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A comparative study of tartrazine degradation using UV and solar fixed bed reactors

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ABSTRACT

The fixed bed reactor was combined with a solar photoreactor and UV lamp reactor. This hybrid photoreactor used a heterogeneous photocatalysis process (TiO₂/UV) as a tertiary treatment for the degradation of tartrazine dye in water. The solar reactor removed almost all organic compounds from the wastewater. Photocatalysis was optimized using a parametric study to improve the influence of different parameters on the degradation efficiency. Color removals when using solar, UV lamp and hybrid reactors present 99%, 30%, and 99%, respectively. Tartrazine removal kinetics followed a pseudo-first order model. The hybrid solar and UV lamp system combination was a feasibility choice for removing both dyes from wastewater.

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Introduction

Water is an essential natural resource for human being and for all life forms [1,2]. One of the major challenges facing mankind today is to provide clean water to a vast majority of the population around the world. Reuse of wastewaters has become an absolute necessity. Therefore, there is an urgent need to develop innovative, more effective and inexpensive techniques for treatment of wastewater [3]. Wastewater from some industries such as textile and paper contain residual dyes, which are not readily biodegradable [4]. One of them is Tartrazine (C.I. Acid Yellow 23, AY23) which is an anionic azo

dye whose presence in thousands of foods and drugs has been reported as a possible cause of asthma, urticaria, and angioedema [5]. It also has phototoxic potentials [6].

Dyes are one of the most used raw materials in food, pharmaceutical and textile industries, among others. In the world, there are about 10,000 kinds of dyes and estimations say that, every year, 700,000 tons of dyes are generated. From these, about 15% are expelled into the environment with no treatment at all [7]. The presence of dyes in water bodies causes environmental consequences: They become an obstacle for the spreading of oxygen and light and, they give water an unaesthetic aspect. Besides, these compounds,

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because of their chemical nature, they are considered as persistent in the environment, and some of their precursors and sub-product are cancer agents.

In this regard and in recent years, advanced oxidation processes (AOPs) have been described as efficient procedures for obtaining high oxidation yields from several kinds of organic compounds. These methods are based on the generation of very reactive agents such as hydroxyl radicals (OH) that are extremely reactive and strong oxidizing agents (Eox = 2.8 V), capable of mineralizing organic pollutants [8]. For enhancement in efficiency, the use of TiO₂ catalyst has gradually attracted more interest. This is due to the fact that TiO₂ is the most acceptable and a very cheap catalytic material; also having the capability of being recovered from treated wastewater [9]. The higher activity of the UV/TiO₂ process is due to the well known fact that when TiO₂ is illuminated with UV light, electrons are promoted from the valence band to the conduction band of the semi-conducting oxide to give electron–hole pairs. The valence band hole, h potential is positive enough to generate hydroxyl radicals at the surface. Also, the conduction band electron (e⁻) is negative enough to reduce the oxygen molecules, present in the solution, which in-turn leads to the generation of another series of hydroxyl radicals [10].

Tartrazine (Acid Yellow 23; FD&C Yellow No. 5), as an azo dye has been chosen for this study due to its extensively use as a colorant in food, cosmetics, pharmaceuticals and textile industry [11], as well as its high stability against biodegradation and conventional wastewater treatment procedures after disposal from industrial effluent [12,13]. Several studies have demonstrated that tartrazine could be degraded employing AOPs like: ozonation [14], electrochemical oxidation [15], photo Fenton oxidation [16], UV/HO [17,18], photolytic [19], and photocatalytic oxidation [10,20].

The aim of the present work is to study the photocatalytic degradation of tartrazine under both solar and artificial light using fixed bed catalyst in two reactors design. The effect of various parameters, such as tartrazine (TAZ) concentration, pH of the solution was investigated using new reactors designs.

Experimental

Chemical and reagents

Tartrazine (C₁₆H₉N₄Na₃O₉S₂) is a synthetic azo dye food Nature, widely used in the food industry and in the manufacture of many cosmetic and pharmaceutical products in Algeria. with a molecular weight of 534,36 g/mol (Fig. 1).

A commercial available titanium dioxide used as a photocatalyst was produced by Degussa (P25) is in 80% anatase with BET specific surface area of 50 (m² g⁻¹) and 20 nm of particle diameter. The titanium dioxide amount (TiO₂) used in this study was: 0.3 mg/cm² in both reactors.

Photocatalytic reactor

The photocatalytic experiments were carried out in different photoreactors designs (Solar and hexagonal glass

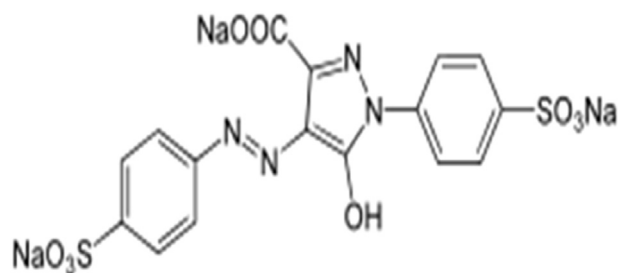


Fig. 1 – Chemical structure of tartrazine.

photoreactor). Solar photochemical experiments were performed in a pilot plan specially developed for photocatalytic application installed at the Solar Equipment Development Unit (UDES) on the north of Algeria (latitude 36°0.39'; longitude 2°0.42') using natural sun-light irradiation. Solar ultraviolet radiation (U.V.) was measured by global UV radiometer (KIPP&ZONEN, CMP11) mounted on a plat form tilted 36° as the reactor. The solar photocatalytic reactor (Fig. 2) used in this experiment consists of an undulating and inclined surface (1 × 0.5 m) which is set TiO₂ catalyst by the impregnation method. The second device is a hexagonal glass photoreactor with a double wall. Six (06) glass plates are used on which the catalyst is fixed. All experiments were carried under a U.V. lamp radiation (Phillips PL-L 24W/10/4P lamps with λ_{max} = 365 nm). Finally, a hybrid system was mounted combining the two reactors in order to ensure a continuous treatment.

The polluted solution was continuously re-circulated for each system at the flow rate of 60 mL s⁻¹, employing an A DC pump through the photoreactor and the reservoir tank (8L). The entire system is linked to photovoltaic panels providing energy supply to the re-circulation pump.

Solution was recycled during 300 min, samples (5 ml) were taken each 10 min periods, from the reservoir by a plastic syringe and then filtered in Millipore disk of 0,45 μm. Tartrazine degradation was evaluated by measuring the absorbance with spectrophotometer UV–VISIBLE type Shimatzu UV1800. The UV absorption spectrum of tartrazine in aqueous solution is given in Fig. 3. The maximum optical density was detected at a wavelength of 427 nm. A correlation curve between pollutant concentration and the absorption was pre-established.

The photocatalytic processes were carried out in the presence of catalyst and were supposed pseudo first-order reactions [21]:

$$r = -\frac{dC}{dt} = kC \quad (1)$$

where r is the reaction rate and k is the apparent constant.

In order to estimate the kinetic of degradation processes in the presence of TiO₂, the following relationship was improved:

$$\ln \frac{C}{C_0} = -kt \quad (2)$$

With: C₀: Initial pollutant concentration; mg L⁻¹ and C: pollutant concentration at time t ; mg L⁻¹.

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