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RESEARCH ARTICLE

DEGRADATION OF CONGO RED DYE USINGHYDRODYNAMIC CAVITATION

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Abstract

Hydrodynamic cavitation (HC) has been applied in the present work for the degradation of Congo red dye. Initially, the Effect of dilution of the Dye on the efficiency of hydrodynamic cavitation has been studied using circular orifice as well as venturi as a cavitator. The process parameters such as initial dye concentration, solution pH, Hydraulic characteristics, comparative study of venturimeter and orificemeter, and flow rate were investigated in detail to evaluate their effects on the decolorization efficiency of Congo red Dye. In terms of removal rate and energy efficiency, an optimal inlet pressure value was found close to 0.4 MPa and cavitation number of 0.25. Maximum decolorization was obtained using orifice is 64%, and that of venturi is 73% in 90 min time at a temperature of 25±2°C.

Introduction:-

Overview:

For decades, water pollution has attracted growing public attention as new toxic, refractory, and chemically stable compounds have been detected in the effluents of wastewater treatment plants (WWTP) all over the world [1]. Synthetic dyes are present in all spheres of our everyday life, and their application is consistently growing. The dye pollutants from the textile industry are the most important of environmental pollution; these effluents are toxic and mostly non-biodegradable. The trades involving production and application of dyes in the wastewater causes the primary threat to the surrounding ecosystems due to health hazard caused by toxicity. Wastewater from the textile industry containing dyes causes a severe environmental problem due to their intense color and potential toxicity. In recent years, effluents from the textile processing industry have become a cause of serious environmental concern. The use of synthetic chemical dyes by the textile industries in the various textile processing operations such as dyeing, printing, bleaching, and finishing operations has resulted in the release of large amounts of dye-containing industrial wastewater. [2]Textile wastewaters are found to have a large quantity of suspended particles, varied pH, dark-colored, with high chemical oxygen demand (COD), and high total organic carbon (TOC) [3] The presence of highly suspended solid particles with their intense color provides high turbidity in the textile effluents. Even a deficient concentration of these dyes (less than 1 ppm for some dyes) induce color in water that is highly observable and undesirable and adversely affects the water bodies such as rivers, lakes, etc. [4]. Most of the dyes are toxic, and bio-recalcitrant in nature, and therefore conventional biological processes are found to be inefficient for the treatment of textile effluents[5] . The untreated textile wastewaters due to the presence of carcinogenic compounds are, therefore, very hazardous and toxic to human beings and animals also. Because the aquatic environment is damaged by the wastewaters discharged from textile dyeing industries, it is required to develop an eco-friendly and energy-efficient technique to treat the textile effluent before its discharge into the aquatic environment. Several

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conventional strategies comprised of various combinations of physical, chemical, and biological oxidation processes were developed for the treatment of textile effluents in the last decade.[6]

In recent years, cavitation as an advanced oxidation process (AOP) has been receiving more considerable attention for the treatment of wastewater [7][8]. Cavitation comprises of the nucleation, growth, and subsequent collapse of micro-bubbles or cavities, occurring in a small time interval at multiple locations in the reactor and thus releases a large magnitude of energy [9]. The collapse of cavities creates the 'hot spots' (very high temperature and pressure region) resulting in the formation of •OH, •H, HO2 •, and cavitation can be produced by pressure variation in a flowing liquid through cavitating devices such as venturi or orifice plates, etc. When, the liquid passes through the geometries, the kinetic energy/velocity of the fluid increases at the expense of the pressure. The pressure at the throat or vena-contracta of the geometry drops below or equals the vapor pressure of the liquid due to sufficient throttling, and the liquid gets vaporized, thus creating several vaporous cavities. These cavities are further collapsed when pressure recovers downstream of the geometry. The collapse of cavities creates hot spots with extremely high temperatures up to 5,000 K and pressure up to 1000 atm[10]

Materials and methods:-

Materials:

Congo Red Dye is an organic azo dye. Its chemical formula is $C_{32}H_{22}N_6Na_2O_6S_2$. with its molecular weight, 697 was purchased from S D Fine chemical ltd. Mumbai. Double distilled water (prepared freshly in the laboratory via distillation unit) was used to prepare the solution of congo red dye. Solution pH was adjusted using NaOH and H_2SO_4. All chemicals, as received from suppliers, were used for the experiments without any further purification.

