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Transport of Cadmium through Molten Salt to Argon Cover Gas in Electrorefiner

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ABSTRACT

Electro refining is one of the important step in the Pyro processing of nuclear spent fuel. The electro refiner is a process vessel consists of anode ,cathodes and stirrers in molten salt and ultra –high pure argon gas is provided at the top for inert atmosphere and at the bottom , a cadmium layer is provided. As the vapour pressure of the cadmium is high at the operating temperature, the cadmium vapour transports through the molten salt and argon cover gas at the top of the electro refiner which may lead to the choking of components /mechanism. An axi-symmetric, 2-dimensional mathematical model in COMSOL Multiphysics® has been developed to study the transport of cadmium vapour through the salt solution and in argon gas region. This paper describes about the heat and mass transfer modelling of Cadmium transport using COMSOL. The analysis results shows that the cadmium vapour trap is necessary in the argon gas region.

INTRODUCTION

In electro refining process, spent fuel will be used as anode and cadmium as cathode. The electrolyte salt will be kept at 500°C, which is sufficiently above the eutectic melting point (360°C). The electrolytic process will be carried out in a crucible containing salt over 50 mm layer of cadmium and argon as a covering gas. Since the melting point and boiling point of Cadmium is 321°C an 767°C respectively, the cadmium will present in the molten state in the bottom layer. Since the vapour pressure of the cadmium at 500°C is high, the vapours of cadmium diffuses through the salt and argon gas and deposits at the cooler regions of the cover gas[1]. This paper describes the transport cadmium in salt and argon gas region.

