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# Bulk Viscous String Cloud with Strange Quark Matter in Self Creation Cosmology

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***Abstract:*** *We have investigated strange quark matter attached to the string cloud with bulk viscous fluid for higher dimensional Friedman-Robertson-Walker (FRW) universe in Self Creation Cosmology (SCC). We have obtained zero string density ($\rho_s = 0$) in this model. Our solutions agree with the studies of Reddy, Sahoo-Mishra and Mohanty et al. in four dimensions.*
***Keywords:*** *FRW universe, higher dimension, bulk viscous, string cloud, strange quark matter, Self creation cosmology, deceleration parameter.*

## I. Introduction

Recent observations demonstrated that our universe is accelerating. Scientists have proposed two potentiality to explain acceleration of universe [1,2]. One of them is phantom, quintessence and k-essence etc. [3]. The other is modified gravitation theories, such as Brans-Dicke theory [4], Lyra geometry [5], f(R) theory [6], Saez and Ballester theory [7], Yılmaz theory [8] and Barber's theories [9]. After Einstein's theory, alternative gravitation theories have been explored by many scientists. Barber [9] suggested two self creation theory by modifying Brans-Dicke [10] and Einstein [11] theories. But Barber's first theory is inconsistent and not agrees with experiments [12]. Also, Barber's second theory is acceptable also the modifications of general relativity and the scalar field $\phi$ do not gravitate in this theory [12]. Using various space-time models, many scientists have researched Barber's second theory. Rai et al. [13] have investigated anisotropic homogeneous cosmological models in presence of perfect fluid in Self-creation cosmology. Singh and Kumar [14] have analyzed Bianchi type-II universe with perfect fluid space-times in Barber's second self-creation theory. Venkateswarlu and Reddy [15] have studied Bianchi type-I models with perfect fluid solutions in Barber's second theory. Katore et al. [16] have studied plane symmetric cosmological models with negative constant deceleration parameter in presence of perfect fluid in self-creation cosmology.

It is well known that our universe was much smaller in early phase than that at present [17] and we could describe present universe with FRW space-time varying κ parameter. In this study, we have investigated higher dimensional FRW universe with bulk viscosity. Because bulk viscosity is assumed to play a very significant role in the early evolution of the universe [18,19]. Katore et al. have investigated homogenous and isotropic FRW universe for bulk viscous in SCC [19]. Reddy and Naidu have investigated five dimensional Kaluza-Klein space-time with perfect fluid in Barber's second self creation theory of gravitation [20]. Higher dimensional FRW cosmological model with perfect has been studied by Venkateswarlu and Kumar fluid in SCC [21]. Pradhan et al. [22] have researched FRW universe with bulk viscous fluid in Lyra geometry. Rahaman et al. [23] have obtained exact solutions for higher dimensional spherically symmetric inhomogeneous metric with mass-less scalar field in Lyra geometry. Also spatially homogeneous isotropic FRW cosmological model with bulk viscosity and zero-mass scalar field has been studied in SCC by Chirde and Rahate [24]. Pradhan et al. [25] have studied LRS Bianchi type-I cosmological models in Barber's second self creation theory. Higher dimensional FRW universe with bulk viscous has been studied in general relativity by Tiwari and Singh [26].

Also, cosmic strings have important role in early universe. Many scientists have studied various solutions with cosmic strings [27,28,29]. It is believed that cosmic strings give rise to density perturbations which lead to the formation of galaxies[30], [31]. Rao [32] has investigated spatially homogeneous and anisotropic Kantowski-Sachs cosmological model in Lyra geometry. Yadav et al. [33] have studied some Bianchi type III cosmological model with bulk viscous and string cloud in general relativity.

