REGULAR ARTICLE

Inflation in Creation Field Cosmology with Bulk Viscosity and Variable Cosmological Constant

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Cosmic inflation in LRS Bianchi Type I space-time under effect of the bulk viscosity and time dependent cosmological constant in C-field cosmology is investigated. To find the deterministic result of the field equations, we assumed R~$e^{H_0 t}$ where H_0 is the Hubble parameter and t is cosmic time. It has been observed that the C-field effect increases with cosmic time, and the obtained result resembles the evidence in HN theory. The real singularity does not exist in the derived model and Particle horizon exists in the model. The spatial volume increases in exponentially manner with proper time favorable to the expansion of the universe. The negative deceleration ($q < 0$) indicates the accelerated phase of the universe and the de-sitter cosmos is investigated. The bulk viscosity coefficient is found to be constant and vacuum energy density found to be negatively in exponential manner with cosmic time which shows that the decay of the energy component λ transfers energy in a continuous way to the material component.The volume of cosmos varies as exponentially way to proper time along with hubble parameter. The geometrical and dynamical properties of physical parameter are investigated in rigorous manner. The behavior of the model under different physical conditions is also discussed.

Keywords: C- Field Cosmology, Bulk Viscosity, early universe Cosmological Constant, HN Theory.

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1. INTRODUCTION

Modern astrophysical evidence indicates that our present universe is not purely symmetric in nature by Hinshaw [1]. The study of Bianchi identities plays an important role in understanding the origin and development of the early cosmos better as compared to the standard model of cosmology. The standard cosmological model is based on the principles of cosmology (homogeneous and isotropic universe) which leads to Friedmann-Robertson-Walker models. These models are based on the predictions that the universe starts with Big Bang and explained successfully the observable data as CMB and Hubble law. Patridge and Winkinson [2] studied whether FRW models are unstable near initial singularities. Standard models of the universe help to provide successive explanations of the Big Bang and other phenomena such as the Hubble principle, CMBT, etc. However, it has been observed by cosmologists in various contexts that cosmological singularities, the horizon problem, and flatness are also challenged by standard cosmology. Bondi and Gold [3] pointed out silent features of the theory of steady-state to understanding the singularity with the fact that the physical universe do not have the beginning with a singular point nor an end on the cosmic time scale, and the creation of matter is at a slow rate in context of standard cosmology, but this theory is not able to explain matter creation continuously and the conservation of energy principle. In support of these aspects, Hoyle & Narlikar [4] justified the theory of C-field, which explains the possible features of the existing inflationary cosmos having a constant density of matter.

To investigate the significance of bulk viscosity in cosmic matter helps us to understand many structural and geometrical features in the dynamics of homogeneity in the model of the universe. Sharma and Poonia [5-7] have derived a viscous fluid model of the cosmos in framework of bulk viscosity in various contexts.

Gron [8] studied a Bianchi-I model consisting of shear, nonlinear bulk viscosity. The importance of the presence of variable bulk viscosity in cosmic inflation is concluded by many researchers, viz. Saha [9], Brevik et al. [10]. The occurrence of suitable negative energy creation fields (in right side of EFE) provides constancy of density of the matter. The negative energy factor presence helps to solve cosmological problems like horizon, monopole and flatness. Hoyle and Narlikar [11] also admitted the possibilities of existing expanding space with constant matter density; they chose the approaches toward the field theory by modified EFE by adding the suitable term for creation of matter. The study of the

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universe's origin, structure, and evolution has long been a cornerstone of cosmological research. Mathematical cosmology provides a robust framework for understanding these phenomena through theoretical models and equations that describe the behavior of spacetime and matter. Within this domain, Bianchi models, particularly Bianchi Type I, have gained prominence due to their ability to capture the effects of anisotropy in the early universe. Unlike isotropic models, which assume uniformity in all directions, anisotropic cosmological models allow for directional dependencies, offering a more nuanced understanding of the universe's initial conditions and subsequent evolution These models are particularly relevant when studying inflation, a period of rapid exponential expansion believed to have smoothed out initial irregularities in the universe