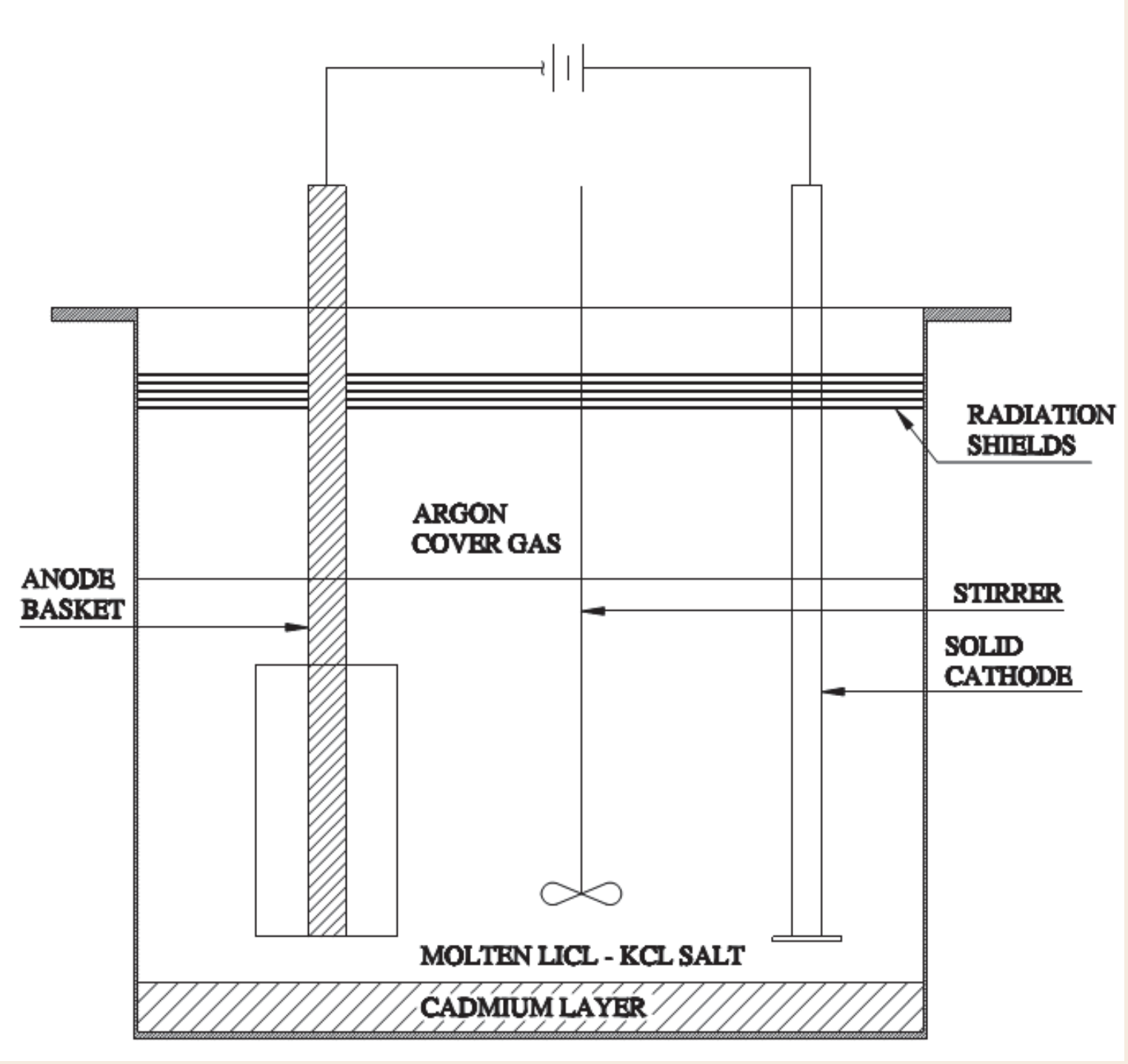


Fig.1: 2D schematic models of Electro Refiner

MODELING IN COMSOL

In this model the transport of cadmium in the salt region and argon gas region under transient condition is considered. The convection in the salt due to the stirrer is modelled using turbulent mixing in the salt and the temperature of salt is uniform at 500°C. The natural convection in the argon gas is modelled using heat transfer in the argon cover gas region. A 2-D axi-symmetric model in cylindrical co-ordinates is considered. The bottom region is filled with eutectic LiCl-KCl salt mixture with stirrer . The argon cover gas is above the salt surface. The diameter of the cylindrical process vessel is 0.880 m .The height of the salt level is 0.320 m and the height of the argon region below the radiation shield is 0.389 m.