However, it is possible to attach strange quark matter to string cloud, because of transitions of Quark Gluon Plasma (QGP) to hadron gas ( named quark-hadron phase transition) when cosmic temperature was T~200 MeV during the phase transitions of the universe [34]. Two suggestions about genesis of strange quark matter (SQM) have been declared by Bodmer [35], Witten [36] and Itoh [37]. The first one is quark-hadron phase transition in the early universe and the second one is conversion of neutron stars into SQM at ultrahigh densities [38]. In this topic, we have quark pressure as follow

$$p_q = \frac{\rho_q}{3} \tag{1}$$

here$\rho_q$ represents the quark energy density. And total energy density can be written as

$$\rho = \rho_q + B_c \tag{2}$$

where$B_c$ is bag constant of quark matter. Also total pressure is given as

$$p = p_q - B_c \tag{3}$$

here$p_q$ represents the quark pressure [34,39]. Rao et al. have researched Bianchi type II, VIII and IX string cosmological in Einstein's theory of gravitation and Barber's second self-creation theory of gravitation [40]. Reddy et al. [41] have investigated LRS Bianchi type-II space-time and Rao and Sireesha [42] have investigated anisotropic axially symmetric cosmological model with bulk viscous in presence of cosmic string as source of gravitation in SCC. Mahanta et al. have obtained string cloud in self Creation cosmology with Bianchi type III space time model [43]. Also, Aktaş and Yılmaz have studied magnetized quark and strange quark matter in the spherical symmetric space-time admitting conformal motion [44].

In this study, we have studied strange quark matter attached to string cloud with bulk viscous in higher dimensional FRW universe for SCC. We have obtained field equations of our model in Sec. 2 and then, we have calculated solutions of them in Sec. 3 for varying deceleration parameter. Also we have discussed our solutions in Sec. 4.

## II. Higher Dimensional FRW Universe and Field Equations in Self Creation Cosmology

The field equations of Barber's second self creation theory can be written as follows [9]

$$R_{ik} - \frac{1}{2} g_{ik} R = -\frac{8\pi}{\phi} T_{ik} \tag{4}$$

here$T_{ik}$ is energy momentum tensor. Also, $\phi$ describes scalar field and satisfied the equation

$$\Box\phi = \phi^{k}_{;k} = \frac{8\pi}{3} \lambda T \tag{5}$$

here$\lambda$ is coupling constant to be obtained by experiments and its value have been found as $\lambda < 10^{-1}$ by some measurements. Also one considers $\lambda \to 0$and $\phi = \text{constant} = G^{-1}$, Barber theory transform to general relativity [40,44].

Homogeneous and isotropic higher dimensional FRW universe is given by

$$ds^2 = dt^2 - R(t)^2 \left[\frac{dr^2}{1-\kappa r^2} + r^2 d\varkappa_n^2\right] \tag{6}$$

where$R(t)$ is the scale factor, $\kappa$ is the curvature parameter and have value as $\kappa = 0, \pm 1$ [16]. Also $d\varkappa_n^2$ seen in eq. (6) can be written as

$$d\varkappa_n^2 = d\theta_1^2 + \sin^2\theta_1 d\theta_2^2 + \cdots + \sin^2\theta_1 \sin^2\theta_2 \ldots \sin^2\theta_{n-1} d\theta_n^2 \,. \tag{7}$$

The energy momentum tensor for the cloud of string dust with bulk viscosity and the conservation equation are given as follows

$$T_{ik} = \rho u_i u_k - \rho_s x_i x_k - \xi u^{l}_{;l}(u_i u_k - g_{ik}) \tag{8}$$

and

$$T^{ik}_{;k} = 0 \tag{9}$$

Where $\rho$ describes the rest energy density of string cloud with particles attached to them, $\rho_s$ represents string density and $\xi$ is the bulk viscous coefficient. Also $u_i$ given in eq. (8) is the velocity of the particles and $x_i$ called unit space-like vector represents the string direction [45, 46]. These quantities satisfy the orthogonal relationship as follows

$$u^i u_i = -x^i x_i = 1 \tag{10}$$

and

$$u^i x_i = 0 \tag{11}$$

Besides all these equations, we have

$$\rho = \rho_p + \rho_s \tag{12}$$

here$\rho_p$ is energy density of the particle. In this study we will take quarks instead of particles in the string cloud. Henceforth using eq. (12), we obtain

$$\rho = \rho_q + \rho_s + B_c \tag{13}$$

Using eqs. (4)-(8) together with eq. (13), we have obtained field equations of Barber's second theory for higher dimensional FRW universe with bulk viscous in the presence of strange quark matter attached to the string cloud as follows

$$\frac{n(n+1)}{2}\left(\frac{\dot{R}^2+\kappa}{R^2}\right) = \frac{8\pi}{\phi}(\rho_q + \rho_s + B_c) \tag{14}$$

