CHAPTER 1

INTRODUCTION

1.1 WORLD TEXTILE SECTOR

Textile industry is one of the oldest and most important sectors of the World economy. The growth of this sector has provided greater opportunities for increased trade between countries and it has also provided greater employment opportunities. World textile sector is likely to grow at a faster pace than the most of the industrial sectors due to increasing population and changes in living trends. Textile sector was normally considered to be a traditional sector in the earlier centuries and now it has developed itself into a fully grown industrial sector. The market is now growing rapidly with innovative textiles and many developments of new products and applications. The trend is towards high tech, high performance textiles with added value in terms of its functionality. This is an industry that has substantial contribution to a country’s economy.

The total volume of fibers manufactured and processed into textiles is close to 60 million tonnes a year and world population is almost 6.1 billion people. Each inhabitant of the planet thus consumes about 10 kg of fibre materials and this is likely to be higher or lower depending on the climate conditions in the region, level of development of the concerned countries. It is much higher in developed countries and countries with colder climates. According to the projections of sociologists, the planet’s population will approach 10 to 11 billion by middle of 21st century and the demand for fibers and materials per capita (including the needs of developed countries) could
reach 12 to 15 kg and higher which corresponds to the current level of demand in the most developed countries. For this reason, the analysis and prediction of the evolution of production and an evaluation of the technical and economic problem in this area are very important (Perepelkin 2003).

One of the primary concerns in the development of textile sector is the use of energy and its effect on environment. Effects to clean up the environment have been made by governments at national, state, and local levels by establishing new regulations and guidance. For example, in the UK textile and clothing sector during the year 2004, the amount of waste generated is about 2 million tonnes with a GHG emission of 3.1 million tonnes CO\textsubscript{2} equivalent. The water consumption is about 90 million tonnes and wastewater generated is about 70 million tonnes (Defra 2006).

The textile industry is gigantically polluting. The textile industry uses substantial amount of water and chemicals. In fact, the textile industry is considered to be number one industrial polluter of water in the world. Water is used at every stage in fabric chemical wet processing to dissolve chemicals to be used in one step, then to wash and rinse out those same chemicals to be ready for the next step. It takes between 10 and 100% of the weight of the fabric in chemicals to produce that fabric. Of all the steps involved in textile processing, wet processing creates the highest volume of wastewater.

Each year, the global textile industry discharges 40000 to 50000 tonnes of dyes into rivers and streams and in Europe alone, 2 lakh tonnes of salt are discharged every year. Further, synthetic dye use can lead to source problem in future because they are made from finite sources, such as petroleum. Textile industries consume over 7 lakh tonnes of dyes annually. Reactive and disperse dyes constitute about 55% of the total dye market while direct dye use is about 10% and vat dyes is about 10%. About 1 Giga tonnes
of effluent are discharged due to use of these dyes in textile materials (Eco textiles 2007).

Toxics Release Inventory 2006 Report of United States Environmental Protection Agency (USEPA 2008) shows that over 1500 tonnes of toxic chemicals were released by US textile mills in 2005. The US textile industry is small compared to other countries.

Most process performed in textile mills produce atmospheric emission. Gaseous emission has been identified as the second greatest pollution problem of the textile industry. An average integrated textile mill produces 15 tonnes of finished cloth per day. It uses a total of approximately 3840 cubic meters of water per day including 1680 cubic meters for finishing and processing. The water used for finishing and processing results in contaminated liquid effluent of approximately 1500 cubic meters per day (Greenstratos 2009).

Based on an annual global textile production of 60 billion kg, the estimated energy consumption is about 1074 billion kwh or 132 million metric tonnes of coal. The annual energy consumption is 989 kiloliters of oil equivalent. A saving of 30% to 50% is easily achievable and cost savings work out to be $ 5.1 billion to $ 8.6 billion (Rupp Jurg 2008 ). Beyond fiber production, the dyeing and finishing sector is the largest energy and water consumer in the whole textile chain and has the highest potential for energy and water savings and efficiency improvements. Major portion of water in the textile industry is used for wet processing of textiles (70%). About 34% of energy is consumed in spinning, 23% in weaving and 38% in chemical wet processing and 5% for miscellaneous purposes. Power dominates the consumption pattern in spinning and weaving, while thermal energy is the major input for chemical wet processing.
In today’s competitive market environment, it is hard to increase the price of any product in spite of higher raw material prices and soaring water and energy costs. Therefore, it is more important than ever to apply modern technology with the greatest potential for energy and water saving resulting in reduced production costs.