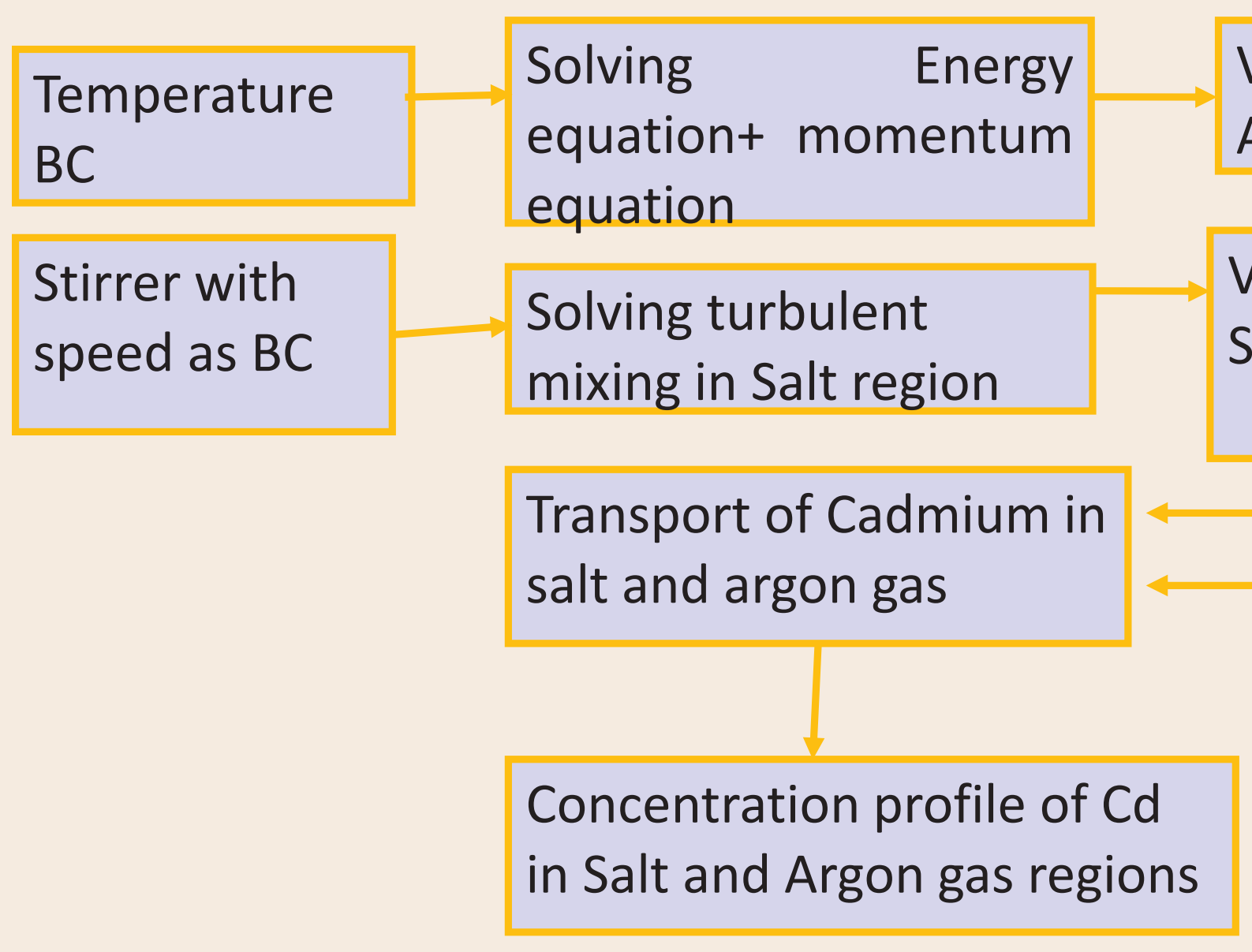
GOVERNING EQUATIONS

$$\frac{\partial c_i}{\partial t} - \nabla.(-D_i \nabla c_i) + u.\nabla c_i = R_i$$

$$\nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial}{\partial t}(\rho u) + [\nabla.\rho u u] = -\nabla p - [\nabla.\tau] + \rho g$$

$$\rho C_p (u.\nabla T) = k\nabla^2 T + \mu\varphi_v$$



Temperature BC

Solving Energy equation+ momentum equation

Velocity Profile in Argon gas region

Stirrer with speed as BC

Solving turbulent mixing in Salt region

Velocity profile in Salt region

Transport of Cadmium in salt and argon gas

Concentration profile of Cd in Salt and Argon gas regions

Fig. 2: Sequential of solution different fields in transport of Cd

S. No	Parameter	Value
1	Vapour pressure of Cd at 500°C	15 mm Hg
2	Concentration of Cd	0.3 mol/m^3
3	Diffusivity of Cd in salt	$0.17x10^{-}cm^2/s$
4	Diffusivity of Cd in Argon	0.17 cm^2/s
5	Speed Stirrer	50,90, 120rpm

Table 1: Important parameters used in simulation

BOUNDARY CONDITIONS

No slip , pressure point constraint - heat transfer module.
Pressure, sliding wall, no slip wal- turbulent flow module.
The axial symmetry, no flux and concentration -transport of mass module.

