'' Plasma Utilization of Aqueous-Organic Compositions as a Nuclear Reactor Waste for Treatment ''

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Abstract

The process of disposing of spent nuclear fuel reprocessing waste in air plasma in the form of water-salt organic compounds is the focal point of the study. The study's objective is to assess the capability of effectively disposing of spent nuclear fuel reprocessing waste in air plasma in the form of compositionally optimal water-salt organic compositions.

More specifically, the following tasks were completed: Using thermodynamic modeling, the spent nuclear fuel reprocessing waste is disposed of in air plasma as water-salt organic compounds.

In an air-plasma flow, droplet evaporation is modeled kinetically. Patterns of the influence of the starting point of the air-plasma flow, droplet properties, as well as the initial mass ratio of the liquid and gaseous phases are formed on the evaporation kinetics of droplets dispersed in aqueous-organic compositions in the air-plasma flow.

It is shown that for aqueous-organic compositions with the adiabatic combustion temperature no lower than 1200°C, the phase of solvent evaporation is the limiting step of the overall process in the air-plasma flow.

The compositions of model water-salt-organic compositions are determined, as well as the modes that ensure the effective plasma utilization in an air-plasma flow for the treatment of radioactive waste. These measurements are made while a plasma have based on the Very High Frequency (VHF) Plasma torch is operating.

Simulation for DC thermal plasma plant using COMSOL Multi-physics simulation to determine the physical, electromagnetic properties variations during its operation, and the variation in the thermodynamic properties of the Uranyal Nitrate UO_2 $(NO_3)_2$ solution in passage through the Air plasma flow.

The results of the modelling and experimental studies carried out, can be used to create an energy-efficient technology for plasma disposal of spent nuclear fuel processing waste and other intermediate level of liquid radioactive waste.

1 Introduction

Thermal plasma processing is one of the technologies that can be utilized to reduce the quantity of radioactive waste that is stored while remaining environmentally friendly. Plasma research and development now focuses on areas of environmental cleanup.

All types of radioactive waste (RW) can be disposed of in order to produce solidified items appropriate for long-term storage according to the idea of a closed nuclear fuel cycle. Both combustible SNF processing waste and SNF processing waste, such as spent extractants used to extract uranium-238 and plutonium 239 isotopes from SNF, are produced during SNF processing. SNF processing waste includes fission products of the uranium-235 isotope [3].

In the current work, patterns of the influence of the initial air-plasma flow parameters (temperature and velocity), as well as droplet parameters (velocities) of distributed aqueous metal salt solutions in the air-plasma flow, are being established using multi-physics modeling approaches.

2. Production of Spent Nuclear Fuel processing waste

The primary objective of reprocessing spent fuel historically has been to separate the burned fuel components from the residual plutonium and less valuable residual uranium. This accomplishes the fuel cycle and increases the energy from the original uranium by 25–30%. As a result, the nation's energy security is improved. The amount of material that needs to be disposed of as high-level waste will be approximately reduced in half. The reprocessing waste also has a significantly lower radiation level [1, 2]

Reprocessing used fuel to produce reprocessed uranium and plutonium (Pu), hence reducing resource waste. It is composed primarily of uranium (about 96%), of which less than 1% (usually between 0.4% and 0.8%) is fissile U-235 and up to 1% is plutonium. Both may be recycled into fresh fuel, reducing down on the requirement for uranium by up to 30%. Reprocessed uranium is extremely valuable because of its fertile potential, which enables it to be transformed into plutonium-239 that can be consumed in the reactor where it is produced [4].

