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SUBSTITUTION OF FOSSIL ENERGY IN THE CEMENT INDUSTRY WITH ALTERNATIVE FUELS FROM WASTE IN ALGERIA

By

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ملخص

تمثل إدارة النفايات الصلبة مشكلة حقيقية تواجه السلطات المحلية في الجزائر. يتم إنتاج أكثر من 13 مليون طن كل عام ، ويتم دفن أو التخلص من ما يصل إلى 90٪ من إجمالي النفايات الصلبة البلدية دون أي معالجة مسبقة مما يؤدي إلى تهديد يمكن قياسه على البيئة والصحة العامة. الثغرات في التشريعات الحالية ذات الصلة ، فضلاً عن عدم وجود الممارسات المناسبة لجمع النفايات الصلبة وإدارتها هي التحديات الرئيسية التي تجعل هذه المشكلة معقدة للغاية بالنسبة للهيئات الحكومية المسؤولة عن التعامل مع النفايات الصلبة وإدارتها في الجزائر.

الهدف من هذه الرسالة هو دراسة ممارسات معالجة النفايات الصلبة البلدية في الجزائر من أجل تقديم مناهج المعالجة للنفايات في صناعة الأسمنت ، والتي يمكن تنفيذها محليًا من أجل إدارة النفايات الصلبة الممكنة وهي الحرق المشترك المستدامة.

الهدف الرئيسي لهذه الأطروحة هو التحقيق في إمكانية إنتاج الوقود المشتق من النفايات الصلبة البلدية واستخدامها كوقود بديل في صناعة الأسمنت في ولاية البليدة بالجزائر. علاوة على ذلك، تم اقتراح سيناريوهات مختلفة لتنفيذ التقنيات المختلفة للمعالجة المسبقة للنفايات وإنتاجها في ولاية البليدة والجزائر بشكل عام، مع الأخذ في الاعتبار عدد السكان وتوليد النفايات الصلبة المحلية وتوافر المساحة اللازمة.

تقنيات التجفيف هي أيضا موضوع في هذه الأطروحة. تم إجراء دراسة تجريبية لتحديد خصائص التجفيف للوقود البديل باستخدام مجفف الهواء الساخن على مستوى المخبر عند درجة حرارة هواء متنوعة وسرعة هواء ثابتة. تم نمذجة حركية التجفيف لـ RDF باستخدام برنامج STATISTICA، وتم تحديد النموذج الرياضي المناسب بالإضافة إلى معامل الانتشار الفعال وطاقة التنشيط لـ RDF. بالإضافة إلى ذلك ، تم اقتراح استخدام هواء العادم من مبرد الكلنكر لتجفيف RDF ، وتم تحديد إجمالي الطاقة اللازمة.

الكلمات المفتاحية- النفايات الصلبة البلدية، الحرق المشترك، الوقود البديل، مصانع الأسمنت، الجزائر، التجفيف، محاكاة ، STATISTICA،

ABSTRACT

Solid waste management (SWM) represents a real problem facing the local authorities in Algeria. More than 13 million ton of municipal solid waste (MSW) is produced each year, up to 90% of the total MSW is been landfilled or dumped without any pretreatment which leads to a measurable threat to the environment and public health. The gaps in current related legislation, as well as the absence of proper practices for solid waste collection and management are the key challenges making this problem highly complicated for the government bodies responsible for handling and managing solid waste in Algeria.

The aim of this thesis is to examine the MSW treatment practices in Algeria in order to submit possible treatment approaches namely Co-incineration of waste in the cement industry, which could be implemented locally for a sustainable SWM.

An investigation on the potential of Refuse Derived Fuel (RDF) production from MSW and utilization as an alternative fuel in the cement industry in the Wilaya of Blida in Algeria is the main objective of this thesis. Furthermore, different scenarios were proposed for the implementation of the different technologies of waste pre-processing and RDF production (MBT and MPS) in the Wilaya of Blida and in Algeria in general, taking into account the population, MSW generation and composition, and the availability of area.

RDF drying technologies are also subject in this thesis. An experimental study was performed to determine the drying characteristics of the RDF fractions using a laboratory scale hot air dryer at a variety air temperature and a constant air flow. The drying kinetics of RDF were modelized using STATISTICA software, and the appropriate mathematical model was determined in addition to the effective diffusivity coefficient and the activation energy of the RDF. In addition, using the exhaust air from the clinker cooler for RDF drying was also suggested, and the total energy needed was determined.

Keywords: MSW, Co-incineration, RDF, cement industry, Algeria, MBT, MPS, drying, simulation, STATISTICA.

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Finally, I dedicate this work to the memory of my father, to my mother, to my sister, to my brothers, to my nieces, and to my cousin Soraya. Thank you all.

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LIST OF ABBREVIATION

SWM: Solid Waste Management

MSW: Municipal Solid Waste

WtE: Waste to Energy

GHG: Greeen-house gases

RDF: Refuse Derived Fuel

AF: Alternative Fuel

PVC: Polyvinyl chloride

SPL: Spent Pot Liner

MBM: Meat and Bone Meal

EU: European Union

WDF: Wood-Derived Fuel

MBT: Mechanical Biological Treatment

MBS: Mechanical Biological Stabilization

MPS: Mechanical Physical Stabilization

MODECOM : Méthode DE Caractérisation des Ordures Ménagères

GICA : Groupe Industriel des Ciments d'Algérie

SCMI : Société des Ciments de la Mitidja

FBD : Fluidized Bed Dryer

R^2 : Determination coefficient

RMSE: Root Mean Square Error

χ^2 : reduced chi-square

EPR: Extended Polluter Responsibility

De: effective diffusivity

Ea: activation energy

INTRODUCTION

Over the last decades, Solid waste management (SWM) has become a major concern and is now one of the main topics under discussion. This is probably due to population growth and increasing per capita municipal solid waste generation. In addition, economic growth is an important parameter influencing the amount of solid waste produced. As the waste quantities increase, additional efforts and capacity are needed to find effective solutions to manage it in an environmentally safe manner [1]. Compared to developed countries, developing countries face many challenges, including limited technical experience and weak financial resources which generally covers only the cost of waste collection and transfer. The choice of adequate solid waste management services is critical because of the potential effect on the environment and public health.

Algeria as one of the developing countries shares the same waste characteristics with the other developing countries. The sharp increase in the volume of solid waste generated made solid waste management more complicated, this increase is due to the significant changes in living standards and conditions of the populations [2]. Many challenges face Algeria in the solid waste management field. Population growth in urban communities, the increase per capita of MSW rates, the gaps in current related legislation, financial problems, the lack of adequate and appropriate equipment, and the limited availability of trained and skilled labour have contributed to the weakness of waste management system in Algeria [3].

Landfilling is the main waste disposal method in the Algerian waste management plan, up to 95% of the total Municipal Solid Waste (MSW) is being landfilled or dumped in different dumping sites. The recycling potential is between 5 to 8%, this low rate is probably due to the low sorting practices and the lack of a government-managed recycling system, as well as the waste collection method of collecting all mixed waste without separation at source, which reduces the potential of recycling the recyclable materials [3]. Effective SWM involves the application of a variety of treatment methods, technologies, and practices. In applying the different technologies and systems, the protection of health and environment protection must be guaranteed. There is a wide range of alternative waste management options available for treating mixed MSW to limit and reduce the amount left for disposal in landfill sites [4].

The control of the polluting effects of solid waste on the environment by applying the proper SWM system make the solid waste a valuable resource and fuel for future sustainable energy. Waste to energy (WtE) concept can convert the energy content of various types of waste into different forms of valuable energy [5]. In addition, the thermal energy, fuels derived from waste, compost, and stabilized products destined for landfill produced by combustion and biological processes are attracting attention worldwide [6].

Today, Algeria generates 13 million tons of MSW from a population of 43 million inhabitant, with an annual growth of rate of 3% [3]. The waste treatment method adopted in Algeria is landfilling, which generates high levels of greenhouse gases (GHG) emissions, due to the high amount of organic fraction and water content. In addition, the lack of space for the construction of landfills and the effect on the environment and human health force the country to find new alternatives for the waste management strategy.

A good alternative for the region is the waste to energy (WtE) concept by which mixed waste is converted to RDF (Refuse Derived Fuel) [4]. This concept contributes to the reduction of the moisture content, which increases the heating value of the final products and decreases the production of leachate in the case of landfilled materials if no further stabilization of the organic fraction is applied [5].

Algeria has a large number of cement plants (17 plant), with a total production of 25 million t per year. This quantity of cement is produced by three sectors in Algeria: public (Industrial Group of Algerian Cement GICA), international private (Lafarge in cooperation with national private industry), and the local private sector. This large volume of cement production generates a massive consumption of raw materials and fossil energy. Most of the cement plants are located in the northern part of the country (4% of the total area), where 65% of the population live. In total, the waste quantities generated in this part of the country represents around 35% of the total country's waste production [3]. The presence of end-users as well as the availability of fresh waste favors the adoption of co-processing of waste as an alternative option for the waste management system in Algeria.

The main energy used in Algeria is natural gas. The energy consumption differs from one cement plant to another, ranging between 870 and 1860 thermal/ t clinker and 100-200 kWh/ t cement. The cement manufacturing plants are energy-consuming, the energy represents two-thirds of the production cost, posing the problem of gas subsidies to these units in

Algeria. Therefore, new techniques to reduce energy consumption are required. To this end, this study provides a technical sustainable solution taking into account the required modifications and proper implementation, considering the legal, financial and environmental aspects.

The potential of RDF production, drying, and utilization as an alternative fuel (AF) in the cement industry has not yet been lunched in Algeria. Therefore, the aim of this thesis is to apply this treatment approach for an integrated waste management in Algeria. Within this context the objectives of this thesis were to;

- Review the current solid waste management system in Algeria in terms of legislation, organizations, and financing aspects,
- Assess the current practices for solid waste collection and treatment,
- Assess the strategies adopted by the different organizations concerned for the future of waste management in Algeria,
- Investigate the potential of the RDF production, the quantity of the RDF produced from MSW in Algeria, and its composition and quality according to the European standards,
- Introducing the RDF production technologies,
- Determination of the total energy needed for RDF drying in case of using the properties of the exhaust air from the clinker cooler as a drying air,
- An experimental study to determine the drying characteristics of the RDF fractions using a laboratory scale hot air dryer. the drying kinetics were modelized using STATISTICA software to determine the appropriate mathematical model which describes the drying process of RDF,

CHAPTER 1

STATE OF ART

1.1. REVIEW ON SOLID WASTE MANAGEMENT (SWM) IN ALGERIA

This chapter presents an overview of the SWM situation and system in Algeria, it focuses on waste generation and composition, the legal, institutional and financial frameworks. The responsibilities of the different sectors involved in the waste management sector as well as the role of the private and informal sectors are also highlighted.

1.1.1. Waste generation and composition

Algeria is home to around 43 million inhabitants on a surface area covering 2,381,000 km^2. The rate of Municipal Solid Waste (MSW) generation is 0.9 and 0.65 kg/capita/day in urban and rural area, respectively. Today, it generates 34 million tons of waste including 13 million tons of MSW with an annual growth of about 3%. Landfilling is the common practice for treating the collected solid waste; up to 95% of the amount of the waste generated is deposited in different standards of landfills without any pre-treatment [3].

Typically, as in many developing countries, the MSW generated in Algeria is dominated by organic fractions with high moisture content Table (1.1). The MSW composition varies according to several parameters including; the nature of the area (urban, rural, industrial, and commercial areas, etc.), the climate, the life style, and standards. Moreover, the development of the food packaging industry has significantly modified the MSW composition as well as the consumption habits in Algeria [2].

Table 1. 1 :Comparison of waste composition (%) of the some cities in Algeria

Mega Cities **Fractions**	**Mostaganem [7]**	**Blida [8]**	**Annaba [9]**	**Constantine [10]**	**Chlef [11]**	**Adrar [12]**
Organic	65.5	55	49.6	70	72	60
Paper-cardboard	13	8	3.38	11	7	12
Plastic	7	18	11.48	13	5	11.8
Glass	4	1	0.8	2	4	7.3
Textile	3	3	13.7	1	4	6.6
Metals	3.5	2	2.36	3	NA	2.2
Hygienic products	NA	10	NA	NA	NA	NA
Packaging	NA	2	2.32	NA	NA	NA
Others	4	1	NA	NA	6	NA

Packaging products (plastic, paper and cardboard), textile, and hygienic products represent a significant potential to be utilized in terms of material and energy recovery.

SWM has become one of the most challenges facing urban communities. The lack of the institutional, legal, human and inadequate financing means to implement the adequate changes is posing a serious problem. Several countries have realized that their way to manage their solid waste does not satisfy the objectives of sustainable development. Therefore, many of these countries, including Algeria have decided to pass from traditional waste management to more integrated waste management strategies.

1.1.2. Overview of the SWM practices in Algeria

Population growth, development of socio-economic activities, and changes in lifestyle and consumption, greatly favor the production of MSW, waste continues to grow in quantity, complexity and even harmfulness. Awareness drives public authorities and all the partners involved (industry, local authorities, and public authorities) to put in place policies for better waste management, seeking to control the environmental and health impacts on the entire chain from production to disposal [13].

Waste management and treatment remain a major challenge, which has been given high priority on the Algerian political agenda. The legal and institutional framework has been established in such a way to ensure proper and effective implementation of the different waste management activities; collection, treatment and disposal.

SWM has been improved over the last 20 years, starting by implementing a basic law related to waste management in 2001. The waste management policy in Algeria is a part of the National Environmental Strategy (SNE), as well as the National Plan of Environmental Actions and Sustainable Development (PNAE-DD) Figure (1.1). It resulted in the announcement of law 01-19, December 2001 relating to the management, control and disposal of waste. The principles of this plan are;

- Prevention and reduction of the production and harmfulness of waste at source;
- Organization of sorting, collection, transport and treatment of waste;
- Waste recovery through reuse and recycling;
- The environmentally sound treatment of waste;
- Information and awareness of citizens on the risks presented by waste and its impact on health and the environment;
- Institution of management tools: national Integrated Solid Waste Management Program (PROGDEM) and the National Special Waste Management Plan (PNAGDES).

Figure 1. 1 :Basic stages of waste management development strategies in Algeria

1.2. LEGAL, INSTITUTIONAL AND FINANCIAL FRAMEWORKS FOR SWM IN ALGERIA

The appropriate waste management system is usually identified to be implemented at the local level and through adopting the technical requirement to the local conditions (waste nature, capacity building, etc.).

The existence of a legal and institutional framework is decisive for the proper functioning of the waste management system and the development of a circular economy. To ensure good waste management, it is necessary that each actor (administrations, local communities, producers and distributors of products, operators of waste collection, treatment, or recycling) precisely identifies the role assigned to them, the measures to be taken into account, and the requirements to be respected.

The development of an effective SWM system should consider the legal, financial and institutional aspects in order to ensure its capability to cope with challenges facing the institutions in the sector. For example, but not limited to, financing is one of the major functional elements, which should be guaranteed when introducing new approach or technology (funded by the public/private sector or waste producer).

Figure (1.2) shows the institutional architecture for waste management in Algeria, it summarizes all the relations between the institutions, organizations, and other actors/agencies that are important in waste management.

The institutional structure provides collaboration and interaction between the different ministries involved, monitoring agencies at different levels, the implementation authorities (municipalities, DEW, AND, etc.). Indeed, the latter is taking place in case of there is a lack of alignment and competency between financial, operational and organizational aspects.

The role of the Ministry of the Environment and Renewable Energies (MEER), previously named Ministry of Water Resources and the Environment, in the field of MSW management is set by Executive Decree No. 16-89 of March 1, 2016. It focuses on the initiated studies in the waste management field, air quality, leachate and biogas treatment from landfills. It initiates and contributes to developing studies, defining the rules of waste management and the techniques for MSW treatment and recovery. It has an inter-link with the sectors concerned (AND, APC, DEW...) in terms of the development, evaluation, implementation of the national program for the MSW management as well as the establishment of the municipal waste Database.

The basic Law No. 01-19-December 2001 for the waste management in Algeria address the creation of a public agency responsible for managing collection, sorting, transport, treatment, recovery and disposal waste activities. By Executive Decree No. 02-175 of May 20, 2012, the National Waste Agency (AND) was created. AND must assist the municipalities in the field of waste management. Therefore, the municipality can benefit from the AND services for the development, validation, and implementation of the MSW management diagram. However, the intervention of the AND must be the subject of an agreement with the president of the municipality concerned.

According to the Wilaya Code in Algeria, the Popular Assembly of Wilaya (APW) is responsible for ensuring environmental protection. To this end, APW consists of a commission for creating a data bank for different areas in the field of waste management. It also assists municipalities that must undertake actions in this perspective. In this same context, the president of the APW must approve the MSW management diagram established by the municipality. Moreover, APW defines the regional development plan for the wilaya and monitors its application.

In case the law does not set out the obligation to include the environmental issues in this plan, it should include a chapter on the environment in general or even specifically on waste management. Accordingly, the plan must comply with the MSW management objectives. The APW president is also responsible for issuing operating permits for MSW treatment facilities.

The Popular Assembly of municipality (APC) Code enunciate that the municipality can choose how the public service will be organized providing MSW management, i.e. collection, transport and treatment (Law No. 01-19, Art. 32). The municipality has the choice between two main options. On the one hand, the municipality can take charge of the service itself in the form of an agency. On the other hand, the municipality can decide to concede the public waste management service to another private or public agency. This concession is then carried out by convention, contract order market. If the municipality takes charge of the waste service in the form of a management company, it assumes the financing of the service and ensures the mobilization of personnel and equipment. The revenue and expenses related to this service are part of the municipality budget, the municipality may also decide to allocate an independent budget to this public service. In the other case, the municipality can grant public service by creating a municipal public establishment with an industrial and commercial character (EPIC). Consequently, the municipality exercises the role of authority of guardianship. EPIC is endowed with legal personality and financial independency; this implies that it has to balance its expenses with its revenues.

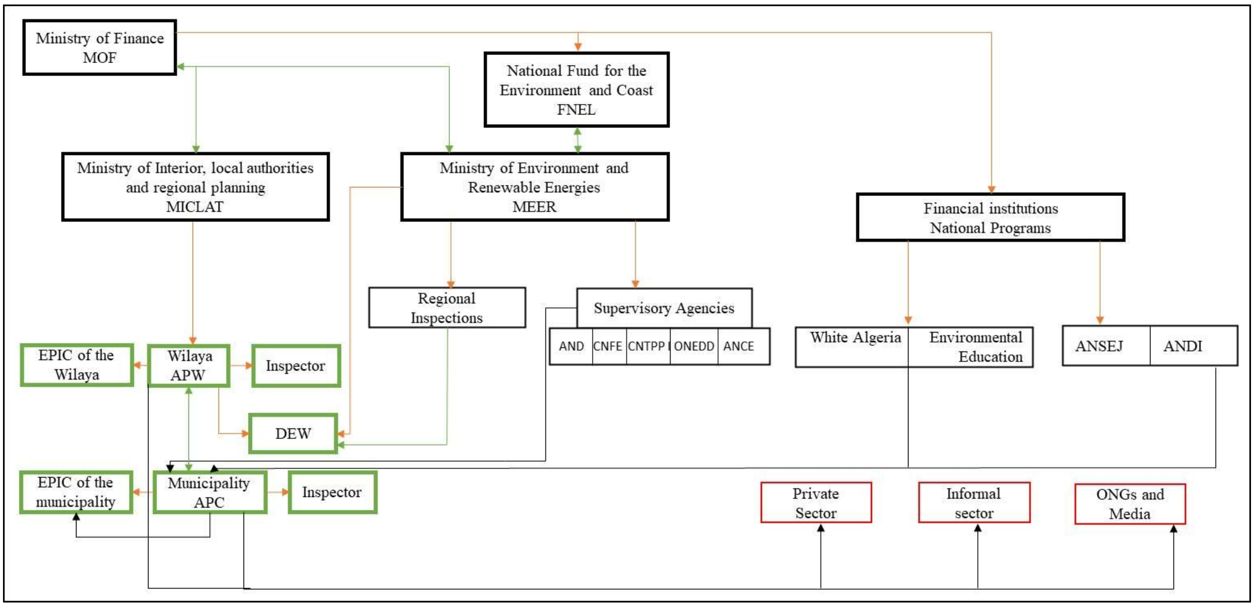


Figure 1. 2 : Institutional framework for the waste management system in Algeria [14]

According to the Law No. 01-19, the collection, transport, storage and disposal of waste or any other services relating to the MSW management, give rise to the collection of taxes, duties and fees. In addition, incentives are granted by the government to encourage the development of collection, sorting, transport, recovery and disposal activities according to terms which are set by regulation. Examples of these incentives are: subsidies granted by the National Fund for Environment and Pollution Control (FEDEP) or the Solidarity and guarantee fund for local authorities. The fund is responsible for the funding to the public services in the environmental field, there are funds destined to the industrial depollution actions, and grants intended to finance the pollution control facilities, carried out by public and private operators. In practice FEDEP also grants subsidies to the private sector in the recycling field. The financial responsibilities are different and depend on the source generation of waste (households, markets, industry, etc.). For the MSW management, an annual tax for the removal of municipal waste is collected by the municipalities in order to finance this service. Collection, transport and the treatment of waste from industrial, commercial, medical or other activities constitute remunerated services and are therefore the responsibility of the generators of this waste (Law No. 01-19, Article 36). MSW and other solid waste management is part of public services for which the municipality is responsible, the 2011 municipal code stated that the municipality fixes a financial contribution from users in relation to the nature and the quality of the service. In this context, different taxes exist to finance the municipalities for the waste management; TEOM is an annual sanitation tax for the municipal waste collection covers all of the household types and to be paid by either owners or tenants.

The absence of the private sector in the waste management field in Algeria is noticed. Up-to-date, only few private collection and transport companies have been identified to date. It may be appropriate to attract foreign investors in order to ensure funds for the needed infrastructure for waste management system. However, the rule must be taken into account "51/49" provided for in Algerian legislation. This rule specifies that foreign investment can only be carried out within the framework of a partnership in which the national shareholders are resident represents at least 51% of the share capital.

As for waste treatment; Law No. 01-19 stated that the recovery and / or disposal of waste must be carried out in conditions that comply with environmental standards. To this end, any applied technology must not impose any impact on the environment and public health. Waste treatment facilities and especially in terms of installation, operation, modification and extension are governed by the regulations relating to impact studies on the environment.

In the same light, the municipality is required to organize on its territory a public service responsible for the MSW treatment and disposal. An authorization from the APW president must be obtained for the installation of the MSW treatment facilities which are only destined for the MSW treatment and should not receive any other types of waste. According to the Executive Decree No. 04-410 of December 14, 2004, Article 3, waste treatment facilities are destined for waste recycling, storage, and disposal namely; Landfilling of MSW and special waste, dumping sites for inert waste, MSW and special waste incineration facilities, Co-incineration facilities and waste recycling centers.

1.2.1. Waste services Management actors

In order to ensure the appropriate functioning of the WM service, several actors are part of the various service segments either on the national, regional and also the local levels. However, WM methods differs from a country to another, from direct management to the public market through assignment and concession. This section will discuss the development of these two points in the case of Algeria.

MSWM is usually organized into three sectors in the developing countries; the public sector which is responsible for monitoring and enforcing the application of provisions of certain urban services including MSWM, the private sector which is involved in MSWM specially in waste collection and recycling, and the informal private sector in the reuse of certain waste fractions.

1.2.1.1. Public Sector

a. Ministry of Environment and Renewable Energies (MEER)

MEER was first launched in 25 May 2017; this new ministry is the successor of the ministry of water resources and environment (MREE). MREE was created by Executive Decree N° 16-89 of March 1-2016 on the organization of the central administration of the MREE. The MREE involve 13 administrations in its sector; these administrations are themselves organized in several directions which have one or more sub-directions. Each of these administrations and sub-directions have their own responsibilities.

Some of the responsibilities of the MREE in waste management field are;

- According to law 01-19; Articles 26 and 42; MREE is responsible to grant authorizations for special waste treatment facilities, and for export of hazardous waste.
- According to the executive decree 16-89, Article 2; MREE must contribute to the development legislative and regulatory texts relating to the environment protection and sustainable development. Ensuring the implementation, evaluation, updating and monitoring the national strategy and the national plan for the environment protection.
- Undertake any action which encourages the recycling, and the recovery of industrial waste and by-products.

Add to that, the MREE is responsible for developing and adopting a national integrated management plan for municipal solid waste. The National Program for the Management of Household and Similar Waste (PROGDEM) was implemented in 2002 and has since evolved. This program is an extension of the basic law n°01-19 and aims to organize the collection, transport and disposal of waste under conditions which guarantee the environment protection. The eradication of illegal dumping is also one of its main objectives. It forms a frame of reference for the new waste management policy.

