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# Residence Time Distribution control in asepting processing using a bypass holding tube

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In the present work the possibility of accelerating the slowest particles in aseptic processing in order to reduce the Resident Time Distribution (RDT) is investigated.
Using an appropriate geometrical configuration of a bypass holding tube, particle in the lower zone of the principal tube are driven by a pressure gradient in a secondary tube where they are accelerated and reinserted in the principal one with an higher value of kinetic energy.

## 1. Introduction

The concept of aseptic processing originated to solve problems associated with conventional 'in-container' sterilization of foods such as low rate of heat penetration to the slowest heating point in the container, the long processing times required to deliver the required lethality, destruction of the nutritional and sensory characteristics of the food, low productivity, and high energy costs (Smith et al., 1990).

Aseptic processing technique has been successfully applied to liquid foods and acid foods containing discrete particulates.

However, the extension of aseptic processing to heterogeneous low-acid liquid foods containing discrete particulates has been difficult due to lack of data on critical factors such as interfacial heat transfer coefficient between the liquid and the particle as well as the residence time distribution of particles in the holding tube of the aseptic system.

Geometry of holding tube represents a primary parameter in determining the residence time distribution of particulate inside an aseptic processing system.

Several configuration had been investigate in the past, including curved geometries in order to minimize widening of RTD. One of factors influencing RTD is the presence of particles travelling near the bottom in the boundary layer, i.e. in the low velocity zone.

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## 2. Process and particle variables

Several process and particle variables are involved in aseptic processing of particulate, and it is far from the purpose of this paper to provide an extensive description of mutual interaction between themselves.

Among them:

1) tube orientation;
2) tube diameter;
3) flow rate;
4) tube geometry;
5) particle size, shape and density;
6) particle concentration.

Phenomena involved in transport mechanisms of particles are rather complex, involving buoyancy effects, wakes and boundary layer, and particles-particles and tube particles collisions.

An interesting effect which appears in a conventional (near horizontal ) tube operating under low particle concentrations and low fluid viscosity is a sedimented layer stratification due to buoyancy effects (see fig. 1).

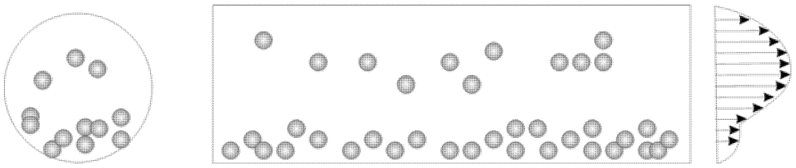

*Figure 1. Channeling, sedimented layer and decreased effective cross sectionat low particle concentration.*

The presence of sedimented layer at the bottom of the tube can cause a flow channeling in upper zone, resulting in a wider residence time distribution (Dutta e Sastry, 1990 a,b, Fregert, 1995), and the effect appears maximum with a particle concentration of 10-20% (Liu et al.,1993).

A possible solution to this problem is the use of a secondary bypass tube collecting slow traveling particles at the bottom and accelerating them in order to reduce the residence time respect to the particles travelling in the fully developed velocity profile in the centre of the holding tube.

## 3. Materials and methods

The design of the bypass tube was obtained by using a numerical approach. A control volume simulation code (Fluent Inc. 6.3.26) as used in a 3D configuration, coupled with a collision detection algorithm in order to model particles interactions. In the preliminary work, described in this paper, the principal target was the design of the bypass tube.

The 6-DOF motion of the particle is computed by solving the Newton-Euler equations for rigid-body motion. The motion is broken into a translation of the center of mass (c.m.) of the body (Newton's equations), and a rotation about a centroidal axis system attached to the body (Euler's equations)

The moving mesh approach was adopted in the simulations: the particle was described as a moving rigid sphere with 3 translational and 3 rotational degrees of freedom, driven by hydrodynamic pressure and shear forces computed in a time dependent way by the numerical code.

The mass center translation is governed by Newton's laws of motion, which are written in the inertial frame as

$$\mathbf{F}_t = \mathbf{F}_a + \mathbf{F}_e + \mathbf{F}_g = m\ddot{\mathbf{r}}_i \qquad (1)$$

where the applied force acting through the center of mass has been broken into three components; the aerodynamic forces computed by the numerical solver $\mathbf{F}_a$, the external applied forces (such as impulses due to collisions) $\mathbf{F}_e$, and the forces due to gravity $\mathbf{F}_g$.

