Influence of 80-mesh Traditional Chinese Medicine Particle Stack Thickness on Percolation Performance

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Abstract. In order to research the influence of 80-mesh traditional Chinese medicine particle characteristics and particle stack thickness on percolation performance, wire screen was used to carry out filtration by the vibratory action of oscillator, screen No. and screen pore size were recorded and weight of screen residue was measured, so as to calculate average distribution density of particles, distribution function of particle size, form factor and specific surface area of particles. Percolation pressure drop was utilized as the index to evaluate percolation performance. Ethanol solution at 20℃ with volumetric concentration of 47% was selected as percolation solution to measure and calculate the percolation pressure drop when ethanol solution flowed through 100mm, 150mm, 180mm, 250mm and 300mm 80-mesh particle layer. The results showed that percolation pressure drop is proportional to particle stack thickness, and it is high relatively due to the small size of 80-mesh particle, which shall result in high energy consumption of percolation system.

1. Introduction
An important process in industrial production of traditional Chinese medicine preparation is extraction and separation of its effective composition, which directly influences the quality, curative effect and production rate of the medicine. Percolation is a dynamic leaching process, which is one of effective methods to extract medicinal materials and is characterized by high utilization rate of solvent, preferable leaching result of effective component, direct collection of leachate, etc.

During percolation, the solvent flows through traditional Chinese medicine powder which is similar to the process of liquid flowing through particulate bed layer. Literature [4] and [5] selected the percolation process parameters of earthworm and tincture of golden flowers respectively, the results showed that for two kinds of traditional Chinese medicine components, it achieved the best percolation performance when the medicine was smashed to coarse powder and mid-coarse powder, respectively. Literature [6] researched the process to percolate dried tangerine peel in Huoxiang zhengqi liquid, the result showed that it achieved the best performance when specific surface size of the medicine powder was 0.5cm×0.5cm. Literature [7] researched the pressure drop when single-phase and gas-liquid two-phase fluid flowed through porous bed layer which was composed of spheres with multiple sizes and irregular sand grain. In conclusion, medicine powder bed layer characteristics not only have influenced percolation effect, but also affects the pressure drop and energy consumption during percolation.

In this paper, average distribution of particle size, distribution function of particle size, form factor and specific surface area of 80-mesh traditional Chinese medicine powder was measured and
calculated, so as to research the influence of medicine powder bed layer characteristics as well as particle stack thickness on percolation pressure drop, and to provide theoretical basis for percolation separation and extraction process of effective component in traditional Chinese medicine.

2. Percolation Process and Pressure Drop Analysis

During percolation process of medicine powder, medicine materials which have already been suitably smashed are placed in percolator, solvent which is added continuously from the top of percolator flows downstream the percolator and penetrate the medicine layer. Meanwhile, effective component in the medicine material is leached out and leachate was generated. In order to fully extract and separate effective component in the medicine material, the contact surface between medicine material and the solvent should be increased as far as possible. Theoretically, the finer the medicine material is smashed, the bigger the contact area, and the better the leaching effect. Meanwhile, if medicine powders are not filled uniformly or they are distributed loosely, which result in too many and too large pores inside medicine powder layer, the solvent shall flow rapidly through pores and flow out of medicine powder layer during percolation, which shall result in a large consumption of solvent and incomplete percolation[8]. However, the finer the material powder, the larger the specific surface area of medicine powder and the percolation pressure drop. This shows that the factors above restrict and supplement each other which have important impact on percolation process especially the percolation pressure drop.