In the technology of textile production, the most significant value added process is wet processing sector. In the wet processing, dyeing is the most important process. The largest producer of dyes in the world is Germany at 25% followed by USA at 18%. Big global players like American colour, Atlantis, Bayer AG and Hoescht controlled about 60% of the total dye output. But new shift is discernible in global dye producers. The overall share of developed nations has now declined from 65 to 50%. Lack of enforcement and liberal regulations relating to environment also make the industrializing countries in lucrative place to set up polluting industries. Thus, the south ends up paying the real ecological costs to produce dyes for north. Industrialized countries are facing the rising cost of disposing of relatively high quantities of hazardous wastes generated during production. Thus, international traditional dyestuff producers shifted and or migrated their production facilities to Southeast Asian Countries and China during the past two decades (Centre for Science and Environment, India, 2005).

Annual per capita consumption of dyes in USA was about 500 gms per person while it was about 50 gm/person until the early 2000 (Yosuke Ishikawa 2008). However, per capita consumption of dye is now growing at a faster rate in developing countries as their populations increase and export of dyed textiles to developed countries continue to grow. The migration of low and medium quality textile production to lower cost countries is expected to continue, demanding further and often painful adjustments for international dyestuff producers.
Treatment of fiber or fabric with dyes to impart colour is called dyeing. The colour arises from chromophore and auxochrome groups in the dyes which cause pollution. In the dyeing process, water is used to transfer dyes and in the form of steam to heat the treatment bath. Cotton which is the world’s mostly widely used fiber is a substrate that requires a large amount of water for processing. For example to dye 1 kg of cotton with reactive dyes, 0.6 to 0.8 kg of NaCl, 30 to 60 g of dyestuff and 70 to 150 L of water are required. More than 700,000 tonnes of dyes are produced in every year. Once the dyeing operation is over, the various treatment baths are drained including the coloured dye bath which has high concentration of salt and organic substances. For example, wastewater produced by reactive dyeing contains hydrolysed reactive dyes not fixed on the substrate (representing 20 to 30% of the reactive dyes applied on an average 2g/l). Dyeing auxiliaries also contribute to the chemicals in the effluents (Chakraborty 2005).

1.2 INDIAN TEXTILE INDUSTRY

The Indian textile industry is one of the oldest and most significant industries in the country. It accounts for about 4% of GDP, 14% of industrial production and over 13% of the country’s total export earnings. Moreover, it provides employment to over 35 million people. The Indian textile industry is estimated to be around US$ 52 billion and is likely to grow to US$ 115 billion by 2012. The domestic market is likely to increase from US$ 34.6 billion to US$ 60 billion by 2012. It is expected that India’s share of exports to the world also would increase from current 4% to 7% during this period. The textile sector registered 50% increase in investment during 2008 – 09 to US$ 10.46 billion from US$ 6.57 billion in 2007 – 08 according to Associated chamber of commerce and industry (ASSOCHAM) study. (Prakash Chandra 2006).
The chemical wet processing segment is the weakest link in India’s textile value chain. This sector is highly fragmented and consists of a number of small hand and power processing units.

The Indian textile industry has generated GHG emission to the tune of 7 to 9 million tonnes in 1992 and 54.8 million tonnes in 2002. Thus there is a quantum jump in emission and with a higher growth rate and it is likely that this emission will go up considerably. The dye market is about 70,000 tonnes per annum. The amount of effluent generation is around 1.6 million tonnes per day, largely untreated. Out of the total dyes, about 55% are reactive and disperse dyes. The use of reactive dyes has led to the problem of high salt concentration in the effluent. Textile chemicals form a chunk of the Indian chemical industry that is believed to be 3rd largest in Asian region and 12th largest in the world. The demand for textile chemicals is projected to jump 6.3% annually touching US $ 1.9 billion in 2012 according to the Freedonia group, a US based market firm. Textile chemicals consist of three categories namely colourants and auxiliaries, coating and sizing chemicals and finishing chemicals.

