

Numerical Simulation of Stacked Step Flow in Centrifugal Force Field for Copper Ore Separation

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Abstract: In this study, the flow field of a stacked step flow device was simulated using Fluent 19.2 software. The simulation results show that: the combination of rotational motion and reverse fluidization of the fluid in the cone of the equipment makes the slurry dispersed and separated in the radial direction, and the upward motion of the fluid can promote the solid phase, especially the smaller particle size and lower density of the silica phase, to realize the separation of the copper phase and the silica phase in the axial direction; the vortex generated by the sudden change of tangential flow velocity at the step can significantly improve the settling efficiency of the copper phase in the upward process. Fluent simulation results show that: when the rotational speed is 50r/min, the feed speed is 0.5m/s, and the reverse fluidization speed is 0.018m/s, the copper recovery rate is 87.70%, and the enrichment ratio is 13.45.

Keywords: Numerical simulation; gravity beneficiation; centrifugal separation.

1. Introduction

Mineral resources are non-renewable and important energy sources that provide the vast majority of energy and industrial raw materials for human beings [1-2]. According to China Mineral Resources Report 2021, China owns 173 kinds of minerals, but compared with the world, China's per capita mineral resources reserves are relatively small. Due to industrialization, China has a high demand for bulk metals such as copper, while copper reserves are small. Copper has a wide range of applications in military, construction and mechanical fields [3-4], China's copper resources as a whole show a lower grade [5], more concentrated distribution, mainly concentrated in Yunnan, Tibet, Qinghai, Sichuan, Jiangxi and other provinces. Re-election method in the separation method due to high efficiency, low cost, no pollution and other advantages, in the mineral processing industry gradually promoted. Centrifugal concentrator among the gravity separation equipment is the popular gravity separation equipment nowadays. It is to amplify the density difference between different ore particles in the pulp by expanding the gravity force applied to the pulp, so as to sort the pulp more effectively. Nelson and Falken are the most representative centrifugal concentrators, which are widely used because of their good sorting effect, wide applicability and high processing capacity [6-7]. However, these two types of equipment are difficult to realize continuous ore discharge because of the limitation of the inner cone structure, resulting in low efficiency of the sorting operation. Therefore, the research on new structure beneficiation devices is the key to the continuous development of the mineral processing industry. The re-election device in this study is designed for the centrifugal concentrator that cannot discharge the ore continuously [8-9]. When the mineral particles are centrifugally sorted, the heavy particles plate in the enrichment tank due to the high centrifugal force, which affects the sorting efficiency. Instead of the centrifugal force generated by the rotation of the cylinder of the existing

centrifugal device, the agitator rotation is used, and the agitator and the crescent-type perforated spacer, as the key components in this equipment, which provide the energy required for the agitation process and a suitable flow field for mineral sorting [10]. Therefore, it is crucial to determine reasonable operating parameters operating parameters, when improving the sorting efficiency. In this study, FLUENT software in CFD package is utilized to simulate this gravity sorting equipment and derive the reasonable operating parameters.

2. Numerical Simulation Model

Stacked step flow sorting device as shown in Fig. 1 mainly consists of tailings outlet, crescent shaped perforated partition, reverse inflow port, concentrate outlet, stirring paddle, inlet, separating disk and other parts.

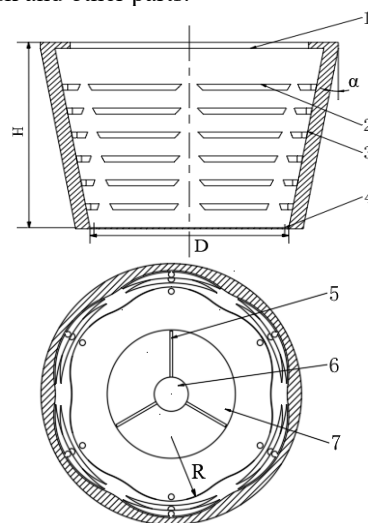


Figure 1. Cross section of stacked step flow model
1-tailings outlet, 2-crescent-shaped perforated partition, 3-reverse inflow,
4-concentrate outlet, 5-stirring paddle, 6-inlet, 7-dividing disk

The model is an inverted cone, with a concave and protruding step flow linear inside the cone, crescent-shaped perforated partitions are uniformly set at each concave and reverse inflow ports are opened at each layer of the partition, the inlet is located in the middle and lower part of the inner cone, the distributing disk is set directly under the inlet, the tailings outlet is located at the top of the inner cone, and the concentrate outlet is located at the edge of the bottom of the inner cone. Its main structural parameters are shown in Table 1.

