String cloud and domain walls with quark matter for a higher dimensional FRW universe in self creation cosmology

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Abstract: In this study, we research a higher dimensional flat Friedmann-Robertson-Walker (FRW) universe in Barber's second theory when strange quark matter (SQM) and normal matter (NM) are attached to the string cloud and domain walls. We obtain zero string tension density for this model. We obtain dust quark matter solutions. This result agrees with Kiran and Reddy, Krori *et al*, Sahoo and Mishra and Reddy. In our solutions the quark matter transforms to other particles over time. We also obtain two different solutions for domain walls with quark and normal matters by using a deceleration parameter. Also, the features of the obtained solutions are discussed and some physical and kinematical quantities are generalized and discussed. Our results are consistent with Yılmaz, Adcox *et al* and Back *et al* in four and five dimensions.

Keywords: string cloud, domain wall, quark matter, higher dimension, FRW universe, self creation cosmology

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1 Introduction

The general theory of relativity is the most consistent and complete theory of gravitation. It defines gravitational interactions successfully and is fundamental for various models. After Einstein's general theory of relativity, there has been considerable interest in alternatives theories of gravitation. These theories have been categorised as scalar-tensor theories, scalar field theories, bimetric theories and vector-tensor theories [1], [2]. Weyl theory [3], $f(R)$ theory [4], Yılmaz theory [5], Lyra theory [6] and Brans-Dicke theory [7] are some examples of these alternative gravitation theories [8]. Using and modifying Brans-Dicke theory and general relativity, Barber [9] suggested two self-creation cosmologies of gravitation. Barber first theory is in disagreement with experiment as well as inconsistent [10]. However, in Barber's second theory, the scalar field does not directly gravitate and this is a modification of general relativity to a variable G-theory [10]. Many authors have studied Barber's second theory with various universe models. Reddy and Venkateswarlu [10] discussed a Bianchi VI_0 universe in self creation cosmology. Pradhan et al have researched LRS Bianchi type-I cosmological models in Barber's second self creation theory with bulk viscous fluid [11]. Pradhan et al [12] have discussed Barber's second self creation theory using a deceleration parameter and perfect fluid energy-momentum tensor for LRS Bianchi I space-time. Rai et al have investigated perfect fluid energy distribution for a Marder type universe in self creation cosmology (SCC) [13]. Chirde and Rahate [14] have obtained Friedmann-Robertson-Walker (FRW) solutions for bulk viscous fluid and zero mass scalar field in self creation cosmology. Yadav and Jain have researched LRS Bianchi type II space-time with a varying Λ term in self creation theory [15]. Sanyasiraju and Rao [16] have investigated Bianchi type VIII and IX models in the presence of self creation cosmology when the source of the gravitational field is a perfect fluid with $p=\rho$. Ramirez and Socorro [17] have researched a FRW universe with radiation, dust and stiff matter using the Hamilton-Jacobi scheme in self creation cosmology. Rai et al [18] have obtained Marder universe solutions in Barber's second self-creation theory of gravitation in the presence of perfect fluid. Soleng [19] and Pimentel [20] have researched FRW solutions using a power law relation between the expansion factor of the universe and the scalar field in self creation cosmology. Belinchón [21] has investigated Bianchi I, VIIo, IX and Kantowski-Sach universe models to obtain the gravitational constant G in SCC. For his aim he compared and discussed the obtained results with current Hulse-Taylor binary pulsar B1913+16 [22] and astereoseismological data from the pulsating white dwarf star G117–B15Al [23] obser-

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vations. Barber has researched the experimental tests of the new self creation cosmology of gravitation using Probe B satellite data [24–26].

Lately the studies of cosmic strings have gained importance in various gravitation theories. Also, many authors have researched cosmic strings in different theories. Adhav et al have examined axially symmetric Bianchi type-I model with massless scalar field and cosmic strings in self-creation cosmology [27]. Rao and Vinutha have obtained plane symmetric string cosmological models in self-creation theory [28]. Katore and Shaikh have discussed an Einstein-Rosen string cosmological model in Barber's second theory [29]. Venkateswarlu et al have obtained string cosmological solutions in self-creation theory [30]. Reddy et al have obtained a Bianchi type-II bulk viscous string cosmological model in a self-creation theory of gravitation [31].