Experimental setup:

Hydrodynamic cavitation reactor setup used in the present work is shown in Fig. 1. HC reactor setup consists: (1) a storage tank with 15 L capacity, (2) a high-pressure centrifugal pump is driven by a motor (power rating 1 kW) (3) flow control valves (V1–V4), and pressure gauges (P1, P2), (4) a flow meter, (5) cavitating device venture and orifice accommodated with flanges. Pipes used in HC reactor have an internal diameter of 25 mm. The suction side of a pump is connected to the bottom of a storage tank. The discharge from the pump branches into mainline and bypass line. The mainline consists of a cavitating device, and the flow rate of water in the mainline was controlled by regulating valve Pressure gauges (P1 and P2) are provided in main line to check the fluid pressure. The details of the cavitating devices used in the present work are given

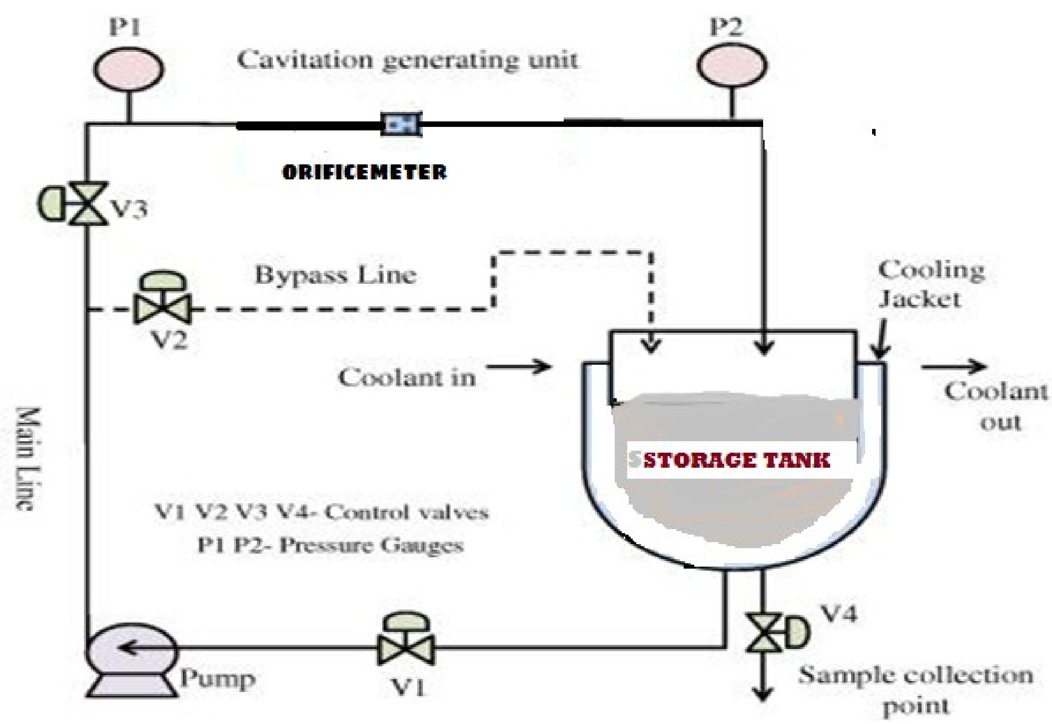

Fig 1:- Diagrammatic representation of the experimental setup.

Fig 2:- Experimental set up.

Experimental and analytical procedure:

Decolorization of Congo red dye has been carried out using HC at various conditions with a fixed aqueous congo red dye solution of 10 L volume. All the experiments were performed for 120 min, and samples were taken from the storage tank at a fixed interval of time for further analysis. During all the experiments, the temperature of the solution (25± 2°C) was kept constant and was maintained by circulating cooling water through the cooling jacket. The concentration of congo red dye was measured by UV/Vis-Spectrophotometer (Jasco800) at the wavelength (λmax) of 495 nm. Firstly, the calibration chart was prepared for the known concentrations of congo red in the range of 10-150 ppm to calculate the concentration of unknown samples during experiments. A pH meter (systronics) was used to determine the pH of the solution throughout the experiments. In the present work, all experiments were repeated three times to evaluate the repeatability of the observed data.

