the most important feedstock for fuel production either in solid or liquid form.

Table 3.23. Polymer as feedstock for fuel production (UNEP, 2009a).

Types of polymer	Descriptions	Examples
Polymers consisting of carbon and hydrogen	Typical feedstock for fuel production due to high heat value and clean exhaust gas.	Polyethylene, polypropylene, polystyrene. Thermoplastics melt to form solid fuel mixed with other combustible wastes and decompose to produce liquid fuel.
Polymers containing oxygen	Lower heat value than above plastics.	PET, phenolic resin, polyvinyl alcohol, polyoxymethylene.
Polymers containing nitrogen or sulphur	Fuel from this type of plastic is a source of hazardous components such as NO _x or SO _x in flue gas. Flue gas cleaning is required to avoid emission of hazardous components in exhaust gas.	<i>Nitrogen:</i> Polyamide, Polyurethane <i>Sulfur:</i> Polyphenylene Sulfide
Polymers containing halogens of chlorine, bromine and fluorine	Source of hazardous and corrosive flue gas upon thermal treatment and combustion.	Polyvinyl chloride, polyvinylidene chloride, bromine-containing flame retardants and fluorocarbon polymers.

3.3.5.1. Pyrolysis/Thermal Degradation

Pyrolysis, also termed thermolysis (Greek: pur = fire; thermos = warm; luo = loosen), is a process of chemical and thermal decomposition, generally leading to

smaller molecules. Semantically, the term thermolysis is more appropriate than pyrolysis, since fire implies the presence of oxygen and hence of reactive and oxygen-bearing intermediates. In most pyrolysis processes, however, air is excluded, for reasons of safety, product quality, and yield.

Pyrolysis can be conducted at various temperature levels, reaction times, pressures, and in the presence or absence of reactive gases or liquids, and of catalysts. Plastics pyrolysis proceeds at low (<400 °C), medium (400 – 600 °C) or high temperature (>600 °C). The pressure is generally atmospheric. Subatmospheric operation, whether using vacuum or diluents, e.g. steam, may be selected if the most desirable products are thermally unstable, e.g. easily repolymerizing, as in the pyrolysis of rubber or styrenics.

The thermal decomposition of polymers yields gases, distillates and char, albeit in widely variable relative amounts. These can be applied as fuels, petrochemicals, and monomers. Depending on the polymers or polymer mixtures fed and the operating conditions used, yields can vary widely. As a rule, both gaseous and liquid products are mixtures of numerous different compounds. The problem of fractionating these effluents and upgrading to commercial specifications -while separating undesirable impurities- must be investigated on a case by case basis. The char incorporates fillers, pigments, and ash.

Pyrolysis processes involve breaking bonds and are often endothermic, so that ensuring a supply of heat to the reacting material is essential and generally rate-determining. Partial oxidation supplies such heat internally, but the pyrolysis products are diluted by oxidation or combustion products.

Cracking and pyrolysis are suitable processes for the tertiary recycling of additive polymers such as polyolefins, mainly polyethylene (PE), polypropylene (PP), polybutadiene (PBD) and polystyrene (PS). Small admixtures of other plastics, such polyethylene terephthalate (PET), polyvinyl chloride (PVC), less than two 2%, are admissible yet not desirable. Taking into account the total share of polyolefins in plastics production (~70 wt% including PS) they are the highest environmental problem. Their chemical composition (carbon and hydrogen) close to crude oil is the reason that this type of waste plastic can be processed simply by the refinery

medium-temperature methods such as thermal and catalytic cracking, visbreaking or coking (temperature generally lower than 500 °C) or high-temperature noncatalytic processes (600 – 800 °C), i.e. pyrolysis. The relatively low density of PE, PP, PS in comparison with PVC and PET is the basis of water separation (Scheirs et.al., 2006).

As shown in Table 3.24.; PE, PP and PS thermoplastics are preferable as feedstock in the production of liquid hydrocarbons. The addition of thermosetting plastics, wood, and paper to the feedstock leads to the formation of carbonous substances and lowers the rate and yield of liquid products (UNEP, 2009a).

Table 3.24. Suitability of some plastics for pyrolysis and their products (UNEP, 2009a).

Main products	Type of plastics	As a feedstock of liquid fuel
Liquid hydrocarbons	Polyethylene (PE) Polypropylene (PP) Polystyrene (PS) Polymethyl metacrylate (PMMA)	Allowed Allowed Allowed Allowed
Liquid hydrocarbons	Acrylonitrile-Butadiene Styrene copolymer (ABS)	Allowed. But not suitable. Nitrogen-containing fuel is obtained. Special attention required to cyanide in oil.
No hydrocarbons suitable for fuel	Polyvinyl alcohol (PVA) Polyoxymethylene (POM)	Not suitable. Formation of water and alcohol. Not suitable. Formation of formaldehyde.
Solid products	Polyethylene terephthalate (PET)	Not suitable. Formation of terephthalic acid and benzoic acid.
Carbonous products	Polyurethane (PUR) Phenol resin (PF)	Not suitable Not suitable
Hydrogen chloride and carbonous products	Polyvinyl chloride (PVC) Polyvinylidene chloride (PVDC)	Not allowed Not allowed

Pyrolysis is a process of thermal degradation of a material in the absence of oxygen. Plastic is fed into a cylindrical chamber. The pyrolytic gases are condensed in a specially designed condenser system, to yield a hydrocarbon distillate

comprising straight and branched chain aliphatic, cyclic aliphatic, and aromatic hydrocarbons, and liquid is separated using fractional distillation to produce the liquid fuel products. The plastic is pyrolysed at 370 °C – 420 °C (Patni et.al., 2013).

The essential steps in the pyrolysis of plastics involve that (Figure 3.6.);

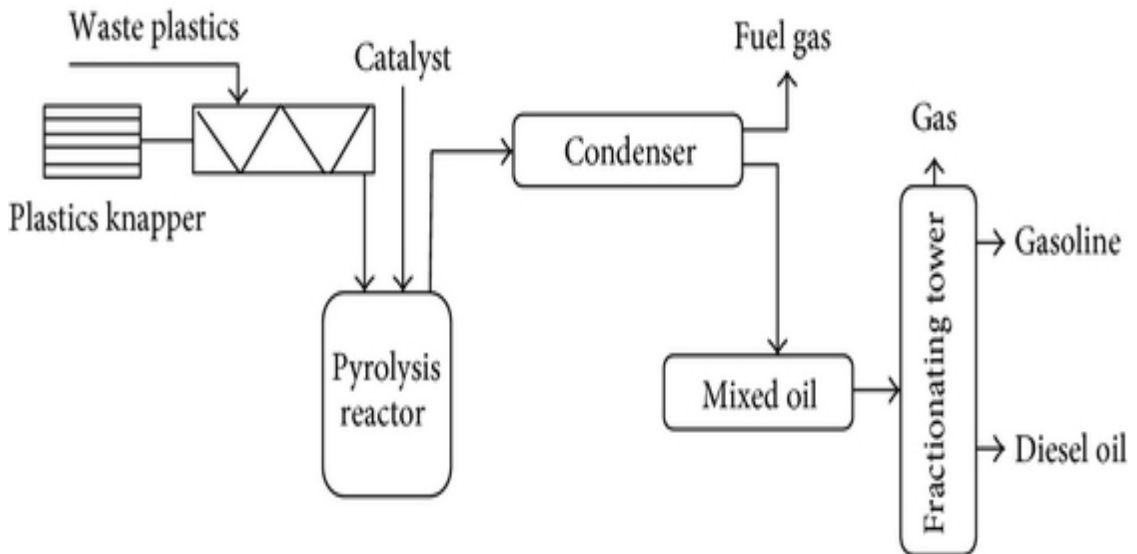


Figure 3.6. Pyrolysis process of generating fuel oil from the waste plastics (Zhang et.al., 2007).

- 1- heating the plastic evenly to a narrow temperature range without excessive temperature variations,
- 2- purging oxygen from pyrolysis chamber,
- 3- managing the carbonaceous char by product before it acts as a thermal insulator and lowers the heat transfer to the plastic,
- 4- careful condensation and fractionation of the pyrolysis vapors to produce distillate of good quality and consistency (Patni et.al., 2013).

Advantages of pyrolysis process are;

- a- significant reduction of waste volume (< 50 – 90%),
- b- solid, liquid, and gaseous fuel can be produced from the waste,
- c- storable/transportable fuel or chemical feed stock is obtained,
- d- environmental problem is reduced,

- e- desirable process as energy is obtained from renewable sources like municipal solid waste or sewage sludge,
- f- the capital cost is low (Allen et.al, 2011).

3.4. Experimental

3.4.1. Reactor

For this study, a pilot cracking reactor which has a 20 liter maximum capacity (Figure 3.7.), was designed and used for waste plastics cracking. Reactor consists of heat exchanger, PT 100 type thermocouple in order to measure the variation of temperature inside the reactor, digital temperature indicator, filler cap, drain cover and manometer. Stainless steel number 316 L is used as the main material for reactor manufacturing. Figure 3.8. shows the technical specifications of reactor.