At the cosmological scale, today the universe is described by FRW space-time, which characterizes an isotropic and homogenous universe [32]. In this study, we have first attached strange quark matter to the string cloud and secondly we have attached normal matter and strange quark matter to the domain walls for a generalized higher dimensional FRW universe in a self-creation theory of gravitation. This method is reasonable, because during the phase transitions of the universe an alternative important transition is Quark Gluon Plasma (QGP)→ hadron gas (called the quark-hadron phase transition) when the cosmic temperature was T∼ 200 MeV [33, 34]. Usually, quark matter is formed with an equation of state (EOS) according to the factual bag model of quark matter. In this model we suppose that the quarks are non-interacting and massless [33–37]. In this case we have quark pressure

$$p_{\mathrm{q}}=\frac{\rho_{\mathrm{q}}}{3}, \tag{1}$$

where ρ_{q} is the quark energy density. The total energy density is

$$\rho=\rho_{\mathrm{q}}+B_{\mathrm{c}}. \tag{2}$$

Also the total pressure is

$$p=p_{\mathrm{q}}-B_{\mathrm{c}} \tag{3}$$

and the equation of state for strange quark matter is given by

$$p_m=\frac{1}{3}(\rho_m-4B_{\mathrm{c}}), \tag{4}$$

where B_{c} is the bag constant [36, 37]. Because quark-gluon plasma has been created as a perfect liquid at Brookhaven National Laboratory [38], we will take into account quark-gluon plasma in the form of a perfect fluid following the equation of state:

$$p_m=(\gamma-1)\rho_m, \tag{5}$$

where $1\leqslant\gamma\preceq 2$ is a constant [39–41]. Recently, many authors have also investigated quark and strange quark matter in self creation cosmology in different alternative gravitation theories. Rao and Neelima have investigated axially symmetric space-time with strange quark matter attached to a string cloud in self creation theory and general relativity [42]. Mahanta et al have obtained string cloud with quark matter for a Bianchi type-III metric in self creation theory [43]. Rao and Neelima have researched a Bianchi VI_0 universe model with strange quark matter attached to a string cloud in self-creation theory [44]. Ulu Doḡru and Baykal have investigated homogeneous cosmologies in scalar tensor theory [45]. Yılmaz et al have researched quark and strange quark matter in $f(R)$ gravity for Bianchi type I and V space-times [46]. Aktaṣ and Yılmaz have studied magnetized quark and strange quark matter in a spherical symmetric space-time admitting conformal motion [47]. Also, Barber's second self-creation theory of gravitation is given by [9]

$$R_{ik}-\frac{1}{2}g_{ik}R=-\frac{8\pi}{\phi}T_{ik} \tag{6}$$

and

$$\Box\phi=\frac{8\pi}{3}\lambda T, \tag{7}$$

where ϕ is Barber's scalar field. λ is a coupling constant to be determined from experiments, and the value of the coupling to $|\lambda|<10^{-1}$. T is the trace of the energy momentum tensor i.e. $T=T^k_k$. In the limit $\lambda\rightarrow 0$ this theory approaches the standard general relativity theory in every respect [10]. In this paper, we investigate strange quark matter attached to string cloud and domain walls in a generalized $(n+2)$ dimensional flat FRW universe in self-creation theory. The paper is organized as follows: the solutions of strange quark matter attached to string cloud in this theory are presented in Section 2. Domain walls with quark matter in self-creation cosmology are presented in Section 3. We then conclude with some discussion in Section 4.

2 Strange quark matter attached to string cloud in self creation cosmology

A homogeneous, isotropic flat FRW universe is represented by:

$$\mathrm{d}s^2=-\mathrm{d}t^2+R(t)^2[\mathrm{d}r^2+r^2\mathrm{d}x_n^2], \tag{8}$$

where $R(t)$ represents the scale factor and [48]

$$\mathrm{d}x_n^2=\mathrm{d}\theta_1^2+\sin^2\theta_1\mathrm{d}\theta_2^2+...+\sin^2\theta_1\sin^2\theta_2...\sin^2\theta_{n-1}\mathrm{d}\theta_n^2. \tag{9}$$

The string cloud energy-momentum tensor is given by [49]

$$T_{ik}=\rho u_i u_k-\rho_{\rm s} X_i X_k. \quad (10)$$

where ρ is the rest energy density for the cloud of strings with particles attached to them and $\rho_{\rm s}$ is the string tension density and they are related by

$$\rho=\rho_{\rm p}+\rho_{\rm s}, \quad (11)$$

where $\rho_{\rm p}$ is the particle energy density. In this study we will take quarks instead of particles in the string cloud. Henceforth, using Eq. (11), we obtain

$$\rho=\rho_{\rm q}+\rho_{\rm s}+B_{\rm c}. \quad (12)$$

Using Eqs. (10) and (12) we get a new energy-momentum tensor for strange quark matter attached to a string cloud as [33]

$$T_{ik}=(\rho_{\rm q}+\rho_{\rm s}+B_{\rm c})u_i u_k-\rho_{\rm s} X_i X_k, \quad (13)$$

where u_i is the velocity of the particles, X_i is the unit space like vector representing the direction of strings, and

$$u_i u^i=-X_i X^i=1; \quad u^i X_i=0. \quad (14)$$

Using Eqs. (6)–(13), we get field equations for an $(n+2)$ dimensional flat FRW universe in self creation theory for strange quark matter attached to a string cloud as follows:

