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SIMULATION OF A THICK-PART INJECTION MOLD

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OVERVIEW

Polymer injection molding of high quality parts requires careful attention to the design of the die systems used to fabricate the parts. Experience has demonstrated that die filling characteristics can have important consequences on the quality of the final product. For instance, the presence of thick regions in an otherwise thin-walled die can lead to the entrapment of air or incomplete filling of the die. Another problem is associated with asymmetric die filling conditions that leave residual stresses causing warping during solidification.

In this note we propose a test case for a thick-walled injection molding die. It is our hope that experiments will be conducted to compare with the FLOW-3D results reported here. The test die consists of a right circular cylinder of radius 0.5 cm and length 5.0 cm cut in half lengthwise. A partition aligned with the cylinder's axis and intersecting the flat, cut surface extends upward to within 0.1 cm of the outer curved surface. The partition separates the cylinder into two long symmetric channels. A single inlet gate is located on the side of the cylinder 0.8 cm from one end. The gate has a square cross section with edge length of 0.2 cm.

Motivation for this test case arose in connection with an investigation of a metal injection molding problem (which has many similarities with plastic injection molding). Attempts to fill a die of this general shape through a single gate were not successful. The resulting parts exhibited a warping that was attributed to incomplete or non-uniform filling of the die. This experimental observation suggests that a test problem based on this thick-walled part and using an asymmetric filling configuration would be a good test case for numerical simulations.

The question we shall investigate here is whether a numerical simulation of the filling process can be used to predict poor performance of this asymmetrically filled die? Of course, the answer to this question depends on the measure one selects to assess performance. One possibility is to look at the residual pressure distribution at the completion of filling. The thinking here is that this gives a measure of the residual stress in the material after filling.

Another possibility is to look at the location of weld lines (i.e., locations where individual free surfaces have welded together). These regions are likely to contain discontinuities in material properties because fluid elements in each surface have probably experienced different flow and temperature histories.

COMPUTATIONAL MODEL

In this example the filling material is polystyrene at 498°K and the filling is assumed to be isothermal. The size of the computing mesh was 35 x 15 x 8 interior cells or 6290 total cells with boundaries. Only a short segment of the one inlet gate was retained in the model. The open volume of the die to be filled is 2.037 cc.

Because of the single runner and the desire to fill the die in about 0.25 s, the inlet flow velocity in the gate was set at 200.34 cm/s. This rate was estimated by dividing the approximate volume to be filled by the gate area and filling time.

To have some indication of where weld lines are likely to exist, a block of marker particles has been inserted in the small portion of the runner included in the model. This use of marker particles has previously been reported in Flow Science Technical Note FSI-92-TN34, "Injection Molding of Polymer Materials."

A complete input file for FLOW-3D for the current simulation is given in Fig. 1. This file includes requests for a variety of graphical output that will be useful in interpreting the computations.

COMPUTATIONAL RESULTS

Computations were performed on an IBM RS6000/320 engineering workstation. A new, dynamic, control feature for pressure iteration convergence was the only modification made to the standard released version, Version 5.0, of the code.

The time needed to reach a 96% filled die was 2.24 CPU hours. After that time there was so little remaining space to be filled the code had difficulty trying to maintain the constant fill rate boundary condition. This difficulty appears in the form of pressure iteration levels reaching a specified maximum iteration number (in this case the default value of 1000 iterations). There is no serious problem with such occurrences, but it does consume additional CPU time with little to show for the effort. The calculation stops itself after 25 maximum iteration levels are tabulated, which in this case occurs with 100% of the die filled and after a total problem CPU time of 3.125 hours. In the next release of the code, features have been added to terminate such computations when all void space is gone or when the die is filled to some prescribed level by the user. In any case, a good picture of the die filling process is evident long before even the 96% fill level is reached.

General Filling Characteristics

The general filling pattern when one gate is employed is shown in Fig. 2. There is an obvious retardation in the filling of the channel on the side of the partition opposite the gate at early times, say before t=0.1 s. At later times the filling appears to be more uniform, with a small retardation on the side of the partition farthest from the gate. Confirmation of this observation is given in Fig. 3, which shows the computed velocities in a surface lying near the bottom of the die cavity.