Percolation process of traditional Chinese medicine is similar to fluid flowing through fixed particulate bed layer. According to Darcy filtration equation and Carman-Kozeny function:

$$\frac{\Delta P}{L} = K' \left(1 - \frac{a^2}{\varepsilon^3}\right)^2 \mu \frac{u}{\varepsilon}$$

(1)

Where, \(\Delta P\) is pressure drop when fluid flows through particulate bed layer, Pa; \(L\) is particle stack thickness, m; \(K'\) is Carman-Kozeny constant and it is taken as 5.0; \(a\) is specific surface area of particle, \(m^2/m^3\); \(\varepsilon\) is porosity of particulate bed layer, %; \(\mu\) is dynamic viscosity of fluid, Pa·s; \(u\) is flow speed, m/s. Carman-Kozeny function is applied to the situation with low Re (<2). It can be seen from above function that factors affecting percolation pressure drop mainly include operating variable \(u\), physical property of fluid \(\mu\) and \(\rho\), characteristics of particulate bed layer \(\varepsilon\) and \(a\). During actual production, fluid status is almost stable. Therefore, the characteristics of medicine powder bed layer affecting percolation pressure drop include particle distribution of medicine powder, specific surface area and stack thickness in this paper.

3. Measurement of Medicine Powder Characteristics

Wire screens with different level were used to carry out filtration by the vibratory action of oscillator, screen No. and screen pore size were recorded and weight of screen residue was measured. Initial total weight of powders was 500g. The results are shown in Table 1 as follows.

| Screen No. | Screen Pore Size (mm) | Screen Residue (g) | Mass concentration of Screen Residue (%) |
|------------|-----------------------|--------------------|-----------------------------------------|
| 80         | 0.175                 | 22                 | 4.4                                     |
| 100        | 0.147                 | 43                 | 7.4                                     |
| 115        | 0.124                 | 131                | 30.1                                    |
| 150        | 0.104                 | 65                 | 21.4                                    |
| 170        | 0.088                 | 36                 | 15.1                                    |
| 200        | 0.074                 | 20                 | 9.1                                     |

In order to analyze particle size distribution, particle size distribution function and frequency function are utilized to describe. Distribution function \(F_i\) is defined as the ratio of screen residue on a kind of screen in total mass of particles. Frequency function \(F_i\) expresses average distribution density of particles when particle size is within the range of \(d_{i-1} \sim d_i\):
Where, $x_i$ is the percentage of particles above screen (residue) in total mass of particles. According to measurement results in Table 1, particle size distribution function and frequency function of 500g 80-mesh particles are shown in Figure 1 and Figure 2, respectively.

\[
\bar{f}_j = \frac{x_j}{d_{j-1} - d_j}
\]  

(2)

\(\sum \) \(d_m \) \(x_m \)

Diameter of particle medicine between two adjacent screen is assumed as \(d_m\), then average diameter of actual average diameter \(d_a\) is:

\[
d_a = \frac{1}{\sum \frac{x_m}{d_m}}
\]  

(3)

Because medicine powder is 3D irregular particle, simplified model should be set up to research its physical property. Cylindrical particle model is a kind of common form\(^9\), which defines shape coefficient \(\psi\) of medicine particle as follows:
\[ \psi = \frac{\text{specific surface area of sphere with the area equal to cylinder}}{\text{specific area of cylinder}} \]  

For non-spherical particle, specific surface area \( a \) is:  

\[ a = \frac{6}{\psi \cdot d_m} \]  

According to measurement and calculation results, average particle diameter \( d_m \), factor coefficient \( \psi \) and specific surface area \( a \) of particle are derived as follows:

**Table 2. Equivalent Characteristics of 80-mesh Fine Powder**

| \( d_m \) (mm) | \( \psi \) | \( a \) (m\(^2\)/m\(^3\)) |
|-----------------|-----------|-----------------------------|
| 0.1724          | 0.8255    | 48811.5                     |

4. Measurement of Medicine Powder Bed Layer Porosity

Porosity is defined as the ratio of pore volume to total volume of particle bed layer, which describes stack density of particles in the bed layer. In the experiments, porosity of 80-mesh fine powder at different stack thickness were measured. Actual method are described as follows:

1. Take a 500mL graduated cylinder and get the weight of it by scale. Take 80-mesh fine powders into it, powder stack thickness is 100mm, 150mm, 180mm, 250mm and 300mm.

