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Varying G and Λ model for a barotropic fluid with Magnetic Field in General Relativity

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ABSTRACT: The Bianchi type V cosmological model for Bulk viscous barotropic fluid with variable gravitational constant [G(t)], and the variable cosmological constant [$\Lambda(t)$], in presence of magnetic field is investigated. To get a determinate model, we impose a physically viable conditions between metric potentials. We have also used, $p = \gamma\rho, and\ \eta = \eta_0\rho^s$, where ρ is energy density, η is shear viscosity, and $P = p - 3\eta H$ with $0 \leq \gamma \leq 1$. H is the well known Hubble parameter. Some physical and kinematical characteristics of the model are also discussed in presence and absence of the magnetic field. We obtained $\frac{\sigma}{\theta} \neq 0$, hence anisotropy is maintained throughout. The considered model represents inflationary scenario.

Keywords: Bianchi Type V models, Barotropic fluid, Varying G and Λ, Magnetic field.

I. INTRODUCTION

Beesham (1986) points out that the observations seems to varying Gravitational constant G is inversely proportional with respect to time Rahman (1990) studied varying Gravitational constant G and cosmological constant Λ and obtained G increases and Λ decreases with time in a manner consistent with conservation of the energy momentum tensor. Berman (1991); Kalligas *et al.* (1992) also find that the cosmological term at early universe was very high. The sign of curvature for Bianchi type-V is always negative and it represents a model with open universe Beesham (1986). The type-V spaces constitute the natural generalization of the $k = -1$, Friedmann-Robertson-Walker models. Open models are favored by low-density Gott (1974) universe. The Bianchi type-V models have been investigated by a number of authors. Schucking and Heckmann have studied Bianchi type-V models with u^i orthogonal to the hypersurfaces of homogeneity. Matzner (1969) have obtained some exact solutions for Bianchi type-V models. Beesham (1986) derived tilted Bianchi type - V cosmological models in the scale-covariant theory for radiative as well as non-radiative case. Nayak and Sahoo (1989) have discussed the evolution of the nontilted, diagonal, nonlocally rotationally symmetric Bianchi Type V models with a matter distribution that allows anisotropic pressure and heat flow. They found that if the entropy of Bianchi type-V models is assumed to be increasing, the anisotropy density necessarily decreases faster than the case with perfect fluid as the source. Billyard *et al.* [9] have studied scalar field cosmologies with barotropic matter models of Bianchi class B. Matter fields such as magnetic fields have a profound influence on the evolution and properties of galaxies Bali & Kumawat (2008). It has been conjectured that the early Universe was an undifferentiated soup of matter and radiation in a state of thermal equilibrium. The incorporation of an electromagnetic field and matter into the space-time of Bianchi type-V with equation of state $p = \epsilon$, has been given by Ftaclas and Cohen. Lorenz (1981) has discussed an exact Bianchi type-V tilted cosmological model with matter and electromagnetic field. Singh has investigated the Bianchi type-V cosmological solutions of massive strings in the presence and absence of the magnetic field. Bali and Sharma (2004) analyzed Tilted Bianchi type I cosmological models for barotropic perfect fluid in general relativity. Bali and Jain (2007) examine the Bianchi type V magnetized string dust cosmological model for perfect fluid distribution is investigated.