A more interesting observation about these velocities, however, is that there is an obvious asymmetry in the flow in approximately the first one third of the die. This asymmetry persists during the entire filling process. We see, in fact, that the flow on the side of the channel with the gate is moving faster than the flow on the opposite side.

This type of flow asymmetry can only happen if there is some flow passing over the top of the partition along most of its length. That such a flow exists, can be seen from Fig. 4 where the flow is given in a plane perpendicular to the long axis of the die at a location 3.175 cm downstream from the gate. The maximum flow velocity over the partition is 6.25 cm/s.

Pressure Distributions

A composite of pressure contours at four times, in a surface laying near the bottom of the die barrel, is shown in Fig. 5. It will be observed that at late times there is a small pressure differential on opposite sides of the partition reflecting the retardation of the filling on the side opposite the gate. The largest pressure difference between the sides occurs close to the gate end and persists throughout the filling process. Asymmetries near the gate reflect the velocity differences observed on the two sides and more generally the overall asymmetric flow configuration.

If pressure packing is used at the end of the mold-filling process, it would be expected that any asymmetry in pressure distribution will disappear. The fact that there is some pressure asymmetry during filling is the most important thing because this indicates the two sides of the channel are filling in different ways and at different rates. Such differences could easily generate corresponding differences in the stress histories at different locations in the final part causing warping or other defects after solidification.

Particle Distributions

Another means of measuring asymmetries is to look at the distribution of marker particles injected with the initial blob of polymer. Figure 6 contains several plots of computed marker particle distributions. Aside from an obvious asymmetric distribution, there are at least three points to note about the location of the particles.

First, the majority of particles flow into the seam made by the partition and the bottom of the die. These particles are then slowly dragged along toward the end of the die. A second point is that some particles are trapped at the upstream end of the die early on and remain there.

Finally, a relatively small portion of the particles make it over the partition, mostly during the first 0.05 to 0.1 s after initiation of filling. These particles are pushed into the outside corner of the die and are carried toward the end of the die at a very slow rate compared to those particles on the other side of the partition.

From these observations we see that on the side of the partition nearest the gate the initial surface is forced into the center of the part. On the other side of the die surface elements are forced into the outside edge of the part. Furthermore, the axial motion of these surface elements is much greater on the side nearer the gate than on the far side.

Trapping of surface particles at the upstream, nearside end of the die may or may not be significant. It will be interesting in future studies to investigate in more detail possible correlations between marker particle distributions and actual part characteristics obtained under a variety of conditions.

SUMMARY

We have presented results obtained with the FLOW-3D program for a thick-walled polymer injection molding problem. This particular example, having only one inlet gate, is likely to suffer warping after solidification. For this reason, the computer simulations were undertaken to see if they could quantify the asymmetries generated by the single gate design.

The results obtained clearly demonstrated a well defined flow asymmetry. This was shown by velocity and pressure plots as well as by marker particle distributions.

The velocities and pressures were biased with respect to the central partition by a flow passing over the top of the partition. Without this flow, of course, the region on the far side of the partition would not fill at all. In any case, the partition has different flow distributions and flow histories on its two sides.

Marker particles inserted in the first blob of polymer to enter the die were shown to exhibit a strong asymmetric behavior. Since particles indicate individual fluid particles, they offer an interesting picture of how a die fills. For instance, we see from the particle plots that the first material to enter the die is not simply pushed toward the far end, to be replaced by new incoming material, but is spread into corners of the die along its entire length.