$$\frac{n(n+1)}{2}\left(\frac{\dot{R}^2}{R^2}\right)=\frac{8\pi}{\phi}(\rho_{\rm q}+\rho_{\rm s}+B_{\rm c}), \quad (15)$$

$$\frac{n(n-1)}{2}\left(\frac{\dot{R}^2}{R^2}\right)+n\frac{\ddot{R}}{R}=\frac{8\pi}{\phi}\rho_{\rm s}, \quad (16)$$

$$\frac{n(n-1)}{2}\left(\frac{\dot{R}^2}{R^2}\right)+n\frac{\ddot{R}}{R}=0, \quad (17)$$

and

$$\Box\phi=(n+1)\frac{\dot{R}\dot{\phi}}{R}+\ddot{\phi}=\frac{8}{3}\pi\lambda(2\rho_{\rm s}+\rho_{\rm q}+B_{\rm c}). \quad (18)$$

Here and hereafter the dot (.) indicates differentiation with respect to cosmic time t. The kinematical quantities such as velocity, cosmic expansion, Hubble parameter, spatial volume and deceleration parameter for an $(n+2)$ dimensional flat FRW universe are respectively given by

$$u_i=(-1,0,0...0), \quad (19)$$

$$\theta=(n+1)\frac{R_t}{R}, \quad (20)$$

$$H=\frac{R_t}{R}, \quad (21)$$

$$V=R^{(n+1)}r^n\left(\prod_{i=2}^{n}\sin^{(i-1)}\theta_{n-i+1}\right), \quad (22)$$

$$q=-\frac{R\ddot{R}}{\dot{R}^2}. \quad (23)$$

To solve the field equations, we first use Eqs. (16) and (17) to find that the string tension density is zero:

$$\rho_{\rm s}=0. \quad (24)$$

In this situation Eq. (16) and Eq. (17) are the same equation. Using Eqs. (16) and (24) or Eq.(17) we obtain the scale factor $R(t)$ for an $(n+2)$ dimensional FRW universe as follows:

$$R=\left[\frac{n+1}{2}(c_1 t+c_2)\right]^{\frac{2}{n+1}}. \quad (25)$$

Here c_1 and c_2 are constants. Also using Eqs. (15), (18) and (25) we get Barber's scalar field ϕ and the quark energy density $\rho_{\rm q}$ as follows:

$$\phi=c_3\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}+\eta}+c_4\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}-\eta}, \quad (26)$$

where $\eta=\dfrac{\sqrt{(n+1)[3(n+1)+8n\lambda]}}{2\sqrt{3}(n+1)}$ and c_3 and c_4 are constants. Using Eqs. (15), (25) and (26) we get $\rho_{\rm q}$

$$\rho_{\rm q}=\frac{nc_1^2}{4\pi}\frac{c_3\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}+\eta}+c_4\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}-\eta}}{(n+1)(c_1 t+c_2)^2}-B_{\rm c}. \quad (27)$$

Substituting Eq. (27) in Eq. (1) we obtain quark pressure as follows:

$$p_{\rm q}=\frac{nc_1^2}{12\pi}\frac{c_3\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}+\eta}+c_4\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}-\eta}}{(n+1)(c_1 t+c_2)^2}-\frac{B_{\rm c}}{3} \quad (28)$$

and using Eqs. (27) and (2) we obtain total energy density as follows:

$$\rho=\frac{nc_1^2}{4\pi}\frac{c_3\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}+\eta}+c_4\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}-\eta}}{(n+1)(c_1 t+c_2)^2}. \quad (29)$$

Substituting Eq. (28) in Eq. (3) we get total pressure as follows:

$$p=\frac{nc_1^2}{12\pi}\frac{c_3\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}+\eta}+c_4\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}-\eta}}{(n+1)(c_1 t+c_2)^2}-\frac{4B_{\rm c}}{3}. \quad (30)$$

Then, using Eqs. (11), (24) and (29) we have the energy density of the particles as follows:

$$\rho_{\rm p}=\frac{nc_1^2}{4\pi}\frac{c_3\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}+\eta}+c_4\left(t+\frac{c_2}{c_1}\right)^{-\frac{1}{2}-\eta}}{(n+1)(c_1 t+c_2)^2}. \quad (31)$$

