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Computational study of different venturi and orifice type hydrodynamic cavitating devices*

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Abstract: This paper reports optimization of various geometrical parameters of two types of hydrodynamic cavitation reactors (HC) such as venturi type and orifice type. Mostly orifice and venturi nozzles are used as HC reactor, a simple valve can also be used to cause cavitation which depends on geometry and area of opening. Different operating and geometrical parameters such as divergence angle, throat height/diameter to length ratio, number of holes and inlet pressure to the cavitating device were selected to study the inception, growth and dynamics of cavities. In this work, a comprehensive computational fluid dynamics simulation is performed to numerically investigate the 3-D flow behaviors within HC reactors using cavitational model with standard k - ε Turbulence model. The study of different geometries of venturi type HC reactor (like slit, circular and elliptical) shows that 1:1 of the ratio of throat height/diameter to length and 6.5° of divergence angle is an optimum geometry for best cavitational activity. In case of orifice, 1:3 of the ratio of diameter to length is best for cavitation and an increase in the total flow area increases the cavitational yield.

Key words: hydrodynamic cavitation (HC), computational fluid dynamics (CFD), cavitation number (CN), venture, orifice

Introduction

In general, cavitation is a fluid mechanics phenomenon which is the formation of cavities in the medium due to pressure fluctuation. Fluctuating pressure field significantly causes damage, erosion on the surface and generation of shock waves. Cavitation was first explained by Lord Rayleigh in 1917, and he analyzed the behavior of spherical bubbles near a marine impeller[1]. He concluded that the gaseous bubbles near impeller get affected by fluctuating pressure field. In low pressure region, the generated bubbles grow in size and tend to shrink when the pressure is recovered. In shrinking, bubble wall velocity start increasing and the inertia of liquid become higher than bubble and hence bubble collapses adiabatically in that condition. This collapse generates the shock wave which causes erosion of impeller. Therefore, cavitation can reduce the performance of hydraulic equipments like impellers, turbines valves, pump and turbo machinery parts etc.[2].

Over the past few years, many scientists have carried out their researches on cavitation to raise the process yield by utilizing large amount of energy which is released at the time of collapse in different fields of engineering applications[3-10]. In hydrodynamic cavitation (HC), cavities are generated in flowing medium using mechanical constriction/geometries like orifice, venturi and valves. When liquid passes through these constrictions, the pressure at throat falls below vapour pressure of liquid and thus rapid formation of vaporous cavities takes place with dissolved gases and suspended solids present in the flowing medium. After generation, cavity undergoes expansion and compression phases. Bubble wall velocity decreases in isothermal expansion phase and increases in compression phase or collapse phase according to conservation of momentum. These implosions of collapse release large amount of energy, generating localized "hot spot" with drastic increase in temperature and pressure (temperature in the order of thousand kelvin and pressure in the order of thousand atm)[5]. Under these conditions, water molecules are thermally

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dissociated into OHand Hfree radicals. These OHfree radicals are then diffused into bulk liquid medium where they oxidize the organic pollutants. These free radicals intensify the chemical reaction or may prompt the chemical reaction at ambient condition which is otherwise not possible and may require high temperature and pressure conditions[6]. In some cases, cavity collapse may break the large molecular weight compound into smaller ones and it can occur at different locations of the reactor simultaneously. This makes cavitation an alternative option in various engineering applications. Cavitation also generates local turbulence and liquid micro circulation at the time of collapse which enhances the transportation rates (mass, momentum and heat) and thereby increasing the reaction rate[1]. These effects are responsible for process intensification and have varied applications in various processes such as microbial cell disruption[3], sonochemistry[4], water and effluent treatment[6-8], leaching[11], enzyme recovery[12], crystallization[13], medical applications[14] and emulsification[15- 17] etc..

Therefore, many researchers have been doing their research on dynamics of cavitation to develop the flow elements such as orifices, valves and venturies which are capable of generating cavities. These types of constrictions are placed in a pipe carrying a stream of fluid which increases the stream kinetic energy at the throat[1]. Throttling in such devices should be sufficient to keep the pressure below the vapour pressure of flowing medium to generate cavities. A venturi has advantage over the orifice due to its smooth converging and diverging sections but orifice can generate high velocity at throat for a given pressure drop and it can accommodate more number of holes in a given cross sectional area and also it is easy to fabricate[18]. In addition, the high speed and high pressure homogenizers also generate cavitating conditions[19]. In view of the industrial application as well as for obtaining efficient design of cavitational reactors, it is very crucial to understand the physics behind the actual phenomenon of cavitation occurring inside the cavitational reactor[19].

Saharan et al.[9] have studied different types of cavitating devices like circular venturi, slit venturi and single hole orifice plate for degradation of waste water pollutant (orange-G). They have concluded that the efficiency of HC depends on geometries of cavitating reactor (open flow area, the ratio of throat height/ diameter to length and divergence section) and operating conditions (initial concentration, pH, cavitation number (CN) and inlet pressure). The cavitational intensity depends on cavity collapse which is controlled by operating conditions.

Sivakumar and Pandit[10] have also studied different multiple holes orifice for the degradation of waste water pollutant (Rhodamine B). They observed that modification of flow geometries and hence turbulent pressure fluctuation frequency (f_T) could enhance the cavitational intensity. The orifice plate with more number of hole openings i.e., having smaller hole size achieve a larger area of the shear layer as compared to the same flow area of larger hole size and because of that the value of f_T increases, which leads to a more cavity formation and intense collapse of generated cavities. Hence, the ratio of perimeter to open area of throat (α) becomes the deterministic parameter for cavity density in a cavitation reactor.

Bashir et al.[20] have optimized important geometrical parameter of cavitating venturi using computational fluid dynamics (CFD). Optimization of different type of venturies was done in terms of cavity inception, cavity growth (throat height to length ratios) and pressure recovery rate (divergence angle).

Badve et al.[19] have modeled and simulated a different type of hydrodynamics cavitational reactor comprising of a stator and rotor assembly to predict the flow patterns by describing the shear rate and pressure variation in the complex flow field. Using high accuracy simulation schemes and Navier-Stokes equation, fluid properties were investigated. They have concluded that higher rotational speeds of the rotor, tends to stabilize the flow, which in turn results in less cavitational activity compared to that observed around 2 200 rpm-2 500 rpm.

In the present study, various designs of the cavitating reactor such as slit venturi, circular venturi, elliptical venturi, single hole orifice and multiple holes orifice by varying different operating and geometrical parameters were studied to observe the cavitating conditions. CFD (ANSYS Fluent 14.5) methodology was used to observe the hydrodynamic behavior inside a cavitator and different cavitating reactors were optimized. Hence, this work employs an idea in the design of optimized cavitating reactors for getting maximum cavitational effect of a HC reactor.

1. An approach in the design of cavitating reactors

The approach followed in this paper is based on the assessment of selected simulation problems which are considered to be typical and represents the cavitation applications. Here, two types of modified cavitational reactor (venturi and orifice) are used to optimize various geometries and different operating conditions. Different flow areas of throats such as venturi type (slit, circular and elliptical) and orifice type (single hole and five holes) are considered for optimization. A venturi has high pressure recovery and low pressure loss due to minimal flow separation but on the other hand, an orifice has limited pressure recovery and medium pressure loss which generate substantial flow separation. Both venturi and orifice have an upstream section, a throat and a downstream section