Results and discussion:-

Hydraulic Characteristics:

In HC, a dimensionless parameter known as cavitation number (Cv) is used to characterize the condition of hydrodynamic cavitation inside a cavitating device. It is defined as the ratio of the pressure drop between the throat and extreme downstream section of the cavitating device to the kinetic head at the throat. Cavitation number is given by the following Eq

$$C_v = \left(\frac{P_2 - P_v}{\frac{1}{2}\rho v_o^2} \right)$$

Where P2 is the fully recovered downstream pressure, Pv is the vapor pressure of the liquid, v0 is the velocity at the throat of the cavitating device, and ρ is the density of the liquid. Two critical parameters, such as operating inlet pressure and cavitation number, affect the cavitational intensity at the downstream side of the cavitating device, i.e., the number of cavities being generated and their final collapse pressure. Thus, it is necessary to optimize the operating inlet pressure and cavitation number for all the cavitating devices.[11] The variation of cavitation number with operating inlet pressure for different cavitating devices is shown in Fig. 3. This figure reveals that the cavitation number decreases with an increase in operating inlet pressure for all the cavitating devices. As the inlet pressure increases, the volumetric flow rate through mainline and velocity at the throat increases, which in turn reduces the cavitation number. Hence, the overall cavitation number is affected by the inlet pressure and volumetric flow rate which also affects the number of cavitational events

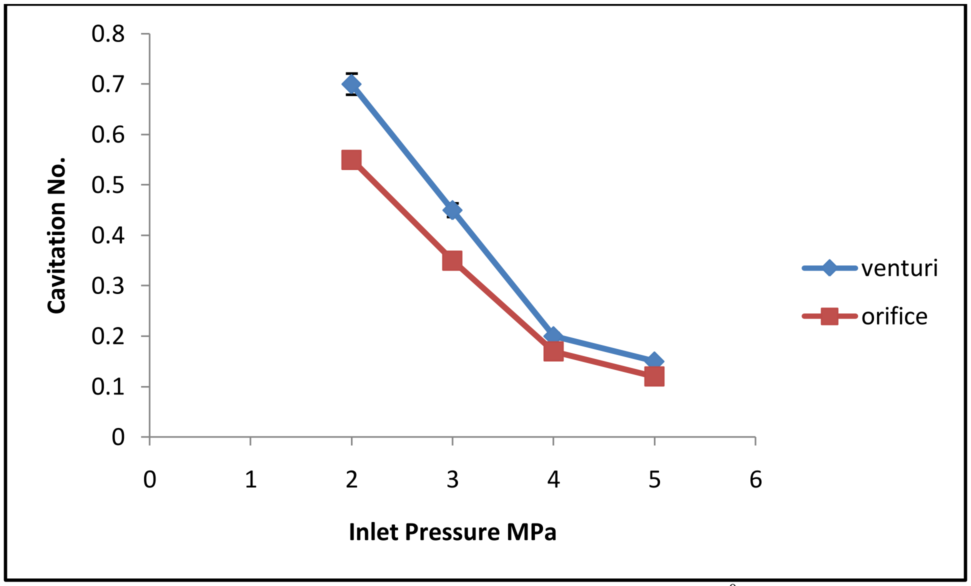

Fig 3:- Hydraulic characteristics (Reaction condition Volume 6 liter, temp 25 ^{0}C, time 90 min, conc. of Dye 30 ppm).

Optimization of solution pH:

The solution pH plays a crucial role in determining the productive decolorization efficiency of pollutants using HC.[12] The experiments related to optimization of solution pH were conducted at different solution pH ranging from 3 to 8 at an operating inlet pressure of 0.4 MPa and dye initial concentration of 120ppm. In this case, orifice was used to generate the hydrodynamic cavitation. The obtained results are shown in Fig.4. The results depict that the extent of decolorization increases with a decrease in solution pH. The maximum decolorization of 63% was obtained at a solution pH of 4.using orifice and 73% using the venturi. The results clearly show that the extent of decolorization at acidic condition was greater as compared to that obtained at essential condition Higher decolorization rate at acidic condition can be attributed to the fact that the production of •OH radicals in HC system are more favorable under acidic condition.