Figure 3.7. Thermal cracking reactor

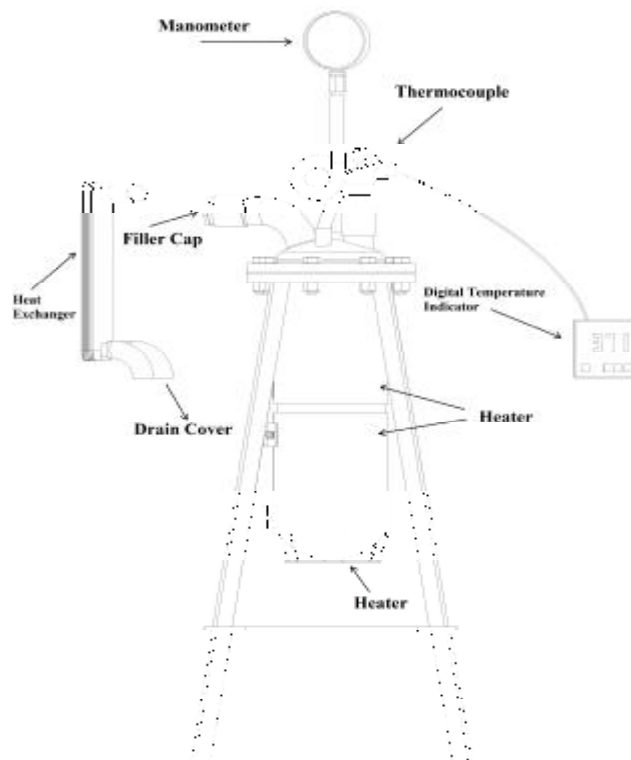


Figure 3.8. Technical draw of reactor system

3.4.2. Properties of Waste Plastics

The types of the waste plastics are LDPE, HDPE, PP, PS, PVC, PETE, PLA and etc. The problems of waste plastics can't be solved by landfilling or incineration, because the safety deposits are expensive and incineration stimulates the growing emission of harmful greenhouse gases; e.g. CO_x, NO_x, SO_x and etc (Sarker, 2011).

At this study; PET bottles, PS cups and nylons are used as a municipal waste plastics (Figure 3.9.). PP and PVC syringes, infusion sets, latex medical gloves, blood and diffusion bags are used as a medical waste plastics (Figure 3.10.).



Figure 3.9. Municipal waste plastic experiment samples



Figure 3.10. Medical waste plastic experiment samples

Properties of waste plastic pyrolysis oil and diesel fuel are presented in Table 3.25.

Table 3.25. Properties of waste plastic pyrolysis oil and diesel fuel (Pawar and Lawankar, 2013).

	Properties	Waste Plastic Pyrolysis Oil	Diesel Fuel
1	Density (kg/m ²)	793	850
2	Ash content (%)	<1.01 % wt	0.045 % wt
3	Calorific value (kJ/kg)	41,800	42,000
4	Kinematic viscosity (cst)	2.149	3.05
5	Cetane number	51	55
6	Flash point °C	40	50
7	Fire point °C	45	56
8	Carbon residue (%)	0.01 % wt	0.20 % wt
9	Sulphur content (%)	<0.002	<0.035
10	Pour point °C	-4	3-15

Plastics have physical and chemical properties. Different types of plastics displayed distinguishable characteristics and properties. Many kinds of plastics are appeared like LDPE, HDPE, PP, PS, PVC & PET etc. Several individual plastics properties are elaborated in shortly, that's given below in Table 3.26., Table 3.27., Table 3.28. and Table 3.29.

Table 3.26. HDPE-2 plastic properties (Sarker, 2011).

Quantity	Value	Units
Thermal expansion	110 - 130	e-6/K
Thermal conductivity	0.46 - 0.52	W/m.K
Specific heat	1800 - 2700	J/kg.K
Melting temperature	108 - 134	°C
Glass temperature	-110 - -110	°C
Service temperature	-30 - 85	°C
Density	940 - 965	kg/m ³
Resistivity	5e+17 - 1e+21	Ohm.mm ² /m
Shrinkage	2 - 4	%
Water absorption	0.01 - 0.01	%

Table 3.27. LDPE-4 plastic properties (Sarker, 2011).

Quantity	Value	Units
Thermal expansion	150 - 200	e-6/K
Thermal conductivity	0.3 - 0.335	W/m.K
Specific heat	1800 - 3400	J/kg.K
Melting temperature	125 - 136	°C
Glass temperature	-110 - -110	°C
Service temperature	-30 - 70	°C
Density	910 - 928	kg/m ³
Resistivity	5e+17 - 1e+21	Ohm.mm ² /m
Breakdown potential	17.7 - 39.4	kV / mm
Shrinkage	1.5 - 3	%
Water absorption	0.005 - 0.015	%

Table 3.28. PP-5 plastic properties (Sarker, 2011).

Quantity	Value	Units
Thermal expansion	180 – 180	e-6/K
Thermal conductivity	0.22 – 0.22	W/m.K
Melting temperature	160 – 165	°C
Glass temperature	-10 - -10	°C
Service temperature	-10 - 110	°C
Density	902 – 907	kg/m ³
Resistivity	5e+17 - 1e+21	Ohm.mm ² /m
Breakdown potential	55 - 90	kV / mm
Shrinkage	0.8 - 2	%

Table 3.29. PS-6 plastic properties (Sarker, 2011).

Quantity	Value	Units
Thermal expansion	60 – 80	e-6/K
Thermal conductivity	0.14 – 0.16	W/m.K
Specific heat	1300 – 1300	J/kg.K
Glass temperature	80 – 98	°C
Service temperature	-10 - 90	°C
Density	1040 – 1050	kg/m ³
Resistivity	1e+22 - 1e+22	Ohm.mm ² /m
Breakdown potential	100 – 160	kV / mm
Shrinkage	0.3 – 0.7	%

3.4.3. Production of Waste Plastic Fuels

PET bottles, PS cups and nylons are used as a municipal waste plastics. PP and PVC syringes, infusion sets, latex medical gloves, blood and diffusion bags are used as a medical waste plastics. Municipal waste plastics were prepared with the suitable form. Medical waste plastics has collected at the health institutions.

Waste plastics were used as initial material in thermal cracking processes. Thermal cracking reactions of waste plastics were carried out particularly in a stainless steel batch reactor. Firstly, reactor was filled up with municipal and medical waste plastics one by one. The reactor was heated up to the starting temperature of reaction for one and half hour, subsequently the reaction was started at 450 °C and finished at 475 °C. The reaction was carried out at atmospheric pressure for 1.5 hour.

After thermal cracking reaction, the gaseous form occurred, then the gaseous form was transformed the liquid form by using plate type heat exchangers. The product was distilled into a receiver and finally the final product was taken from the receiver for all experiments.



Figure 3.11. Distillated medical waste plastic fuel

3.4.4. Preparing Municipal and Medical Waste Plastic Fuel Blends

In this study, three different municipal and medical waste plastic blends were prepared by mixing diesel at volumetric rates of 10%, 20% and 50% and blends.



Figure 3.12. Medical waste plastic fuel-diesel blends

Table 3.30. Municipal waste plastic fuel contents of prepared diesel blends

Sample Number	Samples	Mun. Waste Plastics (ml)	Diesel (ml)	Total (ml)
1	10% Mun.Was. + 90% D	50	450	500
2	20% Mun.Was. + 80% D	100	400	500
3	50% Mun.Was. + 50% D	250	250	500

Table 3.31. Medical waste plastic fuel contents of prepared diesel blends

Sample Number	Samples	Med. Waste Plastics (ml)	Diesel (ml)	Total (ml)
1	10% Med.Was. + 90% D	50	450	500
2	20% Med.Was. + 80% D	100	400	500
3	50% Med.Was. + 50% D	250	250	500

3.4.5. Fuel Quality Measurement Methods

The development of internal combustion engines over the past century has resulted from the complimentary refinement of the engine design and fuel properties. As such, engines have been developed to utilize the properties of the fuels that were available. Replacement of existing fuels with new fuel formulations requires understanding the critical fuel properties to insure that the new fuels can be used

(Gerpen et.al, 2004). The properties listed below; specific gravity (density), kinematic viscosity, cetane number, flash point and pour point and calorific heating value.

3.4.5.1. Density Measurement

The density measurement was done using Kyoto Electronics DA-130 type densimeter. This densimeter uses the resonant frequency method to measure the densities. With the densimeter we can also measure the specific weight, API gravity, % Brix, volume and mass alcohol rates. The measurement interval of the device is 0 to 2 g/cm³ and 0 to 40 °C. The device has a sensitivity of ± 0.001 g/cm³, and a stability of 0.0001 g/cm³. The device is measuring according to the standards of TS 6311, ASTM D 4052-96 (Abdulvahitoğlu et al., 2008).



