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The design of medical micro atomization device based on piezoelectric actuators

Haimin ZHOU[1], Liping Shi[2], Jiliang Tan[3] and Shuai Huang[4]

Heilongjiang University, Harbin 150080, China

[2]shlp1971@163.com(corresponding author), [3]Tanjil @163.com(corresponding author)

[4]2264171455@qq.com (corresponding author)

Abstract. In this paper, there is much demand for more advanced inhaled drug treatment on respiratory diseases treatment, so we design and manufacture a kind of medical micro atomization device based on piezoelectric actuators. In the experiment, the first measuring method we used is the diameter of the fog particles compare with quartz round bead in 1 micron. The second measuring method is weighing bibulous desiccant. The experimental results show that the fog particles produced by micro atomization device is 3 ~ 4 microns in diameter, and fog particles rate is 0.07 ~ 0.08 g/min. These data basically meets medical micro atomization device design requirements for the diameter and flow rate of fog particles on respiratory diseases treatment.

1. Introduce

The medical treatment method of Inhaled drugs in recent years has become a more commonly used treatment of respiratory diseases[1-4]. Glancing through the literature of recent years [5-9], It is a very important drug delivery without injection, faster drug effect, less side effects. Avoiding pain of injection to the patient's body, it is more and more extensive application in clinic. With the aid of atomization device, reagents is scattered in fog particles.
dresses, numbered superscripts should be used after

2. Principle

In this paper, the principle of medical micro atomization device is by driving piezoelectric wafer form the high frequency vibration. When the ultrasonic wave overcome the liquid surface tension, with the help of a micro porous plate extrusion, liquid will break, it can produce 1 ~ 5 microns in diameter fog particles.

In this paper, design of medical micro atomization device structure is shown in figure 1. It is mainly made of cover sheet, sealing ring, tank, micro porous plate atomization, the sealing ring and bracket.structure of tank is heavy metal material, such as 45 steel. Micro porous plate atomization is made of light metals, such as copper. Groove and cover sheet are connected with sealing ring. This structure can not only ensure the consistence of device, but also guarantee the flexibility of micro porous plate with atomization. Micro porous atomization plate in the axial polarization mode, this way fully use the characteristics of the atomization ring oscillator in longitudinal vibration, the mechanical coupling coefficient is higher, so the higher piezoelectric conversion efficiency can be obtained. The structure of the micro porous atomization plate as shown in figure 2, it consists of thin micro porous plate and annular piezoelectric ceramics.

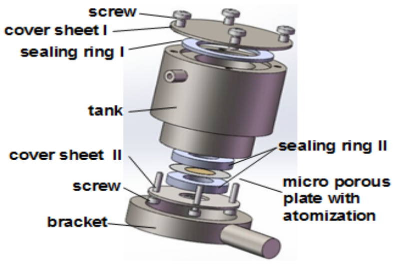

Figure 1. Device structure

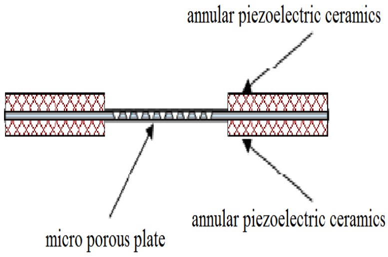

Figure 2. The structure of the micro porous atomization plate

When the piezoelectric ceramic is applied a certain frequency sine excitation, the annular piezoelectric ceramic vibratory direction is its polarization direction and thickness direction. The micro porous plate will also do the axial vibration of high frequency, liquid sprayed as micro porous plate axial vibration through hole, which implements the liquid atomization. The micro porous plate in front of micro atomization device is made of copper, and there are many uniform distribution micro holes on it. The liquid is sprayed from the big hole into from the small hole, the diameter of the small holes range from 3 to 5 microns.

The micro porous atomization plate in the process of high frequency vibration, the gas runs into the liquid tank from outside world every time, the gas existing in the liquid tank will not only affect micro porous plate contact with the liquid, also can reduce the performance of transducer. Therefore, we can use a structure as shown in figure 3. The liquid will be from a line into the tank, which forms a one-way route. The peristaltic pump feeds liquid on-demand, so that the micro atomization device can continuously work.

