

Research Article

# Climate Impact Measurement of Acrylic Manufacturing Unit

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## Abstract

The goal of the study is to examine and assess the influence of various water sources, energy inputs, and their effect on carbon emissions. The approach included site visits to the textile production mill and discussions with them both the production and commercial procurement teams to collect last three calendar year data. The findings and conclusions of this analysis show that Textile manufacturing contributes to a considerable amount of carbon emissions, approximately 3.1kgCO<sub>2</sub>e/kg of Acrylic fabric. Purchasing electricity as an energy source generates the highest carbon emissions 3.03kgCO<sub>2</sub>e/kg of Acrylic fabric, In contrast, the use of LPG fuel and Diesel fuel resulted in notably lower CO<sub>2</sub> emissions. Additionally, this study assessed the emissions in scope 1 and scope 2 categories during the textile processing stage, which contributed to 136535kgCO<sub>2</sub>e. Personalization in the application of sizing chemicals using industry 4.0 techniques such as warping, sizing and weaving can further minimize the consumption of resources, water, and energy. Prioritizing the design of waterless processes should be central to energy optimization efforts. Energy usage which is directly related to amount of water needed for the slashing process. Sizing processors are somewhat reluctant to adopt these changes due to the added production costs. Coordinated efforts from all stakeholders in textile value chain are essential to address the sustainability challenges in textile manufacturing. This case study focuses on five out of the seventeen sustainable development goals (SDGs).6-Clean water and sanitation, 7-Affordable and clean energy, 12-Responsible production and consumption, 13-Climate action, and 15-Life on land.

## Keywords

CO<sub>2</sub> Emission, Greenhouse Gases, Renewable Energy, Sustainable Processing, SDG, Poly Acrylonitrile

## 1. Introduction

Various kinds of fibers (synthetic, synthetic), types of substrates (fiber, yarn, fabric, garment), and processing techniques (batch, semi-continuous, continuous) result in textile processing being very divided and complicated. Typically, the most commonly used fibers for clothing and home textile products, including Acrylic which frequently analyzed for their energy and water usage; the energy effects of other significant fibers, notably Acrylic blend mixtures, have been largely overlooked.

### 1.1. Acrylic (Melt Spinning, Weaving and Wet Processing)

Acrylic a synthetic fiber mainly taken from the fibers of Acrylic plants during melt spinning and gathering. Raw Acrylic manufacture raw material is acrylo nitrile [1]. These contaminants are known as Acrylic heat setting and scouring, and to prepare for dyeing and finishing processes, this synthetic oil is removed during scouring phase through treatments of hot water with mild detergents [2]. Acrylic is primarily colored with disperse dyes, which form a strong hydrogen bonds and van der Waals forces [3]. Typically, proce-

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dures such as melt spinning, texturing, weaving, weight reduction, dyeing, and calendaring are performed to enhance the commercial and functional value of Acrylic. The processing steps, including cleaning Acrylic by eliminating impurities (scouring), heat Setting and weight reduction, Dyeing, printing, and finishing are commonly referred to as the wet processing of Acrylic [4].

## 1.2. Environmental Profile of Acrylic

The synthetic Acrylic defines non-eco-friendly fiber, which is non-biodegradable, recyclable, and non-renewable. Unlike other fibers, Acrylic cause micro plastic pollution in the oceans. Acrylic is linked to the synthetic carbon cycle [5]. As a synthetic fiber, Recycled Acrylic is frequently promoted as a sustainable option compared with synthetic fibers, which recognized for its energy emissions and environmental effects [6]. Even though Acrylic comes from synthetic sources, the melt spinning of Acrylic yarn, as well as the Acrylic production industry, contribute to greenhouse gases (GHG) such as carbon dioxide and carbon monoxide [7].

## 2. Literature Review

The studies released so far have explored the environmental effects of acrylic from melt spinning to the final product. Greenhouse gas (GHG) emissions at the melt spinning level from melt spinning acrylic, as well as transhumance, and production in continental range-lands have been documented [8]. Life cycle assessment (LCA) studies examining on energy and water consumption have been conducted out for acrylic T-shirts [9]. One research examined the energy, water and land used in producing recycle acrylic [10]. However, this study was limited to initial production, concentrating only on the melt spinning for cradle to get impact [11]. Some study looked into methane releases from acrylic operations in Asian countries [12]. All these studies have reviewed the emissions produced by melt spinning in key acrylic manufacturing such as China and Egypt [13]. The GHG profile for producing 1kg of acrylic was evaluated for the apparel industry in Vietnam [14].

