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GRADUATE SCHOOL OF NATURAL AND APLLIED SCIENCES

WASTE MINIMIZATION IN POWDER COATING INDUSTRY

by
İrem EROL

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İZMİR

WASTE MINIMIZATION IN POWDER COATING INDUSTRY

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İrem EROL

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M.Sc THESIS EXAMINATION RESULT FORM

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WASTE MINIMIZATION IN POWDER COATING INDUSTRY

ABSTRACT

The principal objective of the thesis is to prevent pollution and minimize waste in powder coating processes in order to develop a framework for sustainable waste minimization in future. A powder coating producer located in Izmir was selected as a case study. In the examined plant, waste management efforts were focused on the reuse and recycling studies as well as source reduction attempts. Source reduction efforts are realized by an efficient inventory study. Conducted results stated that approximately 95% of total wastes were powder wastes, waste paper and packaging waste, and plastic/nylon and metal wastes. In addition to these, waste oil, e-wastes, waste batteries, cable wastes, contaminated wiping cloths and protective clothing, treatment plant sludge were produced at minor quantities. In the framework of minimization studies, reduction of extruder chips and melts wastes were achieved by implementing a new machine having a mesh on surface. Approximately 40 percentage reduction in wastes was performed by the implementation of the project and 51.750 Euro saving was anticipated. Reduction in the nylon and paper packaging was obtained by using big bag discharge unit. Besides, standardization of the pallet types and reuse of the incoming pallets was resulted savings in cost and waste minimization.As an economic point of view, saving in costs was expected as 118.000 Euro at the end of the year.During the project, resin suppliers were informed about the quality of their product and an improvement in the resin quality was performed by the resin manufacturer. Reduction in powder wastes were also achieved by determining of the sample size of various products required for testing. Finally, in the plant, the standard lights were replaced with LED luminaries. When LED luminaries were used in the plant, electricity consumption was reduced app. 40 percentage Reduction in the electricity consumption was resulted in the reduction in the carbon dioxide emission to the atmosphere, which was one of the positive effects of the action.

Keywords: Non-hazardouswaste, pollution, powder coatings, waste management

TOZ BOYA ENDÜSTRİSİNDE ATIK AZALTIMI

ÖZ

Tezin temel amacı, toz boyama süreçlerinde atıkları en aza indirerek kirliliği önlemek ve gelecekte sürdürülebilir atık azatlımı için bir çerçeve geliştirmektir. İzmir'de bulunan toz boya üretimi yapan fabrika uygulama örneği olarak seçildi. İncelenen fabrikada atık yönetim çalışmaları kaynakta azaltmanın yanı sıra yeniden kullanım, geri dönüşüm çalışmalarına odaklandı. Kaynak azaltma çalışmaları etkin bir envanter çalışması ile gerçekleştirilmiştir. Elde edilen sonuçlar toplam atıkların %95'inin toz boya atığı, kâğıt ve plastik/naylon esaslı ambalaj atıkları ve metal atıklar olduğunu ortaya koydu. Bunlara ek olarak az miktarda atık yağ, elektronik atık, pil ve akü, kablo atıkları, arıtma çamuru, kontamine bez ve kişisel koruyucu malzemeler üretilmiştir. Atık azaltma çalışmaları çerçevesinde,ekstruder eriyik ve cips atıklarının azaltımı, yüzeyinde elek açıklıkları bulunan yeni bir makine kullanılarak elde edilmiştir. Projenin uygulanması ile atık miktarında yaklaşık yüzde 40 oranında azalma olmuştur ve 51.750 Euro tasarruf elde edilmesi beklenmektedir. Big-bag boşaltma ünitesi kullanılarak, naylon ve kağıt ambalaj atıklarında azaltım elde edilmiştir. Ayrıca, palet türlerinin standartlaştırılması ve gelen paletlerin tekrar kullanılmasımaliyetlerde ve atık miktarında azalma ile sonuçlandı. Ekonomik açıdan bakıldığında,yılsonu itibari ile maliyetlerde 118.000 Euro tasarruf edilmesi beklenmektedir.Proje süresince reçine tedarikçilerine ürünleri hakkında bilgi verildi ve reçine üreticisi tarafından reçine kalitesinde iyileştirmeler gerçekleştirildi. Farklı ürünlerin analizinde kullanılacak numune miktarlarının belirlenme için testler yapılarak toz boya atık miktarının azaltılması sağlandı.Son olarak fabrikada, standart aydınlatma armatürleri LED armatürler ile değiştirildi. LED armatürlerin fabrikada kullanılmasıyla elektrik tüketimi yaklaşık olarak yüzde 40 azaldı. Elektrik tüketimindeki azalma, atmosfere verilen karbon dioksit emisyonunun azalmasına da pozitif etkisi olmuştur.

Anahtar kelimeler*:*Tehlikesiz atık,kirlilik,toz boya, atık yönetimi

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CHAPTER ONE
INTRUDUCTION

Management of waste eliminates adverse impacts on the environment and human health and supports economic development. The waste hierarchy is an effective tool that defines the waste management options. The waste hierarchy comprises of five steps, i.e. waste prevention, reuse, recycling, recovery options, and disposal alternatives. Reducing of the waste quantities at source (waste prevention) is regarded as the highest priority in the waste hierarchy. Once waste is created, re-use, recycling, recovery, and disposal (e.g. landfill) opportunities are considered respectively.

Coating is a surface finishing process and used for the corrosion protection of metal surface and for aesthetic appearance. In many applications, the metals are painted with a conventional spray process using volatile organic compounds (VOCs) mixed with the paints. Since VOCs are carcinogenic and their emission has serious environmental problems, most industries have been switching to powder-coating systems. In the powder coating process, dry powder is deposited on metal surfaces by electrostatic spraying, and the deposited powder layer is cured to form a durable film. The coating process is functionally and economically competitive with the organic solvent-based paint.

Powder coating manufacturing consists of premix, extrusion, grinding and packaging stages. Wastes originate from raw material stock site, pre-mix unit, extruder, grinding, and packaging units. From the raw material stock site and pre-mix unit typically emissions (dust), packages, wastewater and powder waste are generated. Extrusion unit produces powder waste (melts & chips waste, leaks etc.), plastic and nylon waste, contaminated absorbents, and wastewater from cleaning of the container and equipment, and air emissions of dust materials. Grinding operations wastes are packages, powder waste that is off-spec, spillage etc., and air pollution control equipment, bags and cartridges from paint filtration equipment, and dust emissions. Finally, packaging unit generates cardboard, plastic and nylon wastes, pallet waste, powder waste (spillage etc.), and powder waste from air pollution control equipment.In order to reduce these wastes inventory control, proper maintenances (cleaning), control of the paint mixing considering the requirements, operator training, use of alternative coatings, recycling of resins on and off site, and using waste exchanges, are recommended. Considering the reduction possibilities, a waste hierarchy in the coating industry includes source reduction, recycling and reuse, and proper disposal.

The overall objective of this research project was to prevent pollution and minimize waste in powder coating processes. In the study, a powder coating producer located in Izmir was selected as an example. In this framework, an inventory of wastes, i.e. quantities and waste sources were carried out, as first. Then, wastes were categorized considering their types and characteristics, and disposal methods. The priority areas which would be focused for minimization were determined considering the waste quantity, and reuse and recycle capabilities. Finally, measures to mitigate the waste were performed for specially defined areas, i.e. powder wastes, package wastes, and electricity consumption, as well.

Conducted results stated that approximately 95% of total wastes were powder wastes, waste paper and packaging waste, and plastic/nylon and metal wastes. In addition to these, waste oil, e-wastes, waste batteries, cable wastes, contaminated wiping cloths and protective clothing, treatment plant sludge were produced at minor quantities. Since the results of the inventory study on waste quantities and sources pointed out powder waste was the highest ones and extruder unit was the main source of the powder waste, minimization efforts were initiated at the extruder unit. Besides, higher amounts of packaging wastes were required that the measures taken in that area.

As it stated above, the extruder unit was required special attention in the powder coating processes to take mitigation measures for waste minimization purpose. An improvement on the reduction of extruder chips and melts wastes were achieved by implementing a new machine having a mesh on surface. Moreover, re-using of waste chips provides reduction in raw material consumption and disposal costs, as well. Approximately 40% reduction in wastes was performed by the implementation of the project and 51.750 € saving was determined.

Reduction in the nylon and paper packaging by using big bag unit was carried out effectively in the plant. The big bags used for purchasingof resins were reused. Besides, reduction of pallet wastes was also carried out. By taking certain measures, standardization of the pallet types, reuse the incoming pallets, cost saving, minimization of the wooden pallet waste was intended. There were various types of pallets of different sizes and weight loads used in the plant. Standardization of the pallet types and reuse of the incoming pallets was resulted savings in cost and waste minimization.The pallet projects started in January, 2013. And within the first 2 months, the following measures were achieved.

- The incoming pallets provided with the raw and packaging materials (25 kg paint boxes) were converted to Euro pallets instead of non-standardized type of pallets without any cost disadvantage
- Some products were transferred with large type of pallets (CP1) instead of Euro pallets
- A part of the purchased Euro pallets were supplied from another company's excess pallets within the free zone.
- As an economic point of view, saving in costs was calculated as € 10.357 within first 2 months. At the end of the year, app. 118.000€ saving has been expected.

During the project, resin suppliers were informed about the quality of their product. Dust contents of the resins were measured and suppliers were informed to take certain measures to reduce their dust contents. Thus, an improvement in the resin quality was performed by the resin manufacturer (supplier).

Reduction in powder wastes were also achieved by determining of the sample size of various products required for testing.

Improvement of total energy consumption was obtained by using LED luminaries. Reduction in the electricity consumption was resulted in the reduction in the CO2 emission to the atmosphere, which was one of the positive effects of the action.

In this framework, the thesis was structured at six major parts. In the first chapter the objective of the thesis was presented. Chapter 2 and 3 includes information about waste minimization principles and powder coating industry. The methods used in the study were summarized in Chapter 4. The results obtained from the inventory study and mitigation measures were explained in Chapter 5. The results of the collected datawere presented at tables and depicted in various figures at Chapter 5. Finally, the results were evaluated and concluded in Chapter 6.

CHAPTER TWO
WASTE MINIMIZATION

2.1 WasteDefinition

Waste is defined in the Waste Framework Directive as any substance or object which the holder discards, or intends or is required to discard (Official Journal of the European Union, 2008). In Basel convention, waste is defined as substances or objects which are disposed or are intended to be disposed or are required to be disposed of by the provisions of national laws.

Each stage of the production process generates a specific type of waste. Wastes may be produces during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities. The schematic representation of waste production pathway is presented in Figure 2.1.

Figure 2.1Generation of waste (Global Resource, Information Database, 1985).

The types of wastes are municipal waste (including household and commercial), industrial waste (including manufacturing), hazardous waste, construction and demolition wastes, mining waste, waste from electrical and electronic equipment, packaging waste, end of life vehicles and tires, agricultural wastes, and biodegradable municipal wastes. Each waste product requires a specific management solution. There are a number of different options available for the treatment and management of waste including prevention, minimization, re-use, recycling, energy recovery and disposal. Under EU policy, landfilling is seen as the last option and should only be used when all the other alternatives have been exhausted, i.e., only material that cannot be prevented, re-used, recycled or otherwise treated should be landfilled.

2.2 Waste Management and Waste Hierarchy

Management of waste reduces or eliminates adverse impacts on the environment and human health and supports economic development and improved quality of life. A number of processes are involved in effectively managing waste for a municipality. These include collection, transport, processing, recycling, disposal, and monitoring as well.

The waste hierarchy (as defined in Article 3 of the Waste Framework Directive) is a tool that defines the waste management options in terms of their environmental impact. As can be seen in Figure 2.2., the waste hierarchy comprises of five steps, i.e. waste prevention, reuse, recycling, recovery options, and disposal alternatives. Reducing of the waste quantities at source (waste prevention) and reducing of the hazardous content of waste is regarded as the highest priority according to the waste hierarchy established in the Waste Framework Directive (article 4). Once waste is created, preparing of the wastes for re-use, recycling, recovery, and disposal (e.g. landfill) opportunities are considered respectively.

Figure 2.2 Waste management hierarchies (U.S. Environmental Protection Agency , 2013)

Waste minimization includes both reduction at source and recycling alternatives. According to the EPA, waste minimization is defined as the reduction, to the extent feasible, of waste that is generated or subsequently treated, sorted, or disposed. It includes any source reduction or recycling activity undertaken by a generator that results in either the reduction of total volume or quantity of waste, or the reduction of toxicity of hazardous waste, or both, so long as such reduction is consistent with the goal of minimizing recent and future threats to human health and the environment (Harry Freeman, 1992).

2.2.1 Waste Prevention

According to the Waste Framework Directive "prevention" is defined as the measures taken before a substance, material or product has become waste, that reduce (a) the quantity of waste, including through the re-use of products or the extension of the life span of products; (b) the adverse impacts of the generated waste on the environment and human health; or (c) the content of harmful substances in materials and products.

The best way of dealing with waste, both economically and environmentally, is to avoid creating it in the first place. People and businesses that use resources wisely not only save money but also have much less impact on the environment. That is why waste prevention rightly occupies the top spot in the so-called “waste hierarchy” set out in the waste legislations.

Waste prevention covers reducing both quantities of waste and the level of hazardousness. The prevention of waste production is the most effective way to prevent the loss of energy and natural resources, as well. It is the main factor in the protection of environment and in the sustainable use of the natural resources. On this ground, waste prevention is considered as the priority in all arrangements regarding the waste management.

The amount of the wastes produced and their hazardousness is directly related with the production processes and the quality of the technology used in production. In most cases waste minimization can be managed through making changes in the production processes with a relatively little costs. For example, instead of solvent-based materials, usage of water-based materials in the production process means a decrease in both the amount of waste generated and the level of hazardousness. Through this implementation, an increase in the efficiency of production is also obtained. Thus, through a number of methods and techniques from re-preparation of the project on product and packaging in the production stage to the selection of the technologies producing fewer wastes; the objective of waste prevention or minimization can be achieved (Köse, Ayaz, & Köroğlu, 2007).

Waste prevention is a policy priority in many countries and countries are obliged by legislative ways to take measures encouraging minimization of the amount and the hazardousness level of wastes. For example, in Europe, waste prevention was integrated in the legislation (Waste Framework Directive 2008/98/EC) and stated that prevention is the first priority of waste management, being at the top of the waste hierarchy, with a requirement from European member states to produce waste prevention plans.In the United States, the US EPA has undertaken a program to support local authorities and waste management organizations to quantitatively assess the consequences of waste prevention on global warming potential (GWP) reduction with the Waste Reduction Model (WARM) but does not include other environmental impact categories (U.S. Environmental Protection Agency , 2013).

Methods of waste reduction include manufacturing products with less packaging, encouraging customers to bring their own reusable bags for packaging, encouraging the public to choose reusable products such as reusable plastic and glass containers, backyard composting and sharing and providing any unwanted items rather than discarding them. All of the methods of waste prevention mentioned require public participation. In order to get the public onboard, training and educational programs need to be undertaken to educate the public about their role in the process.

2.2.2 Preparing for Waste Re-use

According to the Waste Framework Directive, “re-use" is defined as any operation by which products or components that are not waste are used again for the same purpose for which they were conceived. Preparing for re-use relates to checking, cleaning or repairing activities which allow a waste substance, product or material to be re-used without any other pre-processing. For example industrial machinery, clothes, electronic and electrical equipment and furniture can be repaired or refurbished and then sold on (DEFRA Department for Environment Food and Rurall Affairs, 2011). Preparing for reuse is higher in the waste hierarchy of treatment than recycling and energy recovery, sitting just below prevention (see Figure 2.2). It offers a greater impact in terms of carbon emission reduction and savings than all other equipment treatment options.

This hierarchy level was introduced to make waste operators aware of the potential to divert products from the waste stream, as their sorting, cleaning and repair allows them to be used by someone else. Preparing for re-use is therefore regarded as contributing to waste prevention in a wider sense; therefore promotion of re-use is included in the guidelines.

2.2.3 Waste Recycling

According to the Waste Framework Directive, "recycling" is defined as any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. Recycling is a resource recovery practice that refers to the collection and reuse of waste materials.

Recycling occurs in three phases: first the waste is sorted and recyclables collected, the recyclables are used to create raw materials. These raw materials are then used in the production of new products. Material for recycling may be collected separately from general waste using dedicated bins and collection vehicles, or sorted directly from mixed waste streams. The sorting of recyclables may be done at the source (i.e. within the household or office) for selective collection by the municipality or to be dropped off by the waste producer at a recycling centers. Another option is to mix the recyclables with the general waste stream for collection and then sorting and recovery of the recyclable materials can be performed by the municipality at a suitable site. Recycling can encourage better segregation of waste to enable higher recycling rates and improved quality of recycled material and encourage use of recycled materials and products as replacements for virgin materials, where viable.

After collection, the materials are processed for reuse; therefore recyclables are sent to a recovery facility to be sorted, cleaned, dried, or heated. Finally, purchasing new products produced from recycled material is the last step in recycling.

2.2.4 Waste Recovery

According to the Waste Framework Directive, "recovery" is defined as any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfill a particular function, or waste being prepared to fulfill that function, in the plant or in the wider economy. Thus, waste recovery is about using waste to replace other non-waste waste materials to achieve a beneficial outcome in an environmentally sound manner (Environment Agency, 2010).

Energy recovery from waste is the conversion of non-recyclable waste materials into useable heat, electricity, or fuel through a variety of processes, including combustion, gasification, pyrolization, anaerobic digestion, and landfill gas (LFG) recovery.

The waste hierarchy sets out the broad options for waste management, with energy recovery from waste being a preferred option to landfill. However, it recognizes that prior to energy recovery waste reduction; re-use, recycling and composting are preferred, where appropriate. Recovery of wastes through the biologic and chemical conversion processes and thermal processes ensures a great deal of saving both in the costs of production and in the costs of waste disposal due to reduced waste quantities.

2.2.5 Waste Disposal

According to the Waste Framework Directive, "disposal" is defined as any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy. The Landfill Directive (Directive 1999/31/EC on the landfill of waste) applies to disposal of waste to land. This requires specific controls to be applied through the permits.

The safe and reliable long term disposal of wastes is an important component of integrated waste management. Waste residues are waste components that are not recycled, that remain after processing at a materials recovery facility, or that remain after the recovery of conversion products and/or energy. Therefore, landfill provides a safe disposal option for wastes that can’t be recycled, composted or used to generate energy. Modern landfills are engineered to very high specifications ensuring that all waste deposited in a landfill will be safely contained and, that when it is restored, the landfill will blend naturally into the surrounding landscape. Restored landfills are often used for farming, as golf courses, for forestry or as public open space.

2.3 Targets in the Revised Waste Framework Directive

The Waste Framework Directive sets a target that by 2020, preparation for reuse, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70% by weight. In order to achieve the overall targets in Towards Zero Waste, the more easily recyclable materials need to be recycled at a higher rate.

CHAPTER THREE
POWDER COATING INDUSTRY

3.1 General

The major change that has taken place in the coatings industry during the last forty years has been the adoption of new coating technologies. Until the early 1970s, most of the coatings were conventional low-solids, solvent-based formulations mainly used in architectural applications. In the late 1970s, however, impending government regulations on air pollution control focusing on industrial coating operations stimulated the development of low-solvent and solvent less coatings that could reduce the emission of volatile organic compound (VOCs). Energy conservation and rising solvent costs were also contributing factors. These new coating technologies include high-solids coatings, two-component systems, powder coatings and radiation-curable coatings.

Among the various coating technologies, powder coatings have a wide range of applications in end user industries such as automobiles, appliances and furniture. In addition, they are used in industrial manufacturing of machinery and general metals. In terms of volume, the global powder coatings market is expected to grow at a CAGR (compound annual growth rate) of over 6% from 2012 to 2018.

