AERODYNAMIC INVESTIGATION OF FLOW IN SPHERICAL CHAMBERS

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Presented are experimental results on swirling air flow in hollow spherical chambers 250 mm in diameter with one inlet and one or two outlet nozzles.

The problem of efficient combustion of high ash coal with high-melting ash is complicated by the difficulty of obtaining a liquid slag. The high melting point of the coal ash requires a considerable increase in furnace temperature, and the high ash content requires the use of a cyclone furnace capable of trapping a large part of the liquid slag.

An increase in the theoretical combustion temperature is one of the main requirements for increasing furnace temperature, although a decrease in heat losses through the chamber walls is no less important.

Recent experience with the operation of furnaces with liquid slag removal shows that the walls must be cooled, since existing materials will not stand the simultaneous action of high temperatures and the corrosive effect of liquid slag. The problem is to minimize the unavoidable heat losses from the cooling agent.

Means of doing this may easily be found by examining the known relation

$$\frac{t_f}{t_{th}} = 1 - \frac{ks}{q_v V_f}.$$

It is seen that the smaller the surface-to-volume ratio of the furnace, the higher the furnace temperature. This ratio is least for a sphere (for equal volumes). For example, the ratio is 14% less for a sphere than for a cylinder with length equal to diameter.

Thus, a spherical furnace is definitely of interest, although its general suitability for practical purposes can, of course, only be assessed after thorough investigation.

Experiments were conducted on a laboratory setup comprised of a hollow spherical chamber 250 mm in diameter, a traversing system, a five-channel measuring probe (sphere diameter 5 mm), and five micromanometers and thermometers for measuring the air temperature at the chamber inlet and in the room.

The model of the spherical chamber was demountable and consisted of three parts: two segments with outlet nozzles 72 mm in diameter and a spherical collar 20 mm tall, upon which was mounted a tangential rectangular inlet nozzle 15 mm high and 30 mm wide. The centers of the outlet nozzles were located on the same vertical line.

The measuring probe was introduced into the upper hemisphere through four horizontal tubes 12 mm in internal diameter and 100 mm long. The spherical collar had a similar fitting. The chamber was mounted in a special support so that surrounding objects did not interfere with the outlet flow. The inlet nozzle had two connections for mounting a thermometer and a pitot tube. The spherical measuring probe was mounted on a traverse system, which allowed it to be traversed continuously in the vertical and horizontal directions and also to rotate about its axis. The probe position was registered by appropriate vernier scales and dials with 1° divisions. Air was supplied to the chamber by means of a blower.

Our chief object was to investigate the velocity and static pressure fields inside the hollow spherical chamber with the air entering tangentially. A test procedure appropriate to this purpose was developed.

The magnitude and direction of the air velocity was determined with the five-channel spherical probe, the use of which is well known [1]. The probe was suitably calibrated before the measurements. The sequence of measurements to obtain the velocity and pressure fields was as follows. The probe was inserted diametrally into the chamber at vertical distances of 35, 60, 90, and 120 mm above and below the "reference" plane (the plane passing through the center of the inlet nozzle).

The inlet velocity was maintained constant at 53 m/sec in all the experiments, this being the maximum possible value for the given blower.

Two types of chambers were tested: with one and with two outlet nozzles. The first was obtained from the second simply by closing one of the outlet nozzles.

As in similar investigations [1-3], the total velocity vector was broken down into three orthogonal components: axial, tangential, and radial. The axial velocity is parallel to the line passing through the centers of the outlet nozzles, the tangential lies in the plane of horizontal sections of the sphere and is perpendicular to the radius in direction, while the radial is directed along the radius.

The air velocity was measured at points 10, 20, 30, etc. mm from the axis of the chamber.

