Sustainability through Liquid Color Concentrates and future challenges of coloring Polyester Fibers

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Abstract

The use of liquid color concentrates for coloring plastics and textiles is a rising trend due to their cost-effectiveness, aesthetic benefits, color-changing versatility, and reduced waste. However, in India, liquid color concentrates are not widely utilized for coloring polyesterfiber,although some have adopted them for plastic, film, and PET bottle applications. To enter this market, one may need to assess the potential for future growth and plan for new facilities to facilitate a smoother transition to liquid colors.

Liquid color concentrates reduces the time required for shade match, reduces production lead time, permits small lot production quantities to be offered and allows specific shades reproduced on re orders. Change form one color to another is very rapid permitting quicker response to market demands for particular colors with the use of Liquid color injection system for dope dyeing of polyester. The color may be quickly adjusted during production runs which reduces overall waste.[1]

Keywords: Liquid color, Pigment, Polyester, Applications, Challenges

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1. Introduction:

Liquid color concentrates are premixed blends of pigments and dyes in carriers that can be easily added to the base resin used in polymer processing. These concentrates have been used for specialized applications such as coloring polyvinyl chloride (PVC) and polyolefin since the 1990s. However, due to logistical challenges, they have not been widely used for coloring polyesters. Recent technological advancements have led to the increasing popularity of liquid

color concentrates in applications like injection molding, blow molding, and film manufacturing.

One of the key advantages of using liquid color concentrates is their ability to offer several benefits, such as increased flexibility, reduced waste, improved aesthetics, and better economics compared to conventional dyeing methods. Moreover, stringent regulatory measures for environmental contamination caused by dye house discharges have made mass coloration techniques using liquid/solid color concentrates a more eco-friendly and cost-effective alternative to conventional dyeing.

Although dosing liquid colors can be challenging due to the low viscosity of the masterbatch on polymer rheology, it can be addressed by shifting the injection points towards the spinning beam, leading to shorter dwell time and reduced thermal stress on color concentrates. Moreover, liquid color concentrates offer advantages over solid colormasterbatches as they do not require drying and produce less waste.

Both mono-color and tailor-made liquid color concentrates are available, and advanced shade matching software and precise control can ensure identical colormatchings. However, the adoption of liquid color concentrates requires strong logistical support and coordination between the masterbatch manufacturer and fiber spinner to ensure smooth integration into the dyeing process.

2. Liquid color processing

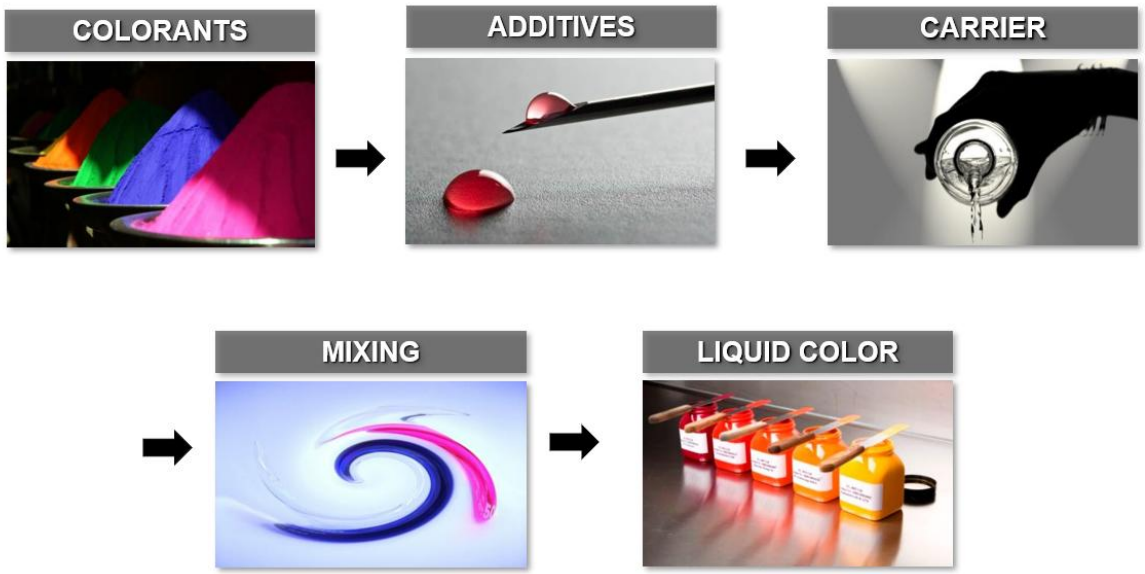

Figure1:Different steps of liquid color[2]

