AIM OF STUDY

a. Major goal of the thesis

The study aimed mainly to investigate and apply a proper energy and waste management systems for the acrylic fiber industry. At the same time study the impact of the manufacturing process on the environment in order to ensure sustainability.

b. Specific goals of the thesis

- Establish and implement an applicable energy policy for energy conservation and calculate related potential savings.
- Investigate means of waste management including minimization policies, waste handling and disposal.
- Identify the environmental impact of acrylic fiber manufacturing.
- Investigate waste streaming approaches using life cycle analysis to select the more appropriate environmental friendly approach.

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II.LITERATURE REVIEW

II.1.Energy Managementin Textile Industry

From the point of view of both public economy and business, energy efficiency is of great importance as it has direct economic benefits like increased competitiveness and higher productivity (Hirst & Brown,1990',Thollander & Ottosson, 2010 and Worrell *et al.,*2010)

Moreover, Jaffe & Stavins (1994) and Sardianou (2008) declared that research has shown that despite the existence of cost-effective energy efficiency measures in industry, these measures are not always implemented due to various barriers to energy efficiency such as information imperfections.

Caffal (1996) and McKane *et al.,* (2011) agreed that previous research emphasises the great importance of a long-term energy strategy in successful energy management practices in industrial organizations. Industries which adopt energy management practices may save up to 40% of their total energy use. However, William *et al.,* (2003) and Christoffersen *et al.,*(2006) reported that up until that date research concerning actual energy management practices in industries with regard to strategic, organizational, and financial issues have been scarce, both regarding theoretical contributions and regarding empirical case studies

Moreover, Hong *et al.,* (2010) indicated that energy savings made by 303 textile firms which implemented an energy-saving plan amounted to a significant amount of energy savings and reduced CO_2 emission through savings in production and production-support systems. In addition, Palanichamy & Babu (2005) declared that numerous analytical studies have been undertaken on energy auditing or energy conservation in textile industry. There are additional studies that recommend improving energy efficiency with the help of energy conservation techniques (Blok *et al.,* 1993 and Lang & Huang, 1993) or through energy management (Caffal, 1996, Christoffer *et al.*, 2006 and Thollander & Ottosson, 2010).

Energy management has been the subject of considerably increased attention as regards policy formulation. For example, standards for energy management have been set both in Europe and in North & South America. A number of previous studies have been conducted in the area of energy audits (Thollander *et al.,* 2005 and Klugman *et al.,* 2007), energy optimization (Klugman *et al.,* 2009 and Cai *et al.,* 2009), energy modeling (Costa *et al.,* 2007 and Kissock & Eger, 2008) and energy audit programs in relation to the adoption of energy efficiency technologies (Anderson & Newell, 2004 and Harris *et al.,* 2000).

At the same time, Ozturk (2005), Nagesha (2005) and Hasanbeigi (2010) agreed that energy usage in the textile industry is inefficient and energy consumption has been growing very rapidly due to population growth, rapid urbanization and industrial development. Moreover, energy efficiency is crucial for the survival of small-scale industries including the textile industry. Ways to reduce energy input without compromising product quality are being continuously researched. Measuring and monitoring the use of energy and utility resources in textile manufacturing processes are necessary to reduce energy losses and to recover lost energy, which are of great importance for cutting cost and supporting sustainable development.

Furthermore, Ozturk (2005) illustrated that the energy requirement for an economy is sensitive to the rate of economic growth and the energy intensity of producing sectors. The energy intensity of industry is a function of technological progress and varies from sector to sector. Energy conservation is one of the important objectives of energy policy. It is important to know the current specific energy balance (energy consumption/production) and the energy intensity (energy consumption/cost of energy) in order to estimate future energy consumption for the textile sector. He added that, the textile industry is energy-intensive, it is very important to optimize its energy consumption and implement energy conservation policies.

Rock & Angel (2007) and IEA (2007) stated that the textile industry is both energy intensive and highly polluting. Most studies in energy and utility management in the textile process tend to focus on the introduction of energy-saving measures and technologies, as well as the potential benefits and energy savings obtained after implementing the adequate measures and technologies.

Palanichamy *et al.,* (2001) conducted an energy conservation project in a textile company. They showed that substantial energy savings are achievable by taking action about problems found during an energy auditing in production-related and production-supporting facilities.

The energy conservation technologies and their potential use for the textile industry can be categorized according to the support and production processes. The production processes are electrical system and boiler system while the support processes are air conditioning system, lighting system, fans, pumps and motors (Trygg & Karlsson, 2005).

Manoloudis (2007) explained that energy management system is the part of the overall management system which is dedicated to the continual energy performance improvement. Both top management's true support and a strategic approach are of outmost importance if an energy management program is to succeed. Some other important elements include an initial energy audit, senior management's support, monitoring of energy use, an energy policy, a program for energy saving projects, staff motivation and training (Caffal, 1996 and McKane *et al.,* 2011).

