Research of Airplane Waste Disposal System Tank Characteristics by Method of Numerical Simulation

S.V. Medvediev

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Abstract

The modern design enhances the role of preliminary research in aircraft development.Reducing iterations in the process of making conceptual decisions, along with the requirements for the project, and obtaining the most reliable models of the future system is one of the important tasks facing a design engineer. The article considers one of the life support systems designed to satisfy the physiological needs of the human body -a vacuum-type waste disposal system. One of the critical elements of the system is a waste storage tank. An important stage in the design of a tank is the determination of its weight and size characteristics in the early stages of development. The tank filling process has a significant influence on these characteristics which is crucial for the placement of equipment in it. The aim of the work presented in the article is to study the process of filling the tank with the help of numerical simulation methods. The results obtained in the process of numerical modeling make it possible, at the preliminary design stage, to evaluate the required air gap, to determine the total volume of the waste tank.

***Index terms*—** vacuum, waste tank, waste disposal system, numerical methods, free surface model.

1 Introduction

he modern design of any system on board an aircraft is a complex, multifactorial, ramified task consisting in finding the optimal ratio of parameters.

Continuous complication and, as a consequence, higher cost of aviation equipment entails a significant increase in costs from errors made at the design stage and, therefore, requires a sharp increase in the quality of design and development work.

Strengthening the systemic principle in the general approach to the creation of aviation technology has increased the role of external design in the development of aircraft, and raised the importance of the stages of preliminary and conceptual design. The role of pre-design studies related to the substantiation of the general concept and the technical appearance of the new aircraft planned to be created has also significantly increased **??**1].

In this regard, obtaining reliable results at these stages becomes an urgent task that the design engineer has to solve when developing the system.

To implement the requirements for ensuring safety and comfort, various life support systems are installed on board a modern aircraft, one of which is a waste disposal system designed to ensure the physiological needs of the human body. On board the aircraft, different types of action systems are used, but preference is given to a vacuum-type action system due to a number of factors (economy, environmental friendliness, comfort).

The development of vacuum-type systems on civilian aircraft begins its history in the mid-70s of the twentieth century. So, in 1975, inventor James Kemper patented a vacuum waste disposal system, the principle of which is used today in modern passenger aircraft [2]. The first vacuum toilet was installed on Boeing aircraft in 1982.

The principle of the system is that rarefied air is the driving force for moving waste from the toilet to the tank. When flying at low altitudes and on the ground, a vacuum generator is used that provides the pressure differential; at high altitude flight, a natural differential is used between the cabin and the atmosphere. The waste tank is connected to the atmosphere and in the system is present atmospheric pressure till the flush valve on the toilet, Fig. 1. Pressing the pushbutton opens the flush valve, and waste from the toilet bowl moves to the tank. The waste enters the tank and is stored there during the flight and does not enter the atmosphere. Tank service takes place on the ground. network, but also by the requirement that the waste be stored in the tank without further movement along the vacuumization subsystem. If the developed system design does not comply with this requirement, the following negative consequences may occur:

? The formation of significant ice formation on the outer surface of the aircraft at the exit point of the vacuumization pipelines, which after separation can damage the structure of the aircraft; ? Waste getting onto the vacuum generator;

? Waste getting onto the surface of the airfield during parking, which entails the imposition of significant fines by the airport administration.

One of the system elements is a waste storage tank. When designing a tank, you must determine:

? Maximum amount of waste that will be stored in the tank; ? Configuration of the waste braking device (at the entrance to the tank); ? Tank configuration acceptable for placement on an airplane; ? Filling capacity of the waste tank (gas-dynamic calculation); ? Strength calculation of the tank.

The total tank volume consists of the waste volume and the air gap volume above the waste.

At the stage of research work, when conducting full-scale tests is extremely difficult and requires significant costs, the urgent task is to determine the volume of the tank that is needed to store a given amount of waste, as well as its configuration, taking into account the zonal distribution of equipment in the aircraft compartments. The required volume of the tank largely depends on the process of its filling, the study of which is presented below.

2 II.

3 Research

The study of the tank filling process is performed by numerical methods. Non-stationary hydraulic processes are considered in the interaction of a two-phase waste-air environment, which are separated by a free surface.