It is hoped that experiments will be undertaken to correlate with these results as another step toward a complete validation of FLOW-3D for thick-walled, injection molding processes.

```
polymer die casting - asymmetric filling through one gate
$xput
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   remark='units are inch, s, 12slugs, psi',
   itb=1,        iwsh=1,       impvis=1,      itvsmx=5,
   avrck=-2.1,
   rhof=0.72e-4,
   mui=0.96,     muctst=1.0,   muc0=1.0,      muc1=0.35,
   muc2=0.3,
   prtdt=5.00,   pltdt=0.025,  twfin=0.25,
   delt=0.001,
   wl=2,   vbct(1,4)=-80.0,
   wr=2,   wbk=6,  wf=2,
   wt=2,   wb=2,
   ilpr=2, jbkpr=2, ktpr=2,
$send
$mesh
   nxcelt=35,
   px(1)=-.276,   px(2)=0.0,      px(3)=0.079,    px(4)=1.97,
   px(5)=2.24,    nxcell(2)=2,
   nycelt=15,
   py(1)=-0.276,  py(2)=-0.02,
   py(3)=0.02,    py(4)=0.276,
   nzcelt=8,
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$send
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   xl(1)=0.0,       xh(1)=1.97,
   iofo(2,1)=2,
   cc(2)=0.0388,    cx2(2)=-1.0,     cy2(2)=-1.0,     cz2(2)=-1.0,
   xh(2)=-0.0001,
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   cc(3)=-3.842,    cx2(3)=-1.0,     cy2(3)=-1.0,     cz2(3)=-1.0,
   cx(3)=3.94,      xl(3)=1.9701,
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   cc(4)=-0.1,      yl(4)=-0.02,     yh(4)=0.02,      zh(4)=0.157,
   iofo(5,1)=5,     ioh(5)=0,
   cc(5)=-0.1,      xh(5)=0.079,     xl(5)=0.0,       zh(5)=0.079,
   yl(5)=0.2,
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$fl
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   fcc(1)=-0.1,     fxl(1)=0.0,      fxh(1)=0.079,   fyl(1)=0.19,
   fzh(1)=0.079,
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$send
$temp
$send
$motn
$send
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   nvplts=2,
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   iperv(2)=1,      zv1(2)=0.001,       zv2(2)=0.001,
   ncplts=2,        contyp(1)='p',      contyp(2)='mu',
                    ictyp(1)=5,         ictyp(2)=5,
                    zc1(1)=0.001,       zc2(1)=0.001,
                    zc1(2)=0.001,       zc2(2)=0.001,
   nsplts=3,        contps(1)='vf',     contps(2)='f',     ipasn(1)=2,
                    ihide(1)=0,         ihide(2)=1,        isvew(2)=2,
                    contps(3)='f',      ihide(3)=0,        isvew(3)=3,
   nvews=3,         xea(2)=-5.0,       yea(2)=-3.5,       zea(2)=3.0,
                    xea(3)=10.0,        yea(3)=5.0,       zea(3)=4.0,
                    xea(1)=15.0,        yea(1)=10.0,       zea(1)=5.0,
$send
$parts
   npx=10,          npy=20,             npz=10,
   xpl=0.0,         xpr=0.079,          ypf=0.19,          ypbk=0.276,
   zpb=0.0,         zpt=0.079,
$send
```

Fig. 1. Input file for FLOW-3D calculation.