Thus, the research conducted to date has concentrated on assessing environmental effects only until the acrylic fiber production phase. Furthermore, the reported greenhouse gas evaluations and life cycle assessment studies come from significant acrylic producing areas such as China. A review of the environmental performance related to acrylic melt spinning and melt spinning indicates that most life cycle assessment studies have defined the cradle-to-gate boundaries for melt spinning for their evaluations [15]. This comprehensive review concerning acrylic melt spinning and melt spinning states, “Additional research is required to identify the effects of “pre and post consumable Recycle” processes like the processing of acrylic products before they reach consumers

and to take into account environmental effects beyond just climate change” [16].

The available literature does not provide enough information on the scope-specific CO<sub>2</sub> emissions generated during the textile processing of acrylic after its production. Because of resource accessibility, adaptable environmental regulations, and low labor costs, significant textile manufacturing occurs in the south asian nations like India, and Vietnam are currently the primary centers for textile manufacturing industries [17]. This study seeks to address the gap in the existing literature that is lacking data on energy emissions and the sustainability factors of acrylic during the manufacturing and wet processing phase.

## 3. Methods

All results detailed in this research were obtained through on-site Assessment of measurable Variables and field data which is collected from an acrylic processing facility situated in Surat District, Gujarat State. Data on fuel sources, energy, and water consumption was gathered from two consecutive years, 2022 & 2023, and analyzed to evaluate some changes in sustainability practices carried out by the acrylic manufacturing facility. Such facility specializes in manufacturing acrylic floor sarees, knitted hosiery and various home textiles upholstery fabrics and products. ISO 14001 internal audit methodology use for analysis a systematic, independent, and documented process to evaluate an organization's Environmental Management System (EMS) against the standard's requirements, identifying areas for improvement and ensuring compliance. Data verification using triangular pillar system use like management interaction, record review and factory site visit system.

The specifics of tools and equipment utilized for gauging power, fuel, and water usage according to the established guidelines of regulatory authorities are outlined in following sections. The assessment and site examination of mill which are carried out in accordance with guidelines outlined in the ISO 14001: 2015 management systems standard [18].

### Consumption of Energy

Table 1 shows that the Energy use from other fuel types such as diesel, liquefied petroleum gas (LPG), and purchased electricity was inferred from the supplier invoices and tracking systems. Reported figures for Diesel (calorific value - 10,800 Kcal/kg) is provided to the mill by a regional supplier. The supplier details and calorific values of other fuel types used in the surveyed mill are as follows: LPG: 25,350 Kcal/Nm<sup>3</sup>, Supplier: Neel Kamal Energies; and electricity sourced from the power grid supply provided by Dakshin Gujarat Vij Company Limited. Up until 2023, the mill was using electricity, diesel, and LPG. [19].

Energy in Mega Joules = Energy usage in independent unit x Conversion factor [20].

**Table 1.** Yearly Energy Usage of the Acrylic Manufacturing Facility.

| Yearly Energy Consumption |          |         |                     |                   |
|---------------------------|----------|---------|---------------------|-------------------|
| Fuel Source               | 2022     | 2023    | Unit of Measurement | Conversion Factor |
| Electricity               | 10003988 | 7331838 | kWh                 | 3.6               |
| Diesel                    | 3194     | 878     | Ltr                 | 2.8               |
| LPG                       | 8816     | 5029    | Kg                  | 25                |

This table presents the yearly energy consumption of three different fuel sources—Electricity, Diesel, and LPG—for the years 2022 and 2023. The consumption values are provided in their respective units: kilowatt-hours (kWh) for electricity, liters (Ltr) for diesel, and kilograms (Kg) for LPG. Additionally, a conversion factor is given for each fuel type, which can be used to convert the consumption values into another unit, likely mega joules (MJ).

1. Electricity consumption was 10,003,988 kWh in 2022 and 7,331,838 kWh in 2023 decretable ased due to en-

ergy monitoring and energy implementation activities start.

2. Diesel consumption was 3,194 liters in 2022 and 878 liters in 2023 decreased due to stop using diesel based equipment.
3. LPG consumption was 8,816kg in 2022 and 5,029kg in 2023 decreased due to start monitoring and avoid excess usage of LPG.