In addition, the MREE is required by law n°01-19, Article 14, to draw up the National Plan for Special Waste Management (PNAGDES) in coordination with the ministries concerned (industry, energy, health, agriculture, transport, commerce, local communities, regional planning, finance, and national defense). The PNAGDES covers;

- Inventory of quantities of special waste, especially those of hazardous nature produced annually on the national level;
- The overall volume of waste stored provisionally and definitively, and classifying them by category;
- The choice of treatment methods for the different categories of waste;
- The location of existing treatment sites and facilities;
- The need for additional waste treatment capacity, taking into account the installed capacities, the priorities adopted for the creation of new facilities as well as the necessary economic and financial resources for their deployment.

Since May 2017, the responsible for the environment has changed its structure and now exists under the name of the Ministry of the Environment and Renewable Energies. Even after this change, the legal provisions of the organization and the obligations for waste management remain the same.

In terms of the environment in general, and specifically in terms of waste management, the MEER has several support structures placed under its supervision to assist the municipalities in their missions;

- National Agency of Waste (AND)
- The National Center for Cleaner Productions Technologies (CNTPP)
- The National Conservatory of Environmental Training (CNFE)
- The National Observatory for the Environment and Sustainable Development (ONEDD).

b. National Agency of Waste (AND)

The basic law n°01-19 stipulates that a public body responsible for promoting the activities of collection, sorting, transport, treatment, recovery and disposal of waste must be created.

Therefore, in 2002 and by executive Decree N°02-175, the AND was founded. It was created as a public industrial and commercial establishment (EPIC) and it is placed under the supervision of the MEER.

The AND provides support for pilot sorting projects (development of the strategic approach, occasional support, etc.). In addition, it implements and manages the public packaging waste treatment system Eco-Jem. It is also in charge of supporting the development, validation and implementation of municipal plans for the management of household and similar waste.

The AND is also in charge of other activities (without these responsibilities being based on a legal basis) namely;

- Development and dissemination of indicators;
- Organization of an industrial waste exchange;
- Support for waste collection in the administrations.

c. The National Center for Cleaner Productions Technologies (CNTPP)

The CNTPP is the institutional and technical body of the diffusion of cleaner production techniques in different economic sectors. It was created by Executive Decree n°02-262 and placed under the supervision of the MEER. Its responsibilities consist of;

- Promoting, sensibilization, and popularization the concept of developing cleaner production techniques;
- Assist and support investment projects in cleaner production techniques;
- Provide industries with all the necessary information for their efforts to improve the production processes through access to cleaner technologies and obtaining the related certifications, if applicable;
- Develop international cooperation in the field of cleaner production technologies.

Specifically, in terms of waste management, the CNTPP can launch projects for the construction of waste treatment facilities such as landfills or regeneration stations for used oil.

d. The National Conservatory of Environmental Training (CNFE)

Regarding sensibilization in the field, the CNFR was created by Executive Decree n°02-263 and placed under the supervision of the MEER. It is responsiblefor;

- Training of various public and private stakeholders in the environmental field;
- Environmental education and awareness of the general public (schools, etc.).

e. The National Observatory for the Environment and Sustainable Development (ONEDD)

ONEDD was created by Executive Decree n°02-115 and placed under the supervision of MEER. Its mission is to collect, process, produce and circulate environmental information on scientific, technical and statistical levels. In particular, it is responsible for;

- Setting up and managing networks for observing and measuring pollution and monitoring natural areas;
- Collecting data and information relating to the environment and sustainable development from national institutions and specialized organizations;
- Processing environmental data and information with a view to developing information tools;
- Initiate, carry out or contribute to studies aimed to improve the environmental knowledge of the areas and the pressures exerted on these areas;
- Publish and circulate environmental information.

I.2.1.2. Establishments with Public, Industrial, and Commercial character (EPIC)

A public industrial and commercial establishment (EPIC) is a legal establishment which its objective is to intervene in public services under the responsibility of public authorities. The EPIC is administered by a board of directors and supervision is exercised by the public creator, this can relate both the local level (local authorities for example) and the national level (ministries for example). The budget is not annexed to that of the public creator and it is subject to the rules of local accounting.

An EPIC status confers two main characteristics or organizations:

- Commercial character in terms of studies and research compared to;
- Role of a public service with the administration, with responsibility for assisting local communities.

In the field of waste, this status facilitates the development of activities relating to integrated management (sorting, collection, treatment, recovery and disposal of waste). The EPICs were legally created by Decree n°83-200 of March 19-1983specifying the conditions for the creation, organization and operation of the local public establishment.

a. EPIC on a national level

At the national level, the EPIC mainly contributes to carrying out studies, research, and demonstration projects, disseminating scientific and technical information and helping to implement awareness and information programs. Relevant EPICs within the framework have been mentioned above; AND, CNTPP, CNFE and ONEDD.

Algerian legislation does not provide for regulations on the operation and competences of EPICs in general. However, the codes of the Wilaya and the Municipality provide for the creation of the EPIC of the Wilaya and the Municipality to take charge of local public services.

b. EPIC on a local level

For the management of its public services, the Wilaya and the Municipality can create public establishment with legal personality and financial independence. EPIC must therefore balance its expenses with its revenues.

In terms of waste management in Algeria, the local EPICs are generally responsible for the collection, transport and treatment of waste. It is therefore possible to delegate public waste management services to municipal EPICs. However, in practice, in most cases, the transport and collection of MSW is done under the direct control of the municipality. When the MSW transport and collection services are still provided via EPICs, in general these EPICs are under supervision of the Wilaya president. Specifically, at the Wilaya level, there was and inter-ministerial instruction in 2006 encouraging the creation of EPIC to ensure the management of technical landfills.

1.3. MUNICIPAL SOLID WASTE MANAGEMENT (MSWM)

According to the Article 3 of law 01-19; MSW is all waste from households as well as similar waste from industrial, commercial and other activities which, by their nature and composition, can be assimilated to household waste.

The MSW management is provided by the basic Law 01-19. In this context, the municipality has an important role. The code of the municipality obliges municipalities to take charge of household and other waste. The municipality is responsible for organizing public services on its territory, according to the terms of municipal plan, in order to meet the needs of residents in terms of collection, transport and where appropriate treatment of MSW. It must ensure the establishment of a sorting system for MSW and promote it to citizens by introducing incentive measures aimed at developing and promoting the sorting system. In addition, the municipality must inform and educate the residents about the harmful effects of waste.

Law 01-19 allows municipalities t group together or join forces for part or all of the MSW management. This intercommunity is also provided for by the code of the municipality.

1.3.1. Methods of waste management by the municipality

The code of the municipality states that the municipality can choose how the public service to provide support for MSW will be organized. The municipality has the choice between two main options; first it can take charge of the service itself in the form of an agency. Second, it may decide to concede the public waste management service to natural or legal persons governed by public or private law. This concession is then carried out by convention, contract, program or order market.

In case that the municipality takes charge of the waste service in the form of a management body, it assumes the financing of the service and ensures the mobilization of the personnel and the equipment itself. The revenues and expenses related to this service are part of the municipal budget. The municipality can also decide to allocate an autonomous budget to this public service.

In the other case, the municipality can concede the public service in three different ways:

- The code of the municipality provides for the possibility of creating a municipal public establishment with an industrial and commercial character (EPIC). Therefore, the municipality exercises the role of the supervisory authority. EPIC has a legal personality and financial independency; this implies that it should balance it expenses with its income.
- The municipality can also choose the mode of management by public market. In this case, the code of the municipality states that the municipality's service provision contracts must be awarded in accordance with the regulations applicable to public contracts (presidential decree n°15-247 of September 16,2015), a service contract is then established with an economic operator after the completion of the tender

procedure governed by that decree. When a contract or an order relates to an amount equal to or less than 4 million DA, an obtaining within the meaning of this Decree is not obligatory. The service provider can be remunerated according to different methods; according to a global and fixed price, on a unit price schedule, on controlled spending or at a mixed price.

- Finally, the public waste management service can be delegated. This kind of concession obeys standards specifications set by regulation and the service is entrusted to the delegate by agreement. The remuneration of the delegate is ensured substantially by the operation of the public service (by operating revenues from the service). This delegation can take several forms according t the presidential decree n°15-247 of September 16,2015, Article 210):

Other organizations and ministries have a pertinent role in the waste management system in Algeria, their link to the subject is described in Table (1) in Appendix 1.

1.4. CO-PROCESSING OF WASTE IN THE CEMENT INDUSTRY WORLDWIDE

Co-processing of RDF from MSW in cement kilns is a feasible alternative that can address the need for decrease the environmental impacts of solid wastes, safely disposes hazardous wastes, decrease GHG emissions, decrease waste handling costs, reduces waste amount for landfilling as well as helps in saving natural energy and material resources [15,16,17].

Cement industry is strongly energy-consuming. The energy generally representing 30 to 40% of production costs. Different sources of fuels are used in traditional cement kilns, such as natural gas, coal, and petroleum oil which are not renewable and being consumed rapidly [18]. Big amounts of energy and raw materials are consumed in cement production, for example, to produce 1 ton of clinker, 3.2-6.3 GJ of energy and 1.7 ton of raw materials are required [18].

Many environmental issues are associated with cement production like air pollution and the efficient use of energy. The main source of emissions is the clinker burning process and it is also the principal user of energy. The calcination process produces CO_2 gas, CO_2 is a by-product of a chemical conversion process, calcium carbonate (CaCO3) is heated in a cement kiln at a temperature of about 1300°C to form lime (i.e., calcium oxide or CaO) and CO_2, this process releases carbon dioxide into the atmosphere. The lime reacts with silica, aluminum, and other materials to produce clinker, which is ground into a fine powder and combined with small amounts of gypsum to create Portland cement. In total the cement industry is responsible for about 5% of global emissions CO_2. In a cement plant, 30% of the CO_2 comes from the fuel combustion in the furnace, 10 percent of other downstream plant operations and 60% from the limestone calcination [19].

Many advantages are offered by the co-processing of waste in cement kilns for the authorities responsible for waste management, for the industry, and for the society. This can be summarized as a (win/win/win), industries can improve the competitiveness and reduce the fossil energy and raw materials consumption by a cost-effective substitution of the natural resources with alternative fuels which leads to an ecological, environmental and sustainable waste management and important saving of natural resources, this leads to a long term and sound solution for the waste produced by the society.

Authors discussed the most common alternative fuels used in cement manufacturing process, like tires because of their low moisture content, low cost and the high calorific value 35.6MJ/Kg [20, 21]. Other alternative fuels are used; the MSW with a heterogenous composition and the high moisture content, make it not so desired to use in the cement kiln as alternative fuel. RDF is the homogenous fraction of the MSW, the MSW is screened and sorted to separate the fraction which could be recycled and also separate the organic fraction, the non-recyclable fraction with a high heating value can be dried to produce RDF. The MSW has a calorific value of 8-11MJ/kg while the RDF has a calorific value of 15-20MJ/Kg which make it more suitable to use as alternative fuel in cement kiln [22]. Using RDF leads to reduce the $CO_2$and CO emissions and the use of conventional fuels, and also reduce the heavy metals emissions [23, 24, 25]. MSW can contain a high fraction of PVC which is the responsible of the high chlorine content, chlorine may lead to highly toxic dioxin and furan emissions if there is a poor incineration.

In aluminum industry and during the manufacturing of aluminum metal in electrolytic cells, a solid waste is produced called the spent pot liner (SPL) [26]. In 1988, SPL was classified as a hazardous waste because of its hazardous properties, it contains toxic fluoride and cyanide compounds which are leached in water, it is corrosive and exhibit a high pH due to the alkali metals and oxides and it reacts with water producing inflammable, toxic and explosive gases.

SPL was widely used in cement factories, the stack emissions testing indicated that the cyanides were destroyed and little of the fluoride was emitted [27]. But some problems were identified with the feed system, because SPL is a very hard material compared to coal.

In 2019 authors investigated the combustion performance and emissions (NO_x and CO_2) characteristics of SPL as alternative fuel, the results of the modeling approach of the combustion of the final treated SPL(water washed followed with NaOH and H_2SO_4 treatment) showed lower temperature, lower NO and CO_2 emissions at the exit from the furnace compared to the fossil fuel (coal) [28]. They suggest that the use of SPL reduce the fuel cost of the cement industry and manage the SPL waste produced by the aluminum industry.

Because it was not allowed any more to landfill the meat and bone meal (MBM) waste or to use as cattle feed because of the pathogens, the utilization of MBM in cement industry increased. The cement kiln could destroy any living organism and the energy potential of the MBM is also utilized. The MBM has a calorific value of 14.47 MJ/Kg and because of its high moisture content (70%), a pre-treatment is needed to reduce that which causes an increase in the processing coast [29]. Additional amount of air may be required, 5-10% more air is needed for combustion if MBM is fed to the burning zone [20]. Compared with coal, MBM has lower fixed carbon and higher chlorine content which may lead to a blockage in preheater units which will lead to reduce the efficiency of the plant [29].

Due to its high calorific value (29-40 MJ/Kg), and the high production worldwide, plastic waste is considered to be one of the most common alternative fuels used in cement industry [30]. The plastic waste could be found in municipal solid waste as well as in industrial waste, it may be fed to the kiln or to the pre-calciner trough a belt-conveyer. Plastic contains high concentration of chlorine which is found in PVC, it represents a concern when using plastic waste in the cement industry, if the chlorine content of the plastic waste exceeds 0.7%, it can influence on the quality of the clinker [31], increase in furans and dioxins [32]. Beside of the disadvantages of the chlorine, using plastic waste in cement industry can reduce the CO_2 emissions; 1 ton of CO_2 per ton of coal replacement [22, 33].

During waste water treatment, big amounts of sewage sludge are produced. Sewage sludge is widely used as an organic fertilizer or been landfilled, but these treatments are not environmentally friendly [29]. Sewage sludge is also used in cement industry as alternative fuel, and the ash is used like raw material in the clinker. The heating value of the raw sewage sludge (dried) range between 23-29 MJ/Kg [34]. Germany used 200.000 tons of dewatered sewage sludge and 40.000 tons of dried municipal sludge [35]. In 2006, the swiss cement industry used 54,964 tons of dried sewage sludge in their kilns. While using sewage sludge as alternative fuel, the NOx emissions are reduced [31], and an increase in SO_2 emissions is noticed [36], also a high concentration of mercury is noticed in the sewage sludge which comes from the cleaning process [22].

Solvent and spent oil are hazardous waste from automotive, marine and industrial sources. Due to its hazardous properties, it is dangerous to store it for long periods especially light and volatile oils which they can increase the risk of fire and explosions, and also the problem of volatile organic compounds (VOC) emissions [37]. Waste oil has a high calorific value 29-36 MJ/Kg and use it as alternative fuel is an effective means of disposal. With the high temperature of the kiln, it could burn and destroy all organic materials and the non-organic compounds could be chemically trapped in the clinker [38]. In EU 1.07 million tons of waste oil is used by cement industries, an un-blended waste oil can also be used to start up the process of the main burner. Using spent solvents, solvent and paint sludge and waste solvent as alternative fuels reduces the NOx and CO_2 emissions and reduce the mercury and other heavy metals content [38, 39, 40].

Other kind of waste is used in cement industry as alternative fuel but it is not common, agricultural biomass like rice husk, hazelnut shells, corn Stover and many varieties of biomass are burnt in cement kilns in India, Malaysia ... [29, 33]. Availability of biomass is one of the major concerns because most of the agricultural residues are not available all year around. The heating value of the biomass is variable and ranges between 14-21 MJ/kg and the moisture content ranges from 6% to 12% [41, 42]. 20% substitution rate is suggested for cement kilns which would not require a major capital investment [42].

Authors found out that using WDF (wood-derived fuel) in the cement industry would minimize the use of conventional fuel and reduces the quantity of waste wood destined to landfills, and it was suitable to be used as an alternative fuel, based on its ultimate chemical properties. No impact on the cement production process or on the quality of the clinker produced was observed, and about 16% reduction of greenhouse gaze's emission was achieved when 20% of WDF was used as co fuel [19].

Among these different types of waste, there are which have been successfully co-processed as alternative fuels and raw materials in cement kilns in Europe, Japan, the USA, Canada, and Australia since the beginning of the 1970s. The utilization of alternative fuels for energy recovery has been increasing gradually in recent years, and this development is set to continue. In addition, the thermal energy share covered by alternative fuels in the cement industry "co-processing in rotary kilns" differs from region to region [21]. Figure 1 shows the substitution rate of alternative fuels in the cement industry in 2016.

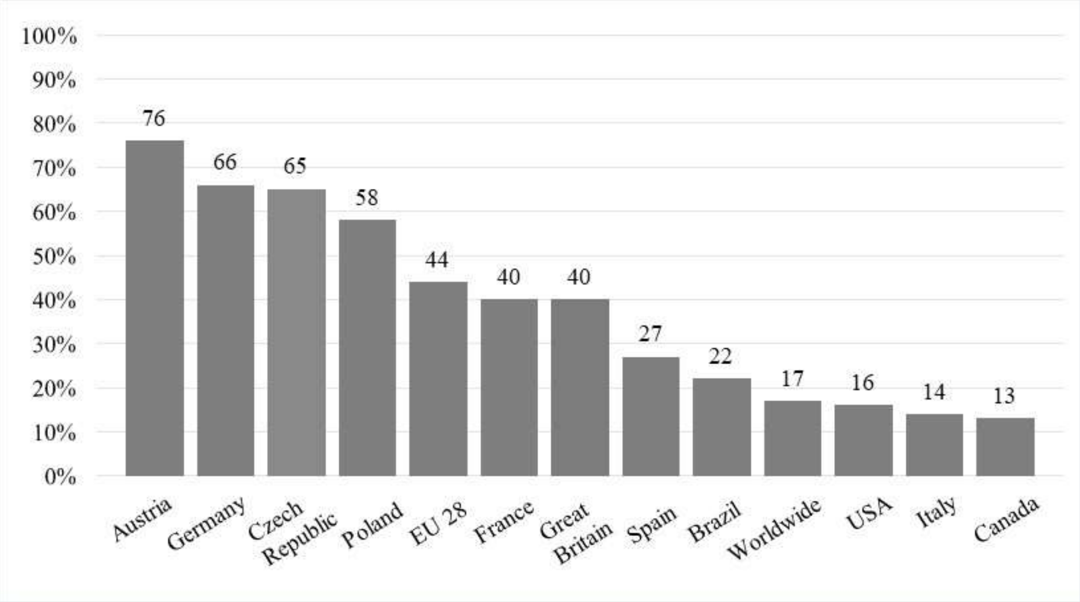


Figure 1. 3:Substitution rate of alternative fuels in the cement industry in 2016

(Sarc et al.,2019) updated the data of the substitution rate worldwide and for some selected countries in 2016. As shown in Figure 1, the average rate of substitution at the worldwide level is about 17%. Austria is the leading country in RDF utilization, where the substitution rate reached 76%. This is followed by Germany with 66%, Czech Republic 65% and Poland 58%. These countries reached higher substitution rates than the EU average; the total average substitution rate in the European Union is about 44%, which is also higher than the worldwide substitution rate. Only a 16% substitution rate is achieved in the USA, 14% in Italy and 13% in Canada [43].

1.5. REFUSE DERIVED FUEL (RDF)

RDF is a combustible high calorific fraction recovered from MSW. On other words, RDF is a kind of alternative solid fuel, which is recovered from recyclable materials municipal or industrial solid wastes, such as plastics or from materials that are hard to recycle after decomposing. RDF typically consists of pelletized or fluffy MSW that remains after the removal of noncombustible materials such as organics, ferrous materials, glass, grit, and other noncombustible materials. The remaining material is then called RDF and used in clinker production as a substitute for conventional fossil fuel [44, 45].

MSW composition is influenced by several factors such as sources (rural, urban, industrial or commercial), culture, economic development, climate, seasons, and energy sources; composition impacts how often waste is collected and how it is disposed. Here, low-income countries have the highest proportion of organic waste, ranging from 40 to 85% of the total [45, 46].

In fact, raw MSW has a heterogeneous composition (e.g., particle size, higher inert material composition, volatile matter, chlorine, alkali and heavy metal content), high moisture content, low calorific value, lower bulk density, lower energy conversion density and high ash content [47, 48, 49]. These properties make using raw MSW as fuel is difficult and unattractive, requiring an integrated system approach to pave the way for maximum resource (materials and energy) recovery and reducing environmental impacts.

1.5.1. RDF production technologies

MSW are mainly disposed into a landfill because it is the simplest and low cost-effective method of waste disposal. Between different fractions the organic ones constituted the major component of MSW because of its biodegradation in landfill under anaerobic condition represents, also, the major fraction affecting waste pollution in landfill [6].

Therefore, modern waste management, whilst advocating avoidance and minimization of waste production, has strong focus on recycling and recovery. In addition, increasingly, the production of high-grade RDF and the separation of value-added materials for recycling became important objectives. However, even with the most successful source separation schemes, there remains a significant quantity of residual waste. Internationally, mechanical biological waste treatment (MBT) technologies are being adopted for pretreatment of MSW in turn to extract RDF.

1.5.1.1. Mechanical Biological Treatment Plants (MBT)

MBT is a technology that involves different processing steps, to separate the mixed waste into different fractions. Each fraction is treated, recycled, and /or recovered. The main processes of an MBT are mechanical or physical technologies and the biological treatment of the organic fraction. The outputs of an MBT can be presented in two fractions, a fine fraction for biological treatment, and a coarse fraction (high calorific) that passes through the mechanical treatment [50] (Figure 1.4).

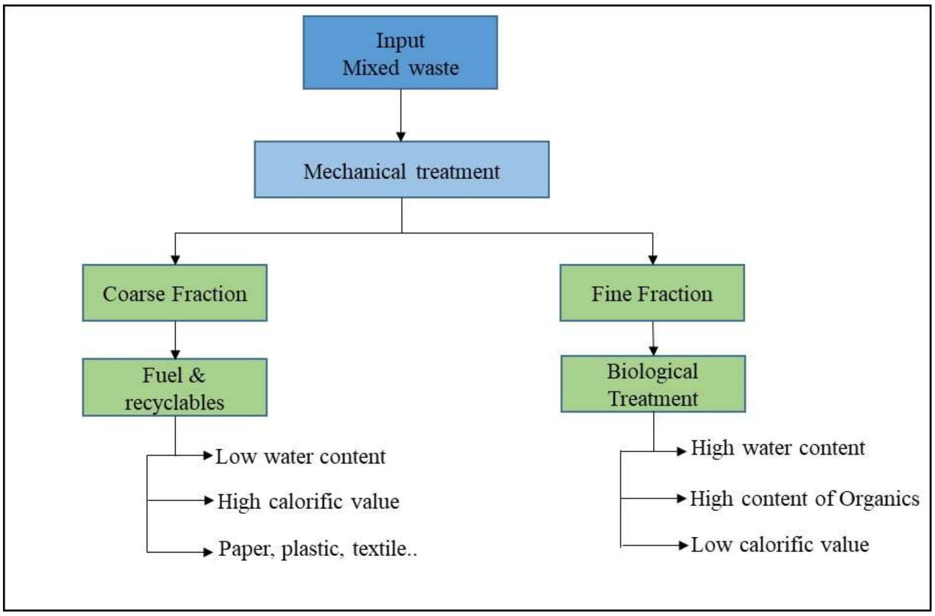


Figure 1. 4: General approach of MBT

The targets of a mechanical-biological treatment of mixed waste depend on the waste streams, location, economic and legal situation. It aims to produce a high calorific AF, separate the recyclable materials, and minimize the thermal waste treatment. This would help to reduce the areas for the construction of new landfills, minimize the quantities of waste for landfills, which will result in decreasing in leachate and greenhouse gases emission (Figure 1.5).