2. Get the total mass of graduated cylinder at five different stack thickness, deduct the mass of graduated cylinder itself and then obtain the mass of medicine powders. Record volume of medicine powders at the same time.

3. According to mass and volume of medicine powders, calculate the density \( \rho \) at five different stack thickness, and get the density \( \rho_0 \) of medicine materials which have not been smashed. Then, porosity of medicine powder bed layer at five different stack thickness are calculate according to Equation (6) and the results are shown in Table 3.

\[ \varepsilon = 1 - \frac{\rho}{\rho_0} \]  

**Table 3. Porosity of 80-mesh Fine Powders at five different stack thickness (%)**

| Stack Thickness (mm) | 100  | 150  | 180  | 250  | 300  |
|----------------------|------|------|------|------|------|
| Porosity             | 48.75| 48.70| 48.64| 48.62| 48.55|

It can be seen from Table 3 that porosity of 80-mesh fine powder bed layer is large relatively, because the finer the powder smashed, the larger the porosity. 80-mesh particle size distribution is uniform, small particle cannot be embedded into the pores among large particles, insertion and overlapping phenomenon between particles are minor, which shall stabilize the total porosity of bed layer. Furthermore, porosity of medicine powder bed layer decreased gradually with the increase of particle stack thinness, this is due to low hardness and variable form of particle. When stack thickness increases, the action of gravity is larger, the bed layer is compressed to a certain degree, which shall decrease the porosity.

5. Results and Discussion on Percolation Pressure Drop

According to actual production process, ethanol solution at 20°C with volumetric concentration of 47% was selected as percolation solution, dynamic viscosity of the solution is 0.00287Pa·s. The solution flowed out of spray equipment at the constant flow rate of 20mL/min. By measurement and calculation, flow rate of ethanol solution through 80-mesh fine powder bed layer was 4.08×10\(^{-6}\)m/s. Particle stack thickness was 100mm, 150mm, 180mm, 250mm and 300mm, respectively. Theoretical percolation pressure drop calculation results at five kinds of stack thickness are shown in Figure 3 (based on Carman-Kozeny function):
It can be seen that percolation pressure drop increased linearly with the increase of particle stack thickness. However, although medicine material is smashed to fine particles which can increase the contact area between solvent and the powder bed layer, so as to improve extraction and separation efficiency of effective component in traditional Chinese medicine, percolation pressure drop is too large which shall result in extremely high energy consumption of percolation system due to too small particles.

Therefore, effective measures shall be taken to reduce percolation pressure drop as far as possible under the premise of improvement of extraction and separation efficiency of effective component in traditional Chinese medicine, so as to reduce energy consumption of percolation system, such as multi-layer modularized percolation system. In such system, the total percolation thickness is divided into multiple small stack thickness\cite{10}, which can achieve high-efficiency and energy-saving percolation process for fine powder bed layer.

6. Conclusions
For a kind of traditional Chinese medicine prescription, screening experiments were carried out for 80-mesh medicine powders, particle size distribution function and frequency function were measured and calculated. Based on the principle of equal specific surface area, average diameter, form coefficient and specific surface area of 80-mesh particles were calculated respectively. Furthermore, porosity of medicine powder bed layer at five different stack thickness was measured, percolation experiment by ethanol solution was carried out. Following conclusions are brought out:

(1) Because 80-mesh powder was smashed to be fine particles, the particle diameter distribution is uniform, insertion and overlapping phenomenon between particles are minor, which results in large porosity.

(2) Due to low hardness and variable form of particles, when powder stack thickness increases, the action of gravity is larger, the bed layer is compressed to a certain degree, which decreases the porosity.

(3) Percolation pressure drop during the extraction of effective component in 80-mesh medicine powders is relatively high at the five different stack thickness, which shall lead to high energy consumption of percolation system.

(4) In order to improve the extraction and separation efficiency of effective component in traditional Chinese medicine, and meanwhile to lower percolation pressure drop as far as possible so as to reduce energy consumption of percolation system, multi-layer modularized percolation system may be applied.
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