The data suggests a reduction in energy consumption across all three fuel sources from 2022 to 2023.

### 3.1. Emissions Produced in Acrylic Manufacturing

**Table 2.** CO<sub>2</sub> emissions in acrylic processing and classification of emission categories.

| Energy Used | Unit | 2022     | 2023    | Emission factor | tCo2-2022 | tCo2-2023 | Category- GHG emission |
|-------------|------|----------|---------|-----------------|-----------|-----------|------------------------|
| Electricity | kWh  | 10003988 | 7331838 | 0.80            | 3403.20   | 5958.51   | Scope 2                |
| Diesel      | Ltr  | 3194     | 878     | 2.8             | 8.637     | 2.521     | Scope 1                |
| LPG         | Kg   | 8816     | 5029    | 1.56            | 13.27     | 7.845     | Scope 1                |
| Total       |      |          |         |                 | 3425.111  | 5968.88   |                        |

It is widely acknowledged that climate change is linked to emissions produced by the human activities. This research, carbon emissions caused by energy which use from every fuel type employed used in manufacturing of acrylic were determined using a greenhouse gas equivalencies calculator [21].

When we talk about keeping an eye on carbon emissions, we usually break them into three groups: scope 1, scope 2, and scope 3. These categories help businesses find out where their emissions are coming from, so they can measure them properly and work on reducing their carbon footprint.

According to Greenhouse Gas (GHG) Protocol and India GHG program guidelines:

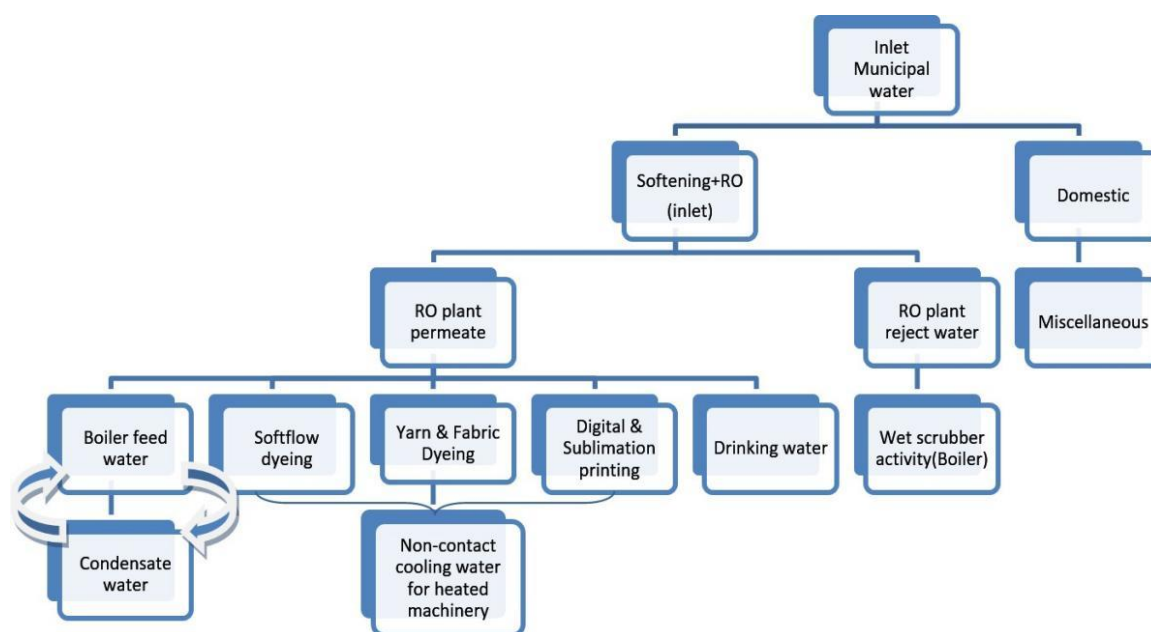
Scope 1 covers direct emissions from things that are

owned or under control of the company. For example, in creating ACRYLIC, any fuel is burnt on the site-such as diesel or LPG-scope 1 emissions used during the manufacturing process.

Scope 2 includes indirect emissions from electricity that the company buys and uses. Therefore, all the power used to run the machines, lightens the factory, and comes under the purview of 2 emissions to run offices in the polyester plant.