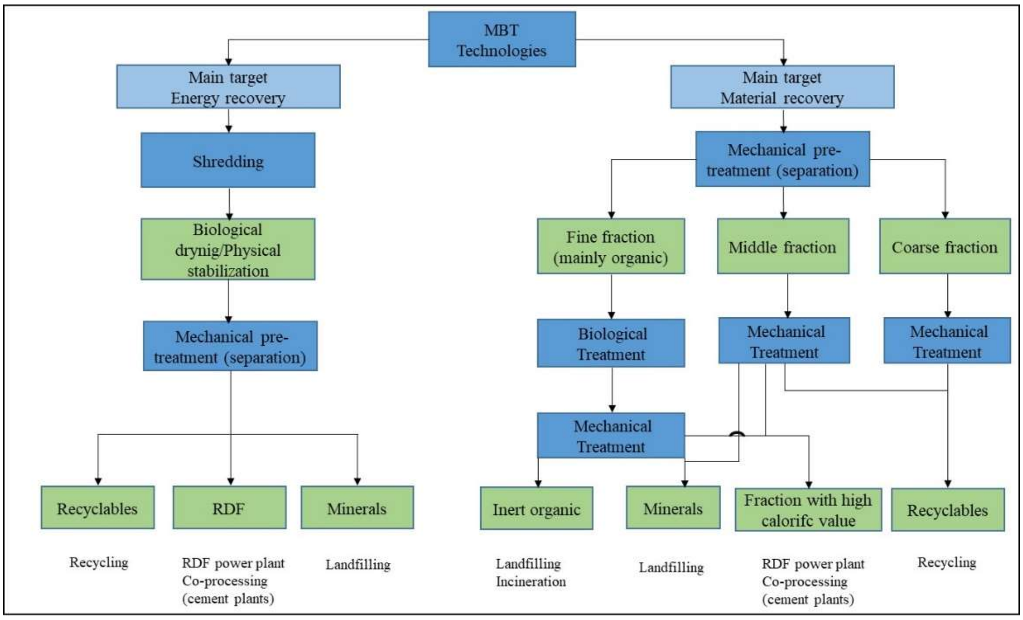


Figure 1. 5: Adopted technologies for the different targets of an MBT

The outputs of the MBT plants depend on the technology adopted and on the main target. If the point is the material recovery, the waste passes directly through shredding to minimize the size, then to biological or physical drying and finally, the mechanical separation to separate the waste into recyclables, RDF for co-processing and mineral fractions for landfilling.

In the other side, in case the waste contains more materials that can be recycled, first it passes through a mechanical treatment in order to have three fractions (fine, medium, and coarse fraction). The coarse and middle fractions again pass through a mechanical treatment to separate the recyclables, and high calorific materials. The fine fraction goes to biological treatment for drying and stabilization which will results as outputs; inert materials and minerals for landfilling.

1.5.1.2. Types of MBT technologies

MBT plants are considered to process MSW as well as industrial and commercial waste. It combines a wide range of techniques and processing operations set by the market needs of the end product, thus, there are different MBT systems according to the complexity and functionality of each MBT plant.

MBT plants aim to produce a stabilized fraction for landfilling, in these MBT plants, the input waste is separated into different material fractions: materials for energy recovery

(RDF), recycling materials, materials for biological treatment (organics) and inert materials [51].

A significant benefit of MBT is that it can be constituted to achieve many objectives like;

- The pre-treatment of waste before landfilling;
- Recycling of the recyclable materials and stabilization of the biodegradable fraction going to landfill through the mechanical sorting and the biological treatment of the input fresh waste;
- The stabilization of the organic fraction going to landfill is achieved by reducing the moisture content and to convert it into a compost like output for use on land;
- Conversion of the waste into combustible biogas for energy recovery;
- Utilization of the dried materials to produce a high calorific organic-rich fraction for use as RDF.

The RDF can be derived from MSW through two other technologies, which can be classified into two main groups; Mechanical biological stabilization (MBS), and Mechanical physical stabilization (MPS). MPS is denominated as mechanical treatment technology, as there is no biological step involved [51, 52] (Figure1.6).

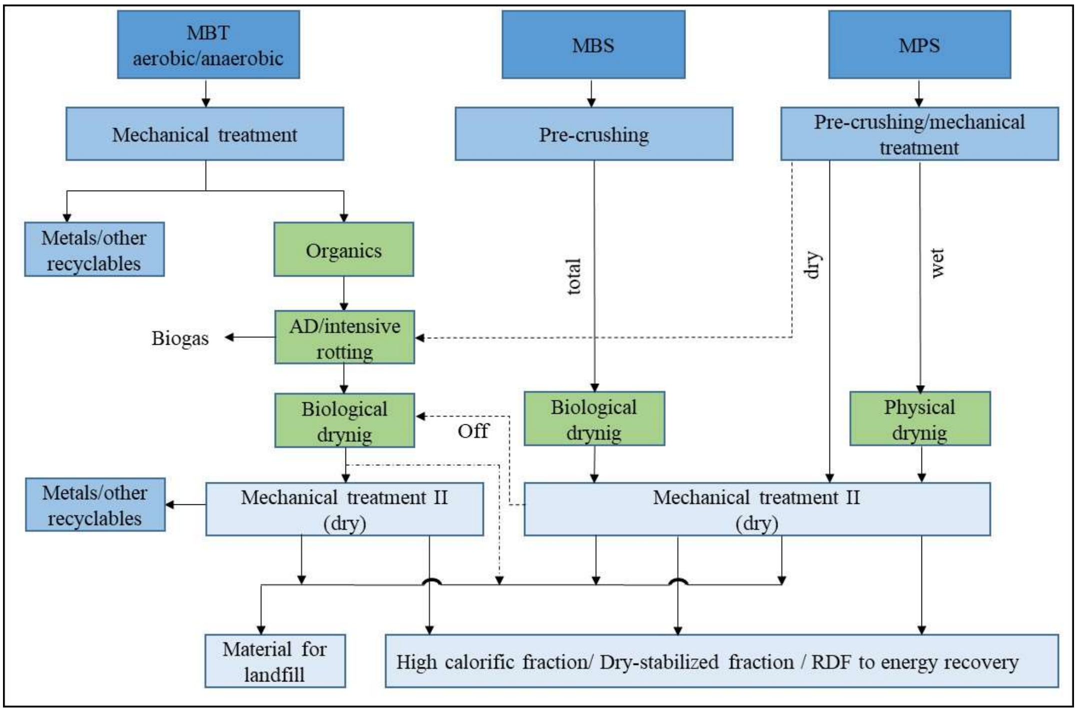


Figure 1. 6: Types of MBT for solid waste pre-processing

a. Mechanical Biological stabilization (MBS)

The main objective of MBS is to produce RDF by stabilizing the carbon as the main source of energy contained in MSW by biological drying (heat generated by microorganisms) and converts it in multiple-stage treatment into the high calorific fraction for use as RDF. Bio-drying is a form of composting where the heat produced during the aerobic biological activity is used to dry the waste, where it will primarily lose moisture and achieve a low degradation of the organic matter. In this way, most of the biomass content from the waste can be included in the RDF, which will reduce the biodegradable materials to be landfilled [53, 54].

b. Mechanical physical stabilization (MPS)

In MPS the waste is dried in a rotary drum (drier) with the supply of external thermal energy (fossil energy) instead of self-heating (bio-drying). This has the advantage of reaching a constant and continuous, pre-defined drying rate despite variations in the qualities of the starting material and different processing quantities. This in turn allows the identification and separation of non-combustible materials. The pre-treatment compromises the separation of the low calorific fraction and metals together with a multistage crushing. If necessary, hazardous fractions are separated and the high calorific fraction dried using the thermal energy (heat). Then the fine processing comes (sorting, classification) for the separation of fractions for RDF production and mineral fractions suitable for landfilling.

1.5.3. RDF drying technologies

The research on solid waste drying has been developed day by day, and new technologies and traditional drying types have recently been brought more discussed. However, the drying of solid waste is still challenging due to the complex process and some differences in solid heterogeneity and physical/chemical and biological properties. Therefore, many process variables need to be considered to efficiently dry materials to the required levels. This means that there may be no single drying method suitable for solid waste [55]. The most common drying methods used around the world for the MSW quality optimization are; Bio-drying, Bio-stabilization, solar drying, and thermal drying [56].

1.5.3.1. Bio-drying

Biological drying is a treatment method that uses natural and forced aeration and the heat generated by the natural aerobic biotransformation of certain organic substances to dry waste [57]. The main principle of the bio-drying process is to utilize the internal energy through the decomposition of organic waste [58]. Generally, the microorganisms involved in the organic matter decomposition during the bio-drying process are bacteria, fungi, actinomycetes and cellulose degrading agents.

Many studies investigated the biological drying process, mainly in laboratory scale and pilot scale, and partly in industrial scale [59, 60], these studies involve solid waste, such as mixed or separated MSW, organic waste, and other waste from the municipal and agricultural sectors. Bio-drying technology can produce high-quality biological drying materials in the shortest residence time (7-15 days) [61, 62]. the temperature range for the normal growth of microorganisms in the biological process is between 40°C and 72°C, with proper ventilation system inside the reactor [63].

1.5.3.2. Bio-stabilization

Bio-stabilization involves the improvement of the biodegradation of organic matter, which can reduce the weight and volume of MSW and reduce environmental pollution such as leachate and landfill gases [64]. Bio-stabilization and bio-drying are similar in the microbial metabolic rate, they only differ in the preparation of materials to be processed, energy balance, emission factors, management standards, and process duration [63]. The time required for an effective stabilization process is much longer than for biological drying. Bio-stabilized materials can be used for agricultural purposes and stored safely in landfills, while biologically dried materials can be used as fuel and other energy sources [65].

1.5.3.3. Solar drying

Solar drying takes place in a modular solar dryer with forced convection, which is designed to support heat and air circulation [66]. Various types, sizes and designs of solar dryers have been adopted, they can be classified based on the air flow, insulation exposure, air flow directions, dryer layout, solar energy contribution, and type of material to be dried.

Several studies reviewed numerous solar drying types, their drying cycle, and efficiency associated with drying of fruits, vegetables, biomass, and solid waste [66, 67, 68]. A potential design for hybrid MSW solar dryer was proposed, with solar absorption panel components and power supply heating coil as external energy source [68].

1.5.3.4. Thermal drying

Thermal drying is a process for dehydrating wet products based on the evaporation of moisture by heating. The heat required for evaporation is transferred to the material to be dried, either by heated hot gas or smoke combustion products (convective heat transfer), or from a surface touched by the material. Heat can also be applied by radiation and high-frequency currents.

The three major categories of thermal drying methods are direct drying, indirect drying and infrared radiant heat drying. In direct drying, heat is transferred through direct contact between the moist solid and the hot dry gas. Hot air acts as a drying medium and moisture carrier. In indirect drying, there is a wall between the dry gas and the wet material. Therefore, heat transfer takes place through the wall or through the hot surface. Therefore, the dry gas no longer plays the role of carrying moisture [69]. In infrared or radiant heat dryers, heat transfer is carried out by radiation. The source of radiant heat may vary. It can come from the power of infrared lamps; it can also come from resistive elements and other sources. This method is not as suitable as direct and indirect methods in the chemical processing industry. In addition, the dryer is also divided into batch and continuous modes [69]. Among different classifications of dryer, the most commercially dryers for RDF treatment are the fluidized bed dryers.

1.5.3.5. Fluidized bed dryer (FBD)

Fluidized-bed dryers (FBD) are well-known in the industry due to their wide range of applications and wide operating conditions. The fluidized bed system consists of cylinder, because the fluidized-bed column is filled with a bed of solid particles to provide proper contact with the gas entering the cylinder [70]. In case of using air as the drying gas, its temperature may be in the range of 100°C to 450°C, depending on the solid to be dried; however, inlet low- temperature drying can reduce fire risk in the dryer [71]. This type of dryer also includes a gas blower to assist the gas flow, a heater and a gas cleaning system to separate some small particles entrained in the gas phase [72].

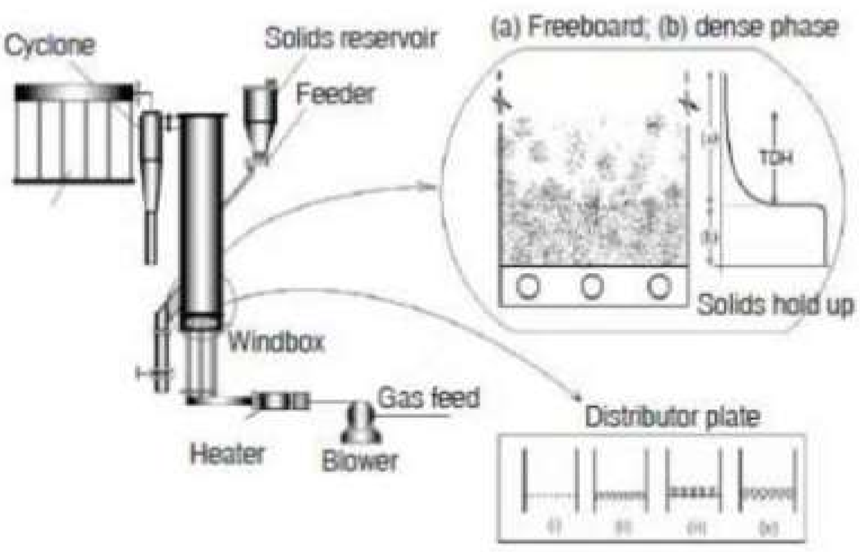


Figure 1. 7: Typical FBD set-up [72]

CHAPTER 2

MATERIAL AND METHODS

2.1. MSW CHARACTERIZATION AND RDF PRODUCTION AND ANALYSIS

2.1.1. Study area

This research was carried out in an established sorting plant in the Soumàa Landfill, located in the Wilaya of Blida, Algeria (northern part). Administratively, the Wilaya of Blida is divided into 25 municipalities with a population of about 1 009 900 inhabitants on a surface area covering 1696 km^2. It is characterized by semi-arid and arid climate conditions.

Figure 2. 1:Geographical location of the Wilaya of Blida

2.1.2. Materials

In the Wilaya of Blida, as in other Algerian cities, municipalities are responsible on a daily basis for municipal cleaning, waste collection and disposal of the MSW generated.

In order to have a representative sample of the waste generated by the Wilaya of Blida, two campaigns of MSW characterization were carried out in different periods of the year (summer and winter). The input raw waste materials were taken from three sectors of the Wilaya of Blida (rural, collective and individual) over a period of three days for each campaign from the Soumàa Landfill site. A total amount of 10 t of MSW was collected (3 t each day) as a sample from the targeted sectors and unloaded at the test site. Overall, for both campaigns, a total amount of 20 t of MSW was collected (Table 2.1).

Table 2. 1 : the quantities of raw MSW used for each trial in ton

Trials	Day	Sector 1	Sector 2	Sector 3	Amount collected
Trial	d1	0.60	1.60	1.20	3.4
	d2	0.70	1.50	1.30	3.5
	d3	0.50	1.50	1.10	3.1
Total		1.8	4.6	3.6	10
Trial 2	d1	0.60	1.50	1.20	3.20
	d2	0.63	1.40	1.10	3.10
	d3	0.60	1.40	1.30	3.30
Total		2.1	4.3	3.6	10

2.1.3. Methodology

After receiving the input raw materials, these were spread on the floor and had been subjected to a quartering process two times to obtain a representative sample of about 200 kg/day. Overall, the sample quantity which had been characterized is 600 kg for each campaign, which means 1.2 t for both campaigns. Sieves were then used to categorize the samples into different fractions based on the particles' size: >100, 80-100, 60-80 and <60 mm (Figure 2.2). The samples were then characterized (manual sorting) into different fractions based on the MODECOM standards: organic matter; plastic; paper; cardboard; textile; hygienic products, packaging; metals; glass; and others [3].

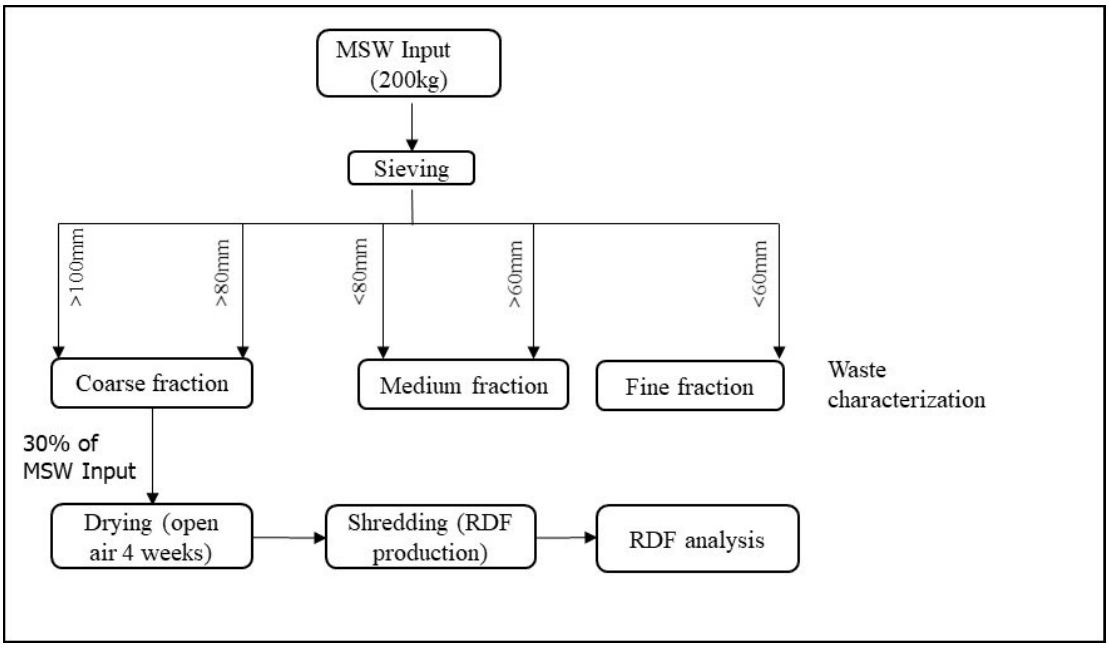


Figure 2. 2:Methodology of the waste characterization and RDF production

After size separation and waste sorting, coarse fractions of >80mm (high calorific materials only; with a low content of organics, hygienic products, metals, etc.) were then subjected to a drying process in an open site area for four weeks. A turning schedule was applied I order to increase the dry matter (DM), which in turn increased the calorific value. Finally, laboratory analysis was carried out in the Laboratory of Rostock University to identify the quality of the final product (RDF). Detailed information about the analysis performed during the study is provided below.

- The determination of the moisture content and the total solid content (TS) was conducted according to DIN 51718 standards. The sample was placed in an oven at 105°c for 24h to 48h. The moisture level was obtained through the following equation:

$$\%M = \left(\frac{wet\ sample\ weight - dry\ sample\ weight}{wet\ sample\ weigh}\right) * 100 \tag{1}$$

The total solid content was obtained through the following equation:

$$\%TS = 100 - \%M \tag{2}$$

- The determination of the ignition loss and the ash content was conducted according to DIN 51719 standards. The ignition loss and the ash fuel of the original sample (OS) and the total solid (TS) were determined by placing the samples in a muffle oven heated up to 550°c for 2h. The ignition loss was obtained through the following equation:

$$\%\ OTS = \frac{(sample\ weigt\ before\ burning - sampl\quad weight\ after\ burning)}{sam\quad weig\quad before\ burning} * 100 \tag{3}$$

The ash content was obtained through the following equation:

$$\%a = 100 - \%\ OTS \tag{4}$$

- Upper heating value was determined according to DIN 5100-DIN EN 15400 standards using a bomb calorimeter. The heating value is usually measured in units of energy per unit of weight: as Kcal $kg^{-1}$and MJ kg^{-1} [1].
- The chlorine content was determined according to DIN 14582 standards.
- Heavy metals (lead, arsenic, cadmium, nickel) were determined according to DIN EN ISO 11885 standards. Mercury level was determined according to DIN ISO 16772 standards.

2.2. POTENTIAL OF RDF UTILIZATION IN THE CEMENT INDUSTRY

A feasible co-processing treatment method depends on the cost of alternative treatment options for the waste streams as well as the price of fossil fuels and raw materials used in the cement industry. In order to be attractive to the cement industry, fuel and raw material costs must be reduced. From the environmental point of view, CO_2 emissions reduction is the main target. For the waste generating industries and municipalities, co-processing can be an attractive option if no other environmentally, socially and financially sound alternative is available. Therefore, the aim of this section is to assess the feasibility of using RDF as a substitute fuel in the cement industry in Algeria from an environmental and economic perspective, by following the previous studies [1, 44], results of the RDF characterization in this study and real data and assumptions that have been obtained from the Mitidja Cement Factory (SCMI) located in the Wilaya of Blida in Algeria, it is one of the public GICA group factories. Constructed in 1975, with a capacity production of one million tons of cement per year. The main fuel used in SCMI is natural gas, 97.08 $Nm^3$is required for the production of 1 ton of clinker. Using the dry process, the cement currently manufactured by this plant is Portland cement with additions of tuff and limestone (CEM II).

Figure 2. 3: Image of the Clinker production line of SCMI (Google Earth)

This feasibility study included an estimation of the CO_2 emissions saving, and the determination of energy saving by replacing gas with RDF. From the economic side, an economic model was proposed. This included five options resulting from adding RDF as a substitute for the fuel currently used in Algerian cement factories, namely natural gas.

- Clinker production: 150 t h^{-1}, 3600t day^{-1}.
- Total energy consumption (natural gas): 97.08 Nm^3 t^{-1} cl, which equals 820.81 kcal kg^{-1} clinker.
- Calorific value of natural gas: 8455 Kcal Nm^{-3}.

- 1 Nm^3 currently cost: 0.015 USD=1.86 DZD.
- CO_2 emissions: 46% of CO_2 is produced from 1t of fossil fuels [73].
- Calorific value of RDF in this study: 16 MJ/kg, which equals to 3820.4 kcal kg^{-1}.
- 1 t of natural gas=833.3 Nm^3 (conditions: pressure= 4.5bar, T°C=19, Density=0.841 kg Nm^{-3}).
- It was reported by [73] that for each 1t of fossil fuel reduced, 0.4 of CO_2 is emitted from the RDF combustion.

Therefore, the next section explains the model adopted in detail. It aims to show the daily energy consumption of gas, gas consumption saving, RDF amount to be substituted, CO_2 emission saving and total cost saving.

(a) Daily energy consumption of gas (Nm^3 day $^{-1}$) = daily production (t day-1) x gas consumption (Nm^3 t^{-1})

(b) Daily energy consumption of gas (kcal day^{-1}) = daily production (t day^{-1}) x 1000 x calorific value of natural gas (kcal kg^{-1})

(c) The annual basic gas price (USD $year^{-1}$) = daily energy consumption of gas (Nm^3 day^{-1}) x 300 x 0.015.

Thus, when RDF is used as a substitute for gas:

(d) The gas consumption saving (Nm^3 day^{-1}) = daily energy consumption of gas (Nm^3 day^{-1}) x substitute rate. The gas consumption saving (kcal day^{-1}) = daily energy consumption saving (kcal day^{-1}) x substitution rate

(e) The RDF amount to be substituted per hour to achieve the required energy (t h^{-1}) = the gas consumption saving (kcal day^{-1})/RDF calorific value (kcal kg^{-1})/1000/24

(f) The rest of the required energy (kcal kg^{-1}) = daily energy consumption of gas (kcal day^{-1})- the gas consumption saving (kcal kg^{-1})

(g) The gas amount per hour to achieve the rest of required energy (t h^{-1}) = the rest of the required energy (kcal day^{-1})/ calorific value of natural gas (kcal kg^{-1})/1000/24

(h) The quantity of RDF needed to substitute 1 t of gas (t) = the RDF amount to be substituted per hour to achieve the required energy (t h^{-1})/gas energy consumption saving (t h^{-1})

(i) When RDF is used, the annual gas saving (t $year^{-1}$) = gas energy consumption saving (t h^{-1}) x 24 x 300

(j) The annual CO_2 emissions from RDF combustion (t $year^{-1}$) = the annual gas saving (t $year^{-1}$) x 0.4

(k) Annual RDF consumption (t year^{-1}) = the RDF amount to be substituted per hour to achieve the required energy (t h^{-1}) x 24 x 300

(l) The annual cost of gas saving (USD year^{-1}) = the annual gas saving (Nm^{3}) x 0.015

(m) The annual RDF production cost (USD year^{-1}) = annual RDF consumption (t year^{-1}) x 24.24

For CO$_2$ emissions, 46% is emitted from 1t of fossil fuel:

(a) The annual CO$_2$ saving in gas amount (t year^{-1}) = gas energy consumption saving (t h^{-1}) x 0.46 x 24 x 300

(b) The total CO$_2$ emissions (in case of co-combustion) (t year^{-1}) = annual CO$_2$ (t year^{-1}) – annual CO$_2$ in gas amount (t year^{-1}) + annual CO$_2$ emissions from RDF combustion (t year^{-1})

(c) The total CO$_2$ saving (t year^{-1}) = annual CO$_2$ (t year^{-1}) – total CO$_2$ emissions (in case of co-combustion) (t year^{-1})

2.3. SELECTION OF RDF TECHNOLOGY PRODUCTION

Waste can be presented in different forms and qualities. The transformation of waste to AF requires certain standards. Some types of waste cannot be used directly as AF, but must pass by a preparation process. This step produces a waste product with defined characteristics that complies with the technical specifications of cement production and guarantees that environmental standards are met.