4 a) Mathematical model of unsteady hydraulic

processes with a free surface An article [3] presents an analysis of existing mathematical models for free-flow flow modeling, which shows that the most widely used method is the Volume of Fluid method. This method uses the fluid volume fraction function ?. This function takes a value of 0 if the medium is filled with gas and 1 if it is filled with liquid. At the boundary of the phase section, the value of the function lies in the range 0 < ? <1. The density, pressure and viscosity of the media under consideration are from the following equations:( ) 2 1 1 ? ? ? ? ? ? + = ( ) 2 1 1 p p p ? ? ? + = ( ) 2 1 1 ? µ ? µ µ ? + =

According to [4], taking into account [5] and using the SST turbulence model, the equations describing non-stationary gas-dynamic processes in two-dimensional formulation with the available free surface are as follows: where the coefficient i -number of the medium, ?density, u and ? -projections of the velocity vector at the coordinates ? and ?, respectively, p -pressure, V = (u, v) T -velocity vector, F = (f x , f y) T -density distribution of bulk forces, ? -elements of the viscous stress tensor, kkinetic energy of turbulence, ? -turbulence specific dissipation rate, P k -the generation of kinetic energy of turbulence. and sixth equation is the SST turbulence model, and the seventh is the transfer equation for the function ?.i i i i i i M y S x R y G x F t Q + ? ? + ? ? = ? ? + ? ? + ? ?

These equations completing the equation of state, as well as the equation of the condition of dynamic equilibrium at the interface:T m R p ? = ( ) ( )e K p p e ? ? ? + ? = ? 2 1 2 1 2 1 u u = , 2 1 ? ? =

where, e -single normal vector, K -surface curvature, and ? -surface tension coefficient.

The elements of the stress tensor are as follows:? ? ? ? ? ? ? ? ? ? + ? ? ? ? ? ? = y x u x u e e xx ? µ µ ? 3 2 2 ? ? ? ? ? ? ? ? ? ? ? + ? ? ? ? ? ? = y x u y e e ? µ ? µ ? 3 2 2 yy ? ? ? ? ? ? ? ? ? ? ? + ? ? = ? ? u e xy ? µ ?

Where ? e -effective coefficient of viscosity:t e µ µ µ + = ? -dynamic viscosity coefficient, ? t -turbulent viscosity coefficient. ? ? µ µ 2 k C t =

For turbulence model equations:

( )x k D t k k x ? ? + = µ ? µ , ( ) y k D t k k y ? ? + = µ ? µ ( ) x D t x ? ? + = ? µ ? µ ? ? , ( )y D t y ? ? + = ? µ ? µ ? ? ( ) x x k F A x ? ? ? ? ? = ? ? ?? ? ? 1 1 2 2 1 , ( )y y k F A y ? ? ? ? ? = ? ? ?? ? ? 1 1 2 2 1

A detailed description of the coefficients included in the turbulence equation is given in **??**6 -7].

Preparing and solving equation systems (1) is carried out with the help of software package numerical modeling Ansys CFX [8].

This software package is capable of solving complex problems with many effects. Two-phase flow studies using the numerical simulation method are considered in [9][10] **??**11].

5 b) Investigation of the storage tank filling processes with numerical simulation

Since the design of aircraft systems is conducted in a confined space, the tanks of the waste disposal system can take many forms. The object of research is a conditional tank for storage of waste, cylindrical shape, Fig. **??**. For research was proposed and developed tanks with a diameter of 0.5 to 10 m. The three-dimensional tank model is made using NX 8.5 software.

6 Fig. 2: Waste tank 3D model

Construction of the estimated grid made using ICEM software package. The tank volume is broken by an unstructured tetrahedral grid using the Robust (octree) method, Fig. 3. The maximum height of the grid element is 20 mm for the inlet and 7 mm for the outlet.

A two-phase air-water environment separated by a free surface is considered. The air is presented as perfect gas. Model of turbulence is SST. tank filling process is 2 sec., and includes the following stages of the system units operation: operation of the vacuum generator from 0 to 1 s, opening of the waste receiver flap from 1 to 2 s, getting water to the tank. At the initial time in the tank there is a certain level of water (waste), the height of which is equal to y h [12].

