Electrohydrodynamic instability in a dielectric fluid saturated porous layer with uniform volumetric heat sources: Effect of boundary conditions

C E Nanjundappa[1a], C S Rachitha[1b]
[1]Department of Mathematics, Dr.Amebdkar institute of technology, Bengaluru 560056, Karnataka, India
Email: nanjundappace@gmail.com; rachithacs1996@gmail.com

1. INTRODUCTION & OBJECTIVE

Electro-hydrodynamics is the study of the relation between the electric field and the motion of dielectric fluids possessing low electrical conductivity. In dielectric fluids, electrical conductivity and dielectric permittivity produces non-uniformities with an applied thermal gradient. Convection in a layer of dielectric fluid can occur even if the temperature gradient is stabilizing and such instability is termed as Benard electro convection. Many studies related to the general electro convection are discussed in Takashima and Aldridg (1), Ravisha et al. (2), Savitha et al (3), Kulacki and Goldstein (4) and Shivakumara et al.(5). To the best of our knowledge, a similar study on BEC has not received any attention in the literature despite the study finds importance in understanding control of convection by different forms of boundary conditions with uniform temperature gradient arising due to internal heating. Therefore intent of this study is to examine the effect of volumetric heat source on the onset of BEC in a dielectric fluid saturated porous medium. This problem might be called "mixed electro convection" in a dielectric fluid layer in the presence of an AC electric field. The stability eigenvalue problem turns out to be one with variable coefficient and solved numerically using the Galerkin method. The results are presented in terms of critical Rayleigh number R_{tc} for various values of electric Rayleigh number R_e, Darcy number Da, ratio of viscosity Λ, internal heating parameter Ns and the Biot number Bi.

2. GOVERNING STABILITY EQUATIONS

$$\left[\Lambda(D^2-a^2)-\frac{1}{Da}\right]W-a^2R_t\Theta-a^2R_e\,f(z)(\Theta+D\Phi)=0 \qquad (1)$$

$$\left(D^2-a^2\right)\Theta+f(z)W=0 \qquad (2)$$

$$\left(D^2-a^2\right)\Phi+D\Theta=0 \qquad (3)$$

where $f(z)=-\dfrac{d}{\Delta T}\dfrac{dT_b}{dz}=2\,z\,Ns$

(i) R-R boundaries

$W=DW=0,\ D\Phi-\Theta=0$ at $z=0,\ 1$ and $D\Theta=0$ at $z=0,\ D\Theta+Bi\,\Theta=0$ at $z=1$

(ii) F-F boundaries

$W=D^2W=0,\ D\Phi-\Theta=0$ at $z=0,\ 1$ and $D\Theta=0$ at $z=0,\ D\Theta+Bi\,\Theta=0$ at $z=1$

(iii) R-F boundaries

$W=DW=0,\ D\Theta=0,\ D\Phi-\Theta=0$ at $z=0$, $W=D^2W=0,\ D\Theta+Bi\,\Theta=0,\ D\Phi-\Theta=0$ at $z=1$

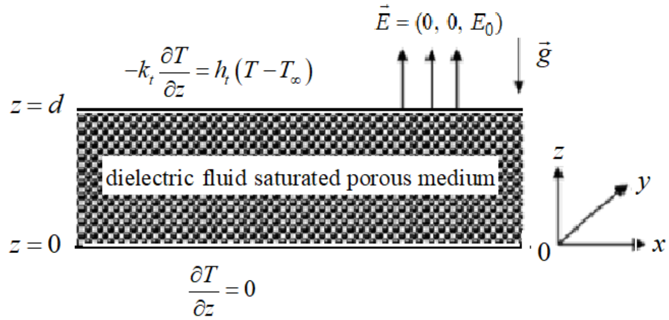
Table 1. Comparison of $(R_{tc}\ \ a_c)$ and $(R^*_{tc},\, a_c)$ with Bi when $R_e = Da^{-1} = 0$ and $\Lambda = Ns = 1$.
(Kulachi and goldstein (4) and Present study)

Bi	R-R Surfaces			R-F Surfaces			F-F Surfaces		
	a_c	R_{tc}	R^*_{tc}	a_c	R_{tc}	R^*_{tc}	a_c	R_{tc}	R^*_{tc}
∞	2.629	1386.624	43.332	2.261	806.316	25.197	1.789	433.888	13.559
100	2.615	1371.206	42.850	2.248	791.824	24.744	1.781	426.153	13.317
0	0.00	720.00	22.500	0.00	288.00	9.00	0.00	120.00	3.75

3. RESULTS & HIGHLIGHTS

The linear stability theory is employed to analyze the impact of AC electric field on the onset of BEC in a dielectric fluid saturated porous layer subject to uniform volumetric heat source owing to the different boundary conditions. The stability eigenvalue problem is solved using the Galerkin method. The parameters influencing the stability characteristics are the Darcy number Da, the ratio of viscosity Λ, the strength of internal heat source Ns, the Biot number Bi and the electric Rayleigh number R_e. The convection sets in at lower values of critical Rayleigh number with increasing Da, Ns and R_e, while increasing Bi shows an opposite trend on the same. The value of R_{ec} decreases with increasing R_{tc} and vice-versa i.e. when the gravitational (electric) force is prominent then the electric (gravitational) force becomes inconspicuous and also $R_{tc} < R_{ec}$. The system is more stable for rigid-rigid and upper conducting $(\Theta = 0)$ surfaces while free-free and upper insulating $(D\Theta = 0)$ surface is least stable.

4. PHYSICAL CONFIGURATION



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