Table 1. Main structural parameters of sorting cone

name (of a thing)	parameters
Height of sorting cone H	155mm
Taper α	10°
Bottom Diameter D	150mm
Step radius R	45mm
Step height	10mm
Number of steps	6
Partition Layers	6floors
Number of reverse flow layers	6floors
Reverse flow seam width	1mm

2.1. Mesh generation

To facilitate the simulation using the MRF method, the interior of the device is divided into two zones: the stirrer and the zone close to the stirrer are the dynamic zone, and the other zones in the interior are the static zones[11]. A hexahedral mesh is used to divide the internal region of the device[12], with about 6.1×10^6 mesh nodes, and the mesh is divided as shown in Fig.2.

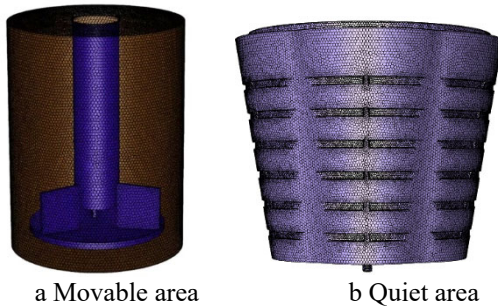


Figure 2. Grid delineation of dynamic and static regions of the stacked step flow basin

2.2. Simulated material system

The calculated material system in the equipment is a water ($\rho = 998 \text{ kg/m}^3$, $\mu = 1 \text{ mPa}\cdot\text{s}$)-copper-silica three-phase system. Copper particles and silica particles were used to represent heavy and light particles, respectively, where the density of copper was 8960 Kg/m^3 and 2200 Kg/m^3 , the particle size was $74 \mu\text{m}$, and the sorting medium was water. The solid-liquid ratio was set to 80% water, 19.93% silica and 0.07% copper.

2.3. Setting of the reference system and boundary conditions

In order to deal with the flow within the stirring zone, the multiple reference system method [13-14] is adopted in this study. The computational area is divided into two main parts:

one part covers the rotating agitator, while the other part is the immobile tank. To perform the calculations, two different reference coordinate systems were used for each of these two regions. The rotating agitator region uses a rotating reference system, while the stationary tank region uses a stationary reference system. In order to match the velocities between these two regions, a velocity transformation is performed by applying an interpolation process on their intersecting surfaces[15]. The specific velocity conversion is described by the following equation:

$$v = v_r + \Omega \bullet r \quad (1)$$

Where v is the velocity in the stationary reference system, m/s; v_r is the velocity in the rotating reference system, m/s; and Ω is the rotating angular velocity, radians/s.

Wall boundary conditions: The agitator, feed pipe and tank wall in the model are set as wall boundaries. For the treatment of flow calculation in the near-wall region, the wall function method is used.

Inlet boundary conditions: the fluid in the device is a low velocity unpressurized flow, so the velocity inlet is used. Inlet turbulent kinetic energy, turbulent dissipation rate is calculated by the formula (2)

$$K = \frac{3}{2}(uI)^2$$

$$K = C_\mu^{\frac{3}{4}} \frac{K^{\frac{3}{2}}}{I} \quad (2)$$

where K is the turbulent kinetic energy per unit mass, m^2/s^2 ; ε is the turbulent dissipation rate per unit mass, $\text{J}/(\text{kg}\cdot\text{s}^3/\text{m})$; u is the turbulent mean velocity, m/s; and I is the turbulence intensity; $C_\mu = \kappa - \varepsilon$ Model parameters.

Outlet boundary conditions: overflow, underflow outlet using pressure outlet boundary

2.4. Selection of solver and computational parameters

Two types of solvers, separated and coupled, are provided in the Fluent software[16]. The separated solver is mainly used for incompressible or slightly compressible flow, while the coupled solver can be used for high velocity compressible flow. The fluid in this research equipment is a low velocity incompressible flow, so the separated solver implicit scheme is chosen for solving.