Important issues in liquid color concentrate selection:

- Polymer compatible and thermally stable carrier
- Fine dispersion of dyes and pigments free from agglomerates
- Impact on polymer rheology
- Trouble-free stable processing in spinning

Formulation should aim for low letdown ratios (LDR) and free-flowing concentrates at the point of injection.

3. Present State of Industry and Market

Masterbatch is a concentrated mixture of pigments or additives that are added to plastic resins to impart color, improve properties, or achieve desired characteristics. Masterbatch is typically sold in pellet form and is used in a wide range of plastic products such as packaging, automotive parts, and household goods.

Recently, there has been a growing demand for liquid color concentrates as an alternative to traditional masterbatch pellets. Liquid color concentrates are pre-dispersed liquid pigments that are added directly into the plastic resin during the manufacturing process. This eliminates the need for the extra step of pelletizing the masterbatch, making the manufacturing process more efficient and cost-effective.

Many big companies in the masterbatch industry have recognized the potential of liquid color concentrates and have started marketing them to their customers. This is because liquid color concentrates offer several advantages over traditional masterbatch pellets, such as better dispersion and consistency of color, faster processing times, and reduced waste.

Overall, the adoption and marketing of liquid color concentrates in the masterbatch industry reflects a trend towards more innovative and efficient manufacturing processes in the plastics industry.

Table 1: The companies listed below are involved in producing liquid color concentrates.

Company	**Home**
CHROMA Corporation	www.chromacolors.com
RIVERDALE Color Company	www.riverdalecolor.com
BADGER Color Concentrates	www.badgercolor.com

Company	Home
Avient	www.avient.com
HOLLAND Colors	www.hollandcolours.com
ROWA	www.rowa-group.com
REPI	www.repi.com

These companies offer liquid color concentrates for use in packaging plastics, PET and other types of plastic bottles, as well as film applications. However, there appears to be little mention of the practical application of these concentrates in fiber applications on their websites. This may be because liquid color concentrates have a negative impact on the rheological properties of the base polymer, which can adversely affect the spinning performance as letdown ratios increase. As a result, liquid color concentrates are typically used for lighter colors in fiber applications, with letdown ratios preferred up to 1.5 to 2.0%. However, for darker shades, the pigment/dye active content varies from 0.5 to 1.5%, which means that letdown ratios for liquid color concentrates can be much higher than 1.5 to 2.0%.
Some companies' active in supplying color concentrates for fiber applications seem to be:

- AVIENT
- COLORMATRIX
- ROWA
- COLORMASTER

However not much details are available about their activity.No information is currently available on the market share of liquid color concentrates for fiber applications as a percentage of the total color masterbatch industry, including plastics and other polymers.
One important aspect of using liquid color concentrates is that it requires close coordination and interaction between the concentrate supplier and end-user. This is because the concentrates need to be supplied in special agitated, returnable container systems with other accessories such as interface controls and metering pumps. Additionally, specially designed hardware such as pressure less injection points in extruders or injection ports in the spinning beam may be required at the customer's end.

Since there is considerable variation in hardware from customer to customer, the color injection system may need to be tailored to meet specific customer requirements. This may require complete logistic support and projections in manufacturing and supply.

Cleaning of returned containers from customers before re-use as per changing shade requirements is another important issue that requires clear long-term understanding between the concentrate supplier and end-user, as recycling and cleaning issues can be complex and may lead to color variations in the end-product.

Minor issues with respect to proper housekeeping due to possible spillage because of frequent connecting and disconnecting dosing vessels and environmental concerns related to equipment cleaning and disposal may also arise.

The color injection system may be a better choice in the melt spinning process where the melt is fed directly from the reactor. In this case, adding the color just before the spinning beam using a dynamic mixer can lead to better flexibility and lower costs.