The purpose of the study is to determine the dependence of the amount of water in the outlet pipe on the amount of air gap between the water and the upper wall of the tank.

The initial values of the velocity vector are 0 m/s. The initial pressure value is given by the P ref function:? ? ? ? = h in h w y y at P y y at P ______P ref ?

where, P in = 1,0332 kg / cm 2 -air pressure; P wwater pressure, which is determined by the function:g y y P P h in w ? ? ? + = 1000) (

The initial temperature value of the two phases is t = 22 ° C. The volume ratio of each phase in the calculation region is determined by the WVF function:? ? ? ? = h h y y at y y at ___1 ___0 WVF air ? air water WVF - 1 WVF =

The results showed that the stability of the calculation is ensured at time step values of 0.001 sec. and less.

Fig. 5 presents the dependence of the volume of water in the outlet pipeline (maximum possible is 1) on the size of the gap between the waste surface and the upper wall of the tank (H) at different diameters of the waste tank (free surface area). The study of the process of vacuumization of the system has made it possible to establish that with the reduction of the thickness of the air gap there is a significant intensification of the separation of water particles (waste) from the surface due to the higher velocities of air flows in the gap, which occur during the process of vacuumization of the system. Further reduction of the thickness of the air gap leads to the formation of waves on the free surface, resulting in significant splashing of water and which can increase even when a new portion of waste enters the tank. The results of numerical simulation of the process of filling the tank made it possible to determine the dependence of the coefficient of bulk water content in the outlet pipeline on different values of the initial water level in the tank.

If the concentration of the water particle is exceeded, we take 5 grams of fluid per drain (volume of water not more than 0.0001), in which the presence of water in the outlet channel becomes visually noticeable. The obtained numerical simulation data for tanks of different diameters made it possible to deduce the allowable minimum height of the air gap between the waste surface to the upper wall of the tank from the tank diameter, which is presented in Fig. **??**, 7.

The first approximation dependency allows for the required tank dimensions (which are determined by taking into account the maximum amount of waste and the place of installation of the tank) to estimate the required additional volume of air gap, which will ensure no waste in the outlet.

The study of the process of vacuumization of the system has made it possible to establish that with the reduction of the thickness of the air gap there is a significant intensification of the separation of water particles (waste) from the surface due to the higher velocities of air flows in the gap, which occur during the process of vacuumization of the system. Further reduction of the thickness of the air gap leads to the formation of waves on the free surface, resulting in significant splashing of water and which can increase even when a new portion of waste enters the tank.

For a real aircraft, the range of tank diameters ranges from 0.5 m to 2 m, Fig. **??**.

7 Conclusion

The study of the processes of evacuation and filling of the storage tank used of waste disposal system showed that the entry of waste into the vacuumization line is due to a significant intensification of the process of waste separation particles at a decrease in the thickness of the air gap during the process vacuumization.

According to the results of numerical studies, the minimum permissible value of the air gap thickness between the waste surface and the tank is determined for different tank diameters, at which the waste concentration in the vacuum line will not exceed critical values. [1]

[1]Year 2020 Research of Airplane Waste Disposal System Tank Characteristics by Method of Numerical Simulation