The results of measurements of the velocity components are presented in Fig. 1. The tangential velocity components at corresponding sections are practically identical for the one- and two-nozzle chambers. This is interesting, since the case may be encountered in practice in connection with cyclone chambers with separate outlets for slag and gases that are more suitable than chambers with one outlet nozzle. It may be seen from the figure that the maximum value of the tangential velocity occurs near the wall of the chamber.

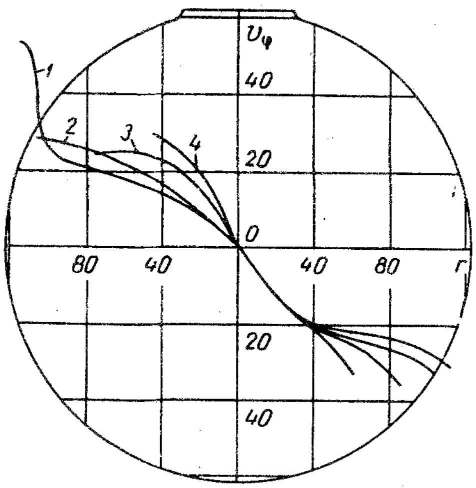

Fig. 1. Tangential velocity in a spherical chamber with one outlet nozzle: 1) in the reference plane; 2) section 60 mm from the reference plane; 3) 90 mm; 4) 120 mm.

Figure 2 shows measured values of the static pressure inside both chambers at the sections z = 0; ±60, ±90 and ±120 mm. It may be seen from the figure that there is a low pressure in the axial region, so that an inflow of air through the central region of the outlet nozzle is observed. The static pressure increases with distance from the chamber axis and reaches a maximum near the wall. Equal values of the static pressure in the central part of the sphere are located on a cylindrical surface that contracts near the outlet nozzles. This is observed in both types of chamber.

It may also be seen from Fig. 2 that the static pressure at corresponding points in the sphere with two outlet nozzles is lower (broken line) than for the sphere with one nozzle (solid line).

The axial velocity in a chamber with one outlet nozzle is shown in Fig. 3, from which it may be seen that on the left of the chamber the air moves both toward the outlet and toward the bottom. On the right the axial velocity is directed only toward the outlet nozzle, except for the near-axial region at the outlet nozzle, where an inflow of air into the chamber is observed. This inflow does not reach the center of the sphere.

An approximately similar picture of external air inflow is observed for the two-nozzle chamber. As far as the rest of its volume is concerned, the axial velocity, which varies along the radius, is directed only toward the outlet nozzle. In the two-nozzle chamber, moreover, the axial velocity field is symmetric relative to the horizontal diameter (due to the symmetry of the chamber itself).

With regard to the radial velocity component, it is generally small and varies within the same limits as the axial velocity. In the near-axial regions at the outlet nozzles, the radial velocity is directed from the axis of the chamber toward the walls. This is a result of the reverse flow in these regions. In the rest of the sphere, the air moves from the wall to the axis.

Investigations show that the aerodynamics of swirling flow in a spherical chamber are in many ways similar to flow in a cylindrical chamber. There are, however, a number of real differences.

The main motion in the chambers in question is rotational, as may be seen by comparing absolute values of the tangential and axial velocity components [1].

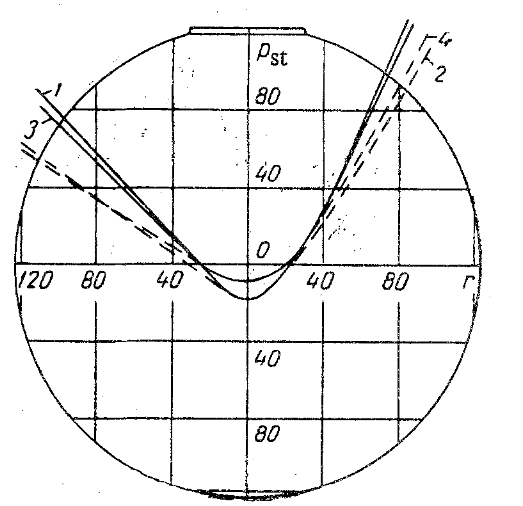

Fig. 2. Static pressure field in the spherical chamber (solid lines – chamber with one outlet nozzle, broken lines – chamber with two): 1 and 2) in the reference plane; 3 and 4) sections 90 mm above and below the reference plane.