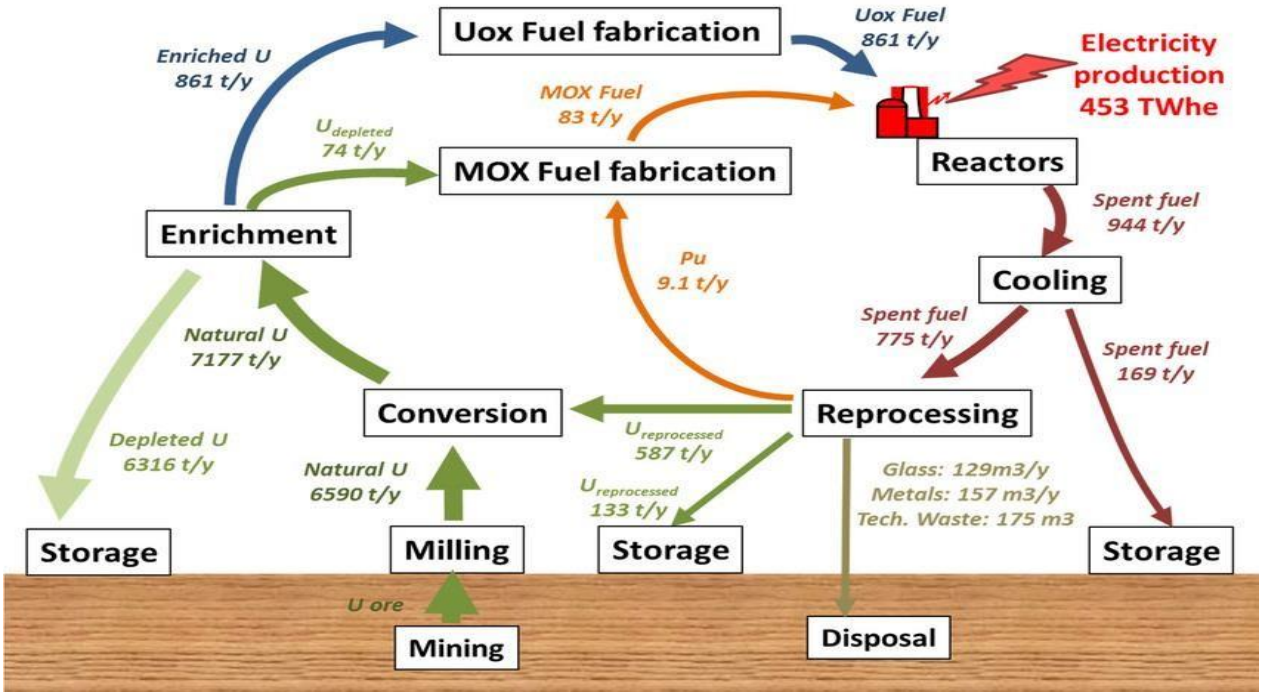

Figure 1- Detailed diagram of the PUREX process [2].

Purex, a hydrometallurgical process, is the primary historical and current method. The most promising ones are electrometallurgical, sometimes known as pyro processing due to the temperature at which it is. It allows for the simultaneous recovery of all actinide anions, most notably uranium and plutonium [5].

3. Dispersed combustible aqueous-organic compositions in a reactor Plasma processing modeling

Zones of the thermal plasma plant can be theoretically separated into a high-temperature flow transporting droplets of aqueous-organic substances (Fig. 2 show, the flow is combined and heated to the temperature needed for droplet evaporation in zone (0–1). A salt residue is created in zone (1-2) as a result of dynamic evaporation occurring in droplets. In zones (3–4) and (2–3), the salt residue decomposes into its gaseous and solid components, respectively [5].

The simultaneous activities occurring in the plasma reactor make the reactor design depicted in Fig. 2 rather hypothetical. Comparative analyses show that stage (1-2) of solvent evaporation can be regarded as a limiting process at temperatures of 1500 K and higher [7]. A multi-Physics model was created to explain the physical process under investigation. It describes the droplet evaporation dynamics in the air-plasma flow of aqueous-organic mixtures [6].

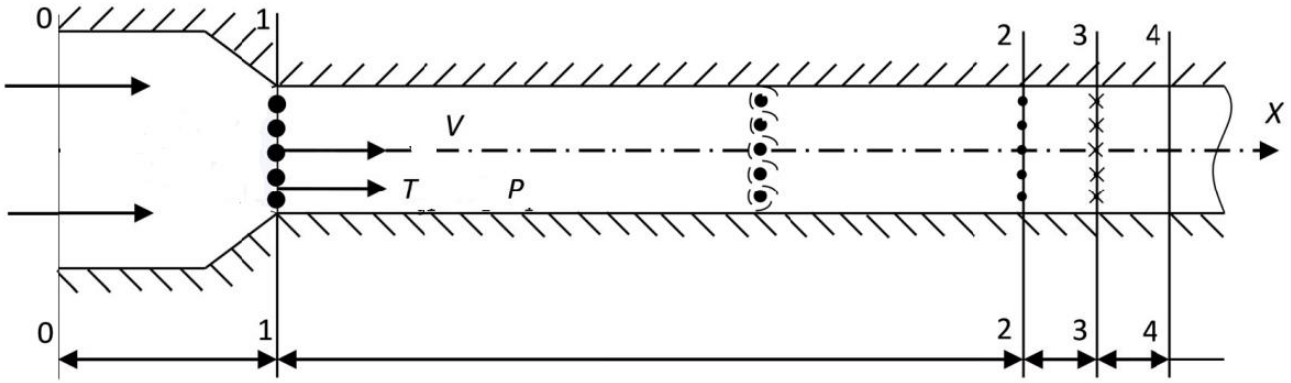

Figure 2- System of the reactor for dispersed combustible aqueous organic composition for treatment using plasma [1].