Figure 3.13. Kyoto electronics DA-130 portable densimeter

3.4.5.2. Viscosity Measurement

The viscosity is a measure of a fluid's resistance to flow. If the viscosity is very high, for instance in pitch, the fluid will appear to be a solid in the short term. A liquid whose viscosity is less than that of water is sometimes known as

a mobile liquid, while a substance with a viscosity substantially greater than water is called a viscous liquid (Anonymous, 2013f). To define kinematic viscosity it is useful to begin with the definition of viscosity. Simply stated, viscosity, which is also called dynamic viscosity (η), is the ease with which a fluid will flow. Technically it is the ratio of the shear stress to the shear rate for a fluid. In contrast, the kinematic viscosity (ν) is the resistance to flow of a fluid under gravity (Gerpen et al., 2004).

The viscosities of the blends are measured with Saybolt Universal Viscosimeter produced from Ubbelohde tube with ASTM D88 standards. The measurement results were recorded in seconds. Then using a conversion table the results were converted from SSU (saybolt universal second) to centistokes (cSt) unit. The measurements were done at 40 °C according to the TS EN 14214 standard (Abdulvahitoğlu et al., 2008).



Figure 3.14. Saybolt universal viscosimeter

3.4.5.3. Cetane Number Measurement

The cetane number measures the ignition quality of a diesel fuel. Cetane number is a measure of a fuel's ignition delay, the time period between the start of injection and the first identifiable pressure increase during combustion of the fuel. In

a particular diesel engine, higher cetane fuels will have shorter ignition delay periods than lower cetane fuels (Anonymous, 2013g).

Perhaps the most important measure of ignition characteristics of diesel and/or biodiesel fuels is the cetane number, since it directly pertains to ignition within compression ignition engines. The cetane number is the primary specification measurement used to match fuels and engines. It is commonly used by refiners, marketers and engine manufacturers to describe diesel fuels (Gerpen et al., 2004).

The cetane number and indexes were measured by Zeltex ZX440 type device, which works under the close infrared spectrometer (NIR) principal. With the help of this principal the cetane number measurement experiment became very fast and cheap with only 3% error compared to the time consuming expensive motor tests (Abdulvahitoğlu et al., 2008).



Figure 3.15. Zeltex ZX 440

3.4.5.4. Flash Point Measurement

The flash point is the lowest temperature at which a combustible mixture can be formed above the liquid fuel. It is dependent on both the lean flammability limit of the fuel as well as the vapor pressure of the fuel constituents. The flash point is determined by heating a sample of the fuel in a stirred container and passing a flame

over the surface of the liquid. If the temperature is at or above the flash point, the vapor will ignite and an easily detectable flash can be observed (Gerpen et al. 2004).

Flash points are measured with ASTM D93. Tanaka Automated Pensky-Martens Closed Cup Flash Point Tester is used for the flash point measurements during the tests which has a measurement range of 20-370 °C (Özcanlı, 2009).



Figure 3.16. Tanaka APM-7

3.4.5.5. Pour Point Measurement

The pour point of a liquid is the temperature at which it becomes semi solid and loses its flow characteristics (Anonymous, 2013h). MPC-102 series has been designed for automatic determination of Pour Point (PP) and Cloud Point (CP) with small specimen size and shorter test cycle time while securing better test precision than the conventional manual methods. PP measurement is made utilizing a new ASTM D6749 on Standart Test Method for Pour Point of Petroleum Products test method namely Air Pressure Method, which yields eventually no bias against the conventional test method, repeatability/reproducibility of 0,5 °C and 2-3 times faster determinations. The epoch-making high accuracy justifies PP determination at 1°C interval, which can help increasing the yields in the process. The CP/PP mode executes a CP determination and then PP determination consecutively, which further improves the test throughput in the lab. Multiple-tests versions with 6 test heads and 3 test heads are also available for higher volume tests.

The typical repeatability and reproducibility are 1 °C and 2 °C respectively, when PP is determined at 1 °C intervals. This high precision attributes to the patented Air Pressure method, in which the disturbance to the formation of wax crystal structure through the test process is kept at a minimal and consistent level. With this high precision, PP can be determined at 1 °C intervals for more precise process control, and therefore a considerable savings in the process can be realized.

Just set up a sample, select a test mode and then press the START key. The sample is cooled at the steepest possible rate without affecting the formation/ growth of wax crystal, which has been to be a critical factor for PP/CP determination. The test cycle time is typically 1/3 to 1/2 of that of the conventional tilting methods.

Since the required sample volume is a mere 4,5 ml and the sample cup is a test-tube type removable jar, the sample handling is extremely easy. Use of Peltier Cells for sample cooling/heating made this mini tester not only compact in design but energy efficient. Depending on the temperature range, air, tap water or small chiller with anti-freeze suffices the cooling requirement (Yilmaz, 2010).



Figure 3.17. Tanaka MPC-102 L

3.4.5.6. Heating Capacity Measurement

The heat capacities of liquid fuels can be measured automatically with IKA-Werke C2000 calorimeter. The working temperatures are between +15 °C to +35 °C.

The combustion is done with a cotton wire instead of a tungsten wire. The results are measured in cal/gr units. The device can measure according to the TS 1740, ASTM 240 D, ISO 1928, DIN 51900, BSI standards (Abdulvahitoğlu et. al., 2008).



Figure 3.18. IKA-WERKE C2000 calorimeter

3.4.6. Diesel Engine Test Rig

In the experiments, Mitsubishi Canter 4D34-2A (Figure 3.17.), four stroke diesel engine with four cylinders which has a maximum torque 295 Nm at 1800 rpm has been used. The maximum torque value and maximum brake power values that obtained in the test engine could be change depending upon the fuel that used in engine. Specifications of the engine are presented in Table 3.32.

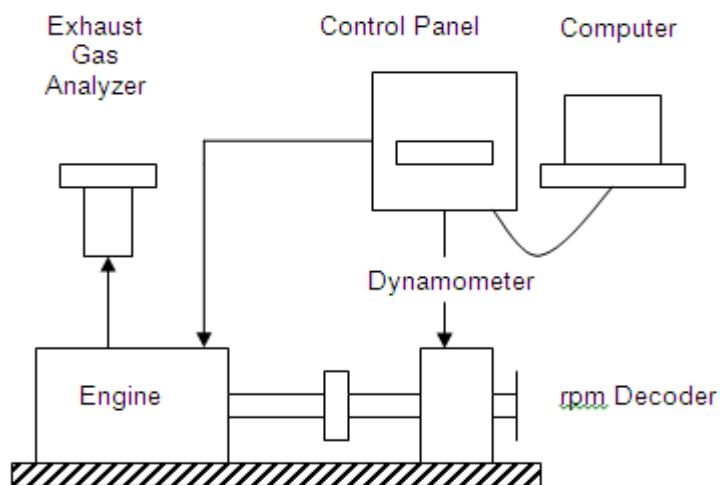


Figure 3.19. Layout of experimental setup

Table 3.32. Technical specifications of the test engine

Brand	Mitsubishi Canter
Model	4D34-2A
Configuration	In line 4
Type	Direct injection diesel with glow plug
Displacement	3907cc
Bore	104mm
Stroke	115mm
Power	89kW @ 3200rpm
Torque	295Nm @ 1800rpm
Oil Cooler	Water cooled
Weight	325kg

The engine torque was measured by the help of a hydraulic dynamometer.

Table 3.33. shows technical specifications of the dynamometer.

Table 3.33. Technical specifications of the dynamometer

Torque range	0-1700 Nm
Speed range	0-7500 rpm
Body weight	45 kgf
Total weight	110 kgf
Body diameter	350 mm
Torque arm length	350mm

The speed sensor used to detect prime mover speed is the magnetic pickup (MPU). When a magnetic material (usually a gear tooth driven by the prime mover) passes through the magnetic field at the end of the magnetic pickup, a voltage is developed. The frequency of this voltage is translated by the speed into a signal which accurately depicts the speed of the prime mover. S type load cell is used to

measure the torque of dynamometer (Stainless steel which has a sensitivity of 1/3000. Dynamometer control unit was used for receiving and collecting all the data that was used by the system (Güngör, 2011).

3.4.7. Exhaust Emission Measurements

TESTO 350 XL gas analyzer is used to measure exhaust emissions. Emission data was collected by the help of a computer program. Measurement accuracy of the gas analyzer is ± 10 ppm for CO, 1% for CO₂ and ± 1 ppm for NO_x. Measurement capacity of the device is 0-10000 ppm for CO, 0-50% for CO₂ emission and 0-3000 ppm for NO_x (Güngör, 2011).

4. RESULTS AND DISCUSSION

4.1. Municipal Waste Plastic-Diesel Blended Fuels

4.1.1. Fuel Properties

Municipal waste plastic fuel has been blended into diesel with various blended rates (10%, 20% and 50%). The blends have been analyzed by the standards of ASTM test methods. The “MUNWP” defines pure municipal waste plastic fuel and the number of next to MUNWP defines the percentage volume of pure municipal waste plastic fuel.

The MUNWP10 means, 10% pure municipal waste plastic fuel was blended with the volumetric ratio 90% diesel. Fuel property results are shown in Table 4.1.