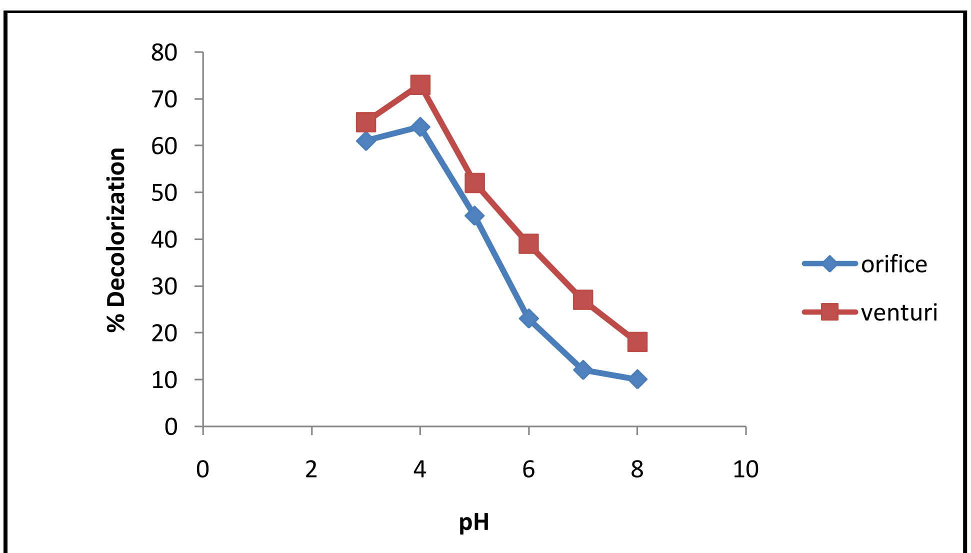

Fig.4:- Effect of pH (Reaction condition Volume 6 liter, temp 25 ^{0}C, time 90 min, conc. of Dye 30 ppm).

Effect of initial Congo red concentration:

The Effect of initial concentration of congo red dye on the decolorization was investigated using orifice and venture as a cavitating device. Experiments were performed with different initial concentrations as 30, 60, 90 and 120 ppm at an operating inlet pressure of 0.4 MPa and solution pH of 4.0. The extent of decolorization is inversely proportional to its initial concentration of Dye. It was observed that % decolorization decreased from 64% to 19% with an increase in the initial concentration of congo red dye from 30 to 120 ppm, .and 73% to 32% by using venturi. The obtained lower decolorization rate at higher concentration can be attributed to the fact that the total quantity of pollutant molecules increases with an increase in the initial concentration, whereas the total concentration of •OH radicals remains constant in the system.[13]

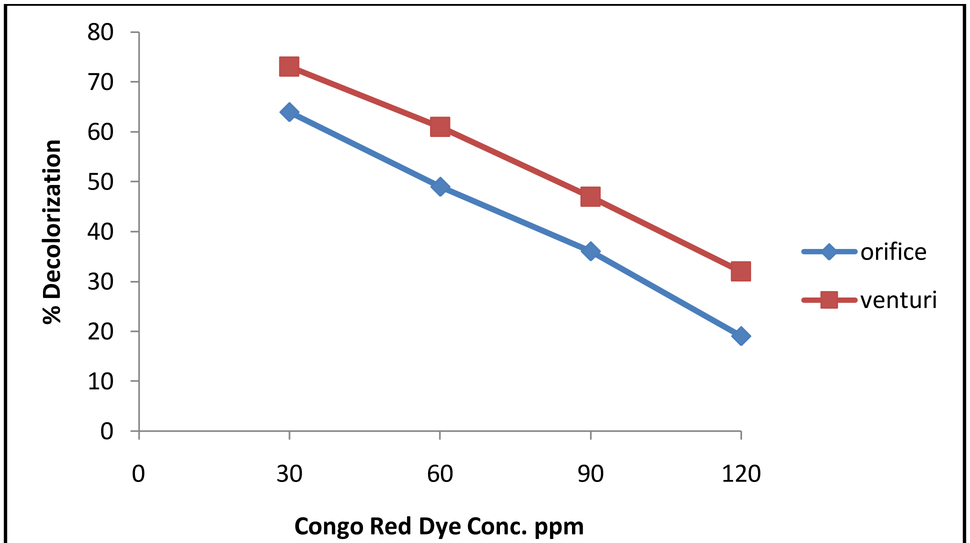

Fig 5:- Effect of dye conc. (Reaction condition Volume 6 liter, temp 25 ^{0}C, time 90 min, pH 4).