4. Brief Review of Competitive Scenario

To date, there are not many companies involved in liquid color concentrates for fiber applications, as the logistics and handling of the concentrate formulation, use, transportation, and disposal present more challenges than conventional solid master batches. These solid master batches are easier to handle and transport. As far as India is concerned, to the best of our knowledge, no party has yet adopted the use of liquid color concentrates for fiber applications.Following two companies seem to be actively engaged in the production and supply of liquid color concentrates:

4.1 ASHA PENN Color Pvt Ltd.

It is a joint venture between ASHA Dispersions Pvt Ltd. in Mumbai and PENN Color Inc., USA.

The company produces a wide range of pigmented chips for dispersions and liquid dispersions used in various applications such as printing inks, automotive paint, wood lacquer, digital ink, and cosmetics. These products are manufactured using different types of resins including nitrocellulose, polyamide, vinyl, PVB, CAB, acrylic, polyester, and acrylic polyol. The company is a significant player in this industry. [3]

4.2 COLORTEK (India) Ltd.

This is a company that has been in operation since 1994 and is certified under ISO 9001:2008. They specialize in the manufacture, supply, and export of Liquid Colorants & Additives, with a product range that includes Liquid Additives and Liquid Color Masterbatches.[4]

SOLID COLOR MASTERBATCH	LIQUID COLOR CONCENTARTE
It's a Continuous production	It's a Discontinuous production
Color is typically the only aspect that quality control checks for randomly.	Every lot undergoes quality control for color, maximum particle size, and viscosity.
Requiring a second extrusion of the batch is necessary if any corrections are needed, but this may result in the polymer and pigments being stressed.	Correcting the entire batch, if necessary, can be done without causing any stress to the polymer or pigments.
Mixing the granules for homogenization afterwards can result in inconsistent quality.	The product is homogenous, 100% quality controlled, and consistently meets the specifications of the customer.

Table2: Difference between solid color master batches and liquid color concentrate. [2]

In the international market, the liquid color industry is not as substantial when considering the entire MB industry, estimated to be around 10-15% for plastics. However, there is a growing preference for liquid color concentrates in areas such as PET bottles, films, and high-end packaging due to their cost advantage and faster implementation.

It appears that many liquid concentrate manufacturers produce for their own use or have long-term agreements with downstream customers for development, supply, and recycling. These suppliers have diversified into liquid color concentrates and offer both palletized and liquid color masterbatches.

Liquid color concentrates are presently used for value-adding applications, including metallic effects, glossy or transparent articles, cosmetics, and other high-end packaging. Statistical data on the industry size and application-wise breakdown are not currently available.

5. Raw Material and auxiliary Additive availability Scenario

The basic components for liquid color concentrate are generally as under:

5.1 The carrier used in the liquid color concentrate should be compatible with the polymer applications.

Products listed below are being used as carriers.

- LiquidPET from Badger Color concentrates. [5]
- Polyalkalinepolyol carrier. The liquid color concentrate using polyalkalinepolyol is compatible with PET, especially to make color polyester, beverage bottles and others Polyester articles.[6]
- A liquid color concentrates comprising of colorant carrier as liquid polymer of an acrylic monomer and sufactants along with functional additives is used for ABS, PVC, PBT, PMMA and SMA polymers.[7]

In addition to the previously mentioned products, the following is a list of potential carriers classified according to their properties.

- Adipate polyester polyols and poly-glycols.
- Refined vegetable oils, for example, hydrogenated castor oil.
- Refined hydrocarbon oil with low viscosity (less than 500 mpa•s).
- Paraffin waxes, which require pre-heating before use.

5.2 Dispersing and wetting agents

- BYK-W 974 from BYK[8] is used for SMC/BMC (Sheet molding compound and Bulk molding compounds) and pultrusion processes to ensure system homogeneity and stability, as well as to enhance color consistency in molding compounds. By improving fiber wetting, this additive can also help optimize the material's properties.

5.3 Free radical scavengers

Tris nonyl-phenyl Phosphate derivatives [9]are commonly employed as a universal antioxidant in a range of applications, including rubber products, plasticizers, hydraulic fluids, textile/fibers, lubricating oils & greases, and more. By intercepting free radicals that trigger the onset of the degradation process, these derivatives effectively reduce the rate of oxidation, resulting in enhanced performance characteristics.