Inflationary models within the framework of Bianchi types not only enhance our understanding of the isotropization process but also address discrepancies between theoretical predictions and observational data, such as the cosmic microwave background (CMB) anisotropies [17-20]. The integration of Einstein field equations and inflationary potential provides a mathematical foundation for exploring these dynamics. The focus on Bianchi Type I, characterized by non-zero spatial curvature, adds a critical layer of complexity to the study, making it a compelling subject for advancing cosmological theories. The solutions of the non-linear field equations admitting radiation with changeless and massless C field is investigated by Narlikar and Padmnabhan [12]. Ghate et al. [13] developed Bianchi type V in LRS in context of the barotropic viscous fluid with time dependent cosmological constant in HN theory. Bali et al. [14] investigated a massive string model with bulk viscosity and vacuum energy density in Bianchi type I model. Malekolkalami and Khalafi [15] constructed local rotationally symmetric Bianchi I space-time with various aspects containing varying cosmological term in creation field theory. Patil et al. [16] constructed a dust-filled model in the existence of perfect fluid distribution in creation field theory.

In this work, we have observed cosmic inflation in the Bianchi- I dust-filled model with the presence of bulk viscosity and an energy density in CF theory. To illustrate the inflationary-like solution, we have taken the condition $R \sim e^{H_0 t}$ where H_0 is the Hubble parameter where R is the scale factor used in condition. It has tried to explain to what extent the existence of bulk viscosity with variable energy density term (λ) in creation field theory matches with the results of Hoyle-Narlikar theory. It is observed that the C-field increases in order with cosmic time t and follows the outcome of the HN theory. The real singularity does not lie in the existing model. The Spatial volume increases in exponential manner with proper time, which is favorable to conditions of inflation. The particle horizon exists, i.e. the observation is in the communicable section. The deceleration parameter (q) is negative show universe is undergoing in expansion state and de-sitter universe is observed. The model approaches isotropy at late time t. The physical and structural features of the model are discussed.

2. HOYLE-NARLIKAR THEORY

The Einstein field equation in C-field cosmology containing variable Λ and the bulk viscosity (ξ) is given as

$$\boldsymbol{R_i^j - \frac{1}{2} R g_i^j = -\left[T_{i(m)}^j + T_{i(c)}^j\right] - \lambda(t) g_i^j} \tag{2.1}$$

Here $T_{i\ (m)}^{j}$ and $T_{i\ (c)}^{j}$ represents the Energy momentum tensor corresponding to bulk viscosity and creation n field is obtained as

$$T_{i\ (m)}^{j} = (p+\rho) v_i v^j - p g_i^j - \xi\theta(v_i v^j - g_i^j) \tag{2.2}$$

Here $8\pi G = 1$, $c = 1$ as geometric unit.
Where ξ denoted the bulk viscosity coefficient and θ denotes the expansion parameter.
We have taken flow component v^i

$$T_{i\ (c)}^{j} = -f\left(C_i C^j - \frac{1}{2} g_i^j C^\beta C_\beta\right) \tag{2.3}$$

In the given equation ρ and p indicates the matter density and pressure. Here f denotes a non-negative coupling constant between matter and the C-field. Also, $C_\beta = \frac{dC}{dx^\beta}$ where C is a scalar field with negative energy factor and the stresses which is consider to be responsible for the inertial influence associated with the continuously matter at a slow rate. Since, left side of eq. (2.1) is divergence less.

The Energy conservation relation is given as

$$\left[\left(T_{i\ (m)}^{j} + T_{i\ (c)}^{j}\right) + \lambda(t) g_i^j\right]_{;j} = 0 \tag{2.4}$$

Since $T_{i\ (c)}^{j} < 0$ indicates gravitational field of repulsive nature developed because of the negative energy density of creation field which accountable for accelerated inflation of the cosmos.

3. SOLUTIONS OF THE FIELD EQUATIONS

The Bianchi Type I can be describe by the metric

$$ds^2 = -dt^2 + A^2(t) dx^2 + B^2(t)(dy^2 + dz^2) \tag{3.1}$$

Here A and B are coefficients of line element.

The comoving coordinates is taken as $u^i = (0,0,0,1)$. The set of the field equations for the metric (3.1) can be obtained as

$$\frac{{B_4}^2}{B^2} + 2\frac{B_{44}}{B} = \left(-p + \xi\theta + \frac{1}{2} f \dot{C}^2\right) + \lambda(t) \tag{3.2}$$

$$\frac{A_{44}}{A} + \frac{B_{44}}{B} + \frac{A_4 B_4}{AB} = \left(-p + \xi\theta + \frac{1}{2} f \dot{C}^2\right) + \lambda(t) \tag{3.3}$$

$$\frac{{B_4}^2}{B^2} + 2\frac{A_4 B_4}{AB} = \left(\rho - \frac{1}{2} f \dot{C}^2\right) + \lambda(t) \tag{3.4}$$

To investigated the deterministic solution, we supposed $\xi\theta = \mu$.