Figure 2. 4:Waste journey for Co-processing

Pre-processing is usually identified as the step which precedes the co-processing step, where the input waste is sorted to recyclables, materials for recovery, etc… (Figure2.4). The quality of output materials increases as the quality of input materials increases. Waste sorting usually results in a metal, plastic and glass fractions for recycling, together with a large amount of AF. Typically, the aim of waste sorting (pre-processing) is to reduce the amount of waste going to landfill, and to produce high calorific materials for co-processing rather than achieving high recovery rates for recycling.

2.3.1. Key consideration for technology selection

In order to select the appropriate technology and conduct a feasibility study, it is important to determine the required information namely;

- The composition and the quantities of the input waste and percentage of variation influence the dimensioning and the selection of equipment. It is important to find out if there is enough raw material to run a desired process in a reasonable size.
- The moisture content of the input waste should be determined because it affects the mechanical treatment, especially the water balance and the duration of the biological or the physical processes. High moisture content can affect technology choices from wastewater charges to demanding water management and purification.
- The importance of identifying the required output qualities for the equipment, the sorting steps, and technology selection.
- Technology influences amount and share of the fractions
- The importance of creating markets (end-users) for the MBT output fractions if they don't already exist, because producing a high calorific fraction (RDF) becomes meaningless when there is no destination for it.
- The technology selected should adopt to the input waste quality and composition changing, so it should be more flexible.
- Choosing the right process, experienced, and successful supplier are the keys for selecting the appropriate technology.

2.4. EVALUATION OF THE WASTE HEAT FROM THE COOLER OF SCMI PLANT FOR RDF DRYING

Although the cement industry is increasingly using alternative fuels around worldwide, the high-water content of these fuels limits their maximum share in cement plant's fuel mix. However, cost-effective drying technology can extend the contribution of these fuels and change the situation regarding the use of alternative fuels. The high-water content of waste streams such as RDF often limits their use as alternative fuel in cement kilns. By evaporating the water content of RDF prior to combustion, a higher fraction can be used. The idea is to use dryers (fluidized bed dryer) that allow cement plants to use the waste heat from the clinker cooler as a cost-effective means of drying these fuels. The exhaust gases, typically between 120-250°c, can be directly applied in the fluidized bed dryer or via a hot water circuit if large distance has to be covered. In order to dry RDF before combustion in the kiln, it is better to use excess heat from the plant to make the drying process more efficient and cost-effective rather than introducing new source of energy.

2.4.1. Cement production

Cement is produced in two main stages:

1- The production of a semi-finished product known as clinker by firing raw materials (limestone, clay, alumina and iron oxide), which have been finely ground and mixed in well-defined proportions.

2- Cement is manufactured by co-grinding clinker with gypsum (a setting regulator) and possibly other materials, called additives, which may have a similar suitability to clinker in terms of mechanical resistance.

Several types of cements are manufactured. Portland CEMI cements (pure cement without additives, made up of clinker and gypsum) and Portland composite CEMII cements (cements with additions of limestone, blast-furnace slag, etc. ....). The latter represent a significant proportion of the cement manufactured worldwide

2.4.2. Description of the dry process

Clinker manufacturing techniques differ in the number of stages of preparation of the raw material before it is introduced into the firing process. Of course, economic considerations remain paramount in the choice of a manufacturing technique that is in keeping with the nature of the quarry. The manufacturing processes have changed dramatically over the course of this century. Dry clinker manufacturing processes are gradually replacing wet, semi-dry and semi-wet processes. The dry processes are currently the most modern and most efficient clinker production methods.

The manufacture and processing of Portland cement by the dry process involves various stages of physico-chemical transformation, under the action of large quantities of mechanical and thermal energy, as illustrated in Figure (2.5)

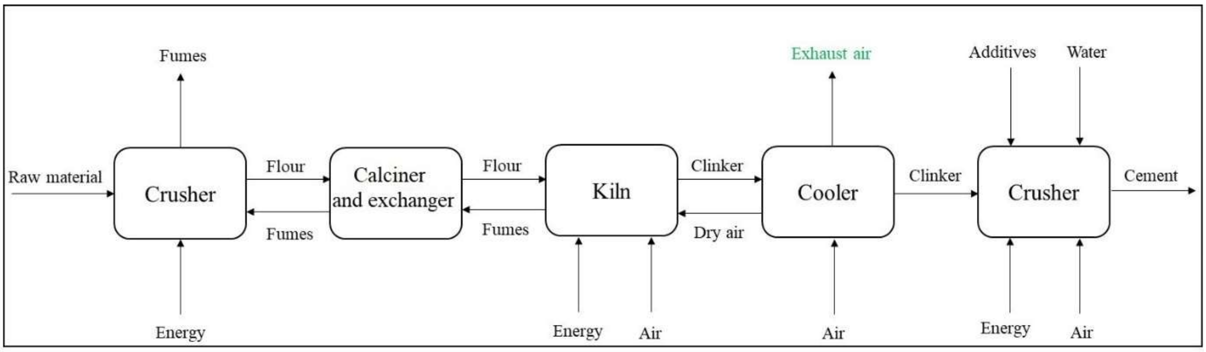


Figure 2. 5: Clinker production line with air and mass balance (dry process)

As the name indicates, this process uses a dry material where the drying stages take place outside the firing system. The recovery of a large part of the calories, contained in the kiln gases, and the absence of dehydration make this method the least voracious in terms of thermal energy consumption.

The development of the dry process was long delayed by the poor quality of the clinker obtained. However, progress in the fine grinding and homogenization of dry mixes now makes it possible to obtain quality Portland cements, which is why the dry process has become more and more widely used in recent decades.

2.4.2.1. Preparation of raw meal

The raw material from which clinker is made is a mixture of natural raw materials of suitable chemical composition. The raw materials extracted from the quarry contain the necessary elements for the production of cement in the right proportions to obtain a quality product. It is therefore necessary to create an optimized mixture of raw materials with the required composition. An intimate combination of the different materials previously crushed and ground must be carried out, so as to have a mixture with uniform chemical and physical characteristics in its mass. A homogenization operation, generally carried out by pneumatic means, makes it possible to obtain a constant property on an industrial production scale. It is carried out in two stages: the pre-homogenization of materials coming directly from the quarries and then the perfect homogenization after crushing of these materials. The preparation of the raw meal consists of making a homogeneous mixture of limestone, clay and possibly complementary materials in proportions that make it possible to obtain a clinker with a chemical composition that respects the limits.

2.4.2.2. Clinker firing

Firing is the process of transforming raw meal into clinker, by means of sufficient heat input, to obtain complete chemical reactions leading to the formation of the main compounds of this semi-finished product (clinkering). The firing process (Figure 2.6) involves:

- a raw meal preheating system
- a part for decarbonation
- a clinkerization section
- a cooler

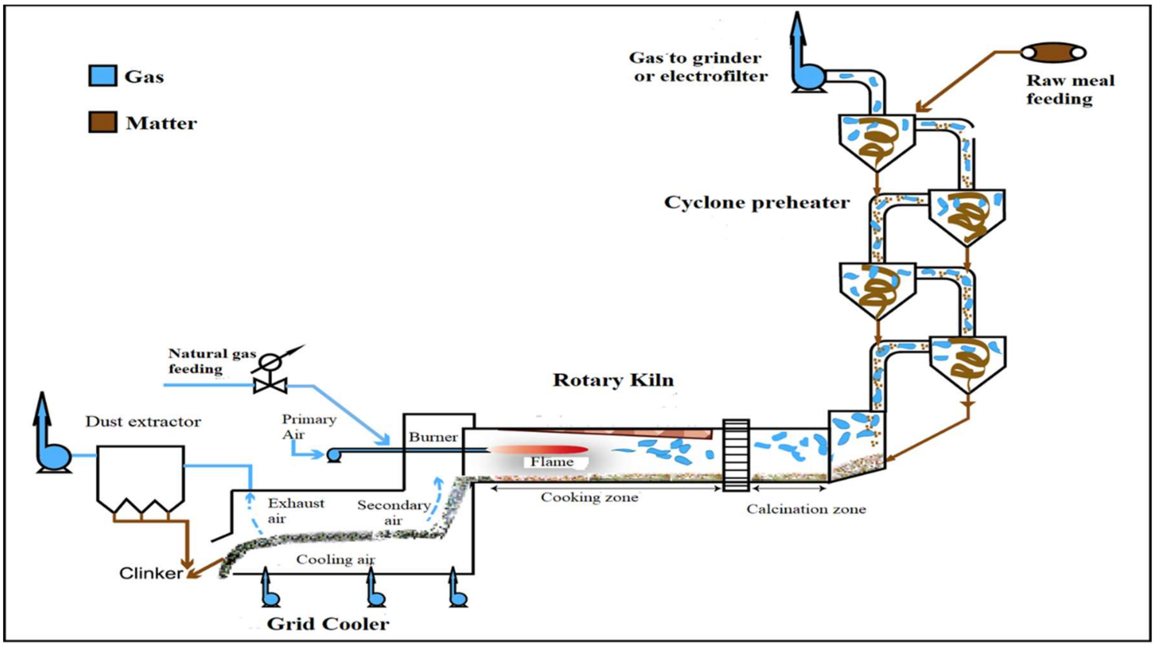


Figure 2. 6 : Example of a dry firing line

Preheating of the raw meal, with a sieve rejection of 160 m (in the order of 1 to 1.5%) and a moisture content of 8 to 9%, takes place in the upper part of the suspension preheater (cyclones). Decarbonation takes place in the lower part of the preheater and the upper part of the rotary kiln. Clinkerization always takes place in the downstream part of the rotary kiln. The hot gases are produced in the kiln by burning coal, oil, gas or any product with a high calorific value. Fans located after the preheater and the cooler convey the gases through these installations. After passing through the preheater, the flour progresses downstream due to the rotation and slope of the kiln. As it travels, the material heats up until it clinkers at around 1400 to 1500°C. On leaving the kiln, the clinker, which is very heterogeneous in terms of grain size (0.1 - 40mm), falls into a cooler where heat exchanges take place, allowing heat recovery and the cooling of the clinker. The clinker essentially comprises the two calcium silicates 3CaOSiO2 and 2CaOSiO2. The aluminium and iron pass, for the most part, as 3CaOAl2O3 and a solid solution of approximate composition 4CaOAl2O3Fe2O3. The proportions of these elements depend on the quarries, the type of cement produced and the firing process.

The alternative fuels can be injected in four different points namely;
(1) Via the main burner at the rotary kiln outlet end;
(2) Via secondary burners to the riser duct at the kiln inlet;
(3) Via precalciner burners to the precalciner;
(4) Via a feed chute to the precalciner (for lump fuel).

2.4.2.3. Clinker grinding

Cement is obtained by grinding clinker granules, with the addition of a small percentage of gypsum (4 - 5%) and possibly one or two secondary constituents. The purpose of cement grinding operations is to increase the reactivity of the clinker, by increasing its specific surface and by creating crystal defects on the surface of the grains. This treatment develops the hydraulic properties of the cement and gives it its rheological properties. The Blaine specific surface area of an ordinary portland cement, with a value of 300 m2/kg or more in the cement industry, is a prime requirement for concrete preparation. The comminution of clinker grains of a given size in a ball mill leads to the production of grains of smaller size by successive fragmentations, produced by the effect of shocks and friction between ball and material.

2.4.3. Introduction of MPS technology in the cement plant

As explained previously, MPS technology uses external thermal energy to dry the waste streams using dryers that use fossil energy as the thermal energy source. However, different studies and experiences in different sectors such as food, biomass and sludge drying use excess heat as the thermal energy source for the dryer.

In this part of the research, a suggestion is made to install an MPS plant with a fluidized-bed dryer in the cement plant to dry the RDF using the excess hot air from clinker production before co-processing in the main kiln burner. The assessment of the impacts of the dryer project is necessary, starting with the technical assessment to address the technical specifications of the technology. Add to that, the environmental benefits of using available heat from the production process in the dryer instead of other heat sources.

The choice of site for the implementation of the MPS plant is an important point, the plant should be near the cement production line in order to use the excess heat as a source of thermal energy for drying the waste.

2.4.4. Waste heat available at the cement plant

In order to utilize the waste heat of the cement plant, it is important to select the different waste heat points to choose the appropriate waste heat source. Waste heat can be generated from different parts of the cement manufacturing process, namely; the clinker cooler.

2.4.4.1. Mass balance

In the cement industry, as in all other industries, the mass balance is based on the conservation of mass. Depending on the purpose and the type of process, the mass balance is characterized by the Input and Output materials in terms of flow, and specific flow or mass.

Mass: expresses the quantity of material introduced or removed from the system in grams (g), kilograms (kg) or tones (t) for solids.

In (L), (m^3) or (Nm^3) for gases.

Flow rate: expresses the quantity of material entering or leaving the system in relation to time, the unit of measurement for the clinker firing line is in t/h for solids and in Nm^3/h for gases.

Solid flow (t/h): $$\dot{m} = m \times T^{-1} \quad (5)$$

Gas flow (Nm^3/h): $$\dot{v} = v \times T^{-1} \quad (6)$$

The specific flow: is a unit of quantification relative to another flow, in our case of the clinker firing line, the specific flow is expressed in (kg/kg cl), or (kg/t cl), for solids. In (Nm^3/t cl) or (Nm^3/kg cl) for gases.

Solids flowrate in (kg/t cl): $$\dot{M} = \dot{m} \times \dot{m}^{-1} \quad (7)$$

- $\dot{m}^{-1}$: the clinker flow rate (t/h)

- $\dot{m}$: Mass flow rate (kg/h)

Gas flow rate in (Nm^3/t cl): $$\dot{V} = \dot{v} \times m^{-1} \quad (8)$$

- $\dot{v}$: Gas flow in (Nm^3/h)

2.4.4.2. Thermal Balance

It is based on and follows the mass balance, in order to carry out an energy profile of a system, adding to the mass flows, their calorific characteristics to have heat flows. The main objective of a heat balance is to highlight the energy consumption in a system, for economic, energetic or environmental interests.

Fuels are characterized by their net calorific value (NCV) or gross calorific value (GCV) in Kcal/kg for solids and Kcal/Nm3 for gases. Non-combustibles are characterized by their calorific value Cp, expressed in our case in Kcal/kg for solids and in Kcal/Nm3 for gases. The calculation of the specific heat quantity is done by the following equations:

For combustible materials: $\dot{Q} = \dot{M}.PCI + \dot{M}.Cp.\int_{T0}^{T} dT$ (9)

For non-combustible materials: $\dot{Q} = \dot{M}.Cp.\int_{T0}^{T} dT \; Q = \dot{M}.Cp.(T - T0)$ (10)

Replacing $\dot{M}$ by $\dot{V}$ in the case of gases.

The exhaust air leaving the clinker cooler is considered to be a waste heat, which can be used for drying the RDF streams. Bellow, is the description of the clinker cooler and the different air mass balances.

a. Clinker cooler of SCMI cement plant

After baking at approximately 1450°C, the clinker leaving the kiln enters a grate cooler to be cooled to 75-100°C. Different operating parameters can influence the energy loss in the clinker cooler process. These parameters are related to the air and the clinker (Flow rate, temperature, pressure, particle size), or to the process (clinker residence time, speed of the grids).

The cooling system of SCMI plant consists of the grate cooler, a heat exchanger and a dust collection system. In order to cool the clinker as it passes through the bed, the cooling air is blown under the bed by a group of cooling fans (8 fans), and sucked over it in two directions by two groups of fans: suction fans for the combustion air and flue gases through the kiln (2 fans), and exhaust fans for excess air through the dust collection system.

The compartment under the bed is divided into 6 rooms separated by walls and each room is supplied with air by its own fan (the first room is supplied by 3 fans). The compartment above the bed is undivided. However, by drawing air from the bed in two different directions through two openings, two zones can be distinguished according to the orientation of the air currents; one zone where the air is directed towards the oven, and a second where the air is directed towards the outside.

b. Air mass balance

The representation of the air circuit is given in Figure (2.6), makes the following different gas streams appear;

AR: Total cooling air flow

SA: Secondary air flow;

AFR: False cooling air flow;

EA: Exhaust air flow;

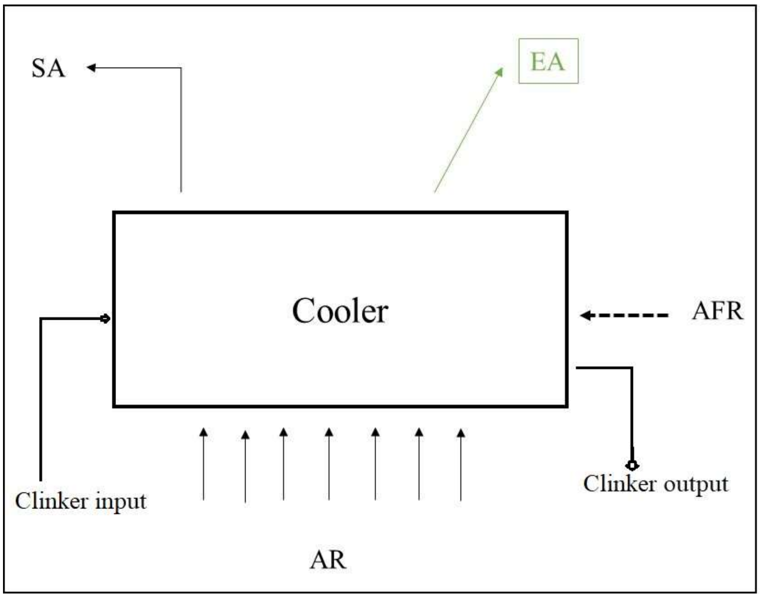


Figure 2. 7: Air mass balance; different air streams

Tables (2.2) and (2.3) gather the DATA of the different input and output flows in the clinker cooler, these DATA were taken from the control room of the SCMI cement plant.

Table 2. 2: Cooler air mass balance (SCMI)

Mater flow	Flow (Nm^3/t cl)	
	Input	Output
AR	2227.85	/
AFR	512.27	/
SA	/	868.73
EA	/	1871.4

c. Air temperature balance

Table 2. 3: Cooler air Temperatures (SCMI)

Mater flow	T°C	
	Input	Output
AF	19	/
AFR	19	/
SA	/	1050
EA	/	170

The exhaust air heat represents 33.79% of the total lost from the clinker cooler and it is calculated as follows;

$$\dot{Q} = \dot{M} \,.\, Cp \,.\, (T - T0) \qquad (11)$$

$$Q = 1.87 \,.\, 0.33 \,.\, (170 - 19)$$

$$\dot{Q} = 93.18 \text{kcal/kg } ^\circ\text{C cl}$$

The total clinker production per hour is 150 t, therefore; the total energy of the exhaust air getting out from the cooler is:

$$\dot{Q} = 93.18 * 1000 * 150 \qquad (12)$$

$$\dot{Q} = 13\,977\ 10^3 \text{ kcal/h}$$

$$\dot{Q} = 58\,423\,860 \text{ kJ/h}$$

2.5. EXPERIMENTAL STUDY ON RDF DRYING AT THE LAB SCALE

The moisture content parameter plays a crucial role in the design and process optimization of thermal utilization or compaction of the RDF. The presence of moisture has a great influence on the calorific value of the fuel, and therefore has a great influence on the possibility of heat treatment [74]. For example, for a cement kiln, humidity cannot exceed 15% [75]. It has been proved that thermal drying to reduce the moisture is an effective [76]. In many branches of industry, drying plays a vital role: food industry, agriculture, paper industry. There are many methods of drying available: contact, convection, microwave, radiation, dielectric and others [77]. Drying involves removing moisture from the material by evaporating water while providing heat to the process. The most common and simplest method is drying by convection using gas, usually warm air, as a drying medium. In this process, the transport of heat and mass from the interior of the material to its surface is carried out by diffusion, and further on into the surrounding atmosphere by convection [74].

There are articles about drying of paper, paper sludge [78], textiles [79], or food waste [80]. These studies focused on drying kinetics analysis, drying curves analysis, determination and calculation of the Effective moisture diffusivity (Deff) and Activation energies (Ea) in terms of variable factors (i.e. drying temperature, air velocity, initial moisture). However, the literature on RDF drying is rarely mentioned. The purpose of this study is to observe the influence of different temperatures on the kinetics of RDF drying during convective drying.

2.5.1. Laboratory scale dryer (fluidized bed dryer)

The drying tests were carried out in a laboratory-scale hot-air wind tunnel which is similar to an FBD (Figure 2.7), this wind tunnel is a kind of convective tunnel dryer and whose constitutive elements are:

- an air compressor to provide airflow at a flow of 20 m^3/h,

- a set of heating resistors to heat the flowing air,

- thermometer to control the temperature,

- a balance to record the measured weight instantaneously,

- a test section equipped with a perforated grid on which a single layer of the product to be dried is exposed,

- temperature and humidity sensor linked to an Arduino UNO card,

-Computer.

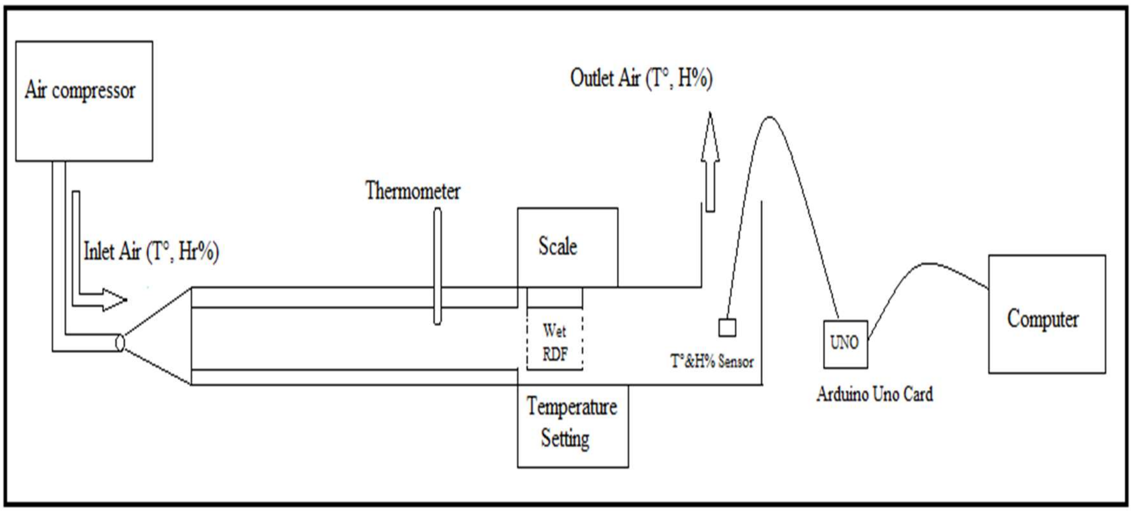


Figure 2. 8 : Experimental FBD for RDF drying at the laboratory scale

2.5.2. Drying procedure

The same RDF samples produced from MSW of the Wilaya of Blida were taken for this test, it had an initial moisture content of 40%, it was determined by drying in an oven at 100 °C until constant weight was obtained.

The RDF samples (40g for each experiment) were placed in a test section and had been dried at temperatures of 40, 50, 75, 90 °C and a constant air flow of 20 m^3/h. The loss of the samples mass was measured in a continues manner until the equilibrium moisture content was reached. The drying velocity was extracted from the drying curves for each Temperature.

Before each experiment, the temperature, and flow of the drying air were fixed and measured directly in the tunnel without the sample. The temperature was fixed using a heat generator (RFT SPARSTELL TRAFO, Type LSS 010, Germany). The air flow was measured using flow meter (URSAFLUX , VEBMLW PRUFGERATE-WERK? Type GF 4020031, Germany). The Temperature and Humidity of the Inlet and Outlet air were measured using sensors linked to and Arduino UNO card which in turn linked to a computer to register instantaneously the temperature and Humidity.

Once the fixed drying temperature was reached, the test section containing the sample was placed inside the dryer. The progressing of the drying process was followed by weighting the test section with the sample at regular intervals of 5min using a digital balance (NAGEMA, Type 34.004, VEB Wagetechnik Rapido, Germany). Drying procedure was continued until there was no weight change for three successive readings.