The following presumptions were made: the plasma reactor is a plug-flow reactor, the investigated processes are quasi-stationary, the air-plasma flow is adiabatic, the droplets are monodispersed and have no interactions with one another or the reactor walls, and the chemical reactions between the air plasma heat carrier and the water vapor do not occur [7].

4. Modelling a DC plasma torch with COMSOL Multi physics

Plasma torches are used in the energy sector to treat materials and produce plasma. Under the theory of local thermodynamic equilibrium, a DC non-transferred arc plasma torch was modeled using the Equilibrium Discharge interface in COMSOL Multi-physics 5.4.

A DC plasma torch contains numerous simultaneous physical mechanisms, making modeling it challenging. As a result, simplifications are needed to arrive at practical approaches [4].

$$\nabla \cdot (\rho u) = 0 \quad (4.1)$$

$$(u \cdot \nabla)u = \nabla \cdot [-pI + (\nabla u + (\nabla u)^{T}] - \frac{2}{3}\eta(\nabla \cdot U)I] + F \quad (4.2)$$

The fluid density and dynamic viscosity are the scalar magnitudes in the previous, Equations. Represent different types of motion, u, for example, stands forfluid velocity, P for pressure, and I for the identity tensor.,F represents the force of gravity, including the force of Lorentz force F_L. The Fourier equation with source and convection variables illustrates the torches [9].

Thermal energy conservation.

$$\rho Cpu\nabla T = \nabla \cdot (K\nabla T) + Q \quad (4.3)$$

The temperature is T, and the thermal conductivity, specific heat capacity, and heat source are all k, Cp, and Q, respectively. The Joule heating QJ, the net volumetric radiative loss, which is described by a total volumetric emissivity, and the enthalpy transport, i. H [6-10].

The energy transported by the electric current, are all explained by the Quantity The magnetic vector A and electric scalar V potentials are used to definesteady-state electromagnetic phenomena in the plasma torch [11].