Weinberg (1967) suggested that Λ is a function of temperature and is related to the spontaneous symmetry breaking process. FRW cosmology in such a way that the models without a cosmological constant seem to be effectively ruled out [16]. Bali and Bali and Tinker (2008) have investigate the Bianchi type-V bulk viscous barotropic fluid cosmological model with variable gravitational constant G and the cosmological constant Λ. Using these two forms, Einstein's field equations for perfect fluid Bianchi type-V models are solved separately that correspond to singular and non-singular models respectively. Bali (2008) proposed Bianchi Type V magnetized string dust universe with variable magnetic permeability is investigated. The magnetic field is due to an electric current produced along x-axis. Thus F_{23} is the only non-vanishing component of electro-magnetic field tensor F_{ij}. Maxwells equations $F[ij;k] = 0; F_{ij;j} = 0$ are satisfied by F_{23} = constant. Kumar and Srivastava (2013) have studied some new aspects of the Bianchi type-V space time. The Electric and Magnetic parts of Weyl tensors are calculated in terms of tilted congruence and discussed the purely magnetic Weyl tensor. Einstein field equations for purely magnetic space time are obtained and solution of such field equations called purely magnetic solution. Borkar *et al.* (2013) have studied Bianchi type I bulk viscous barotropic fluid cosmological model with varying Λ and functional relation on Hubble parameter in self-creation theory of gravitation Borkar & Ashtankar (2013). The cosmological constant Λ is found to be a positive decreasing function of time Chawla *et al.* (2012); Chaubey and Shukla (2017) have corroborated by results from recent Supernovae Ia observations.

Tiwari *et al.* (2021) have studied Accelerating universe with varying Λ in *f(R, T)* theory of gravity. The possibility of variable G is considered by Dirac (1937). Weinberg (1967) suggested that Λ is a function of temperature and is related to the spontaneous symmetry breaking process. Many author's obtained that gravitational constant G and cosmological constant Λ are $\sim R^{-2} \sim t^{-2}$. Recently modification taken by Bali and Tinker (2008) have Bianchi type-V bulk viscous barotropic fluid cosmological model with variable G and Λ, throughout the paper the author's obtained $\Lambda \propto \frac{1}{t^2}$ and the gravitational constant G increases with time t. The organization of this paper as follows: In section 2, we have established Einstein field Equation in next section we solve them when using $B = C^n$, $\eta = \eta_0 \rho^s$ and $p = \gamma\rho$, $(0 \le \gamma < 1)$. In section 4 we discussed the graphical behavior of the models, finally we conclude.

II. BIANCHI TYPE-V MODEL AND FIELD EQUATIONS

Let us consider Bianchi Type V model representation in the form

$$ds^2 = -dt^2 + A^2dx^2 + e^{2x}(B^2dy^2 + C^2dz^2) \tag{2.1}$$

Einstein's Field Equation is given by

$$R_i^j - \frac{1}{2}Rg_i^j = -8\pi G T_i^j + \Lambda g_i^j \tag{2.2}$$

Where G and Λdefined gravitational constant and cosmological constant respectively, function of time t.

The representation of energy momentum tensor, T_i^j as,

$$T_i^j = (\rho + P)v_i v^j + P g_i^j + E_i^j \tag{2.3}$$

Here E_i^j denoted as Magnetic field [15, **3**] and expansion of it

$$E_i^j = \bar{\mu}\left[|h|^2\left(v_i v^j + \frac{1}{2}g_i^j\right) - h_i h^j\right] \tag{2.4}$$

with

$$h_i = \frac{\sqrt{-g}}{2\bar{\mu}}\epsilon_{ijkl}F^{kl}v^j \tag{2.5}$$

The non-vanishing component of electromagnetic field tensor is, $F_{23} = K$, where K is constant.

We assume

$$P = p - 3\eta H \tag{2.6}$$

where p is the equilibrium pressure, η is the coefficient of viscosity and $\rho$is the energy density, together with $v_i v^j = -1$.

To get deterministic model in terms of cosmic time t, we have assume that magnetic permeability $\bar{\mu}$ is a variable quantity and assumed as $\bar{\mu} = e^{-4x}$.

Einstein's field equation (2.2) for the Bianchi Type-V metric (2.1) with using equations [2.3-2.5] gives,

$$\frac{B_{44}}{B} + \frac{C_{44}}{C} + \frac{B_4C_4}{BC} - \frac{1}{A^2} = -8\pi G\left(P - \frac{K^2}{2B^2C^2}\right) + \Lambda \tag{2.7}$$

$$\frac{A_{44}}{A} + \frac{C_{44}}{C} + \frac{A_4C_4}{AC} - \frac{1}{A^2} = -8\pi G\left(P + \frac{K^2}{2B^2C^2}\right) + \Lambda \tag{2.8}$$