Table 3.1 Powder coating demand (Functional & Protective Coating Technologies & Equipment, n.d.)

	Powder Coating Demand				**% Annual Growth**	
Item	**1990**	**2000**	**2005**	**2010**	**00/90**	**05/00**
Powder coating demand (million kg)	63	157	229	333	9.4	7.9
By type:						
Thermoset (million kg)	59	145	213	311	935	8.0
Thermoplastics (million kg)	5	12	16	23	8.6	7.0
By type:						
By market:						
Motor vehicles (million kg)	11	31	100	45	11.0	8.0

Table 3.1 Powder coating demand (Continued) (Functional & Protective Coating Technologies & Equipment, n.d.)

Furniture (million kg)	13	29	95	61	8.4	7.9
Appliances and housewares (million kg)	14	29	39	52	7.7	5.8
Industrial Mach. and materials (million kg)	7	22	33	50	9.7	8.7
Other markets (million kg)	17	45	68	104	10.3	8.8
$/kg:	2.39	2.94	3.19	3.44	2.1	1.6
Powder coating demand (million $)	335	1016	1610	2530	11.7	9.6

The growth of powder coatings is primarily driven by the increased demand of consumer goods such as appliances and automobiles in emerging economies such as China, India and Brazil. In addition, support by regulatory bodies such as E.P.A. and R.E.A.C.H. is also another primary factor responsible for the growth of the powder coatings market.

3.2 Powder Coatings

Powder coating is a dry finishing technique and applied to the surface in powdered form. Coating powders used in the finishing process are mainly mixture of finely ground particles of resin, pigments, and additives. Coating powders are generally electrostatically charged and sprayed onto the metal surface to be coated using an electrostatic spray gun. The charged powder particles adhere to the parts and are held there until melted and fused into a smooth coating in a curing oven. Unlike liquid paints, the powder coating process does not involve the use of any solvents, therefore is virtually harmless to the environment.

Powder coatings are relatively hard, abrasion-resistant (depending on the specification) and tough. Thin powder coatings can be flexible but this is not recommended for exterior applications. Powder coatings are available in wide range of colors and finishes. Color matching is quite acceptable batch to batch. When powder coating matters are put in properly, i.e. without damage and clean, the coating should be relatively permanent. And, any chip, peel or crack is not formed when appropriate coating is completed.

Powder coating offers certain advantages and disadvantages to the consumer. The list of these benefits and handicaps are summarized in Table 3.2. As it stated above, powder coating is highly protective process for the environment. While liquid finishes contain solvents which have pollutants known as volatile organic compounds (VOC's), powder coating contains no solvents and release negligible amounts, if any, VOC's into the atmosphere. Besides, powder coating production produces less hazardous waste than conventional liquid coatings. Powder coatings can produce much thicker coatings than conventional liquid coatings without running or sagging. Powder coating overspray can be recycled and thus it is possible to achieve nearly 100% use of the coating.

Table 3.2Advantages and disadvantages of powder coatings

	Advantages	**Disadvantages**
Economic	Lower operating costs due to energy saving, labor cost saving, high operating efficiencies, lowered environmental costs & increased plant safety	Capital costs slightly higher than waterborne or high-solids; frequent color changes could entail extensive down-time; operational conditions requiring clean & dry parts
Environmental	No VOCs; reduced energy use; over-spray can be reused; easy disposal	Phosphates & chromates used in part preparation / pretreatment; carcinogenic additives; high-curing temperatures of non-UV and IR-curing powders
Appearance/ Performance	High durability and variation in texture, color & coating thicknesses possible	Very thin applications of coatings (less than 0.001 inches [1 mil]), coating sharp inside corners and heat-sensitive parts have generally been difficult to achieve

Table 3.2 Advantages and disadvantages of powder coatings (Continued)

Safety	Non-flammable and low spark hazard; personnel are not exposed to solvent fumes	Storage and handling of powder coatings requires special climate controls.

3.3 Coating Powder

There are two types of powder coatings - thermoplastic and thermosetting. A thermoplastic powder coating is one that melts and flows when heat is applied, but continues to have the same chemical composition once it cools and solidifies. Thermosetting powder coatings are based on lower molecular weight solid resins, and melt when exposed to heat. Typical properties of these coating are explained herein.

Thermoset Coatings:

These newly formed materials are heat stable and, will not soften back to the liquid phase when heated. During the curing process,they chemically crosslink within themselves or with other reactive components, to form a product having higher molecular weight. Thermosetting powders are derived from three generic types of resins: epoxy, polyester and acrylic. Typically particle sizes of the thermosetting powders are between 30-50µm.

Thermosetting powders are also tougher, have better adhesion to metal substrates, and are more resistant to solvents and chemicals than thermoplastic coatings. Appearance is much better; cost is much lower, and more strength and stabile. However, thermoset powder coats cannot recycle and re-shape.

Thermoplastic coatings:

Thermoplastic powders are typically high molecular weight materials that require high temperatures to melt and flow. They are generally applied to a surface that has been preheated to a temperature significantly higher than the melting point of the powder. As a thermoplastic powder material is applied to the hot surface it will melt and then "flow out" into a strong, continuous film. As the film cools it develops its physical properties.Nylon powder coating materials are the most commonly used thermoplastic powders.

Typical particle size of thermoplastic powder coatings is about 100µm. Some powders have mostly large particles and have no potential to emit particulate matter to the air. Powders with more than 95% by weight above 75µm may justify exemption from Local Authority Air Pollution Control (LAPC) / Local Authority Pollution Prevention and Control (LAPPC).

The primary advantage of thermoplastic coatings is that they form a smoother finish and require less energy. They are commonly applied by fluidized bed application, and the parts are both pre-heated and post-heated. Most of the thermoplastic powder coatings have marginal adhesion so that the substrate must be pretreated and sometimes primed prior to coating application. Thermoplastic powders exhibit excellent chemical resistance, toughness, and flexibility. Other advantages are high lubricity or tack; be recyclable; able to remolded and/or reshaped. However, higher cost may be disadvantage together with the melt-off characteristics when they overheated.

3.4 Composition of Coating Powders

Powder coatings are composed of resin, hardener, filler, pigment and additives.

Resin: For powder coatings thermoplastics or thermo settings resins are used. Resins used in thermosetting powders can be ground into fine particles necessary for spray application and a thin film finish. The most common thermosetting powders are composed of one or more of the following resins: epoxy, polyester, polyester-urethane, and acrylic. Epoxy powder coatings exhibit inherent toughness, corrosion resistance, chemical resistance, flexibility, and adhesion and abrasion resistance.

Urethane powder coatings have excellent gloss retention and long-term resistance to humidity and corrosion in thin film applications. Polyester powder coatings show long-term exterior durability and overheat resistance. Many automotive trim components and other exterior components are coated with polyester powders. Acrylic powder is specified where the decorative requirements and resistance to ultraviolet rays from sunlight for a longer period of time is critical. Many critical automotive trim components are also coated with acrylic powder.

Hardener: The hardener is one of the most important components of coating powder. It is responsible for the curing of the powder in conjunction with the resin.

Pigment: Pigments are used to give color. There are organic as well as inorganic pigments. Pigment is the microscopic insoluble particles that give a coating color and opacity. Some pigments are used primarily to improve coating appearance, while others are used primarily to improve coating function.

Filler: Also called an extender pigment, a pigment used primarily to reduce coating cost, while also enhancing coating performance. Filler pigments are often substituted for more expensive functional color pigments. Fillers are used to resist sagging out of the film, to improve abrasion resistance, and to improve resistance to humidity.

Additive: Additives used in the powder coating are classified into five groups. These are;

- accelerators (to accelerate the reaction of the curing)
- degassing additives (to release of the enclosed gases through the pores of the coating)
- thyrotrophic additives (to resist sagging outs = viscosity regulator)
- flow-control agent (to improve the flow on the surface)
- matting agent (to reduce the gloss of powder coatings)

3.5 Production of Coating Powder

Powder coating production consists of premix, extrusion, grinding and packaging stages (see Figure 3.1).

2.3.1 Premix

The different dry raw materials (resin, hardener, pigment, additive, and filler) are weighed in exact quantity and put in a container. In order to obtain well mixing of raw materials, container should be mixed for a pre-set period of time. Homogeneous mixture of the raw materials is obtained in the contained and following to homogeneity control, the mixture in the container is transferred to the extruder.

2.3.2 Extrusion of the Pre-mix

The pre-mix (pre-blended raw materials) is fed into the extruder. The extruder barrel is maintained at a predetermined temperature (between 70 & 120ºC, depending on the product type). The barrel temperature is set so that the resin is only just liquefied (melt) and its contents are mixed using the screw in the barrel. Consequently, the individual ingredients are dispersed and wetted by the resin, which produces a homogeneous composite. Finally, this homogenous melt is discharged from the extruder.

The next stage converts this hot melt into a cooled, hard and brittle strip by passing it through cooling transportation device. Depending on the size of the extruder and its production rate, extrude may be further cooled on a cooling band. The final operation in the cooling stage is to break the cold, brittle extrude into small flakes between 5 to 15 millimeters using rotating hammers fitted at the end of the cooling stage.At the end of the cooling conveyer, the continuous powder plate is broken down into little pieces (named “chips”) that will be caught up in containers.

2.3.3 Grinding & Packaging

The final stages of the manufacturing process are milling or grinding, and classification which convert the chipsinto a fine powder within a specified particle size range.Chipsare transferred from a feed hopper into the mill by a screw feed. This screw further reduces the product size as it feeds the mill. The product is carried on an air-stream into the milling stage(s). Material enters a pulverizing chamber where it is reduced to a fine powder by a rotating disc fitted with metal pins. Some toner powder processes use jet mills to achieve this fine powder. Jet mills feed the material into air streams which are either fired directly at ceramic collision plates, or multiple air streams are fired at each other. The milling or pulverizing is caused by the product particles impacting with ceramic plates, each other or with the rotating pins depending upon the milling stage design (British Coatings Federation, 2010).

Then, crushed coating powder is transferred from pulverize / jet mill(s) on an airstream. This air-stream is designed so that oversized particles drop down and are returned to the milling chamber. So, by a combination of rate of feed, speed of rotating pin disc and air velocity, it is possible to produce a powder with a controlled particle size distribution. In toner applications either cyclonic or mechanical wheel separation is used to separate the oversize particles for further milling. In most toner manufacturing plants between two to four classifications stages are used to get the final particle distribution needed. Powder transport between each classification stage is done by vacuum transfer. The transport air is separated from the powder using either cyclonic or mechanical wheel separation. The extracted air is filtered to remove any unwanted fine powder (British Coatings Federation, 2010).

The milled / classified powder is then transferred to a collection chamber. This may be a cyclone where the powder falls to the bottom, while the air is exhausted from the top, filtered and exhausted to the atmosphere. The other method of collection is where the powder/air mix is passed into a chamber fitted with bag filters. In toner applications the powder is generally collected in a weighing vessel. This allows batch processing with other additives (such as silicates) required for the copy process. These additives are fed by separate screw feed system & the batches are mixed together mechanically then discharged to the packing stage (British Coatings Federation, 2010).

Once the powder is in the required configuration it is generally sieved to remove any possible contaminants before being packed ready for sale or use. When an optimum particle size is obtained, powder is placed in boxes (5, 10, 15, 20, 25 kg) or big-bags (about 450kg).

The powder can be safely stored if kept in its unopened packaging in a dry, cool place (30ºC) for up to 12 months. Higher temperatures and longer storage periods will result in absorption of moisture. Storage conditions can vary for some powders so the product data sheet should be referred to at all times.

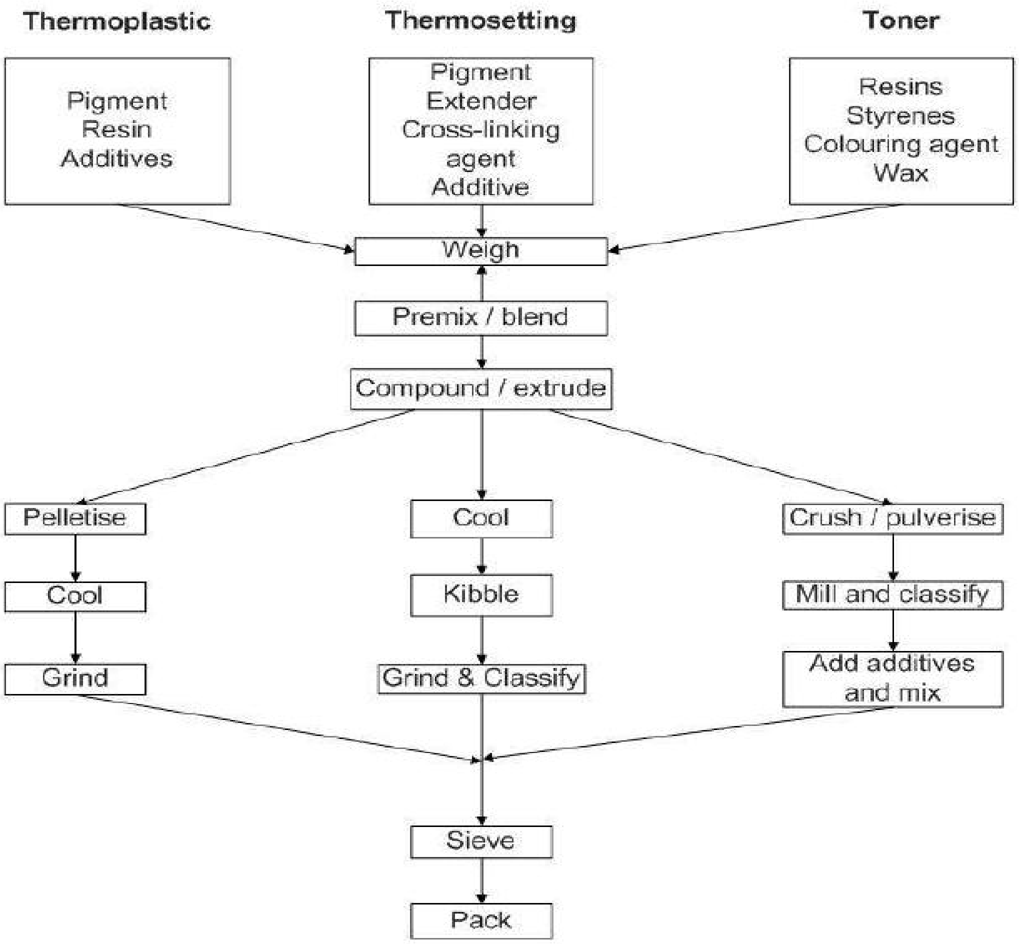


Figure 3.1 Processes used in the powder coatings production

3.6 Powder Coating Application

There is essentially three common ways of applying powder coating: by electrostatic spray, and by fluidized bed, and electrostatic fluidized bed powder coating. There are several other processes that have been developed, but they are far less used. These include flame spraying, spraying with a plasma gun, airless hot spray, and coating by electophoretic deposition.

The fluidized bed is still the primary technique used for the application of thermoplastic powders. The fluidized bed is also used for the application of some thermoset powders where high film build is required. Thermoset powders designed for electrical insulation often use the fluidized bed technique. The parts are pre-heated to a temperature significantly higher than the melting point of the powder. The parts are then immersed into a "fluidized bed" of the coating powder where the plastic powder is melted onto the part.

An electrostatic fluidized bed is essentially a fluidized bed with a high voltage dc grid installed above the porous plate to charge the finely divided particles. Once charged, the particles are repelled by the grid, and they repel each other, forming a cloud of powder above the grid. These electrostatically charged particles are attracted to and coat products that are at ground potential. Film thicknesses are similar to what can be achieved in the electrostatic spray process. The advantages of electrostatic fluidized bed coating is that preheating of parts is generally not necessary and small products, such as electrical components, can be coated uniformly and quickly. The disadvantages are that the product size is limited and inside corners have low film thickness owing to the well-known Faraday cage effect.

Electrostatic spray is the primary technique used for thermoset powders. The particles of powder are given an electrical charge in the powder coating gun. The target part is attached to a fixture that is grounded. The electrically charged powder particles are attracted to the grounded part and attach themselves like little magnets to the part. The particles build-up on the surface of the part until it is covered with charged particles and the part surface is charged. At this point the oncoming particles are actually repelled by the charged particles on the part and the coating process stops. This provides an even film thickness.

In the thesis, since electrostatic spraying technique is used in the examined plant, only the electrostatic spraying technique will be described in detail in the following sections.

The process is impulsion of the air through a spray gun, in which it becomes electrically charged. The movement of the particles between the charged gun and the substrate to which the power is applied is governed by a combination of electrical and mechanical forces. The electrical forces are the result of interaction between the charged powder particles and the electric field between the substrate and the gun, while the mechanical forces are derived from the air that blows the powder through the gun. Powder particles as electrically insulating material retains their charge and adhere to the work piece.

Electrostatic spray powder coating uses a powder-air mixture from a small fluidized bed in a powder feed hopper. In some cases, the feed hoppers vibrate to help prevent clogging or clumping of powders prior to entry into the transport lines. The powder is supplied by a hose to the spray gun, which has a charged electrode in the nozzle fed by a high voltage dc power.

Electrostatic powder spray guns direct the flow of powder; control the deposition rate; control the pattern size, shape, and density of the spray; and charge the powder being sprayed .The spray guns can be manual or automatic, fixed or reciprocating, and mounted on one or both sides of a spray booth. Electrostatic spray powder coating operations use collectors to reclaim over-spray. This reclaimed powder is then reused, adding significantly to the powder coating's high transfer efficiency.

The film thickness is dependent on the powder chemistry, preheat temperature, and residence time. Film thicknesses of 1.5 - 5.0 mils (i.e. 37.5 - 125 µm) can generally be applied on cooled products. If the products are preheated slightly, 20 - 25 mils (i.e. 500 - 625 µm) coatings can easily be applied in a single coat.

There are various gun designs that mainly differ in the method of applying electrostatic charge to the powder. In some cases, the powder is electrostatically charged by friction. The advantage is that the powder is free to deposit in an even layer over the entire surface of the part, and deposition into recesses is improved.

2.4.1 Corona Gun System

Corona charging guns are the most widely used devices for charging the powder particles. Charging of the powder particles is imparted by high voltage applied to at least one electrode located inside the sprayer (İbakimya A.Ş., 2010).

- Powder coating particles are charged by negative charge with high voltage electric by means of gun terminal
- High electric field occurs between gun and substrate
- Charging process control more efficient
- Faraday cage effect may occur in angular, recessed surfaces
- Ensures high spay rate
- Requires less equipment
- Back ionization may occur when thick coating film applied and/or high voltage used (İbakimya A.Ş., 2010).