$$\frac{n(n-1)}{2}\left(\frac{\dot{R}^2+\kappa}{R^2}\right) + n\frac{\ddot{R}}{R} = \frac{8\pi}{\phi}[\xi\dot{R}(n+1)] \tag{15}$$

$$\frac{n(n-1)}{2}\left(\frac{\dot{R}^2+\kappa}{R^2}\right) + n\frac{\ddot{R}}{R} = \frac{8\pi}{\phi}[\rho_s + \xi\dot{R}(n+1)] \tag{16}$$

and

$$\frac{(n+1)\dot{R}\dot{\phi}}{R} + \ddot{\phi} = \frac{8\pi\lambda}{3}\left[2\rho_s + \rho_q + B_c + \frac{(n+1)^2\dot{R}}{R}\right] \quad (17)$$

here and thereafter the dot (.) shows that differentiation with respect to cosmic time. Also using eq. (9) we have

$$\frac{(n+1)\dot{R}}{R}\left[\rho_q + B_c - \frac{(n+1)\xi\dot{R}}{R}\right] + \frac{n\rho_s\dot{R}}{R} + \dot{\rho}_q + \dot{\rho}_s = 0 \quad (18)$$

From eqs. (15) and (16) we get

$$\rho_s = 0 \quad (19)$$

## III. Solutions of Field Equations for FRW Universe

In this paper we have two independent field eqs. (14) and (15) with four unknowns $R$, $\rho_q$, $\phi$ and $\xi$. In order to solve the system we use conservation equation (eq. (9)) and varying deceleration parameter (q) as follows

$$q = -\frac{R\ddot{R}}{\dot{R}^2} = m - 1 \quad (20)$$

here$m$ is a constant. The sign of q is so important to determine the fate of the universe. Also q indicates whether the model accelerates or not. If,

i) $q < -1$ then universe has super-exponential expansion
ii) $q = -1$ then universe has exponential expansion
iii) $-1 < q < 0$ then universe has accelerating power law expansion
iv) $q = 0$ then universe has constant expansion
v) $q > 0$then universe has decelerating expansion [47, 48] (and references there in).

If we solve eq. (20), we get two solutions as follows

$$R = [m(c_1 t + c_2)]^{\frac{1}{m}} form \neq 0 \quad (21)$$

$$R = s_1 e^{s_2 t} form = 0 \quad (22)$$

where $c_1$, $c_2$, $s_1$ and $s_2$ are arbitrary constants.

### 1.1. SOLUTIONS OF FIELD EQUATIONS FOR FRW UNIVERSE$m \neq 0$

Using eq. (21) in eqs. (14), (15) and (18) we get scalar field function, bulk viscous coefficient and quark energy density in higher dimensional FRW universe respectively,

$$\phi = \frac{16\pi(c_1^2 c_3 + m^2 c_2^2 B_c)}{c_1^2 n(n+1)} \quad (23)$$

$$\xi = \frac{(c_1^2 c_3 + m^2 c_2^2 B_c)\left[c_1^6(n+1-2m)A^{\frac{4}{m}} + \kappa^2 c_1^2(3n-1-2m)A^4 + \kappa c_1^4(3n+1-4m)A^{\frac{2m+2}{m}} + (n-1)\kappa^3 A^{\frac{6m-2}{m}}\right]}{(n+1)^2 c_1^3 A\left(c_1^2 A^{\frac{2}{m}} + \kappa A^2\right)^2} \quad (24)$$

$$\rho_q = \frac{c_1(c_1 c_3 - mt B_c A)}{A^2} + \frac{\kappa(m^2 c_2^2 B_c + c_1^2 c_3)}{c_1^2 A^{\frac{2}{m}}} \quad (25)$$

here$c_3$ is an arbitrary constant and $A = m(c_1 t + c_2)$. Also using eq. (25) in eq. (1) we get quark pressure as follows

$$p_q = \frac{\rho_q}{3} = \frac{c_1(c_1 c_3 - mt B_c A)}{3A^2} + \frac{\kappa(m^2 c_2^2 B_c + c_1^2 c_3)}{3c_1^2 A^{\frac{2}{m}}} \quad (26)$$