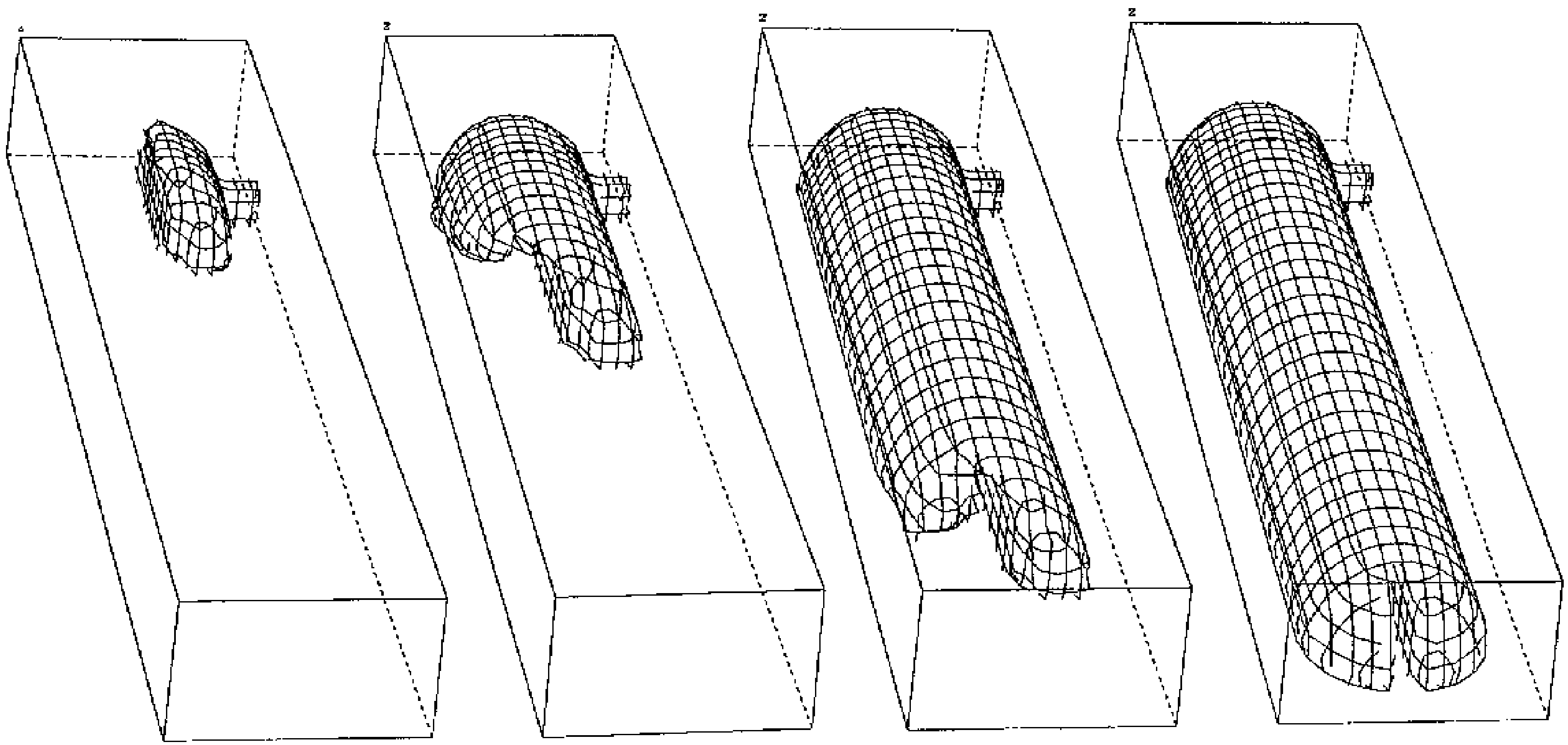

Fig. 2. Fluid configuration during filling at times 0.025, 0.075, 0.2 and 0.25 s.

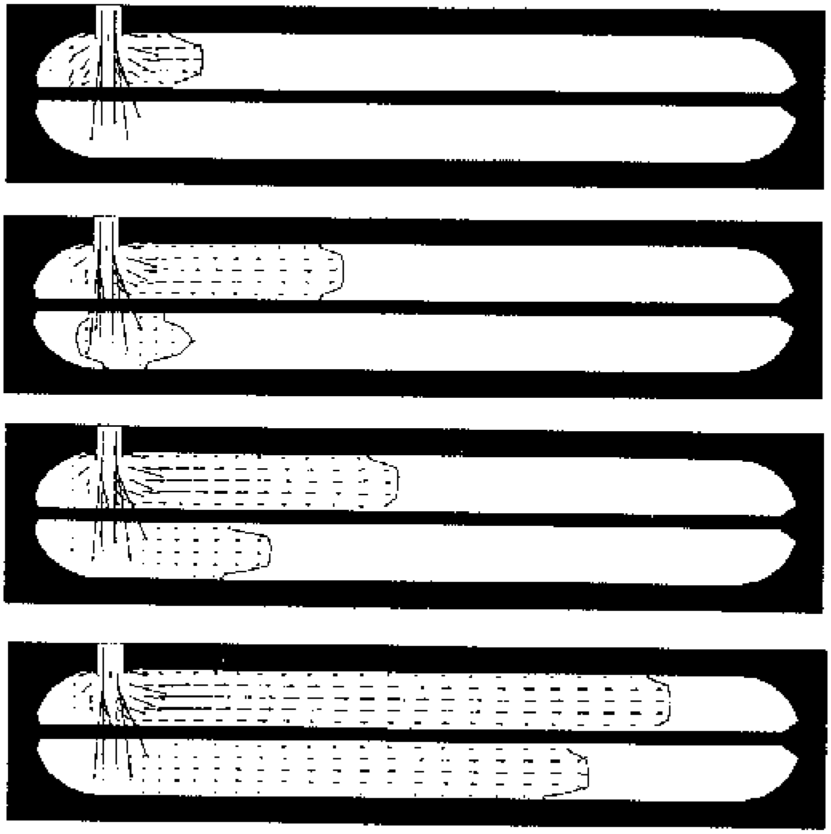

Fig. 3. Velocities and free surface configurations in bottom surface of die at times 0.025, 0.075, 0.1 and 0.2 s.