2.5.3. Amperic and semi-amperic modeling of drying curves

Six simplified drying models given in table (2.4) have been used to describe the drying kinetics of RDF. in these models, MR represents dimensionless moisture ratio expressed by the following equation:

$$MR = \frac{Mt-Me}{M0-Me} \qquad (13)$$

Where M_t is the moisture content at time t, and M_0 and M_e the initial and equilibrium moisture contents, respectively, on dry basis. M_e is relatively small compared to M_t and M_0. Thus, MR can be simplified to:

$$MR = \frac{Mt}{M0} \qquad (14)$$

Table 2. 4: Amperic and semi-amperic models applied to drying curves “Slomka., et al., 2018”.

Model name	Model
Newton (Lewis)	$MR= \exp(-k\ t)$
Page	$MR= \exp(-k\ t^{n})$
Handerson and Pabis	$MR= a \exp(-k\ t)$
Logarithmic	$MR= a \exp(-k\ t) + c$
Diffusion approach	$MR= a \exp(-k\ t) + (1-a) \exp(-k\ b\ t)$
Midilli et al	$MR= a \exp(-k\ t^{n}) + b\ t$

The non-linear regression analysis was performed using STATISTICA software (version 8, Statsoft, USA) to fit the experimental data to select mathematical models. The coefficient of determination (R^2) is one of the primary criteria in order to evaluate the fit quality of these models. In addition to R^2, reduced chi-square (χ^2) and root mean square error (RMSE) are used to determine suitability of the fit. χ^2 and RMSE are calculated as follows ;

$$\chi^2 = \frac{\sum_{i=1}^{N}(MRei-MRpi)^\wedge 2}{N-Z} \qquad (15)$$

$$\text{RMSE}= [\frac{1}{N} \sum_{i=1}^{N}(MRei - MRpi)\hat{}2]\hat{}\,\frac{1}{2} \qquad (16)$$

Where MR_{ei} is the ith experimental moisture ratio, MR_{pi} is ith predicted moisture ratio, N is the number of observations and Z is the number of constants in a model.

The higher the R^2 values and the lower the χ^2 and RMSE values, the better are the goodness of the fit [74].

Let us note that, in all cases, the fit of the tested mathematical models to the experimental data was evaluated by taking the final content moisture of each drying experiment approximately equal to 15%, which is the accepted moisture content of RDF in the cement industries.

CHAPTER 3

RESULTS AND DISCUSSION

3.1. MSW CHARACTERIZATION

Identifying the composition and the quantity of waste helps to determine the type of collection system and the appropriate treatment to be selected for each type of waste – recycling, composting, incineration or landfill. It can be used to calculate the capacity of the treatment plants as well as the equipment needed. As mentioned previously, waste characterization was based on the MODECOM method (Method of characterization of the household waste, the protocol recommended by ADEME (in France). However, the results obtained demonstrate that more than 50% of the municipal solid waste generated in the area studied was organic in both trials. Figure (3.1) shows the composition of MSW of the first trial, and Figure (3.2) shows the MSW composition of the second Trial.

The MSW composition of the first trial consisted of organic matter (57%), paper (3,47%), cardboard (4%), plastics (8,7%), plastic film (8%), glass (0.9%), textiles (2.8%), packaging (1.92%), metals (0.98%), hygienic products (11.5%) and others (0.7%).

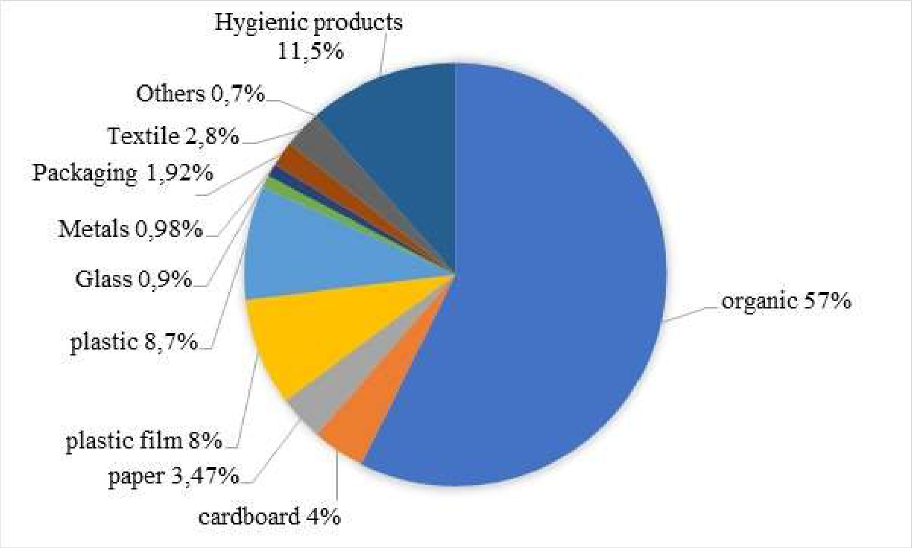


Figure 3. 1 :MSW composition of the first Trial

The MSW composition of the second Trial (Figure 3.2) consisted of organic matter (51.5%), paper (4.7%), cardboard (7.7%), plastics (8%), plastic film (11%), glass (0.5%), textiles (3%), packaging (2%), metals (3.6%), hygienic products (7.9%) and others (1.05%).

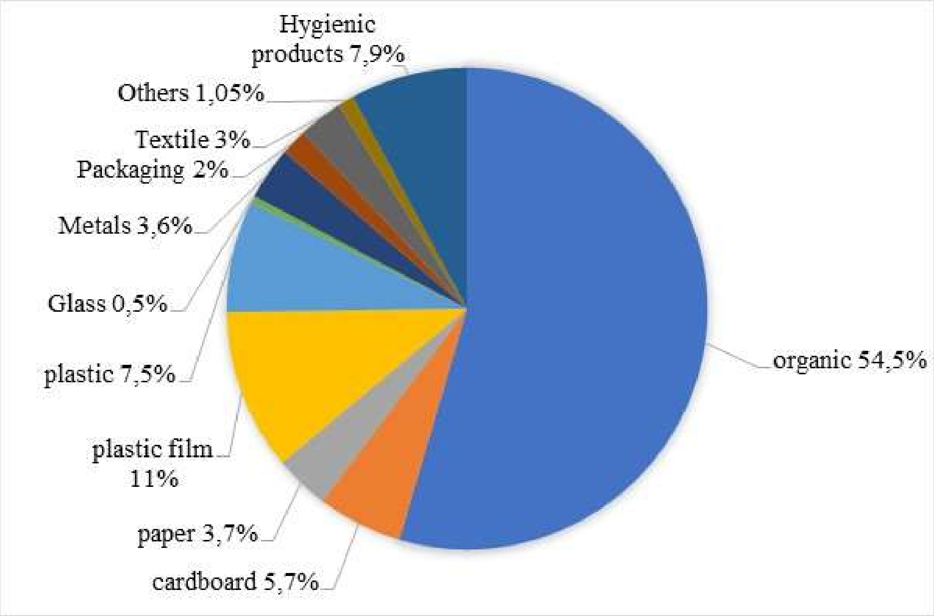


Figure 3. 2:MSW composition of the second Trial

Furthermore, the overall waste composition of the Wilaya of Blida was investigated (Average of MSW composition of both Trials), Figure (3.3). The overall waste composition consisted of organic matter (55%), paper (3%), cardboard (5%), plastics (8%), plastic film (10%), textiles (3%), glass (1%), packaging (2%), metals (2%), hygienic products (10%) and others (1%).

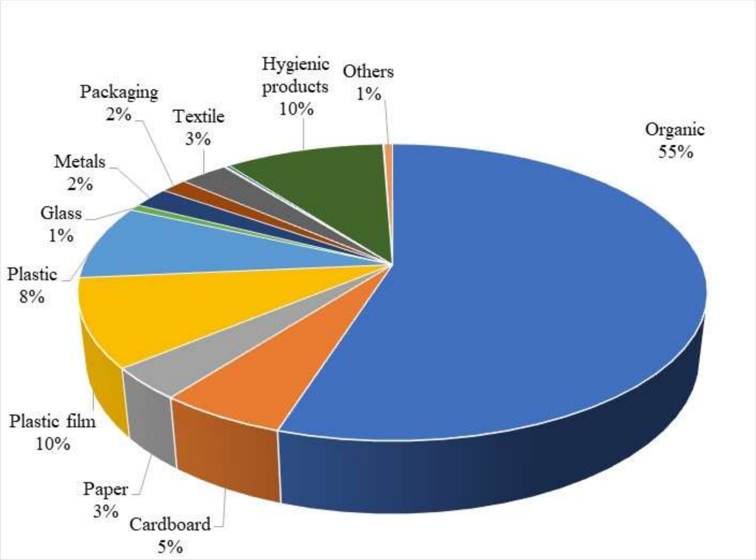


Figure 3. 3:MSW composition of Blida (Algeria)

The findings showed that Blida's waste has typically the same composition as developing countries in terms of the large volume of organic matter, paper and plastic, which reflects the similarity of the lifestyle and consumption behaviour.

3.1.1. Size distribution of MSW

The findings of the research experiments revealed that most of the fresh waste was <60mm, which was found to be around 43% Figure (3.4). The coarse fraction >80 and > 100mm represented 49% of the total fresh waste size distribution, while the medium fraction 60–80mm represented 8%. Around 30% of the coarse fraction waste could be recovered as materials with high calorific value (paper-cardboard, plastic, textiles) in order to produce RDF.

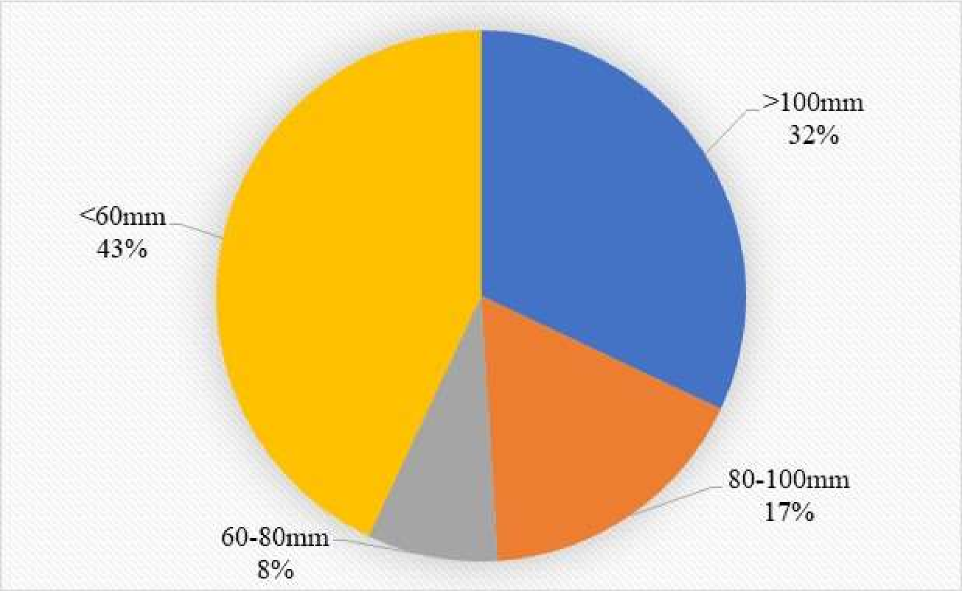


Figure 3. 4:Size distribution of municipal solid waste investigated

The sorting analysis of the fresh waste found that about 75% of the fine fraction (<60 mm) was organic matter. Examination of the other fractions' composition found that about 45% and 23% of the total organic matter was included in the 60–80 mm and 80–100 mm fractions, respectively. Only 8% of the organic matter was included in the waste fraction of >100mm Figure (3.5). As for the solid waste fraction, this ranged between 80–100 mm. The results showed that the overall waste composition consisted of organic matter (23%) and combustible material (49%), while the rest accounted for 28% and contained hygienic products and inert materials.

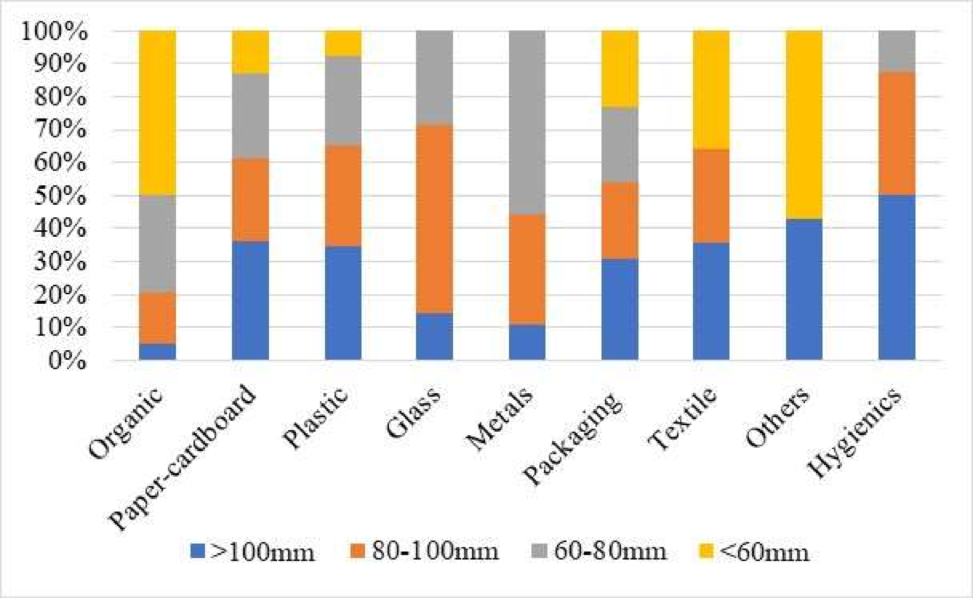


Figure 3. 5:Composition of each fraction of waste

Combustible materials within the waste fraction of >100mm accounted for about 59% (plastic 36%, paper-cardboard 14%, packaging 4% and textiles 5%). The other non-combustible fractions were glass (1%), metals (1%) and others (3%). Overall, the results revealed that 59% of waste fraction > 100 mm and 49% of waste fraction 80–100 mm can be recovered as a substitute fuel (RDF).

3.1.2. Characterization of the coarse fraction >80mm

After the drying process, 30% of the input waste was found to be >80mm Figure (3.6). It was clearly apparent that the major combustible materials of the RDF were plastic film (19%), plastic 3D (15%), cardboard (7%), paper (7%), textiles (5%) and packaging (4%).

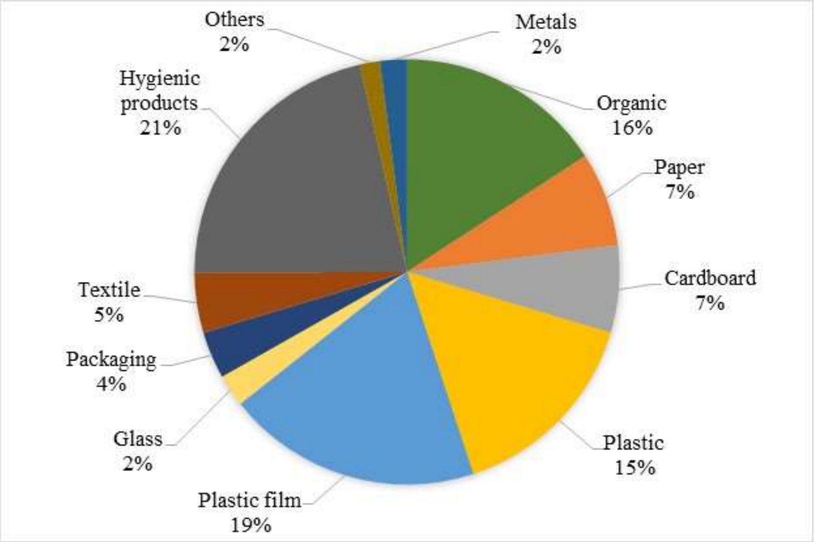


Figure 3. 6: Average composition of the coarse fractions of more than 80mm

The remaining 41% comprised organic (16%), hygienic products (21%), metals (2%) and glass (2%). Note that these materials are considered to be impurities and non-combustible materials and can be further reduced by an optimized sorting of waste.

3.2.3. Chemical analysis of the RDF

In order to use any alternative fuels in the cement industry, it is obligatory to identify the chemical properties of the substitute fuel produced (RDF). The fuel's energy content (low heating value), ash content, moisture, volatile matter content, chlorine content and heavy metals concentrations are the most important parameters that should be deeply examined when introducing a new alternative fuel in place of a traditional one that is already used (fossil fuel). Table (3.1) shows the results of the basic properties of the RDF produced from the MSW. At the end of the drying process, all of the collected RDF samples were subjected to a comprehensive analysis program performed at the laboratories of Rostock University.

Table 3. 1:Chemical properties of RDF from MSW of the study area

Parameter		Trial 1	Trial 2	Average
Water content (%)		12.2	14.2	13.2
Dry matter (%TS)		87.8	85.8	86.8
Ignition loss (%OS)		74.6	85.13	79.86
Fuel ash (%OS)		13.2	14.87	14.03
Upper heating value (MJ Kg^{-1}of TS)		17.07	18.12	17.59
Lower heating value (MJ Kg^{-1}of TS)		15.19	16.79	16
Chlorine (%TS)		0.37	0.8	0.58
Heavy metals (Mg Kg^{-1}TS)	Pb	30	15.3	22.65
	As	<1	<1	<1
	Cd	0.18	<0.4	0.29
	Ni	3.7	7.7	5.73
	Hg	<0.1	0.27	0.18

TS: Total solid content, OS: Original sample.

Dry matter (DM) was increased by 54% to reach 87% after four weeks and, therefore, there was no need for extra heat energy to evaporate the water in the waste. This increase was offset by an increase in the low heating value (LHV) by 66% to reach on average 16 MJ Kg^{-1}. This value of LHV reflected the physical composition of RDF, which was mainly composed of high calorific materials (plastics, paper-cardboard, textiles) and the absence of organic matter which is responsible for decreasing the LHV because of its high moisture content. The ash content of the RDF samples appeared to be in low ranges between 13.2% and 14.87%. Chlorine is also a limiting parameter for RDF quality. It is considered to be a source of acidic pollutants and causes the formation of dioxins. It is usually related to the content of PVC and plastic in the waste. In this study, it was in the range of 0.37% to 0.8% [81].

Overall, the RDF produced was of high calorific value, with low moisture and acceptable chlorine content (0.37–0.80% w w^{-1}), which made it a viable and environmentally sound option as a substitute fuel to be utilized in the cement industry in Algeria.

Regarding the heavy metals concentrations, all of the samples collected showed various concentration, however; they were below the limits set by European countries standards (Table 3.2).

Table 3. 2:Comparison of the Heavy metals content of the RDF produced in Blida with the limit value of different European guidelines integrated in the CEN/TC 343 standardization [82].

Parameter	Germany (BGS,2008)		Switzerland (BUWAL,2005)	Austria (AVV,2011) Co-incineration in cement kilns		Blida
	Median (mg kg^{-1} TS)	80th percentile (mg kg^{-1} TS)	Average (mg MJ^{-1} TS)	Median (mg MJ^{-1} TS)	80th percentile (mg MJ^{-1} TS)	Average (mg kg^{-1} TS)
Pb	190	400	8	20	36	22.65
As	5	13	0.6	2	3	<1
Cd	4	9	0.08	0.23	0.46	0.29
Ni	80	160	4	10	18	5.73
Hg	0.6	1.2	0.02	0.075	0.15	0.18

Conversion: Pollutant content [mg MJ^{-1}] = Pollutant content [mg kg^{-1} DM]/Net calorific value [MJ kg^{-1} DM] [83].

Overall, the findings of the experimental research demonstrate that RDF derived from mixed municipal solid waste in the Wilaya of Blida is one of the most viable treatment options and should be considered when planning to introduce an integrated solid waste management system in Algeria.

3.2. POTENTIAL OF RDF UTILIZATION IN THE CEMENT INDUSTRY

Table (3.3) summarizes the calculations following the model above for different substitution rates.

Table 3. 3: The economic model for the savings associated with RDF and natural gas

parameter	Unit	Case 0	Case 1	Case 2	Case 3	Case 4
Gas substitution rate	%	100	90	85	80	70
RDF substitution rate	%	0	10	15	20	30
Gas consumption	$Nm^3\ h^{-1}$	14 562	13 106	12 378	11 650	10 193
Gas consumption	$t\ h^{-1}$	17.47	12.95	12.25	11.51	10.07
Gas saving	$t\ h^{-1}$	0	4.52	5.22	5.96	7.4
RDF consumption	$t\ h^{-1}$	0	3.18	4.7	6.36	9.55
RDF rate to substitute 1 tonne	-	0	1:0.7	1:0.9	1:1.06	1:1.29
CO_2 produced from RDF combustion	$t\ h^{-1}$	0	1.8	2.08	2.38	2.96
Annual CO_2 produced from RDF combustion	$t\ year^{-1}$	0	13 017.6	15 033.6	17 167.8	21 312
RDF production cost	USD $year^{-1}$	0	572 400	846 000	1 144 800	1 719 000

Gas saving	Mio Nm^3 $year^{-1}$	0	27.1	31.3	35.7	44.4
Gas cost saving	USD $year^{-1}$	0	406 500	469 500	535 500	666 000
CO_2 emissions saving in gas	t $year^{-1}$	0	14 970.24	17 288.6	19 739.52	24 508.8
Total CO_2 emissions in case of co-combustion	t $year^{-1}$	57 860.64	55 908.24	55 605.64	55 288.92	54 663.84
Total CO_2 savings in case of co-combustion	t $year^{-1}$	0	1 952.4	2 255	2 571.72	3 196.8

From a net cost savings point of view, based on the above calculations. the option 2 achieved 469 500 USD annual gas cost savings after adding 33 840 t $year^{-1}$ of RDF to the traditional fuel, while the current cost of using gas on an annual basis is about 1 572 700 USD. From the CO_2 emission side, and taking into account the CO_2 saved from the gas consumption reduction, and the CO_2 from the RDF combustion, it was found that around 2 255 t $year^{-1}$ are saved while using 15% of RDF as a substitute fuel for natural gas. The RDF production cost in this case was around 846 000 USD $year^{-1}$.

The RDF production cost was not taking into account when calculating the net cost saving in this study because, it is proposed in this study that the municipality will be the responsible for the RDF production as an alternative for the waste landfilling. In this case, the cement industry will not pay for using RDF in its kiln, especially if we take into account that the fossil energy cost in Algeria is very cheap. However, still the RDF utilization instead of fossil fuel is a good option to contribute to the environment protection by reducing the CO_2 emissions and the waste quantities for landfilling.

3.2.1. Gas consumption and CO_2 emissions savings

The main source of emissions (NO_x, SO_x, CO_2) is the clinker combustion process, which is also the main energy consumer. The calcination process produces CO_2 gas. Thisis a by-product of a chemical conversion process in which limestone (calcium carbonate, ($CaCO_3$) is heated at a temperature of about 1300°C to form lime (i.e., calcium oxide, CaO) and CO_2 which will be released into the atmosphere [18].

For the clinker combustion process, large quantities of fossil fuels are used, which in turn are responsible for a large part of the CO_2 emissions. One of the main objectives of using alternative fuels in cement plants is to reduce the fossil fuels consumption, thus reducing CO_2 emissions. Figure (3.7) shows the results of the CO_2 emissions savings according to the reduction of Natural gas consumption.

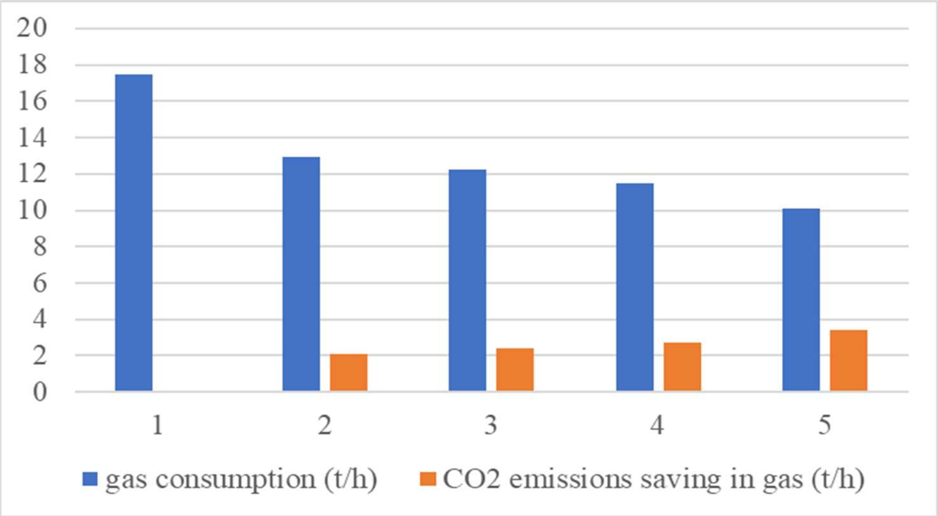


Figure 3. 7:CO_2 emissions savings according to the gas consumption.