According to "Austrian Energy Agency" (2007) there are in practice barriers that prevent the successful implementation of energy-efficiency measures recommended in the energy audit report. Therefore, it is necessary to establish a clear procedure, which ensures the successful realization of improvements. The action plan should be described in a simple way with clear aims, saving targets and definition of roles and responsibilities for its execution.

Worrell *et al.,* (2010) stated that changing how energy is managed by implementing an organization-wide energy management program is one of the most successful and cost-effective ways to bring about energy-efficiency improvements. Ideally, such a program would include facility, operation, environmental, health, safety and personnel management. A sound energy management program is required to create a foundation for positive change and to provide guidance for managing energy throughout an organization. Continuous improvements to energy-efficiency, therefore, only occur when a strong organizational commitment exists. Energy management programs help to ensure that energy-efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in a process of continuous improvement. They assured that the successful energy management program begins with a strong organizational commitment to the continuous improvement of energy-efficiency. This involves assigning oversight and management duties to an energy director, establishing an

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energy policy, and creating a cross-functional energy team. Steps and procedures are then put in place to assess performance through regular reviews of energy data, technical assessments and benchmarking. From this assessment, an organization is able to develop a baseline of energy use and set goals for improvement. Such performance goals help to shape the development and implementation of an action plan.

Jones *et al.,* (2011) stated through their study on energy efficiency that the goal of continuous energy improvement programs is to enable industrial facilities to build and sustain a culture of energy efficiency within their organizations. Strategic Energy Management (SEM) provides a framework and process to establish managing energy as a standard operating procedure. By addressing organizational energy behaviors and management practices, SEM can deliver reliable and persistent energy savings. Companies which implement SEM resulted in dramatic energy improvements, savings and business productivity as a result of embedding SEM into their organizational structure. Improved energy efficiency is not only an integral utility resource but also presents opportunities for diverse regional manufacturers to achieve and maintain competitive advantage.

ISO 50001:2011 is the international standard for energy management systems. It enables organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency, use and consumption. Implementation of this international standard leads to reduction in greenhouse gas emissions, related environmental impacts and energy cost through systematic management of energy. This international standard specifies "Energy Management System" (EMS) requirements, upon which an organization can develop and implement an energy policy, and establish objectives, targets and action plans. It is applicable to all types and sizes of organizations, irrespective of geographical, cultural or social conditions. Successful implementation depends on commitment from all levels and functions of the organization, and especially from top management.

According to ISO 50001:2011 the major elements in a strategic energy management program are shown in Figure (1). Energy management system is built on the ISO quality management system's philosophy of Plan-Do-Check-Act/Review (PDCA) continual improvement framework and incorporates energy management into everyday organizational practices. Worldwide application of this international standard contributes to more efficient use of available energy sources, to enhance competitiveness, to reduce greenhouse gas emissions and other related environmental impacts. This international standard is applicable in all cases irrespective of the types of energy used.

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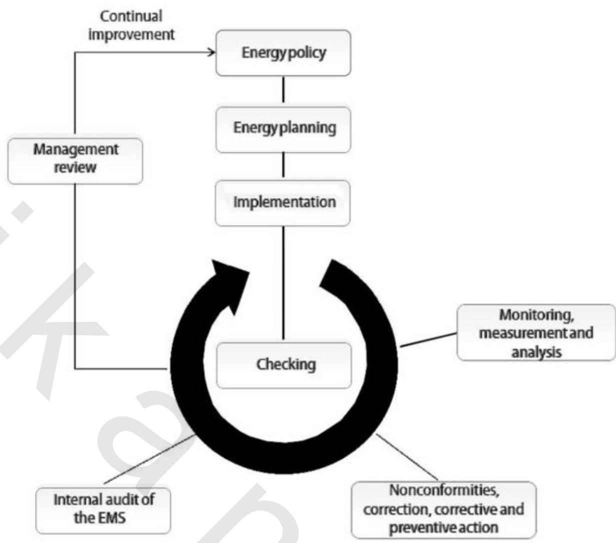

Figure 1: Energy management system (EMS) model (ISO 50001:2011)

II.2. Waste Management in Textile Industry

Woodard (2001) clarified that wastes from industries are customarily classified as liquid wastes, solid wastes or air pollutants and often the three are managed by different people or departments. The three categories of wastes are closely interrelated, both as they impact on the environment and as they are generated and managed. Solid wastes disposed in the ground can influence the quality of groundwater and surface waters by way of leachate entering the groundwater and traveling with it through the ground. Air pollutants can fall out to become surface water or groundwater pollutants and water pollutants can infiltrate into the ground or volatilize into the air. Waste treatment processes can also transfer substances from one of the three waste categories to one or both of the others. Waste treatment or disposal systems themselves can directly impact the quality of air, water or ground. The total spectrum of industrial wastes, then, must be managed as substances resulting from a system of interrelated activities.