$$\nabla \times A = B \quad (4.4)$$

$$E = -\nabla V \quad (4.5)$$

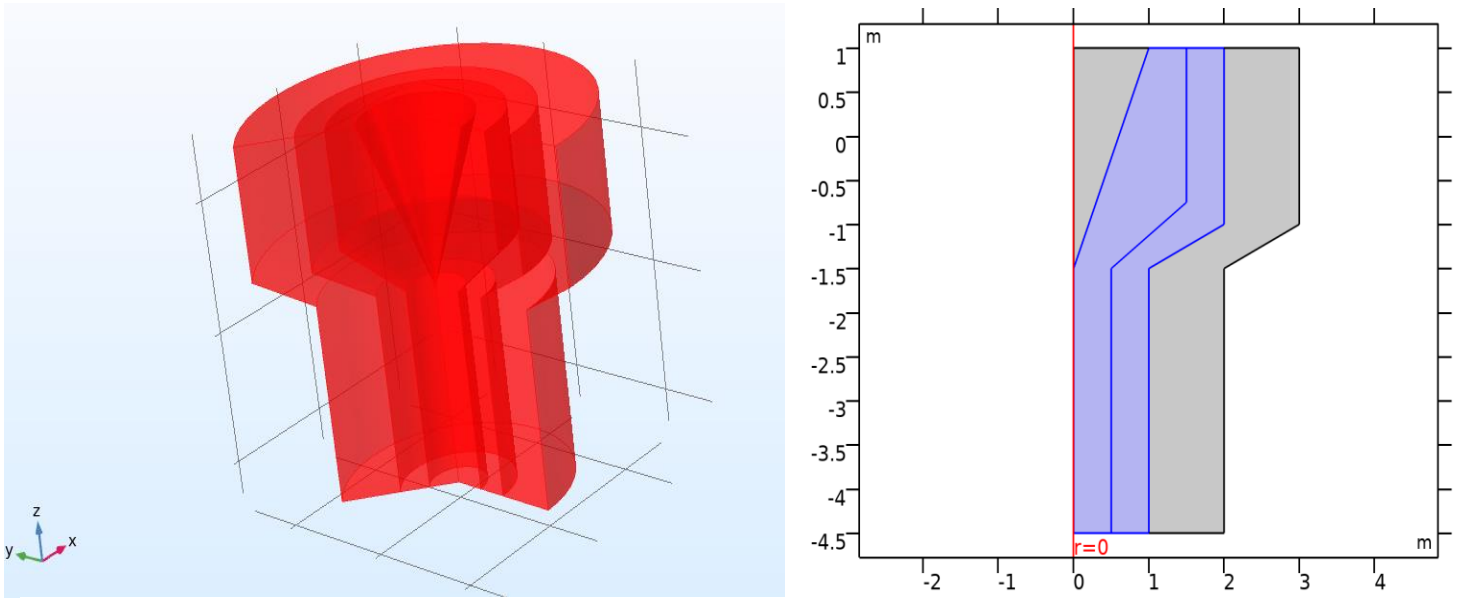

Figure 3- DC thermal with specific domains for Arc plasma flow and Uranyl Nitrate solution. Plasma Plant 3D Distribution, and 2D Plan [6].

Boundary condition for DC Arc Plasma torch is the strength of the electric field, and B is the magnetic flux density. Electric and magnetic field behavior is described by Maxwell's equations [7].

$$\nabla \times H = J \quad (4.6)$$

$$\nabla \times E = 0 \quad (4.7)$$

$$\nabla \cdot D = 0 \quad (4.8)$$

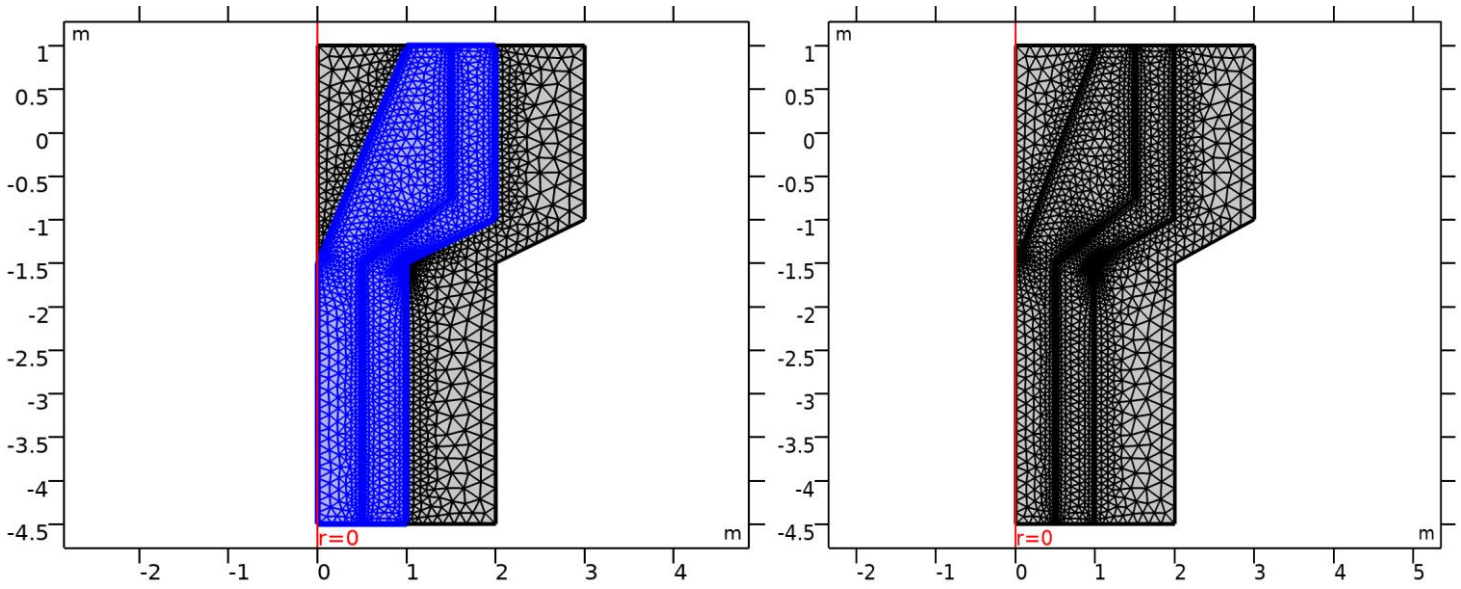

Figure 4 - DC thermal Plasma Plant Mesh, and 2D Plan Mesh with specific domains for Arc plasma flow and Uranyl Nitrate solution.