5.4 Catalyst deactivator

- ❖ Additives like aryl- and diphenyl-phosphate compounds can be used to slow down the reaction.

5.5 Carrier compatible pigments/dyes

Liquid color concentrates typically utilize the same pigments and dyes found in traditional palletized masterbatch formulations. However, the carrier used in the liquid color concentrate must undergo testing to evaluate its compatibility with the polymer system and rheological behavior. Currently, there are no independent carrier suppliers for color concentrates, except for SCHILL & SEILACHER. It manufactures wide range of specialty chemicals like EVORAL, AFROTIN, UKANOL etc, suitable for technical textiles [10]. Most color concentrate manufacturers produce their own carriers, which may differ from those of other companies. As a result, it may be necessary to either develop carriers in-house with expert assistance or establish partnerships with companies already operating in the market or recognized for their products in relevant end-use sectors. Companies like BYK offer carriers for specific applications, such as PVC. Another option is to partner with existing players for access to carriers, technological expertise, and know-how.

6. Characteristics of Liquid Color Concentrates

Liquid color concentrates possess several essential features, which include:

a) Compatibility with the intended polymer application.
b) Thermal stability at spinning processing temperatures.
c) Stable and fine dispersion, free of agglomerates and thermal shock.

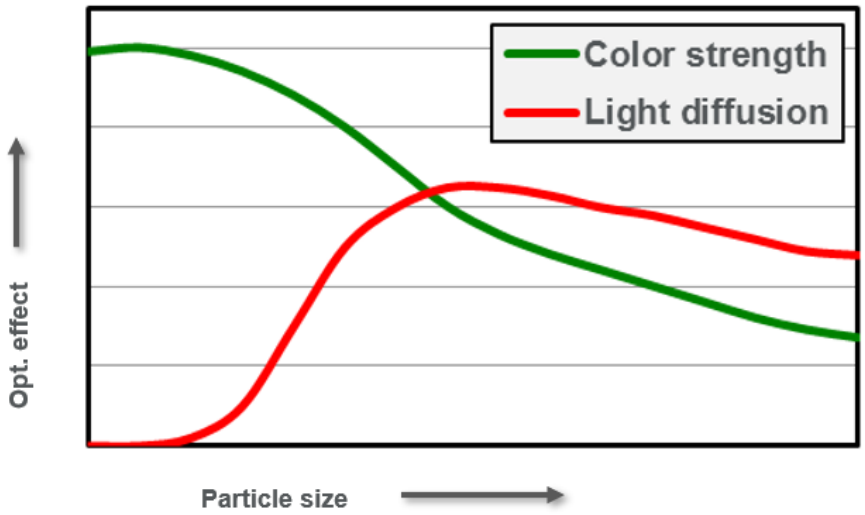

Fig2: Liquid color strength and Light diffusion wrt Particle size.[11]

d) Sub-micron particle size distribution, ensuring good spinning performance.

e) Minimal impact on polymer processing during spinning.

f) Ability to change-over with minimal waste.

g) Minimal handling waste and maximum utilization.

h) No plate-out in the case of matched shades using different pigment/dye combinations.

i) Homogeneous and uniform color shades.

j) Better economics due to relatively lower LDR and better uniformity.

k) LCs offer more dosing flexibility since they can be dosed at very low levels without sacrificing uniformity. Suppliers of LCs indicate that the lowest dosing level with excellent reproducibility can be as low as 0.6 to 2.0 %for opaque shades and 0.3to 0.5% for transparent shades, while the highest recommended dosing levels are between 2% and 3%.

l) Developing mono color concentrates is comparatively easier and less critical than developing matched shades.

m) It offers fine particle size distribution leading to higher color strength. Hence, less colorant is needed to achieve the desired shades when compared to solid color masterbatch.

n) Liquid colors are solutions that are dispersed to a high degree, resulting in minimal or very low levels of light scattering. As a result, the degree of light diffusion depends on the particle size of the liquid color concentrate.