3 Domain wall solutions in self creation cosmology

The energy-momentum tensor of a domain wall in the classical form is given by

$$T_{ik}^{D}=(\rho+p)u_i u_k+pg_{ik}. \tag{32}$$

This perfect-fluid form of the domain wall includes quark matter (described by $\rho_m=\rho_{\rm q}+B_{\rm c}$ and $p_m=p_{\rm q}-B_{\rm c}$) as well as domain wall tension σ_w; i.e. $\rho=\rho_m+\sigma_w$ and $p=p_m-\sigma_w$. Also p_m and ρ_m are related by the bag model equation of state, i.e. Eq. (4) and the equation of state, i.e. Eq. (5), [39, 50]. Using Eqs. (6)–(9) and (32) we get field equations for an $(n+2)$ dimensional FRW metric for domain walls with quark matter as follows:

$$\frac{n(n+1)}{2}\left(\frac{\dot{R}^2}{R^2}\right)=\frac{8\pi\rho}{\phi}, \tag{33}$$

$$\frac{n(n-1)}{2}\left(\frac{\dot{R}^2}{R^2}\right)+n\frac{\ddot{R}}{R}=-\frac{8\pi p}{\phi}, \tag{34}$$

$$\Box\phi=(n+1)\frac{\dot{R}}{R}\dot{\phi}+\ddot{\phi}=\frac{8}{3}\pi\lambda[(n+1)p-\rho]. \tag{35}$$

We have three equations (33)–(35) with four unknowns R, ρ, p and ϕ. To solve the system completely we need an approximation. One of the considerations is a varying deceleration parameter for this model, because a deceleration parameter is so important for the fate of the universe. Also q indicates whether the model accelerates or not [51, 52] and is given by

$$q=-\frac{R\ddot{R}}{\dot{R}^2}=m-1, \tag{36}$$

where m is a constant. If we solve Eq. (36), we get two solutions as follows:

$$R=[m(k_1t+k_2)]^{\frac{1}{m}} \qquad \text{for} \quad m\neq 0, \tag{37}$$

$$R=s_1{\rm e}^{s_2t} \qquad \text{for} \quad m=0, \tag{38}$$

where s_1, s_2, k_1 and k_2 are constants. In this study we will investigate two different solutions for $m\neq 0$ and $m=0$ situations in a higher dimensional FRW universe, respectively.

3.1 Solutions of domain walls in self creation cosmology for $m\neq 0$

In this section we will investigate the $m\neq 0$ situation for an $(n+2)$ dimensional FRW universe. Substituting Eq. (37) in Eqs. (33)–(35) we find Barber's scalar field (ϕ) as follows:

$$\phi=k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})}+k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}. \tag{39}$$

Here, k_3 and k_4 are constants of integration, $\phi_1=\dfrac{1}{k_1}(k_1t+k_2)$ and $\phi_2=\sqrt{\dfrac{2n(n+1)(2m-n-2)\lambda}{3}+(m-n-1)^2}$. So, energy density and pressure are obtained respectively as follows:

$$\rho=\rho_m+\sigma_w=\frac{n(n+1)k_1^2}{16\pi m^2(k_1t+k_2)^2}\left[k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})}+k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}\right], \tag{40}$$

$$p=p_m-\sigma_w=\frac{n(2m-n-1)k_1^2}{16\pi m^2(k_1t+k_2)^2}\left[k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})}+k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}\right]. \tag{41}$$

i) Strange quark matter (SQM) attached to the domain wall

If we use Eq. (4) in Eqs. (40) and (41), i.e. strange quark matter coupled to the domain walls, we get

$$\rho_{\rm q}=\frac{3nk_1^2[k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})}+k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}]}{32\pi m(k_1t+k_2)^2}, \tag{42}$$

$$p_{\rm q}=\frac{nk_1^2[k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})}+k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}]}{32\pi m(k_1t+k_2)^2}, \tag{43}$$

$$\sigma_w=\frac{nk_1^2[2(n+1)-3m]}{32\pi m^2(k_1t+k_2)^2}\left[k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})}+k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}\right]-B_{\rm c}. \tag{44}$$

ii) Normal matter (NM) attached to the domain wall

If we use Eq. (5) in Eqs. (40) and (41), i.e. normal matter coupled to the domain walls, we get

$$\rho_m=\frac{nk_1^2[k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})}+k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}]}{8\gamma\pi m(k_1t+k_2)^2}, \tag{45}$$

$$p_m=\frac{nk_1^2(\gamma-1)[k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})}+k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}]}{8\gamma\pi m(k_1t+k_2)^2}, \tag{46}$$

$$\sigma_w=\frac{nk_1^2((n+1)\gamma-2m)}{16\gamma\pi m^2(k_1t+k_2)^2}\left[k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})}+k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}\right]. \tag{47}$$

3.2 Solutions of domain walls in self creation cosmology for $m=0$

In this section we will investigate the $m=0$ situation for an $(n+2)$ dimensional FRW universe. Substituting Eq. (38) in Eqs. (33)–(35) we find Barber's scalar field as follows;

$$\phi=\frac{s_3{\rm e}^{\phi_3}+s_4{\rm e}^{-\phi_3}}{{\rm e}^{\frac{(n+1)s_2t}{2}}}. \tag{48}$$