3. Simulation Results and Analysis

3.1. Effect of stirring speed on sorting

The other parameters in the simulation process are unchanged, and the effect of different rotational speeds of the stirrer on the separation effect of the copper phase is investigated. the distribution of the copper phase at $Z=40$ is shown in Fig.3, the pressure distribution of the internal flow field is shown in Fig.4, and the curve of the recovery rate is shown in Fig.5.

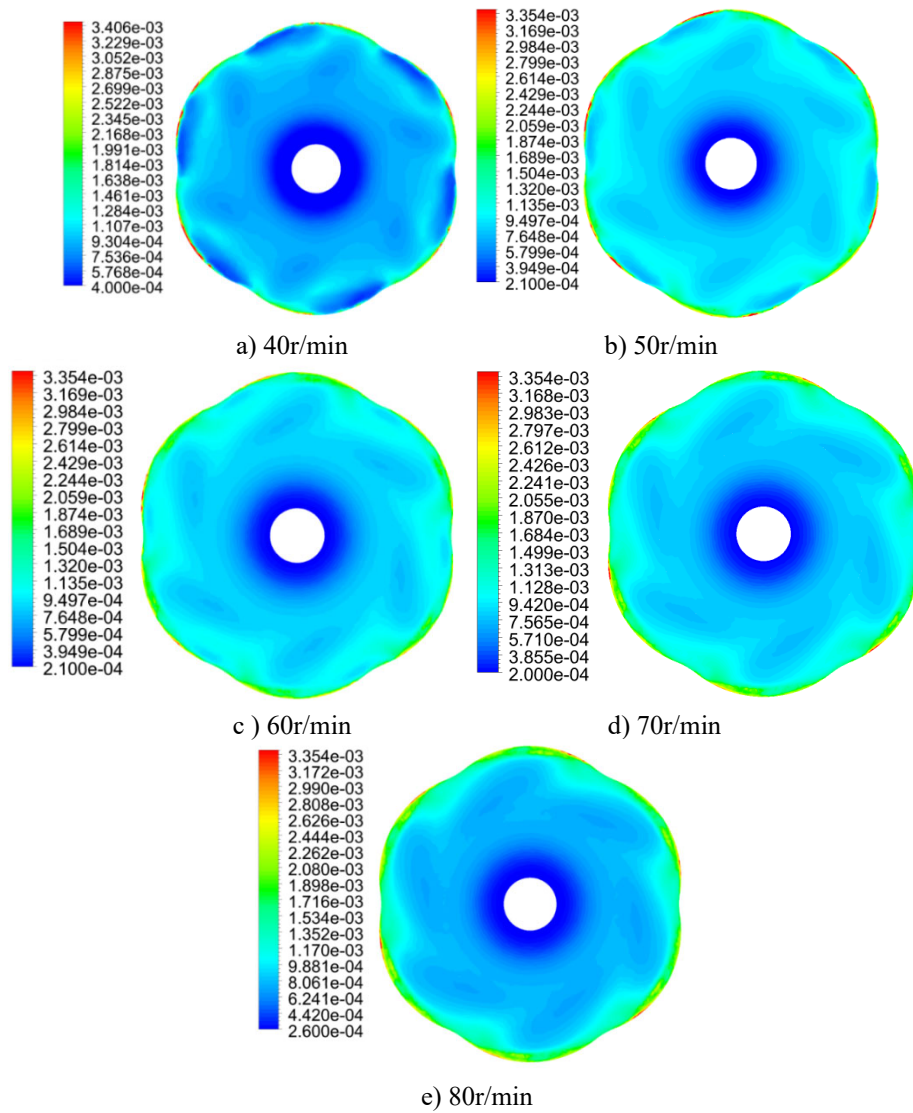


Figure 3. Cloud diagram of the effect of rotational speed on the volume fraction of heavy particles