By organizing emissions in these categories, companies can better understand how their activities affect the environment. This makes it easy to find ways to cut carbon emissions - such as switching on cleaner fuel, using energy more efficiently, or adopting renewable energy sources.

### 3.2. Inlet Water Usage and Recycling



**Figure 1.** Water Mapping in Acrylic Processing Unit.

This table presents the yearly water usage at the facility for the years 2022 and 2023. The values are measured in kiloliters (KL) and categorized based on different areas of consumption.

**Table 3.** Analysis of yearly water usage at the facility.

| Usage of Water                                              | 2022 (Kiloliters) | 2023 (Kiloliters) |
|-------------------------------------------------------------|-------------------|-------------------|
| Municipal Water (Inlet water)                               | 63628             | 53932             |
| Condensate water which reused for boiler operations (input) | 0                 | 21230             |
| Reverse reject water recycled in wet scrubber               | 0                 | 2796              |
| RO Feed                                                     | 9817              | 8741              |
| Boiler (Steam generation)                                   | 7144              | 5944              |
| Fabric Dyeing +soft flow                                    | 24204             | 23393             |
| Digital printing                                            | 2278              | 2290              |
| Sublimation printing                                        | 596               | 556               |
| Yarn dyeing                                                 | 10871             | 14720             |
| Domestic                                                    | 15170             | 2511              |
| Miscellaneous                                               | 690               | 1718              |

All measurements and terms related to water use are recorded in line with the principles of the ISO 14046 water footprint standards [22]. The water brought in from municipal sources is distributed throughout the mill for various stages of textile wet-processing such as scouring, dyeing,

printing, and final processing. The main decrease in water use is due to re circulation and reuse. Processes like bleaching to achieve full white and dyeing lighter shades for acrylic require ideal bath pH, low water hardness, and minimal total dissolved solids (TDS).

The facility solves this using a softening plant and a reverse osmosis (RO) system. The untreated water supplied by municipalities first goes through a softening machine, then through RO. Water from the RO (reverse osmosis) system is divided into two streams: permit and reject. Permit water, which is high in purity, is used in procedures where pH balance and chemical control are important - such as sensitive industrial operations and even drinking water.

Instead of wasting, instead of wasting water, the wet scrubber system associated with the industrial boiler is reused smartly. These scrubbers help to trap well boiler ash particles and prevent them from polluting the air.

Meanwhile, the boiler-condensed water is recycled back into the system as feed-water, which helps to produce wet steam again, making the process more efficient.

In addition, wet processing machines such as calendaring units, liver, and soft flow dyeing machines also require addi-

tional cooling to maintain optimal performance during operation. The Water used for such non-contact cooling which is collected and recycled. As shown in Table 3 for the facility's annual water consumption which was decreased by about 15%. That change is clear Due to strategies such as reuse and re-circulation, which were not implemented in 2021. Among all wet processes, fabric dyeing consumes more water than yarn dyeing. The material-to-liquid ratio in the Jigger and soft flow machine is higher than in the Winch and cabinet dyeing machine used for dyeing yarn/ hank or fabric [23].

### 3.3. Waste Produced at the Facility - Hazardous and Non-Hazardous

The table presents data on different types of waste produced in 2022 and 2023, along with their respective disposal methods.

**Table 4.** Waste generation and disposal Methods.

| Waste Produced                                 | 2022 | 2023 | Final disposal method    |
|------------------------------------------------|------|------|--------------------------|
| Fabric (waste material)                        | 449  | 439  | Recycle                  |
| Plastic (polybag and plastic scrap)            | 1147 | 1312 | Recycle                  |
| Paper waste                                    | 935  | 976  | Reuse and recycle        |
| Food                                           | 951  | 853  | Reuse                    |
| Empty Drums of Chemical and boxes (production) |      |      | Reuse and recycle        |
| Waste from Tube light                          | 4.5  | 4.6  | Landfill                 |
| Electronic waste                               | 16.4 | 17.8 | Recycle and landfill     |
| Used Oil (waste oil)                           | 27.1 | 19.8 | Recycle and incineration |

When evaluating GHG emissions from human activities, it is important to consider the amount of waste generated during industrial operations and its environmental impact after disposal. According to a notification by the Gujarat State Pollution Control Board (GPCB) in 2010, this feature is classified as high air emissions. The solid waste produced in the acrylic processing mill was identified and carefully evaluated how it is dealt with. This feature produces both dangerous waste, such as oil, tube lights and electronic waste as well as non-stringent waste, resulting in food waste from the waste of acrylic, plastic waste, paper waste and food waste from the waste of food.