It is clear from Figure (3.7) that reducing gas consumption by replacing a part of it with alternative fuels will lead to an increase in CO_2 emissions savings associated with natural gas, which confirms the previous studies on the environmental benefits of the co-incineration [23, 24].

3.2.2. Gas savings and CO_2 emissions in case of co-combustion for the different substitution rates

In parallel, Figure (3.8) shows the compatibility between the Gas and CO_2 emissions savings in case of co-combustion.

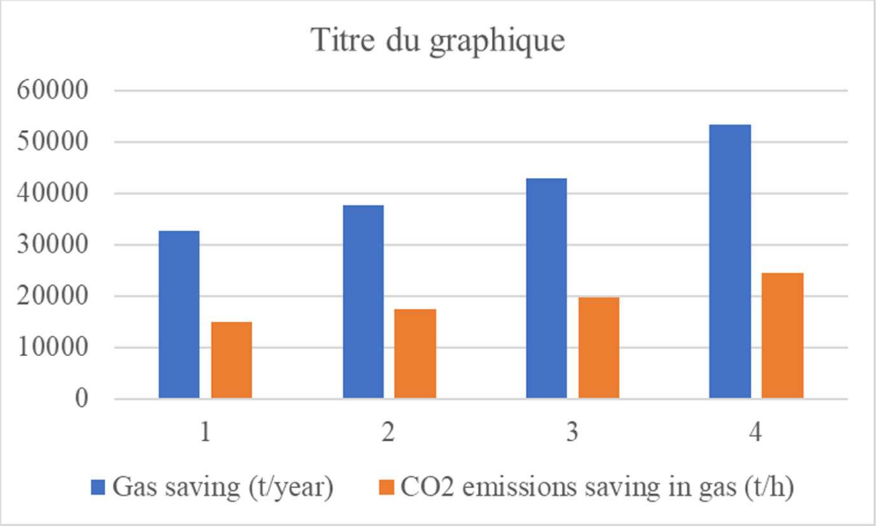


Figure 3. 8: CO_2 emissions savings according to the gas saving

As previously confirmed, in case of co-incineration and when replacing a part of natural gas with alternative fuels, this will result in an increase in gas consumption and thus an increase in CO_2 emissions savings [25].

3.2.3. Gas and RDF consumption in case of co-combustion for the different substitution rates

Several studies have shown that the main objective of using alternative fuels to in the cement industry is to replace a part of the fossil fuels and reduce their consumption [23, 24, 25]. Figure (3.9) shows the relation between the RDF and the gas consumption.

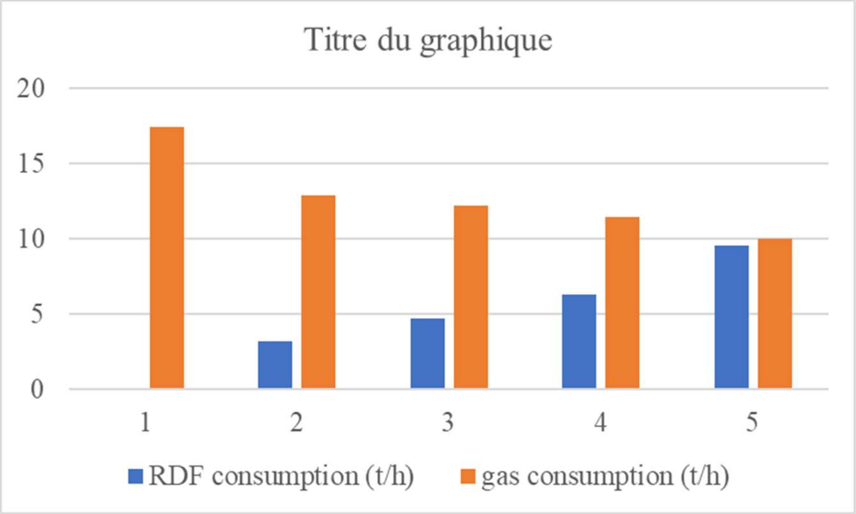


Figure 3. 9: Relation between the RDF consumption and gas consumption

The RDF consumption depends on its calorific value and the substitution rate. It is obvious from Figure (3.9), that the relation between RDF and Gas consumption is an inverse relationship. Replacing part of natural gas with RDF will result in a saving in gas consumption and an increase in RDF consumption depending on the substitution rate.

When replacing a part of natural gas with RDF, many factors should be taken into consideration such as the calorific value of fuels, environmental and economic benefits. This demonstrates the importance of following this type of waste treatment method (co-incineration) rather than the traditional methods.

It was reported by the [84], that the financial organization along the value chain is not easy. Local authorities expect to sell the waste to cement plants and earn money, while the cement plants expect to be paid for using RDF in their kilns, which often leads to misunderstanding and difficulties in communication. Both sides require common knowledge of the financial implications of the application of co-combustion as a long-term option for sustainable waste management, rather than a short-term solution. Conversely, municipalities responsible for waste management must guarantee the availability of waste for a minimum of ten years, and it must meet the properties required by the cement industry.

3.3. SUSTAINABLE SWM; CHALLENGES AND SOLUTIONS

SWM faces many challenges around the world and particularly in developing countries such as Algeria. Most of the challenges are related to the country policies, and to the division of labour of each organization or administration. Financing is also a limiting parameter, if this sector is not adequately financed, this will affect the behaviour of other sectors responsible for waste management. All these parameters together have a direct effect on the environment, as it is influenced by everything that is deposited and managed (from waste) inappropriately. Table (3.4) brings together the most well-known challenges in waste management and proposes solutions for sustainable solid waste management for a country like Algeria taking into account the existed legislation, organizations, and the financing system, by enforcing and introducing the co-processing of waste as one of the solutions that Algeria should adopt. Waste management is a complex and costly process. The proposed solutions, government support, and financing projects in this regard must compete with other priorities such as clean water, education, and health care.

Table 3. 4: Proposed solutions for the challenges facing the SWM

Challenges	Solution
Legislation, Politic, laws…	- Enforce the sectors concerned in the waste management field to adopt the appropriate technologies which is beneficial for the country's policy by laws, taxes, … - Adoption of circular economy concept
Organizational, administration level…	Division of labour, serious work, guiding
Financing	Special budgets, fond, taxes, EPR (Extended Polluter Responsibility) system
Technical	Appropriate technologies for better waste valorization and reuse (MBT, MPS, co-processing…etc.)
Environmental	Environnement protection, limits, standardization (emissions and sol control)

3.3.1. Recycling and valorization

Waste utilization and recycling refer to any industrial processing activity that aims to reuse, recycle or composting from waste. It usually takes the form of one of the following activities: processing residues or by-products into raw materials, using waste finished or semi-finished products as raw materials or energy, using waste materials at the manufacturing process stage, and adding waste materials to the finished product. The value of waste considers the treatment of a large number of wastes and by-products related to production. These wastes and by-products are different from household waste because they are more homogeneous and larger in quantity [85].

Recycling, reuse, and recovery industry does not represent an important share in the waste management strategy in Algeria. the share of waste recycled in general is less than 7% and composting less than 1%. Ferrous heavy metals are the most important recovery stream 628,915 t/year of ferrous metals, followed by 108,396 t/year of paper and cardboard. More than 4813 employees are involved in the MSW collection and treatment in which; 345 collectors of health care waste, used oil, batteries, and used tires. In addition, there exist 240 operators in plastic waste, 210 operators in paper-cardboard, 171 operators in wood, and 128 operators in glass [86].

As an immediate response for a sustainable waste management in Algeria, it is essential today to:

- Recycle, repair and reuse materials used by both households and industry, rather than landfilling after use.
- The adoption of circular economy concept is also a key and was reinforced in the objectives of the sustainable development (ODD), which establishes the sustainable consumption and production patterns, to "do more and better with less" with the target of halving the amount of food waste per capita worldwide by 2035 and significantly reducing waste generation through prevention, reduction, recycling and reuse.
- Launch major operations on the selective collection of organic flows, paper and cardboard, metals, glass, batteries and other waste to encourage sorting at source.
- Encourage private sector investment in the construction of transfer, sorting, composting and recycling centers.
- Upgrading existing landfill sites to international standards.

The need for significant investment in new technologies, capital mobilization, expertise and professional public-private operators, as part of the new business model in order to ensure high quality of recycling, eliminate landfilling, and limit the energy recovery to non-recyclable materials. This can be developed as a solution at a short to medium term.

3.3.2. Circular economy concept

Circular economy is an economic system that aims to eliminate waste and the continual use of resources. The recycling system uses reuse, sharing, repair, refurbishment, remanufacturing and recycling to create a closed loop system that minimizes the use of resources and the generation of waste, pollution and carbon emissions. Circular economy aims to make products, equipment and infrastructure last longer, thereby increasing the productivity of these resources. Waste and energy should be inputs to other processes: as part of another industrial process or recycled resources, or as natural renewable resources (such as compost). This regeneration method contrasts with the traditional linear economy, which has a production model of "acquisition, manufacture, and disposal [87].

The adoption of the circular economy concept needs to connect the key actors in the waste value chain to promote waste recovery in a broader circular economy context, with the aim of finding sustainable solutions to the challenges of waste management in a country like Algeria. The transition to the circular economy concept can be done by:

- Connecting stakeholders and improving information flows for better coordination and collaboration,
- Providing a space to encourage citizens to refuse, reduce, reuse, and recycle,
- Providing scientific data and tools for planning and investment,
- Facilitate new types of collaboration between research and the private sector for the development and testing of innovative solutions,
- Demonstrate the economic, social and environmental benefits of business models for sustainable waste recovery.

3.3.3. EPR system

The Extended Polluter Responsibility (EPR) concept is an economic instrument to encourage the producers to take the financial and material responsibility of waste. EPR completes the Polluter Pays concept, it consists on analyzing the product life cycle and guarantee the non-pollution given by the producer to the consumer. The producer provides the consumer with the means to dispose of the waste in a controlled manner.

The main actor in the EPR concept is the producer/ marketer because it is responsible for the design of the product, the choice of materials, the method of manufacture and use, and the collection at the end of the product's life. Other actors have an important role in this EPR system namely; waste preservers, local authorities, and the final waste holders/ consumers.

EPR consist on adding all of the environmental costs associated with a product throughout the product life cycle to the market price of that product.

3.4. ROAD MAP OF AN MBT IMPLEMENTAION IN ALGERIA

As in many developing countries, Landfilling is the most common treatment method for MSW in Algeria. The MSW composition is characterized by a large fraction of organic materials, a lot of plastic, and low calorific value, however; still landfilling the unsuitable treatment method due to the no use of raw materials, and the high environmental pollution due to the gas emissions and leachate. In addition, huge lands are required for landfills construction.

For decades, developed countries have begun to use alternative waste disposal methods of waste rather than landfilling like; incineration, WtE, and MBT. Incineration is widely used for waste treatment, (disadvantages; high environmental pollution due to emissions (dioxin), low acceptance in the population, high investment cost, fossil energy consumption)

MBT and MPS seem to be appropriate waste treatment methods, which have high acceptance among the population, use of raw materials for recycling and energy recovery, and it contributes in minimizing environmental pollution.

In order to introduce MBT technology, many conditions should be taken into account namely;

3.4.1. Infrastructural conditions

The MBT plant can basically be implemented at any site; the best case is to be set up at location accessible to roads and transportation network, and close to areas where waste is generated or deposited. For waste components rich in organic matter, the shortest distance to the nearest disposal area is required to avoid any potential hazards caused by odors, insects and other disturbing factors.

3.4.2. Climatic conditions

The climatic conditions in any area where the MBT is set up will not affect the operation of the MBT plant, in fact, these conditions should be considered in the technical settings. Being exposed to high temperatures or excessive moisture, the operation of open rotting techniques for biological treatment is subject to some restrictions. This can be avoided by covering with semipermeable membranes, in the other side; in case of excessively high temperature, an additional heating system can be used to accelerate the biological treatment of the anaerobic digester.

3.4.3. Availability of raw material (MSW) in Algeria

Before considering the implementation of an MBT plant in any region, it is necessary to investigate the amount of waste generated, the collection rate and its composition. It is recommended that the plant only receives MSW and commercial waste.

There are many different forms of MBT, and the technology proposed in this study involves the mechanical separation of waste, shredding than drying to produce recovered fuel (RDF). It will be then transported to the cement industry for co-processing. The process can also recover metals, glass, paper, and etc. Our suggestion is to implement an MBT plant near the cement industry or implement an MPS within the cement industry.

Our research focuses on the locations where the Cement plants are implemented. There are 17 cement plants in Algeria, located in different regions of the country and different 17 Wilayas. The quantity and quality of waste generated by these Wilayas vary according to population, climatic conditions and citizens' lifestyle. However, our estimation of waste generation and composition are based on the national level. In fact, for the waste generation estimation, the national rate (0.9Kg/capita) has been considered to calculate the waste generation in each Wilaya. Table (3.5) summarizes the population of the different Wilayas, and the amount of MSW generated by each Wilaya every year.

Table 3. 5: Population and waste generation in each Wilaya where the cement plants are located (fr.db-city.com)

Cement industry	Wilaya	Population	Waste generation (t/year)
Cement and derivative materials (ECDE)	Chlef	1 130125	371 250
Cement company (SCT)	Tébessa	648 705	213 160
Cement company of Beni saf (SCIBS)	Ain temouchent	382 890	125 925
Cement company of Hadj Soud (SCHS)	Skikda	898 680	295 285
Cement Company of Hamma Bouziane (SCHB)	Constantine	947 712	311 345
Cement company of Mitidja (SCMI)	Blida	1 002 936	329 595
Cement company of Sour Elghozlane (SCSEG)	Bouira	695 585	228 490
-Cement company of Zahana (SCIZ) - Lafarge cement plant Oggaz (Grey) -Lafarge cement plant Oggaz(white)	Mascara	768 301	252 215
Cement company of Ain elkbira (SCEAK)	Sétif	1 489 495	489 465
Cement company of Ain touta (SCIMAT)	Batna	1 122 384	368 650
Cement company of the Algerian (SCAL)	Algiers	3 136 582	1 030 395
Cement company of Saida (SCIS)	Saida	332 556	109 500
Cement company of Sigus (SCS)	Oum El Bouaghi	621 614	204 400
Lafarge Msila cement plant	Msila	990 592	325 580
-Biskria Cement company -Djemorah cement plant (CILAS)	Biskra	721 356	236 885
Adrar Cement plant	Adrar	399 712	131 400
Amouda Cement	Laghouat	455 602	149650
Total		**15 744 826**	**7 442 945**

The overall population in Algeria is estimated at around 43 million inhabitants, spread over 48 Wilayas. It is unevenly distributed over the territory; indeed, the population is mainly concentrated within 250 km of the Mediterranean coast. Beyond 250 km south of the coast, the population is scarce, except in few towns that correspond to oasis.

12 Wilayas with a density of less than 20 inhabitants per km^2 including; Laghouat, and Adrar. The other 36 Wilayas all have a density of more than 20 inhabitants per km^2 and they are all located in the northern part of the country, representing 11% of the total surface area and gathering 87% of the total population. Among these Wilayas; the highest densities are found around the large agglomerations such as; Algiers, Blida and Constantine. Then come the more rural coastal wilayas including; Chlef, Ain Temouchent and Skikda, then the interior wilayas like; Bouira, Sétif, Mascara, and finally the wilayas near the Sahara like; Batna, Biskra, Oum el Bouaghi, Tébessa, Msila, and Saida.

Of course, this difference in density and climatic conditions, as well as the consumption habits of citizens in each wilaya, have a direct impact on production and composition of waste. The average population of the selected Wilayas represents around 37% of the total population of the country. For the waste generation, the national rate of the waste generation in Algeria is taking into account (0.9%) to calculate the waste generation in each wilaya and to estimate the average waste quantities from all the wilayas. The total waste generation from all the Wilayas represents around 57% of the total country's MSW.

3.4.4. Proposed MBT plants for each Wilaya

In this section, we tried to propose different scenarios for the MBT plants based on the waste generation and collection rate, and estimate the RDF production percentage. According to AND, at the national level, the waste collection rate is estimated to be about 90%, and this rate was taking into account when calculating the amount of waste collected each year. Table (3.6) gathers the quantities of waste collected each year, the potential output of RDF, and the number of MBT plants proposed for each Wilaya.

Table 3. 6 :Proposed MBT for the targeted Wilayas

Wilaya	90% of waste collected t/year	Number of MBT required	RDF Potential (30%) t/year
Chlef	297 000	-S1:1MBT(200.000t/year)+1MBT (100.000t/year) -S2: 2MBT (150.000t/year)	89 100
Tébessa	170 500	1MBT (150.000t/year)	51 150
Ain temouchent	100 740	1MBT (100.000t/year)	30 200
Skikda	236 230	-S1: 1MBT (200.000t/year) -S2: 2MBT (100.000t/year)	70 870
Constantine	249 100	1MBT (150.000t/year) +1MBT (100.000t/year)	74 730
Blida	296 550	-S1:2MBT (150.000t/year) -S2: 1MBT (200.000t/year) +1MBT (100.000t/year)	88 965
Bouira	182 800	1MBT (200.000t/year)	54 840
Mascara	201 800	1MBT (200.000t/year)	60 540
Sétif	391 580	-S1: 2MBT (200.000t/year) -S2: 2MBT (150.000t/year) + 1MBT (100.000t/year)	117 500
Batna	294 900	-S1: 1MBT (200.000t/year) +1MBT (100.000t/year) -S2: 2MBT (150.000t/year)	88 500
Algiers	824 300	-S1: 4MBT (200.000t/year)	247 300
Saida	87 600	1MBT (100.000t/year)	26 300
Oumelbouaghi	163 520	1MBT (100.000t/year)	49 000
Msila	260 460	-S1:1MBT(200.000t/year) +1MBT (100.000t/year) -S2: 2MBT (150.000t/year)	78 000
Biskra	189 500	1MBT (200.000t/year)	56 850

Adrar	105 120	1MBT (100.000t/year)	31 500
Laghouat	119 720	1MBT (100.000t/year)	35 900
Total	4 139 000	-S1: 13 MBT (200.000t/year) + 10 MBT (100.000t/year) +3 MBT (150.000t/year) -S2: 7 MBT (200.000t/year) + 10 MBT (100.000t/year) +11 MBT (150.000t/year)	1 241 700

As we mentioned earlier, the amount of waste varies from a Wilaya to another. The same is true for the waste collection rate, in rural areas; the waste collection rate is about 65-70%, while in urban areas is about 85-90%. In our study, we took an average waste collection rate of 90% across all Wilayas. Based on these calculations (amount of waste collected), for the number of MBT plants in each Wilaya, two scenarios are assumed. Generally, MBT plants exist in different capacities according to the amount of waste generated.

According to our estimate, the minimum capacity of an MBT is 100 000 tons per year, and the maximum is 200 000 tons per year. Another capacity for an MBT plant is also recommended to be 150 000 tons per year. For example, for a large city like Algiers, it is recommended to build 4 plants with an annual capacity of 200 000 tons due to the annual generation of about 800,000 tons of MSW.

For the Wilayas (Chlef, Batna, Sétif), which generate about 300 000 tons of MSW per year; two options are proposed. The first option is to implement two different MBT plants with different capacities, one with an annual capacity of 200 000 tons, plus one MBT plant with an annual capacity of 100 000 tons. The second option is to build two MBT plants with an annual capacity of 150 000 tons.

For wilayas with an annual MSW production of about 200 000 tons, one option is suggested which is to implement one MBT plant with a total capacity of 200 000 tons per year. For the Wilayas, which generate approximately 100 000 tons per year of MSW (Saida, Adrar, Laghouat), the same scheme is recommended which is to build one MBT plant with an annual capacity of 100 000 tons.

3.4.5. A case of study: Wilaya of Blida

The purpose of this section is to propose different options for MBT and MPS implementation. Only one Wilaya is selected, and it can be applied forward for all the Wilayas.

3.4.5.1. First option; MBT implementation for the Wilaya of Blida

MBT technology can integrate different processes in a variety of combinations, and it can be used for multiple purposes. The purpose of developing the first batch of MBT plants is to reduce the environmental impact of landfilling. Therefore, as part of an integrated waste management system, MBT supplements but does not replace other waste management systems such as recycling and composting.

Since the study research on the potential of RDF production was conducted in the Wilaya of Blida, and the availability of the waste generation and composition, continuing to work on the same Wilaya seemed to be the best option. The Wilaya of Blida is divided into 25 cities, they differ in population and in the waste generation and composition.

As mentioned above, the cement plant of Mitidja is located in the Wilaya of Blida, specifically in the city of "Meftah" which is located at the extreme northeast of the Wilaya of Blida (Figure 3.10).

Figure 3. 10: Division of the Wilaya of Blida's cities

An estimation of the waste generation in each city of the Wilaya of Blida is studied, taking into account the national rate of waste generation (0.9kg/capita) to calculate the annual waste generation (Table 3.7).

Table 3. 7 : Population and MSW generation in the different cities of the Wilaya of Blida

City	Population	Waste generation t/year	Waste collected t/year
Meftah	64 980	21 345	19 210
Djebabra	3 400	1 120	1 008
Souhane	260	120	108
Larbaà	83 820	27 540	24 790
Ouled Slama	29 300	9 620	8 660
Bougara	51 200	16 820	15 140
Chebli	29 660	9 750	8 770
Bouinane	31 070	10 200	9 180
Hammam melounae	6 080	2 000	1 800
Boufarik	71 450	23 470	21 120
Soumàa	37 460	12 300	11 070
Chrea	780	260	234
Benkhelil	29 400	9 660	8 700
Oued Alleug	40 700	13 370	12 030
Guerouaou	17 300	5 680	5 110
Beni Mered	34 860	11 450	10 300
Ouled Yaich	87 130	28 620	25 760
Beni Tamou	36 230	11 900	10 700
Blida	590	53 740	48 370
Bouarfa	35 900	11 800	10 620
Chiffa	34 270	11 260	10 130
Mouzaia	52 560	17 260	15 530
Ain Romana	12 530	4 120	3 700
Al afroun	42 470	13 950	12 560
Oued Djer	6 430	2 150	1 940
Total	**850 000**	**329 500**	**296 550**

As mentioned in the results of Chapter (3), in case of RDF substitution rate of 15%; 4.7 t/h of RDF is consumed which represents around 40 600 tons per year.

The percentage of RDF production from the raw MSW is 30%, so to guarantee the RDF availability with the sufficient quantity (40 600 tons per year), 135 300 tons per year of MSW at least are required.

$$100\% \text{ (MSW)} \rightarrow 30\% \text{ (RDF)} \quad (1)$$

$$\text{(MSW)} \rightarrow 40\,600 \text{ tons/year}$$

$$\text{(MSW)} = 135\,300 \text{ tons/year}$$

The total waste generation in the Wilaya of Blida is about 330 000 ton per year, taking into account the national collection rate (90%), the quantities of the waste collected is about 270 000 ton per year. The quantities of waste generated can satisfy the necessary streams for the RDF production required to achieve until 30% of substitution rate in the cement industry. As proposed in Table (3.7), the total number of the MBT plants suggested for the Wilaya of Blida is 2 MBT's with a capacity of 150 000 ton per year, or 1 MBT with a capacity of 200 000 ton per year plus 1MBT with a capacity of 100 000 Ton per year. The suggestions of the different capacities of the MBT plants depends on the literature, and on the availability of the information about this type of MBT plants in terms of the total area needed, the approximative cost of implementation …etc. Table (3.8) gives examples on some MBT plants areas.

Table 3. 8: Examples of the necessary areas for MBT implementation depending on the plant capacity [88].

Plant	Capacity ton per year	Building's area m^2	Total land take m^2
1	135 000	5927.5	89 000
2	100 000	5913	38 000
3	225 000	-	170 000
4	200 000	16 200(+MRF 27130.5)	56 000

An average MBT plant may have a height of 10-20m. Some plants may also have a stack in case of using particular air cleaning system, potentially increasing overall height.

The total buildings areas and the total land take of an MBT plant depend on the capacity, the equipment and the materials installed in each plant. Many aspects should be taken into account in terms of the site situation, the necessary equipment and materials which are related to the quantities and the composition of the waste generated in the Wilaya of Blida.

