Simulation of irradiation intensity distribution of electrodeless ultraviolet lamp in cylindrical resonator by CFD

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Abstract. To improve the catalytic efficiency of the microwave single-mode sintering furnace to heat the catalyst and the carrier to catalyse the oxidation of toluene, the SJ-1 microwave single-mode sintering furnace was modified to place a microwave electrodeless ultraviolet lamp in the resonant cavity. The distribution of pollutants in the reactor and the intensity of UV light were calculated by CFD and visualized. The distribution of UV field can be seen from the results of light field, which provides a scientific basis for the placement of catalyst and a reference for the simulation of UV field. Under the conditions of relative humidity of 50%, space velocity of 6336.93 h⁻¹, input power of 392.8 W, bed height of manganese oxide catalyst is 30 mm, initial toluene concentration of 235.23 mg/m³, input power of 595.3 W, toluene conversion efficiency of 94%. It has certain guiding significance.

Keywords: CFD, Ultraviolet Irradiation Intensity, Catalytic Oxidation, Toluene.

1. Introduction
In the photodegradation reactor, the uniformity of UV light intensity distribution determines the degradation efficiency, and the area with high light intensity means that more UV dose can be given to the gas. The gas in different areas may receive different UV dose, which causes instability of degradation efficiency and low energy utilization. To understand the fluid flow and the distribution of ultraviolet light intensity in the photodegradation reactor, the numerical simulation of fluid and ultraviolet radiation is often carried out. Ling Tang [1] used CFD to simulate the UV field of the UV disinfection reactor, studied the light intensity distribution in the UV disinfection reactor model, and obtained that the average light intensity of two lamps in the relative position was higher than that of two adjacent lamps. Xin Wang [2] verified the feasibility of simulating the photocatalytic reaction process by simulating the photocatalytic degradation of TCE (trichloroethylene). Based on previous studies, this paper simulated the distribution of ultraviolet field by placing the electrodeless ultraviolet lamp in the modified microwave sintering furnace. According to the distribution of the ultraviolet field, the position of the catalyst is determined to improve the utilization efficiency of ultraviolet light, which provides a reference for the simulation of the ultraviolet field distribution.

2. Brief introduction of CFD
CFD refers to the technology of using computer to solve various partial differential equations of fluid simulation [3]. Its processing flow is mainly divided into three independent stages, namely, pre-
processing stage, solving stage and post-processing stage. The basic idea of CFD simulation is to use a set of variable values of a series of finite discrete points to represent the field of continuous physical quantities in the space domain, such as the velocity field and pressure field in the fluid. Through the relationship between these discrete points and field variables, the algebraic equations are established, and then the algebraic equations are solved to obtain the field of continuous physical quantities in space domain [4]. The pre-processing stage refers to the abstraction and simplification of physical phenomena to form a geometric model. The geometric model is meshed (Gambit, ICEM, Meshing, Fluent Meshing, etc.) and the boundary is processed to form the calculation area that meets the calculation conditions. The second stage is the setting of computational solution. By importing the data processed in the first step into the solver, the solvers of general CFD software mainly include fluent, CFX, etc. These solvers solve the computational domain by reading the grid data, boundary conditions, solving control parameters, etc. this topic uses the widely used fluent solver. The third stage is to visualize the calculated data. The calculation data is presented more intuitively in graphic mode.

3. The establishment of the model and the setting of related parameters
Solid Words is used to build the model according to the actual conditions. Figure.1 shows the model. The inner height of the cavity is 300 mm, and the inner diameter is 160 mm. Place three quartz electrodeless ultraviolet lamps with height of 300 mm, diameter of 19 mm and luminous part height of 200 mm, as shown in the figure. Then it is imported into mech for mesh generation and boundary naming, and then it is imported into fluent for solution. Fluent simulation is based on the computational grid to divide the spatial continuous calculation area into small enough calculation area. The k-silon (2 eqn) is selected as the fluid model, and the Discrete Ordinate (Do) is used as the radiation model. The density of the gas in the cavity is 1.225 kg/m³, CP (specific heat) is 1006.43 J/(kgꞏK), heat conduction is 0.0242 w/(mꞏK), viscosity is 1.7894e-05 kg/(mꞏs), and refraction is 1. Then the data of the calculation domain is initialized, and finally the iterative calculation is carried out. After 500 iterations, the calculation converges. Finally, the CFD post module is opened to output the simulation results.