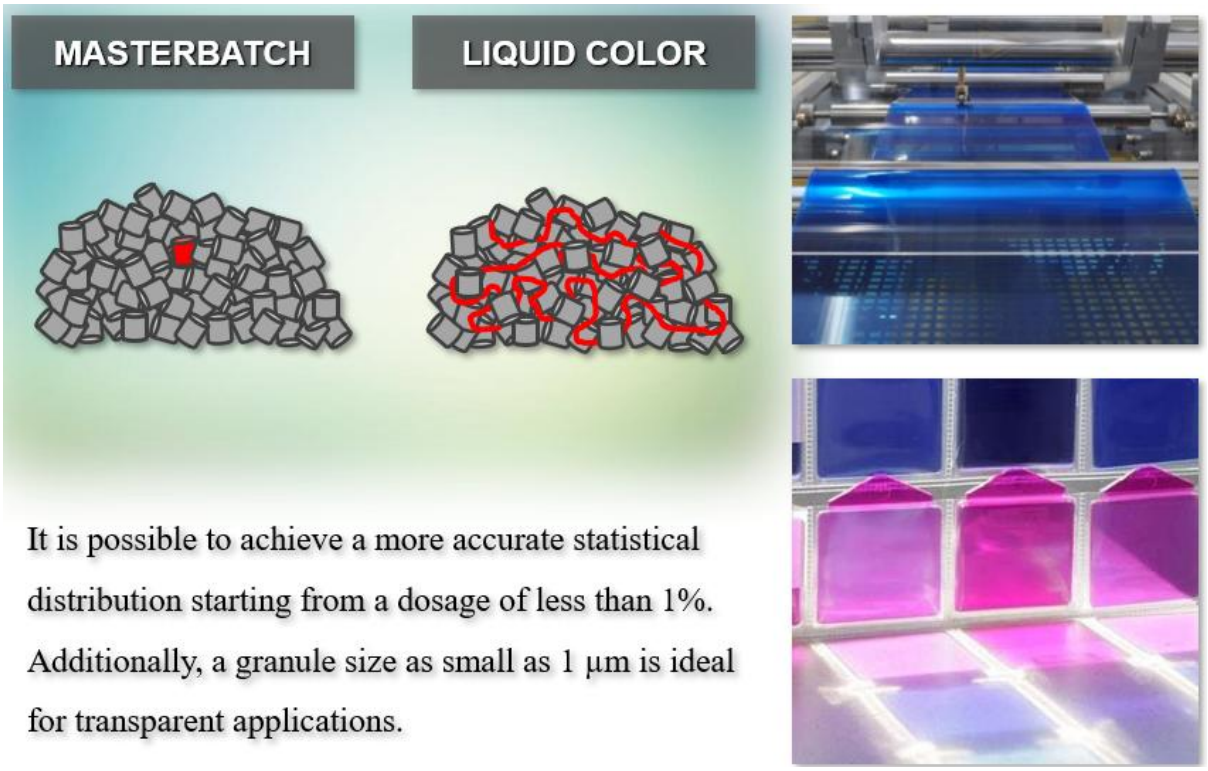

Figure 3: Liquid color and solid color master batch distribution and superiority of product.[2]

7. Technology Status

7.1 Hard ware - and soft-ware for manufacturing and development:

The necessary equipment for formulating liquid color concentrates includes:

a) Simple agitated dissolvers/mixers for mixing/dispersing pigments/dyes, which can be obtained from companies like NETZSCH.[12]

b) Dispersers to break up agglomerates and disperse difficult-to-disperse materials such as those that tend to float, settle down, or re-agglomerate in the carrier. NETZSCH also provides such equipment.

c) Control hard- and software to enable precise and seamless formulation and color matching of concentrates with minimum waste and spillage.

d) For shade development and matching, a pilot color spinning system, injection molding systems, precision flow-control and monitoring systems, spectrophotometers, and other quality control and monitoring equipment are necessary.

e) In addition, facilities must be planned for storage, pumping, and metering of liquid carriers, additives, and auxiliaries, along with a complete logistics and control network for very precise let-down of additives and colors for compounding

concentrates. Some existing facilities such as quality control, yarn processing, and color matching and quality check systems may be used.