3.4.5.2. Total MBT cost investment according to the plant size

The total cost investment of an MBT plant depends on its size and other different parameters like the construction, civil engineering, the equipment costs… etc. Table (3.9) shows the average investment cost, operational cost, and the total treatment cost for one Ton of MSW.

Table 3. 9: Total investment, operational, and treatment Cost of an MBT according to its capacity [89]

		Station size		
Cost	Unit	100.000t/year	150.000t/year	200.000t/year
Investment cost	Euro	12 000 000	13 000 000	14 000 000
	DZD	1 578 611 863	1 831 975 851	1 923 142 823
Operational cost	Euro/t	26	19	14
Total treatment cost	Euro/t	30	23	18

This cost evaluation was conducted for different MBT’s with different capacities. The total investment cost for an MBT with a capacity of 100 000t/year is estimated to be 11 212 458 Euros which is approximatively equal to 1 578 611 863 DZD. The operation cost for 1 ton of MSW in this plant is estimated of 2840 DZD, while the total treatment cost is about 2264 DZD/t.

For an MBT plant with a capacity of 150 000t/year, the total investment cost is estimated to be 13 012 035 Euros which is equal to 1 831 975 851DZD. The operational cost and the total treatment cost for 1 ton of MSW in this MBT are estimated to be 3640 and 3062 DZD successively.

For the MBT plant with a capacity of 200 000t/year, the total investment cost is estimated to be 13 659 570 Euros which is equal to 1 923 142 823 DZD. The operational cost and the total treatment cost for 1 ton of MSW in this MBT are estimated to be 4705 and 4127 DZD successively.

Following in detail all the costs for the different MBT sizes. Tables (3.10), (3.11), and (3.12) summarize all the different costs for MBT investments for the different sizes (100 000, 150 000, and 200 000 t/year). The costs include the civil, process, and electrical engineering, some additional costs are included also with the mobile technical equipment.

Table 3. 10: Investment cost in details of an MBT with a capacity of 100 000 ton per year [89]

Mechanical-Biological treatment plant Algeria investment costs				
Input: 100.000t/year				
pos	Donation	Quantity	Unit Price	Total price
1.0	**Civil engineering**			
1.1	Infrastructure/outdoor installations		**DZD**	**78 256 425**
	Earth works		**DZD**	22 031 651
	Paved Area		**DZD**	25 821 095
	Building construction in outdoor installations		**DZD**	10 707 382
	Technical equipment in outdoor installations		**DZD**	4 935 090
	Fixture in outdoor installations		**DZD**	440 633
	Plant and seed areas	$500m^2$	**DZD**	1 101 583
	Other outdoor installations incl. construction site equipment		**DZD**	13 218 991
1.2	Mechanical treatment hall		**DZD**	**232 654 235**
1.2.1	Building-building Construction		**DZD**	198 284 857
1.2.2	Building -Technical construction		**DZD**	343 396 376
1.3	Open composting hall		**DZD**	**158 627 888**
1.3.1	Building-Building construction		**DZD**	132 189 907
1.3.2	Building -Technical construction		**DZD**	26 437 981
1.4	Biofilter		**DZD**	**10 575 193**
1.4.1	Building-building Construction		**DZD**	10 575 193
1.4.2	Building -Technical construction			
1.5	Administrational building		**DZD**	**113 022 370**

1.5.1	Building-Building construction		**DZD**	70 501 283
1.5.2	Building -Technical construction		**DZD**	42 521 087
1.6	Weighing and input control		**DZD**	**9 914 243**
1.6.1	Input Control		**DZD**	1 982 849
1.6.2	Weighing bridge incl equipment		**DZD**	7 931 394
Total	**Civil engineering**		**DZD**	**603 050 353**
2.0	**Process engineering**		**DZD**	
2.1	Processing and conveyor technique		**DZD**	**383 350 729**
	Conveying system, aggregates		**DZD**	96 392 265
	Conveying system, others		**DZD**	4 406 330
	Usage-specific systems, aggregates		**DZD**	224 722 841
	Usage-specific systems, others		**DZD**	57 282 293
2.2	Ventilation technique		**DZD**	
	Ventilation system		**DZD**	**30 844 312**
Total	**Process engineering**		**DZD**	**414 195 040**
3.0	**Electrical engineering**		**DZD**	
	Building-technical equipment		**DZD**	**154 221 558**
	Power plant		**DZD**	88 126 604
	Central control system		**DZD**	66 094 953
Total	**Electrical engineering**		**DZD**	**154 221 558**
Total construction costs			**DZD**	**1171 466 951**
4.0	**Additional costs/contingencies**			
Total	Additional costs (engineering and expert services, permit fees) 15% of the construction costs		**DZD**	**175 812 576**
5.0	**Mobile technical equipment**			
Total	Excavator, wheel loader, lift truck, pile turner, drum screen		**DZD**	**231 332 336**
Total investment costs			**DZD**	**1 578 611 863**

Table 3. 11: Investment cost in details of an MBT with a capacity of 150 000 ton per year [89]

Mechanical-Biological treatment plant Algeria investment costs				
Input: 150.000t/year				
pos	Donation	Quantity	Unit Price	Total price
1.0	**Civil engineering**			
1.1	Infrastructure/outdoor installations		**DZD**	**78 256 425**
	Earth works		**DZD**	22 031 651
	Paved Area		**DZD**	25 821 095
	Building construction in outdoor installations		**DZD**	10 707 382
	Technical equipment in outdoor installations		**DZD**	4 935 090
	Fixture in outdoor installations		**DZD**	440 633
	Plant and seed areas	500m^2	**DZD**	1 101 583
	Other outdoor installations incl. construction site equipment		**DZD**	13 218 991
1.2	Mechanical treatment hall		**DZD**	**232 654 235**
1.2.1	Building-building Construction		**DZD**	198 284 857
1.2.2	Building -Technical construction		**DZD**	343 396 376
1.3	Open composting hall		**DZD**	**237 941 832**
1.3.1	Building-Building construction		**DZD**	198 284 860
1.3.2	Building -Technical construction		**DZD**	39 656 972
1.4	Biofilter		**DZD**	**10 575 193**
1.4.1	Building-building Construction		**DZD**	10 575 193
1.4.2	Building -Technical construction			
1.5	Administrational building		**DZD**	**113 022 370**
1.5.1	Building-Building construction		**DZD**	70 501 283
1.5.2	Building -Technical construction		**DZD**	42 521 087
1.6	Weighing and input control		**DZD**	**9 914 243**
1.6.1	Input Control		**DZD**	1 982 849
1.6.2	Weighing bridge incl equipment		**DZD**	7 931 394
Total	**Civil engineering**		**DZD**	**761 678 241**
2.0	**Process engineering**		**DZD**	
2.1	Processing and conveyor technique		**DZD**	**524 353 296**
	Conveying system, aggregates		**DZD**	110 158 255

	Conveying system, others		**DZD**	4 406 330
	Usage-specific systems, aggregates		**DZD**	330 474 766
	Usage-specific systems, others		**DZD**	79 313 944
2.2	Ventilation technique		**DZD**	
	Ventilation system		**DZD**	**30 844 312**
Total	**Process engineering**		**DZD**	**414 195 040**
3.0	**Electrical engineering**		**DZD**	
	Building-technical equipment		**DZD**	**154 221 558**
	Power plant		**DZD**	88 126 604
	Central control system		**DZD**	66 094 953
Total	**Electrical engineering**		**DZD**	**154 221 558**
Total construction costs			**DZD**	**1391 783 492**
4.0	**Additional costs/contingencies**			
Total	Additional costs (engineering and expert services, permit fees) 15% of the construction costs		**DZD**	**208 860 052**
5.0	**Mobile technical equipment**			
Total	Excavator, wheel loader, lift truck, pile turner, drum screen		**DZD**	**231 332 336**
Total investment costs			**DZD**	**1 831 975 851**

Table 3. 12: Investment cost in details of an MBT with a capacity of 200 000 ton per year [89]

Mechanical-Biological treatment plant Algeria investment costs				
Input: 200.000t/year				
pos	Donation	Quantity	Unit Price	Total price
1.0	**Civil engineering**			
1.1	Infrastructure/outdoor installations		**DZD**	**78 256 425**
	Earth works		**DZD**	22 031 651
	Paved Area		**DZD**	25 821 095
	Building construction in outdoor installations		**DZD**	10 707 382
	Technical equipment in outdoor installations		**DZD**	4 935 090
	Fixture in outdoor installations		**DZD**	440 633
	Plant and seed areas	$500m^2$	**DZD**	1 101 583
	Other outdoor installations incl. construction site equipment		**DZD**	13 218 991
1.2	Mechanical treatment hall		**DZD**	**232 654 235**
1.2.1	Building-building Construction		**DZD**	198 284 857
1.2.2	Building -Technical construction		**DZD**	343 396 376
1.3	Open composting hall		**DZD**	**475 883 664**
1.3.1	Building-Building construction		**DZD**	396 569 714
1.3.2	Building -Technical construction		**DZD**	79 313 944
1.4	Biofilter		**DZD**	**10 575 193**
1.4.1	Building-building Construction		**DZD**	10 575 193
1.4.2	Building -Technical construction			
1.5	Administrational building		**DZD**	**113 022 370**
1.5.1	Building-Building construction		**DZD**	70 501 283
1.5.2	Building -Technical construction		**DZD**	42 521 087
1.6	Weighing and input control		**DZD**	**9 914 243**
1.6.1	Input Control		**DZD**	1 982 849
1.6.2	Weighing bridge incl equipment		**DZD**	7 931 394
Total	**Civil engineering**		**DZD**	**761 678 241**
2.0	**Process engineering**		**DZD**	
2.1	Processing and conveyor technique		**DZD**	**524 353 296**
	Conveying system, aggregates		**DZD**	110 158 255

	Conveying system, others		**DZD**	4 406 330
	Usage-specific systems, aggregates		**DZD**	330 474 766
	Usage-specific systems, others		**DZD**	79 313 944
2.2	Ventilation technique		**DZD**	
	Ventilation system		**DZD**	**30 844 312**
Total	**Process engineering**		**DZD**	**414 195 040**
3.0	**Electrical engineering**		**DZD**	
	Building-technical equipment		**DZD**	**154 221 558**
	Power plant		**DZD**	88 126 604
	Central control system		**DZD**	66 094 953
Total	**Electrical engineering**		**DZD**	**154 221 558**
Total construction costs			**DZD**	**1471 097 406**
4.0	**Additional costs/contingencies**			
Total	Additional costs (engineering and expert services, permit fees) 15% of the construction costs		**DZD**	**220 757 144**
5.0	**Mobile technical equipment**			
Total	Excavator, wheel loader, lift truck, pile turner, drum screen		**DZD**	**231 332 336**
Total investment costs			**DZD**	**1 923 142 823**

3.4.5.3. Second option; Mechanical-physical stabilization (MPS) inside the cement industry

A second scenario which can be proposed; is to implement an MPS plant inside the cement plant which will reduce the transportation cost and guarantee the availability of RDF with big quantities from a side, because up to 60% of the waste can be converted to RDF in the MPS plants. and to use the heat excess from the clinker production to dry the waste streams in shorter time from another side.

MPS is widely utilized, it consists of different treatment process namely mechanical treatment and physical drying. The drying of waste in this technology happens with the help of an external thermal energy. After the mechanical processing, the overflow of waste enters into a dryer which works with an external heat like; gas or other fossil energy in order to dry the waste in shorter time, and to have a stabilized output with a high calorific value. It consists of 5 main steps; acceptance of the input waste, processing (mechanical treatment), drying, screening, and finally packing for transportation to the incineration or Co-processing plant or directly fed into the kiln (Figure 3.11).

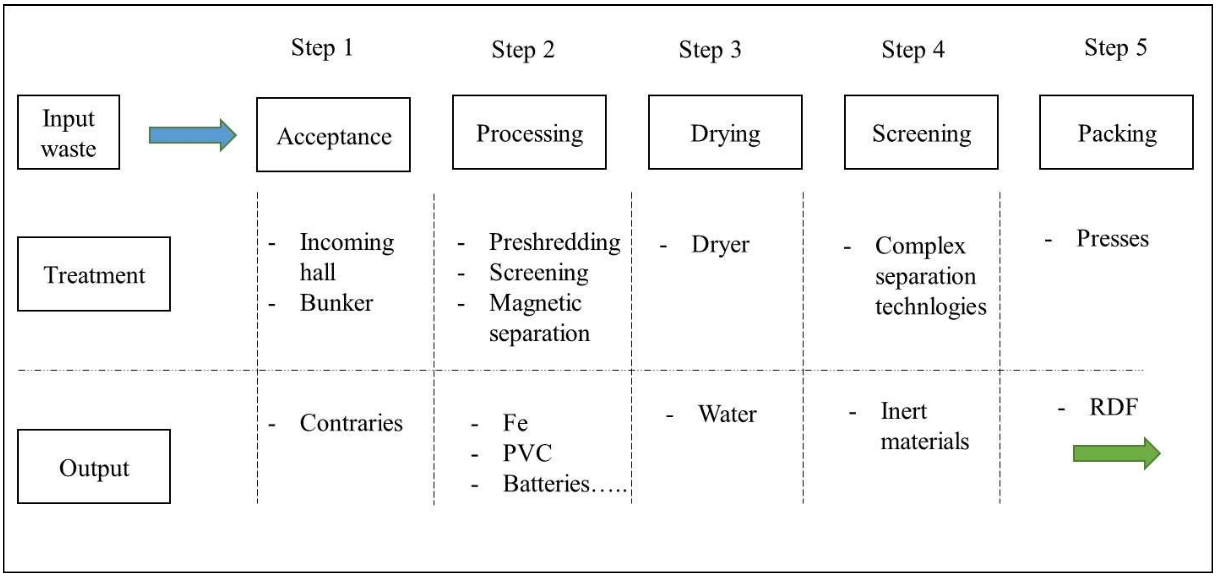


Figure 3. 11: The different steps of MPS pre-processing technology

3.4.5.4. MSW source for the MPS plant

The choice of the source of the MSW generation depends on the composition of the waste, the cities of the wilaya of Blida differ in the waste composition because of the location and consumption habits. The distance between the waste collection points and the cement plant is also a critical point (transportation). The composition of MSW destined for RDF production should contain the high calorific fractions, usually this kind of waste comes from the industrial, commercial, and urban cities. For this purpose, we selected these cities in order to provide a good quality of MSW for the production of a suitable RDF with high calorific value and with less impurities. The cities of; Meftah, Larbàa, Bougara, Boufarik, Ouled Yaich, and Blida are the most suitable cities for the quality of the waste generated. They are characterized by an urban, and commercial profile. The composition of the waste in these cities is quite suitable for RDF production because, the waste contains big fraction of combustible materials (plastic, paper-cardboard...). Also, the overall waste quantities generated in these cities are sufficient to produce the sufficient quantities of RDF required to be substituted in case of 15% of rate substitution.

3.4.5.5. Site selection of MPS and area needed

The cement plant of SCMI has a surface of 356 811 m^2 in which 72 708 m^2 is built. The technical buildings represent 42 457 m^2 and 22 810 m^2 are for other buildings. The choice of the site for the MPS implementation depends on the surface availability and the easy access of the trucks for the waste disposal. For the location of the dryer, it should be near the clinker cooler in order to use the exhaust air for the RDF drying, and near to the feed point which is the kiln. In SCMI plant, the distance between the entrance and the clinker production line is about 500 m, between these two there are the reception, administration, control buildings, and limestone storage area.

Figure 3. 12: Location of the clinker production line and cooler in the SCMI (Google Earth)

As shown in chapter (3), for different RDF substitution rates, different quantities of RDF are consumed, however to guarantee the availability of these quantities we must guarantee the waste streams with sufficient quantities and with chosen composition to ensure that the RDF produced is with the sufficient quantities and with the required properties.

Table (3.13) summarizes the calculations of the required quantities of the waste streams for the production of the needed RDF quantities for the different substitution rates taking into account that the percentage of the RDF produced as output from the input waste represent around 50 to 60%. This will help also to estimate the capacities of the MPS plant to be implemented.

Table 3. 13:summary of the MSW quantities needed for RDF production and the MPS plant capacity

Substitution rate %	RDF consumption tph	RDF consumption tpa	MSW Input tpa	MSW Input tph	MPS capacity tpa
10	3.15	22 680	37 800-45 360	5.25-6.3	50 000
15	4.7	33 840	56 400-67 680	7.8-9.4	70 000
20	6.28	45 216	75 360-90 430	10.5-12.5	100 000
30	9.43	67 900	113 170-135 800	15.7-18.9	140 000

3.4.5.6. RDF drying using the exhaust air as a source of drying

Based on the available excess heat in cement production plants, such as heat waste from raw mill, clinker, kiln, and pre-heater cyclones; three theoretical possibilities to use excess energy in the plant to provide RDF drying energy as following;

1- Direct stream drying; producing super-heated steam from available hot air in the plant and its utilization as drying medium in a dryer with direct mode
2- Indirect steam drying; producing steam using available hot air energy in the plant and applying that indirectly in the dryer
3- Hot air drying; taking available hot air in the plant as drying medium and applying that directly into the dryer.

In order to select the most appropriate drying method from all three suggested systems, different factors should be taken into account, such as, energy consumption of the system, existence of auxiliary equipment, operability and controllability of the process and cost of the drying system.

Based upon the survey conducted by some authors; Hot air drying is the most recommended process for this purpose. The reasons to choose direct drying with hot air are firstly, it will reduce total equipment cost to some extent. Secondly, from the energy point of view, it does not need to have an intermediate heating medium. From this case, some heat loss will be avoided. In addition, the dryer will have no steam equipment, results in lower capital and operating cost, lowering maintenance requirements and simpler control system. The exhaust air from the clinker cooler could be an excellent option to use as source of heat for waste drying for its high heating value from a side, and for the recycling and valorization and environmental point of vu from another side.

3.4.5.7. Energy needed for RDF drying from the exhaust air

This section will describe in details the calculations of the energy needed to dry the quantities of RDF according to the substitution rate taking into account the information bellow;

Input RDF moisture: W_{input}=40%

Output RDF moisture: W_{output}=15% (acceptable)

So, for example in case of 15% of substitution rate; 4.7t/h of RDF is required (Output of the dryer), so the necessary quantity of RDF as input to the dryer is;

$$4.7\ t * 0.85 \rightarrow 3.9\ t\ DM,\ \text{with } 0.8\ t \text{ of moisture} \qquad (1)$$

0.8 t (moisture) → 15%

X→40%

X=2.13 t

M_{input}= 3.9+2.13

M_{input} = 6.03 t

Quantity of evaporated water is:

$$W_{evap} = m_{RDF\ input}\ (1-\frac{100-W\ input}{100-Woutpu}) \qquad (2)$$

$$W_{evap} = 6.03\ (1-\frac{100-4}{100-15})$$

$$W_{evap} = 1.8\ t/h$$

The minimum energy required to evaporate water is 2465.9 kJ/kg, with 1kw= 3600 kJ/h [90];

So, the minimum quantity required of energy Q_{evap}(kw) to evaporate 1.8 t/h is:

$$Q_{evap} = \frac{2465.9*1.8*1000}{3600} \qquad (3)$$

$$Q_{evap} = 1232.95\ kw$$

Overall, the minimum quantity required of energy Q $_{evap}$(kw) to evaporate 1t/h of the input RDF is:

$$1.8\ t/h \rightarrow 1232.95\ kw \qquad (4)$$

$$1\ t/h \rightarrow 684.97\ kw$$

The drying process or the thermal transfer in the different types of dryers happens by convection, and it is called “Forced convection” because it is produced by an external force which can be by hot-air pumping as in our case.

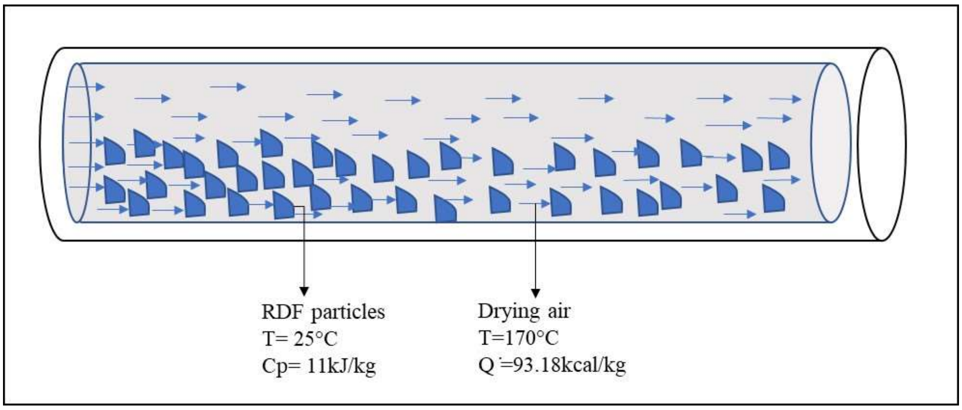


Figure 3. 13: RDF drying using the exhaust air (Forced convection)

In addition, it is important to calculate the total gained energy of the RDF to be heated and increase its temperature to 170°C.

$$Q\ (\dot{R}DF) = \dot{M} * Cp\ * (T - T0) \qquad (5)$$

$$\dot{Q}(RDF) = 6.03 *\ 11 *\ (170 - 25)$$

$$\dot{Q}(RDF) = 9\ 617{,}85\ kJ/kg$$

$$\dot{Q}(RDF) = 2671.62kw$$

Moreover, the total energy needed for RDF drying is:

$$\dot{Q} = \dot{Q}(RDF) + Q\ evap \qquad (6)$$

$$\dot{Q} = 2671.62 + 1232.95$$

$$\dot{Q} =\ 3\ 904.57kw$$

The same method is used to calculate the input mass of RDF, $\dot{Q}(RDF)$, Q evap, and total energy needed for RDF drying in case of the different substitution rates. The table (3.14) summarizes the quantities of RDF $_{\text{input}}$ needed according to the substitution rate, quantities of water evaporation and the minimum quantity required of energy to evaporate water, total energy needed for RDF drying, and the percentage of the total energy needed from the exhaust air energy.

Table 3. 14: Energy required for water evaporation

Parameter	Case 1	Case 2	Case 3	Case 4
Substitution rate	10	15	20	30
RDF $_{\text{output}}$ (t/h)	3.15	4.7	6.28	9.43
RDF $_{\text{input}}$ (t/h)	3.95	6.03	7.86	11.79
W_{evap}(t/h)	1.18	1.8	2.35	3.53
Q $_{\text{evap}}$(kw)	808.26	1232.95	1609.67	2417.94
Q $_{\text{RDF}}$ (kw)	1754.5	2671.62	3482.41	5228.05
Total energy needed (kw)	2 562.76	3 904.57	5 092.08	7 646

The calculations above describe only the energy needed to dry different quantities of RDF; however, other parameters should be taken into account like the capacity of the dryer used, time of residence, maximum energy and temperature in the dryer, RDF density and particle size.

3.5. DRYING KINETICS OF RDF: EXPERIMENTAL INVESTIGATION AND MODELIZATION USING STATISTICA SOFTWARE

The drying tests were carried out in a laboratory-scale hot-air wind tunnel which is similar to a fluidized bed dryer. the drying kinetics were studied using STATISTICA software.

3.5.1. Analysis of drying curves

The initial moisture content of the RDF samples was determined by the same method described in equation (1) in chapter 2. The average value of the RDF initial moisture content is found to be 40%. Drying experiments were determined at different temperatures (40,50, 75, and 90 °C). Figure (3.14) shows the results of moisture ratio changes with time at different temperatures. The moisture content decreases continuously with the drying time. It is seen from the drying curve that the drying air temperature has a significant effect on the drying kinetics of RDF.