Numerical Results:

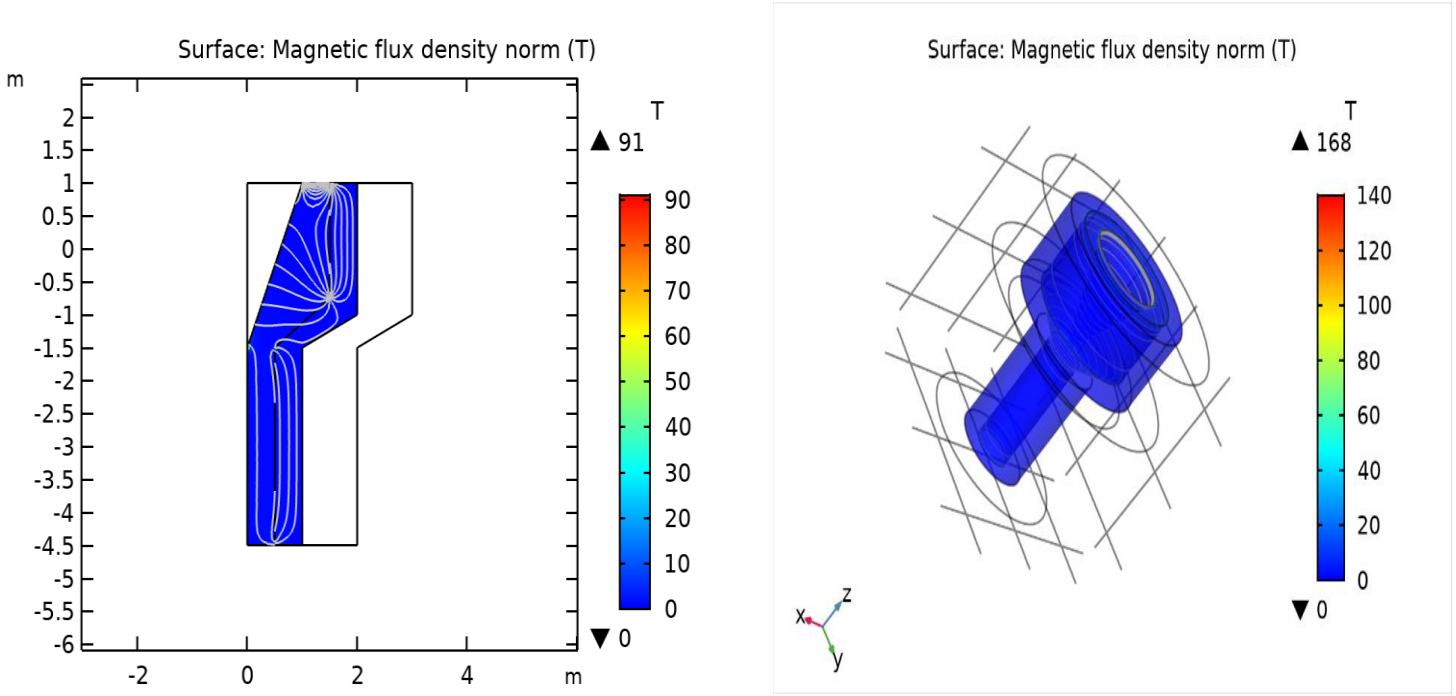

Figure 5- Magnetic flux density distribution.