Here s_3 and s_4 are constant of integration, and $\phi_3 = \frac{s_2 t}{2}\sqrt{(n+1)^2-\frac{2n(n+1)(n+2)\lambda}{3}}$. From Eqs. (48) and (33)–(35) the energy density and pressure are obtained respectively, as follows:

$$\rho=\rho_m+\sigma_w=\frac{n(n+1)s_2^2}{16\pi}[\mathrm{e}^{(-\frac{n+1}{2}s_2t)}(s_3\mathrm{e}^{\phi_3}+s_4\mathrm{e}^{-\phi_3})], \quad (49)$$

$$p=p_m-\sigma_w=-\frac{n(n+1)s_2^2}{16\pi}[\mathrm{e}^{(-\frac{n+1}{2}s_2t)}(s_3\mathrm{e}^{\phi_3}+s_4\mathrm{e}^{-\phi_3})]. \quad (50)$$

i) Strange quark matter attached to the domain wall

If we use Eq. (4) in Eqs. (49) and (50), i.e. strange quark matter coupled to the domain walls, we get

$$\rho_{\mathrm{q}}=0, \quad (51)$$

$$p_{\mathrm{q}}=0, \quad (52)$$

$$\sigma_w=\frac{n(n+1)s_2^2}{16\pi}[\mathrm{e}^{(-\frac{n+1}{2}s_2t)}(s_3\mathrm{e}^{\phi_3}+s_4\mathrm{e}^{-\phi_3})]-B_{\mathrm{c}}. \quad (53)$$

ii) Normal matter attached to the domain wall

If we use Eq. (5) in Eqs. (49) and (50), i.e. normal matter coupled to the domain walls, we get

$$\rho_m=0, \quad (54)$$

$$p_m=0, \quad (55)$$

$$\sigma_w=\frac{n(n+1)s_2^2}{16\pi}[\mathrm{e}^{(-\frac{n+1}{2}s_2t)}(s_3\mathrm{e}^{\phi_3}+s_4\mathrm{e}^{-\phi_3})]. \quad (56)$$

4 Discussion

In this study we have obtained exact solutions of strange quark matter attached to string cloud and domain walls for an $(n+2)$ dimensional FRW universe in self creation cosmology.

Strange quark matter attached to string cloud in self creation cosmology

In this part we discuss strange quark matter solutions with string cloud for a generalized higher dimensional FRW universe. We find that string tension density vanishes ($\rho_{\mathrm{s}}=0$) for our universe model, similar to solutions obtained in various gravitation theories [53–56]. We get a dust quark matter solution. From these results, we could say that the perturbations of the strings may have created the strange quarks. Also, there is no contribution from strings for a generalized higher dimensional FRW universe with attached strange quark matter in self creation cosmology. The matter contribution comes from the quark energy density. From Eqs. (8), (9) and (25) we get a new line element for strange quark matter attached to the string cloud in self creation cosmology for a generalized higher dimensional FRW universe as follows:

$$\mathrm{d}s^2=-\mathrm{d}t^2+\left[\frac{n+1}{2}(c_1t+c_2)\right]^{\frac{4}{n+1}}[\mathrm{d}r^2+r^2\mathrm{d}x_n^2]. \quad (57)$$

We see that c_1 is an important constant and must be different from zero, $c_1\neq 0$, in our solutions. If the dimensions of the universe increase, the scale factor (Eq. (25)) increases in this model. However, using Eqs. (20)–(23) we get the kinematical quantities such as cosmic expansion, Hubble parameter, spatial volume and deceleration parameter for an $(n+2)$ dimensional FRW universe as follows:

$$\theta=\frac{2c_1}{c_1t+c_2}, \quad (58)$$

$$H=\frac{2c_1}{(n+1)(c_1t+c_2)}, \quad (59)$$

$$V=\left[\frac{n+1}{2}(c_1t+c_2)\right]^2 r^n\left(\prod_{i=2}^{n}(\sin(\theta_{n-i+1}))^{i-1}\right), \quad (60)$$