From eqs. (2) and (25) we have total energy density as follows

$$\rho = \rho_q + B_c = \frac{c_1(c_1 c_3 - mt B_c A)}{A^2} + \frac{\kappa(m^2 c_2^2 B_c + c_1^2 c_3)}{c_1^2 A^{\frac{2}{m}}} + B_c \quad (27)$$

Also total pressure has been calculated from eqs. (3) and (26) as follows

$$p = p_q - B_c = \frac{c_1(c_1 c_3 - mt B_c A)}{3A^2} + \frac{\kappa(m^2 c_2^2 B_c + c_1^2 c_3)}{3c_1^2 A^{\frac{2}{m}}} - B_c \quad (28)$$

### 1.2. SOLUTIONS OF FIELD EQUATIONS FOR FRW UNIVERSE$m = 0$

Using eq. (22) in eqs. (14), (15) and (18) we find scalar field function, bulk viscous coefficient and quark energy density in higher dimensional FRW universe respectively,

$$\phi = \frac{16\pi(s_1^2 s_2^2 s_3 + B_c)}{s_2^2 n(n+1)} \quad (29)$$

$$\xi = \frac{(s_1^2 s_2^2 s_3 + B_c)\left[s_1^6 s_2^6(n+1)e^{4s_2 t} + s_1^4 s_2^4 \kappa(3n+1)e^{2s_2 t} + s_1^2 s_2^2 \kappa^2(3n-1) + \kappa^3(n-1)e^{-2s_2 t}\right]}{s_2^3\left[s_1(n+1)(s_2^2 e^{2s_2 t} + \kappa)\right]^2} \quad (30)$$

$$\rho_q = \frac{(s_1^4 s_2^4 s_3 e^{2s_2 t} + s_1^2 s_2^2 s_3 \kappa + \kappa B_c)(s_1^2 s_2^2 + \kappa e^{-2s_2 t})}{s_1^2 s_2^2(s_1^2 s_2^2 e^{2s_2 t} + \kappa)} \quad (31)$$

here$s_3$ is an arbitrary constant. Also using eq. (31) in eq. (1) we have quark pressure as follows;

$$p_q = \frac{\rho_q}{3} = \frac{(s_1^4 s_2^4 s_3 e^{2s_2 t} + s_1^2 s_2^2 s_3 \kappa + \kappa B_c)(s_1^2 s_2^2 + \kappa e^{-2s_2 t})}{3s_1^2 s_2^2(s_1^2 s_2^2 e^{2s_2 t} + \kappa)} \quad (32)$$

From eqs. (2) and (31) we have total energy density as follow

$$\rho = \rho_q + B_c = \frac{(s_1^4 s_2^4 s_3 e^{2s_2 t} + s_1^2 s_2^2 s_3 \kappa + \kappa B_c)(s_1^2 s_2^2 + \kappa e^{-2s_2 t})}{s_1^2 s_2^2 (s_1^2 s_2^2 e^{2s_2 t} + \kappa)} + B_c \tag{33}$$

Also total pressure has been calculated from eqs. (3) and (32) as follows

$$p = p_q - B_c = \frac{(s_1^4 s_2^4 s_3 e^{2s_2 t} + s_1^2 s_2^2 s_3 \kappa + \kappa B_c)(s_1^2 s_2^2 + \kappa e^{-2s_2 t})}{3 s_1^2 s_2^2 (s_1^2 s_2^2 e^{2s_2 t} + \kappa)} - B_c \tag{34}$$

## IV. Discussion and Conclusion

In this paper, we have investigated higher dimensional FRW universe with bulk viscous in presence of quark matter attached to string cloud in Barber's second self creation theory. We get zero string tension density ($\rho_s = 0$). Thus, strings do not survive in our model. Also we have used varying deceleration parameter as shown eq. (20) to solve field equations (for $m \neq 0$ and for $m = 0$). We will discuss our solution as following subsections.

### 1.3. DISCUSSION AND CONCLUSION OF THE MODEL FOR $m \neq 0$

Using eqs. (20) and (21) in eq. (6) we get new line element for higher dimensional FRW universe as follows

$$ds^2 = dt^2 - [m(c_1 t + c_2)]^{\frac{2}{m}} [\frac{dr^2}{1-\kappa r^2} + r^2 d\varkappa_n^2] \tag{35}$$

here$c_1$ is an important constant which has to be different zero for our model because of the line element must depend on cosmic time for $m \neq 0$.