7.2 Supply hardware and logistics for liquid color concentrates to customers:

For supplying concentrate to customers, specially designed vessels are required along with logistics for recycling of leftovers and cleaning of returned equipment etc. Customer needs a smaller warehouse to store these concentrates.

Fig 4: Both the 5 pounds of pellet concentrates and the 1/2 pound jar of liquid color will color 100 pounds of resin equally. [5]

Normally, the storage vessels are equipped with an agitator and a system for color injection. Customer then, has to simply connect and disconnect it to the spinning equipment. There are various companies which deals in providing integrated system development for formulations of liquid color concentrates such as-

- ROWASOL, Dosing System by BARMAG
- VISCOTECH of Germany,
- REPI, Switzerland
- AVIENT

8. Customers and their technological competence (Review Indian Context)

To our knowledge, liquid color concentrates have not been widely used for mass coloration of polyester fibers. They are mostly used in applications such as injection molding, blow molding, and film extrusion, where clarity and transparency are crucial. Reliable data on the

volume and consumers of liquid concentrates is not currently available, so a market study would need to be conducted if we were to pursue such a project. Close coordination and interaction with end-users is crucial for a successful liquid color concentrate project, as the containers must be specially designed to fit the facilities at the customer's end. The containers are agitated prior to use and may also have an integrated injection pump and quick connect/disconnect facilities for injection at the fiber spinner. Cleaning the used containers to ensure exact matching at the spinning plant is another issue that the liquid concentrate manufacturer would need to address. Due to the timing and costs involved, supplying color concentrates to export markets may not be practical, except for nearby countries.

8.1 Chosen product mix, pricing and cost analysis.

The benefits of liquid colors over solid color masterbatch will be demonstrated by two samples chosen from the home pages of liquid color operators.

A benefit of LCs over solid masterbatches is the theoretically feasible increase in active content. This may affect the price of coloring in general.

Just as an indication, following example for costs from a supplier's homepage based on a preparation of *Pigment Black 7*:

Concentrate	**Solid Masterbatch**	**Liquid Masterbatch**
LDR	2.00%	0.45%
USD/lb	0.83 (1.8 USD/kg)	2.08 (4.6 USD/kg)
Coloration Costs	1.66	0.93

Table-3: Liquid color and solid color master batch cost comparison.

9. Liquid technology for sustainable development.

REPI is a Swiss manufacturer that creates products for use in a wide variety of applications within the polyurethanes and thermoplastics industries [13].Recently, in 2021 the company has acquired Novosystems GmbH, an independent German company that specializes in liquid color systems. Over time, REPI has set itself apart by providing a wide selection of colors and high-performance additives. Additionally, the company has developed custom-made products that are tailored to each specific application, ensuring optimal compatibility with the

base material and meeting the end user's specific performance needs. REPI's custom-made formulations are meticulously created to ensure maximum compatibility and performance for specific polymers, including PET, HDPE, PP, PVC, ABS, PC, PMMA, and recycled polymers.

The REPI GROUP is committed to operating its facilities in strict adherence to current environmental protection regulations, while minimizing energy consumption and combatting the waste of resources. The company places a strong emphasis on the proper collection and recycling of waste within its plants to prevent the loss of any recyclable materials. REPI's focus on sustainable development is motivated by a desire to protect both the surrounding area and future generations. The company offers solutions that prioritize the use of recycled plastics, such as its liquid coloring and additive technology, which can be considered a sustainable technology due to its minimal contribution to CO2 emissions (Carbon Footprint) throughout its entire lifecycle. In fact, this technology produces lower emissions than traditional methods used to produce solid masterbatches that are used to color plastics.

The lower environmental impact of liquid technology compared to solid MB technology can be found in all phases of the colour / additive life cycle, as shown below.