$$q=\frac{1}{2}(n-1). \quad (61)$$

At the initial stage of the universe, when $t\rightarrow 0$, the scale factor R(t), Barber's scalar field, quark pressure and density, particle energy density, total pressure and density and the kinematical quantities are constants in self creation cosmology. When t increases, the quark pressure, quark density, particle energy density, total pressure and density decrease and they vanish when $t\rightarrow\infty$. From the obtained results, we could say that the quarks have combined to create neutrons and protons and also transform to other fundamental particles. For the $(n+2)$ dimensional FRW model, the universe starts at an initial epoch $t=-c_2/c_1$. When $t=-c_2/c_1$ the proper volume will be zero. As t increases, θ and the Hubble parameter decrease and finally vanish when $t\rightarrow\infty$. These results agree with the studies of Yılmaz [39], Back et al [40] and Adcox et al [41] at Brookhaven National Laboratory. If $q>0$ the model decelerates in its standard way and while $q<0$, the model inflates. From Eq.(61) we have obtained that if $q>0$ in our model then the universe has decelerating expansion. It is well known that strings and other topological defects formed in the early universe [57]. So our model includes the behaviour of strange quark matter attached to strings in the early universe. Therefore our string solutions are not consistent with the present Supernova Ia observations. Also Barber's scalar field (ϕ) is extremely effective on quark energy density, quark pressure and particle energy density for a higher dimensional FRW universe. However we obtain strange quark matter attached to string cloud in four-dimensional FRW solutions for $n=2$ in self creation cosmology. The results can be seen in Table 1.

Table 1. Results of $(n+2)-D$ FRW universe with quark matter attached to string cloud.

scale factor	$R=\left[\frac{n+1}{2}(c_1t+c_2)\right]^{\frac{2}{n+1}}$
scalar field	$\phi=c_3(t+\frac{c_2}{c_1})^{-\frac{1}{2}+\eta}+c_4(t+\frac{c_2}{c_1})^{-\frac{1}{2}-\eta}$
quark energy density	$\rho_{\rm q}=\frac{nc_1^2}{4\pi(n+1)(c_1t+c_2)^2}[\phi]-B_{\rm c}$
quark pressure	$p_{\rm q}=\frac{nc_1^2}{12\pi(n+1)(c_1t+c_2)^2}[\phi]-\frac{B_{\rm c}}{3}$
rest energy density	$\rho=\frac{nc_1^2}{4\pi(n+1)(c_1t+c_2)^2}[\phi]$
total pressure	$p=\frac{nc_1^2}{12\pi(n+1)(c_1t+c_2)^2}[\phi]-\frac{4}{3}B_{\rm c}$
particle energy density	$\rho_{\rm p}=\frac{nc_1^2}{4\pi(n+1)(c_1t+c_2)^2}[\phi]$
string tension density	$\rho_{\rm s}=0$

Domain walls in self creation cosmology:

In this part we discuss domain wall results with strange quarks and normal matter for $m\neq0$ and $m=0$ situations for an $(n+2)$ dimensions FRW universe, respectively.

For $m\neq0$, from Eqs. (8) and (37), we obtain a new line element with perfect-fluid form of the domain wall in self creation cosmology for a generalized higher dimensional FRW universe as follows:

$$\mathrm{d}s^2=-\mathrm{d}t^2+[m(k_1t+k_2)]^{\frac{2}{m}}[\mathrm{d}r^2+r^2\mathrm{d}x_n^2]. \qquad (62)$$

Here we note that the universe starts at an initial epoch $t=-k_2/k_1$ and k_1 is an important constant for this universe model; it must be different from zero, $k_1\neq0$, for meaningful results. We find that all physical parameters such as R, ϕ, ρ, p, $\rho_{\rm q}$, $p_{\rm q}$, ρ_m, p_m and σ_w are constant for strange quark matter and σ_w for normal matter is constant as $t\to0$.

When t increases, the scale factor and Barber's scalar field increase and other physical parameters such as ρ, p, $\rho_{\rm q}$, $p_{\rm q}$, ρ_m, p_m and the tension of normal matter σ_w decrease. When $t\to\infty$ we get negative tension ($\sigma_w=-B_{\rm c}$) for strange quark matter attached to the domain wall with a bag constant. Because of this solution strange quark matter attached to the domain wall behaves like invisible matter due to its negative tension [39]. Also the value of m is important for these results. From Eqs. (36) and (37) we obtain $q=m-1$ for domain wall solutions in SCC. For $0<m<1$, we get $-1<q<0$ and in this model the universe has accelerating power law expansion. In the case of normal matter coupled to the domain walls (i.e. case ii), if we take $\gamma=1$ in Eq. (45)–(46), we obtain domain wall solutions with dust matter. When $\gamma=2$ we get a stiff matter solution. When $\gamma=\frac{4}{3}$ we obtain domain wall solutions with normal matter like radiation in self creation cosmology as proposed [36, 37]. Also, for $n=2$ we obtain four-dimensional flat FRW solutions in Barber's second theory. Barber's scalar field is extremely effective on domain wall density-pressure, SQM and normal matter energy density-pressure, domain wall and normal matter tensions for an $(n+2)$ dimensional FRW universe in SCC.