$$\frac{B_{44}}{B} + \frac{A_{44}}{A} + \frac{B_4A_4}{BA} - \frac{1}{A^2} = -8\pi G\left(P + \frac{K^2}{2B^2C^2}\right) + \Lambda \tag{2.9}$$

$$\frac{A_4B_4}{AB} + \frac{A_4C_4}{AC} + \frac{B_4C_4}{BC} - \frac{3}{A^2} = 8\pi G\left(\rho + \frac{K^2}{2B^2C^2}\right) + \Lambda \tag{2.10}$$

$$\frac{2A_4}{A} - \frac{B_4}{B} - \frac{C_4}{C} = 0 \tag{2.11}$$

In the above field equations Suffix 4 represents differentiation with respect to time t.

The divergence of Einstein tensor gives one extra equation, the relation between $[G(t)]$ and $[\Lambda(t)]$, i.e. $\left(R_i^j - \frac{1}{2}g_i^j\right)_{;j} = 0$

Which leads to $\left(8\pi G T_i^j - \Lambda g_i^j\right)_{;j} = 0$, then

$$8\pi G\left[\frac{2K^2}{B^2C^2} + (P + \rho)\left(\frac{A_4}{A} + \frac{B_4}{B} + \frac{C_4}{C}\right) + \rho_4\right] + 8\pi G_4\left(\rho + \frac{K^2}{2B^2C^2}\right) + \Lambda_4 = 0, \tag{2.12}$$

the conservation of energy after using

$$\frac{2K^2}{B^2C^2} + (p + \rho)\left(\frac{A_4}{A} + \frac{B_4}{B} + \frac{C_4}{C}\right) + \rho_4 = 0 \tag{2.13}$$

Now taking the relation,

$$\eta = \eta_0 \rho^s \tag{2.14}$$

η_0 is a positive number and s is constant. To find the complete solution for the model, we assume the condition

$$p = \gamma\rho, (0 \le \gamma < 1) \tag{2.15}$$

III. SOLUTIONS OF THE FIELD EQUATIONS

Here we solve the Einstein field equations

Equations (2.8) and (2.9) lead to

$$\frac{C_{44}}{C} + \frac{A_4C_4}{AC} = \frac{B_{44}}{B} + \frac{A_4B_4}{AB} \tag{3.1}$$

Using equation (2.11) in equation (3.1) we obtain,

$$\frac{B_{44}}{B} + \frac{1}{2}\left(\frac{B_4}{B}\right)^2 = \frac{C_{44}}{C} + \frac{1}{2}\left(\frac{C_4}{C}\right)^2 \tag{3.2}$$

These field equations are five nonlinear ordinary differential equations in seven unknowns, so we need at least two constraints to solve them exactly. We take,

$$B = C^n \tag{3.3}$$

Where n is a positive constant.

Using equation (3.3) in equation (3.2) we get,

$$\frac{C_{44}}{C} = \frac{\left(n-\frac{3}{2}n^2+\frac{1}{2}\right)}{(n-1)} \cdot \left(\frac{C_4}{C}\right)^2 \tag{3.4}$$

Integrating equation (3.4) with respect to the time variable we get,

$$C = [(1-\alpha)(k_1 t + k_2)]^{\frac{1}{(1-\alpha)}} \tag{3.5}$$

Here $\alpha = \frac{2n-3n^2+1}{2(n-1)}$, k_1 and k_2 are constants of integration.

Putting the value of C from equation (3.5) in equation (3.3) we have

$$B = [(1-\alpha)(k_1 t + k_2)]^{\frac{n}{(1-\alpha)}} \tag{3.6}$$

and

$$A = k_3[(1-\alpha)(k_1 t + k_2)]^{\frac{n+1}{2(1-\alpha)}} \quad , \tag{3.7}$$

where k_3 is a constant of integration.