At initial stage of universe, when $t \to 0$, scale factor $R(t)$, scalar field $\phi$, bulk viscous coefficient $\xi$, quark energy density, quark pressure, total energy density, total pressure and particle energy density are constant in condition $m \neq 0$. As $t$ increases, scale factor $R(t)$ increases also scalar field function $\phi$ is a constant in this situation. In subsections, we will discuss obtained results for variable curvature parameter $\kappa$. It takes $-1, 0, +1$ values to describe space-time curvature [49].

#### 1.3.1. $\kappa = -1$ SITUATION FOR $m \neq 0$

Using $\kappa = -1$, we get the results given from eqs. (23)-(28) as follows

$$\phi = \frac{16\pi(c_1^2 c_3 + m^2 c_2^2 B_c)}{c_1^2 n(n+1)} \tag{36}$$

$$\xi = \frac{(c_1^2 c_3 + m^2 c_2^2 B_c)\,[c_1^6 (n+1-2m) A^{\frac{4}{m}} + c_1^2 (3n-1-2m) A^4 - c_1^4 (3n+1-4m) A^{\frac{2m+2}{m}} - (n-1) A^{\frac{6m-2}{m}}]}{(n+1)^2 c_1^3 A \left(c_1^2 A^{\frac{2}{m}} - A^2\right)^2} \tag{37}$$

$$\rho_q = \frac{c_1(c_1 c_3 - mt\, B_c A)}{A^2} - \frac{(m^2 c_2^2 B_c + c_1^2 c_3)}{c_1^2 A^{\frac{2}{m}}} \tag{38}$$

we have obtain quark pressure as

$$p_q = \frac{c_1(c_1 c_3 - mt\, B_c A)}{3A^2} - \frac{(m^2 c_2^2 B_c + c_1^2 c_3)}{3 c_1^2 A^{\frac{2}{m}}} \tag{39}$$

We get total energy density as follows

$$\rho = \frac{c_1(c_1 c_3 - mt\, B_c A)}{A^2} - \frac{(m^2 c_2^2 B_c + c_1^2 c_3)}{c_1^2 A^{\frac{2}{m}}} + B_c \tag{40}$$

Also total pressure has been calculated as follows

$$p = \frac{c_1(c_1 c_3 - mt\, B_c A)}{3A^2} - \frac{(m^2 c_2^2 B_c + c_1^2 c_3)}{3 c_1^2 A^{\frac{2}{m}}} - B_c \tag{41}$$

#### 1.3.2. $\kappa = 0$ SITUATION FOR $m \neq 0$

Using $\kappa = 0$, we get the results given from eqs. (23)-(28) as follows

$$\phi = \frac{16\pi(c_1^2 c_3 + m^2 c_2^2 B_c)}{c_1^2 n(n+1)} \tag{42}$$

$$\xi = \frac{(c_1^2 c_3 + m^2 c_2^2 B_c)\,(n+1-2m)}{(n+1)^2 A c_1} \tag{43}$$

$$\rho_q = \frac{c_1(c_1 c_3 - mt\, B_c A)}{A^2} \tag{44}$$

Also we obtain quark pressure as follows

$$p_q = \frac{c_1(c_1 c_3 - mt\, B_c A)}{3A^2} \tag{45}$$

We get total energy density as follows

$$\rho = \frac{c_1(c_1 c_3 - mt\, B_c A)}{A^2} + B_c \tag{46}$$

Also total pressure has been calculated as follows

$$p=\frac{c_1(c_1c_3-mt\,B_cA)}{3A^2}-B_c \tag{47}$$

#### 1.3.3. $\kappa=1$ SITUATION FOR $m\neq 0$

Using $\kappa=1$, we get the results given from eqs. (23)-(28) as follows

$$\phi=\frac{16\pi(c_1^2c_3+m^2c_2^2B_c)}{c_1^2n(n+1)} \tag{48}$$

$$\xi=\frac{(c_1^2c_3+m^2c_2^2B_c)\,[c_1^6(n+1-2m)A^{\frac{4}{m}}+c_1^2(3n-1-2m)A^4+c_1^4(3n+1-4m)A^{\frac{2m+2}{m}}+(n-1)A^{\frac{6m-2}{m}}]}{(n+1)^2c_1^3A\left(c_1^2A^{\frac{2}{m}}+A^2\right)^2} \tag{49}$$