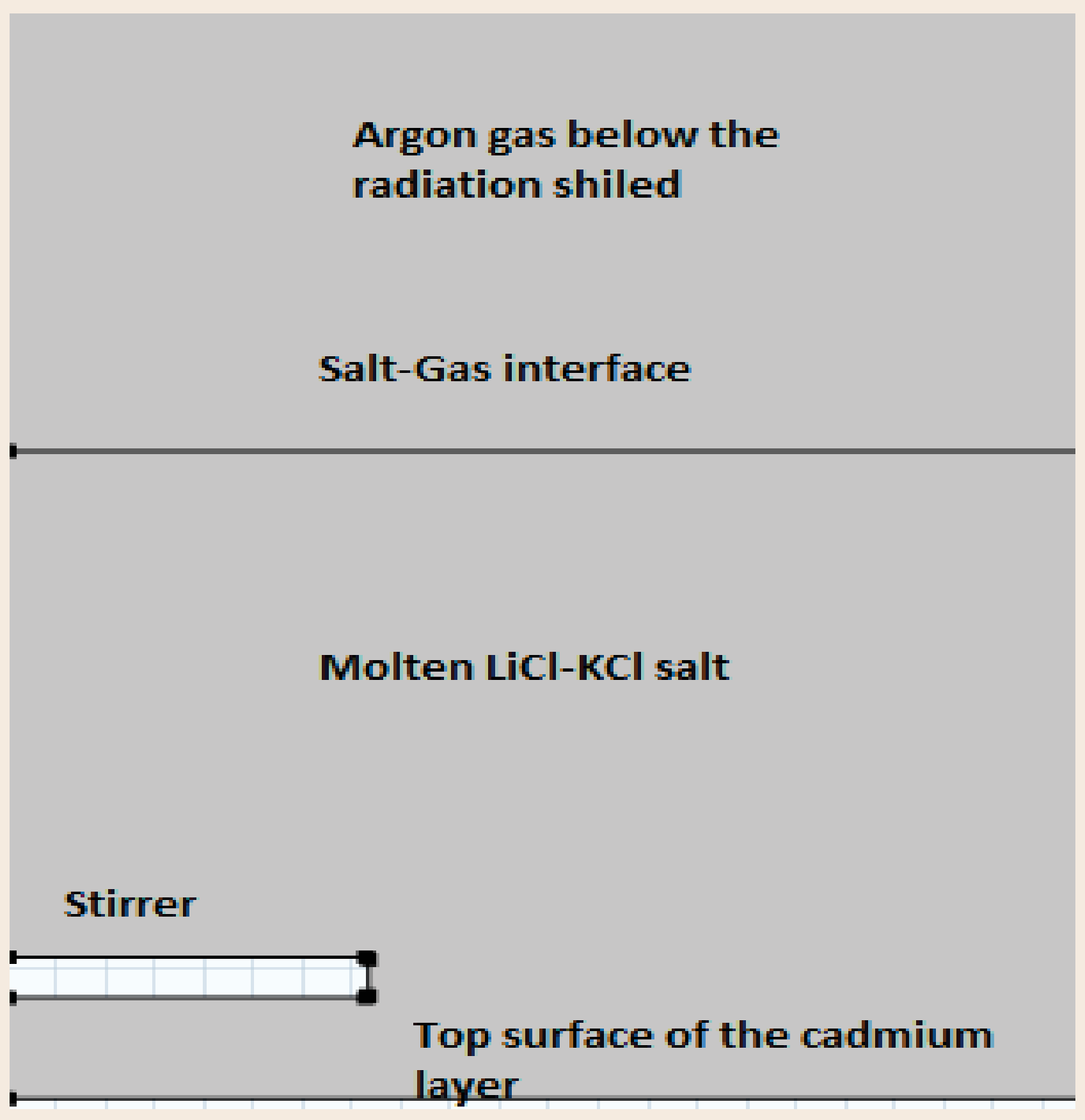


Fig.3: 2D axi-symmetric models of Electro Refiner

RESULTS