Hence metric (2.1) leads to the following form

$$ds^2 = -dt^2 + {k_3}^2[(1-\alpha)(k_1 t + k_2)]^{\frac{(n+1)}{(1-\alpha)}} dx^2 + e^{2x}\left([(1-\alpha)k_1 t + k_2]^{\frac{2n}{(1-\alpha)}} dy^2 + [(1-\alpha)k_1 t + k_2]^{\frac{2}{(1-\alpha)}} dz^2\right) \tag{3.8}$$

After using suitable transformation the metric (2.1) reduces to

$$dS^2 = -\frac{1}{{k_1}^2} dT^2 + [(1-\alpha)T]^{\frac{n+1}{(1-\alpha)}} dX^2 + e^{2x}[(1-\alpha)T]^{\frac{2n}{(1-\alpha)}} dY^2 + e^{2x}[(1-\alpha)T]^{\frac{2}{(1-\alpha)}} dZ^2 \tag{3.9}$$

Where $k_3 x = X$,

$y = Y$,

$z = Z$,

$s = S$, and

$k_1 t + k_2 = T$.

IV. SOME PHYSICAL PARAMETERS

Subtracting equation (2.7) from (2.10) we get,

$$\frac{B_{44}}{B} + \frac{C_{44}}{C} - \frac{A_4 B_4}{AB} - \frac{A_4 C_4}{AC} + \frac{2}{A^2} = -8\pi G(P+\rho) \tag{4.1}$$

Using equations (3.5)-(3.7) and (2.15) the equation (4.1) becomes

$$-8\pi G = \frac{\left\{(n+1)\frac{C_{44}}{C} - \left(\frac{(n+1)^2}{2}\right)\left(\frac{C_4}{C}\right)^2 + \frac{8}{C^{(2n+2)}}\right\}}{(1+\gamma)\rho - 3\eta H} \tag{4.2}$$

From equation (2.13)

$$\rho_4 + \frac{3(1+\gamma)(n+1)}{2} \cdot \frac{C_4}{C} \cdot \rho = -\frac{2K^2}{C^{(2n+2)}} \tag{4.3}$$

Using first order linear differential equations techniques we get density of the model is,

$$\rho = \frac{1}{T^b} \cdot \left\{\frac{-2K^2}{d} \cdot \frac{1}{k_1} \cdot \frac{T^{(c+1)}}{(c+1)} + L\right\} \tag{4.4}$$

Where L is constant of integration.

Where,

$$b = \frac{3(1+\gamma)(n+1)}{2(1-\alpha)} \tag{4.5}$$

$$c = \frac{(3\gamma-1)(n+1)}{2(1-\alpha)} \tag{4.6}$$

$$d = (1-\alpha)^{\left(\frac{2(n+1)}{1-\alpha}\right)} \tag{4.7}$$

Equation (2.15) gives pressure of the model as,

$$p = \frac{\gamma}{T^b} \cdot \left\{\frac{-2K^2}{d} \cdot \frac{1}{k_1} \cdot \frac{T^{(c+1)}}{(c+1)} + L\right\} \tag{4.8}$$

Using the equation (3.5) and equation (4.4) in equation (4.2)

$$8\pi G = -\frac{\left\{(n+1){k_1}^2\alpha - \left(\frac{(n+1)^2}{2}\right){k_1}^2 + 8[(1-\alpha)T]^{\frac{-2(n+1)}{(1-\alpha)}+2}\right\}}{\left\{\frac{(1-\alpha)^2(1+\gamma)}{T^{b-2}} \cdot \left(\frac{-2K^2}{d} \cdot \frac{1}{k_1} \cdot \frac{T^{(c+1)}}{(c+1)} + L\right) - 3\eta_0\left(\frac{1}{T^b} \cdot \left(\frac{-2K^2}{d} \cdot \frac{1}{k_1} \cdot \frac{T^{(c+1)}}{(c+1)} + L\right)\right)^S \cdot \frac{(n+1)}{2} \cdot k_1[(1-\alpha)T]\right\}} \tag{4.9}$$