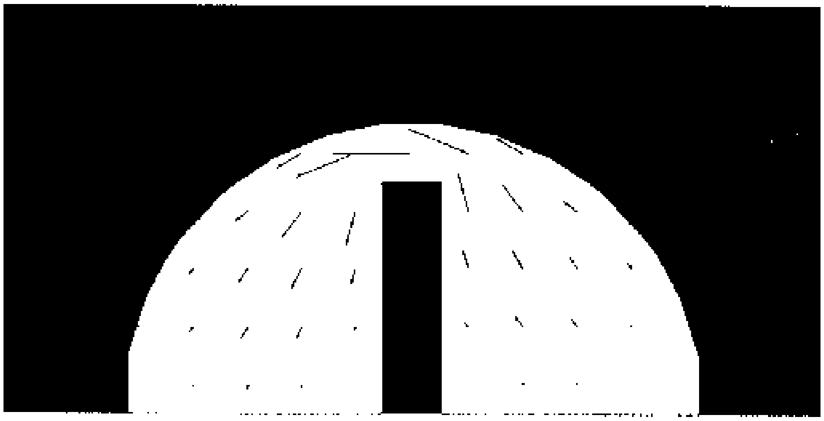

Fig. 4. Velocity distribution in plane normal to cylinder axis and 3.175 cm downstream from the gate. Shows how flow passes from the one side of the partition to the other.

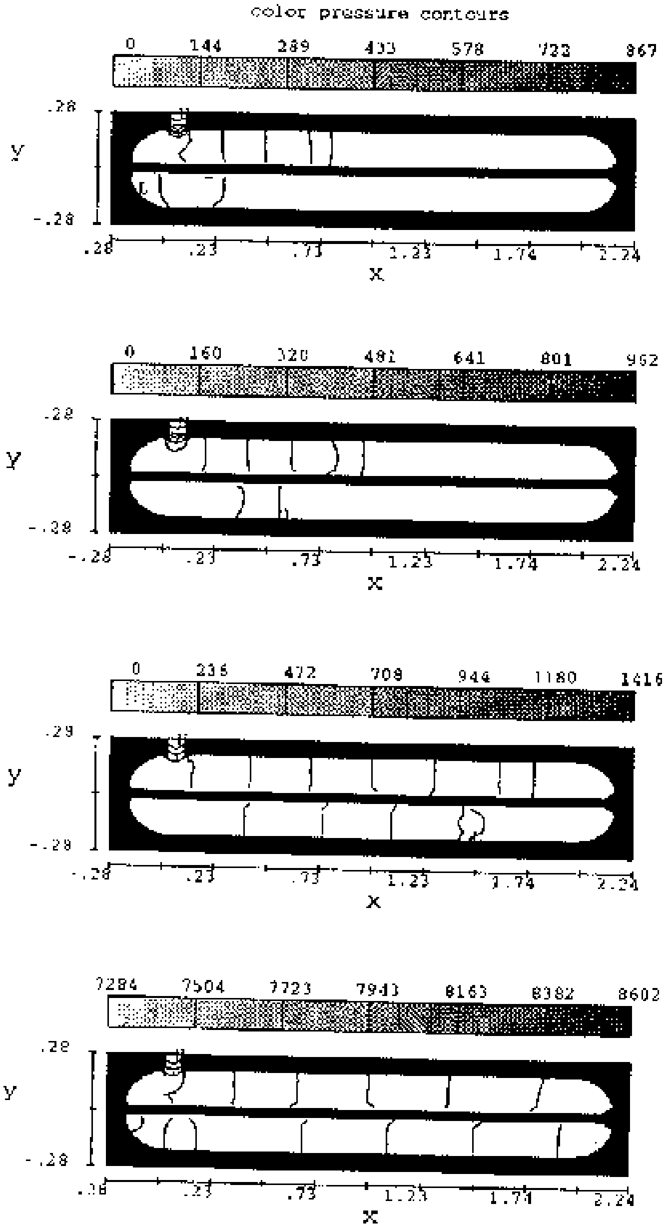

Fig. 5. Pressure contours in bottom surface of die at times 0.075, 0.1, 0.2 and 0.25 s. The rightmost contours in the two channels have the same value, except in the bottom plot where the last contour in the top channel has the same value as the next to last contour in the bottom channel.