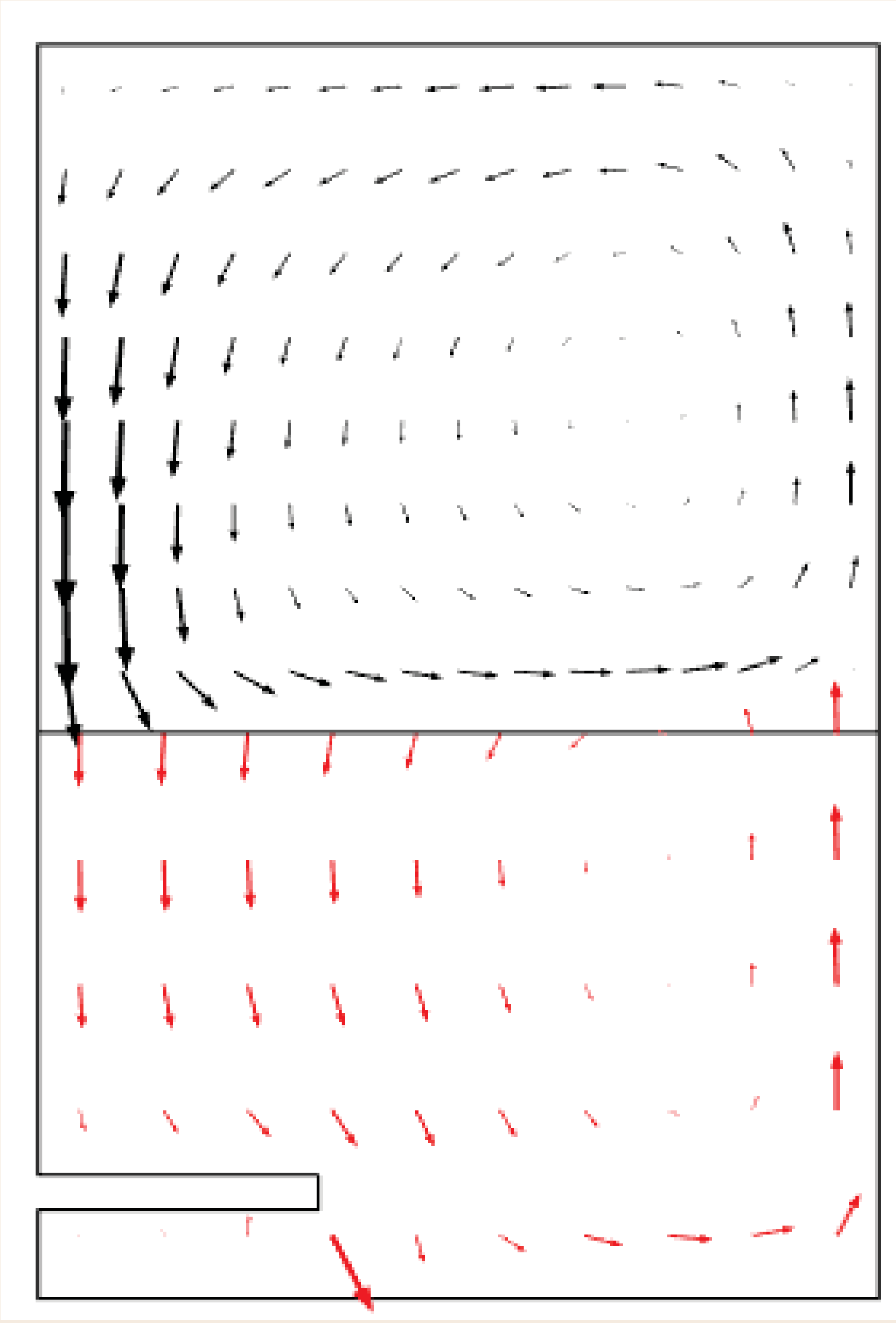


Fig. 3: Velocity profiles in argon and salt regions.