For variable cosmological constant Λ from equation (2.10)

$$\Lambda(t) = \frac{\left\{(n+1){k_1}^2\alpha - \left(\frac{(n+1)^2}{2}\right){k_1}^2 + 8[(1-\alpha)T]^{\frac{-2(n+1)}{(1-\alpha)}+2}\right\} \cdot \left\{\frac{1}{T^b} \cdot \left(\frac{-2K^2}{d} \cdot \frac{1}{k_1} \cdot \frac{T^{(c+1)}}{(c+1)} + L\right) + \frac{K^2}{2[(1-\alpha)T]^{\frac{2(n+1)}{(1-\alpha)}}}\right\}}{\left\{\frac{(1-\alpha)^2(1+\gamma)}{T^{b-2}} \cdot \left(\frac{-2K^2}{d} \cdot \frac{1}{k_1} \cdot \frac{T^{(c+1)}}{(c+1)} + L\right) - 3\eta_0\left(\frac{1}{T^b} \cdot \left(\frac{-2K^2}{d} \cdot \frac{1}{k_1} \cdot \frac{T^{(c+1)}}{(c+1)} + L\right)\right)^S \cdot \frac{(n+1)}{2} \cdot k_1[(1-\alpha)T]\right\}}$$

$$+ \frac{(n^2+4n+1){k_1}^2}{2[(1-\alpha)T]^2} - \frac{12}{[(1-\alpha)T]^{\frac{2(n+1)}{(1-\alpha)}}} \tag{4.10}$$

As we have taken condition for bulk viscosity

$$\eta = \eta_0 . \left[\frac{1}{T^b} . \left(\frac{-2K^2}{d} . \frac{1}{k_1} . \frac{T^{(c+1)}}{(c+1)} + L\right)\right]^s \tag{4.11}$$

And from equation (6), the total pressure is defined as

$$P = p - 3\eta H$$

$$P = \frac{\gamma}{T^b} . \left\{\frac{-2K^2}{d} . \frac{1}{k_1} . \frac{T^{(c+1)}}{(c+1)} + L\right\} - 3 . \eta_0 . \left\{\frac{1}{T^b} . \left(\frac{-2K^2}{d} . \frac{1}{k_1} . \frac{T^{(c+1)}}{(c+1)} + L\right)\right\}^s . \frac{(n+1)}{2} . \frac{k_1}{[(1-\alpha)T]} \tag{4.12}$$

Hubble parameter is defined as,

$$H = \frac{1}{3}\left(\frac{A_4}{A} + \frac{B_4}{B} + \frac{C_4}{C}\right)$$

$$H = \frac{(n+1)}{2} . \frac{k_1}{[(1-\alpha)T]} \tag{4.13}$$

Volume of the universe is defined as follows,

$$V = ABC = k_3 . [(1-\alpha)T]^{\frac{3(n+1)}{2(1-\alpha)}} \tag{4.14}$$

Scale factor

$$a(t) = {k_3}^{1/3} . [(1-\alpha)T]^{\frac{(n+1)}{2(1-\alpha)}} \tag{4.15}$$

Anisotropy parameter

$$A_m = \frac{2(n-1)^2}{3(n+1)^2} \tag{4.16}$$

Shear scalar

$$\sigma^2 = \frac{(n-1)^2}{4} . \frac{{k_1}^2}{[(1-\alpha)(k_1 t + k_2)]^2} \tag{4.17}$$

$$\theta = \frac{3(n+1)k_1}{[(1-\alpha)(k_1 t + k_2)]} \tag{4.18}$$

$$\frac{\sigma}{\theta} = \frac{(n-1)}{3(n+1)} \tag{4.19}$$

V. GRAPHICAL REPRESENTATION

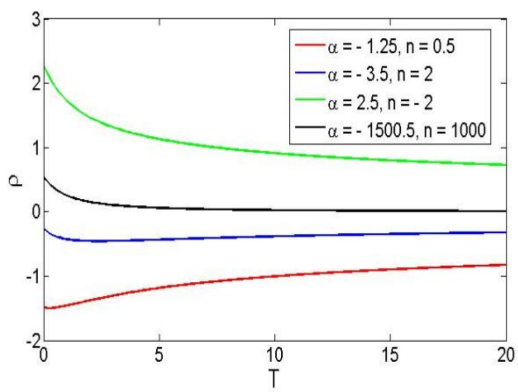

Fig. 1. Variation of density with time.