Table 4.1. Fuel properties of municipal waste plastic-diesel blended fuels

Properties	Diesel	MUNWP 10	MUNWP 20	MUNWP 50	MUNWP 100	EN Standards ⁽¹⁾	
						Min.	Max.
Density (kg/lt)	0.830	0.838	0.847	0.866	0.891	0.820	0.845
Cetane Number	55.57	53.64	52.35	51.49	48.58	51.0	-
Pour Point (°C)	-16.0	-13.5	-11.0	-6.5	2.0	- 34.0	-10.0
Viscosity (cSt)	2.45	2.44	2.43	2.41	2.37	2.00	4.50
Calorific Value (kcal/kg)	11 320	11 020	10 942	10 740	10 150	10 220 (2)	10 931 (3)
Flash Point (°C)	70.5	70.5	70.5	70.5	70.5	Above 55	-

(1) EN 590 Standards,

(2) Lower Heating Value of U.S. Conventional Diesel, Biomass Energy Data Book, U.S. Department of Energy, 2011,

(3) Higher Heating Value of U.S. Conventional Diesel, Biomass Energy Data Book, U.S. Department of Energy, 2011.

The density of municipal waste plastic fuel (MUNWP) is higher than diesel, which are 0.891 kg/L and 0.830 kg/L respectively. Due to the higher density of MUNWP in accordance with the diesel, blending with MUNWP was caused an increment in the density values.

As it can be seen from Table 4.1. cetane number can be decreased by mixing MUNWP with diesel. The decrease in cetane number will have long ignition delay periods in a particular diesel engine.

Generally, waste plastic fuels have high pour points. High pour point of a fuel can shows disquieting problems about transferring, storing and using in cold weather. To add the MUNWP to the blends caused an increment in the pour point values.

Fuel property experiments showed that, MUNWP has lower viscosity value than diesel (2.37 and 2.45 mm²/s respectively). It is observed that, MUNWP addition to diesel caused a decrease in the viscosity values. It shows that MUNWP can flow easier than diesel fuel.

The experiments showed that MUNWP has lower calorific value than diesel. It is observed that, MUNWP addition to diesel caused a decrease in the calorific values. The amount of heat released by a unit weight or unit volume of MUNWP is lower than diesel, during complete combustion.

The flash point of a fuel is the lowest temperature at which it can form an ignitable mix with air. The flash point is an important value for the safe transportation and storage of the fuel. The experiments showed that MUNWP has same flash point with diesel so that all blends have same flash point with diesel.

4.1.2. Engine Performances

4.1.2.1. Brake Power Outputs

Figure 4.1. shows the variation of brake power according to different engine speed values with different ratio of municipal waste plastic-diesel blended fuels. As it can easily be seen in Figure 4.1. there were similar differences in the measured engine power output diesel, MUNWP10, MUNWP20 and MUNWP50 at low engine

speeds. The characteristics of power curve were not changed, according to the type of fuel. It was observed that the maximum power values of diesel was obtained at 2400 rpm, the maximum power values of MUNWP10, MUNWP20 and MUNWP50 were obtained at an engine speed of 2200 rpm.

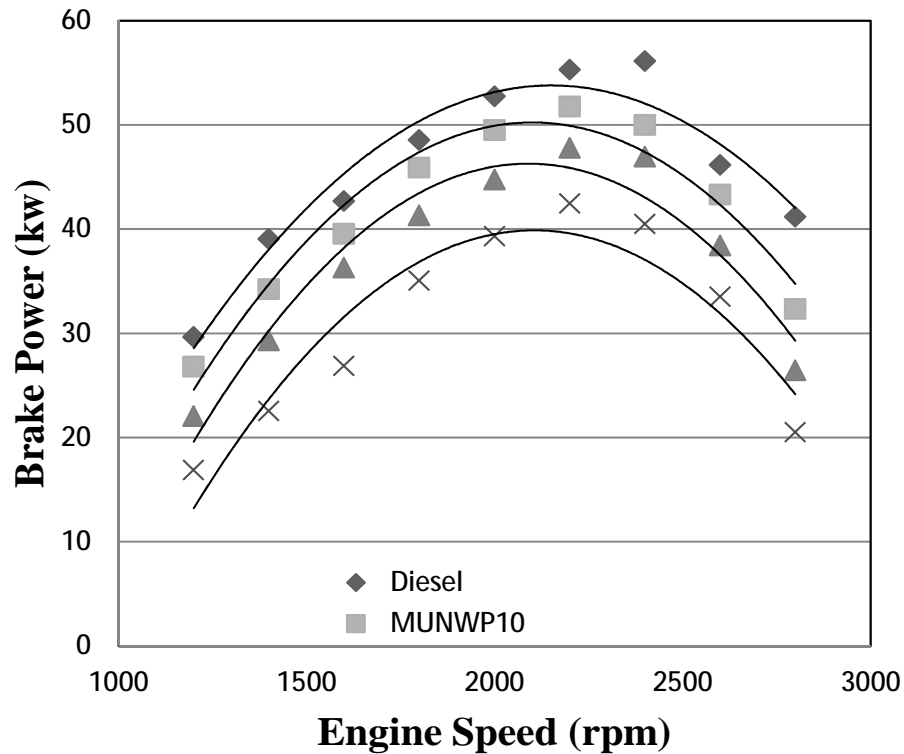


Figure 4.1. Brake power outputs versus engine speed of diesel, MUNWP10, MUNWP20 and MUNWP50

Table 4.2. shows R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of brake power with engine speed values.

Table 4.2. R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of brake power with engine speed values

	R^2 value	Equation
Diesel	0,9384	$y = -3E - 05x^2 + 0,12x - 75,235$
MUNWP10	0,9483	$y = -3E - 05x^2 + 0,1328x - 89,285$
MUNWP20	0,9355	$y = -3E - 05x^2 + 0,1407x - 100,74$
MUNWP50	0,8927	$y = -3E - 05x^2 + 0,137x - 104,37$

4.1.2.2. Torque Outputs

The torque outputs of municipal waste plastic-diesel blended fuels is shown in Figure 4.2. The value of the torque outputs increase at low engine speeds, decrease at high engine speeds. The maximum torque values for diesel was obtained at 1400 - 1600 rpm., MUNWP10, MUNWP20 and MUNWP50 were obtained at an engine speed of 1800-2000 rpm.

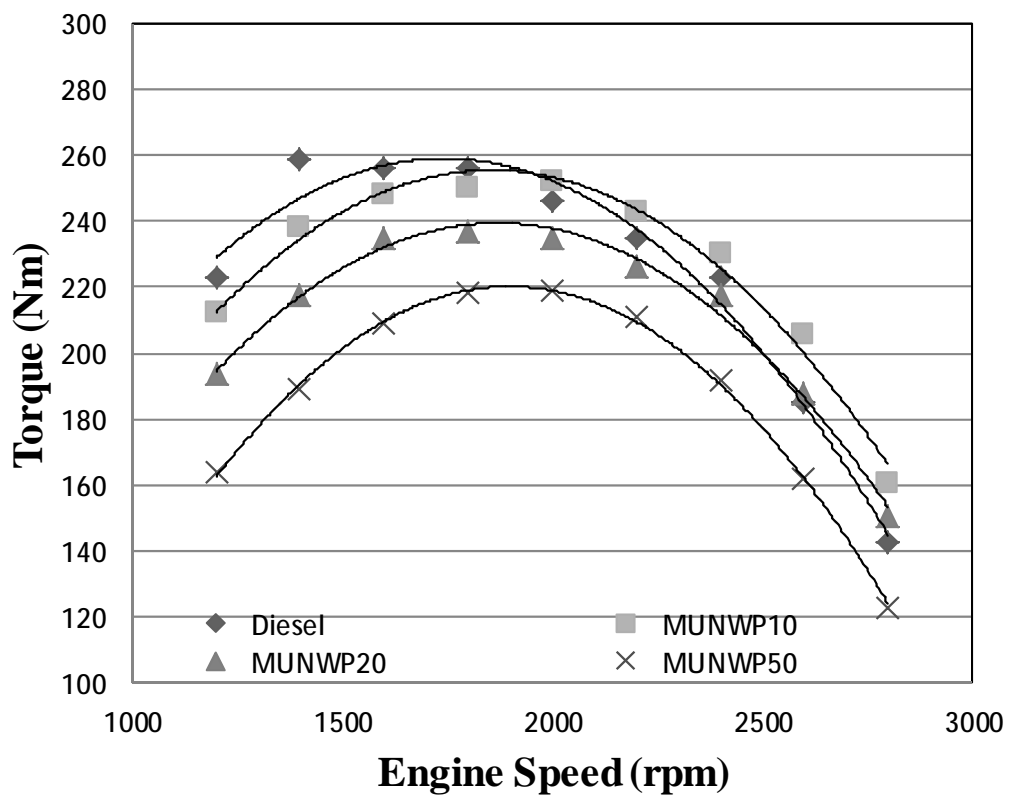


Figure 4.2. Torque outputs versus engine speed of diesel, MUNWP10, MUNWP20 and MUNWP50

Table 4.3. shows R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of torque with engine speed values.