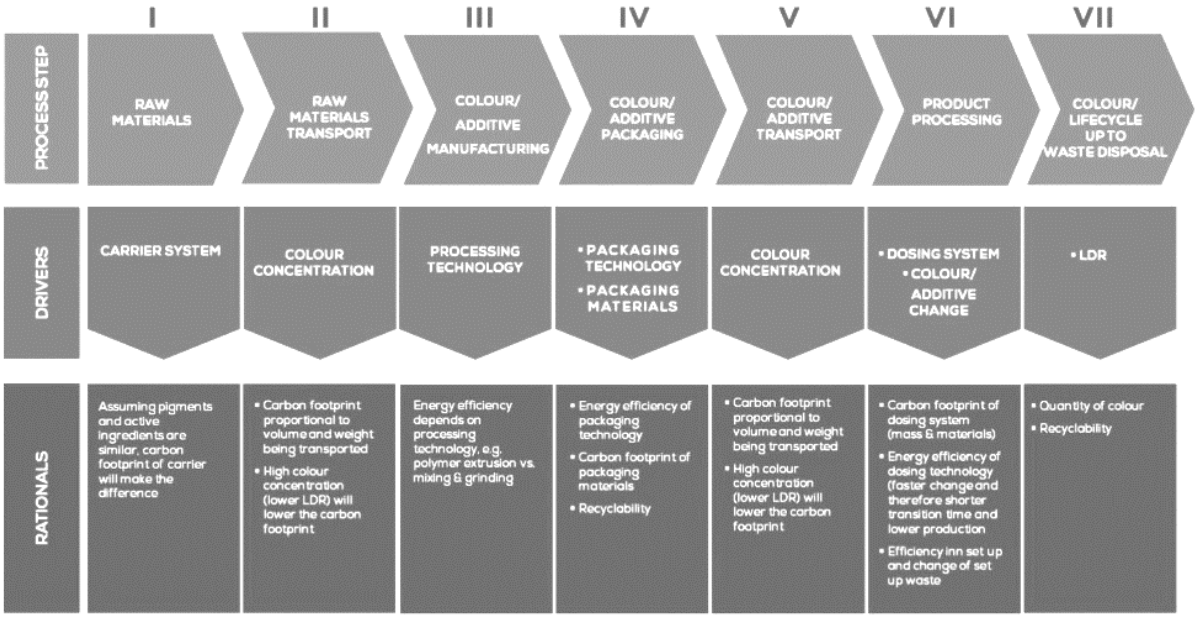

Fig 5: REPI Liquid Technology- Carbon Footprint Contribution. [13]

At each stage of the liquid technology life cycle, a lower environmental impact is evident, largely due to the following factors:

- The manufacturing technology requires significantly less energy since it does not necessitate high temperatures, making it more eco-friendly.
- The high concentration and coloring power of the liquid color in contrast to a solid masterbatch enables the usage of fewer amounts of raw materials, reducing the volume of transportation and storage, and lowering the amount of product used by the consumer.

REPI actively supports the use of recycled polymers for various applications, particularly plastic packaging. In addition, REPI offers additives that facilitate the recovery and reuse of recycled PU and TPU, ensuring no resources are wasted.

10. SWOT-Analysis (Strength, Weakness, Opportunity and Threat)for the potential established companies who want to venture into Liquid color concentrate business.

10.1Strengths

a) The company possesses experienced manpower in manufacturing, developing, and marketing all types of coloring solutions for the synthetic fiber and plastic industry, which is a significant advantage.
b) Adding liquid color concentrate facilities to the existing solid color masterbatch& dyes and pigments business can be done in a shorter time frame and more economically than setting up new greenfield facilities.
c) By developing liquid color concentrate facilities in collaboration with established customers, the company can benefit from a guaranteed market and proven product trials for development. Hence, due to its market presence, the company is in a better position to collaborate with consumers.
d) Liquid colors are particularly suitable for special products such as aesthetic packaging, metallic feel, and transparent films, creating a niche market opportunity due to the company's market presence and customer trust.

10.2Weaknesses

a) Currently, no fiber manufacturing company has the facilities to use a liquid color injection system, which means that the market for such a system needs to be created.

b) Customers may not be ready to adopt the liquid color injection system as it will require either modifications to existing spinning systems or new facilities.
c) The domestic market for liquid colors is currently inadequate, and it may take time for the market to grow.
d) Penetrating the export market may be difficult due to the logistics of handling, transportation, and return of used containers.
e) Before venturing into the market for liquid concentrates, the economics of handling, production, and capacity utilization need to be evaluated.
f) Thorough market research should be undertaken to identify potential customers and secure their support, especially since the model works better with captive consumers.