The major difficulty was to develop a collision detection algorithm, as in the real world a perfect collision would require a zero volume control volume between the colliding particles or the tube, resulting in an error in the numerical simulation. To this purpose, the collision was detected by leaving a minimum variable height computational layer BL between the two collided bodies as described in Fig. 2, choosing an appropriate time step Δt in order to skip the exact collision time $t_0$.

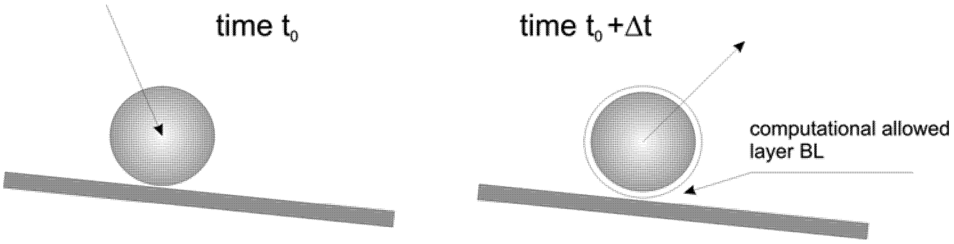

*Figure 2. Collision detection algorithm: computational layer BL .*

The height of this layer was computed by using an impulse approach based on trajectory tracking and collision prediction with a momentum restitution coefficient due to the anaelastic effects set to 0.9.

In order to capture particles at the bottom of the principal tube, a particular design of the bypass tube was obtained (see fig. 3b) starting from fig. 3a configuration and using an Optimal Shape Design approach, a numerical technique (Anagnostou et al., 1992; Mohammadi and Pironneau, 2001; Pironneau, 1984) allowing an automatic design of an optimal functional shape. In such approach, the solution is obtained by coupling together a discrete model of the process parameters, in this case obtained by solving the Navier-Stokes equations for a non-newtonian fluid, including the geometrical shape as a part of the degrees of freedom of the problem, and a constrained multivariate minimization algorithm is used in order to minimize an objective mathematical function describing the efficiency of the process.

In this case the angle of insertion of the lower tube B1 and the tube insertion diameter was optimized in order to maximize the pressure gradient due to the Venturi effect between the upper and lower tubes in proximity of the hole C1.

The presence of a convergent-divergent section C2 in the upper tube enhances the pressure rise in the zone behind the connection hole C1.

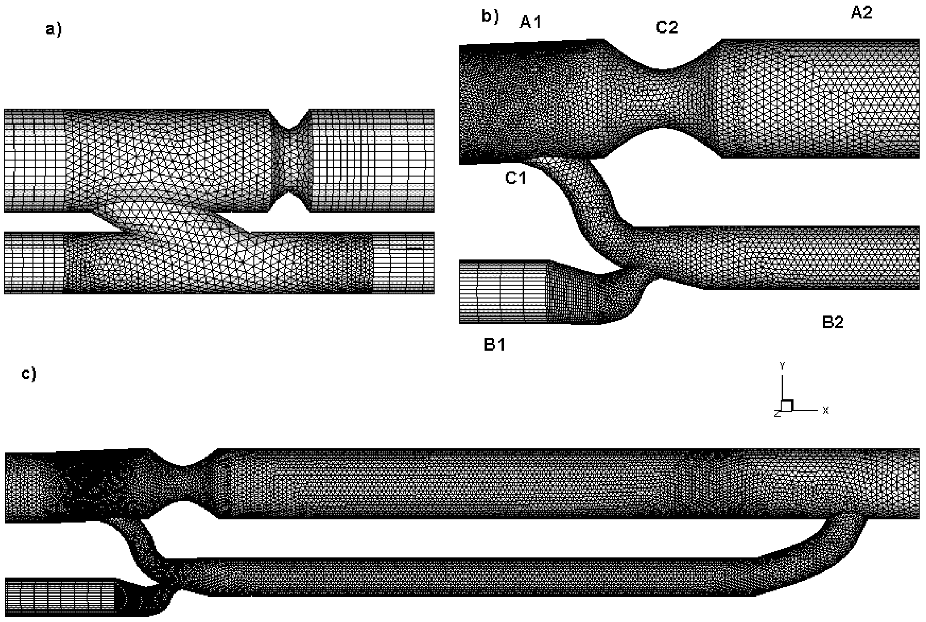

*Figure 3.Initial (a) and final (b) configuration of bypass holding tube (c) after optimization.*

## 4. Test configuration

Results shown are referred to the following test configuration: transported particles are green pees with 0.006 m diameter, density equal to 1060 Kg/m$^3$, inlet velocity V1 in the upper tube equal to 0.5 m/s (flow rate 21 l/min) and V2 in the lower tube set to 0.7 m/s (flow rate 8.4 l/min).