Vandevivere *et al.,* (1998) and Melnyk *et al.,*(2003) agreed that the objectives of environmental management systems are to reduce redundant production procedures, packaging, raw materials needed, energy and water consumption, and toxics release to the environment. Furthermore, environmental management systems adopted by firms are required to monitor waste and pollution levels, they should take corrective actions when needed. Accordingly, effective implementation of environmental management systems should enhance the utilization of fabrics, water, and energy in textile firms. Environmental management systems in adopted firms are required to re-design their products or processes with the goal of optimizing the materials used. It was emphasized by those authors that, environmental management system adoption improvements leads to cost reduction, quality improvement, waste reduction in design and equipment selection, and lead-time reduction for manufacturers.

Stapleton *et al.,* (2001) explained that building or improving an environmental management system provides an opportunity to assess how the organization manages environmental obligations and to find better and more cost-effective solutions. By reviewing what the organization does and how well it works, the environmental management system can ensure to be viable and effective, both now and in the future. They added that, an effective environmental management system is built on total quality management (TQM) concepts. To improve the environmental working conditions, the organization needs to focus not only on what things happen but also on why they happen. Over time, the systematic identification and correction of system deficiencies leads to better environmental and overall organizational performance.

Brito *et al.,* (2008) and Lo *et al.,* (2012) studied the impact of environmental management systems in textiles industries and stated that the dyeing process could produce huge amount of toxic emissions that would lead to fines and high restoration costs. Therefore, managing the environmental impacts of their production processes is particularly important to textiles related firms. In spite of that they stated that the environmental issues in the textiles industry had received only little attention from both academics and practitioners. The "Europe State Council" has started enforcing green practices by legislation in hopes of motivating textile factories to adopt environmental management systems, such as ISO14000. Furthermore, the production of textiles and related products often requires high levels of energy and water consumption, and emits large quantities of pollutants to the environment. Therefore, the adoption of environmental management systems is important and could have a significant impact on firms' operational

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performance. They revealed that the adoption of ISO14001:2004, improves manufacturers' profitability.

The textile industry uses large amount of water in the different processes from getting the fiber to colouring and consequently waste water is another concern in this industry. Solid waste as an amount might not be as large but as type it raises another issue that needs good management. The specific water intake for the textile industry varies from 95 to 400 Liter/kg fabric depending on the type of processes used and water efficiency (Robertson & Kirsten, 1993).

Textile wastewater is an important pollution source that contains natural impurities extracted from the fibers and a mixture of process chemicals such as organic compounds, dissolved inorganic salts, dyes and heavy metals. In general, the effluent is highly-coloured, high in biological oxygen demand (BOD) and chemical oxygen demand (COD), has a high conductivity and is alkaline in nature (Lawrence, 1996 and Badani *et al.,* 2005).

IPPC (2001) stated that the main environmental concern in the textile industry is about the amount of water discharged and the chemical load it carries. Other important issues are energy consumption, air emissions, solid wastes and odours, which can be a significant nuisance in certain treatments. Air emissions are usually collected at their point of origin. Water effluent is a result of various streams coming from the different processes mixed together to produce a final effluent. Its characteristics are the result of a complex of factors such as: the type of fiber, make-up process, the techniques applied, the types of chemicals and auxiliaries used.

According to the "European Commission Environment" (ECE, 2003) the main purpose of waste management is to give an outline of waste streams and treatment options. Waste management plans are important instruments contributing to implementation and achievement of policies and targets set up in the field of waste management at the national level. In addition to giving an outline of waste streams and quantities to be managed, the established policies and targets should ensure that the capacity, the nature of collection and treatment systems are in line with the waste to be managed. Waste management plans should identify measures to eliminate or minimize certain types of waste. Also waste management plans make way for a statement of financial requirements for the operation of collection schemes and treatment of waste. On this basis, the need for future investments in waste treatment plans may be determined.

McDougall *et al,.* (2001) studied the integrated solid waste management system in a number of case studies in Spain, Italy, England, Finland, Germany, Sweden, Switzerland, Denmark, USA and India. They provide data that support the concept of integrated waste management as a sustainable method of managing solid waste. They present detailed descriptions and data on current waste management practices, such as waste generation, collection, sorting, biological treatment, thermal treatment, landfill and recycling

Accordingly, the authors declared that in waste management the joint treatment of a wide range of different types of waste in a single treatment method is commonly observed. For instance, any solid waste can be landfilled: Landfilling is "the only waste disposal method that can deal with all materials in the solid waste stream". In the same way, any flammable waste can be incinerated to meet distinct objectives such as volume reduction, stabilization, energy recovery and sterilization

Briga-Sá *et al.,* (2013) investigated the potential of reusing textile wastes. They illustrated that in the European Union, around 5.8 million tons of textiles are discarded by the consumers per year. Only 1.5 million tons (25%) of these textiles are recycled by charities and industrial enterprises. The remaining 4.3 million tons goes to landfill or to municipal waste incinerators.