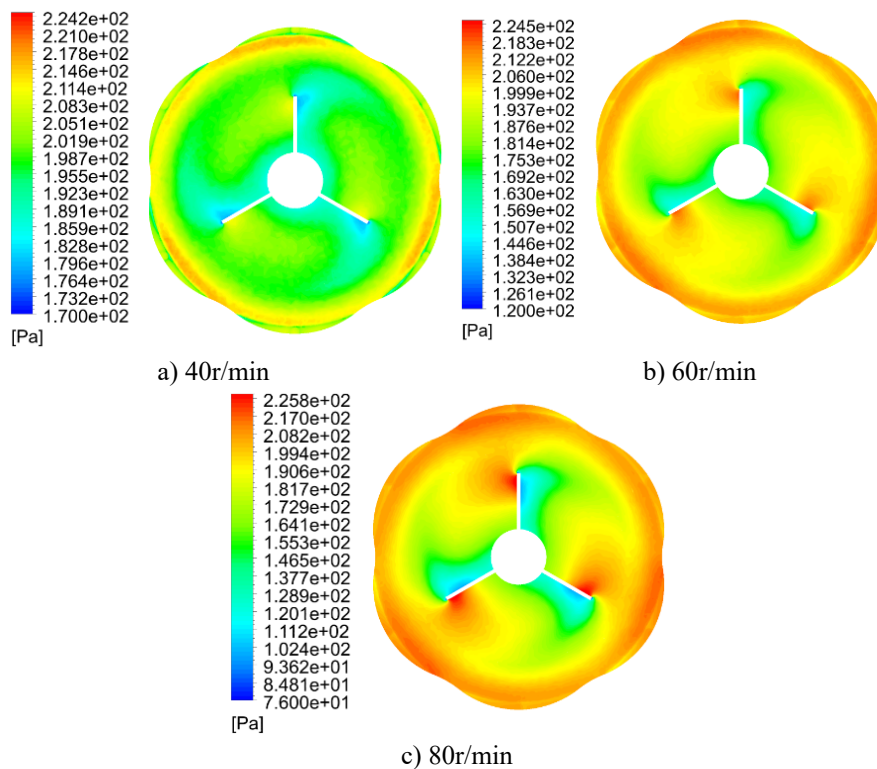


Figure 4. Cloud diagram of pressure distribution

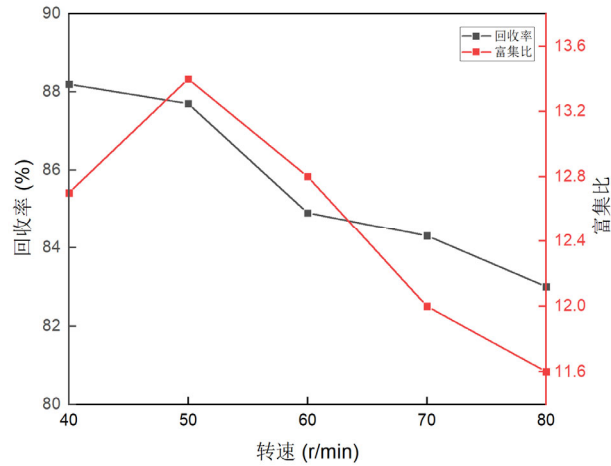


Figure 5. Effect of rotational speed on the recovery and enrichment ratio of heavy particles

As can be seen from Figure 3, with the increase of the rotational speed of the center stirring paddle, the volume concentration of the heavy particles shows a gradual tendency to close to the wall, and the thickness of the concentration concentration area gradually increases. When the rotational speed of the center stirring paddle is 40r/min, due to the small centrifugal force on the particles in the flow field, most of the heavy particles are difficult to overcome the reverse force generated by the reverse flow, and can not be close to the wall for sorting, resulting in light and heavy particles can not be effectively sorted; with the increase in rotational speed, the volume concentration of heavy particles near the wall is gradually increasing, and the gradient of the reduction of the volume concentration of heavy particles from the wall to the center is gradually increasing, which is the result of the increase in the volume concentration of heavy particles in the center. As the rotational speed increases, the centrifugal acceleration gradually increases, the heavy particles to overcome the reverse flow generated by the reverse force; when the center of the stirring paddle speed of 80r/min, a large number of heavy particles have been completely close to the wall, at this time some of the heavy particles will be completely overcome the reverse flow generated by the reverse force, will be out of the wall out of the accumulation of the mobility of mineral particles weakened, light and heavy particles are difficult to sort, thus affecting the results of the sorting. This will affect the result of sorting.