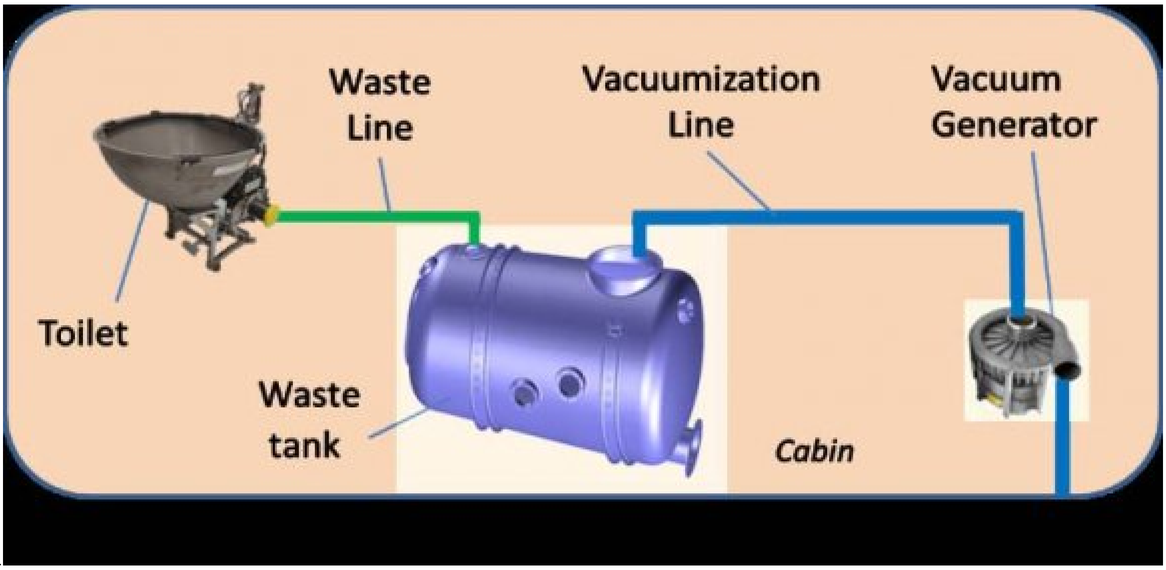
1 

Figure 1: Fig. 1 :