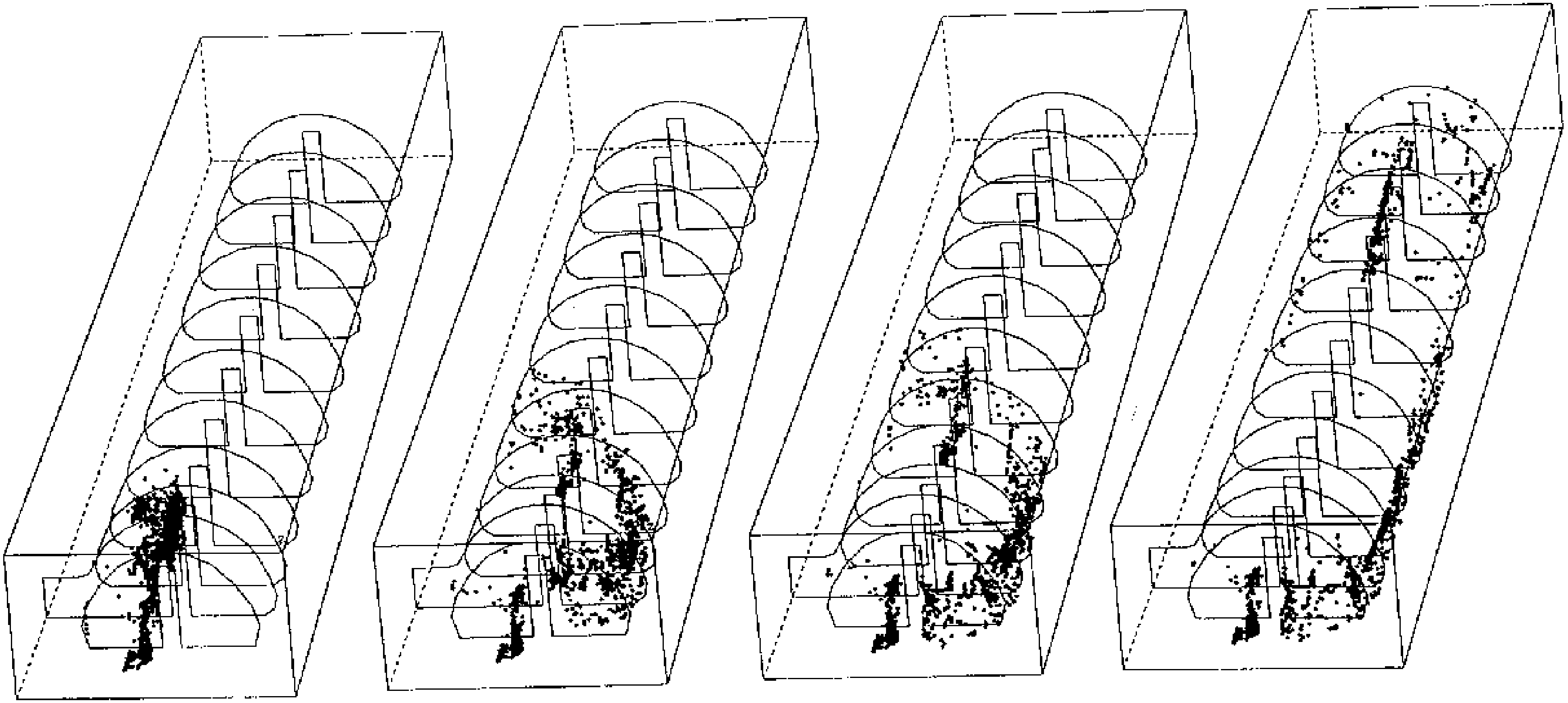

Fig. 6. Distribution of initial blob of marker particles at times 0.025, 0.075, 0.1 and 0.25 s.