There is a difference in the distribution of tangential components. In a cylindrical chamber, as the distance from the axis increases, the tangential velocity at first increases from some value near the wall to a maximum, located approximately on a line passing through the section of the outlet nozzle, and then decreases to zero at the chamber axis. In a spherical chamber, the maximum value of this velocity is located near the wall. In this case the swirl conservation factor, with respect to both the velocity at the wall and the maximum velocity $\varepsilon = v_\varphi / v_{in}$, has a higher value in the spherical than in the cylindrical chamber. In our case its average value for all sections is 0.5, while for a cylindrical chamber with one outlet nozzle ε_{st} = 0.29 [1]. This is a matter of considerable interest, since the intensity of the processes occurring in cyclone systems depends appreciably on the relative gas velocity near the walls.

As may be seen from Figs. 1 and 2, the tangential velocity at the wall increases as one approaches the outlet nozzle, as a result of which the swirl conservation factor also increases, being 0.52 at the section z = ±90 mm. This is significant, since the increase in tangential velocity with simultaneous decrease in radius adds considerably to the centrifugal effect, so that the separation properties of the chamber are improved (especially for liquid ash particles).

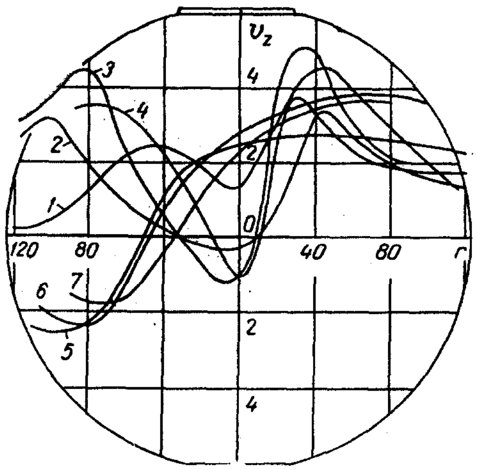

Fig. 3. Axial velocity distribution in a spherical chamber with one outlet nozzle: 1) in the reference plane; 2) section 35 mm above the reference plane; 3) 60 mm; 4) 90 mm; 5) section 35 mm below the reference plane; 6) 60 mm; 7) 90 mm.

Near the axes of both spherical and cylindrical chambers the air rotates with less angular velocity, which is explained by the inflow of air from outside the chamber. The extent of the inflow is, however, appreciably less in a spherical than in a cylindrical chamber.

For example, in a chamber with one outlet, suction extends only over one third of the diameter, while in a cylindrical chamber it reaches the forward end wall. Therefore, in a sphere the amount of air that does not share in the rotation is less than in a cylinder.

The distribution of static pressure in a spherical chamber has been shown to be similar to that in a cylindrical one [1]: there is a pressure maximum at the chamber wall, and low pressure on the axis. In both cases the static pressure does not vary appreciably in a direction parallel to the chamber axis, but the radial variation is much greater.

The spherical chambers that were investigated had outlets in the form of orifices. For this reason there was no "cupping" in the chambers and reverse motion of the air was only weakly expressed.

Conical or cylindrical nozzles at the outlet would evidently create conditions favoring more pronounced reverse motion of the air.

The investigations showed that the use of such nozzles is by no means essential in burning liquid or gaseous fuel. They are necessary only for solid fuel.

NOTATION

t_f – furnace temperature; t_{th} – theoretical combustion temperature; k – heat transfer coefficient; q_V – heat of combustion per unit volume; s – wall area of furnace chamber; V_f – volume of furnace chamber.

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