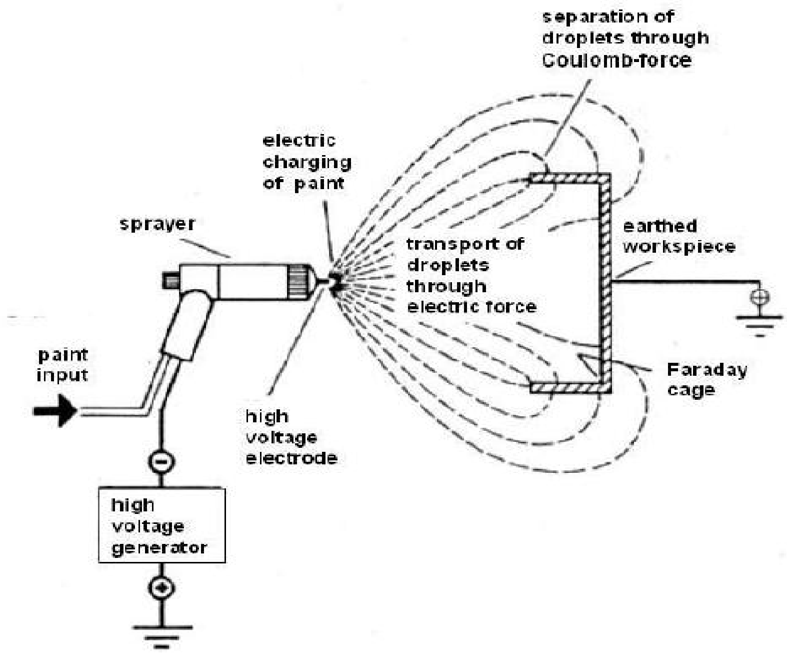


Figure 3.2 Electrostatic assisted spray for corona gun system

2.4.2 Tribo Gun System

Tribo charging guns operates with the principle of frictional charging. The construction of the tribo gun is very simple. It is in most cases a Teflon-made tube through which the powder coating is propelled by means of compressed air, exhibiting a turbulent flow inside the gun.The tube walls are earthed, so that the charge generated on the walls is permanently drained to the earth (İbakimya A.Ş., 2010).

- Powder coating particles charge positively by friction with Teflon surface
- Weak electric field forms between gun and the substrate
- Faraday cage is not formed
- Back ionization is less
- More sensitive to environmental effects (RH < % 40)
- Ensures low spray rate
- Requires more equipment
- Not suitable for metallic powder coatings application

Figure 3.3 Electrostatic assisted spray for tribo gun system

3.7 Wastes from Powder Coating

Wastes generated from powder coating manufacturing include the following:

- Equipment cleaning waste
- Air emissions of dust materials
- Pigment, resin etc. dust from air pollution control equipment
- Empty raw material packages, bags and containers
- Bags and cartridges from paint filtration equipment
- Powder coat that is "off-spec" (i.e., did not meet quality or customers specifications),
- Powder coating returned from the retailer (e.g., because it had exceeded its lifespan),
- Powder waste or raw materials from accidental spills and discharges.

Some of these wastes, such as off-spec and returned powder coatings, are commonly recycled and do not enter the waste stream.

Powder coating applications create a fine dust containing reparable particles in the working area. Powder coating spray application systems produce certain amount of waste particles which is not deposited on the part. Fluidized bed systems require extra powder coating materials to maintain proper levels in the dip chamber. The excess coating materials ultimately turn into waste.

Powder coating application systems may require preheating of work piece which consumes extra energy. Powder coating application systems create solid waste in the form of filters, masking materials, clothing, personnel protective equipment, and other materials. Liquid waste can be created from the water and solvents used for cleaning equipment such as coating receptacles, pumps, valves, and hoses.

Most powder coating manufacturers produce many different types and colors of paint, including both thermoplastic powders and thermosetting powders coating. Each type and color of paint is manufactured in a separate batch, and all manufacturing equipment is generally cleaned between batches different types or colors of paint to prevent contamination.

Equipment cleaning is the largest source of waste from paint manufacturing.

2.5.1 Sources of Pollution

Wastes originate from raw material warehouse, pre-mix unit, extruder, grinding, and packaging units. From the raw material warehouse and pre-mix unit typically emissions (dust), packages, wastewater and powder waste are generated. Extrusion unit produces powder waste (melts & chips waste, leaks etc.), plastic & nylon waste, contaminated absorbents, wastewater from cleaning of the container & equipments, and air emissions of dust materials. Grinding operations wastes are packages, powder waste that is off-spec, spillage etc., and air pollution control equipment, bags and cartridges from paint filtration equipment, and dust emissions. Finally, packaging unit generates cardboard, plastic & nylon and pallet waste, powder waste (spillage etc.), and powder waste from air pollution control equipment. The Figure 3.4 provides a general overview of the powder coating process and presents a waste flow diagram:

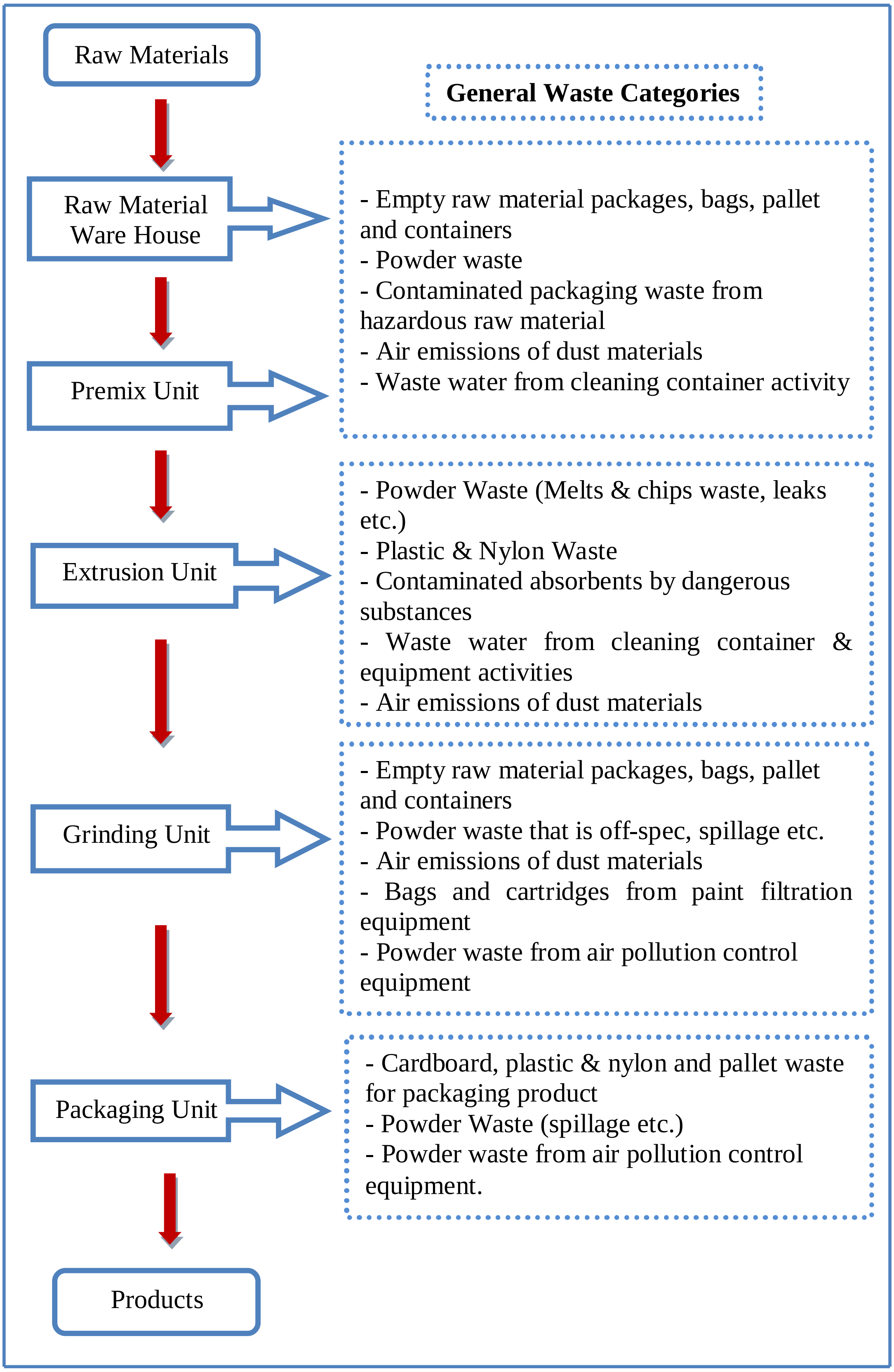


Figure 3.4Waste flow diagrams in powder coating manufacture

2.5.2 Waste Categories

Powder coating waste is officially classified as controlled waste and special waste. Additionally, the waste management industry has designated a third, unofficial category that is difficult waste (BFC British Coating Federation Ltd., 2000).

3.7.2.1. Controlled Wastes

All industrial wastes, including powder coating material no longer required or discarded from the process for disposal, are classified as controlled wastes, as defined in the Environmental Protection Act (EPA) and the Controlled Waste Regulations. (BFC British Coating Federation Ltd., 2000)

Anyone who imports, produces, carries keeps, treats or disposes of controlled waste has a “duty of care” under the EPA to:

- ensure the waste is safely contained and transferred only to an authorized person (usually a licensed waste carrier)
- complete and sign, and ensure recipients sign, transfer notes indicating the nature and disposal route of the waste
- keep transfer notes for two years (BFC British Coating Federation Ltd., 2000)

3.7.2.2. Special Wastes

Certain wastes, which are designated as being dangerous, are classified as special wastes and are subject to a greater level of control than other wastes, as set out in the Special Waste Regulations. As well as having to comply with the Duty of Care, the following additional requirements apply (BFC British Coating Federation Ltd., 2000):

- the Environment Agency (England and Wales) or SEPA (Scotland) or DoE(NI) (Northern Ireland) must be pre-notified of the nature of the waste and details of the intended transfer before the waste is moved from the site where it was generated

- a consignment note, with a unique number, purchased from the agency is normally used for pre-notification
- the remaining consignment note sheets are completed at each stage of the waste transfer chain
- The waste producer must keep his copy of the consignment note for a minimum of three years (BFC British Coating Federation Ltd., 2000).

Classification as Special Waste

A waste is classifiable as special, dependent on the percentage of hazardous substances present. Specific concentration thresholds apply and are related to the CHIP hazard classification of the particular substances. Essentially, the more hazardous the substance is the lower the threshold for classification as special of a waste containing that substance (BFC British Coating Federation Ltd., 2000).

In most cases, powder coating wastes do not meet the special waste criteria. However, three particular categories of wastes deserve more specific guidance (BFC British Coating Federation Ltd., 2000):

Triglycidyl Isocyanurate (TGIC): The Special Waste Regulations apply to triglycidyl isocyanurate (TGIC) containing powder coating wastes, when there is 3% or more of TGIC, by weight, in the waste. In the case of individual products, the safety data sheet will provide information on the TGIC content (BFC British Coating Federation Ltd., 2000).The regulations do not prevent the level of TGIC being reduced below the 3% threshold and thereby allowing the waste to be disposed of as controlled, rather than special waste. Whilst the decision on use of this option must rest with the producer of the waste in question, the following points of clarification and guidance are offered (BFC British Coating Federation Ltd., 2000):

- One way of reducing the TGIC content is by blending the TGIC waste with a non-TGIC containing powder. For this to be acceptable as a controlled waste, the whole amount must be of a uniform composition and any sample, whichmight be taken, has to contain less than 3% of TGIC. This can only be achieved by thoroughly mixing all components to ensure an even distribution. Thus a waste consisting of 10 boxes of powder containing 4% TGIC and 10 with TGIC-free powder would be a special waste; 20 boxes of the material evenly blended together would not be.

- If wastes are to be mixed before disposal, due regard must be given to the requirements of the COSHH Regulations i.e. to carry out a risk assessment and to ensure the appropriate protection of those carrying out the mixing and of others in the vicinity.

- Another way of reducing the TGIC content is by chemically converting the TGIC in the powder. Powder coaters should be aware that the already-established practice of placing part-used or full boxes of powder in stoving ovens and "solidifying" the contents is not necessarily an appropriate form of treatment.

Whilst suitable for eliminating dusts created in the general handling of wastes, by sealing the outer surface of the material, it is only of value here, if it can be proved that the level of TGIC is reduced below the 3% threshold. Arguments that the TGIC is "locked" in a fused matrix are not acceptable to the authorities. The absence of TGIC can only be achieved by chemically reacting all the TGIC present throughout the melt of the waste, with other components of the powder coating. Although this is theoretically possible, the following points need to be taken into account (BFC British Coating Federation Ltd., 2000):

- to achieve the necessary reaction conditions, the powder must be heated to, and held at, the curing temperature required for normal film curing (up to 200oC). The time required for the material to be held at this temperature will be significantly longer than in the normal curing cycle, as the TGIC content has to be reduced below 3% throughout the melt, particularly at the centre. It should be noted even if the centre is "solid", that the TGIC has notnecessarily reacted. Coatings manufacturers are not in a position to give any advice on appropriate schedules for such activities, which are outside the intended uses of the material, as supplied

- there is a potential fire risk involved in placing flammable packaging materials, such as cardboard boxes and plastic inner bags in stoving ovens for any period of time

- any evaluation/testing of a waste subjected to the above process, to demonstrate reaction of the TGIC content, would only be valid for that particular configuration of product/pack size/quantity/oven conditions. Variation to any of these would require re-evaluation.

Irritant Substances:Certain powder coatings may contain cross-linking substances that are classified as irritant (if present, these will be listed in Section 2 of the product safety data sheet, with the Xi notation). Whilst the Special Waste Regulations apply to waste containing irritant substances, the threshold for classification as special is that 20% or more of substances assigned the risk phrases R36, R37 or R38 has to be present (BFC British Coating Federation Ltd., 2000).This is far higher than the cross-linker levels found in powder coatings (typically 4-6%, maximum 9%), and thus such wastes will not be classifiable as special

Lead Chromates:Whilst lead chromate containing powder coatings may be classified and labeled as toxic, the criteria do not lead to wastes containing these substances being classified as special wastes. However, the waste management industry designates these as difficult wastes (see 3.5.3) and both powder and empty packaging is usually required to be disposed of as if they were special wastes (BFC British Coating Federation Ltd., 2000).

3.7.2.3. Difficult Wastes

The waste management industry has introduced this designation for wastes that are not officially classifiable as special wastes (i.e. do not meet the relevant compositional criteria or exhibit flammable, explosive etc properties), but which that industry considers should be subject to a comparable level of control (BFC British Coating Federation Ltd., 2000).

3.8 Pollution Prevention in the Coating Industry

As it indicated in the previous chapter, pollution prevention, or P2, means preventing wastes rather than using expensive treatment and control technologies on end-of-pipe wastes. It may be as simple as preventing spills and leaks through better housekeeping and maintenance, or as complex as switching solvent-cleaning systems.

Paint application wastes include leftover paints, dirty thinner from cleaning spray guns and paint cups, air emissions of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs), dirty spray booth filters, dirty rags, and disposal of outdated supplies. In order to reduce these wastes inventory control, proper maintenances (cleaning), control of the paint mixing considering the requirements, operator training, appropriate cleaning methods, use of alternative coatings, use of styrofoam filters, recycling of solvents on and off site, and using waste exchanges, are offered. Considering the reduction possibilities, a waste hierarchy in the coating industry may be defined as indicated in Figure 3.5. As can be seen in the figure, waste management efforts are focused on the waste reduction and reuse-recycling studies. Source reduction efforts are realized by inventory control, better management, operator training, transferring of high efficient equipment, using of alternative coatings, and better cleaning methods measures. Besides the wastes minimization at source, recycling and reuse of solvents both on and off-site, and waste exchange supports the reduction in wastes quantities and types, as well.

Following to these stages, finally, wastes that can't be recycled or reused are disposed of considering the legal requirements.

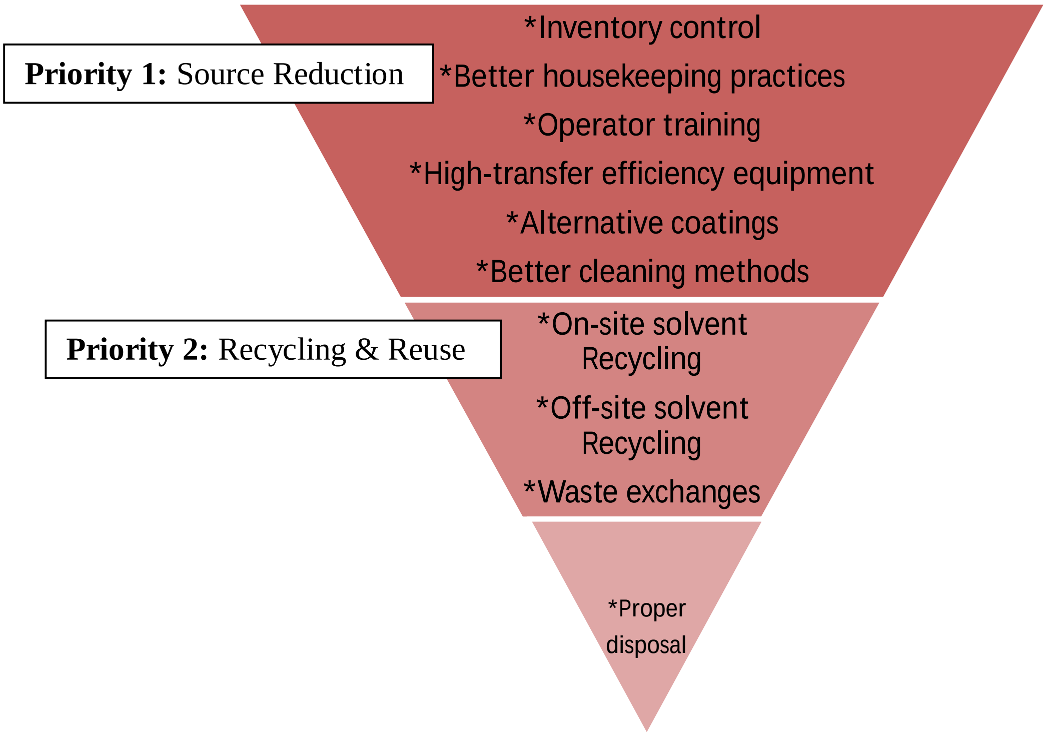


Figure 3.5 Hierarchy of pollution prevention strategies for coating operations

Better operating practices or management applies to all waste streams and requires minimal capital investment, andmay be very effective in the waste reduction. The effectiveness of such efforts is strongly connected to the employee awareness on the benefits of pollution prevention, and preventive measures taken for leaks and spills.

Wastes assessments help identify the waste quantities and waste types generated in the facility. Definition of waste quantities and types are essential to organize the study and determine the places taken measures for waste reduction. Any waste management program is an organized and continuous effort to systematically reduce waste generation, and should reflect the goals and policies of management. An effective program also includes the involvement and enthusiasm of employees, especially those who have an understanding of the processes being examined.

Waste reduction options especially for paint manufacturers include the following (Center for Economics Research, 1992):

- using less toxic raw materials;
- using less toxic cleaning solutions
- using less cleaning solutions by using mechanical cleaning methods, and by scheduling paint batches to reduce the number of times equipment must be cleaned;
- reusing cleaning solutions by adding as a raw material in a compatible batch or recovering organic solvents, if applicable;
- redesigning equipment and storage tanks to reduce VOC emissions; and
- implementing quality controls to reduce off-spec and returned paint, and relending any off-spec or returned paints that are generated (Center for Economics Research, 1992)

These waste reduction options do not apply to all paint manufacturing operations. The greatest barriers to implementing these changes are customer and quality specification. (Center for Economics Research, 1992).

Powder coating application systems provide pollution prevention over traditional spray application systems due to the higher transfer efficiency (above 90%), and very low volatilization of organic solvents.Booth recovery systems collect overspray powder particles from the exhaust air so that they may be reused. Thus, installing a booth recovery system for electrostatic spraying and flocking applications may provide reduction in powder particles in a certain extent.

Reduce or eliminate contamination of coatings are achieved by enclosing and covering work areas.

Scheduling of the painting is used to minimize the powder quantities, as well. For instance, during the application, painting with light colors should be applied at first, and then darker ones should be achieved. Lighter coating does not need to be completely removed from the equipment, but can blend into the darker coating.

Modified consecutive powder coating systems are applied for different coating materials. The distance between the streams are increased and separate recovery systems are used for each to keep the different coating materials in order to separate, thereby allowing them to be reused.

Powder coating application equipment is cleaned regularly to prevent build-up of coating materials. Moreover, water is used in cleaning steps in order to reduce the amount of organic solvents and hazardous wastes.