Indian textile industry produces 400 million meters of cloth and around 1000 million kg/annum. Textile wet processing activity contributes to 70% pollution in textile industry. It is estimated that there are around 12500 textile processing units. More than 14000 dyes and chemicals are used in textile wet processing (Subrata Das 2006).

The Indian dye industry is valued at around US $ 3 billion with exports of about US $ 1 billion. The industry is highly fragmented with 50 players in the organized sector and 900 in the unorganized sector. At present, India’s share of the dye output globally stands at 5% with a manufacturing capacity of 150,000 tonnes/annum. India is the second largest exporter of
dyestuffs and intermediates among developing countries after China (Mathur 2005).

1.3 DYEING

Generally, the textile industries use synthetic dyes, which fall into a number of categories: basic dye, direct dye, vat dye, sulphur dye, disperse dye, reactive dye, acid dye, mordant dye, azo dye and low impact dye. Their characteristics are given in the following paragraphs.

1.3.1 Basic Dye

These are water soluble cationic dyes that are applied to wool, silk, cotton and modified acrylic fibres. Usually acetic acid is added to the dye bath to help the take up of the dye onto the fibre. Diarylmethanes, triarylmethanes, anthraquinones and azo dyes are the basic dyes.

1.3.2 Direct Dye

Dyeing is normally carried out in a neutral or slightly alkaline dye bath, at or near the boil, with the addition of either sodium chloride (NaCl) or sodium sulphate (Na₂SO₄). Direct dyes are used on cotton, paper, leather, wool, silk and nylon. They are also used as pH indicators and as biological stains. Direct dyes contain multi azo, phtalocyanines, stilbenes and oxazines.

1.3.3 Vat Dye

These dyes are essentially insoluble in water and incapable of dyeing fibres directly. However, reduction in alkaline liquor produces the water soluble alkali metal salt of the dye. In this leuco form, these dyes have an affinity for the textile fibre. Subsequent oxidation reforms the original insoluble dye. This group contains anthraquinones and indigoids compounds.
1.3.4 Sulphur Dye

Sulphur dyeing is a relatively cheap method of obtaining good colour strength and acceptable fastness of dyeing. It’s often used for low cost fabrics and garments such as working clothes. 70,000 tonnes of sulphur dyes are used annually, with just one colour, Sulphur Black 1, making up 20-25% of the dyestuff market for cotton. Environmentally speaking, it’s free from heavy metals and other toxics. So it’s not too bad when compared to reactive dyes, except for the fact that 90% of all sulphur dyes make use of sodium sulphide, which makes the process’s effluent more toxic than any other’s. This discharge endangers life and possibly alters its DNA, corrodes sewage systems, damages treatment works and often leads to high pH and unpleasant odours. This effluent also contains between 30% to 40% of the dye that was originally added to the bath, as well as alkalis and salt.

1.3.5 Disperse Dye

This was originally developed for the dyeing of cellulose acetate. They are substantially water insoluble. The dyes are finely ground in the presence of a dispersing agent then sold as a paste or spray dried and sold as a powder. They can also be used to dye nylon, triacetate, polyester and acrylic fibres. In some cases, a dyeing temperature of 130 °C is required and a pressurised dye bath is used. The very fine particle size gives a large surface area that aids dissolution to allow uptake by the fibre. The dyeing rate can be significantly influenced by the choice of dispersing agent used during the grinding. Disperse dyes contain small azo or nitro compounds, metal complex azo and anthraquinones.
1.3.6 Reactive Dye

They are used to dye cellulose fibres. The dyes contain a reactive group that, when applied to a fibre in a weakly alkaline dye bath, form a chemical bond with the fibre. Reactive dyes can also be used to dye wool and nylon, in the latter case they are applied under weakly acidic conditions. Azo or metal complex azo, anthraquinones and phtalocyanines are some of the reactive dyes.

