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Supercritical carbon dioxide for textile applications and recent developments

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Abstract
In textile industry, supercritical carbon dioxide (scCO2), possessing liquid-like densities, mostly find an application on textile dyeing processes such as providing hydrophobic dyes an advantage on dissolving. Their gas-like low viscosities and diffusion properties can result in shorter dyeing periods in comparison with the conventional water dyeing process. Supercritical carbon dioxide dyeing is an anhydrous dyeing and this process comprises the usage of less energy and chemicals when compared to conventional water dyeing processes leading to a potential of up to 50% lower operation costs. The advantages of supercritical carbon dioxide dyeing method especially on synthetic fiber fabrics hearten leading textile companies to alter their dyeing method to this privileged waterless dyeing technology. Supercritical carbon dioxide (scCO2) waterless dyeing is widely known and applied green method for sustainable and eco-friendly textile industry. However, not only the dyeing but also scouring, desizing and different finishing applications take the advantage of supercritical carbon dioxide (scCO2). In this review, not only the principle, advantages and disadvantages of dyeing in supercritical carbon dioxide but also recent developments of scCO2 usage in different textile processing steps such as scouring, desizing and finishing are explained and commercial developments are stated and summed up.

1. Introduction
Approximately 60% of the humankind cannot reach clean water resources and moreover changing climate and environmental conditions may result in harsh droughts in the future leading to more water scarcity for more people; therefore, water sustainability is very critical for world sustainability. Roughly 100-150 litres clean water is required to process 1 kg of textile materials and scCO2 treatment possess great opportunities for water savings in textile finishing processes [1, 2].

2. Apparatus for Supercritical Carbon Dioxide Treatment of Textiles
A commercially available supercritical carbon dioxide beam dyeing machine with a capacity of 100 to 200 kg of fabric, as fabric roll, per batch in an open width of 60 or 80 inches was produced by DyeCoo Textile Systems BV and FeyeCon Co., Ltd. for Yeh Group of Thailand in 2010 [3].

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Figure 1. Commercial supercritical carbon dioxide beam dyeing machine developed by DyeCoo company [3]

Recently, for the first time, novel water-free fabric rope fabric dyeing machine in supercritical carbon dioxide fluid media was effectively designed, produced and built in a pilot scale plant (Figure 1) [3]. The results of the novel rope dyeing in supercritical carbon dioxide media were satisfactory and commercially acceptable with good wet-wash and rub color fastness levels (4 to 5 gray scale ratings) and color uniformity [2].

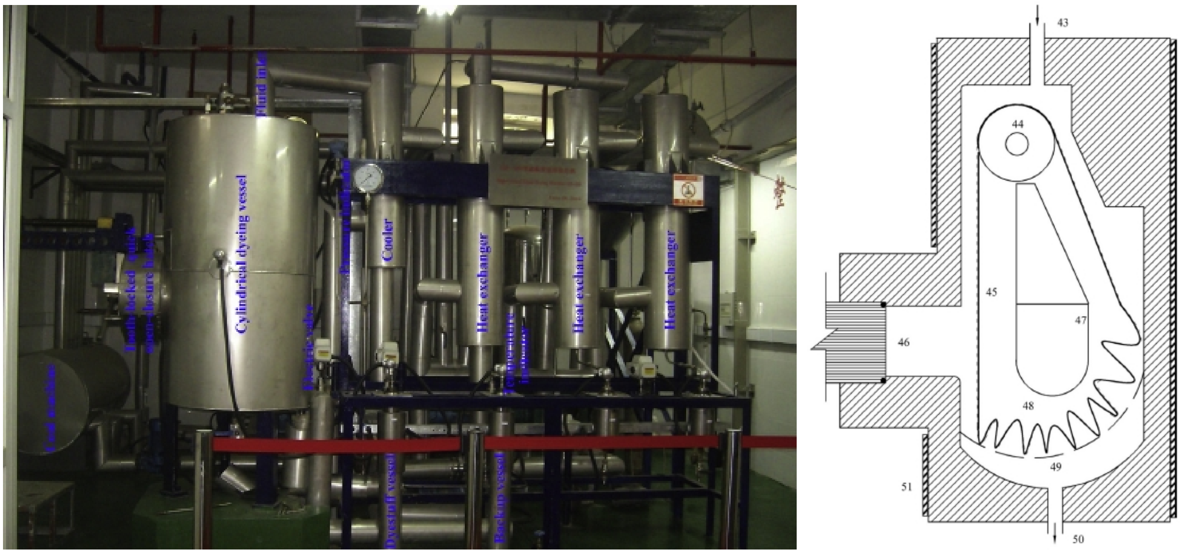

Figure 2. The pilot scale plant for supercritical carbon dioxide rope fabric dyeing machine and profile of the dyeing vessel