Non-hazardous coating solids and water are segregated from hazardous solvents and thinners, and label containers to prevent mixing. Separation of the materials reduces the amount of hazardous waste. Coating material solids can be dried and treated as a solid waste disposing at landfill site.

Powder coating application equipment is maintained to sustain proper operation. It is of great importance to make sure valves, gauges, pumps, and filters are in proper working order. Powder coating application areas should be cleaned so that problems with equipment can be found and fixed quickly, and accidents can be prevented.

Employees are also trained about on safe handling of materials and wastes and they are encouraged to sustain continuous improvement. Training familiarizes workers with their responsibilities, which reduces spills and accidents.

CHAPTER FOUR
WASTE MINIMIZATION STUDY IN A POWDER COATINGS MANUFACTURING PLANT

4.1 Methodology

The objective of the study is to reduce the wastes produced from the powder coating industry. A powder coating producer located in Izmir is selected as an example. In order to minimize the wastes, an inventory of wastes, i.e. quantities and waste sources were carried out, as first. Then, wastes were categorized considering their types and characteristics, and disposal methods. The priority areas which would be focused for minimization were determined considering the waste quantity, and reuse and recycle capabilities. In this framework, factors affecting the waste quantities were determined together with the control measures. In this chapter, the manufacturing processes of the plant were presented together with the waste sources. And, minimization studies are explained in detail.

4.2 Manufacturing Processes and Wastes

The production of powder coating is complex process involving dispersion of pigments and additives into a mixture of resin and hardener, followed by relatively simple mixing operations. In the examined plant, processes used in the production are material preparation, filling, pre-mixing, extruding, milling and classification and packaging. The basic process diagram of the plant is presented in Figure 4.1.

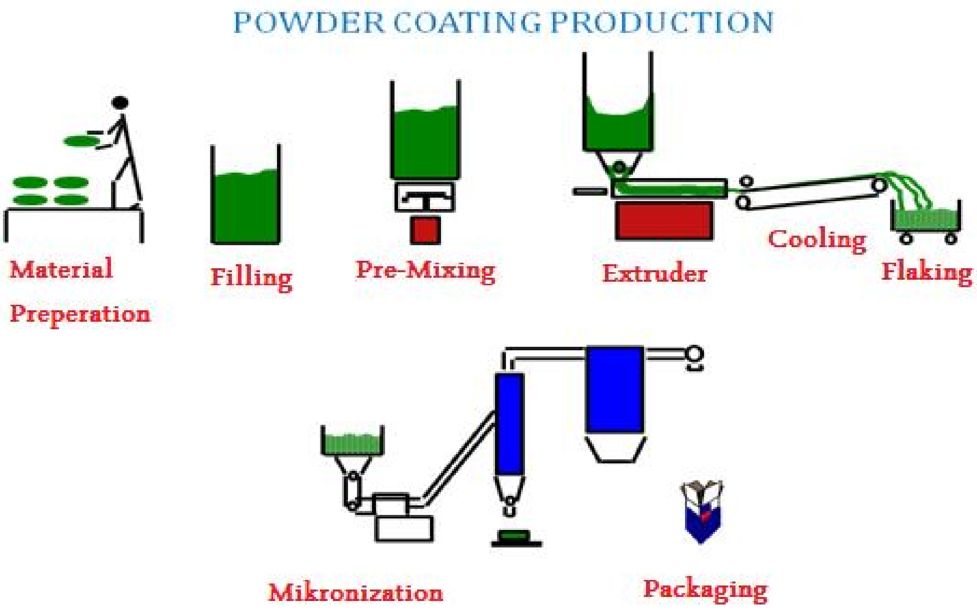


Figure 4.1 Stages of powder coating production

Generally, powder coatings are made by mixing the basic polymer with charge agents and other additives and then heating until they form a melt. Themixture is then extruded into chips or pellets by grinder. The powder passes through a single or double cyclone separator in order to remove very fine particles. The coarse product is then removed from the bottom of the cyclone and bagged directly. The fines are collected separately to be recycled. In many cases, grinding is done in batch runs to switch the operation for variety of coating products.Color is added to powder coatings during the manufacturing process, i.e. before the powder reaches the powder coater.

The processes used in the production together with the waste sources are explained in detail in this chapter.

3.2.1 Material Preparation & Filling

Raw materials written in the formula for production are resin and hardener, contribution, sealant, and pigment. All materials are placed onto an empty pallet and are respectively poured into the premix boiler as **Resin – titan – sealant – other materials – titan – sealant – resin**

3.2.2 Pre-mixing & Dry Blending

Following the material preparation, weighed dry powders are mixed to prepare a homogenous mixture of the raw materials prior to extrusion. Color-matching adjustments are also made in the pre-mixing stage. The photograph of premix is presented in Figure 4.2. Small quantities of water are used for pre-mixing unit cleaning. The wastewater generated from pre-mixing unit cleaning is collected and treated in the plant.

Figure 4.2 Photograph of premix (i.e. resin, titan, sealant, and other materials)

3.2.3 Extrusion

Premix is then transferred into the extruder and is compacted and heated until it melts. Shear forces break down the pigment aggregates to form a homogenous dispersion which is subsequently discharged from the extruder. The zone of a typical extruder used in powder coating production is exhibited in Figure 4.3.

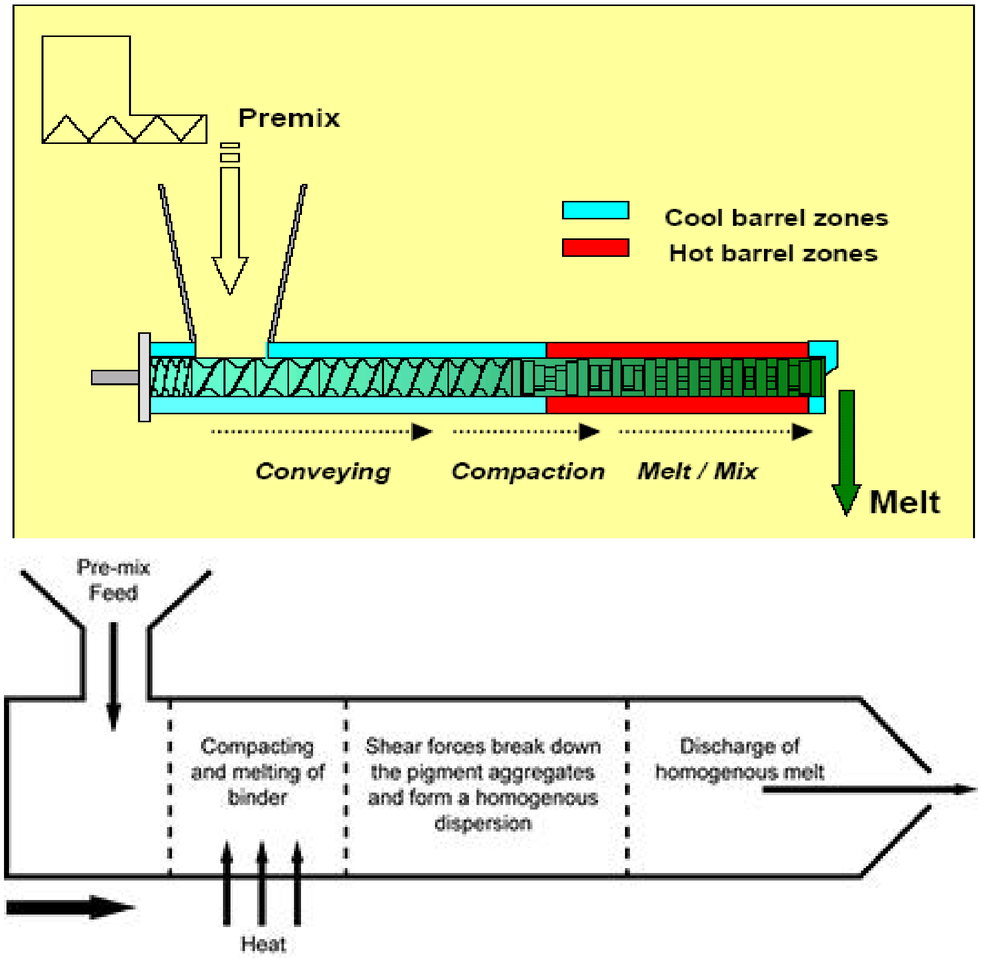


Figure 4.3 Extruder processing zones

Then, melted mixtureis converted to cool, hard, brittle strips by rollers. Depending on the size (capacity) of the extruder and its production rate, extrude may be further cooled on a cooling band. The photograph of extruder cooling band is indicated in Figure 4.4.

Figure 4.4 Photograph of extruder cooling band

The extrude is pieced into small flakes (called kibble) around 5 to 15 mm in diameter by using rotating hammers installed at the end of the cooling part. Figure 4.5 shows the powder coating chips after the extrusion processes. Toner powders are sometimes further pulverized down to between 50 to 250μm to give a product called as “kneaded toner”. Cleaning of the extruder is achieved by using PVC (cleaning agent) or resin. 5 kg of PVC or resin are used at each batch to clean the screw in the extruder, and then contamination on the surface of the machine is removed by flushing of water.

Figure 4.5 Photograph of powder coating chips

3.2.4 Milling &Classification

The final stages of the manufacturing process are milling or grinding, and classification. The aim of the grinding process is to produce a powder having a homogeneous particle size distribution. Because, existence of very fine or large particles within the mixture, result with negative impacts on the powder coating process.

Kibble or kneaded toner is transferred from a feed hopper into the mill/pulverizer by a screw feed. This screw further reduces the product size as it feeds the mill. The chips are carried by air stream into the milling stage(s) and they are crushed to a fine powder by a rotating disc. Classification of the particles in the powdered form is done by air-classifier. Particles are transferred to the air classifier by centrifugal and driving forces, and then classified to their sizes. Figure 4.6 shows the photograph of the powder coating dust.

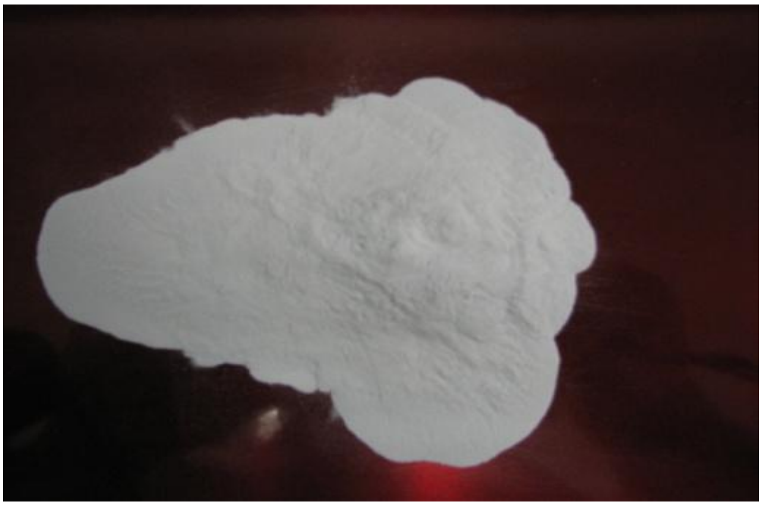


Figure 4.6 Photograph of powder coating dust

The milled powder is transferred from the mill/pulverizer on an air stream designed to ensure that oversized particles drop down for return to the milling chamber. Particle size distribution is effectively controlled using a combination of rate of feed and mill parameters such as speed of rotating pin disc and/or air velocity.

In toner applications either cyclonic or mechanical wheel separation is used to separate the oversize particles for further milling. Most toner manufacturing plants have between 2 to 4 classification stages to deliver the final particle distribution needed. Powder transport at each classification stage is done by vacuum transfer. The transport air is separated from the powder using either cyclonic or mechanical wheel separation. The extracted air is filtered to remove any unwanted fine powder.

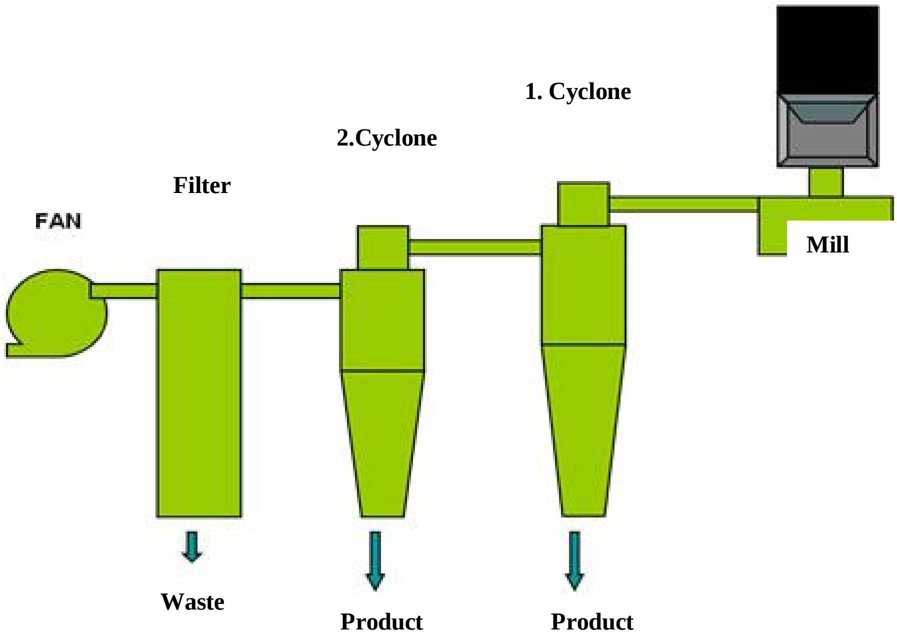


Figure 4.7Stages of milling/grinding process

3.2.5 Collection / Packaging

The milled/classified powder is then transferred to a collection chamber. This may be a cyclone in which powder falls to the bottom whilst air is exhausted from the top, filtered and then exhausted to atmosphere, or a bag filter system. From the filter system waste is produced. In toner applications the powder is generally collected in a weighing vessel. This allows batch processing with other additives (such as silicates) which are required for the copy process. These additives are fed by separate screw feed system and the batches are mixed together mechanically then discharged to the packing stage. Finished powder generally undergoes a final sieving process to remove any possible contaminants before being packed ready for sale or use.

The flow diagrams of the powder coating processes applied in the Izmir plant is presented in Figure 4.8 together with wastes. The parenthesis used in the boxes defines the waste categories. In the examined plant, wastes generated from the processes were classified 6 categories. These are;

1) Powder waste originated from each process stage, i.e. material preparation, filling, pre-mixing, extruding, milling, and packaging.
2) Packaging wastes (i.e. paper) obtained from the raw material packages are generated from material preparation, filling, and milling.
3) Cartoon wastes (25 kg packages) are originated only from the packaging.
4) Metal wastes are originated only from the extruder due to the maintenance operations.
5) Packaging wastes (i.e. plastic, nylon) obtained from the raw material packages are generated from material preparation, filling, milling (nylon casing is used for dust contamination in container), and packaging.
6) Hazardous wastes are originated from each stage

Besides the manufacturing processes, Research &Development (R & D) Department in the examined plat produces certain wastes. Because, R & D Department has responsibility for modification of existing functional formulations considering the customer needs or production needs in cooperation. Therefore, R&D department is responsible from powder preparation, spraying, testing, and evaluation of powder coatings to meet specific project requirements, from product transfer documentation including formulations and specifications, etc. In order to investigate these properties and develop the coating process, routine tests are carried out. As results of these studies, certain amounts of wastes are produced during the material preparation, premixing and milling stages.

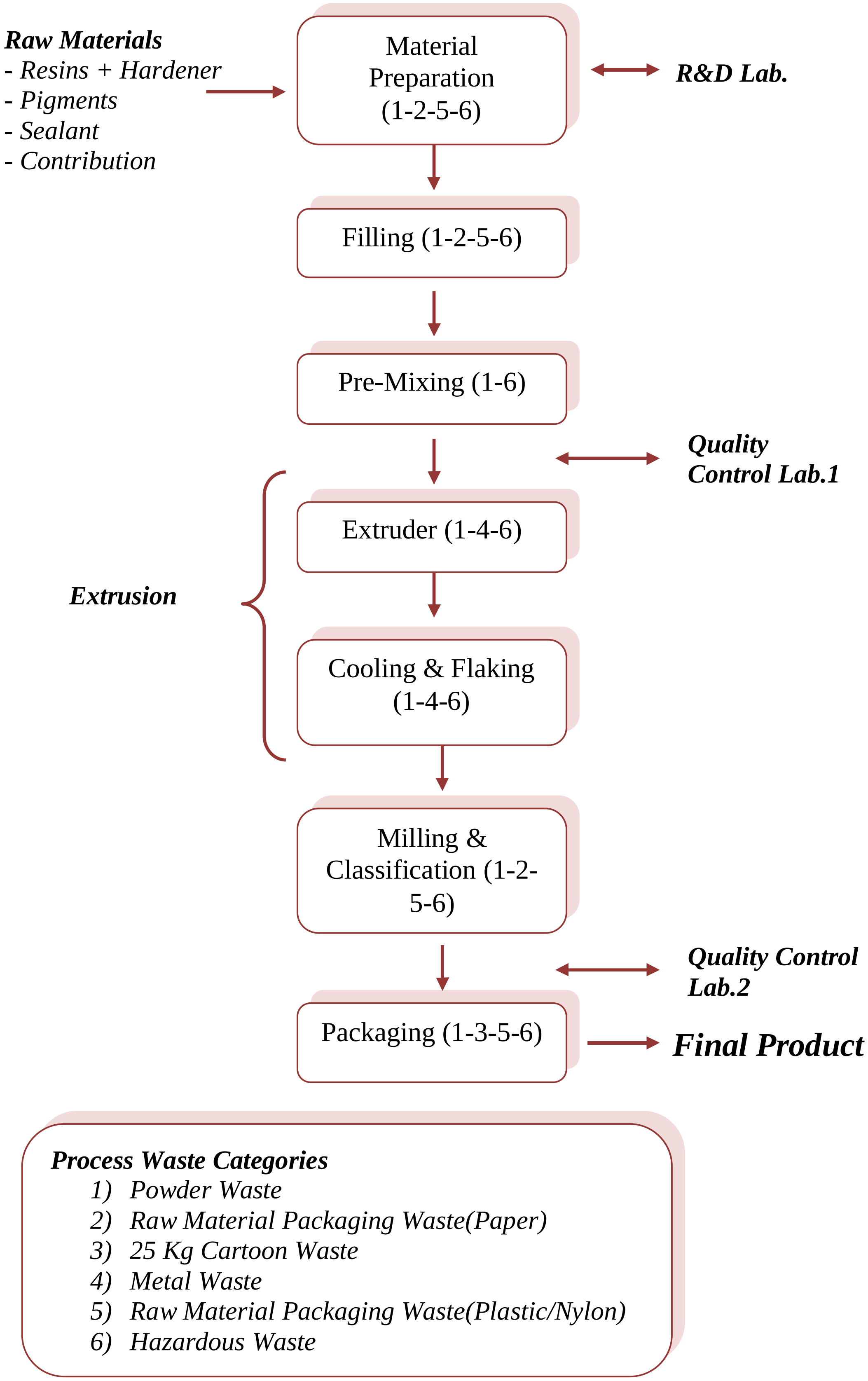


Figure 4.8 Flow diagrams for powder coating manufacture

As it can see from the Figure 4.8., wastes are generated at each stage of the powder coating manufacturing process. According to the raw material inventory, certain amounts of material are lost due to spills, spoilage, and obsolescence. In addition, off-specification powder coatings due to errors in the manufacturingare produced and they virtually are accepted as waste.