The scale factor S for the metric is taken as

$$R^3 = AB^2 = e^{3H_0 t} \tag{3.5}$$

where H_0 represent the Hubble parameter.

Equation (3.2) and (3.3) provided

$$\frac{\left(\frac{A_4}{A} - \frac{B_4}{B}\right)_4}{\left(\frac{A_4}{A} - \frac{B_4}{B}\right)} + \left(\frac{A_4}{A} + 2\frac{B_4}{B}\right) = 0 \tag{3.6}$$

which provides

$$\left(\frac{A_4}{A} - \frac{B_4}{B}\right) = \frac{K}{AB^2} = Ke^{-3H_0t} \qquad (3.7)$$

From equation (3.2-3.4) we obtained

$$\left(\frac{A_4}{A} + 2\,\frac{B_4}{B}\right)_4 + \frac{{A_4}^2}{A^2} + 2\,\frac{{B_4}^2}{B^2} = -\frac{3}{2}p + \frac{3}{2}\xi\theta + f\dot{C}^2 + \lambda(t)(3.8)$$

Equation (3.5) provides

$$\frac{A_4}{A} + 2\,\frac{B_4}{B} = 3H_0 \qquad (3.9)$$

we obtained

$$\frac{A_4}{A} = \frac{2}{3}Ke^{-3H_0t} + H_0 \qquad (3.10)$$

$$\frac{B_4}{B} = -\frac{1}{3}\,Ke^{-3H_0t} + H_0 \qquad (3.11)$$

Finally we obtained results

$$A = D_1 e^{H_0 t} exp\left[-\left(\frac{2K}{9H_0}\right)e^{-3H_0t}\right] \qquad (3.12)$$

$$B = D_2 e^{H_0 t} exp\left[-\left(\frac{K}{9H_0}\right)e^{-3H_0t}\right] \qquad (3.13)$$

Here D_1 and D_2 are the constant of integration. Since the metric (3.1) is obtained as

$$ds^2 = -dt^{*2} + e^{2H_0t}exp\left[-2\left(\frac{2K}{9H_0}\right)e^{-3H_0t}\right]dx^{*2} + e^{2H_0t}exp\left[-2\left(\frac{K}{9H_0}\right)e^{-3H_0t}\right](dy^{*2} + dz^{*2} \qquad (3.14)$$

Taking transformation

$$t = t^*,\ D_1x = x^*,\ D_2y = y^*,\ \text{and}\ D_2z = z^* \ (3.15)$$

3.1 The Condition of Conservation

The equation for conservation ($p = 0$) is given by

$$\left[\left(T_{i\ (m)}^{j} + T_{i\ (c)}^{j}\right) + \lambda(t)g_i^j\right]_{,j} = 0 \qquad (3.16)$$

lead to

$$(\dot{\rho} - f\dot{C}\,\ddot{C}) + (\rho - \xi\theta - f\dot{C}^2)\left(\frac{A_4}{A} + 2\,\frac{B_4}{B}\right) + \dot{\lambda} = 0 \qquad (3.17)$$

Where $\lambda(t)$ indicated the vacuum energy density, equation (3.17) shows the decay of the energy component λ transfers energy in a continuous way to the material component. The variable cosmological constant is regarded as the second component of the fluid

$$\rho_{vacuum} = \lambda(t) \qquad (3.18)$$

where we have assumed the pressure zero in matter field ($P = 0$) by Hoyle-Narlikar

$$\lambda = \frac{\beta}{R^6} \qquad (3.19)$$

Here R be the scale factor and β is the arbitrary constant.