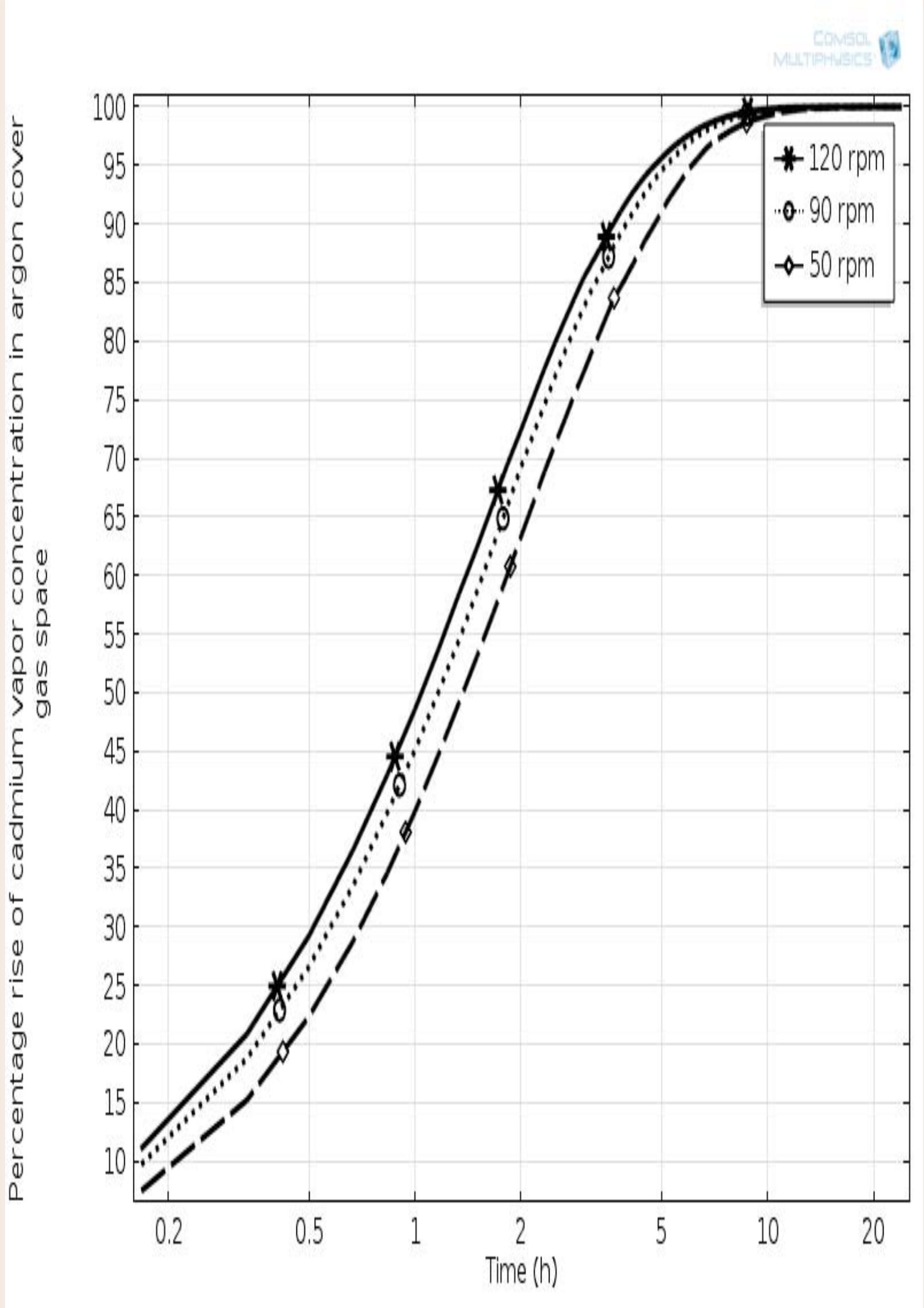


Fig. 4: Percentage rise of Cd concentration in argon for different speed of stirrer in salt space.