Equipment clean-up is another source of waste generation. Equipment must be cleaned in the manufacture after each batch especially for the paints having different formula. In the examined plant, resin and PVC (Polyvinyl chloride) has been primarily used for equipment clean-up.

A number of waste reduction methods for cleaning wastes were started to implement in the plant. For example, Resins or PVC has been used for cleaning of the extruder. These materials have been returned to the extruder cooling band providing the chips and then reused in the paint sector. Another waste reduction method in equipment cleaning is the schedule production to minimize cleaning wastes. In order to protect the paint contamination after each party (batch), surface of the machine is cleaned and thus wastewater is produced. During the cleaning of the screw in the extruder, melt wastes are generated due to resin and PVC consumption. Cleaning repetition can be reduced by circulation similar products in same lines, and then wastes of cleaning equipment can be decreased by effective scheduling. Finally, standardization of resin and PVC quantities resulted with the reductions in cleaning wastes. Increasing doses of cleaning agents results with increase in the melt wastes. Therefore, in the plant, a standardized pot for every line is defined and used by the operator.

Table 4.1 Waste reduction methods at this plant

Waste Streams	**Waste Reduction Method**
- Equipment cleaning waste	- Use of the retreated equipment cleaning waste - Schedule production to minimize cleaning - Standardized the amount of resin and PVC

4.3 Attempts for Minimization

The inventory study on waste quantities and sources pointed out among the various wastes, powder waste was the highest ones. Besides, extruder unit was the main source of the powder waste. Thus, minimization efforts were initiated at the extruder unit.

3.3.1 Minimization of the Extruder Wastes

In extrusion, cleaning of the extruder is an important issue for product quality. Resin is used for cleaning of the extruder barrels at the end of each batch. Since resin is used for cleaning, the melt wastes are generated. Melt extrude from cleaning and start-up processes of extruders have been discharged directly to the floor. Before the project, these cleaning resins were sent to incineration facilities as non-hazardous waste. The photograph of melt / melt wastes are indicated in Figure 4.10.

Figure 4.9 Photograph of extruder cleaning with resin and PVC

Figure 4.10 Photograph of extruder melts/melts

Besides the cleaning resins, certain amounts of chip particles (see Figure 4.11) were left in the extruder kibble unit and chips residuals from extruder cooling band at the end of each batch. Chip particles and residues have been collected as waste from extruder kibble unit and cooling band via water jet injection. In the project, a new tank having a mesh was designed to separate the water and chips. The chips stored on the surface of the mesh were collected and reused as second quality products. The view of the new tank is presented in Figure 4.12 and 4.13.

Figure 4.11 Photograph of extruder chips

Figure 4.12General view of the machine

Figure 4.13Cleaning of the kibble with water jet

Figure 4.14 Cleaning resins collected in the new container (tank)

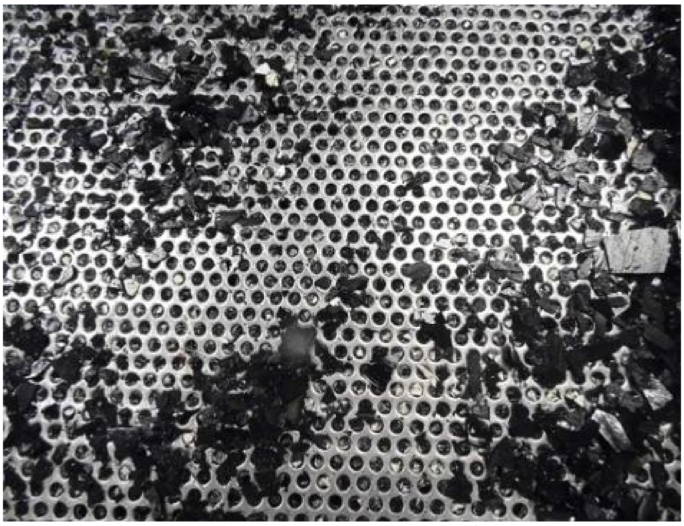


Figure 4.15Resins on the surface of the mesh

3.3.2 Minimization of Packaging Wastes

The packaging wastes, i.e. paper/cartoon waste, metal waste, plastic/nylon waste, and pellet wastes were second highest waste group. Therefore, minimization efforts were also carried out for packaging wastes. In the facility, resins have been purchased by both in big bags and in nylon packages. Nylon packages have been sold to the third partieshaving a license from the government for recycle. The big bags are not disposed as waste. They have been reused to store the fines from mill filters, i.e. dust collectors in mill filters.

In the project, 4 big bag discharging units were installed (see Figure 4.16). The discharge systems were equipped with lifting gear and a big bag connection system with a press-on lid or inflatable collar. Installation of the big bag discharging system resulted with the purchasing of the polyester resins in big bags and reduction in the plastic/nylon packages.

Figure 4.16Photos of big bag discharge unit projects

Besides the plastic packages, pallet which is a flat transport structure supports goods while being lifted by a forklift, pallet jack, front loader, work saver or other jacking device has been used in the plant. In the project, reuse of incoming pallets and minimization of the pallet wastes by optimizing and standardizing the type of the incoming & outgoing pallets was intended.

3.3.3 Minimization of Resin

The powder ratio of resins is one of the important factors in powder coating wastes. Therefore, particle size distribution of various resins was investigated by sieve analysis (see Figure 4.17). Dust rate of various resin samples was determined and the resins having lowest dust ratio was expressed.

Figure 4.17 Photograph of sieve (250 micron)

3.3.4 Sample Size Standardization

Samples of resins used in the powder coating production has been tested and investigated in Research &Development and Quality Control (QC) Laboratories. In the project, standardization of samples was achieved for the favorite products. This was the first stage of the minimization study. The ultimate goal was the waste reduction in samplings. However, in thesis, increasing of the awareness was intended.

3.3.5 Efficient Utilization of the Electricity

In the examined plant, energy - efficient lighting, i.e. light-emitting diodes (LEDs) was implemented in warehouse, to save the energy consumption.

CHAPTER FIVE
RESULTS AND DISCUSSIONS

5.1 Waste Quantity and Type

As it stated in previous chapter, in order to minimize the wastes, an inventory of wastes, i.e. quantities and waste sources were carried out, as first. The wastes collected in the plant through 12 months are presented in Table 5.1 together with their codes, types, disposal methods, etc. Waste codes are taken from the European Waste Codes (EWC). Disposal methods are defined considering to method applied currently in the plant. R1 defines disposal by incineration with heat recovery. R12 means that exchange of wastes for submission to any of the operations numbered R1-R11Powder waste has been generated at each process step and is generated at highest ratio in the plant. In the year of 2013, the amount of powder waste was 265.000 kg. Approximately, 47% of whole wastes were powder wastes. Paper and cartoon wastes are especially generated form material preparation, filling, milling, and packaging stages. The amount of waste paper and packaging was 146.000 kg in yearly basis that corresponds 26% of total wastes. Plastic/nylon and metal wastes were also high. Their quantities were 90.000 kg/year for plastic wastes and 40.000 kg/year for metal wastes. Approximately 95% of total wastes were powder wastes, waste paper and packaging waste, and plastic/nylon and metal wastes. In addition to these, waste oil, e-wastes, waste batteries, cable wastes, contaminated wiping cloths and protective clothing, treatment plant sludge were produced at minor quantities. The graphical representation of waste quantities is shown in Figure 5.1. The examination of the waste quantities and their sources provided data for waste management activities in the plant. Since the results of the inventory study on waste quantities and sources pointed out powder waste was the highest ones and extruder unit was the main source of the powder waste, minimization efforts were initiated at the extruder unit. Besides, higher amounts of packaging wastes were required that the measures taken in that area.

Table 5.1 Waste generation in the examined plant through 2013

Waste Code	Types of Waste Produced	Sub - Categories of Waste Type	Hazardous/ Non-hazardous	Disposal Method	Waste Quantity (kg/year)
08 01 12	Powder Waste	- Treatment Chips - Outside Space Spillage - Extruder Melt & Chips - Scrape Powder Waste - R&D (Lab-1) Powder Waste - QC (Lab-2) Powder Waste - Material Preparation Powder Waste - Pre-Mixing Powder Waste	NH	R1	363.790 Kg
15 02 02	Contaminated Wiping Cloths & Protective Clothing	-	H	R12	3.620 Kg
20 01 01 & 15 01 01	Paper and Cardboard & Packaging Waste	25 Kg Cartoon Box (KL25) Waste Paper Packaging Waste	NH	Recycling	201.715 Kg
13 02 05	Oil Waste	-	H	R12	6.140 Kg
16 02 13	Electrical & Electronic Waste	-	H	R12	1.200 Kg
16 06 01	Battery Waste	-	H	R12	3.420 Kg
20 01 39 & 15 01 02	Plastic/Nylon Waste & Plastic/Nylon Packaging Waste	-	NH	Recycling	106.320 Kg

Table 5.1 Waste generation in the examined plant through 2013 (Continued)

IZMIR - WASTE DEFINATION & CATEGORIES					
Waste Code	**Types of Waste Produced**	**Sub - Categories of Waste Type**	**Hazardous/ Non-hazardous**	**Disposal Method**	**Amount of Waste (kg/year)**
20 01 40	Metal Waste	- Metal Aluminum Panel Waste - Metal Packaging Waste - Metal Scrap Waste	NH	Recycling	62.740 Kg
08 01 16	Treatment Sludge	-	NH	R1	19.220 Kg
17 04 11	Cable Waste	-	NH	Recycling	2.940 Kg
15 01 03	Pallet Waste	- Coming with raw materials	NH	Recycling	5.000 Kg

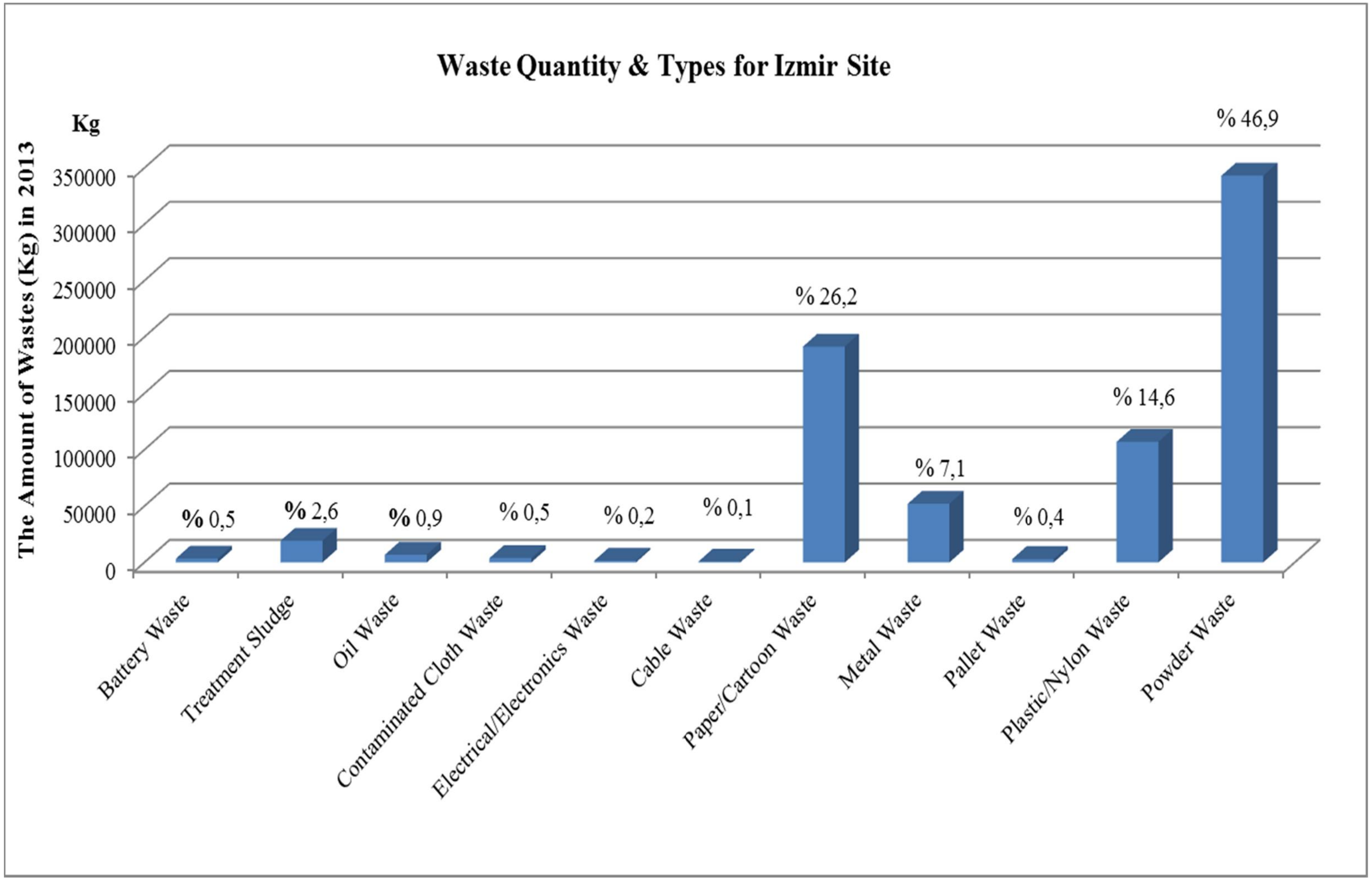


Figure 5.1 The graphical representation of waste quantities generated at examined plant for 2013

Considering data given in Table 5.1, hazardousness properties of the waste are produced. The variation of the waste quantities with respect to months is presented in Table 5.2, and depicted in Figure 5.2. Among the various types of wastes generated in the site, contaminated wiping cloths and protective clothing, waste oil, e-wastes, and batteries were defined as hazardous. The amount of the hazardous wastes produced through 2013 was 14.380 kg whilst 761.745 kg non-hazardous wastes were produced in a year.

Table 5.2 Hazardous and nonhazardous waste quantities in the examined plant

2013	Hazardous Waste (Kg)	% Hazardous Waste	Non-Hazardous Waste(Kg)	% Non-Hazardous Waste	Total Waste (Kg)
January	1500	2.51	58300	97.49	59800
February	5520	9.37	53420	90.63	58940
March	0	0.00	65220	100.00	65220
April	740	1.96	36980	98.04	37720
May	0	0.00	64640	100.00	64640
June	620	1.32	46365	98.68	46985
July	1580	2.12	73070	97.88	74650
August	0	0.00	61400	100.00	61400
September	0	0.00	77120	100.00	77120
October	4420	6.65	62050	93.35	66470
November	0	0.00	69760	100.00	69760
December	0	0.00	93400	100.00	93400
Total Waste(Kg)	**14380**	**1.85**	**761745**	**98.15**	**776105**

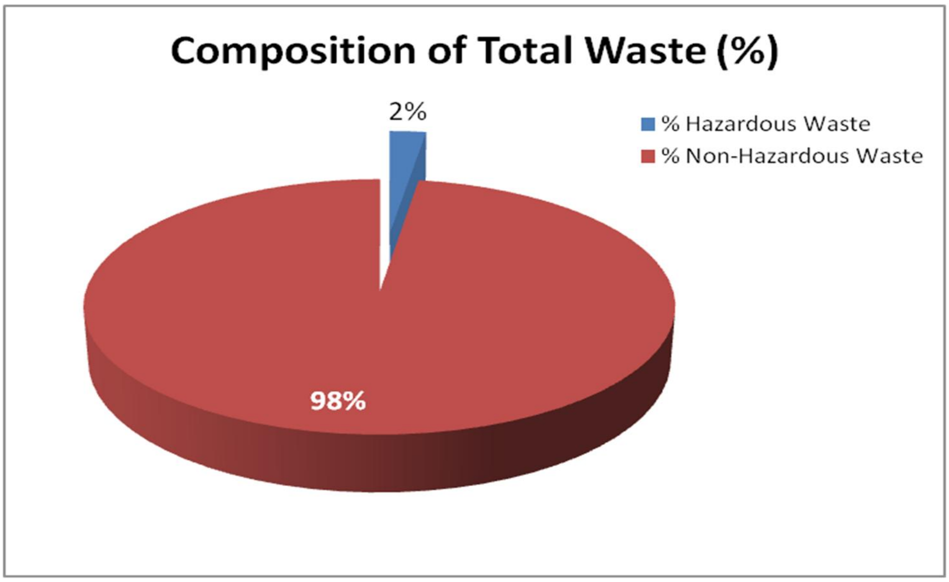


Figure 5.2 Ratio of hazardous and non-hazardous waste production in the examined plant

The non-hazardous wastes consist of powder wastes which was the highest ones, paper and cardboard packaging wastes, plastic/nylon packaging wastes, metal wastes, cable wastes, and treatment plant sludge. Approximately, 98% of the total waste was non-hazardous and have recycling and re-use potential. The variation of non-hazardous waste production with respect to months is shown in Figure 5.3.

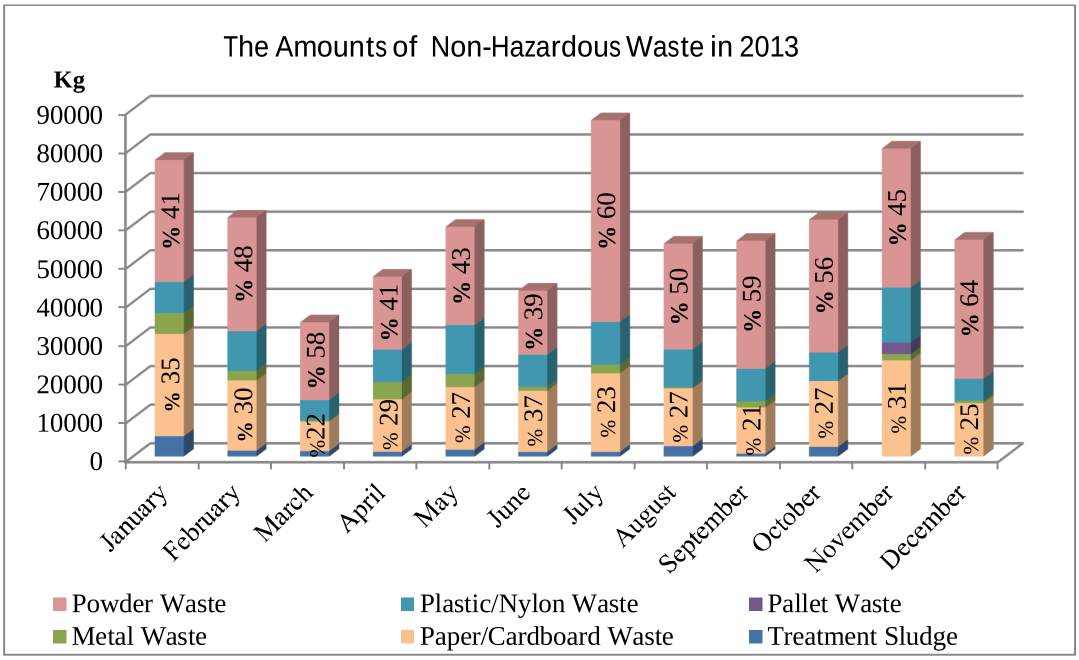


Figure 5.3 Monthly variations of non-hazardous waste quantities

In order to identify the main sources of powder wastes, they were collected separately in the thesis, and thus composition of the powder waste was determined. As can be seen in Figure 5.4, 52% of powder wastes were extruder bulk and chips and collected from the extruder. Dust collectors (10, 4, 2, 8, 3) were also produced certain amounts of powder waste form different units, however, analyzing of these waste considering their source was not carried out. Besides, the particles in the equipment cleaning wastewater have been settled in the channels. These channels are cleaned at weekly and the solid material, i.e. channel sludge, is disposed together with the powder waste. Finally, laborites used for research and development facilities and quality control studies contribute the amounts of powder wastes in a certain extent. Therefore, extruder unit is required special attention in the thesis to take measures for waste minimization purpose.