The density of matter is obtained by relation

$$\rho = \frac{B'^2}{B^2} + 2\frac{A'B'}{AB} + \frac{1}{2}f - \lambda \qquad (3.20)$$

From equation (3.10-3.3.11) and (3.17) with $\dot{C} = 1$ as in HN theory we get

$$\rho = -\frac{1}{3}\eta e^{-6H_0t} + 3{H_0}^2 + \frac{1}{2}f \qquad (3.21)$$

Where

$$\eta = (3\alpha + K^2)\ \text{and}\ \rho = 2H_0\eta e^{-6H_0t} \qquad (3.22)$$

3.2 Determination of *C*- Field

From equation of conservation

$$(\dot{\rho} - f\dot{C}\,\ddot{C}) + (\rho - \xi\theta - f\dot{C}^2)(3H_0) - 6\alpha H_0 e^{-6H_0t} = 0 \ (3.23)$$

Where $AB^2 = e^{3Ht}$ and $\lambda = \frac{\alpha}{R^6}$.

Equation (3.3.18) leads to

$$\frac{d}{dt}(\dot{C}^2) + 6H_0(\dot{C}^2) = 2\frac{H}{f}e^{-6H_0t}(-\eta + 2K^2) + 18\frac{{H_0}^3}{f} + 3H_0 - 6\frac{H_0}{f}(\xi\theta) \qquad (3.24)$$

which gives $\dot{C}^2 = {\omega_0}^2$

$$C \propto t \qquad (3.25)$$

Where

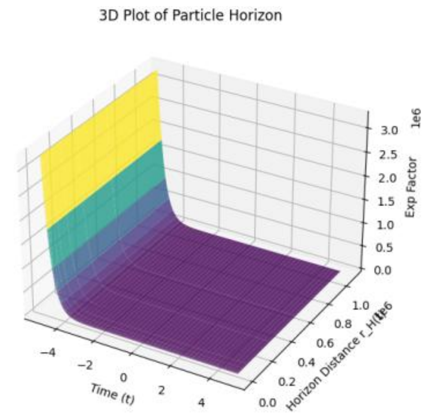
$${w_0}^2 = 3\frac{{H_0}^2}{f} + \frac{1}{2} + \frac{\xi\theta}{f}\ \text{and}\ 2K^2 - \eta = 0$$

Thus the *C*-field is directly proportional to time, which matches with facts obtained in HN theory.

3.3 The Particle Horizon

The coordinate distance to the Horizon $r_H(t)$ is maximum distance; a null ray may have travel at proper time t starting from past infinitely

$$r_H(t) = \int_{-\infty}^{\infty}\frac{dt}{R^3(t)} = \int_{-\infty}^{\infty}e^{-3H_0t}dt = \frac{1}{3H_0} = \text{Finite}(3.26)$$

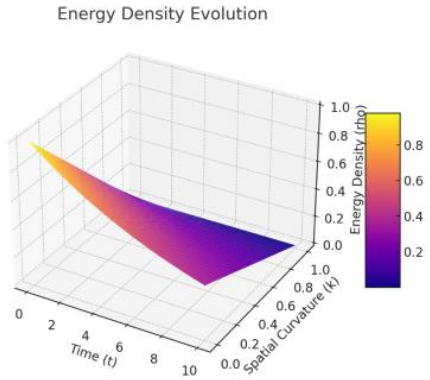


The particle horizon $r_H(t)$ exist, which indicated an existence of observers in communicable region.

4. THE PHYSICAL AND STRUCTURAL FEATURES OF MODEL

The Homogenous matter density (ρ) is provided by the relation

$$\rho = -\frac{1}{3}\eta e^{-6H_0 t} + 3{H_0}^2 + \frac{1}{2}f \tag{4.1}$$



The expansion scalar (θ) is provided by the relation

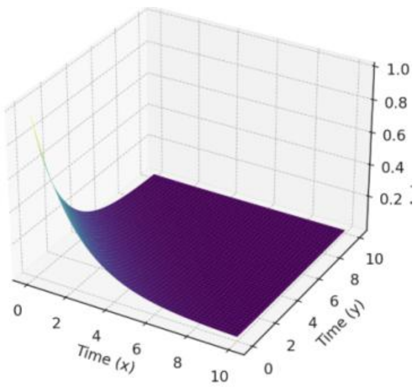
$$\theta = \frac{A_4}{A} + 2\frac{B_4}{B} = 3H_0 \tag{4.2}$$