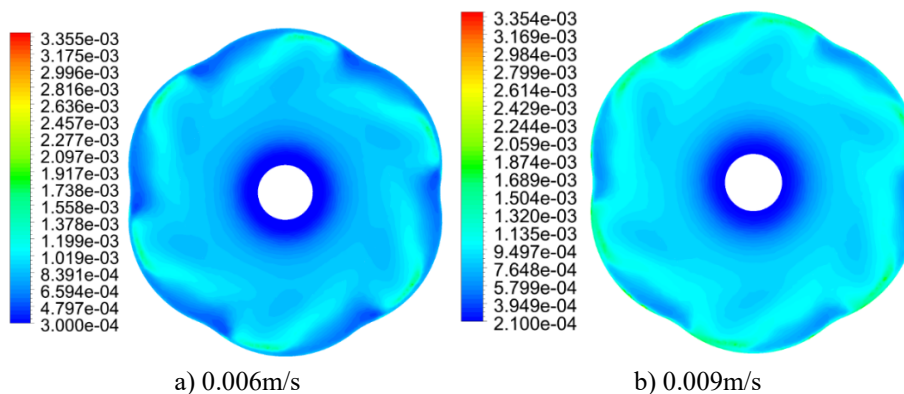
As can be seen from Fig. 4 from the figure, the magnitude of pressure varies at different rotational speeds, but the distribution pattern of pressure is approximately the same. Near the wall, the pressure is the largest, the reason is that the increment of rotation radius, centrifugal force gradually

increases, so from the center to the wall, the pressure value gradually increases. In addition, due to the effect of reverse flow, the location of the maximum pressure is not completely attached to the wall. In the sorting of copper particles, copper and silica particles in the centrifugal force at the same time to the wall movement, when the particles into the reverse flow region, due to the greater density of copper particles, subject to greater centrifugal force; silica particles less dense, subject to less centrifugal force, so the copper particles can better overcome the pressure of the reverse flow, more enriched in the wall, in order to realize the sorting of copper particles.

Comprehensively analyzing the above cloud diagrams of the effect of rotational speed on the volume fraction of light and heavy particles and the recovery curves, the stirring rotational speed is too low or too high, which is unfavorable to the sorting of minerals. According to the calculated enrichment ratio and recovery rate obtained when the rotational speed is 50r/min, the model sorting effect is the best, the recovery rate is 87.70% and the enrichment ratio is 13.45.

3.2. Effect of reverse fluidization rate on sorting

The above simulation results show that the enrichment effect of copper phase is better than other parameters when the stirring speed is 50 r/min. For this reason, the effect of reverse fluidization of stacked step flow model on copper ore sorting is investigated at a speed of 50 r/min and the reverse fluidization velocity speeds of 0.006 m/s, 0.009 m/s, 0.012 m/s, 0.015 m/s, and 0.018 m/s, respectively. Influence. The copper phase distribution is shown in Figure 5.