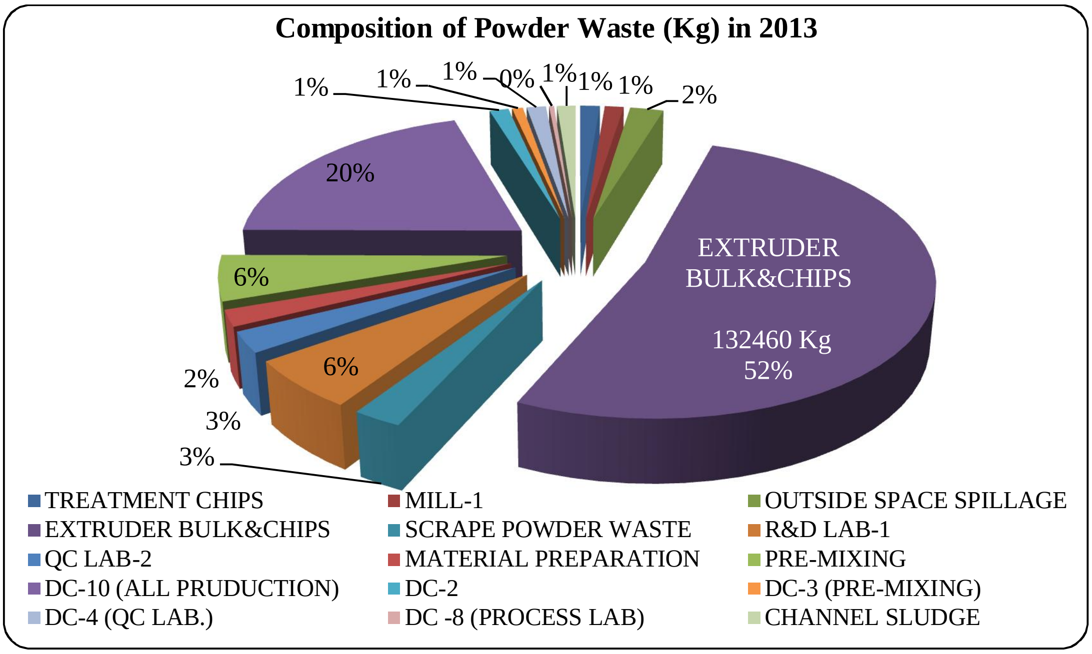


Figure 5.4 Composition of powder waste (kg) in 2013

5.2 Extruder Wastes Reduction

In the project, as it explained in previous chapter, a new tank having a mesh on its surface was designed to separate the chips. The chips stored on the surface of the mesh were collected and reused as second quality products. These efforts were initiated in January 2013. The quantity of extruder melts and chips was measured during the January and June, 2013, and then compared with previous year at the same months. The amount of the extruder melts and chips wastes were measured as 107.630 kg as totally through January and June 2012. After the implementation of the project, total amount of extruder melts and chips wastes were reduced to 71.930 kg which yield 40% reduction in wastes.

Table 5.3 Extruder melts & chips generations during the 2012-2013

2012	January	February	March	April	May	June
Powder Waste (Kg)	33360	60540	75920	45160	61200	36480
Extruder Melt &Chips Wastes (Kg)	20765	15995	16050	15655	20845	18320
The ratio of the extruder melt &chips Wastes in whole powder waste (%)	**62.25**	**26.42**	**21.14**	**34.67**	**34.06**	**50.22**

2013	January	February	March	April	May	June
Powder Waste (Kg)	29100	20400	29460	16780	23240	22020
Extruder Melt &Chips Wastes (Kg)	15040	14350	8360	8905	14330	10945
The ratio of the extruder melt &chips Wastes in whole powder waste (%)	**51.68**	**70.34**	**28.38**	**53.07**	**61.66**	**49.70**
Improvement of Reduction Amount of Extruder Melt &Chips Wastes (%) (According to 2012)	**27.57**	**10.28**	**47.91**	**43.11**	**31.25**	**40.26**

Reductions in extruder melts and chips are depicted graphically in Figure 5.5. The total amount of extruder melts & chips wastes were reduced by average 40% which is compared to 2nd quarter of 2012.

Economic analysis of the improvement was also performed in the thesis. The amount of the resin used for cleaning was 1. 5 tons/month. Cleaning process was repeated approximately 350 times in a month and 5 kg resin was used in each batch. In the project, 8 kg waste (yield) per batch as an average would be reused as second quality product. Therefore, the amount of waste was estimated asapproximately

18.500 kg for 357 batches in 2013.Re-using of waste chips (i.e. 18 tons waste per year)are expected to provide improvement in the waste performance and carbon footprint instead of dispose of.Using of these wastes provides reduction in raw material consumption and disposal costs, as well. The expected saving is determined as 51.750 € in the project and calculations are presented in Table 5.4 and 5.5.

Table 5.4 The amount of extruder melts & chips wastes in 2013

	Num. of Batches Produced	**Average Batch Size (2013)**	**Excluding Texture Coatings – (%20 of Total Production)**	**Avg. Yield Per Batch**	**Total Estimated Avg. Yield (2013)**
January	**409**	**357**	**289**	**8 Kg**	**18.500 kg**
February	**358**				
April	**304**				

Table 5.5The expected saving (in Euro)

Economic Aspects of This Project	**(€ / Kg)**	**Avg. Amount of Reduction Melt Waste (Kg)**	**The Expected Saving (€)**
The Raw Material Price	2,8 € / Kg	18.000 Kg	50.400 €
The Disposal Price	0,075 €	18.000 Kg	1.350 €
		TOTAL	**51.750 €**

5.3 Reduction in Packaging wastes

Since the packaging wastes in the examined plant were high, taking certain measures to reduce them was intended. The variations of packaging wastes throughout 2010-2013 are presented in Figure 5.5.

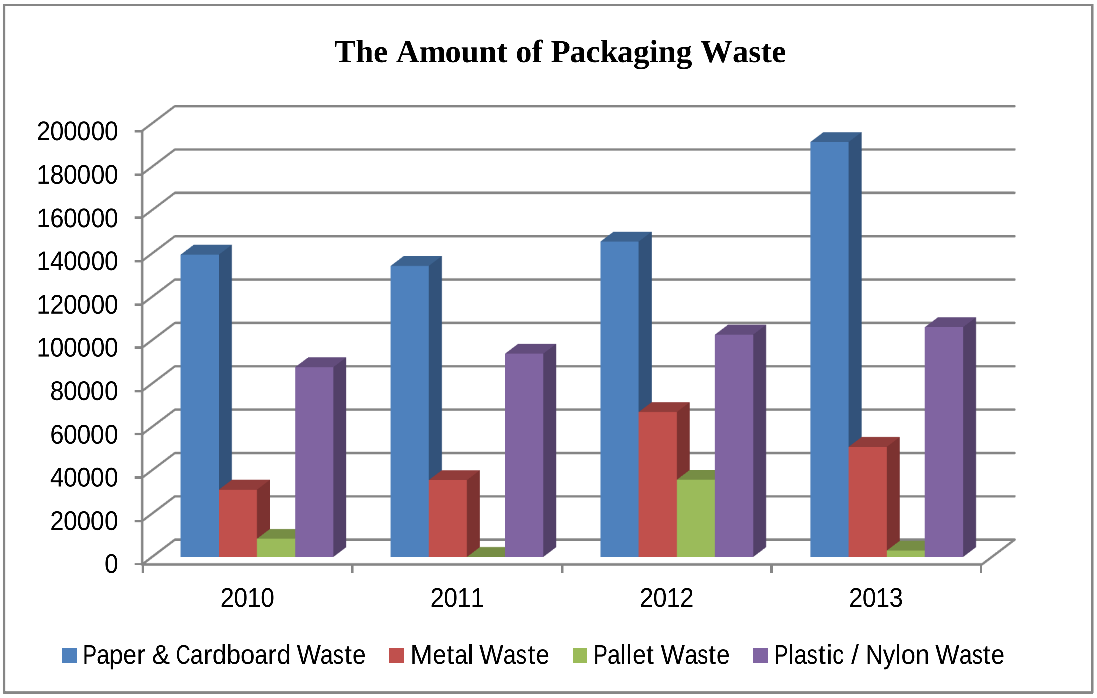


Figure 5.5Variation of packaging waste components between the years of 2010 - 2012

The resins have been purchased either big bags or nylon packages. Nylon packages have been sold to licensed firms for recycling. The big bags have not been disposed of as waste. Fines from mill filters and dust collectors have been collected in big bags thus they have been recycled. Reuse of big bags contributes to reduce the amount of nylon package waste. In 2013, 4 big bag discharging units were implemented. Big bag discharge stations were used for discharging of the big bags. Following to the new big bag unit construction, purchasing of polyester resins in big bags were carried out. This project was resulted positive impact in waste reduction (see Figure 5.6).

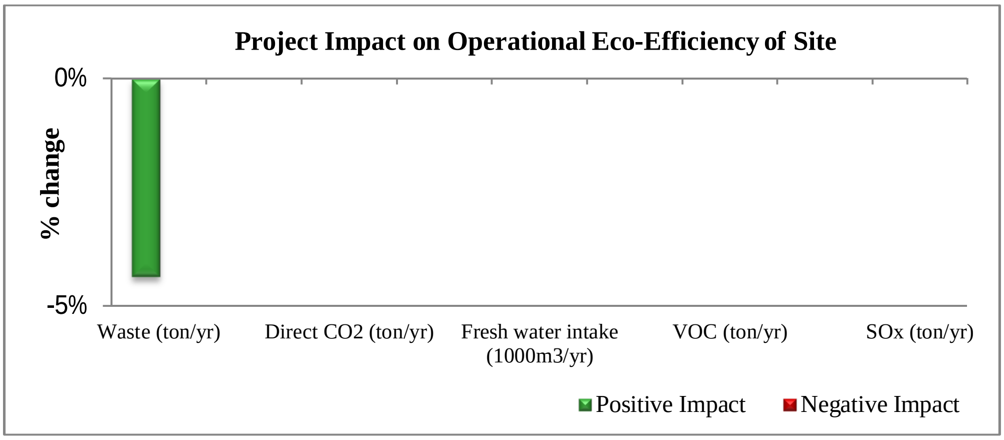


Figure 5.6 Impact of the operational measures to eco-efficiency

Pallet is a flat transport structure producing from wood material that supports goods in a stable fashion while being lifted by a forklift, pallet jack, front loader, work saver or other jacking device. Use of wood pallets generates waste. There are several problems considering the pallet wastes. These are;

- High amount of wooden pallet waste (Negative effect on amount of waste)
- No data analysis for the pallet process and cycle
- External problems during customs clearance process of pallet wastes based on customs regulation
- Safety problems based on the improper storage of the pallets
- Non-standardized incoming pallets from suppliers of raw materials and packaging materials
- Lack of storage area of the waste pallets
- Purchasing additional Euro pallets for the products even though several non-standardized pallets are sent to waste without any damage.

Therefore, in the examined plant, in order to reduce those impacts, reduction of pallet wastes was also projected. By taking certain measures, standardization of the pallet types, reuse the incoming pallets, cost saving, minimization of the wooden pallet waste was intended. There were various types of pallets of different sizes and weight loads used in the plant (see table 5.6). The need for standardization in pallet size was essential due to its interconnecting nature and restriction of pallet movement from the lack of uniformity.

Table 5.6 Properties of pallets used in the plant

Pallet Type	**Dimensions (mm)**	**Explanations**	**Representative Picture**
CP1	1000 x1200	Coming with raw materials Reused for packaging process & delivery with the product	

Table 5.6 Properties of pallets used in the plant (Continued)

CP3	1140 x1140	Coming with raw materials Intra-regional sales (a company)	
CP7	1300 x1100	Coming with raw materials Intra-regional sales (a company)	
Euro Pallet	800 x1200	Coming with raw materials Used for some of product delivery Additional purchasing is done	
Other Types	Several dimensions	Coming with raw materials & packaging materials Sent to waste area or intra-regional sales	 

Standardizing pallet sizes promotes reuse and recycling possibilities. In current situation, approximately extra 25.000 euro pallets have been purchased every year with a cost of € 118.000. Thus, one of the principal objectives of this project was to improve the pallet recycling in site by optimizing and standardizing the type of the incoming & outgoing pallets.The pallet cycle before the implementation of the project is indicated in Figure 5.7. In the operation, pallets having different sizes and standards are transmitted to the delivery area for handling. Pallets which are damaged had been disposed by a firm having a license. Some parts of the undamaged CP1 type pallets had been reused in the manufacturing processes. The rest of the incoming pallets, i.e. called as unstandardized types, had been sold to another company for reusing purpose. In this procedure, additional pallet requirement for the own products of the examined plant had been supplied by the external purchasing.

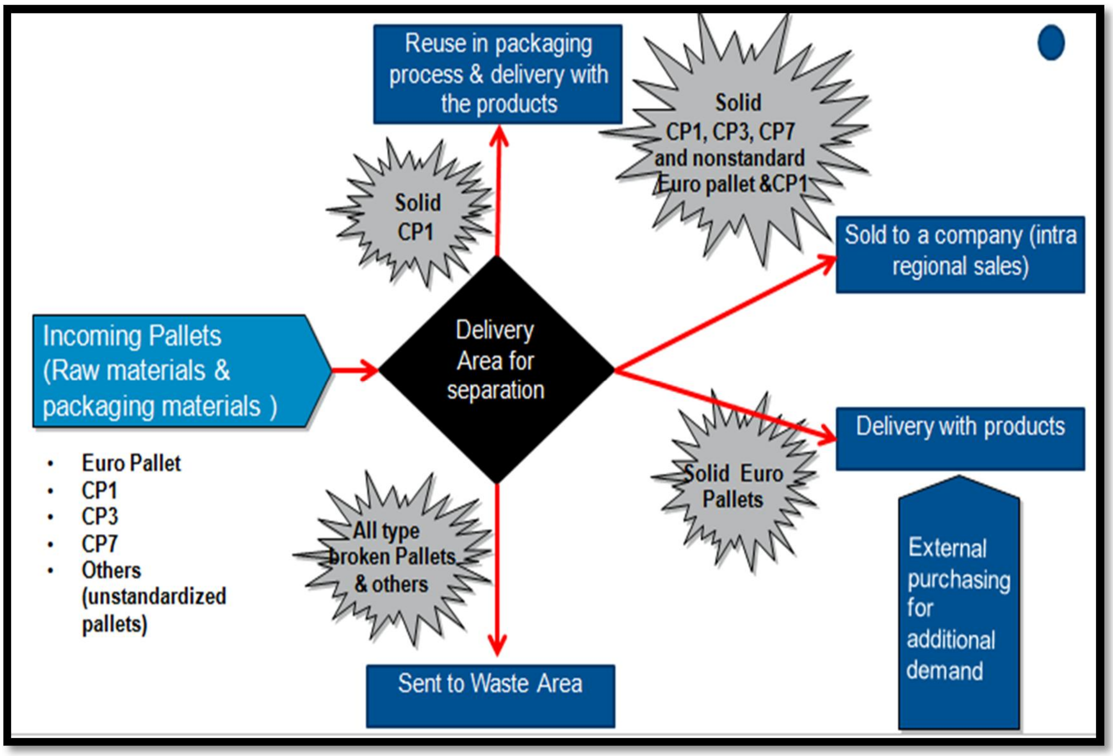


Figure 5.7 The pallet cycle for the examined plant before the waste minimization study

Before the implementation of the project, there was no data analysis for the pallet use and pallet cycle in the plant. After the study, quantities of standardized or non-standardized pallets were determined. The pallet types provided from the supplies were CP-1, CP-3, CP-6, CP-7, EURO, and non-standard pallets. Data obtained from the analysis in the plant, approximately 58% of incoming pallets from suppliers of raw materials and packaging materials were CP-1 (see Figure 5.8). Although CP-1 type pallets have been reused in the manufacturing processes, reuse of the non-standardized pallets is problematic. Therefore, in the second stage of the project, types of the non-standardized pallets were analyzed to improve their reuse capabilities. Results from the analysis stated that 60% of the non-standardized pallets have been conveyed with the paint boxes (25 kg). In addition, 36% of the non-standardized pallets have been provided with the raw materials (see Figure 5.8 & 5.9).

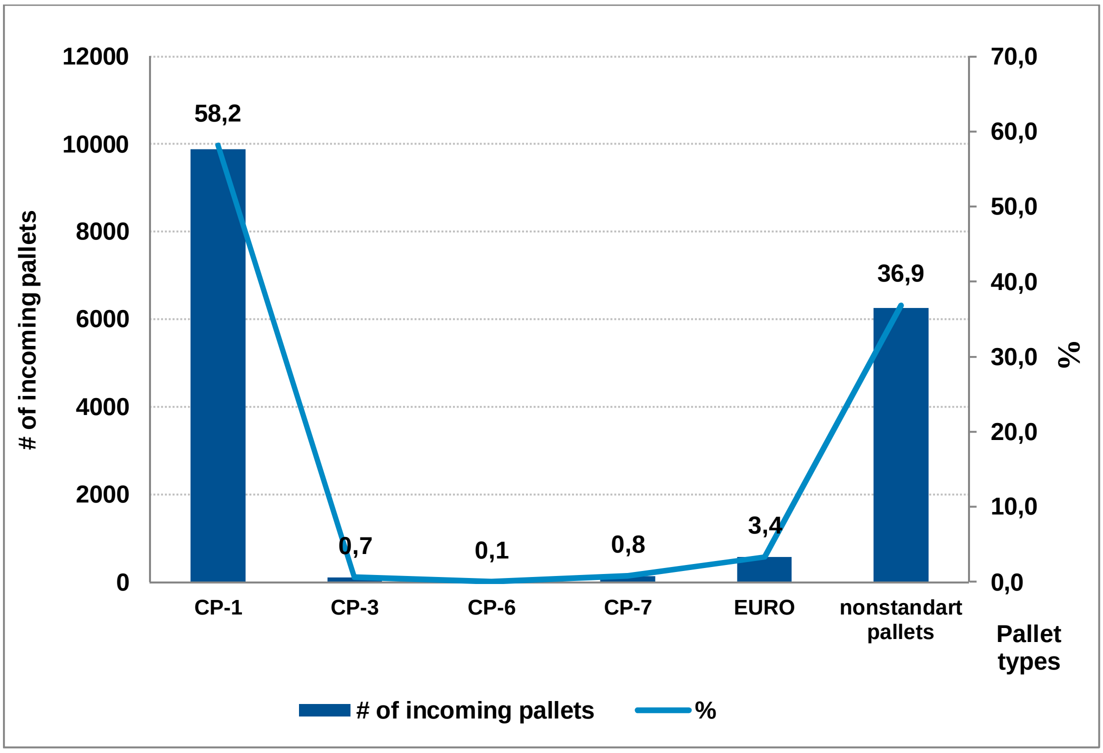


Figure 5.8 Types of the pallet used in the plant

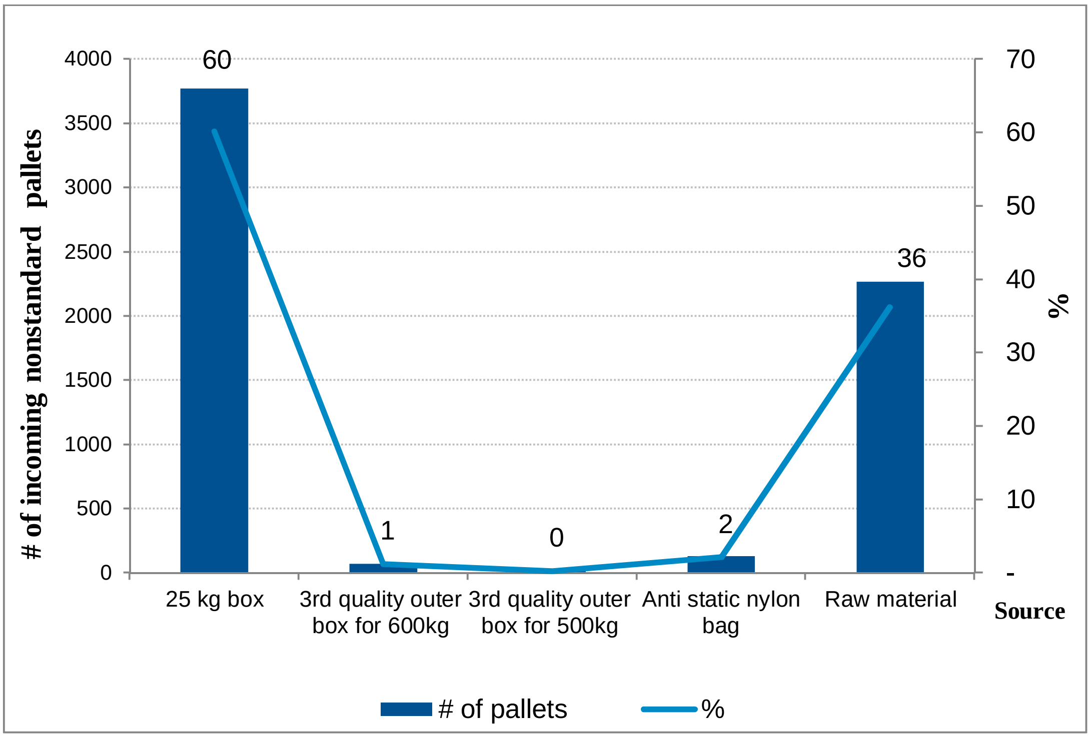


Figure 5.9 Data on non-standard pallets in the plant

In the framework of the project, following actions were taken to optimize and standardize these pallets.