Table 4.3. R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of torque with engine speed values

	R^2 value	Equation
Diesel	0,9753	$y = -0,0001x^2 + 0,3567x - 51,766$
MUNWP10	0,9827	$y = -0,0001x^2 + 0,3725x - 90,151$
MUNWP20	0,9892	$y = -0,0001x^2 + 0,3745x - 110,88$
MUNWP50	0,9984	$y = -0,0001x^2 + 0,4512x - 208,27$

4.1.3. Exhaust Emissions

4.1.3.1. CO Emissions

Generally, CI engine operates with lean mixtures and hence the CO emission would be low. CO emission is toxic and must be controlled. It is an intermediate product in the combustion of a hydrocarbon fuel, so its emission results from incomplete combustion. Emission of CO is therefore greatly dependent on the air fuel ratio relative to the stoichiometric proportions. Rich combustion invariably produces CO, and emissions increase nearly linearly with the deviation from the stoichiometry (Güngör, 2011). The variation of carbon monoxide with engine speed is shown in Figure 4.3. It can easily be seen from the figure that there is an average of 5,5%, 11,43% and 23,65% reduction in CO emission values when MUNWP10, MUNWP20 and MUNWP50 were used instead of diesel fuel. The reductions in CO emission could be due to the better combustion.

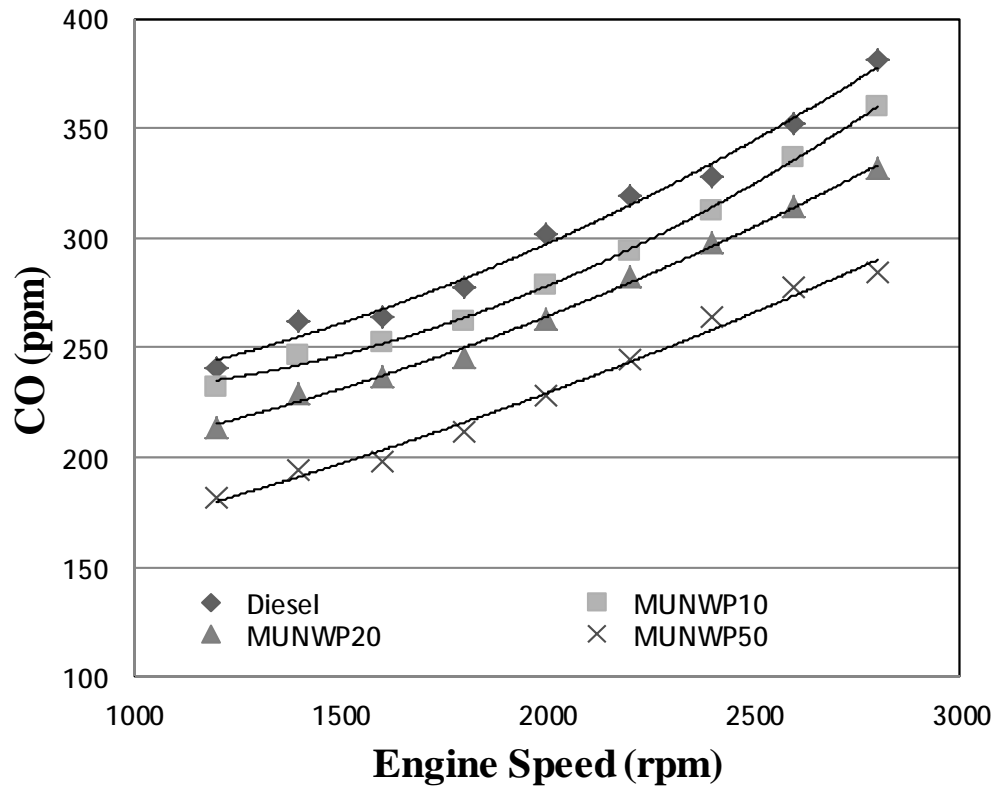


Figure 4.3. CO emission values of diesel, MUNWP10, MUNWP20 and MUNWP50

Table 4.4. shows R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of CO with engine speed values.

Table 4.4. R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of CO with engine speed values

	R^2 value	Equation
Diesel	0,9894	$y = 2E-05x^2 - 0,0021x + 216,2$
MUNWP10	0,9971	$y = 3E-05x^2 - 0,0434x + 243,58$
MUNWP20	0,9968	$y = 2E-05x^2 + 0,0117x + 178,71$
MUNWP50	0,9874	$y = 9E-06x^2 + 0,0334x + 127,2$

4.1.3.2. CO₂ Emissions

Figure 4.4. shows the variation of measured CO₂ emission values of test fuels for different engine speeds. There is an average of 2,22%, 6,47% and 13,3%

reduction in CO₂ emission values when MUN10, MUNWP20 and MUNWP50 were used instead of diesel fuel. The maximum CO₂ values for diesel, MUNWP10, MUNWP20 and MUNWP50 were obtained at an engine speed of 1800 - 2000 rpm.

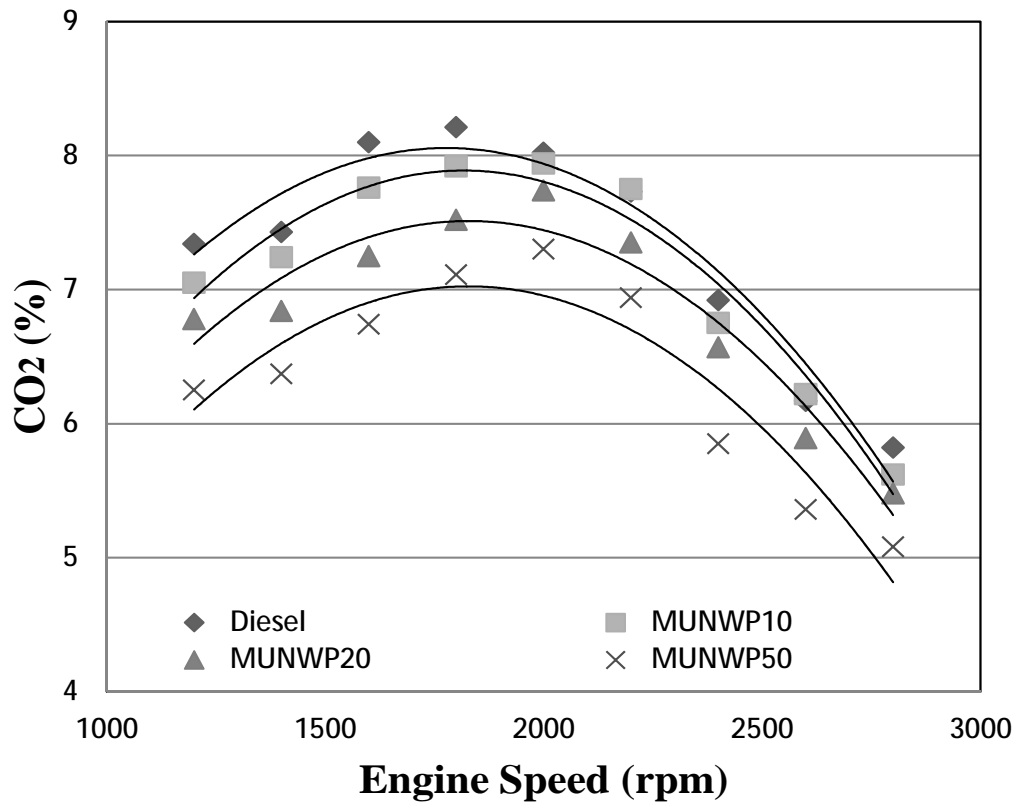


Figure 4.4. CO₂ emission values of diesel, MUNWP10, MUNWP20 and MUNWP50

Table 4.5. shows R² and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of CO₂ with engine speed values.

Table 4.5. R² and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of CO₂ with engine speed values

	R ² value	Equation
Diesel	0,9434	$y = -2E-06x^2 + 0,0085x + 0,5464$
MUNWP10	0,9524	$y = -2E-06x^2 + 0,0091x - 0,355$
MUNWP20	0,924	$y = -2E-06x^2 + 0,0085x - 0,2415$
MUNWP50	0,877	$y = -2E-06x^2 + 0,0085x - 0,7658$

4.1.3.3. NO_x Emissions

The oxides of nitrogen in the emissions contain nitric oxid (NO) and nitrogen dioxide (NO₂). The formation of nitrogen oxides (NO_x) is highly dependent on in-cylinder temperature, oxygen concentration and residence time for the reactions to take place. The nitrogen oxides (NO_x) emissions of tests fuels in shown in Figure 4.5. On an average of 4,3% increment in NO_x was obtained for MUNWP10 and as compared to diesel. On an average of 9,7% increment in NO_x was obtained for MUNWP20 and as compared to diesel. On an average of 20,3% increment in NO_x was obtained for MUNWP50 and as compared to diesel.