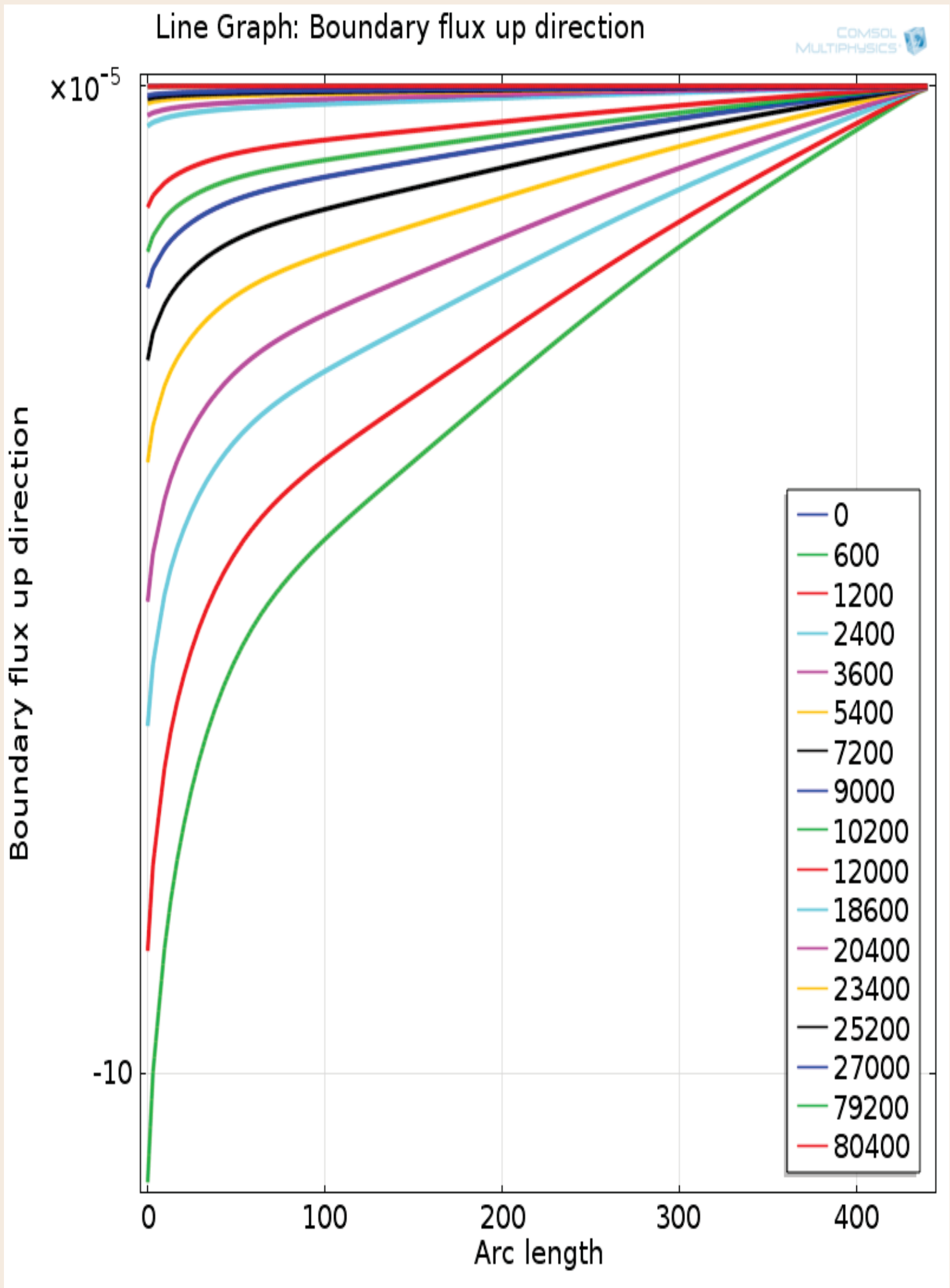


Fig.5: Boundary flux along the salt –argon interface under transient condition.