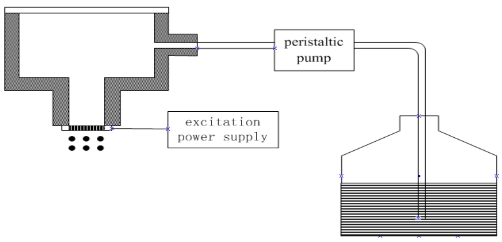

Figure 3. The feed liquid process of micro

The quality of micro atomization device is generally related to the droplet diameter size, the dispersity of particle and flow velocity. The diameter of the droplets is an important parameter of atomization quality, and the fog particles diameter is associated with many factors[8]. According to the forming process of droplets, the droplet diameter is shown in Eq. 1.

$$d = \eta \bullet \left(\frac{3vD^2}{2f}\right)^{\frac{1}{3}} \tag{1}$$

Where v is the velocity of droplet through micro porous, D is micro hole diameter, fis the frequency of piezoelectric transducer. ηis an important parameter related to fluid density, viscosity and surface tension. In general, the greater the amplitude of micro porous plate, the larger micro hole diameter, the more uniform distribution micro holes, atomization efficiency is higher; the smaller micro hole diameter, the greater the driving frequency of transducer, the greater micro porous plate vibration frequency, droplet diameter is smaller. Micro porous atomization plate work most effectively in the resonance point, meanwhile the amplitude of it is largest.

3. Finite element analysis of micro porous atomization plate

3.1. Parameter Settings

ANSYS13 is used for simulating coupling effect of piezoelectric ceramics in this experiment. First, we need to define material properties of piezoelectric materials and geometric properties. Micro porous plate using alloy steel, and piezoelectric ceramic is PZT-8A, the parameters of the material shown in table 1:

Table 1. The material and parameters of micro porous atomization plate

	Mcro porous plate(copper)	Annular piezoelectric ceramic (PZT-8A)
density（$10^3kg/m^3$）	7.5	8.92
young modulus（GPa）	108	7.2
poisson ratio	0.35	0.29

According to piezoelectric materials in mechanical freedom and the stress of short circuit, electric equation Eq. 2 and displacement equation Eq. 3 are shown below.

$$S = sT + dE \tag{2}$$

$$D = cT + \varepsilon E \tag{3}$$

Eq. 4 can be obtained from the above equation.

$$\begin{Bmatrix} \{S\} \\ \{D\} \end{Bmatrix} = \begin{bmatrix} [s] & [d] \\ [c] & [\varepsilon] \end{bmatrix} \begin{Bmatrix} \{T\} \\ \{E\} \end{Bmatrix} \tag{4}$$

Where, s piezoelectric smooth coefficient matrix, d piezoelectric strain coefficient matrix c stiffness coefficient matrix, dielectric constant matrix. The specific parameters are as follows:

$$c = \begin{bmatrix} 13.2 & 7.3 & 7.3 & 0 & 0 & 0 \\ 7.3 & 13.2 & 7.3 & 0 & 0 & 0 \\ 7.3 & 7.3 & 11.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2.6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2.6 \end{bmatrix} \times 10^{10} Pa \tag{5}$$

$$e = \begin{bmatrix} 0 & 0 & -4.1 \\ 0 & 0 & -4.1 \\ 0 & 0 & 14.1 \\ 0 & 10.5 & 0 \\ 10.5 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} C/m^3 \tag{6}$$

$$\varepsilon = \begin{bmatrix} 804.6 & 0 & 0 \\ 0 & 804.6 & 0 \\ 0 & 0 & 659.7 \end{bmatrix} \times 10^{-9} F/m \tag{7}$$

3.2. Modeling and simulation

In order to facilitate ANSYS 13 modeling and simulation, the structure of micro porous plate can be simplified from figure 2. Because the model has good symmetry, we can use a quarter of the model, structure simplified diagram is shown in figure 4. H is the thickness of the piezoelectric ceramic, and h is micro porous plate thickness. R is the radius of micro porous plate, and r is the radius of the center area of micro porous plate. R, r, H, h, are 10mm, 6mm, 0.3mm and0.3mm.