![Figure 1. Watershed model.](image1)

![Figure 2. Results of mech partition.](image2)
4. Numerical simulation of photodegradation reactor

4.1. Meshing
The simulation grid is divided by mesh software. Before calculation, simplify the model to avoid unnecessary boundary and chamfering and increase the amount of calculation. The results of mesh generation are shown in Figure.2. The total number of grids is 1445085. In this model, element quality is used to test the grid quality. Generally speaking, the value of element quality is between 0-1. The closer to 1, the more perfect the table is 0.82231, so the experimental grid is more accurate for CFD calculation.

4.2. Simulation results and analysis
In this simulation, the mesh is imported into fluent to set the parameters of the flow field and carry out iterative calculation, and the ultraviolet radiation simulation diagram in the cavity is obtained as shown in Figure.3. According to the results of simulated light field, the light intensity is relatively weak at the lamp cap of the ultraviolet lamp, and relatively strong in the middle of the ultraviolet lamp, which is in line with the phenomenon of the electrodeless ultraviolet lamp used in this device. As shown in Figure.3, the ultraviolet light is evenly distributed in the cavity.

![Intensity distribution of 185-254nm ultraviolet radiation in cavity.](image)

Figure 3. Intensity distribution of 185-254nm ultraviolet radiation in cavity.

Figure.4 (a) and (c) show the distribution of ultraviolet irradiation intensity in the longitudinal section and transverse section of the cavity. As shown in the figure, there is irradiation intensity in the cavity. The radiation intensity is the highest at the light-emitting surface of the lamp, and the radiation intensity is uniform in the central part of the cavity.

Figure 4 (b) is a broken line diagram of irradiation intensity corresponding to the central axis position in (a). Represents the radiation intensity corresponding to the black line (99.8 mm ~ 219.5 mm) in (a), which is 845.22 ~ 935.37 w/m². The distribution of ultraviolet radiation is uniform. Figure. 4 (d) is a broken line diagram of the irradiation intensity corresponding to the position from the lamp surface to the center of the section in (c). As shown in the figure, the irradiation intensity from the surface of the electrodeless ultraviolet lamp to the center of the cross section decreases with the increase of the distance, and the central ultraviolet radiation intensity is 935.37 w/m². The catalyst can be placed in this position.
Figure 4. Distribution of ultraviolet radiation intensity in cavity section and broken line diagram of corresponding radiation intensity at simulated position.

(a. The distribution of ultraviolet irradiation intensity in the longitudinal section of the cavity; b. Is the line chart of irradiation intensity corresponding to the central axis position in (a); c. The distribution of ultraviolet irradiation intensity in the transverse section of the cavity; d. Is the line chart of the irradiation intensity corresponding to the position from the lamp surface to the center of the section in (c) )

4.3. Catalytic oxidation of toluene

Therefore, the prepared catalyst is placed in the middle of the quartz tube in the center of the cavity, so that the catalyst can catalyse ozone, fully irradiate the catalyst by ultraviolet light, and cooperate with the catalyst to degrade VOCs and achieve the full utilization of energy. Figure 5 shows that when the relative humidity is 50 %, the space velocity is 6336.93 h⁻¹, the input power is 392.8 W, bed height of manganese oxide catalyst is 30mm, the initial concentration of toluene is 235.23 mg/m³, and the input power is 595.3 W, the toluene conversion efficiency can reach 94%.
5. Conclusion

In this chapter, the simulation conditions of computational fluid and light field are determined by the characteristics of CFD software. The distribution state of pollutants in the reactor and the intensity of ultraviolet light are calculated by the solver and visualized. The distribution of ultraviolet field can be seen in the light field results, which provides a scientific basis for the placement of catalyst and a reference for the simulation of ultraviolet field. According to the simulation results, the catalyst was placed, and the experimental results showed that the device had good catalytic effect. Under the conditions of relative humidity of 50%, space velocity of 6336.93 h⁻¹, input power of 392.8 W, the bed height of manganese oxide catalyst is 30mm, initial toluene concentration of 235.23 mg/m³, input power of 595.3 W, toluene conversion efficiency of 94%. It has certain guiding significance.

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