1.3.7 Acid Dye

These are water soluble anionic dyes that are applied to fibres such as silk, wool, nylon and modified acrylic fibres from neutral to acid dye baths. Attachment to the fibre is attributed, at least partly, to salt formation between anionic groups in the dyes and cationic groups in the fibre. This group contains azo, anthraquinones and triarylmethane compounds.

1.3.8 Mordant Dye

These dyes require a mordant. This improves the fastness of the dye on the fibre. The choice of mordant is very important as different mordents can change the final colour significantly. Most natural dyes are mordant dyes.

1.3.9 Azo Dye

This uses a dyeing technique in which an insoluble azo dye is fixed directly onto or within the fibre. This is achieved by treating a fibre with a diazo component and a coupling component. With suitable adjustment of dye bath conditions, the two components react to produce the required insoluble azo dye. This technique of dyeing is unique in that the final colour is controlled by the choice of the diazo and coupling components.
1.3.10 Low-Impact Dye

Low-impact reactive dyes have been developed, which have been classified by the European Union (EU) as eco-friendly. They contain no heavy metals or other known toxic substances, and do not need mordants. The high cost of this dye becomes an environmental advantage, as it is cheaper to reclaim dye from its effluent rather than discharge it all and start from scratch. The water can also be recycled. The dye cycle is shorter than it is for other dye processes, meaning less water, salt and chemicals are needed. The entire process normally occurs at a pH of around 7.0, meaning no acids or alkalis need to be added to the water.

The disadvantages are that like other environmentally damaging dyes, these dyes are made from synthetic petrochemicals. The process requires very high concentrations of salt (20%-80% of the weight of the goods dyed), alkali and large amounts of water are needed even though the average T-shirt uses 16-20 litres of water to be dyed, and this process can require each shirt to require up to 30 litres. Around 40g of dye per shirt is also needed. Even if the unfixed dye is reclaimed, the effluent from this process can still contain high concentrations of salts, surfactants and defoamers, and are strongly alkaline. It’s also quite expensive, whereas conventional dye is cheap. This process effluent normally contains salt, alkali, detergent and between 20% to 50% of dye used. As reactive dyes currently make up 30% of world dye consumption, more knowledge on how to improve upon this method is needed.

1.4 ENERGY EFFICIENCY AND CONSERVATION IN TEXTILE DYEING

Energy is a vital factor for economic prosperity, but it is also a major contributor to pollution, environmental degradation and resource
depletion. By improving the energy efficiency of dyeing, it is possible to reduce the energy consumption substantially and control the waste generation resulting in significant cost savings. The energy used for the whole chemical wet processing is roughly equivalent to twice the weight of the textile. This means that when a tonne of fabric is brought into the factory, two tonnes of fuels enter from the other side. Another datum is that the energy costs approximately as much as the dyestuffs. Hence, the necessity to manage it at best comes up.

Another point of environmental consideration in textile industry is the emission of greenhouse gases responsible for global warming. About 12 million tonnes of carbon dioxide is being emitted from Indian textile dyeing units due to use of various types of fuel required for generation of thermal energy. As the textile demand goes up, the GHG emission will go up proportionately. Already efforts are on to reduce these emissions to the 1990 year level under Kyoto protocol.

Therefore, energy efficiency and conservation has become essential in textile industries. Textile wet processing is one of the most important value addition process and therefore energy use study in wet processing has attracted the attention of the researchers world over. Dyeing is a major process in textile wet processing. It imparts colour to the fabrics without affecting the quality of the fibre. Conventional dyeing consumes more thermal energy in the form of steam and it is not environmental friendly. Most of these processes involve the use of chemicals for assisting, accelerating or retarding their rates and must be carried out at elevated temperature to transfer mass from processing liquid medium across the surface of textile material in a reasonable period of time. Like all chemical processes, these transport processes are time and temperature dependent and compromising either of them could affect product quality.
1.5 NON-CONVENTIONAL TECHNOLOGIES IN TEXTILE DYEING

In view of these problems faced by World textile industries in general and Indian textile industries in particular, Conventional dyeing techniques have to be replaced by energy efficient technologies which require low liquor ratio, less dyes and chemicals and lower operating parameters like time, temperature and concentration. Hence, the following non-conventional technologies have been considered for improved energy efficiency in this study.