Table 5.7 Efforts for optimization of the pallets

	Action Topics	Details of Action
Action 1	**Data Analysis:** Incoming-outgoing pallet balance from the previous records	• Incoming pallet numbers (percentage) of each pallet type • Purchasing number of euro pallets with cost • Number of pallets sent to waste • Number of pallets sold to a company based on types
Action 2	Pallet Standardization of the incoming raw& packaging materials	• Minimization of the non-standardized pallet types

Table 5.7 Efforts for optimization of the pallets (Continued)

Action 3	Increase the large type of pallet (CP1) usage in product delivery	• Minimization of Euro pallet usage in the products • Maximization of CP1 (large type of pallets) in the product delivery
Action 4	Search for alternative sources Euro pallets within the free zone	

One way to handle excess pallets is through exchanges between businesses. These arrangements can be made by the businesses themselves or facilitated by local government recycling coordinators and groups such as the Chamber of Commerce. Another good exchange possibility is finding a sister facility that can exchange pallets with your plant. The resulting agreement to exchange pallets keeps used pallets out of the solid waste stream and reduces costs for new materials. Exchanges work especially well when participating businesses do not require top quality pallets (Arkansas Department of Environmental Quality, 1998). The following table gives an overview of action descriptions and annual cost advantages.

Table 5.8 Explanation of the measures and their costs

Measures		Project Timeline	Annual Cost Savings
Action 1	The incoming pallets coming with the raw & packaging materials has been converted to Euro pallets	December 2013	12.760 €
Action 2	The Euro pallets obtained from the market used in some products is changed with the CP1 pallets.	December 2013	5.429 €
Action 3	The waste euro pallets are supplied from another company and used in the plant.	January 2014	116.000 €
		Approx. Total Cost Advantage (€ / year)	**134.000 €**

Measure 1 - Non-standardized pallets conveying with the paint boxes (25 kg) and incoming raw materials were converted to the original euro pallets. Regarding to the project, 3772 non-standardized pallets have been used in the plant in a year. These pallets have been converted to the euro pallets reducing the external pallet purchasing. The prices of euro pallets are 5,8 Euro/pallet, therefore action 1 will be resulted 12.760 € savings (2200* 5,8€= 12.760 €).

Measures 2 - Revision of the pallet types for some delivered products from Euro pallets (which is purchased additionally) to large type of pallets, i.e. CP1 (it was provided with the raw material without paying money with) was achieved. Annual production of the X and Y was 360 tons and 108 tons, respectively. The capacity of the euro pallets was about 500 kg which means 936 pallets are required in a year. Utilization of CP1 instead of the euro pallets results with 936 Euro pallets saving.

Measure 3 – Waste Euro pallets having similar size and durability were obtained without any cost from another company in the field. Since the company has been operated in the free zone having strict customs regulations, they have been suffering from the pallet wastes and can not send their pallet wastes out of the free zone. At the beginning a comprensive analysis was performed in the field. A trial was done for 15 pallets that intended to use in the product delivery. No problem was observed with the trial. Annual amount of the purchasing pallets was 25000 in the examined plant. Approximately 80% of this number have been expected to obtain from the company in the free zone. Thus, 116.000 Euro savings in the pallet purchasing has been expected with this measure.

The pallet projects started in January, 2013. And within the first 2 months, the following measures were achieved.

- The incoming pallets provided with the raw & packaging materials (25 kg paint boxes) were converted to Euro pallets instead of non-standardized type of pallets without any cost disadvantage

- Some products were send with large type of pallets (CP1) instead of Euro pallets
- A part of the purchased Euro pallets were supplied from another company's excess pallets within the free zone.
- As an economic point of view, saving in costs was calculated as € 10.357 within first 2 months. At the end of the year, app. 118.000€ saving has been expected.

5.4 Reduction in Powder Ratio in Resins

The ratio of the dust in resin is an important factor in powder waste quantity. Therefore, in the plant determination of dust rate was performed with the most commonly used resin codes. Resin samples were taken and sieved by using 250 microns screen. The results are presented in Table 5.9.And, resin coded as X_1 was determined as the highestone in terms of dust content.

Table 5.9 Dust rate of resins used in the plant

Codes of the Resins	Amount	The amount powder of remaining sifter	The Rate of Dust
X_1	500 g	58 g	% 11.6
X_2	500 g	41 g	% 8.2
X_3	500 g	25.2 g	% 5.0
X_4	500 g	23.2 g	% 4.6
X_5	500 g	14.8 g	% 3.0
X_6	500 g	14 g	% 2.8
X_7	500 g	10.5 g	% 2.1
X_8	500 g	7.2 g	% 1.4
X_9	500 g	6 g	% 1.2
X_{10}	500 g	4.3 g	% 0.9
X_{11}	500 g	2.7 g	% 0.5

After that, higher amount of samples (4000 g) of X_1 and X_4 were sieved in 2 mm x 2mm size sieve. The results arepresented in Tables 5.10 and 5.11.

Table 5.10 Results obtained for X_1

Resin Code	Amount (g)	The amount powder of remaining sifter (g)	The Rate of Dust (%)
X_1	4000	2081	52%
X_1	4000	1510	37%
X_1	4000	1720	43%
X_1	4000	1650	41%

Table 5.11 Results obtained for X_4

Resin Code	Amount (g)	The amount powder of remaining sifter (g)	The Rate of Dust (%)
X_4	4000	1072	26%
X_4	4000	1559	38%
X_4	4000	1330	33%
X_4	4000	1650	41%

As a result of these analyses, the resin manufacturer (supplier) was informed regarding the dust content of their product and to improve their product quality.

5.5 Reduction of the Wastes in the Quality Control Laboratories

In the plant, product quality has been determined in the laboratories by taking samples and testing. Before the project, sample quantity was not determined considering the test methods, etc. In order to reduce the wastes form excess samples, the sample size of various products required for testing was determined. The results are shown in Table 5.12. As can be seen in Table 5.12, certain amounts of wastes have been produced from the quality tests. These tests have been repeated many times therefore remaining wastes from quality tests increases the powder wastes in a certain extent, as well.

Table 5.12 Remaining powder quantity in samplings

Product	Product Code	Amount of Mix. (g)	Mix. Amount of Used (g)	Powder Remaining Quantity. (g)
A	A_1	448	375	73
B	B_1	425	387	40
C	C_1	391	340	51
D	D_1	545	509	55
E	E_1	348	323	25
F	F_1	444	392	60

5.6 Reduction in Electricity

Besides the measures taken in the process wastes, efficient use of electricity in the plant was also investigated. Improving of the indoor lighting efficiency was intended in the project. In practice, halogen incandescent, compact fluorescent lamps (CFLs), and light-emitting diodes (LEDs) are available for lightings (see Figure 5.10).

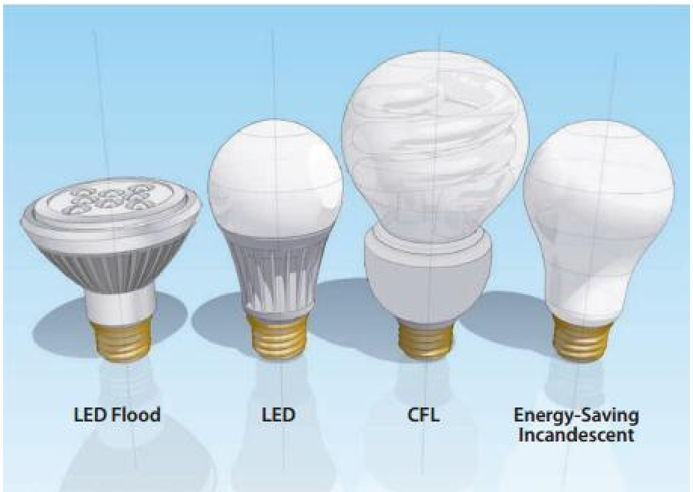


Figure 5.10 Photos of type of lightening

Among them, halogen incandescent light bulbs are energy efficient incandescent bulbs and can last up to three times longer than traditional incandescent light bulbs. CFLs use app. 75% less energy and last up to 10 times longer than traditional incandescent (see Figure 5.11). However, LED bulbs offer similar light quality to traditional incandescent, last 25 times as long, and use even less energy than CFLs. LEDs is the highest quality and energy savings. Therefore, LED bulbs have been rapidly expanding in household use. The comparison chart of LED lights, incandescent light bulbs and CFLs is indicated in table 5.13.

Figure 5.11 Photos of CFLs

Figure 5.12 Photos of LEDs

Table 5.13The comparison chart of LED lights, incandescent light bulbs and CFLs

Comparison Chart LED Lights etc. Incandescent Light Bulbs etc. CFLs			
Energy Efficiency & Energy Costs	 Light Emitting Diodes (LEDs)	 Incandescent Light Bulbs	 Compact Fluorescents (CFLs)
Life Span (average)	50,000 hours	1,200 hours	8,000 hours

Table 5.13 The comparison chart of LED lights, incandescent light bulbs and CFLs (Continued)

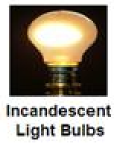
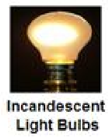
Watts of electricity used (equivalent to 60 watt bulb) LEDs use less power (watt) per unit of light generated humans. LEDs help reduce greenhouse gas emissions from power plants and lower electric bills	6-8 watts	60 watts	13-15 watts
Kilo-watts of electricity used (30 Incandescent Bulbs per year equivalent)	329 KWh/yr.	3285 KWh/yr.	767 KWh/yr.
Annual Operating Cost(30 Incandescent Bulbs per year equivalent)	$32.85/year	$328.59 /year	$76.65/year
Environmental Impact			
Contains the TOXIC Mercury	No	No	Yes - Mercury is very toxic to your health and the environment
RoHS Compliant	Yes	Yes	No – Contains 1mg-5mg of mercury and is a major risk to the environment
Carbon Dioxide Emissions (30 bulbs per year) Lower energy consumption decreases: CO_2 emissions, sulfur oxide, and high-level nuclear waste.	451 pounds/yr.	4500 pounds/yr.	1051 pounds/yr.
Important Facts			
Sensitivity to low temperatures	None	Some	Yes - may not work under -10 degrees Fahrenheit or over 120 deg. Fahrenheit

Table 5.13 The comparison chart of LED lights, incandescent light bulbs and CFLs (Continued)

On/off Cycling Switching a CFL on/off quickly, in a closet for instance, may decrease the lifespan of the bulb	No Effect	Some	Yes – can reduce lifespan drastically
Turns on instantly	Yes	Yes	No – takes time to warm up
Durability	Very Durable – LEDs can handle jarring and bumping	Not Very Durable - glass or filament can break easily	Not Very Durable - glass can break easily
Heat Emitted	3.4 btu's/hour	85 btu's/hour	30 btu's/hour
Light Output	 Light Emitting Diodes (LEDs)	 Incandescent Light Bulbs	 Compact Fluorescents (CFLs)
Lumens	Watts	Watts	Watts
450	4-5	40	9-13
800	6-8	60	13-15
1100	9-13	75	18-25
1600	16-20	100	23-30
2600	25-28	150	30-55

In the framework of the energy efficiency studies, current situations in terms of bulb types, their energy consumptions and working hours were identified as first. Then, the situation after the LED transformation was explained and energy and cost savings were determined. In the plant, bulbs were exchanged with LED luminaries. When LED luminaries were used in the plant, electricity consumption was reduced from 129.120 kW / year to 77.472 kW/year, which corresponds app. 40% reduction in the electricity consumption.Reduction in the electricity consumption was resulted in the reduction in the CO2 emission to the atmosphere, which was one of the positive effects of the action.

Table 5.14 Current situation

	Existing Armature	Bulb Value (W)	Bulb + Ballast (W)	Total Armature	Monthly Working Hours	Monthly Total Energy Consumed (kW)
Warehouses	125 W Saving Bulb	125	150	128	732	14.054
	Total	125	150	128	732	14.054

Table 5.15 LED Transformation Project

	Existing Armature	Bulb Value (W)	Bulb + Ballast (W)	Total Armature	Monthly Working Hours	Monthly Total Energy Consumed (kW)
Warehouses	125 W Saving Bulb	125	150	128	732	14.054
	Total	125	150	128	732	14.054

Table 5.15 Calculation of annual saving (Continued)

	Lamp Total Energy Consumption (kW /month)	Annual Consumption (kW / year)	Electric Amount (TL/ year) Maintenance Cost	Lamp + Transformer + Maintenance Cost	Frequency Lamp Care	Total Annual Maintenance Amount	Total Annual Costs
Current Situation	14.054	129.120	31.609 TL	20 TL	<1 year	2.360,00 TL	33.969,00 TL
90W LED luminaries	8.433	77.472	18.965 TL	0 TL	10 year	0,00 TL	18.965,00 TL
Annual Savings Rate		%44					
Available Monthly Lighting Electrical payment		2.831,00 TL					
After Change Monthly Payment Lighting Electrical		1.580,00 TL					
Annual Savings		15.003,00 TL					

Table 5.15 Calculation of annual saving (Continued)

	Unit List Price	Number	List Price Calculated on the Total Amount	Discount (51%) Total Amount
90W LED luminaries	391 TL	128	50.048 TL	50.048 TL

Total Investment	**50.048 TL**
INVESTMENT RETURN TIME (YEARS)	**3,34**

	Annual electricity consumed (kw / year)	Amount of CO2 Emitted (KG)
The current situation	129.120	64.560
After LED luminaries Solutions	**77.472**	**38.736**

Assumptions: Electrical Cable Loss was 6%; electrical Transformer Loss was 3%; Daily Working Hours were 24h; electricity price (TL / kWh) was 0, 24 TL; and transformer costs and compensation costs were not taken into notice.

5.7 Using of Powder Coating Wastes in Other Supplier Industries

In the project, utilization potential of the powder coating wastes in supplier industries were also investigated. The results of these research and development studies are summarized herein.

Two different powder coating samples were prepared with all solid raw materials and especially to paint metals produced. The reaction between the resin and hardener creates paint film which is applied a hard surface. Properties of these products are summarized in Table 5.16.

Table 5.16 Properties of powder coating samples

Properties	Sample 1	Sample 2
Resin type	Epoxy-Polyester	Polyester
Resin content (%)	60	66
Particle Size (µm)	<10	<10
Curing time / temperature (min/°C)	10/200	15/180

Fine powder which is separated in cyclone during the milling process is applied by electrostatic spray gun to the surface. According to literature, research has shown that these powder coating materials are used as the filler content and the binder due to the resin composite material. Especially waste powder coating, sawdust and wood composite which are made from waste fiberboard, when considering moisture resistance and mechanical properties of its constitutive materials provide superior properties.

Various studies are reported the sustainable usage of powder coating waste in industries. These are;

Powder coatings - wood composites: The forest products industry (both primary and secondary manufacturing) is facing a critical problem in disposing of millions of tons of adhesive-coated/chemically treated wood sawdust produced annually. According to literature, these powder coating materials are used as the filler content and the binder due to the resin composite material (Anuradha C. Abhyankar, 2014).

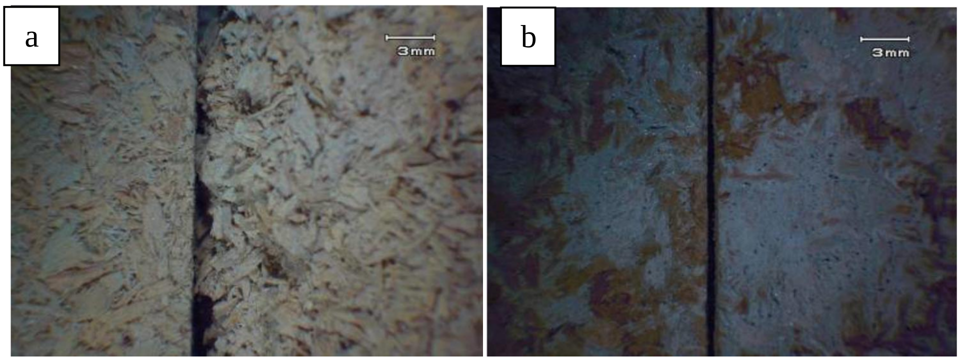


Figure 5.13 Images of weathered boards and control samples. (a), boards with no secondary binder; (b), boards with secondary binder (Anuradha and Abhyankar, 2014)

Powder coatings - recycling of plastic waste: Epoxy resin cured by polyester is used to improve the melt flow ability of Polypropylene-talc composites. Epoxy resins are polar materials with weak adhesion strength to Polypropylene. They inherently interact with the mineral filler particles surface and hence affect the flow ability and also thermal stability of the composite by deactivating the metallic impurities on filler surface. The positive effect of resin on mechanical properties of the composites has shown in the following graphics for PP 20% talc; PP 30% talc; PP 40% talc (Anuradha and Abhyankar, 2014).

