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Supercritical CO_2: An Alternative of Water in Textile Dyeing

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ABSTRACT

Textile industry is the most water polluting of the industrial sectors. An attempt has been made in this paper to explore an efficient process that reduces both energy and water consumption in the textile industry. In this paper procedures are proposed for the affluent execution of supercritical carbon dioxide ($ScCO_2$) polyester dyeing technology in the textile industry. The innovation has been created, pilot plants have been tried profitably and big organizations have taken up the know-how. This paper reveals that the chemistry and skill required for commercialization of this innovation is available and it can resolve the textile dyeing water pollution issue.

KEYWORDS: Supercritical CO_2, Textile Industry, Azo-dye, Polyester, Waterless, Sustainable.

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INTRODUCTION

Excessive water consumption in dyeing processes of textile industry[5] has made it one of the largest water consuming industries.[4] The traditional wet textile dyeing process is incompetent and released huge amounts of unused dye in its wastewater.[1] Wastewater treatment plants in many countries are not equipped to cope with all the effluents and a large portion of these dyes enter into the environment.[1] Due to high stability and confrontation to biological degradation characteristics these dyes persist.[1] Most of the organic dyes being comprised of azo dyes and the high stability is due to azo groups with arenes (R-N=N-R', where R' is arene).[1] These arenes destabilize the molecule's system and thusly stabilize the azo dye incredibly. This stability leads not only to success of dye in the textile industry but unfortunately also leads to the longevity of these dyes in the environment. This is need of the textile industry that its dyes must resist harsh conditions, for example, soap, bleach, water, high temperatures and light[1], making azo dyes a perfect option, only if their toxicity and persistence are ignored. Neglecting these two effects on the other hand has shown extraordinary interference in aquatic ecosystems. Primarily through the hindrance of photosynthesis and oxygenation due to the decrease in water transparency and the threat to the health from the carcinogenic, mutagenic and synergistic properties of some dye constituents such as chlorine and heavy metals.[1]

Taking into account the harmful ecological consequences of this effluent, the textile industry must be considered responsible for its waste. One responsibility has been found in some nations that charge industries for their water supply and discharge.[4] This has encouraged industries to moderate their procedures to cut down their expenses.[4] Though, this costing does not cover all of the effects that the wastewater has on the eco system. In light of this pattern from putting a cost on the water and release, control on wastewater released must be executed in every nation to push industry to receive waterless innovation to stay focused.

THE WATERLESS TECHNIQUE

The elimination of water from the dyeing process can abolish problem of high water consumption and contamination of textile industry. Replacement of water with supercritical CO_2 results in productivity as well as in energy savings.[2] This will also reduce impact of the textile industry on the environment.[6] Due to chemical properties of $ScCO_2$ productivity increases. Hydrophobic dyes are dissolve into it $ScCO_2$ because of critical point of CO_2, since above critical point, CO_2 has both liquid and gas properties which facilitate dissolving process. Also, dyeing with $ScCO_2$ takes shorter dyeing times than wet dyeing, when combined with a low-viscosity and gas-like diffusion.[7] Another advantage of $ScCO_2$ is that, stains from salts (remarkably calcium and magnesium salts), also be eliminated [7] with the use of $ScCO_2$ dyeing. This increases the productivity of the process by wiping out the requirement of stain removal. There are also temperature and density controllable dyes[2] which not only boost productivity but also reduce energy consumption as they take into consideration for the control on the dye outcome through temperature and pressure changes.

In a study at Shanto Mariam Univeristy, Dhaka, Bangladesh it was found that the dry process requires only 20% of the wet method's energy.[7] Energy savings are consequence of removing the wet dyeing's drying step[2] and the water pre and post dyeing steps such as washing, scouring, bleaching and finishing steps.[7] These steps are responsible for 100-145L of water approximately per 1kg of textile material dyed.[7] Additionally, energy use is also reduced in terms of removing the water impurities at the beginning of the wet process and treating the wastewater at the end of process. The previously mentioned process decreases the time, which also reduce the energy input per kg of dyed textile. This energy reduction is a monetary benefit for the dyer. Apart from monetary benefits, energy reduction is also helpful in reducing pollutant emissions from fossil fuel dependent textile dyeing factories.[7] Thus, with this technology one will pay less to fuel its process additionally decreases emissions of CO_2, N_2O, and SO_2.[4]

By removal of water from the process, this technology reduces the textile industry's environmental impact. A waterless process not only abolishes demand for clean water but also protect the environment from wastewater. This adds to ease the worldwide strain for clean water as well as prevent water pollution that harms aquatic ecosystems. The utilization of $ScCO_2$ prevents contamination because of effective dye separation from CO_2 through depressurization at the end of the process.[5] This allows for trouble-free collection of the dye at the end of the process, in contrary to the wet process where dye separation from the wastewater is exceptionally troublesome.[1] Also, it permits for CO_2 recycling[8], a process that has been advanced to 90% recyclability.[4] CO_2 as a solvent is eco-friendly because it is nontoxic and nonflammable. Linear molecular structure and non-polarity characteristics classify CO_2 as an inert gas in many conditions.[2]

THE PILOT PLANTS AND CURRENT SCENARIO

In the course of recent years successful pilot plants have risen for supercritical CO_2 textile dyeing over the globe. $ScCO_2$ dyeing process of polyester is technologically and economically feasible was concluded by North Carolina State University College of textiles in year 2000 when they started up a pilot-plant machine.[2] In 2008, $ScCO_2$ dyed polyester yarn bobbins with low crocking, high reproducibility and dye evenness was produced by an Italian pilot plant at the Polytechnic University of Turin.[3] In 2014, the Soochow University College of Textile and Clothing Engineering developed a $ScCO_2$ rope dyeing pilot plant which produced economically feasible products with low crocking and high color diffusivity.[9] These are sign of $ScCO_2$ dyeing's commercial potential and recognition of this technology.

The commercialization of $ScCO_2$ polyester dyeing has started, and various companies have successfully introduced this technology into the textile dyeing bazaar. In addition to these companies, there are also producers that desire to shift to $ScCO_2$ technology. This shows that there is an interest for ScCO2 polyester dyeing technology; subsequently supporting $ScCO_2$ dyeing's commercialization feasibility.

DISCUSSION

It seems that main obstacles for commercialization of $ScCO_2$ dyeing process are its excessive investment costs and its lack of ability to dye natural fibers. However, high cost factor can be solved with price subsidies[10] and the inability issue is already in its improving stage.[4] The subsidies would make $ScCO_2$ dyeing technology available to the textile industry easily and ensure the longevity of this technology in the industry.[10] Incompatibility of natural fibers with $ScCO_2$ is an interim issue and research has improved dye ability of natural fibers. One distinguished example is the 100% dye fixation of cotton using $ScCO_2$ dyeing technology in combination with fluorotriazine reactive dyes.[11] Despite the fact that $ScCO_2$ dyeing of natural fibers is so far not ready to be commercialized, it will benefit immensely from the usage of $ScCO_2$ dyeing framework for polyester, as the latter will ease the entry of former into the industry.

CONCLUSION

To finish up, right now is an ideal opportunity for supercritical CO_2 polyester dyeing technology to be upscale and popularized in the textile industry. As the technology has been improved and executed with successful results, subsidies will be helpful in commercialization of this technology.

The existing pace of textile wastewater release is hazardous for both the environment and humanity as clean water becomes progressively rare. If the textile industry is honestly paying attention on sustainable manufacturing, as expressed in their objectives during the World Textile Summit-2015 [12], it is vital that it implements supercritical CO_2.

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