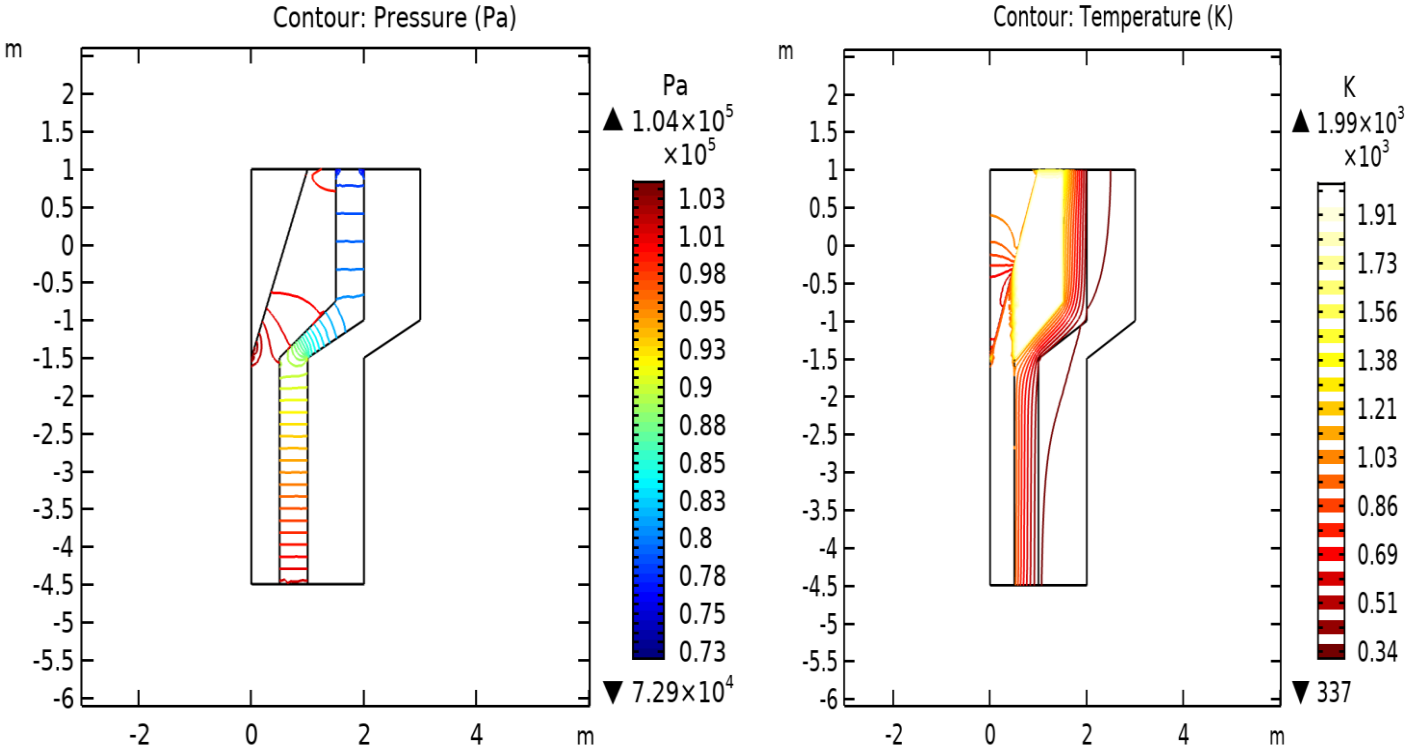

Figure 6- Pressure & Temperature Contour.