$$\rho_q=\frac{c_1(c_1c_3-mt\,B_cA)}{A^2}+\frac{(m^2c_2^2B_c+c_1^2c_3)}{c_1^2A^{\frac{2}{m}}} \tag{50}$$

also we have quark pressure as follows

$$p_q=\frac{c_1(c_1c_3-mt\,B_cA)}{3A^2}+\frac{(m^2c_2^2B_c+c_1^2c_3)}{3c_1^2A^{\frac{2}{m}}} \tag{51}$$

We get total energy density as follows

$$\rho=\frac{c_1(c_1c_3-mt\,B_cA)}{A^2}+\frac{(m^2c_2^2B_c+c_1^2c_3)}{c_1^2A^{\frac{2}{m}}}+B_c \tag{52}$$

Also total pressure has been calculated as follows

$$p=\frac{c_1(c_1c_3-mt\,B_cA)}{3A^2}+\frac{(m^2c_2^2B_c+c_1^2c_3)}{3c_1^2A^{\frac{2}{m}}}-B_c \tag{53}$$

### 1.4. DISCUSSION AND CONCLUSION OF THE MODEL FOR $m=0$

Using eq. (22) in eq. (6) we get new line element for higher dimensional FRW universe as follows

$$ds^2=dt^2-(s_1e^{s_2t})^2\,[\frac{dr^2}{1-\kappa r^2}+r^2d\varkappa_n^2] \tag{54}$$

Here $s_1$ is an important constant which have to be different zero for our model because of the higher dimensional FRW universe line element must depend on cosmic time for $m=0$. At initial stage of universe, when $t\to 0$, scale factor $R(t)$, scalar field $\phi$, bulk viscous coefficient $\xi$, quark energy density, quark pressure, total energy density, total pressure and particle energy density are constant in condition $m=0$. As $t$ increases, scalar field $\phi$ is a constant and scale factor $R(t)$ increases for $m=0$. In subsections, we will discuss obtained results for variable curvature parameter $\kappa=-1,0,+1$, respectively.

#### 1.4.1. $\kappa=-1$ SITUATION FOR $m=0$

Using $\kappa=-1$, using eqs. (29)-(34) we get scalar field, bulk viscous coefficient and quark energy density, respectively.

$$\phi=\frac{16\pi(s_1^2s_2^2s_3+B_c)}{s_2^2n(n+1)} \tag{55}$$

$$\xi=\frac{(s_1^2s_2^2s_3+B_c)[s_1^6s_2^6(n+1)e^{4s_2t}-s_1^4s_2^4(3n+1)e^{2s_2t}+s_1^2s_2^2(3n-1)-(n-1)e^{-2s_2t}]}{s_2^3[s_1(n+1)(s_2^2e^{2s_2t}-1)]^2} \tag{56}$$

$$\rho_q=\frac{(s_1^4s_2^4s_3e^{2s_2t}-s_1^2s_2^2s_3-B_c)(s_1^2s_2^2-e^{-2s_2t})}{s_1^2s_2^2(s_1^2s_2^2e^{2s_2t}-1)} \tag{57}$$

Also we obtain quark pressure as follows;

$$p_q=\frac{(s_1^4s_2^4s_3e^{2s_2t}-s_1^2s_2^2s_3-B_c)(s_1^2s_2^2-e^{-2s_2t})}{3s_1^2s_2^2(s_1^2s_2^2e^{2s_2t}-1)} \tag{58}$$

we get total energy density as follows

$$\rho=\frac{(s_1^4s_2^4s_3e^{2s_2t}-s_1^2s_2^2s_3-B_c)(s_1^2s_2^2-e^{-2s_2t})}{s_1^2s_2^2(s_1^2s_2^2e^{2s_2t}-1)}+B_c \tag{59}$$