For $m=0$, from Eqs. (8) and (38), we obtain a new line element with perfect-fluid form for the domain wall in self creation cosmology for a generalized higher dimensional FRW universe as follows:

$$\mathrm{d}s^2=-\mathrm{d}t^2+[s_2\mathrm{e}^{s_1t}]^2[\mathrm{d}r^2+r^2\mathrm{d}x_n^2], \qquad (63)$$

where s_2 is an important constant for this universe model and must be different from zero, $s_2\neq0$, for meaningful results. When $t\to0$, we find that R, ϕ, ρ, p, and σ_w for strange quark matter and normal matter are constant. When t increases, the scale factor increases, while ϕ, ρ, p, and σ_w decrease for normal matter and σ_w decreases for strange quark matter. When $t\to\infty$ we get negative tension $\sigma_w=-B_{\rm c}$ for normal matter. We observe domain wall tension (σ_w) for strange quark matter and normal matter but we do not observe pressure and density for these models. From Eqs. (49) and (50) we find a dark energy model for domain walls with positive density and negative pressure ($p=-\rho$) in self creation cosmology. From Eqs. (36) and (38) we get $q=-1$ for domain walls in SCC. In this model the universe has exponential expansion. This result agrees with recent observations. The acceleration of the universe could be explained by dark energy. If we take $n=2$ we get four-dimensional flat FRW solutions in Barber's second theory. The scalar

Table 2. Results of $(n+2)-$D FRW universe with quark matter attached to domain walls.

situation	$m\neq0$	$m=0$
scale factor	$[m(k_1t+k_2)]^{\frac{1}{m}}$	$s_1\mathrm{e}^{s_2t}$
D.W. density	$\frac{n(n+1)k_1^2}{16\pi m^2(k_1t+k_2)^2}[\phi]$	$\frac{n(n+1)s_2^2}{16\pi}[\phi]$
D.W. pressure	$\frac{n(2m-n-1)k_1^2}{16\pi m^2(k_1t+k_2)^2}[\phi]$	$-\frac{n(n+1)s_2^2}{16\pi}[\phi]$
SQM Energy density	$\frac{3nk_1^2}{32\pi m(k_1t+k_2)^2}[\phi]$	0
SQM pressure	$\frac{nk_1^2}{32\pi m(k_1t+k_2)^2}[\phi]$	0
SQM σ_w	$\frac{nk_1^2[2(n+1)-3m]}{32\pi m^2(k_1t+k_2)^2}[\phi]-B_{\rm c}$	$\frac{n(n+1)s_2^2}{16\pi}[\phi]-B_{\rm c}$
N.M. Energy density	$\frac{nk_1^2}{8\gamma\pi m(k_1t+k_2)^2}[\phi]$	0
NM pressure	$\frac{nk_1^2(\gamma-1)}{8\gamma\pi m(k_1t+k_2)^2}[\phi]$	0
NM σ_ω	$\frac{nk_1^2((n+1)\gamma-2m)}{16\gamma\pi m^2(k_1t+k_2)^2}[\phi]$	$\frac{n(n+1)s_2^2}{16\pi}[\phi]$

field ϕ is extremely powerful on domain wall density and pressure as well as on domain wall and normal matter tensions for the $m = 0$ situation in our model. These results can be seen in Table 2.

We get $\phi = k_3\phi_1^{(\frac{m-n-1+\phi_2}{2m})} + k_4\phi_1^{(\frac{m-n-1-\phi_2}{2m})}$ for $m \neq 0$ and $\phi = \frac{s_3 e^{\phi_3} + s_4 e^{-\phi_3}}{e^{\frac{(n+1)s_2 t}{2}}}$ for $m = 0$ in Table 2.