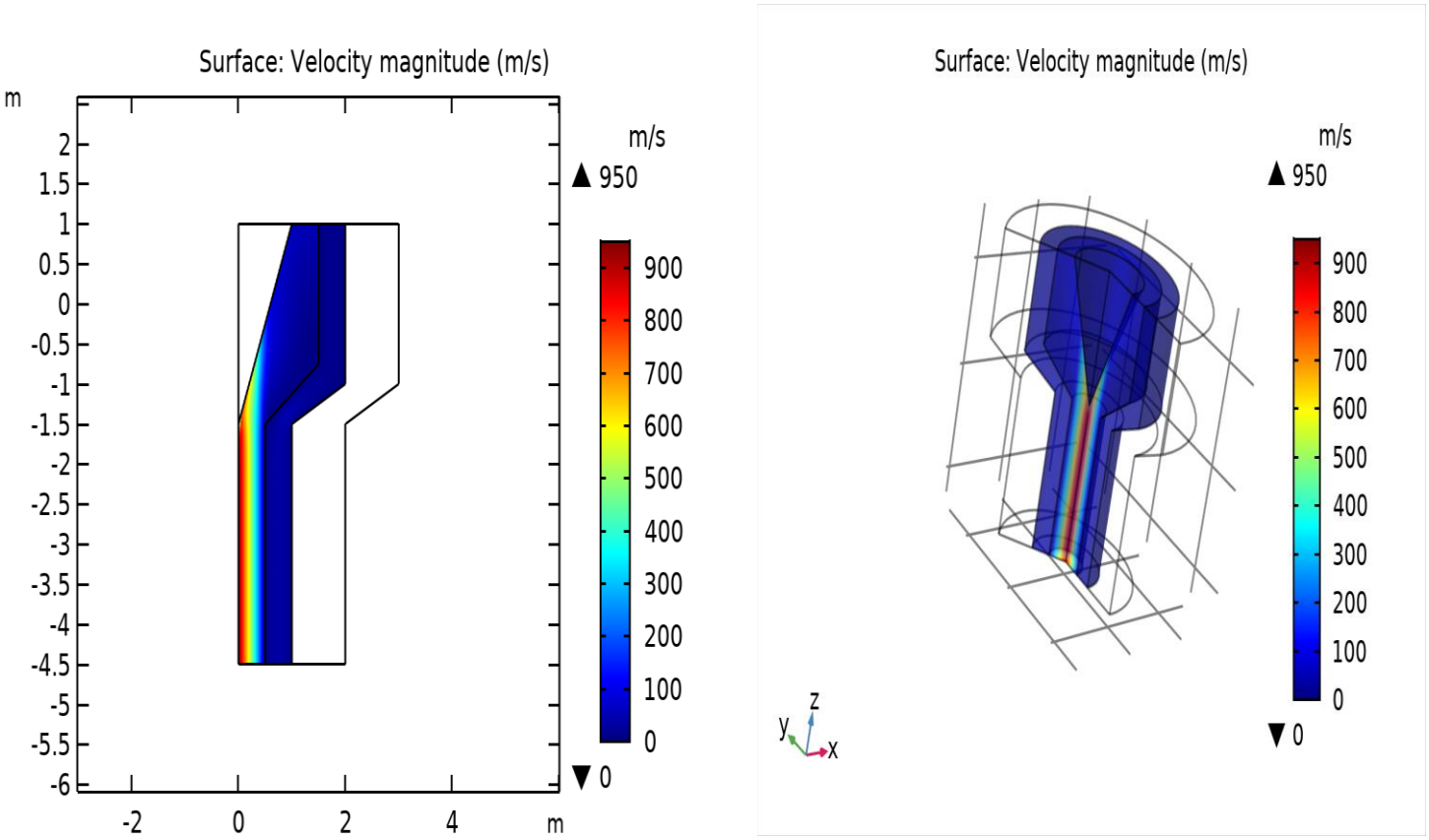

Figure 7-Surface velocity distribution 2 D&3 D.