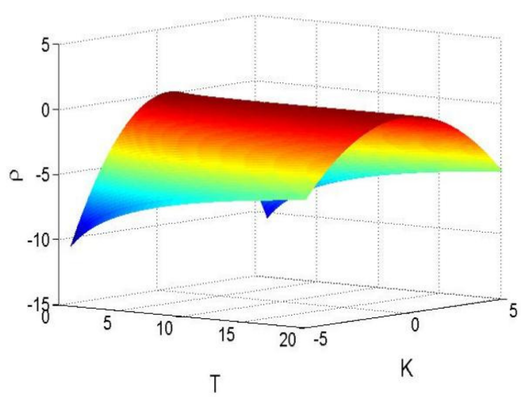

Fig. 2. Variation of density with time.

From equations (4.4) we have plotted Fig. 1, the density reaches to zero from negative value shown by red and blue line whereas green and black line represents decreasing density nature at late times to zero for K=2 , $k_1 = 1, k_2 = 1.5, k_3 = 2, L = 1\ \gamma = 0.5$ in 2-D diagram with cosmic time. From Fig. 2 for different values of K from -5 to 5 also gives symmetry nature with center K=0, for $\alpha = 1.25, k_1 = 1, k_2 = 1.5, k_3 = 2,\ K = 2, L = 1\ \gamma = 0.5$ and $n = 0.5$.

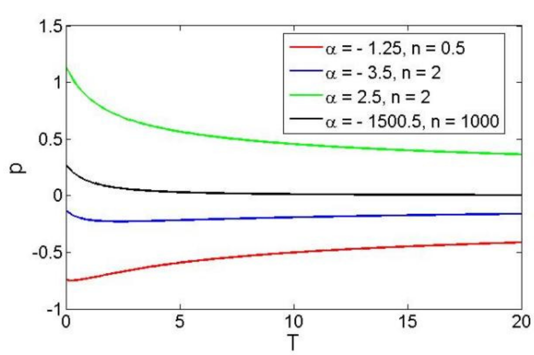

Fig. 3. Variation of pressure with time.

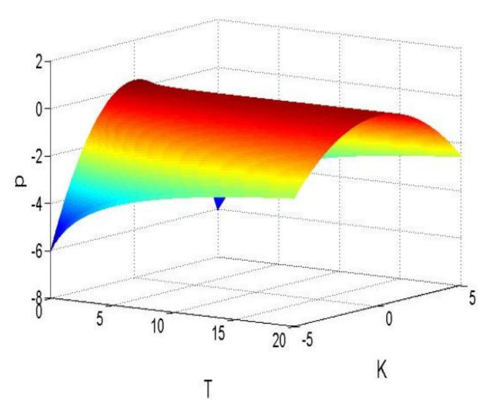

Fig. 4. Variation of pressure with time.

From equations (4.8) we have plotted Fig. 3, here red and black line overlapped, green line also decreasing equilibrium pressure to zero from positive value for K=2 ,$k_1 = 1, k_2 = 1.5, k_3 = 2$, $L = 1$ $\gamma = 0.5$ in 2-D diagram with cosmic time. From Fig. 4, for different values of K from -5 to 5 also gives symmetry nature with center K=0, for $\alpha = -1.25, k_1 = 1, k_2 = 1.5, k_3 = 2,$ $K = 2, L = 1$ $\gamma = 0.5$ and $n = 0.5$.

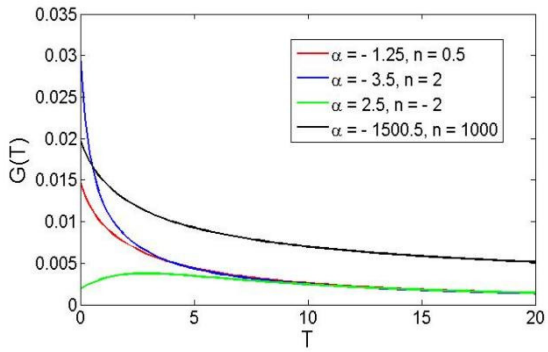

Fig. 5. Variation of [G(T)] with time.