Adding to this type of waste, there is also the textile waste from the textile industry. This shows that there is an enormous source of secondary raw material that is not used, but can be re-injected into the market. Thus, environmental concerns with the waste resulting from the textile industry have been increasing.

According to ISO14001:2004 the environmental management system requires the control of activities so that any environmental negative impacts are minimized. The environmental management system (ISO14001:2004) is based on the implementation of a continuous improvement cycle, which is presented in Figure (2).

Stapleton *et al.,* (2001) pointed the initial steps in the environmental management planning process (figure 3). It was also stated that using a team approach to planning and building an environmental management system is an excellent way to promote commitment and ensure that the objectives, procedures and other system elements are realistic, achievable, and cost-effective.

According to Lo *et al.,* (2012) there are a few case studies that explore how environmental management systems adoption could improve textiles firms' performance. For example, Fresner (1998) analyzed an Austrian textile mill and found that the adoption of ISO14001:2004 helps the firm to reduce waste production and thus its overall productivity. Brito *et al.,* (2008) found that firms that adopt ISO14000 improve their customer services and reduce costs, leading to eventual improvement in the overall performance of their supply chains. Nevertheless, these studies do not investigate whether the adoption of EMSs could improve firms' profitability, which is often the major concern for practitioners.

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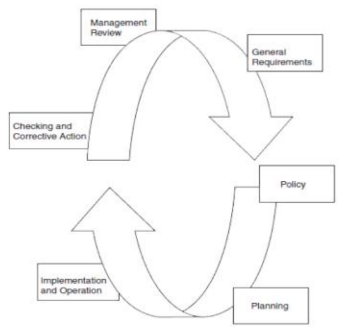

Figure 2: Implementation cycle for continuous improvement (ISO14001:2004)

Figure 3: Initial steps in environmental management process (Stapleton *et al.*, 2001)

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II.3. Life Cycle Assessment in Textile Industry

Life cycle assessment (LCA) is a technique used to assess the environmental aspects and potential impacts associated with a product, process or service. It is a tool with an array of applications that can aid in the understanding and management of environmental impacts, a substantial part of these environmental problems relate in one way or another to energy (Rebitzer *et al.,* 2004).

The LCA method determines the environmental impacts generated throughout the life cycle of product such as: climate change, stratospheric ozone depletion, eutrophication, acidification, toxicological stress on human health, ecosystems, depletion of resources, water use, land use, and noise (Rebitzer *et al.,* 2004, Udo de Haes & Heigungs, 2007, and Thorn *et al.,* 2011).

According to De-Smet *et al.,* (1996) LCA consists of four main elements: goal and scope definition, life-cycle inventory analysis, life-cycle impact assessment and life-cycle interpretation.

Boustead (1996) and Hertwich *et al.,* (2002) agreed that life cycle assessment methodology is an internationally standardized method that has been developed from various aspects including engineering principles, energy analysis, environmental sciences and economics.

Moreover, according to Clift *et al.,*(2000) and McDougall *et al.,* (2001) it is generally considered the best environmental management tool that can be used to obtain a proper understanding and an objective quantification of all the environmental impacts related with different best management scenarios. The term life cycle indicates that every stage of the life cycle of the service, from resource extraction to ultimate end-of-life treatment, is taken into account. They clarified that for each operation within a stage, the inputs (raw materials, resources and energy) and outputs (emission to air, water and solid waste) are calculated and then aggregated over the life cycle by means of material and energy balances, drawn over the system boundary. Kalliala *et al.,* (2000) clarified that life cycle thinking notes all environmental effects across the entire product chain, from the production of raw material to waste management. The main objective is to decrease emissions from the product chain. The Life cycle assessment is an important environmental management tool and is used in many industries nowadays in the world.

Furthermore, Udo de Haes & Heijungs (2007) explained that economic activity is closely associated with depletion of resources and pollution of the environment. This can be studied at the level of single processes or activities, but also at higher systems level of networks of processes. The main aim of LCA is to quantify potential environmental impacts of products over their full life-cycle. A life-cycle approach is also called a ''cradle-to-grave'' approach. LCA is a form of chain analysis connected to environmental problems, it can be seen as an extension of energy analysis.

Regarding the textile industry Lai-Li *et al.,* (2009) stated that the environmental protection capabilities of textiles and competition strengths of textile corporations can be improved with application of LCA in textile industry. Tobler (2000) studied life cycle assessment in textile finishing and reported that LCA results in textile process are highly depending on water and energy management of the company. Furthermore, LCA results vary according to the prime source for energy.