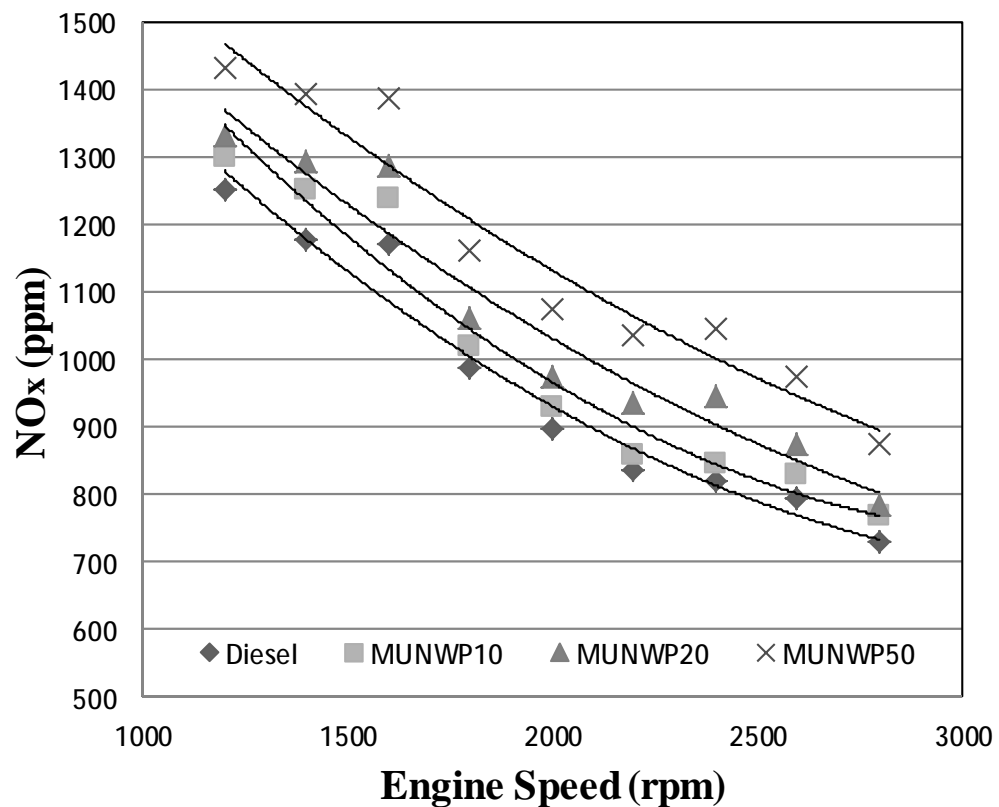


Figure 4.5. NO_x emission values of diesel, MUNWP10, MUNWP20 and MUNWP50

Table 4.6. shows R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of NO_x with engine speed values.

Table 4.6. R^2 and equation values of diesel, MUNWP10, MUNWP20 and MUNWP50 curves of NO_x with engine speed values

	R^2 value	Equation
Diesel	0,9624	$y = 0,0001x^2 - 0,8125x + 2085,4$
MUNWP10	0,947	$y = 0,0001x^2 - 0,9333x + 2262$
MUNWP20	0,938	$y = 9E-05x^2 - 0,6957x + 2082,8$
MUNWP50	0,937	$y = 8E-05x^2 - 0,6687x + 2160$

4.2. Medical Waste Plastic-Diesel Blended Fuels

4.2.1. Fuel Properties

Medical waste plastic fuel has been blended into diesel with various blended rates (10%, 20% and 50%). The blends have been analyzed by the standards of ASTM test methods. The “MEDWP” defines pure medical waste plastic fuel and the number of next to MEDWP defines the percentage volume of pure medical waste plastic fuel.

The MEDWP10 means, 10% pure medical waste plastic fuel was blended with the volumetric ratio 90% diesel. Fuel property results are shown in Table 4.7.

Table 4.7. Fuel properties of medical waste plastic-diesel blended fuels

Properties	Diesel	MEDWP 10	MEDWP 20	MEDWP 50	MEDWP 100	EN Standards ⁽¹⁾	
						Min.	Max.
Density (kg/lit)	0.830	0.845	0.858	0.894	0.940	0.820	0.845
Cetane Number	55.57	54.52	53.20	51.48	46.58	51.0	-
Pour Point (°C)	-16.0	-13	-10.5	-6.0	3.0	- 34.0	- 10
Viscosity (cSt)	2.45	2.42	2.41	2.39	2.30	2.00	4.50
Calorific Value (kcal/kg)	11 320	11 105	10 980	10 650	9850	10 220 ⁽²⁾	10 931 ⁽³⁾
Flash Point (°C)	70.5	65.5	65.5	65.5	65.5	Above 55	-

(1) EN 590 Standards,

(2) Lower Heating Value of U.S. Conventional Diesel, Biomass Energy Data Book, U.S. Department of Energy, 2011,

(3) Higher Heating Value of U.S. Conventional Diesel, Biomass Energy Data Book, U.S. Department of Energy, 2011.

The density of medical waste plastic fuel (MEDWP) is higher than diesel, which are 0.94 kg/lit and 0.830 kg/lit respectively. Due to the higher density of MEDWP in accordance with the diesel, blending with MEDWP was caused an increment in the density values.

As it can be seen from Table 4.7. cetane number can be decreased by mixing MEDWP with diesel. The decrease in cetane number will have long ignition delay periods in a particular diesel engine.

Generally, waste plastic fuels have high pour points. High pour point of a fuel can shows disquieting problems about transferring, storing and using in cold weather. To add the MEDWP to the blends caused an increment in the pour point values.

Fuel property experiments showed that, MEDWP has lower viscosity value than diesel (2.30 and 2.45 mm²/s respectively). It is observed that, MEDWP addition to diesel caused a decrease in the viscosity values. It shows that MEDWP can flow easier than diesel fuel.

The experiments showed that MEDWP has lower calorific value than diesel. It is observed that, MEDWP addition to diesel caused a decrease in the calorific

values. The amount of heat released by a unit weight or unit volume of MEDWP is lower than diesel, during complete combustion.

The flash point of a fuel is the lowest temperature at which it can form an ignitable mix with air. The flash point is an important value for the safe transportation and storage of the fuel. The experiments showed that MEDWP has lower flash point than diesel. So that the blends flash points are lower than diesel.

4.2.2. Engine Performances

4.2.2.1. Brake Power Outputs

Figure 4.6. shows the variation of brake power according to different engine speed values with different ratio of medical waste plastic-diesel blended fuels. As it can easily be seen in Figure 4.6. there were similar differences in the measured engine power output diesel, MEDWP10, MEDWP20 and MEDWP50 at low engine speeds. The characteristics of power curve were not changed, according to the type of fuel. It was observed that the maximum power values of diesel were obtained at 2400 rpm., MEDWP10 and MEDWP50 were obtained at an engine speed of 2200 rpm. MEDWP20 were obtained at an engine speed of 2000 rpm.

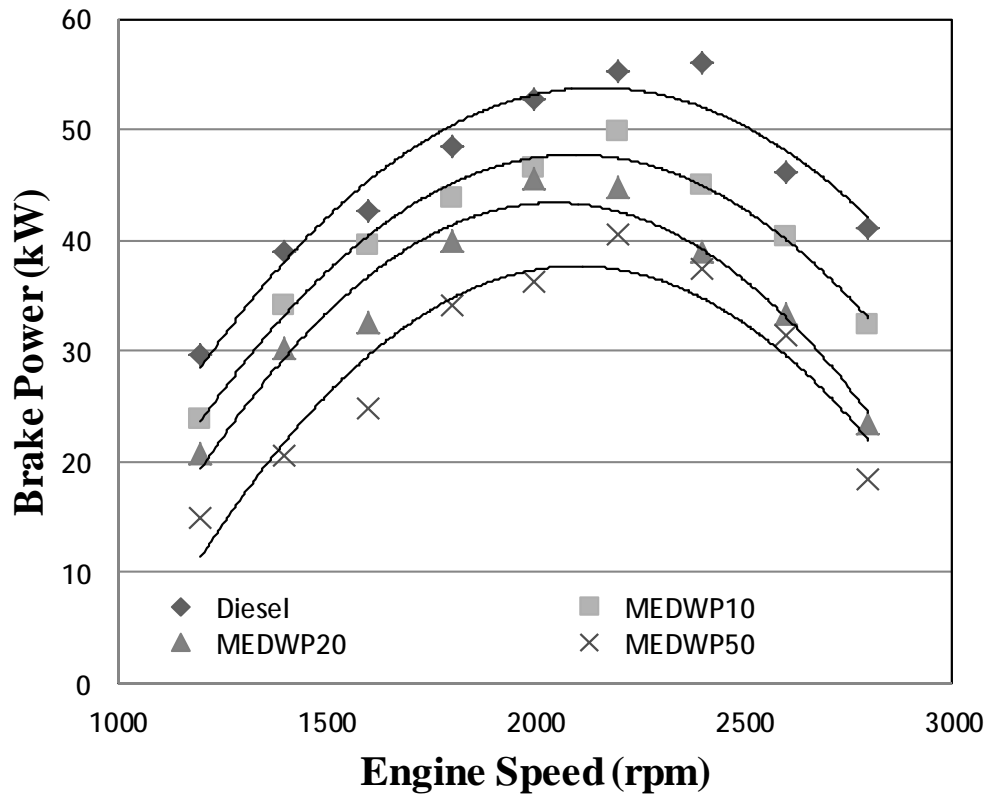


Figure 4.6. Brake power outputs versus engine speed for diesel, MEDWP10, MEDWP20 and MEDWP50

Table 4.8. shows R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of brake power with engine speed values.