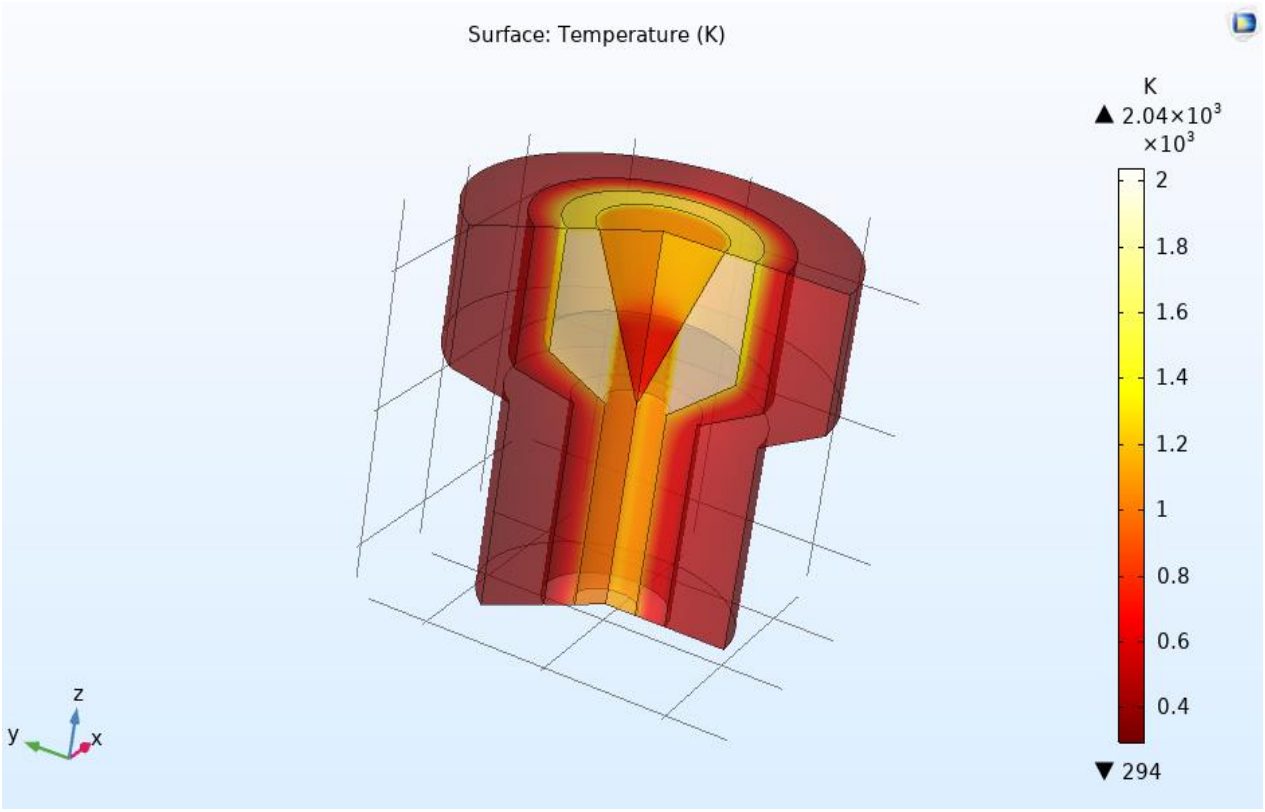

Figure 8- Surface Temperature 3D Distribution for DC Thermal Plasma Plant.

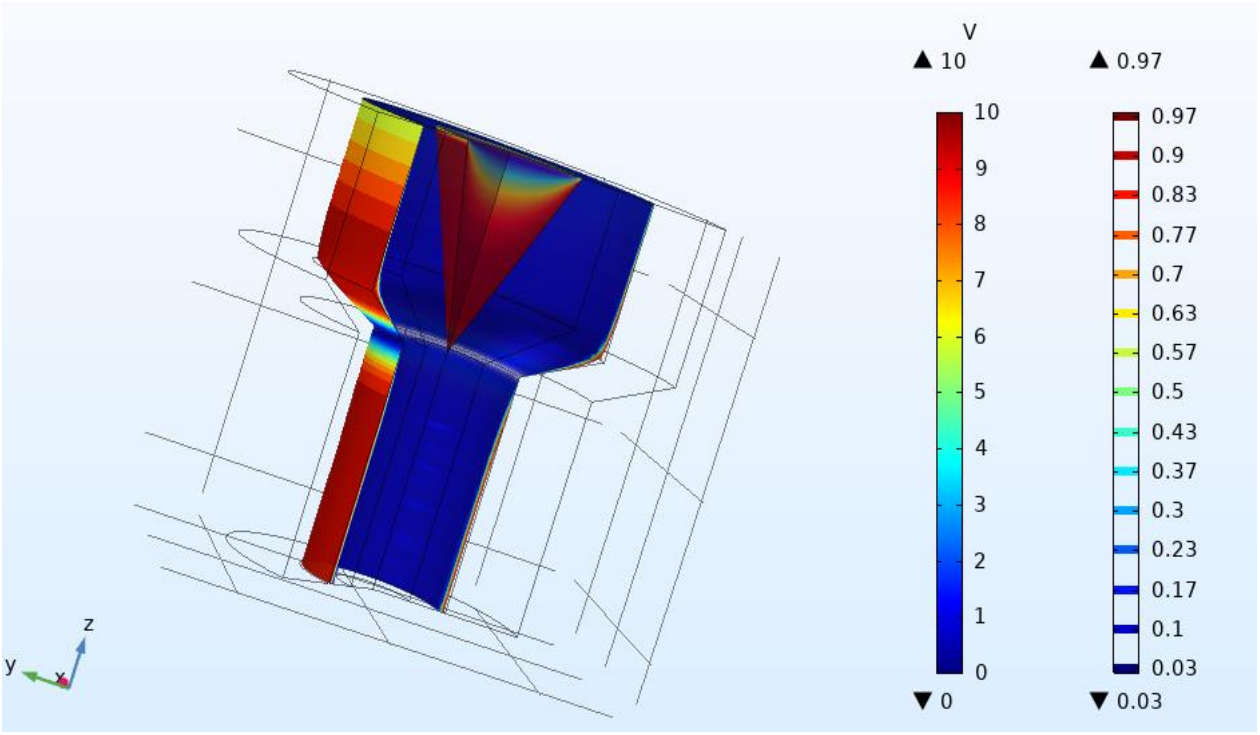

Figure 9- Iso Surface Phase Indicator from Phase 1 to Phase 2, and electric potential 3 D distribution.

5. Conclusion

The results of the research can be used to develop mechanical and technological solutions for securely disposing spent nuclear fuel reprocessing trash at Mining and Chemical Combine and other closed nuclear fuel cycle companies.

As a result of our research for the created COMSOL Multi-Physics model, patterns of the influence of the initial air-plasma flow parameters (temperature and velocity), liquid, and gaseous phases on the kinetics of evaporation of the dispersed aqueous-organic compositions in the air-plasma flow have been identified.

6. Acknowledgment

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7. References

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