Also total pressure has been calculated as follows

$$p=\frac{(s_1^4s_2^4s_3e^{2s_2t}-s_1^2s_2^2s_3-B_c)(s_1^2s_2^2-e^{-2s_2t})}{3s_1^2s_2^2(s_1^2s_2^2e^{2s_2t}-1)}-B_c \tag{60}$$

#### 1.4.2. $\kappa=0$ SITUATION FOR $m=0$

Using $\kappa=0$, in eqs. (29)-(34) we get scalar field, bulk viscous and quark energy density, respectively.

$$\phi=\frac{16\pi(s_1^2s_2^2s_3+B_c)}{s_2^2n(n+1)} \tag{61}$$

$$\xi=\frac{(s_1^2s_2^2s_3+B_c)s_1^4}{(n+1)s_2} \tag{62}$$

$$\rho_q=s_1^2s_2^2s_3 \tag{63}$$

Also we obtain quark pressure as follows;

$$p_q=\frac{s_1^2s_2^2s_3}{3} \tag{64}$$

We get total energy density as follows

$$\rho = s_1^2 s_2^2 s_3 + B_c \tag{65}$$

Also total pressure has been calculated as follows

$$p = \frac{s_1^2 s_2^2 s_3}{3} - B_c \tag{66}$$

For $\kappa = 0$, we get constant scalar field, quark pressure and density also bulk viscous coefficient. When $t \to 0$, we find constant bulk viscous coefficient in our model.

### 1.4.3. $\kappa = 1$ SITUATION FOR $m = 0$

Using $\kappa = 1$, in eqs. (29)-(34) we get scalar field, bulk viscous coefficient and quark energy density, respectively.

$$\phi = \frac{16\pi(s_1^2 s_2^2 s_3 + B_c)}{s_2^2 n(n+1)} \tag{67}$$

$$\xi = \frac{(s_1^2 s_2^2 s_3 + B_c)[s_1^6 s_2^6 (n+1) e^{4s_2 t} + s_1^4 s_2^4 (3n+1) e^{2s_2 t} + s_1^2 s_2^2 (3n-1) + (n-1) e^{-2s_2 t}]}{s_2^3 [s_1 (n+1)(s_2^2 e^{2s_2 t} + 1)]^2} \tag{68}$$

$$\rho_q = \frac{(s_1^4 s_2^4 s_3 e^{2s_2 t} + s_1^2 s_2^2 s_3 + B_c)(s_1^2 s_2^2 + e^{-2s_2 t})}{s_1^2 s_2^2 (s_1^2 s_2^2 e^{2s_2 t} + 1)} \tag{69}$$

We obtain quark pressure as follows;

$$p_q = \frac{(s_1^4 s_2^4 s_3 e^{2s_2 t} + s_1^2 s_2^2 s_3 + B_c)(s_1^2 s_2^2 + e^{-2s_2 t})}{3 s_1^2 s_2^2 (s_1^2 s_2^2 e^{2s_2 t} + 1)} \tag{70}$$

We get total energy density as follows

$$\rho = \frac{(s_1^4 s_2^4 s_3 e^{2s_2 t} + s_1^2 s_2^2 s_3 + B_c)(s_1^2 s_2^2 + e^{-2s_2 t})}{s_1^2 s_2^2 (s_1^2 s_2^2 e^{2s_2 t} + 1)} + B_c \tag{71}$$

Also total pressure has been calculated as follows

$$p = \frac{(s_1^4 s_2^4 s_3 e^{2s_2 t} + s_1^2 s_2^2 s_3 + B_c)(s_1^2 s_2^2 + e^{-2s_2 t})}{3 s_1^2 s_2^2 (s_1^2 s_2^2 e^{2s_2 t} + 1)} - B_c \tag{72}$$

In all situations we have obtained constant scalar field $\phi$ for generalized higher dimensional FRW universe model in SCC theory. From eq. (19), we get $\rho_s = 0$ for this universe model and we could say that there is no contribution from strings for FRW universe with attached strange quark matter in SCC. Also, the matter contribution comes from the quark energy density. This result agrees with the studies of Reddy [50], Sahoo-Mishra [51, 52] and Mohanty et al. [53] in four dimensions. If we take n = 2 in the study we obtain four-dimensional results for FRW universe in Barber's second theory.

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