The upper tube diameter was set to D1=0.03 m and the bypass one D2=0.017 m, and the bypass tube length is 0.35 m. The carrier fluid viscosity was modelled as a 0.5% solution of aqueous solution of sodium carboxymethylcellulose, with a power-law viscosity with the values for K and n set to 0.297 Pa s$^n$ and 0.7025, respectively.

## 5. Results and conclusions

In Fig 4 local differential pressure (Pa) and vector velocity distribution in a mid-plane in the bypass holding tube zone is shown, highlighting the pressure gradient and bypass flow rate from the upper tube at slower velocity to the bypass one.

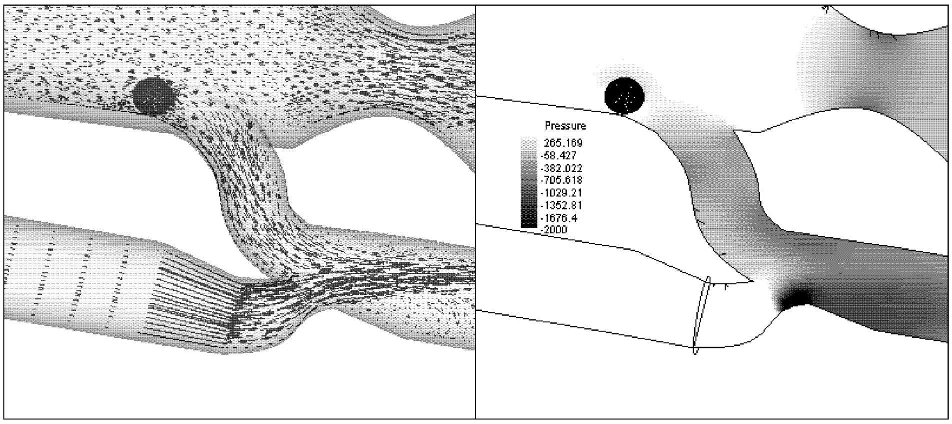

*Figure 4.Vector velocity distribution and differential pressure gradient on a normal section in the bypass holding tube zone.*

The particle was driven by hydrodynamic and gravitational forces (see sequence in Fig. 5 a-f), and the bypass tube residence time $t_1$ was globally 0.28 s, compared with $t_2$= 0.76 necessary to travel the same distance for particles in the upper tube .

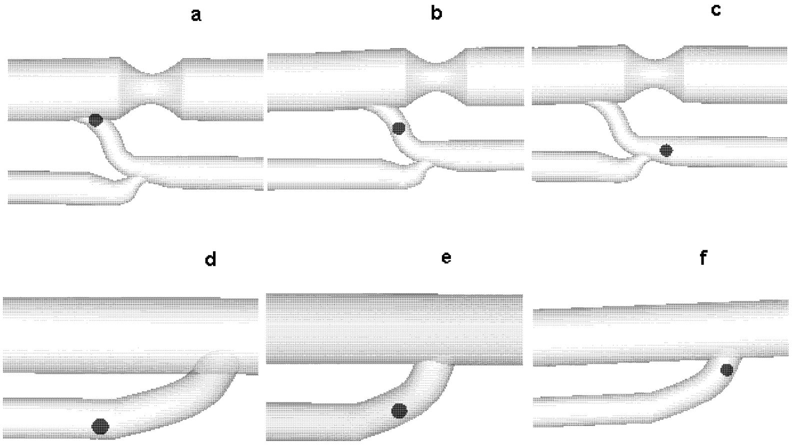

*Figure 5. Particle position at different time step in the entrance and leaving zone of the bypass tube.*

Results in a test section showed the possibility of controlling RDT by using an appropriate geometrical configuration of the holding tubes. In order to generalize the obtained results a wider range of process and particles parameters need to be investigated.

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