10.3 Opportunities

a) The liquid color concentrates project may seem futuristic due to the low penetration of the liquid concentrate industry in the country, but it offers a good opportunity to diversify into new application areas.
b) The company can gain a first mover advantage by roping in customers and effectively implementing the project. Liquid colors have gained popularity in overseas markets for segments like packaging and films, and may catch up for fiber applications as well.
c) Liquid colors offer advantages of superior color depth, shine, lesser waste, quicker color change, and low LDR.
d) Venturing into liquid color MB will enable the company to broaden its product range and position itself as a niche company addressing various customer needs.
e) Liquid color MBs have a higher loading of pigments/dyes compared to pelletized MBs, resulting in reduced LDR. For example, a typical black MB used 0.45% of liquid MB against 2.00% of solid MB.
f) This shows that liquid color MBs have a two-fold advantage of higher loading of pigments and better color depth versus solid MBs at comparable active content.
g) Liquid colors can be used at very low LDR without losing color uniformity. In contrast, LDR less than 1.0% is not preferred in solid MBs due to issues related to uniformity, while liquid MBs can be used at an LDR as low as 0.3 to 0.5%.

10.4 Threats

a) There is a risk in venturing into liquid color concentrate supply as it requires captive consumers, and there may not be enough customers available or they may switch to competitors even for small issues.
b) Customers may also plan to establish their own captive liquid color formulation facilities.
c) Established companies like AVIENT, COLORMATRIX, REPI and RIVERDALE color have already diversified into liquid colors for a considerable period and have better production, development, and marketing capabilities. Some of these companies have already established a presence in the country, and if they set up a shop to manufacture liquid concentrates, they could provide tough competition due to their experience in the field.
d) Technological obsolescence is always a factor that needs to be taken into consideration.

11. Companies planning to enter the market of liquid color concentrates should consider the following recommendations:

Many companies offer liquid color concentrates, and most of them are active in the plastics and films industries. PET bottles and films are the main applications for liquid colors, but not much information is available for PET fiber applications, although companies like ROWA, AVIENT&REPI seem to be active in this area.

The production of liquid color concentrates requires specialized hardware and software, and several companies such as NETZSCH[12], VISCOTEC[14], ROWASOL[2] and BARMAG[15] offer these products.According to available information, liquid colors offer better economics and color uniformity than solid MB's due to their lower LDR requirements, lower coloring costs, and improved color effects at similar active content.Because of the benefits of color consistency and substantially lower coloration cost, more and more companies may adopt liquid color concentrates. Although the use of liquid colors in India is not currently widespread, the trend may catch on. This presents an opportune time for the company to enter this field.

The company should first introduce liquid color concentrates into the plastics/PET bottles and films industries, where the logistics of application are less complex. Once the company gains market acceptance and experience, it can venture into PET fiber.Before entering this

business, the company should commission a market study and consider tying up with a captive consumer for trials, development, and supply of liquid color concentrates. This will give the company first-hand experience before entering the PET fiber application.

Liquid concentrates are preferred below 2-3% LDR due to drop in viscosity and the risk of screw slippage. Therefore, there may be some limitations in offering a complete range. Those who want to switch to liquid colors from solid MB's will need to modify their hardware to adapt to this technology.Currently, liquid concentrate suppliers provide concentrate in returnable storage vessels, so close interaction between supplier and customer is necessary.

Conclusion:

Liquid color concentrates have emerged as a viable alternative to conventional dyeing methods for coloring polyesters. They offer several advantages such as increased flexibility, reduced waste, improved aesthetics, and better economics, making them a more eco-friendly and cost-effective option. Although there are some challenges associated with dosing liquid colors, they can be addressed by shifting injection points towards the spinning beam, resulting in shorter dwell time and reduced thermal stress on color concentrates. Advanced shade matching software and precise control can ensure identical color matchings. However, the adoption of liquid color concentrates requires strong logistical support and coordination between the masterbatch manufacturer and fiber spinner. Overall, liquid color concentrates have the potential to revolutionize the polyester dyeing industry with their numerous benefits and advancements in technology.

Declaration of competing interest

The authors hereby declare that they have no known competing financial interests or personal relationships that may have influenced the research work presented in this review paper. This statement is being made with the intention of providing full transparency and accountability to the readers of this paper.

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