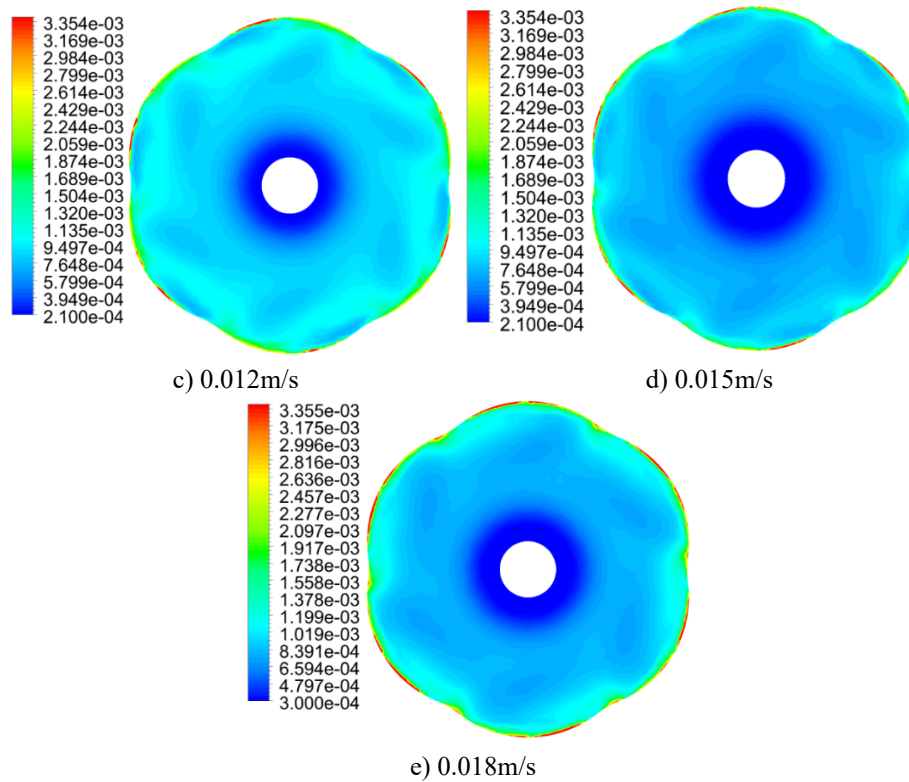


Figure 6. Cloud plot of the effect of reverse fluidization velocity on the volume fraction of heavy particles

From Fig. 5, we can know that the volume concentration of heavy particles is maximum when the reverse fluidization velocity is 0.012 m/s. As the reverse fluidization velocity continues to increase, the volume concentration of heavy particles appears to decrease, the reason for this phenomenon is that the reverse fluidization velocity is too large, so that some of the heavy particles can not overcome the reverse force, along with the light particles with the spiral upward flow from the upper outlet. It shows that too small or too large reverse fluidization speed will affect the sorting effect of the stacked step flow model, therefore, under the premise of maintaining the consistency of the rest of the process parameters, the appropriate reverse fluidization speed can improve the sorting effect of the stacked step flow model.

In order to evaluate the effect of reverse fluidization velocity on the sorting effect in the stacked step flow model, the effect of reverse fluidization velocity on the recovery and enrichment ratio of heavy particles was calculated by counting the mass flow rates of light and heavy particles at the inlet and outlet as shown in Fig. 6.

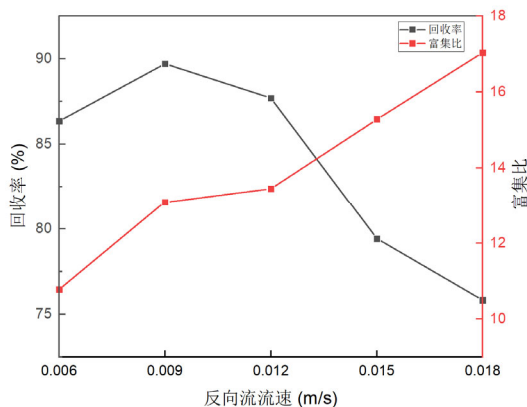


Figure 7. Effect of reverse fluidization velocity on the recovery and enrichment ratio of heavy particles

Figure 7 shows that the recovery of heavy particles increases and then decreases when other parameters are kept constant. The reverse fluidization velocity at which the maximum recovery is reached is 0.009 m/s. Above 0.012 m/s the recovery decreases because the force from the larger reverse flow causes some of the particles to be discharged from the upper opening. The enrichment ratio increases with the increase of reverse fluidization velocity. 0.006m/s velocity, the recovery is high but the grade is low; 0.018m/s, the enrichment ratio is the highest, 17.04%.

4. Conclusion

(1) At the same rotational speed, the pattern of distribution is similar, although the magnitude of the pressure will vary. The pressure is greatest at the wall because the centrifugal force increases with the radius of rotation. However, the maximum pressure is not located directly above the wall due to the presence of reverse flow. In the copper particle sorting process, both copper and silica are subject to centrifugal force and move towards the wall. However, due to the greater density of the copper particles, they can effectively resist the influence of the reverse flow and be enriched at the wall surface, thus realizing the effective sorting of the particles.

(2) The simulation results show that: with the increase of stirring speed, the recovery of heavy particles in the concentrate decreases gradually, and the enrichment ratio increases and then decreases, and the optimal stirring speed is 20 r/min, at which time the recovery rate and enrichment ratio are 87.7% and 13.45%, respectively. With the increase of reverse fluidization rate, the recovery rate of heavy particles in the concentrate first increased and then decreased, but the enrichment ratio gradually increased. At the reverse fluidization rate of 0.0018m/s, the recovery was 75.83%, although lower, but the enrichment ratio reached a high 17.04%.

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