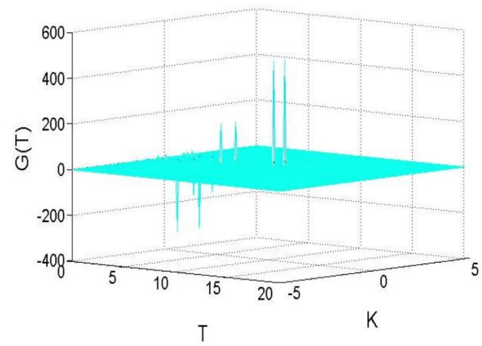

Fig. 6. Variation of [G(T)] with time.

From equations (4.9) we have plotted Fig. 5, shows that all lines of the gravitational constant [G(t)] reaches to zero in late times for K=2 in 2-D diagram from Fig. 6, for different values of K from -5 to 5 shows sometimes upwards to zero and sometime downwards for different values of K, for $\alpha = -1.25, k_1 = 1, k_2 = 1.5, k_3 = 2$, $K = 2, L = 1, \gamma = 0.5, s = 4, \pi = \frac{22}{7}, \eta = 0.4$ and $n = 0.5$.

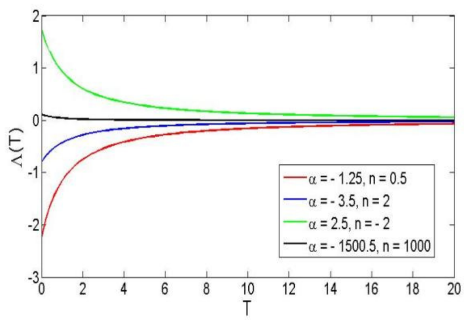

Fig. 7. Variation of $\Lambda(T)$ with time.

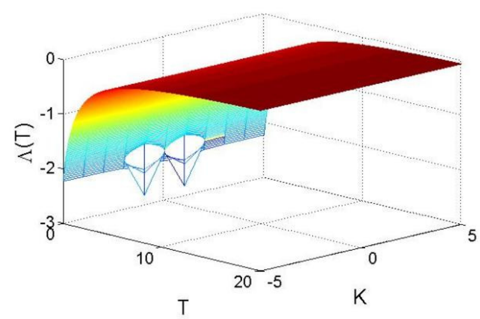

Fig. 8. Variation of $\Lambda(T)$ with time.

From equations (4.10) we have plotted Fig. 7, shows that green and black line of the cosmological constant $\Lambda(T)$ reaches positive to zero whereas red and blue line decreases negative to zero in late times for K=2 in 2-D diagram from Fig. 8, for different values of K from -5 to 5 gives symmetry nature with center K=0, for $\alpha = -1.25, k_1 = 1, k_2 = 1.5, k_3 = 2$, $K = 2, L = 1, \gamma = 0.5, s = 4, \pi = \frac{22}{7}, \eta = 0.4$ and $n = 0.5$.

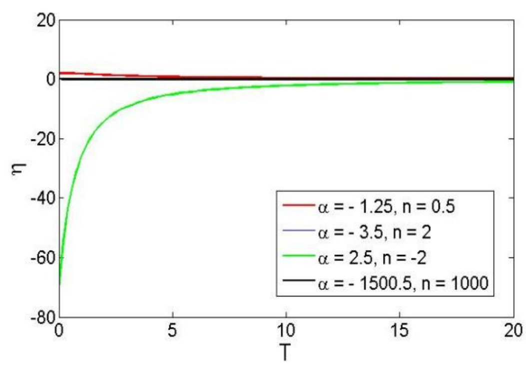

Fig. 9. Variation of η with time.