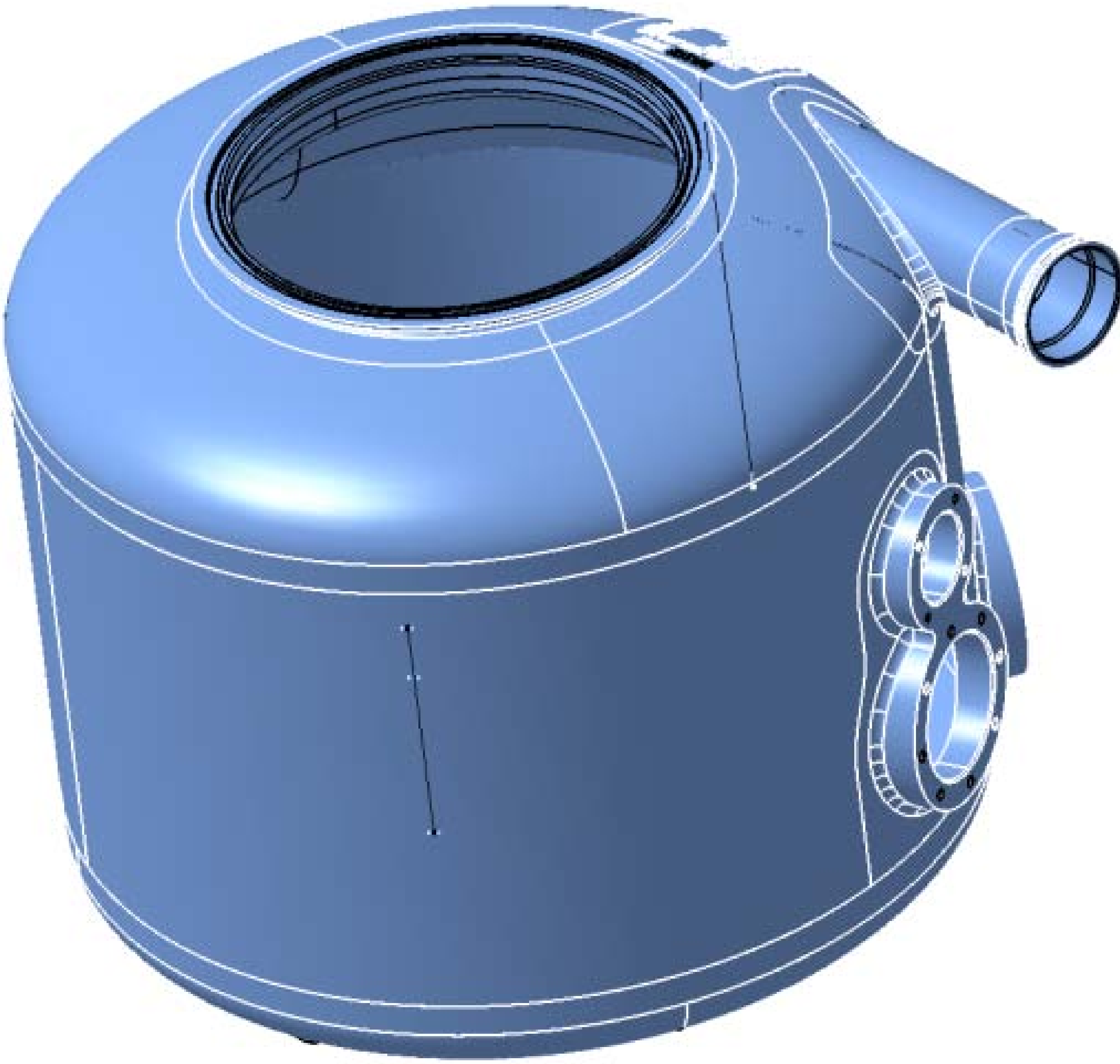


Figure 2:

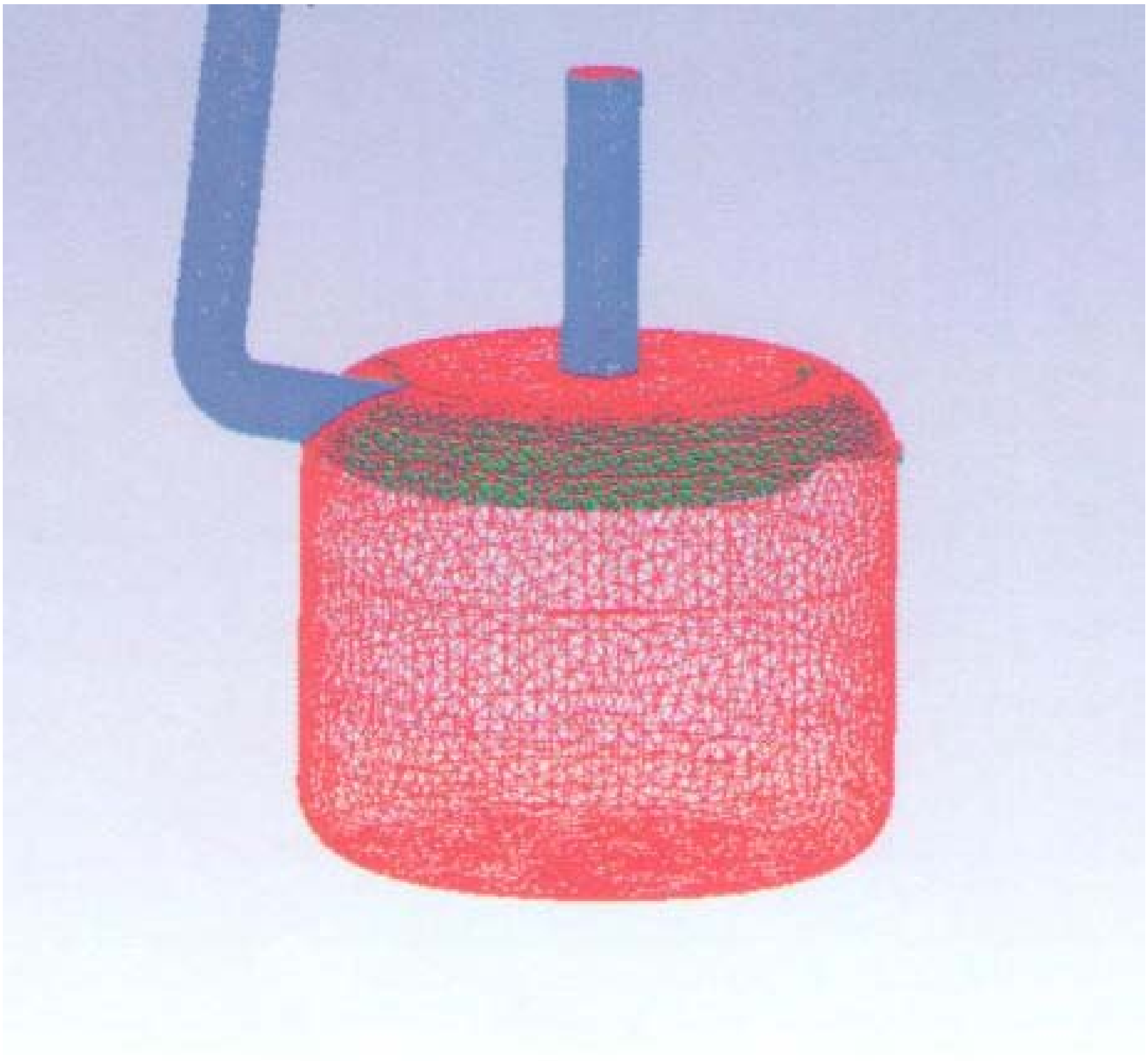


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Figure 3: Fig. 3 :