Nieminen (2003) examined the manufacturing processes of natural fibers, synthetic fibers and fiber mixtures as textiles, by using the life cycle assessment method. The experimental data was derived from measurements of the manufacturing processes, wastewater analyses and annual energy consumption of the production facilities.The Life Cycle Inventory (LCI), was carried out in accordance with ISO 14040:2006 standard guidelines for LCA. Accordingly, he stated that more research is required on environmental indicators for textile products.

An initial action established by the "European Science Foundation for life cycle assessment" of textile products and eco-efficiency was conducted by Nieminen *et al.,* (2007). The action research network collected a wide European database of textile processing and performed several life cycle inventory analyses and looked at new, emerging cleaner technologies, in order to minimize the use of natural resources, consumption patterns and to move towards zero emissions. They declared that life cycle assessment is considered to be the appropriate scientific base for an environmental impact assessment.

Nakamura & Kondo (2002) studied the different models of waste management assessment and illustrated that the main concern of waste management LCA consists of the economic and environmental impacts that may result from the introduction of alternative waste-recycling methods and/or alternative waste treatment methods.

Ekvall *et al.,* (2007) investigated the importance of LCA on waste management assessments. They declared that in assessments of the environmental impacts of waste management, life-cycle assessment helps expanding the perspective beyond the waste management system. In particular, the broad perspective of LCA makes it possible to take into account the significant environmental benefits that can be obtained through different waste management processes such as: waste incineration with energy recovery reduces the need for other energy sources, and also material from recycling processes replaces production of virgin material. The broad system perspective makes LCA a powerful tool for environmental comparison of different options for waste management of a specific product, a material or a complex waste flow.

Udo de Haes & Heijungs (2007) also studied LCA applications regarding waste hierarchy and integrated waste-management. They stated that the waste hierarchy implies a fixed order of waste management options, from most to least preferable: product reuse, materials recycling, incineration with energy recovery, incineration without energy recovery, and finally landfill.

Cherubini *et al.,* (2009) illustrated that there is an increasing interest in the several options for management of resources and waste in order to design strategies for integrated, sustainable resource and waste management policies. LCA methodologies can be used in this context as an input to decision-making regarding the choice of waste management systems or strategic decisions concerning resource use priority. In fact, LCA is able to provide an overview of the environmental aspects of different waste management strategies and makes possible to compare the potential environmental impacts of these options.Their research focused on a life cycle assessment of four waste management strategies: landfill without biogas utilization, landfill with biogas combustion to generate electricity, sorting plant which splits the inorganic waste and direct incineration of waste. These scenarios were evaluated under different points of view: global and local emissions, total material demands, total energy requirements and ecological footprints. Results show landfill system was the worst waste management options and significant environmental savings at global scale are achieved from undertaking energy recycling.

Regarding the potential of life-cycle assessment for energy analysis and management Udo de Haes & Heijungs (2007) found that energy is involved in all life cycles. First, the energetic aspects are fully incorporated in the calculations, and aggregated with the non-energy related processes in the life cycle. Energy does not show up as a separate result of the inventory analysis or the impact assessment, but is translated into inventory issues like extraction of crude oil and emission of carbon dioxide, or into impact-assessment issues like depletion of resources and climate change. Secondly, a separate analysis of the energetic aspects of a life cycle can be

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performed. Thirdly, LCA can be applied to analyze energy systems, which can range from small scale energy systems to large ones.

Van der Velden *et al.,* (2014) provided an improved (up-to-date) insight into the environmental burden of textiles made of the base materials cotton, polyester, nylon, acrylic, and elastane. They investigated which life cycle stage (cradle-to-gate as well as cradle-to-grave) have the biggest impact on the environment. They explained that in recent years, life cycle assessment has been increasingly adopted by textile and apparel companies. Many actors in the textile and clothing chain such as fiber manufacturers use LCA to assess the environmental impacts of textile-related products.Their results demonstrates that textiles made out of acrylic and polyester have the least impact on the environment, followed by elastane, nylon, and cotton. They agreed that further LCI data studies on textiles and garments are urgently needed to lower the uncertainties in contemporary LCA of textile materials and products.

ISO 14040:2006 (International standard for Environmental Management) and ISO 14041:2006 (International standard for Life Cycle Assessment) provide an internationally accepted framework for conducting LCA. Details of ISO 14040:2006 (International standard for Environmental Management – LCA – Principles and Frameworks) are illustrated in Appendix (A). ISO 14041:2006 deals with two phases of LCA, goal and scope definition and life cycle inventory analysis. The goal and scope definition phase is important because it determines why an LCA is being conducted including the intended use of the results and describes the system to be studied and the data categories to be involved. The purpose, scope and intended use of the study would influence the direction and depth of the study. The LCI involves the collection of the data necessary to meet the goals of the defined study. It is essentially an inventory of input/output data with respect to the system under investigation.