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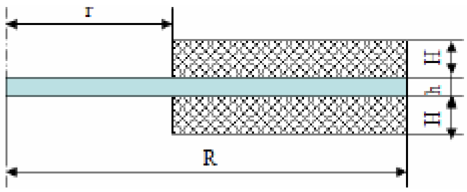
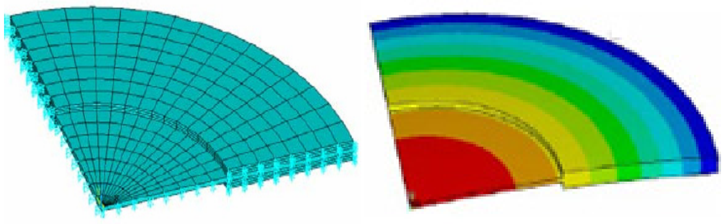


Figure 4. Simplified structure

ANSYSY13, piezoelectric ceramic is selected for unit Solid5, piezoelectric ceramic micro porous plate chooses unit Solid45. Two piezoelectric ceramic rings are the same polarity. When they connect with circuit, micro porous atomization plate is vibrating. We proceed with finite element analysis about the piezoelectric coupling.

First, full constraints imposed on the boundary of the model, as shown in figure 5(a), CYLIND instruction in ANSYS can generate model. Then, post-processing is collecting calculated results. By using general processor (POST1), we observe the vibration form of micro porous atomization plate. When piezoelectric ceramic is supplied by 5 v electric field, the result is shown in figure 5-b. Micro porous atomization plate changes shape under the action of electric field, the maximum amplitude location is the center area of micro porous atomization plate.



(a)model (b)structural deformation

Figure 5. Model analysis in ANSYS

For resonance frequency of micro porous atomization plate, we need to implement harmonic response analysis, which analyze the forced vibration of linear structure and dynamic behavior connection with time. The displacement of the structure changed with frequency response curve is shown in figure 6. Micro porous atomization plate has the largest amplitude in the frequency 105 KHZ, then this frequency is resonance frequency of micro porous atomization plate.

4. The experimental research of micro porous atomization plate

4.1. Space considerations

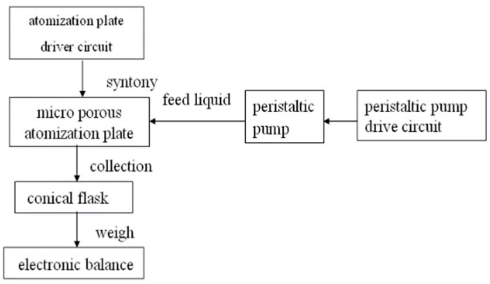


Figure 6. The experimental flow graph of medical micro atomization device

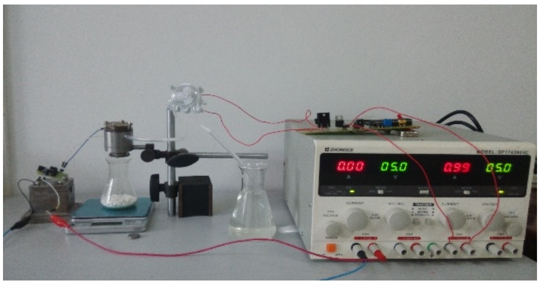


Figure 7. TThe whole experiment platform of medical micro atomization device

The equipments and materials are used in this experiment as follow: micro porous atomization plate, DC regulated power supply, electronic balance, conical flask, bracket, atomization plate driver circuit, peristaltic pump, peristaltic pump drive circuit.