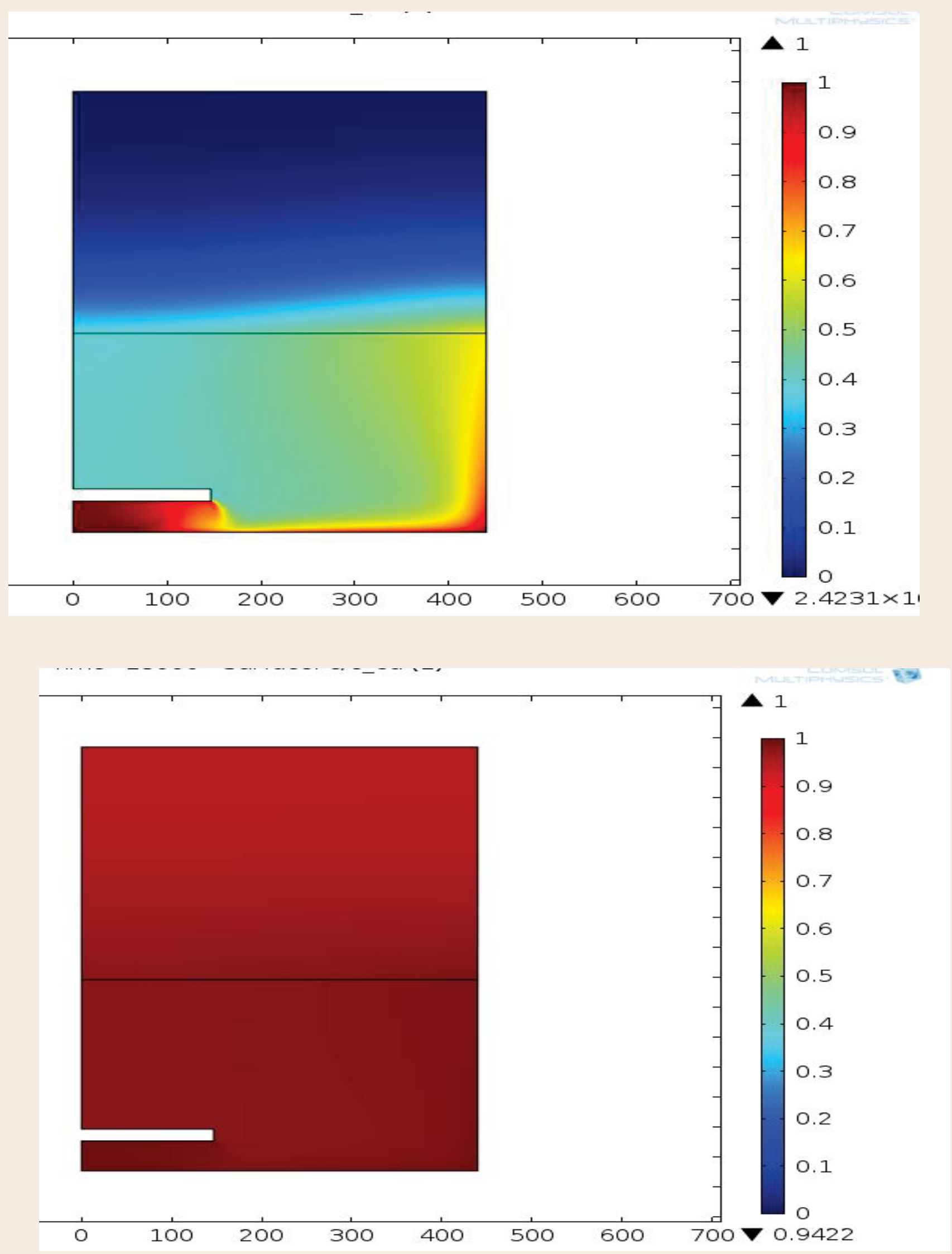


Fig. 6a&6b: Cd concentration profiles in the salt and in argon gas space after 0.1 hr and after 5 hr.

CONCLUSIONS

A detailed mass and thermal analysis were carried out for transport of cadmium vapours through molten salt to argon gas space for the unsteady state condition in HTER. From the analysis, the turbulence due to the stirrer in the molten salt will increase the transport of cadmium vapour to argon gas. Similarly the larger temperature difference along the height of the argon gas will enhance convection which in turn increase the transport rate of cadmium vapours. The approximate rate of cadmium vapour to argon gas space is 0.012 g/hr. So, the cadmium vapour trap is necessary in the argon gas region.

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