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References

1 B. M. Barker, Astrophysical Journal, **219**: 5 (1978)
2 J. D. Bekenstein, Phys. Rev. D, **70**: 083509 (2004)
3 H. Weyl, K. Sitzungsber, Preuss, akad. Wissi Berlin, **465**: (1918)
4 F. S. N. Lobo, M. A. Oliveira, Phys. Rev. D, **80**: 104012 (2009).
5 H. Yılmaz, Phys. Rev. **111**: 1417 (1958)
6 G. Lyra, Math. Z, **54**: 52 (1951)
7 C. Brans, R. H. Dicke, Phys. Rev., **124**: 52 (1961)
8 C. Aktaş, S. Aygün, İ. Yılmaz, Phys. Lett. B, **707**: 237 (2012)
9 G. A. Barber, Gen. Relativ. Gravit., **14**: 117 (1982)
10 D. R. K. Reddy, R. Venkateshwarlu, Astrophys. Space Sci., **155**: 135 (1989)
11 A. Pradhan, A. K. Vishwakarma, A. Dolgov, Int. J. Mod. Phys. D, **11**: 1195 (2002)
12 A. Pradhan, S. Agarwal, G. P. Singh, Int. J. Theo. Phys., **48**: 158 (2009)
13 P. Rai, L.N. Rai, V.K. Singh, Int. J. Theo. Phys., **51**: 2503 (2012)
14 V. R. Chirde, P.N. Rahate, Int. J. Theo. Phys., **51**: 2262 (2012)
15 M. K. Yadav, V.C. Jain, Astrophys. Space Sci., **331**: 343 (2011)
16 Y.V. S. S. Sanyasiraju, V.U.M. Rao, Astrophys. Space Sci., **189**: 39 (1992)
17 J. M. Ramirez , J. Socorro, Int J Theor Phys., **52**: 2867 (2013)
18 L. N. Rai, P. Rai, V. K. Singh, Astrophys. Space Sci., **51**: 1572 (2012)
19 H. H. Soleng, Astrophys. Space Sci., **139**: 13 (1987)
20 L. O. Pimentel, Astrophys. Space Sci., **116**: 935 (1985)
21 J. A. Belinchón, Astrophys Space Sci., **346**: 237 (2013)
22 T. Damour, et al., Phys. Rev. Lett., **61**: 1151 (1988)
23 M. Biesiada, B. Malec, Mon. Not. R. Astron. Soc., **350**: 644 (2004)
24 G. A. Barber, Astrophys. Space Sci., **305**: 169 (2006)
25 G. A. Barber, arXiv:gr-qc/0405094v5
26 G. A. Barber arXiv:1009.5862v2
27 K. S. Adhav, A.S. Nimkar, V.G. Mete, M.V. Dawande, Int. J. Theor. Phys., **49**: 1127 (2010)
28 V. U. M. Rao, T. Vinutha, Astrophys. Space Sci., **325**: 59 (2010)
29 S. D. Katore, A. Y. Shaikh, Int. J. Mod. Phys. A, **26**: 1651 (2011)
30 R.Venkateswarlu, V. U. M. Rao, K. Pavan Kumar, Int. J. Theo. Phys., **47** (3): 640 (2008)
31 D. R. K. Reddy, M. P. V. V. Bhaskara Rao, K. Sobhan Babu, Astrophys. Space Sci., **351** (1): 385 (2014)
32 S. Ram, P. Singh, Astrophys. Space Sci., **200**: 35 (1993)
33 İ. Yavuz, İ. Yılmaz, H. Baysal, Int. J. Mod. Phys. D, **14**: 1365 (2005)
34 K.S. Adhav, A.S. Nimkar, M.V. Dawande, Int. J. Theor. Phys. **47**, 2002 (2008)
35 A.Pradhan, et al, Chin. Phys. Lett., **24**: 3013 (2007)
36 A.R. Bodmer, Phys. Rev. D, **4**: 1601 (1971)
37 E. Witten, Phys. Rev. D, **30**: 272 (1984)
38 J. Adams, J. et al, STAR Collab. Nucl Phys. A, **757**: 102 (2005)
39 İ. Yılmaz, Gen. Relativ. Gravit., **38**: 1397 (2006)
40 B.B. Back, et al, (PHOBOS Collab.) Nucl. Phys. A, **28**: 757 (2005)
41 K. Adcox, et al, (PHENIX Collab.) Nucl. Phys. A, **184**: 757 (2005)
42 V. U. M. Rao, D. Neelima, Int. J. Theor. Phys., **52**: 354 (2013)
43 K. L. Mahanta, S. K. Biswal, P. K. Sahoo, M. C. Adhikary, Int. J. Theor. Phys., **51**: 1538 (2012)
44 V. U. M. Rao, D. Neelima, The African Rev. of Phys., **9**: 0004 (2014)
45 M. Ulu Doğru, D. Baykal, 2012arXiv1209.6328U
46 İ. Yılmaz, H. Baysal, C. Aktaş, Gen. Relativ. Gravit., **44**: 2313 (2012)
47 C. Aktaş, İ. Yılmaz, Gen. Relativ. Gravit., **39**: 849 (2007)
48 C. P.Singh, A. Beesham, Int. J. Theor. Phys., **51**: 3951 (2012)
49 P. S. Lettelier, Phys. Rev. D, **28**: 2414 (1983)
50 G.S. Khadekar, R. Wanjari, C. Ozel, Int. J. Theor. Phys., **48**: 2550 (2009)
51 K. S. Adhav, Eur. Phys. J. Plus, **126**: 122 (2011)
52 Ö. Akarsu, T. Dereli, Int. J. Theor. Phys., **51**: 612 (2012)
53 M. Kiran, D. R. K. Reddy, Astrophys. Space Sci., **346**: 521 (2013)
54 K. D. Krori, T. Chaudhury, C. R. Mahanta, Gen. Rel. Grav., **26**: 265 (1994)
55 D. R. K. Reddy, Astrophys. Space Sci., **286**: 397 (2003)
56 P. K. Sahoo, B. Mishra, J. Theor. Appl. Phys., **7**: 12 (2013)
57 A. Vilenkın, E. P. S. Shellard, Cosmic Strings and Other Topological Defects, Cambridge University Press, (2000)