The experimental flow graph of medical micro atomization device is shown in figure6. We select power supply producing 5 V, 105 KHZ as the resonant frequency of medical micro atomization device. Peristaltic pump driving circuit control liquid flow rate, for maintaining the stability of device internal level. Conical flask with desiccant can rapidly collect fog particles, preventing overflow, ultimately it provides timely and accurate measurement of electronic balance. The whole experiment platform is shown in figure 7.

4.2. Fog particles diameter measurement

The size of fog particles is an important droplets quality index. Because of the diameter of fog particles under test between 1 ~ 10 microns, we use optical tweezers microscope system, the fog particles are sprayed on glass slides with lots of quartz round beads. Theses beads are fused silica beads in deionized water, 1 micron in diameter, used in fog particles diameter measurement comparison.

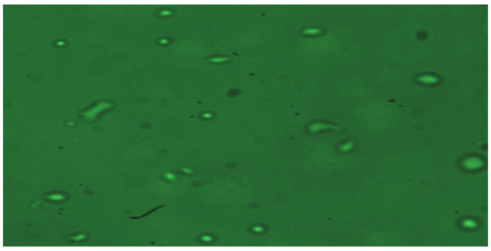


Figure 8. Fog particles imaging in the optical tweezers microscope

Fog particle shapes as shown in figure 8, some regular shapes are the fused silica round beads. By pixel scale measurement, we select 500 fog particles to measure the diameter of them and count the number of them.

Because the diameter of fog particles on glass slides is not the actual one, fog particles diameter data need be fixed through measured parameters. Finally, we get the fog particle diameter distribution in table 2, the following conclusions: 1 to 2 microns (5.4%), 2-5 microns (83.4%), 5-8 microns (11.2%). Fog particles diameter data basically meets medical micro atomization device design requirements.

Table 2. Fog particles imaging in the optical t

diameter (μm)	<1	1~2	2~3	3~4	4~5	5~8
amount	3	24	105	185	127	56

4.3. Flow rate measurement

Nozzle gets close to the conical flask in measurement, but they should not have touch with each other. Hob fix nozzle, and there is a conical flask equipped with CaCl2 powder above the electronic balance. the liquid that nozzle spray is purified water. Because CaCl2 powder has strong moisture absorption, it can be used to absorb the fog particles from nozzle. CaCl2 constantly absorbs fog particles, which makes its own weight increasing in the whole spray process. This dynamic change process can be displayed on the screen in the electronic balance.

In figure 9, blue curve represents amount of atomization in different time, the red curve represents the flow rate in different time. In the whole process of spraying, the spray quantity is steady rising, and there is no a big fluctuation. However, the flow rate has a big fluctuation in the first 2 min, and there is a peak flow rate in 1 min. it may be that nozzle starts work but liquid did not fill with the tank, the greater the amplitude of micro porous atomization plate, the higher the atomization efficiency. After filled with fluid, the amplitude of micro porous atomization plate stabilizes, nozzle atomizing rate is becoming more stable, and the flow rate was 0.07 ~ 0.08 g/min.

5. Conclusions

We design and manufacture a kind of medical micro atomization device in this paper, by introducing its structure and working principle. Using the function of modal analysis and harmonic response in ANSYS software, we analyze the work form of micro atomization device, so as to find that the resonant frequency of micro atomization device work is 105 KHZ. The experimental results show that the fog particles produced by micro atomization device is 3 ~ 4 microns in diameter, and fog particles rate is 0.07 ~ 0.08 g/min. These data basically meets medical micro atomization device design requirements.

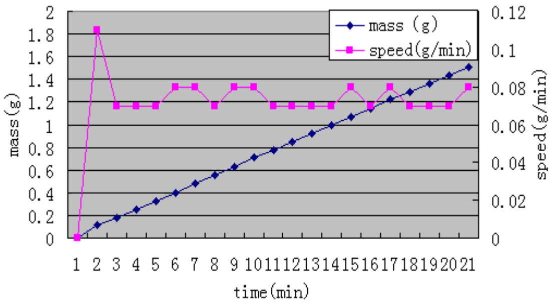


Figure 9. The curve graph of amount of atomization and flow rate

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