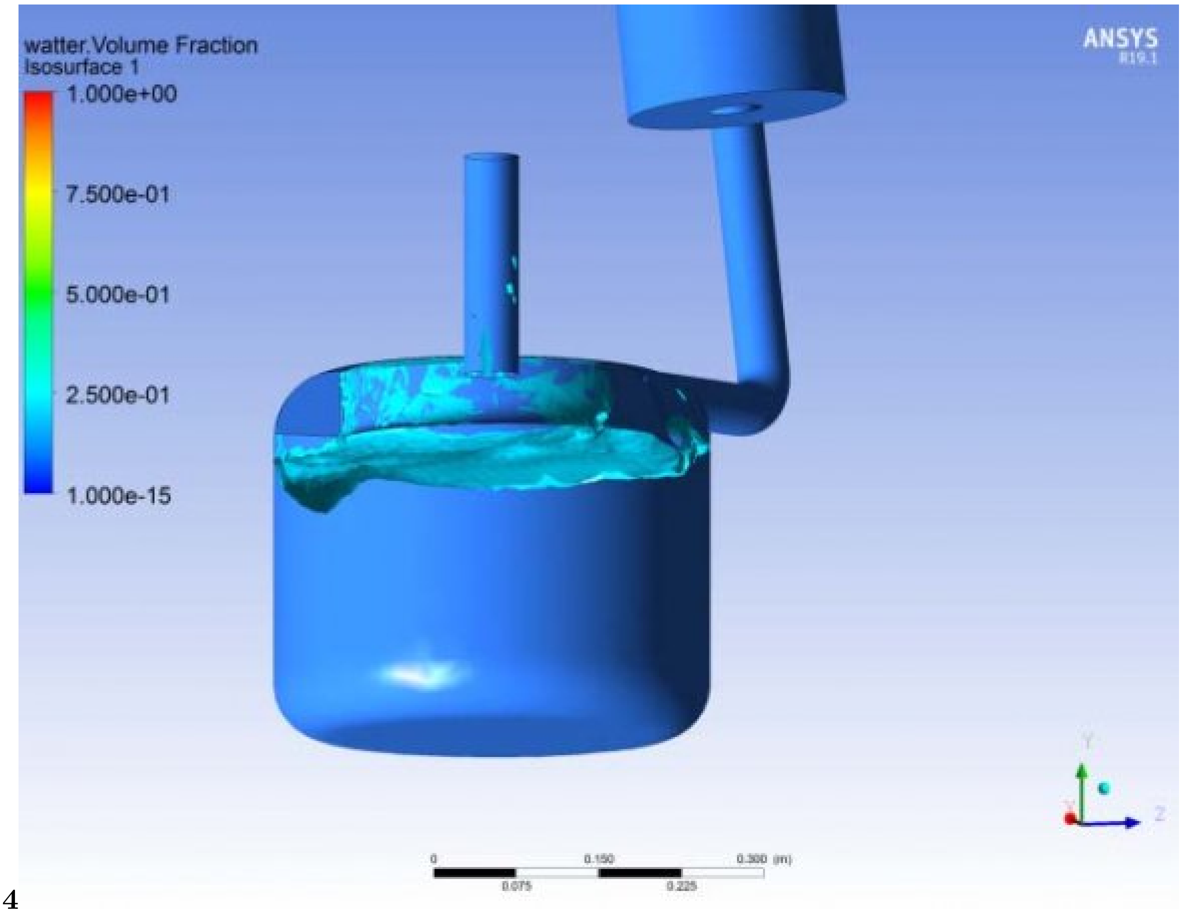

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Figure 4: Fig. 4 :

[A/En] , A/En .

[Cfx] , Ansys Cfx . http://www.ansys.com

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