Table 4.8. R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of brake power with engine speed values

	R^2 value	Equation
Diesel	0,9384	$y = -3E - 05x^2 + 0,12x - 75,235$
MEDWP10	0,9813	$y = -3E - 05x^2 + 0,1254x - 83,754$
MEDWP20	0,9466	$y = -3E - 05x^2 + 0,1372x - 97,034$
MEDWP50	0,8995	$y = -3E - 05x^2 + 0,1356x - 104,87$

4.2.2.2. Torque Outputs

The torque outputs of medical waste plastic-diesel blended fuels is shown in Figure 4.7. The value of the torque outputs increase at low engine speeds, decrease at

high engine speeds. The maximum torque values for diesel was obtained at 1400 - 1600 rpm. MEDWP10, MEDWP20 and MEDWP50 were obtained at an engine speed of 1600-1800 rpm.

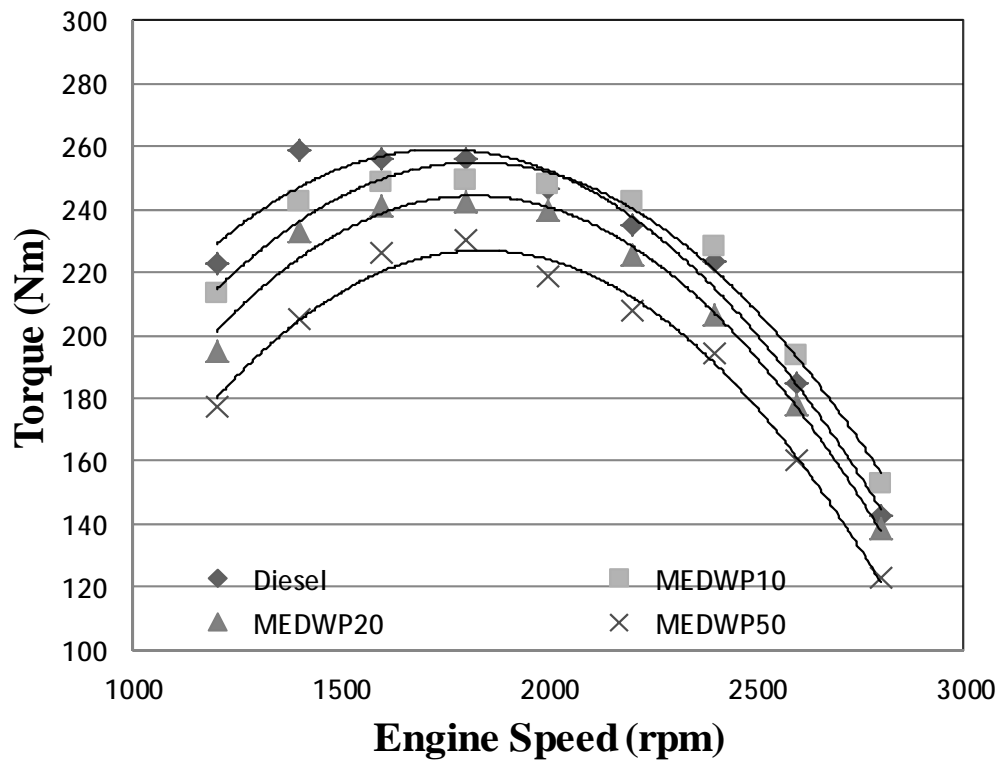


Figure 4.7. Torque outputs versus engine speed for diesel, MEDWP10, MEDWP20 and MEDWP50

Table 4.9. shows R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of torque with engine speed values.

Table 4.9. R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of torque with engine speed values

	R^2 value	Equation
Diesel	0,9753	$y = -0,0001x^2 + 0,3567x - 51,766$
MEDWP10	0,9808	$y = -0,0001x^2 + 0,3784x - 90,363$
MEDWP20	0,9874	$y = -0,0001x^2 + 0,4057x - 125,22$
MEDWP50	0,989	$y = -0,0001x^2 + 0,4217x - 161,13$

4.2.3. Exhaust Emissions

4.2.3.1. CO Emissions

Generally, CI engine operates with lean mixtures and hence the CO emission would be low. CO emission is toxic and must be controlled. It is an intermediate product in the combustion of a hydrocarbon fuel, so its emission results from incomplete combustion. Emission of CO is therefore greatly dependent on the air fuel ratio relative to the stoichiometric proportions. Rich combustion invariably produces CO, and emissions increase nearly linearly with the deviation from the stoichiometry (Güngör, 2011). The variation of carbon monoxide with engine speed is shown in Figure 4.8. It can easily be seen from the figure that there is an average of 10,79%, 20,08% and 32,66% reduction in CO emission values when MEDWP10, MEDWP20 and MEDWP50 were used instead of diesel fuel. The reductions in CO emission could be due to the better combustion.

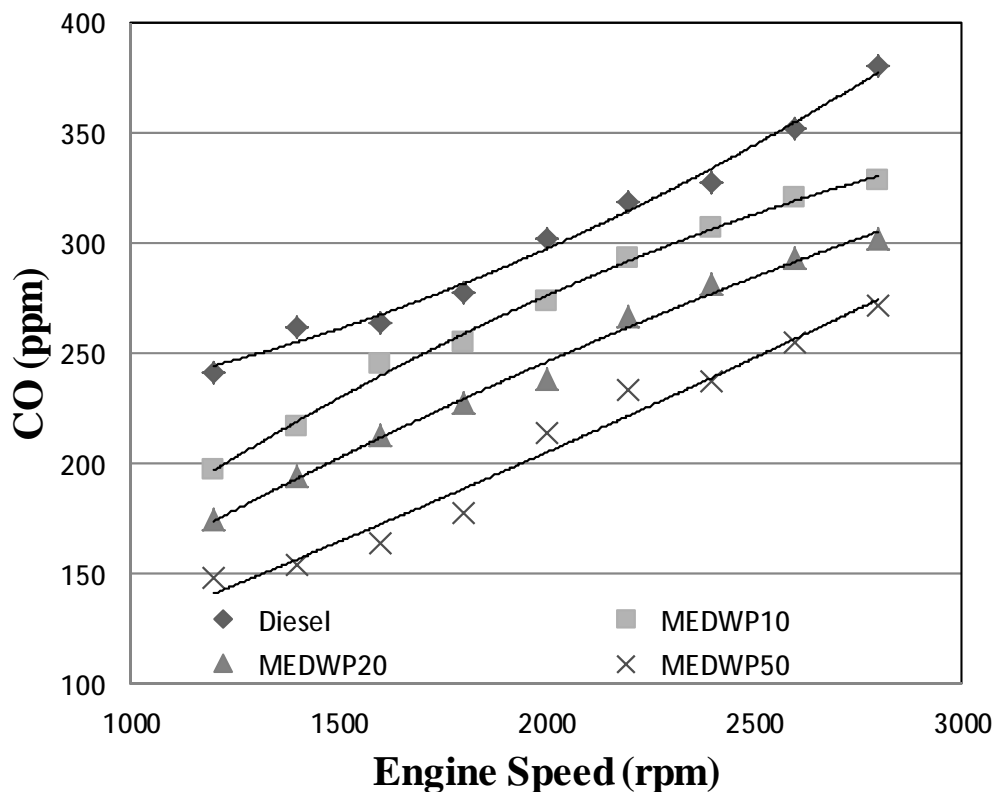


Figure 4.8. CO emission values of diesel, MEDWP10, MEDWP20, and MEDWP50

Table 4.10. shows R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of CO with engine speed values.

Table 4.10. R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of CO with engine speed values

	R^2 value	Equation
Diesel	0,9894	$y = 2E-05x^2 - 0,0021x + 216,2$
MEDWP10	0,9966	$y = -2E-05x^2 + 0,1612x + 31,364$
MEDWP20	0,9925	$y = -1E-05x^2 + 0,1225x + 41,379$
MEDWP50	0,9724	$y = 4E-06x^2 + 0,0656x + 55,833$

4.2.3.2. CO₂ Emissions

Figure 4.9. shows the variation of measured CO₂ emission values of test fuels for different engine speeds. There is an average of 1,34%, 7,45% and 14,75% reduction in CO₂ emission values when MEDWP10, MEDWP20 and MEDWP50 were used instead of diesel fuel. The maximum CO₂ values for diesel, MEDWP10, MEDWP20 and MEDWP50 were obtained at an engine speed of 1800 - 2000 rpm.