The bulk viscosity coefficient is provided by the relation

$$\xi = \frac{\mu}{3H_0} \tag{4.3}$$

The vacuum energy density is provided by relation

$$\lambda = \alpha e^{-6H_0 t} \tag{4.4}$$



The deceleration parameter (q) is provided by relation

$$q = -1$$

The matter density ($\rho > 0$) leads to

$$18{H_0}^2 + 3f > 2\eta e^{-6H_0 t}$$

At large time t, $\rho > 0$ we obtained

$$18{H_0}^2 + 3f > 0$$

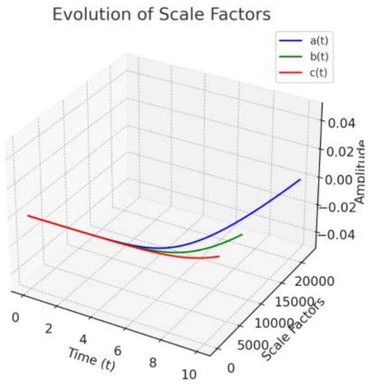
At large time t, the density of matter becomes finite with the occurrence of the C-Field, Thus in C-field theory, there is neither beginning nor the end of the universe.

The spatial volume of the developed model is provided by relation

$$V = AB^2 = e^{3H_0 t} \tag{4.5}$$

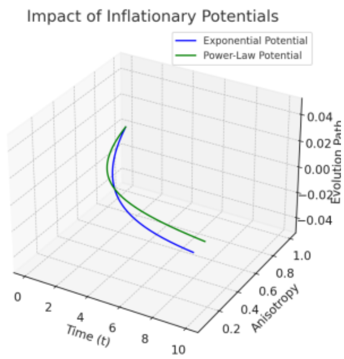
The shear scalar is provided by relation

$$\sigma^2 = \frac{1}{3}K^2 e^{-6H_0 t} \tag{4.6}$$



The anisotropic condition is provided by the relation we observe anisotropy decreases as the cosmic time t increases and approaches to the finite for large t. The model approaches isotropy at a late time t, i.e. the developed model isotropize at a late time

$$\frac{\sigma}{\theta} = \frac{1}{\sqrt{3}}\frac{Ke^{-H_0 t}}{3H_0} \tag{4.7}$$



5. CONCLUSION

The C-Field field is directly proportional to proper time i.e. it increases with time, matches with observations obtained in Hoyle-Narlikar theory. The Energy density term $\lambda(t)$ decreases with cosmic time in exponential way and approaches to zero as t approaches to infinity. The Spatial volume V increases in exponential order with time t, which agreed with inflationary criteria of physical universe and represents accelerated phase of the universe. There no real singularity exists initially in the investigated model. The deceleration parameter (q) is negative show universe is undergoing in expansion state and de-sitter universe is observed.

In the current model, particle horizon exists i.e. the observation is in the communicable section. The bulk viscosity coefficient inversely proportional to scalar of expansion, we have obtained a locally rotationally symmetric Bianchi-I dust-filled space time in creation field theory which fulfilled astronomical observations in HN theory.

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Інфляція в космології поля творіння з об’ємною в’язкістю та змінною космологічною константою

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Досліджено космічну інфляцію в просторі-часі типу I LRS Bianchi під впливом об'ємної в'язкості та залежної від часу космологічної константи в космології C-поля. Щоб знайти детермінований результат рівнянь поля, ми припустили R$\sim e^{H_0 t}$, де H_0 – параметр Хаббла, а t – космічний час. Було помічено, що ефект C-поля зростає з космічним часом, і отриманий результат нагадує дані теорії HN. Реальна сингулярність не існує в отриманій моделі, але в моделі існує горизонт частинок. Просторовий об’єм зростає експоненціально з власним часом, сприятливим для розширення Всесвіту. Негативне уповільнення ($q < 0$) вказує на прискорену фазу Всесвіту, і досліджується космос де-ситтера. Виявлено, що коефіцієнт об'ємної в'язкості є постійним, а густина енергії вакууму – негативно експоненціально з космічним часом, що показує, що розпад енергетичної складової λ безперервно передає енергію матеріальній складовій. Об’єм космосу змінюється експоненціально відносно власного часу разом з параметром Хаббла. Геометричні та динамічні властивості фізичних параметрів досліджуються ретельно. Також обговорюється поведінка моделі за різних фізичних умов.

Ключові слова: Космологія C-поля, Об’ємна в’язкість, Космологічна стала раннього Всесвіту, Теорія HN.