1. Ultrasound assisted dyeing
2. Microwave assisted dyeing
3. Infrared assisted dyeing
4. Magnetic stirred hot plate dyeing

This work deals with an experimental study of energy efficiency and energy conservation potential achievable by possible application of these technologies. The operating parameters like temperature, time and concentration are varied and its effect on energy consumption are evaluated. The materials that are used in the experiment are cotton, polyester and a blend of cotton and polyester. The study also deals with possible reduction in GHG emission due to the likely implementation of these technologies. The basic characteristics of these processes are given in Chapter.2.

1.6 OBJECTIVES

With reference to previous works, it has been observed that adoption of these non-conventional technologies led to saving in energy, water, dyes and chemicals. However, sufficient data has not been provided to show the extent of energy saving possible. Hence, in order to make an
objective assessment and compare the different technologies for application, this work is being carried out. The major objectives of this work are to carry out a comparative evaluation of energy efficiency for these non-conventional dyeing technologies in different textile materials. The following are the objectives with the proposed activities.

- To conduct the dyeing experiments using the alternate equipments like ultrasonicator, microwave oven, magnetic stirrer and infrared dyeing equipment.
- To estimate the apparent diffusion coefficient under different technologies.
- To conduct dyeing by varying the process parameters like time, temperature and concentration of dye in cotton, polyester, and cotton-polyester blend fabric and measuring the dye uptake.
- To compare energy consumption in different technologies and estimation of possible energy savings by the alternative technologies with respect to that of conventional method of dyeing.
- To develop mathematical relations for specific energy consumption in cotton, polyester, blend with respect to temperature, concentration and time variables.
- To study the impact of these alternate technologies intervention on overall Indian textile dyeing industry’s energy consumption and emission reduction potential achievable in the coming decade.
1.7 WORK PLAN

To fulfill the above objectives, experimental investigations were conducted by using equipments like sonicator, infrared machine, magnetic stirrer, microwave oven and conventional electrical heater. Cotton, polyester and blend were dyed at different temperatures, time and concentrations and power consumption during these experiments were measured. Based on these readings, calculations were made to estimate different parameters like dye uptake, K/S value, fastness and specific energy consumption. The energy saving were estimated. These data were used to estimate the emissions in the Indian textile dyeing sector and possible reduction potential in GHG emission.

1.8 ORGANIZATION OF THE THESIS

The Thesis has been divided into nine chapters. Chapter 1 deals with the status of world textile sector, Indian textile sector including the dyeing sector. Dyeing processes along with different dyes are also discussed along with the objectives of the study and the work plan. The problem of effluent generation along with air pollution due to energy use is highlighted and need for new technologies for reducing the pollution are also emphasized. Chapter 2 deals with energy conservation and energy transfer characteristics of the non-conventional dyeing technologies. This covers about the mechanism, principles, advantages and disadvantages, energy efficiency and transfer processes and application of these processes to textile chemical wet processing. Chapter 3 deals with literature review regarding the non-conventional dyeing technologies and associated energy models. Chapter 4 deals with experimental methodology and dyeing procedures adopted in the experiment for various materials. Chapter 5 deals with analysis of results obtained in the experiment and dyeing parameters like dye uptake, apparent diffusion coefficient, K/S values, fastness are evaluated based on these
results. Chapter 6 deals with calculation of specific energy consumption along with dye uptake. Based on this, energy saving has been estimated for different technologies. Chapter 7 deals with empirical relations developed for normalized specific energy consumption in terms of variables like time, temperature and concentration. Chapter 8 deals with estimation of GHG emission in Indian textile dyeing sector and reduction potential possible due to application of the technologies in this sector. Chapter 9 deals with the results of the study with suggestions for future work.