Effect of Flowrate:

Inlet pressure is an important operating parameter of HC system.[14] In order to investigate the influence of inlet pressure on the decolorization rate of congo red dye. Experiments were conducted by varying flow rates from 0.2 to 0.6 L/s. The congo red dye concentration was kept constant at 30 mg/L, and the pH value was fixed at 4.0 for a time period of 90 min. Figure 6 showed the Effect of flow rate on the decolorization rate concerning time. The experimental results indicated that the rate of decolorization increased with an increase in flow rate ranging from 0.2 to 0.5 L/s, but beyond which no significant increase in the rate of decolorization

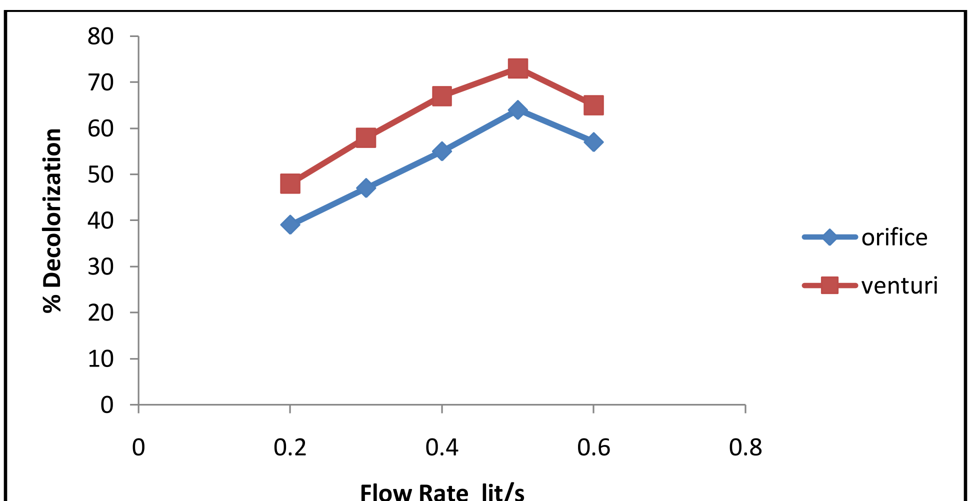

Fig 6:- Effect of flow rate (Reaction condition Volume 6 liter, temp 25 ^{0}C, time 90 min, conc. of Dye 30 ppm, pH 4).

Effect of geometrical configurations (Comparison of venturi and orifice plates):

It has been reported that venturi has advantages over an orifice plate due to their smooth convergent and divergent section, which prevents the early cavity collapse and enhances the cavity life. It is noted in the literature that venturi gave higher decolorization than orifice plates.[15] But while operating with the venturi, experimental set up repeatedly broke down due to high pressure developed. When venturi was compared with orifice plate having a circular hole. It was found that venturi gave higher decolorization than orifice plate, i.e., 73% in venturi and 64% in orifice) In case of orifice plates, the generated cavities in the downstream section do not reach their maximum size due to the sudden pressure drop, resulting into a lower cavitational activity as compared to venturi. Hence, organic pollutant molecules will get longer exposure time under cavitating condition in case of venturi than orifice plates. These results clearly show that venturi are better than orifice plates of the same flow area.

Conclusions:-

This work shows that the efficiency of hydrodynamic cavitation is strongly influenced by the geometrical parameters The maximum extent of decolorization of congo red dye was obtained using slit venturi at an optimum inlet pressure of 0.4 MPa is 73% and using orificemeter is 64%. It has been found that higher flow area is better for higher cavitational yield. Furthermore, it was observed that solution pH also affects the degradation efficiency of pollutants. These processes differ from the other treatment processes because wastewater compounds are degraded rather than concentrated or transferred into a different phase, and secondary waste materials are not generated.

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