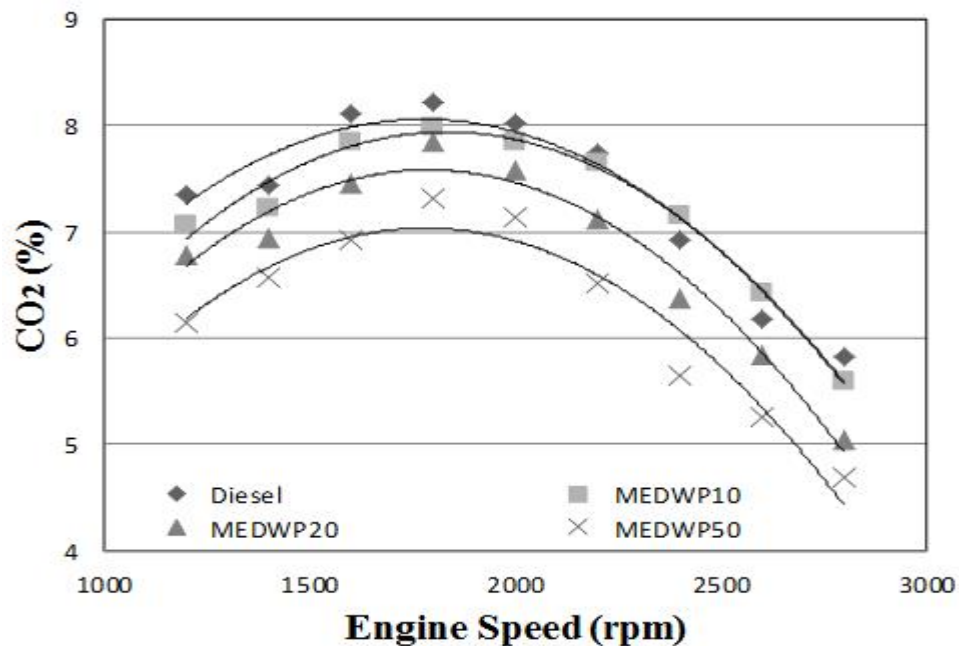


Figure 4.9. CO₂ emission values of diesel, MEDWP10, MEDWP20 and MEDWP50

Table 4.11. shows R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of CO_2 with engine speed values.

Table 4.11. R^2 and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of CO_2 with engine speed values

	R^2 value	Equation
Diesel	0,9434	$y = -2E-06x^2 + 0,0085x + 0,5464$
MEDWP10	0,9817	$y = -3E-06x^2 + 0,0092x - 0,4959$
MEDWP20	0,965	$y = -3E-06x^2 + 0,0093x - 0,7029$
MEDWP50	0,9376	$y = -3E-06x^2 + 0,0089x - 0,937$

4.2.3.3. NO_x Emissions

The oxides of nitrogen in the emissions contain nitric oxid (NO) and nitrogen dioxide (NO_2). The formation of nitrogen oxides (NO_x) is highly dependent on in-cylinder temperature, oxygen concentration and residence time for the reactions to take place. The nitrogen oxides (NO_x) emissions of tests fuels in shown in Figure 4.10. On an average of 6,6% increment in NO_x was obtained for MEDWP10 and as compared to diesel. On an average of 11% increment in NO_x was obtained for MEDWP20 and as compared to diesel. On an average of 20,7% increment in NO_x was obtained for MEDWP50 and as compared to diesel.

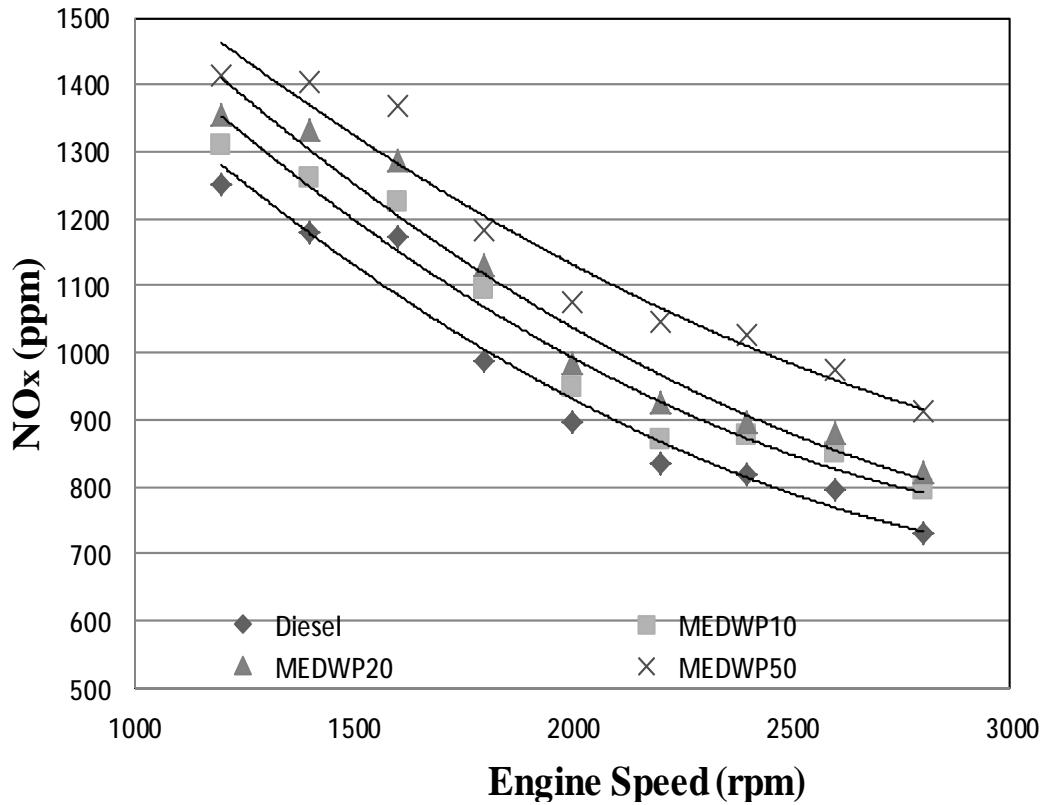


Figure 4.10. NO_x emission values of diesel, MEDWP10, MEDWP20 and MEDWP50

Table 4.12. shows R² and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of NO_x with engine speed values.

Table 4.12. R² and equation values of diesel, MEDWP10, MEDWP20 and MEDWP50 curves of NO_x with engine speed values

	R ² value	Equation
Diesel	0,9624	$y = 0,0001x^2 - 0,8125x + 2085,4$
MEDWP10	0,9569	$y = 0,0001x^2 - 0,847x + 2191,1$
MEDWP20	0,955	$y = 0,0001x^2 - 0,8281x + 2239,8$
MEDWP50	0,9491	$y = 9E-05x^2 - 0,6997x + 2173,4$

5. CONCLUSION AND RECOMMENDATIONS

In this study, municipal and medical waste plastics were transformed by thermal cracking method as waste plastic fuel. Then waste plastic fuels were blended with the diesel different ratios (10%, 20% and 50%). For each blends, fuel properties, engine performance and exhaust emission experimental studies were analyzed.

Densities of municipal and medical waste plastic fuels are higher than diesel. Due to the higher densities of MUNWP and MEDWP in accordance with the diesel, blending with MUNWP and MEDWP were caused an increment in the density values. PP, PVC and PET structures of waste plastics are effectual for density values.

Cetane numbers of municipal and medical waste fuels are lower than diesel. Cetane numbers of blends can be decreased by mixing MUNWP and MEDWP with diesel. For waste plastic fuel-diesel blends, best cetane number is MEDWP10.

One of the negative situation of waste plastic fuel is the high pour point. High pour point of a fuel can shows disquieting problems about transferring, storing and using in cold weather. MUNWP and MEDWP have high pour point. To add the MUNWP and MEDWP to the blends caused an increment in the pour point values. Pour points of waste plastic fuel-diesel blends are acceptable according to the EN 590 diesel standards.

Kinematic viscosities of municipal and medical waste plastic fuels are lower than diesel. It is observed that, MUNWP and MEDWP addition to diesel caused a decrease in the viscosity values. It shows that MUNWP and MEDWP can flow easier than diesel fuel.

There are no measurable differences observed for the flash point tests of MUNWP. Flash points of MEDWP fuel-diesel blends are lower than diesel.

The experiments showed that MUNWP and MEDWP has lower calorific value than diesel. It is observed that, MUNWP and MEDWP addition to diesel caused a decrease in the calorific values.

There are similar differences in the measured brake power and torque outputs for waste plastic-diesel blended fuels at low engine speeds. The characteristics of brake power and torque curves were not changed, according to the type of fuel.

Reduction and increment ratios of CO, CO₂ and NO_x emissions are shown at Table 4.13.

Table 4.13. Reduction and increment ratios of CO, CO₂ and NO_x emissions

	MUNWP 10	MUNWP 20	MUNWP 50	MEDWP 10	MEDWP 20	MEDWP 50
CO	5,5% reduction	11,43% reduction	23,65% reduction	10,79% reduction	20,08% reduction	32,66% reduction
CO ₂	2,22% reduction	6,47% reduction	13,3% reduction	1,34% reduction	7,45% reduction	14,75% reduction
NO _x	4,3% increment	9,7% increment	20,3% increment	6,6% increment	11% increment	20,7% increment

Finally MUNWP10 and MEDWP10 can be the best alternative fuel blends for diesel engines not only for its performance characteristics but also for the environmental aspects.

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