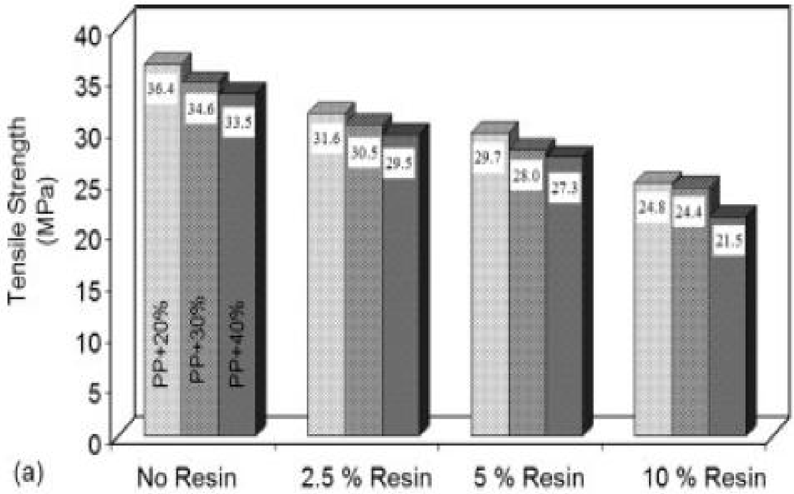


Figure 5.14 Tensile strength (Anuradha and Abhyankar, 2014)

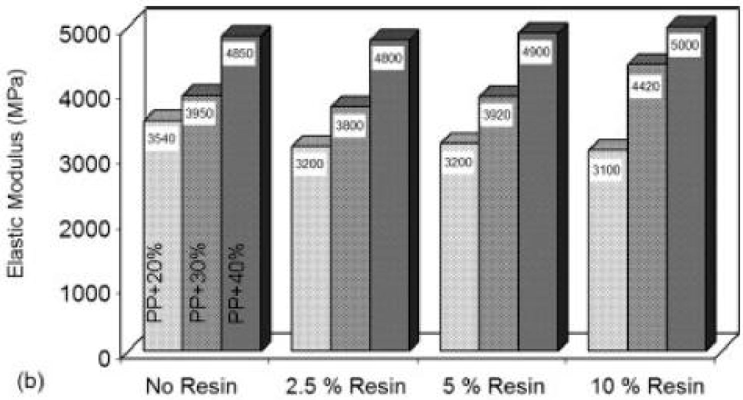


Figure 5.15 Elastic modulus (Anuradha and Abhyankar, 2014)

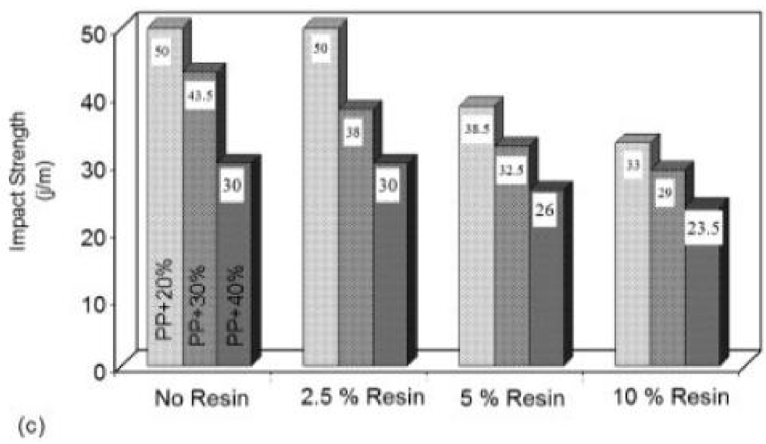


Figure 5.16 Impact strength (Anuradha and Abhyankar, 2014)

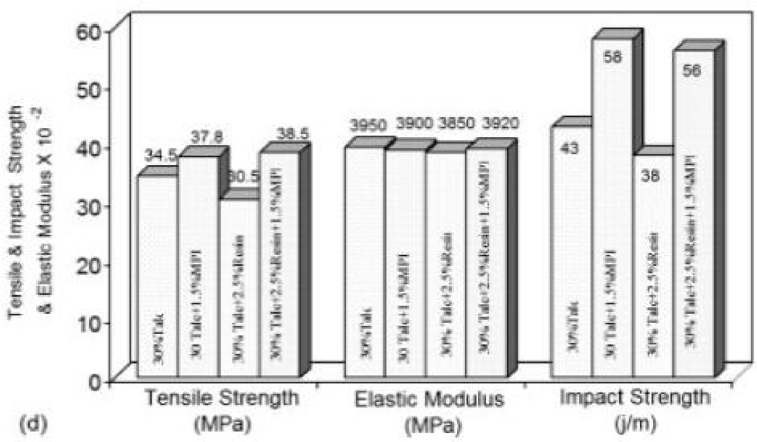


Figure 5.17The effect of MPP on mechanical properties (Anuradha and Abhyankar, 2014)

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

The waste hierarchy in the coating industry comprises of three steps, i.e.source reduction, recycling and reuse, and finally proper disposal. In the examined plant, waste management efforts are focused on the reuse and recycling studies as well as source reduction attempts. Source reduction efforts are realized by efficient inventory study. Thus types and quantities of wastes in the examined plant in Izmir were completed and summary of data are presented in Table 6.1 together with their codes and disposal methods. Besides the wastes minimization at source, recycling and reuse of solvents both on and off-site, and waste exchange supports the reduction in wastes quantities and types, as well. Following to these stages, finally, wastes that can't be recycled or reused are disposed of considering the legal requirements.

The benefits explained herein are obtained by implementation of waste hierarchy in the powder coating plant:

- Extruder unit was required special attention in the powder coating processes to take mitigation measures for waste minimization purpose. Approximately %40 improvement on the reduction of extruder chips and melts wastes were achieved by implementing a re- designed new machine. Moreover, re-using of waste chips (i.e. 18 tons waste per year) have been expected to provide an improvement in the waste performance and carbon footprint instead of dispose of. Using of these wastes provides reduction in raw material consumption and disposal costs, as well.

- Reduction in the nylon and paper packaging by using big bag unit and waste pallets were carried out effectively in the plant. Standardization of the pallet types and reuse of the incoming pallets was resulted savings in cost and waste minimization.

- During the project, resin suppliers were informed about the quality of their product. Dust contents of the resins were measured and suppliers were informed to take certain measures to reduce their dust contents. Thus, an improvement in the resin quality was performed by the resin manufacturer (supplier).

Table 6.1 Types and quantities of wastes in the examined plant

TURKEY POWDER WASTE CATEGORIES				
Process Origin	**Waste Code**	**The definition of waste**	**Activity**	**Disposal Method**
Raw Material Ware House	*** 08 01 12**	*Waste paint and varnish other than those mentioned in 08 01 11	*trash and spillages of raw materials,petrified raw materials,	*(R1) It sent for disposal by incineration with heat recovery.
	***15 01 01**	*Paper and cardboard packaging	* raw material package waste	*Recycling
	***15 01 02**	*Plastic packaging	* raw material package waste	*Recycling
Material Preparation	***15 01 10**	*Packaging containing residues of or contaminated by dangerous substances	*hazardous raw materials packaging waste	*(R12) Exchange of wastes for submission to any of the operations numbered R1-R11
	***08 01 12**	*Waste paint and varnish other than those mentioned in 08 01 11	*incorrect weighing, trash and spillages of raw materials, dust collector unit to ensure dust-free environment	*(R1) It sent for disposal by incineration with heat recovery.
	***15 02 02**	*Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by dangerous substances	*cleaning machine with water-based cleaner, contaminated by dangerous substances absorbent material and personnel protection equipment,	*(R12) Exchange of wastes for submission to any of the operations numbered R1-R11
	***15 01 01**	*Paper and cardboard packaging	* raw material package waste	*Recycling
	***15 01 02**	*Plastic packaging	* raw material package waste	*Recycling

Table 6.1 Types and quantities of wastes in the examined plant. (Continued)

Pre-Mixing & Filling	***08 01 12**	* Waste paint and varnish other than those mentioned in 08 01 11	* trash and spillages of raw materials,dust collector unit to ensure dust-free environment,	*(R1) It sent for disposal by incineration with heat recovery.
	***15 01 10**	*Packaging containing residues of or contaminated by dangerous substances	*hazardous raw materials packaging waste	*(R12) Exchange of wastes for submission to any of the operations numbered R1-R11
	***15 02 02**	*Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by dangerous substances	*contaminated absorbent material, cloth and personnel protection equipment, by dangerous substances	*(R12) Exchange of wastes for submission to any of the operations numbered R1-R11
	***15 01 01**	*Paper and cardboard packaging	* raw material package waste	*Recycling
	***15 01 02**	*Plastic packaging	* raw material package waste,container cover	*Recycling
Extruder	***15 02 02**	*Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by dangerous substances	*cleaning machine with water-based cleaner, contaminated absorbent material and personnel protection equipment by dangerous substances, maintenance and repair activities	*(R12) Exchange of wastes for submission to any of the operations numbered R1-R11
	***20 01 39**	*Plastics	*container cover,nylons captured on extruder cooling band	*Recycling
	***08 01 12**	*Waste paint and varnish other than those mentioned in 08 01 11	*Extruder melts &chips, leaks from extruder feeding, dust collector unit to ensure dust-free environment,	*(R1) It sent for disposal by incineration with heat recovery.

Table 6.1 Types and quantities of wastes in the examined plant (Continued)

Milling & Packaging	***15 02 02**	*Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by dangerous substances	* cleaning machine with water-based cleaner, contaminated absorbent material and personnel protection equipment by dangerous substances, maintenance and repair activities	*(R12) Exchange of wastes for submission to any of the operations numbered R1-R11
	***20 01 01**	*Paper and cardboard	*product boxes, contribution (raw material) packaging	*Recycling
	***20 01 39**	*Plastics	*coli laces,pallet cover, product plastic bag	*Recycling
	***08 01 12**	*Waste paint and varnish other than those mentioned in 08 01 11	* Dust collector unit to ensure dust-free environment, trash and spillages, mill filter	*(R1) It sent for disposal by incineration with heat recovery.
Auxiliary facilities	***15 02 02**	* Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by dangerous substances	* cleaning machine with water-based cleaner, contaminated absorbent material and personnel protection equipment by dangerous substances, maintenance and repair activities	*(R12) Exchange of wastes for submission to any of the operations numbered R1-R11
	***13 02 05**	*Oil waste	*maintenance and repair activities	*(R9) Used oil re-refining or other reuses of previously used oil
	***20 01 21**	*Fluorescent Waste	*maintenance and repair activities	*(R12) Exchange of wastes for submission to any of the operations numbered R1-R11
	***08 01 16**	*Treatment Sludge	*Waste water treatment system	*(R1) It sent for disposal by incineration with heat recovery.

- Reduction in powder wastes were also achieved by determining of the sample size of various products required for testing.

- Improvement of total energy consumption was obtained by using LED luminaries. Reduction in the electricity consumption was resulted in the reduction in the CO_2 emission to the atmosphere, which was one of the positive effects of the action.

REFERENCES

Anuradha, C., Abhyankar, N. R. (2014). *Composite manufacture from waste powder coatings:a step toward industrial ecology.* New Zealand: Centre for Advanced Composite Materials, The University of Auckland,.

Arkansas Department of Environmental Quality (1998). Pallet Management and Waste Reduction - Arkansas Department. 5301 Northshore, 5301 Northshore, North Little Rock,. Fonte: Pallet Management and Waste Reduction.

BFC British Coating Federation Ltd. (December de 2000). *Powder coating wastes:guidance on disposal.* Acesso em 5 de 11 de 2012, disponível em http://www.rjstokes.co.uk/images/content/Powder_Waste.pdf

BioIntelligence Service S.A.S. (2012). *Preparing a waste prevention programme.* Paris: Copenhagen Resource Institute, Copenhagen Regional Environmental Center, Szentendre.

British Coatings Federation (2010). *Code of practice for the manufacture of coating Powder.* Leatherhead Surrey: British Coatings Federation.

Center for Economics Research (1992). *Paint waste reduction and disposal options.* Urbana: Authority of the State of IIIinois.

DEFRA Department for Environment Food and Rurall Affairs (2011). *Guidance on applying the waste hierarchy.* London: Waste Hierarchy Guidance Producer Responsibility Unit.

Environment Agency (2010). *Defining waste recovery:Permanent deposit of waste on land.* Bristol: Environment Agency Rio House Waterside Drive.

Functional & Protective Coating Technologies & Equipment (n.d.). Acesso em 25 de Nisan de 2014, disponível em Powder Coatings Industry Overview: http://thecoatingmotnctu.blogspot.com.tr/2007/12/powder-coatings-industry-overview.html

Harry Freeman, T. H. (1992). Industrial pollution prevention! A Critical Review. *Air & Waste Management Association* , 618.

İbakimya A.Ş. (2010). *Company & powder coatig catalog.* Retrieved December 12, 2013, from http://www.iba.com.tr/f/edokuman/ibacatalog.pdf

Köse, D., Ayaz, S., & Köroğlu, B. (2007). *Waste management in Turkey National regulations and evaluation of implementation results.* Ankara: General Assembly of Turkish Court of Accounts.

Malvern Instruments Ltd. (2013). Retrieved November 15, 2013, from http://www.malvern.com/en/industry-applications/industries/process-integrators/milling-grinding/default.aspx

McDougall, F. R. (2001). *Integrated solid waste management.* UK: Blackwell Science Ltd, a Blackwell Publishing Company.

Global Resource Information Database (GRID) (1985). 30 April 2014,: http://www.grid.unep.ch

U.S. Environmental Protection Agency (2013). Retrieved July 27, 2014 from http://www.epa.gov/: http://www.epa.gov/waste/nonhaz/municipal/hierarchy.htm

Worrell, C. G. (2008). *Energy efficiency improvement and cost saving opportunities for the vehicle assembly industry.* İzmir: Lawrence Berkeley National Laboratory.

Yousef Jahani, M. E. (2009). *The rheological modification of talc-filled polypropylene by epoxy-polyester hybrid resin and its effect on morphology, crystallinity,and mechanical properties.* Tehran, Iran: Wiley InterScience.

APPENDICES

Code	Phrase
R1	Explosive when dry
R2	Risk of explosion by shock, friction, fire or other sources of ignition
R3	Extreme risk of explosion by shock, friction, fire or other sources of ignition
R4	Forms very sensitive explosive metallic compounds
R5	Heating may cause an explosion
R6	Explosive with or without contact with air
R7	May cause fire
R8	Contact with combustible material may cause fire
R9	Explosive when mixed with combustible material
R10	Flammable
R11	Highly flammable
R12	Extremely flammable
R14	Reacts violently with water
R15	Contact with water liberates extremely flammable gases
R16	Explosive when mixed with oxidising substances
R17	Spontaneously flammable in air
R18	In use, may form flammable/explosive vapour-air mixture
R19	May form explosive peroxides
R20	Harmful by inhalation
R21	Harmful in contact with skin
R22	Harmful if swallowed
R23	Toxic by inhalation
R24	Toxic in contact with skin
R25	Toxic if swallowed
R26	Very toxic by inhalation
R27	Very toxic in contact with skin
R28	Very toxic if swallowed
R29	Contact with water liberates toxic gas.
R30	Can become highly flammable in use
R31	Contact with acids liberates toxic gas
R32	Contact with acids liberates very toxic gas
R33	Danger of cumulative effects
R34	Causes burns
R35	Causes severe burns
R36	Irritating to eyes
R37	Irritating to respiratory system

R38 Irritating to skin
R39 Danger of very serious irreversible effects
R40 Limited evidence of a carcinogenic effect
R41 Risk of serious damage to eyes
R42 May cause sensitisation by inhalation
R43 May cause sensitisation by skin contact
R44 Risk of explosion if heated under confinement
R45 May cause cancer
R46 May cause inheritable genetic damage
R48 Danger of serious damage to health by prolonged exposure
R49 May cause cancer by inhalation
R50 Very toxic to aquatic organisms
R51 Toxic to aquatic organisms
R52 Harmful to aquatic organisms
R53 May cause long-term adverse effects in the aquatic environment
R54 Toxic to flora
R55 Toxic to fauna
R56 Toxic to soil organisms
R57 Toxic to bees
R58 May cause long-term adverse effects in the environment
R59 Dangerous for the ozone layer
R60 May impair fertility
R61 May cause harm to the unborn child
R62 Possible risk of impaired fertility
R63 Possible risk of harm to the unborn child
R64 May cause harm to breast-fed babies
R65 Harmful: may cause lung damage if swallowed
R66 Repeated exposure may cause skin dryness or cracking
R67 Vapours may cause drowsiness and dizziness
R68 Possible risk of irreversible effects

Combinations

Code Combination	Statement
R14/15	Reacts violently with water, liberating extremely flammable gases
R15/29	Contact with water liberates toxic, extremely flammable gases
R14/15/29	Reacts violently with water, liberating toxic, extremely flammable gases
R20/21	Harmful by inhalation and in contact with skin
R20/22	Harmful by inhalation and if swallowed

R20/21/22	Harmful by inhalation, in contact with skin and if swallowed
R21/22	Harmful in contact with skin and if swallowed
R23/24	Toxic by inhalation and in contact with skin
R23/25	Toxic by inhalation and if swallowed
R23/24/25	Toxic by inhalation, in contact with skin and if swallowed
R24/25	Toxic in contact with skin and if swallowed
R26/27	Very toxic by inhalation and in contact with skin
R26/28	Very toxic by inhalation and if swallowed
R26/27/28	Very toxic by inhalation, in contact with skin and if swallowed
R27/28	Very toxic in contact with skin and if swallowed
R36/37	Irritating to eyes and respiratory system
R36/38	Irritating to eyes and skin
R36/37/38	Irritating to eyes, respiratory system and skin
R37/38	Irritating to respiratory system and skin
R39/23	Toxic: danger of very serious irreversible effects through inhalation
R39/24	Toxic: danger of very serious irreversible effects in contact with skin
R39/25	Toxic: danger of very serious irreversible effects if swallowed
R39/23/24	Toxic: danger of very serious irreversible effects through inhalation and in contact with skin
R39/23/25	Toxic: danger of very serious irreversible effects through inhalation and if swallowed
R39/24/25	Toxic: danger of very serious irreversible effects in contact with skin and if swallowed
R39/23/24/25	Toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed
R39/26	Very Toxic: danger of very serious irreversible effects through inhalation
R39/27	Very Toxic: danger of very serious irreversible effects in contact with skin
R39/28	Very Toxic: danger of very serious irreversible effects if swallowed
R39/26/27	Very Toxic: danger of very serious irreversible effects through inhalation and in contact with skin
R39/26/28	Very Toxic: danger of very serious irreversible effects through inhalation and if swallowed
R39/27/28	Very Toxic: danger of very serious irreversible effects in contact with skin and if swallowed
R39/26/27/28	Very Toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed
R42/43	May cause sensitization by inhalation and skin contact
R45/46	May cause cancer and heritable genetic damage

R48/20	Harmful: danger of serious damage to health by prolonged exposure through inhalation
R48/21	Harmful: danger of serious damage to health by prolonged exposure in contact with skin
R48/22	Harmful: danger of serious damage to health by prolonged exposure if swallowed
R48/20/21	Harmful: danger of serious damage to health by prolonged exposure through inhalation and in contact with skin
R48/20/22	Harmful: danger of serious damage to health by prolonged exposure through inhalation and if swallowed
R48/21/22	Harmful: danger of serious damage to health by prolonged exposure in contact with skin and if swallowed
R48/20/21/22	Harmful: danger of serious damage to health by prolonged exposure through inhalation, in contact with skin and if swallowed
R48/23	Toxic: danger of serious damage to health by prolonged exposure through inhalation
R48/24	Toxic: danger of serious damage to health by prolonged exposure in contact with skin
R48/25	Toxic: danger of serious damage to health by prolonged exposure if swallowed
R48/23/24	Toxic: danger of serious damage to health by prolonged exposure through inhalation and in contact with skin
R48/23/25	Toxic: danger of serious damage to health by prolonged exposure through inhalation and if swallowed
R48/24/25	Toxic: danger of serious damage to health by prolonged exposure in contact with skin and if swallowed
R48/23/24/25	Toxic: danger of serious damage to health by prolonged exposure through inhalation, in contact with skin and if swallowed
R50/53	Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment
R51/53	Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment
R52/53	Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment
R68/20	Harmful: possible risk of irreversible effects through inhalation
R68/21	Harmful: possible risk of irreversible effects in contact with skin
R68/22	Harmful: possible risk of irreversible effects if swallowed
R68/20/21	Harmful: possible risk of irreversible effects through inhalation and in contact with skin
R68/20/22	Harmful: possible risk of irreversible effects through inhalation and if swallowed
R68/21/22	Harmful: possible risk of irreversible effects in contact with skin and if swallowed

R68/20/21/22	Harmful: possible risk of irreversible effects through inhalation, in contact with skin and if swallowed