LCA studies are conducted by developing models that describe the key elements of physical systems. It is often not practical to study all the relationships between all the unit processes in a product system, or all the relationships between a product system and the environment. The choice of elements of the physical system to be modeled is dependent on the definition of the goal and scope of the study.

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III.MATERIAL AND METHODS

III.1.Guidelines

III.1.1.Energy and waste management

According to ISO 50001:2011and ISO 14001:2004 energy and waste management programs were established based on the Plan - Do - Check – Act/Review (PDCA) continual improvement framework. The PDCA approach is outlined as following:

- Plan: conduct reviews and establish the baseline, performance indicators, objectives, targets and action plans necessary to deliver results that will improve performance in accordance with organization's policy.
- Do: implement the action plans.
- Check: monitor and measure processes and the key characteristics of operations that determine energy and waste performance against the policy and objectives, and report the results.
- Act/Review: review progress and take actions to continually improve performance.

III.1.2.Auditing of energy and waste systems

ISO 19011:2002 and ISO 50001:2011 the organization performed internal audits on weekly basis to identify any leakages of steam, air, water or raw material, recognize abnormalities or losses in a specific area. Appendix (B) shows some check sheets used in the internal audit for leakages.

An external agency for technical services support acted as an external auditor. According to Derashri (1999) and William *et al.,* (2003) the energy audit was conducted in three phases: preparing for the audit visit, performing the facility survey and implementing the audit recommendations.

Within the first phase: energy data was collected from reports, data sheets and actual measurements to determine energy usage and its variation with time. Preliminary information on the facility was compiled. The compiled data for the audit included: Process description documentation, Process flow diagram, Plot plan layout, Historical data for power consumption and cost, Historical data for steam consumption and cost, Main single line diagram, in addition appendix (B) present the related check sheets of: Motor data, Variable speed data, Capacitor data, Lighting data and Energy meters data

The necessary auditing tools were gathered and a technical in-house team was assembled to assist the external auditors in the audit. Phase two was the plant survey for different areas in the facility and information record for later use. Phase Three was the preparation of an audit report.

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III.2.Energy Measurements Equipment

Below details of each instrument used in the audit, its major function and areas of usage:

a) Multimeter

Used to determine the operating voltage and currents of the equipment.

b) Portable Ultrasonic Flow meter

Measured the velocity of the liquid through the pipes. It was used for measurements on pipes with diameters between 10 to 2500 mm and temperatures from -30°C to 100°C. Figure (4) shows the portable ultrasonic flow meter, model Portalok 7SZ (EESIFLO, USA).

c) Stroboscope

Stroboscope Testo 476 (TESTO, USA) measured the rotation and vibration motion (Figure 5). Measuring range from 30 to 12,500 rpm, accuracy ±1 digit: ±0.02 % of m.v. and resolution: 1 rpm

d) Ultrasonic leakage detector

The detector was used to identify leak valves, bearings air or steam. It was used to receive sound pressure waves of ultrasound frequency. Figure (6) shows the used detector ULTRAPROBE® 10,000 (UE Systems Inc., USA).

e) Thermal Image Camera

The used camera was a Fluke Ti32 industrial thermal imager (Fluke, USA) (Figure 7). It handhelds thermal images used for preventive and predictive maintenance, equipment troubleshooting, repair verification, building inspections as well as energy audits. Temperature measurement range is from -20 °C to +600 °C. Thermal and visual images were displayed on imager LCD and saved for data analysis.

f) Temperature - Humidity meter

A humidity and temperature meter Vaisala HUMICAP® HM70 (Vaisala, Finland) (Figure 8) was used. It had an RH measurement range from 0 to 100 %, user interface showed the measurement trends graphically. Temperature measurement ranges between -70 and +180 °C.

g) Thermometer

A thermometer Raynger ST80 Pro thermometer (RaytekRaynger, China) was used as well (Figure 9). The thermometer had a temperature range of -32 to 760° C, response time of .05 second and weight of 320g.

h) Power Quality Analyzer

Figure (10) shows the Fluke 43 power quality analyzer (Fluke, USA). It measures power harmonics, power factor, captures voltage sags and inrush current. It was used for measurements needed to maintain power systems, troubleshoot power problems and diagnose equipment failures.