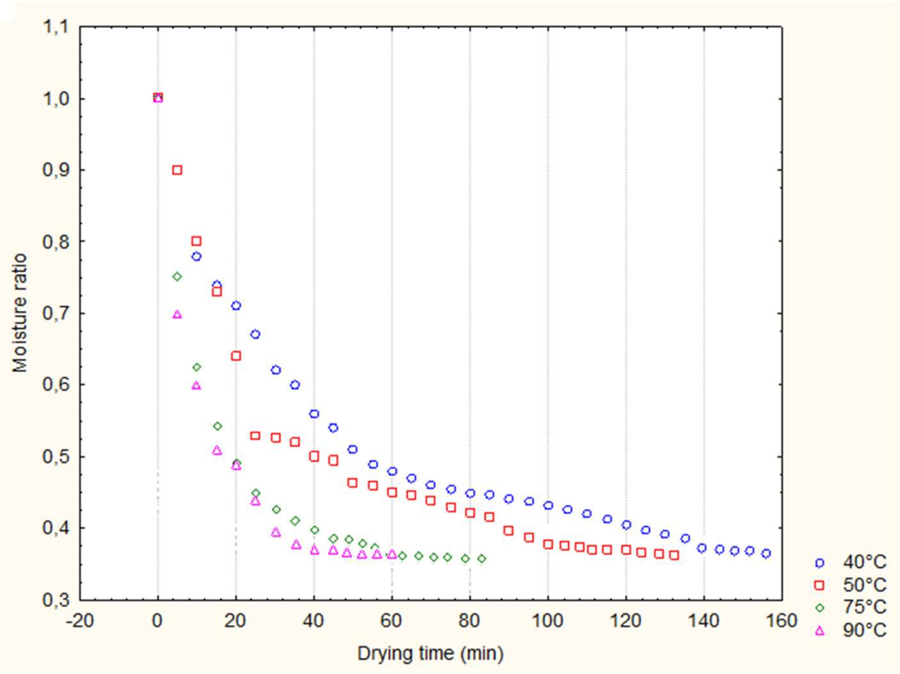


Figure 3. 14: Variation of moisture ratio at different Temperatures (40, 50, 75, 90°C)

The characteristic of the drying process is that the moisture content gradually decreases with time, and then stabilizes, reaching a constant value, especially at high temperature. In view of the data provided, and for the same drying air pressure, the time required to dry the RDF decreases as the temperature increases.

At 40, 50, 75, and 90°C, the drying time to reach approximately 15% of the moisture content value is 130, 110, 50, and 30 min respectively.

The increase in drying potential and the decrease in drying time are explained by the fact that an increase in temperature leads to an increase in the heat transfer intensity. The increase in the drying temperature is the reason for the increase in energy of water molecules, which will accelerate the migration of water in the product, which makes it easier and faster to escape.

3.5.2. Mathematical modeling of drying curves

The moisture content DATA obtained from the drying experiments were fitted to the 6 mathematical models listed in Table (2.4). the determination coefficient (R^2) values for the different air temperatures determined by non-linear regression analysis are presented in

Table (3.15). As it is shown, the R^2, χ^2, and RMSE values range from 0.8156 to 0.99997, 0.00000058 to 0.0025, and 0.003-0.0637, respectively. The high values of R^2 and the low values of χ^2, and RMSE indicate a good fit in most cases.

Table 3. 15: statistical results of 6 mathematical models at different drying temperatures

Model	T°C (40)			T°C (50)			T°C (75)			
	R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2
Newton (Lewis)	0.8156	0.0000862	0.0091	0.7948	0.000067	0.008	0.82300	0.0014083	0.036	0.8768
Page	0.9880	0.0002343	0.0147	0.9725	0.000560	0.0232	0.99170	0.0003051	0.0160	0.9971
Handerson and Pabis	0.9225	0.0016972	0.0398	0.8902	0.002421	0.0472	0.89810	0.004809	0.0637	0.9237
Logarithmic	0.9961	0.0000403	0.0060	0.9925	0.0000009	0.0009	0.99860	0.0000324	0.0049	0.9937
Diffusion approach	0.9978	0.0000001	0.0003	0.9938	0.0000495	0.0066	0.99960	0.0000169	0.00360	0.9972
Midilli et al	0.9968	0.0000047	0.0023	0.9882	0.0000400	0.0058	0.99967	0.00000058	0.00063	0.9986

Among the considered models, Logarithmic, Diffusion approach, and Midilli et al models gave R^2 values higher than 0.99. These models seem to be more suitable for describing the drying process of RDF under the experimental conditions studied. In addition, the diffusion approach model gave relatively high R^2 in all cases, while the values of χ^2 and RMSE were low. The highest value of R^2 (0.9978), the lowest value of χ^2 (0.0000001) and RMSE (0.0003) were observed at drying air temperature (40°C). Therefore, it can be supposed that this model represents the drying kinetics of RDF in laboratory-scale dryer, which is similar to a fluidized bed dryer with the experimental research scope. The other mathematical models studied (Lewis, Page, Handerson and Pabis) seem to be the least fit models for the RDF drying behavior. (Slomka et al.,2018) used Handerson and Pabis, Lewis, and Page models to study the drying kinetics of the different the best fit to the experimental DATA [74]. The obtained values for R^2 were greater than 0.98, and χ^2 test values were in the range of 0.0003-0.0024. However, none of the mathematical models were able to satisfactory describe the performance of the RDF drying at the temperature of 90°C.

3.5.3. Analysis of drying rates

The drying rate (DR) is expressed as the amount of evaporated moisture over time. The drying rates of the RDF samples were determined as follows;

$$DR=\frac{Mt+dt-Mt}{dt} \qquad (7)$$

Where M_{t+dt} and M_t are the moisture content at time t+dt and t (g water/g dry matter), respectively, t is drying time (min).

Figure (3.15) shows the changes in drying rates with drying time at different air temperatures. As can be seen, drying rates decreased continuously with drying time and decreasing moisture content.

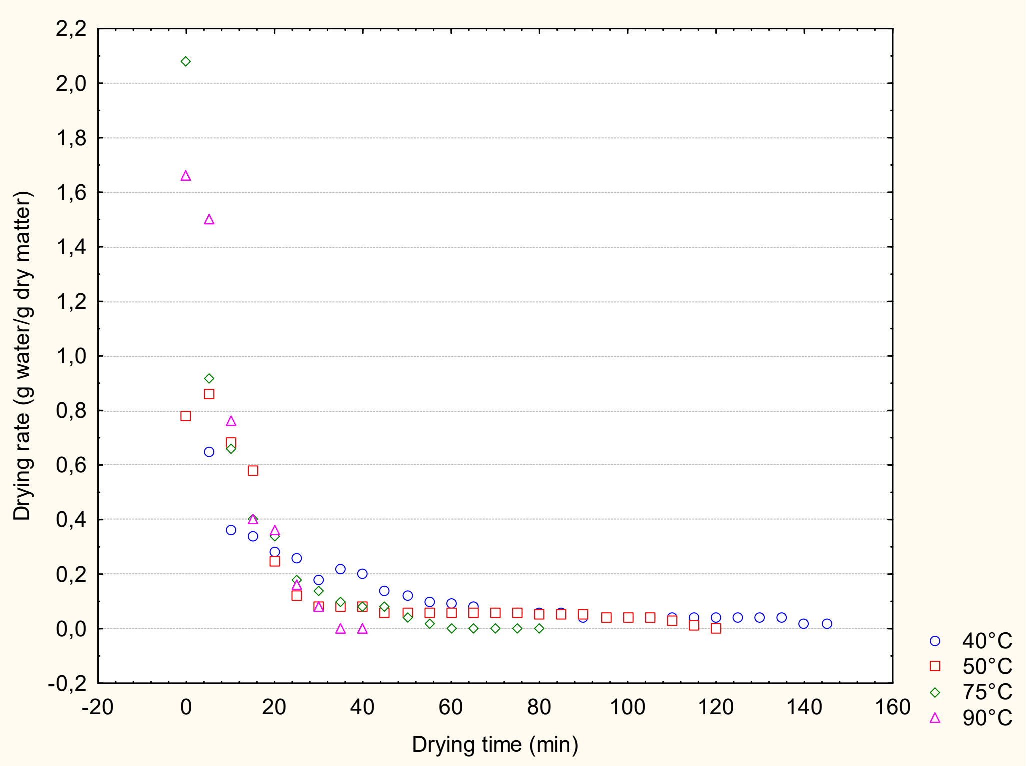


Figure 3. 15: Drying rate of RDF versus time at different temperatures

It can be seen from the curve that there is no constant drying rate in the first stage of the RDF drying. All the drying process occurred during the deceleration period, indicating that the internal mass transfer is carried out by diffusion. Also as expected, the drying rate increased as the air temperature increases, thereby reducing the drying time. This increase is due to the increase in heat transfer potential between drying air and RDF, thus improving the evaporation of water from the RDF.

3.5.4. Valuation of effective diffusivity and activation energy

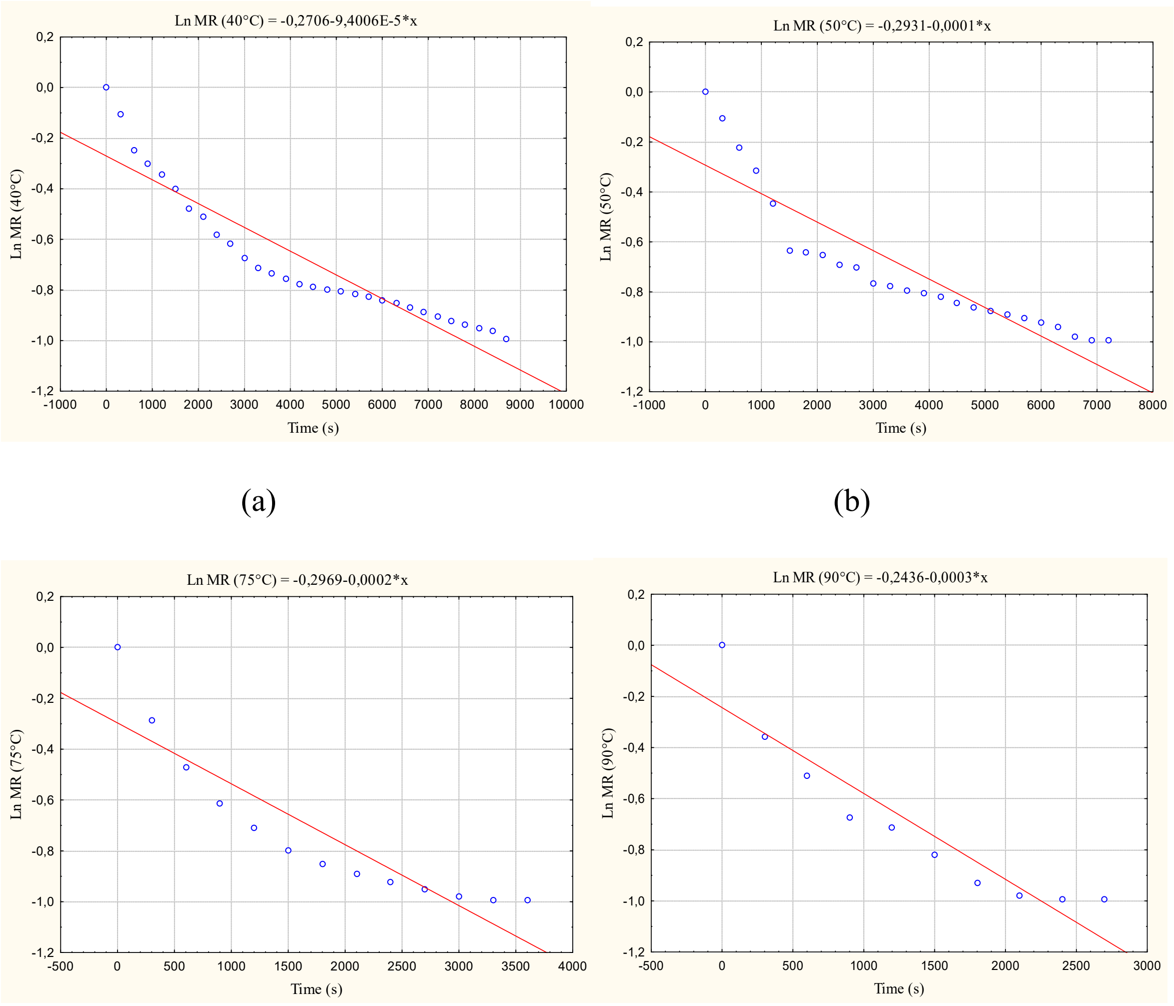
The effective diffusivity coefficient is the characteristic quantity of the substance diffusion phenomenon. It measures the ratio between the molar flow caused by molecular diffusion and the concentration gradient of the sample under consideration (usually, the effort causing this diffusion). Fick’s second law of diffusion is considered to be the most commonly used to study the theoretical models of waste drying. For long drying periods, Fick’s law can be simplified into logarithmic form as follows;

$$\ln \mathrm{MR} = \ln[\frac{8}{\pi\hat{}2}] - [\frac{\pi\hat{}2 * \mathrm{De}}{4 * \mathrm{L}\hat{}2}] * \mathrm{t} \qquad (8)$$

The effective moisture diffusivity De (m^2/s) can be determined from the slope of the normalized graph of Ln MR versus time, which gives a straight line with a slope of;

$$Slope = -\left[\frac{\pi^2 * De}{4 * L^2}\right] \qquad (9)$$

Where L is the thickness of the sample (slab) of 0.025 m.



(a) (b)

(c) (d)

Figure 3. 16: Ln MR versus time (s) (a: 40°C, b: 50°C, c: 75°C, d: 90°C)

Table (3.16) gathers the effective diffusivity value of RDF for the different temperatures. As it is shown, the effective diffusivity values increased with increasing in the air-drying temperature, they were found to be in the range of $2.36*10^{-8}$ and $7.6*10^{-8}$ (m^2/s) within the range of the temperature range studied.

Table 3. 16 : effective diffusivity values of RDF

T°C	40	50	75	90
$D_e(m^2/s)$	$2.36*10^{-8}$	$2.53*10^{-8}$	$5.07*10^{-8}$	$7.6*10^{-8}$

The activation energy (E_a) is determined by plotting the natural logarithm of Deff versus reciprocal of the absolute temperature T [K]. This can be described by Arrhenius type equation;

$$De = De0 \exp(-\frac{Ea}{Rg*Ta}) \qquad (10)$$

Where D_{e0} is the moisture effective diffusivity for an infinite temperature (m^2/s), E_a is the activation energy for moisture diffusion (kJ/mol), Rg the universal gas constant ($8.314 *10^{-3}$ kJ mol^{-1} K^{-1}, and Ta the absolute temperature (K).

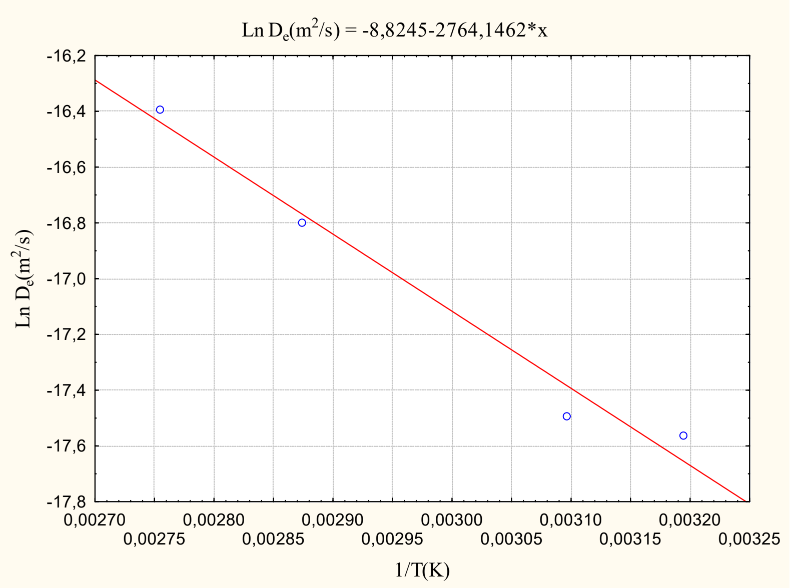


Figure 3. 17: Determination of the activation energy by plotting Ln D_e versus 1/T (K)

The activation energy of RDF and in the temperature range studied was found to be;

$$E_a = 22.97 \text{ kJ/mol} \qquad (11)$$

CONCLUSION

The aim of this thesis was to evaluate the solid waste management system in order to improve the strategy adopted from the authorities for an integrated waste management in Algeria. Therefore, an overview on the SWM practices in Algeria, legislation, waste services management actors, and the MSW management strategy was exposed in the art statement part.

The experimental research aimed to examine the potential of production of RDF from mixed MSW in one of the mega cities in Algeria—the Wilaya of Blida. To this end, two trials were conducted in an established municipal waste sorting plant in the city.

After receiving the fresh municipal raw materials, representative samples were taken (200 kg per each trial). A screen unit was used to distinguish the waste into different categories based on their particle sizes in the form of fractions of >100, 80–100, 60–80 and<60 mm. The materials of >80 mm excluding organics and non-combustible materials were then subjected to a drying process in an open site area. Laboratory analysis was performed and the results obtained were evaluated and compared with some EU countries in order to identify the quality of the final product, RDF. At the end of the drying process, as a consequence of the waste's moisture reduction, the LHV was increased by 66% to reach 16 MJ kg−1. The DM was increased by 54% to reach 87%by the treatment process. The results showed that the heavy metal concentrations were within the set limits and much lower than those values set by some European countries' standards. The quality of the RDF produced did not differ from the RDF quality set by those countries. Overall, the RDF produced in the Wilaya of Blida was of market-oriented product standard in terms of the high calorific value, low moisture and acceptable chlorine content (0.37–0.80% ww−1), which made it a suitable treatment option for the handling of MSW in the city. Furthermore, adding 15% RDF, which equals33,840 Mt year−1 to the fuel used at cement kilns would saves31.3 Mio Nm3 year−1 in natural gas, 846,000 USD year−1 from gas costs and 2255 Mt year−1 of CO2 emissions into the atmosphere.

MBT technology can incorporate different processes in a variety of combinations, it can be built for a range of purposes mainly the RDF production. The RDF production rate from the raw MSW is 30%, in case of 15% of substitution rate; 40 600 t/year of RDF is required. In order to guarantee the RDF availability with this sufficient quantity, 135 300 t/year of MSW at least is required. The total waste collected in the Wilaya of Blida is about 270 000 t/year, therefore; the total number of the MBT plants suggested for the Wilaya of Blida is 2 MBT's with a capacity of 150 000 t/year or 1 MBT with a capacity of 200 000 t/year plus 1 MBT with a capacity of 100 000 t/year.

direct drying (fluidized bed dryer) using exhaust air from the clinker cooler is proposed with the implementation of an MPS inside the cement plant. The RDF inters to the dryer with a water content of about 40%, in case of 15% of substitution rate; 4.7t/h of RDF is required (Output of the dryer), therefore; the necessary quantity of RDF as input to the dryer is 6.03 t/h, and the quantity of the evaporated water is 1.8 t/h. the minimum quantity required of energy Q_{evap} to evaporate this quantity of water is 1232.95 kw, while the total energy needed to dry the RDF in case of using of the exhaust air with a temperature of 170°C is 3 904.57 kw. For the RDF drying, an experimental lab scale dryer was used for drying RDF at different drying air temperatures (40, 50, 75, and 90°) and fixed flow (20 m^3/h). the drying kinetics were modelized using STAISTICA software, and the appropriate mathematical model was extracted according to R^2, RMSE and χ^2, the effective diffusivity and activation energy of RDF were also determined. Among the considered models, Logarithmic, Diffusion approach, and Midilli et al models gave R^2 values higher than 0.99. These models seem to be more suitable for describing the drying process of RDF under the experimental conditions studied. In addition, the diffusion approach model gave relatively high R^2 in all cases, while the values of χ^2 and RMSE were low. The highest value of R^2 (0.9978), the lowest value of χ^2 (0.0000001) and RMSE (0.0003) were observed at drying air temperature (40°C). The effective diffusivity values increased with increasing in the air-drying temperature, they were found to be in the range of $2.36*10^{-8}$ and $8.46*10^{-8}$ (m^2/s), the activation energy of RDF was found to be; E_a= 24.8 kJ/mol within the range of the temperature range studied.

When introducing a new strategy for managing the MSW, part of it being co-processing, numerous functional elements should be considered including legal, institutional, financial and technical aspects. As a first step for introducing co-processing of waste, an identification of the value added to the waste management system must be taken into account, and whether the availability of RDF is guaranteed for the cement producers. The main interests of cement plants are whether the use of RDF is cost-effective and environmentally beneficial compared with fossil fuels. The same considerations exist for local authorities responsible for waste management. If there is interest within the region for the initiative of adopting co-processing as an alternative waste treatment option, the relevant regional authority would be responsible for guaranteeing and producing RDF for cement plants.

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APPENDIXES

Appendix 1: Other relevant ministries in the field of waste management

Ministry	Link with the waste management/circular economy
Ministry of the Interior, local authorities, and Territorial planning	Financial support for municipalities and for the management of household and similar waste. Collaborative structure
Ministry of Finance	Defines environmental taxation (subsidies, taxes, fees, etc.), budgets and customs

Ministry of National Education	Awareness raising and education of the sorting reflex Waste management projects and selective sorting in school
Ministry of Industry and Mines	Important sector for the generation of special waste of industrial and extractive special waste
Ministry of Agriculture, Rural and Fisheries Development	Important sector of agricultural waste generation An important actor in the recovery of compost
Ministry of Housing, Urbanism and the City	A major player in waste management planning, development of neighbourhoods based on 'circular' needs
Ministry of Commerce	Major waste generation sector, and manages the commercial registrations of waste management companies
Ministry of Communication	Education, information, awareness-raising for the general public
Ministry of Public Works and Transport	Important sector of waste generation port waste. Construction of infrastructure, recovery of inert waste, transportation of waste
Ministry of Health, Population and Hospital Reform	support to health care institutions in the field of health care waste management
Ministry of Labour, Employment and Social Security	Employment planning in the waste management sector Green job generation in the circular economy
Ministry of justice	Monitoring and enforcement of the law in the waste management field Penalization of non-compliance: littering waste, permits
Ministry of Energy	Extraction and refinery waste and CO_2 emissions
Ministry of Higher Education and Scientific Research	The circular economy in education and research

Appendix2: Financing of waste management (Law 01-19, Article 36)

Generator	Financing method
Households	Annual tax for the collection of household waste

Generator of MSW from industrial, commercial, craft, care or other activities	Paid collection, transport and processing servicesand treatment by the municipality at the expense of thegenerator
Inert waste generator	Financial responsibility for collection, sorting,transport and disposal by the generator
Special waste generator	The costs of transport and treatment of the waste are at the expense of the generator

Appendix 3: The regulatory framework of the waste management in Algeria

Legal reference	Description
Constitution	the Constitution contains a general statement on the environment: Art. 19: The State guarantees the rational use of natural resources and their preservation for the benefit of future generations. The State shall protect agricultural land. The State shall also protect the public hydraulic domain The law shall determine the modalities of implementation of this provision Art. 68: The citizen has the right to a healthy environment. The State shall work for the preservation of the environment. The law determines the obligations of natural and legal persons for the protection of the environment.
Law n° 91-25 of 18December 1991	Law establishing a tax on polluting or dangerous activities(TAPD) for the environment by setting rates and a multiplier coefficient.
Law n° 01-19 of 12December 2001	Law on the management, control and disposal of waste, dealing with aspects of waste management
Law n° 02-11 of 24December 2002, & the Codeof direct taxes and similar taxes	Introduces an annual, flat-rate, and local taxon the household waste removal service (TEOM) and sets the applicable tariffs
Law n° 03-10 of 19 July 2003	Law on environmental protection and sustainable development, enshrines the general principles of environmentally sound management. The principles of prevention, precaution, polluter pays,information and awareness are the subject of this law

Law No. 15-15 of 15 July2015	Amends and supplements Ordinance No. 03-04 of 19 July 2003 on general rules applicable to the import and export of merchandise
Executive Decree No. 98-147of 13 May 1998	Creates and sets the terms of operation of the special allocation account n°302-065 entitled"National Fund for the Environment andPollution Control " (FEDEP)
Executive Decree No. 06-104 of 28 February 2006	Sets out the nomenclature for waste, including special and hazardous waste
Executive Decree No. 07-144 of 19 May 2007	Establishes the nomenclature of installations classified forthe environment protection
Specific legislation for MSW	
Law n° 03-22 of 28 December 2003	Introduces and sets the amount of the specific tax on plastic bags
Executive Decree No. 07-205 of 30 June 2007	Establishes the modalities and procedures for the elaboration, publication and revision of the municipal plan for the management of household similar waste
Executive Decree No. 09-87 of 17 February 2009	Fixes the modalities of application of the tax on the imported plastic bags and/or locally produced plastic bags

Overview of the number of decrees by subject

Waste streams	Number of Law	Number of Decrees	Number of inter-ministerial orders
MSW	3	6	1
Special waste (dangerous)	1	11	2
Inert waste	1	1	
Health care waste	1	1	1

Appendix 4: photos of the material used for MSW characterization

Sieves

<u>Scale</u>

Appendix5: MSW preparation, loadring, and quartering method

Appendix 6: RDF shredding

Appendix 7: RDF sample

Appendix 8: Preparation of RDF for the calorific value measurement using calorific bombe at the laboratory of Rostock

Appendix 9 : Experimental RDF drying

Arduino UNO card