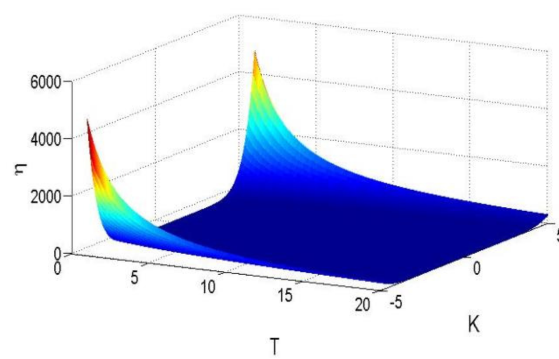

Fig. 10. Variation of η with time.

From equations (4.11) we have plotted Fig. 9, shows that the bulk viscosity η of red , blue and black line reaches positive to zero whereas green lines reaches negative to zero but blue line constantly zero in late times for K=2 in 2-D diagram from Fig. 10, for different values of K from -5 to 5 also represents the same for different values of K, for $\alpha = -1.25, k_1 = 1, k_2 = 1.5, k_3 = 2,$ $K = 2, L = 1, \gamma = 0.5, s = 4, \pi = \frac{22}{7}, \eta = 0.4$ and $n = 0.5$.

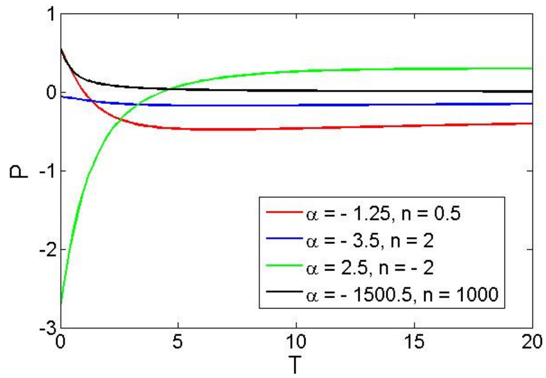

Fig. 11. Variation of total pressure with time.

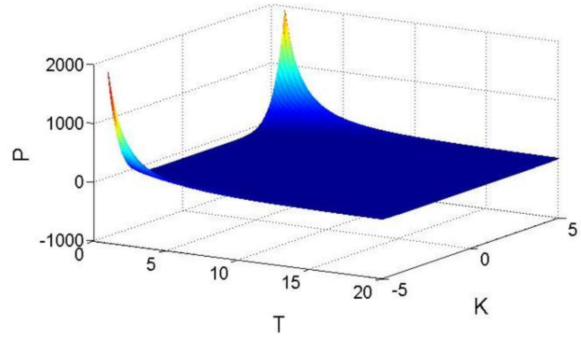

Fig. 12. Variation of total pressure with time.

From equations (4.12) we have plotted Fig. 11, here only black line shows positive nature of the total pressure P, but red line from positive to negative blue always negative and green negative to positive in late times for K=2 in 2-D diagram from Fig. 12, for different values of K from -5 to 5 also represents the same for different values of K, for $\alpha = -1.25, k_1 = 1, k_2 = 1.5, k_3 = 2, K = 2, L = 1, \gamma = 0.5, s = 4, \pi = \frac{22}{7}, \eta = 0.4$ and $n = 0.5$.

CONCLUSION

In this paper we have presented Bianchi Type V barotropic fluid with magnetic field in general relativity.
The model (3.9) starts with a big bang at $T = 0$ and the expression in the model decreases as the time increases. The spatial volume (V) increases as time (T) increases, when $n \neq -1$ or $\alpha \neq 1$. The matter density $\rho \to \infty$ when $T \to 0$, and $\rho \to 0$ when $T \to \infty$ provided $\gamma > -1$ and $n > -1$.
The model (3.9) has point type singularity at $T = 0$. Shear scalar (σ) increases as $n > \rho, \alpha < 1$. Time (t) decreases and σ increases as T increases. Since $\frac{\sigma}{\theta} \neq 0$, hence anisotropy is maintained throughout. However at $n = 1$, the model (3.9) isotropizes. Hence the model (3.9) represents inflationary scenario.
We have observed that in presence of magnetic field, pressure p, energy density ρ and cosmological constant Λ varies from negative to zero at late times. The gravitational constant G varies from zero to negative infinity when cosmic time tends to infinity.

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