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Figure 4: Portable ultrasonic flow meter

Figure 5: Stroboscope- Testo 476

Figure 6: Ultrasonic leakages detector

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Figure 7: Thermal imager camera

Figure 8: Temperature - humidity meter

Figure 9: Thermometer

Figure 10: Power quality analyzer

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III.3.Methods

III.3.1.Data collection

According to ISO 50001:2011 and ISO 19011:2002 the organization recorded and maintained energy and waste review data. Historical data for monthly power consumption was gathered from 2009 till 2012, monthly steam data was collected for 2011 and 2012 and monthly waste data was available for 2012. The collection and monitoring of daily power, steam and waste data started by the initiation of the programs on 2012. The following data was collected:

a) Power consumption by material preparation area (kWh/Day)
b) Power consumption by production area (kWh/Day)
c) Power consumption by utilities (kWh/Day)
d) Total power consumption (kWh/Day)
e) Total steam consumption (MT/Day)
f) Waste fiber generated (TF/Day)
g) Low grade fiber generated (TF/Day)
h) Liquefied waste (TF/Day)
i) Total production (TF /Day)

Using these data the consumption ratio for power in different areas was calculated, overall steam consumption ratio and waste generation ratio were also calculated.

III.3.2.Creation of action plan and goals setting

According to ISO50001:2011and ISO 14001:2004 a tracking system was followed to review the action plan, it contained:

- Status of action (Not started, In progress, Completed).
- Goal description
- Actions required to be taken to achieve each goal
- Accountability/responsible of implementing the action
- Date of completion, revised completion and actual completion
- Expected savings (EGP)

Status of actions was being updated on the system by the assigned persons in coordination with management coordinator and committee manager.

III.3.3.Life cycle impact assessment

The used method in the current study as an indicator for climate change, acidification, eutrophication, eco-toxicity, carcinogens and respiratory inorganic impacts was “Eco-indicator 99 (E) V2.06/Europe EI 99 E/E”. It includes impact categories which cover the most important environmental issues. The eleven impact categories taken into consideration as compiled by the Eco-indicator 99 methodology were: Global Warming Potential (GWP) represented by climate change, Acidification Potential (AP), Eutrophication Potential (EP), Carcinogens Potential (CP), Ecotoxicity Potential (ETP), Respiratory Inorganic Formation Potential (RIFP), Respiratory Organic Formation Potential (ROFP), Radiation Potential (RP), Ozone Layer Depletion (OLD), Minerals Depletion (MD), Land Use (LU), and Fossil Fuels Depletion (FFD) (Figure 11). These impact categories are grouped in three groups: impact on human health, impact on ecosystem quality and impact on resources. As for fossil fuels depletion the used methodology was “Cumulative Energy Demand (CED)”. The evaluation of the impact categories were expressed in mega points (mPt) to evaluate the impact of a product or process, more points mean worst environmental burden (Goedkoop *et al.*, 2008).

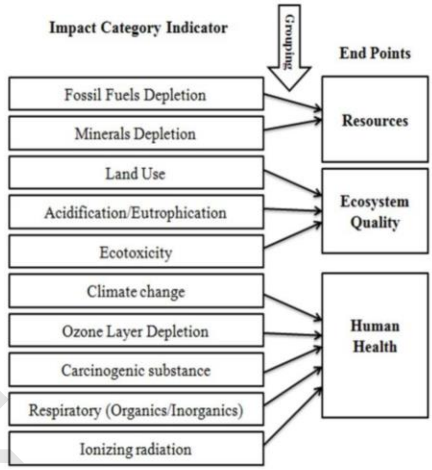

Figure 11: Impact category indicators on Eco-indicator 99 (Goedkoop *et al.*, 2008)

The two life cycle assessments for evaluating the environmental impact of acrylic fiber manufacturing and for waste streaming approaches in acrylic fiber industry were realized by software SimaPro7 a software and database for life cycle engineering (Appendix A). SimaPro7 software contains a number of databases and Ecoinvent libraries. These libraries contain over 2500 processes, covering a very wide range of processes. It contains a number of impact assessment methods as well.

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IV. STUDY AREA: Alexandria Fiber Company

IV.1. General Background Information

Alexandria Fiber Company is the only acrylic fiber plant in the Middle East region that produces high grade fiber (tow, tops andstaple fiber) and exports to more than 25 countries. The plant was established in 2006, with a designed production capacity of 18,000 Ton per year and islocated in operation at Amreya district, Alexandria. It is close to the end user spinning mills, many of which are located in Alexandria and Tenth of Ramadan.

Acrylic fiber production process in Alexandria Fiber Company takes place through many stages in two main areas: material preparation and production. Different wastes are produced during the manufacturing process. Both hazardous and non-hazardous wastes result from the main production areas. They are treated carefully and handed by proper methods.

IV.2. Site and Surrounding Premises

The plant is established at the industrial zone of El Nahda region. The region is considered as a natural expansion of the north west delta region and is characterized by mild topography. The location is traversed by a network of roads connecting it to the main cities of the region (namely, Alexandria, Matruh and Burg El Arab). Nile water is provided by El Nahda canal. The site of the plant is surrounded by a number of large industries, the Carbon Black Company, Alexandria Tyres and the Egyptian Petrochemicals Company across the road. On the same side of the road, there are the Mostawdaat club and a small company producing agricultural sulfur AFCO-EIA (2007).