The acrylic process waste arises during various wet processing activities such as scoring, heat settings, weight loss, dyeing and finishing. Paper waste from printing material is renovated in useful items such as recipe cards and shed cards. Plastic waste comes mainly from packaging activities, including both raw material and finished product packaging. Food waste is produced by canteen and pantry operations.

Tube lights and electronic waste are generated from operational activities such as lighting. Electronic waste includes items such as computer parts, keyboards, cables and other similar components. On average, acrylic wet processing produces about 14.8kg of waste. The waste produced in the convenience, both hazardous and non-hazardous, waste handler agreements, reporting to the site, transaction challans and manifest copies are verified. This feature also sends its food waste in a pig melted spinning process for re -use in food production. Meanwhile, paper, plastic and empty chemical containers are recycled through the authorized waste handlers to ensure proper settlement and stability.

## 4. Results

The results from this onsite survey allowed us to determine the net emissions generated in the acrylic processing sector. Due to environmental regulations and demands from

leading clothing brands such as Inditex (Zara), William Sonoma (WSI), Next Brand, C&A, Tommy Hilfiger, Ralph & Lauren, and Bestseller to eliminate non-renewable fuels like coal. The recycling and reuse of water have achieved a 15% reduction in blue water usage.

## 5. Discussions

Traditional processing of acrylic, such as scoring, heat settings, weight reduction, dyeing and printing, require large amounts of water. However, using machinery with low content-seal ratio can help reduce water consumption, especially in dyeing and dyeing procedures. Watering the temperature required for scoring, bleaching, dying and printing also demands significant energy. The amount of energy used is directly related to the amount of water required in the processing of the bath. In addition to the main processes such as scoring, dyeing and finishing, excess water is also used for supportive activities such as neutralizing, wash and cooling. To reduce the need for water use and additional heating, one can be helpful to reduce pH changes continuously during processing, as well as continuous pH changes during processing. Industries such as digital printing and digital finishing are fine to adopt 4.0 methods and can reduce the consumption of resources, water and energy to colors and colors to apply colors. The final goal should develop water -free procedures to increase energy efficiency. This paper also exposes four of the seventeen continuous development goals (SDG): 7 - inexpensive and clean energy; 12 - responsible consumption and production; 13 - Climate action; And 15 - Life on land.

## 6. Conclusion

1. The carbon emissions generated in each stage of acrylic processing were calculated separately. It is noted that the acrylic wet processing contributes significantly to carbon emissions at approximately 3.03 tCO<sub>2</sub>e/product.
2. After identifying the various energy types needed for the different production phases, it was discovered that coal resulted in the highest carbon emissions, totaling 3.033 tCO<sub>2</sub>e/product.
3. Carbon emissions from other energy sources during production were 3.033 tCO<sub>2</sub>e/product from electricity, 0.0013 tCO<sub>2</sub>e from Diesel, and 0.0039 tCO<sub>2</sub>e from LPG source.
4. This study assessed the emissions in the scope 1 and scope 2 categories produced during the acrylic processing phase. The emissions in scope 1 and scope 2 during acrylic processing amounted to 10.366 tCO<sub>2</sub>e and 5958.508 tCO<sub>2</sub>e respectively. Future studies should assess the corporate footprint of acrylic processing to determine scope 3 emissions and grasp total carbon emissions.

## Abbreviations

|                 |                                                |
|-----------------|------------------------------------------------|
| CO <sub>2</sub> | Carbon Dioxide                                 |
| LPG             | Liquefied Petroleum Gas                        |
| GHG             | Greenhouse Gases                               |
| GHG             | Sustainable Development Goals                  |
| ISO             | International Organization for Standardization |
| EMS             | Environmental Management System                |
| KL              | Kiloliter                                      |
| RO              | Reverse Osmosis                                |
| TDS             | Total Dissolved Solids                         |
| GPCB            | Gujarat Pollution Control Board                |
| LCA             | Life Cycle Assessment                          |

## Conflicts of Interest

The authors declare no conflicts of interest.

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