(43) fluid inlet; (44) drive reel; (45) fabric rope along with a special guide tape; (46) tooth-locked quick open-closure hatch; (47) grid baffle; (48) fabric container; (49) grid tray; (50) fluid outlet; (51) electrically aided heating jacket. [2]

3. Apparatus for Supercritical Carbon Dioxide Treatment of Textiles

Supercritical carbon dioxide (scCO2) waterless dyeing is widely known and applied green method for sustainable and eco-friendly textile industry. However, recently, not only dyeing but also pretreatment processes such as scouring, desizing and different finishing applications take the advantage of Supercritical carbon dioxide (scCO2) leading to enormous fresh water saving, cleaner and greener way of production and massive amount of contribution for world sustainability.

One of these usage applications of supercritical carbon dioxide (scCO2) is in surface modification of polyester fabrics as a pretreatment. In their study, glycerol polyglycidyl ether was impregnated as a cross-linking agent into polyester fabric through supercritical carbon dioxide, afterwards, immobilization operations were performed, containing pad-dry cure application and the solution process to finish the glycerol polyglycidyl ether-polyester fabric via natural functional agents such as sericin, collagen, or chitosan. It is reported that glycerol polyglycidyl ether can penetrate to the surface of polyester fabric in supercritical carbon dioxide pretreatment process. Moreover, used natural functional agents (sericin, collagen, or chitosan) can similarly be immobilized on the surface of this fabric (glycerol polyglycidyl ether-polyester fabric) particularly for the process of pad-dry-cure. The modified polyester fabric exhibited progression in surface hydrophilicity and wettability, moisturisation efficiency, and antibacterial activities [5].

C. Wang et Al. [6] studied the scouring possibility of polyester fibers by utilizing $scCO_2$ as a medium, the oil removal efficiency from polyester fibers reached to +99%. It is stated that successful scouring was carried out for polyester fibers in supercritical carbon dioxide media.

Supercritical carbon dioxide has recently found different application types also in textile finishing. For instance, A.L.Mohamed et. Al. [5] studied supercritical carbon dioxide assisted silicon based finishing on cotton fabric. In here, researchers used supercritical carbon dioxide as a medium for finishing cotton fabrics with modified dimethylsiloxane polymers terminated with silanol groups. 3-isocyanatepropyltriethoxysilane and tetraethylorthosilicate were utilized as cross-linkers for covalent bonding formation between silicon and cellulose polymers of cotton fiber. It is reported that all cotton fibers applied with silicon (PDMS) and 3-isocyanatepropyltriethoxysilane possess larger silicon amounts than those applied with tetraethylorthosilicate. Supercritical carbon dioxide medium procures nice cotton surface coating via a 3D network of DMS compound and cross linker leading to the highest DMS concentration formation in a layer between 1 and 2 micron under the cotton fiber surface [5].

In the case of antimicrobial finishing attainment, T. Baba et. al. [7] impregnated chitin and chitosan to polyester (PET) fabric using supercritical carbon dioxide in order to achieve high anti-bacteria property durable to washing. Chitosan-lactic acid salt was effectively applied to polyester fabric using supercritical carbon dioxide media. On the other hand, chitin could not be impregnated successfully. Even after 50 home washing cycles, 70% of the chitosan still stayed on polyester fabrics and therefore polyester fabric still continues to exhibit anti-microbial properties. It is known that it is very difficult to impregnate chitosan to polyester fabric permanently in an aqueous system. However in here, it is important to state that chitosan could be fixed by impregnation onto polyester fabric strongly through the medium of supercritical carbon dioxide [7].

4. Result

Waterless dyeing exhibits environmental benefits for sustainable world. Similarly waterless scouring, desizing and finishing bring about the same advantages for sustainable textile pre-treatment and finishing leading to more sustainable future.

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