IV.3. Plant Description

According to AFCO-EIA (2007) the existing manufacturing facility can be divided into the following sections:

- ❖ Tank Farm area: for receiving and storing raw materials.
- ❖ Material Preparation area: contains the polymerization section, dope section and solvent recovery.
- ❖ Production area: where the fiber is shaped into the final form.
- ❖ Water Treatment Plant (WTP): the raw water from Nubariya canal is processed to produce filtered water and demineralized water. It contains units for Reverses Osmosis (RO) and a Deminerilized Water (DW).
- ❖ Cooling Towers: the cooling requirement for the process and utilities is met by cross flow, counter current cooling towers.
- ❖ Chillers: The chilling plant has water chillers for normal low temperature and the brine chillers for subzero temperatures.
- ❖ Air Compressors and Nitrogen Plant: the requirement of air and nitrogen for the process and utilities is met by oil free screw compressors and the pressure swing adsorption nitrogen plant.
- ❖ Effluent Treatment Plant (E.T.P.): The effluent generated from the process is treated in a chemical/ biological treatment process where the sodium thiocyanate and free cyanide are

chemically broken by alkyl-chlorination process. The subsequent reduction in COD and BOD is achieved by biological treatment in the aeration tank.

IV.4. Process Description

The manufacturing process of acrylic fiber is divided into two areas, namely material preparation and production area. Figure (12) presents the process flow diagram of acrylic fiber production.

The material preparation areaconsists of polymerization, dope making and solvent recovery. In the polymerization process acrylonitrile reacts with vinyl acetate in the polymer reactor. Recovered monomer and other additives are also added into the reactor. Reaction is exothermic and process is continuous. This reaction produces a slurry with polymers. This slurry is then fed to the monomer recovery tower. It is a stripping column where monomer is separated and recycled back to the reactor. Polymer slurry obtained from monomer recovery tower is washed in polymer washing section to remove impurities and then stored in storage tanks to be supplied to dope making section.

In the dope making the polymer slurry is converted to spinable dope solution by addition of a strong solvent as a dissolver to the slurry in the dissolver tank. The outlet dope is filter and sent to the spinning section.

Solvent recovery is an essential process used for recovery of the used solvent. Spent solvent is received from the spinning section. It is filtered and passed through carbon bed to remove impurities. It is then fed to five effect falling film type evaporator to remove water from it. Concentrated solvent obtained from evaporator is purified and its concentration is adjusted in the second recovery section. Recovered solvent is sent to production area for reuse.

In the production area fiber formation starts when the dope is heated, then it is extruded through spinnerets, coagulated, washed, dyed, stretched, conditioned, applied to finish oil, crimped and final dried. Dope is heated to 65 ^{o}C for extrusion after filtration. The coagulation of dope solution is done in a cold spinning bath (dilute sodium thiocyanate solution) of about 3^{o}C. Filaments from the individual spinning heads are combined at coagulation bath to form a tow. The tow is then stretched slightly in solvent stretch bath and washed with a counter current stream of hot de-ionized water. The tow is then dyed in the dye bath where dye solution is continuously circulated. The dye solution is prepared by an automated dye kitchen. The tow is then stretched between two sets of rolls. The stretched tow is collapsed in the conditioner by drying under controlled condition to develop the fiber properties. The tow is then relaxed in steamer and crimped after finish application. Subsequently the crimped tow is dried in the tow dryer to a desired level of moisture. The dried tow is either packed as “tow” or cut as a “ stable fiber” of standard length.

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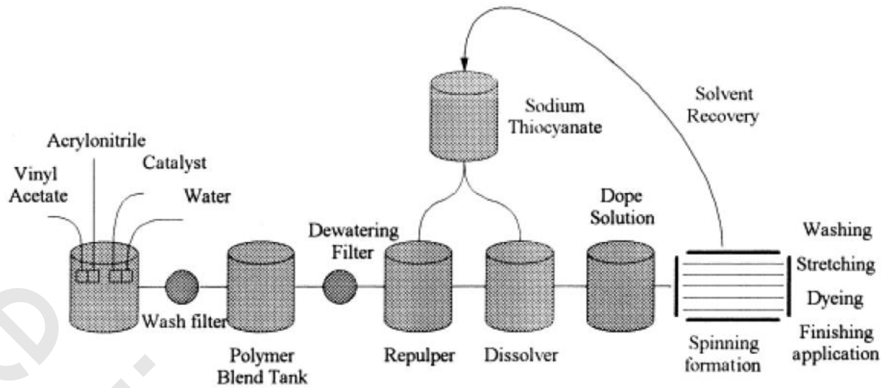

Figure 12: Process flow diagram of acrylic fiber production (Blanco *et al.*, 1999)

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