Journal of Dynamical Systems & Geomatric Theories
ISSN : 1726-037X (Print) 2169-0057 (Online)
Vol. 17(2) November 2019, pp. 239–266
DOI : 10.1080/1726037X.2019.1668149

HOLOGRAPHIC DARK ENERGY WITH EXTENDED CHAPLYGIN GAS MODEL

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(Received: 15 February 2019, Accepted: 1 April 2019)

Abstract. In this paper we consider a correspondence between holographic dark energy density and extended Chaplygin gas energy density proposed by Pourhassan and Kahya [2014] (Advances in High Energy Physics, 231452, 2014) in FRW universe. We solve the Friedmann equation and investigate the behaviour of cosmological parameters and also we reconstruct the potential and dynamics of the scalar field which describe the extended Chaplygin gas cosmology.

AMS Classification: 54H20
Keywords: Holographic dark energy; Extended Chaplygin gas

1. Introduction

Accelerated expansion of the universe can be described by dark energy [12, 35]. In that case there are several dark energy candidates. One of the candidate of the dark energy is Einstein's cosmological constant which has two crucial problems so called 'fine tuning' and 'cosmic coincidence' [23]. There are also other models to describe dark energy such as k-essence model [2] and tachyon model [29]. An interesting model to describe dark energy is Chaplygin Gas (CG) [5, 17] that are based on Chaplygin equation of state (EoS) [9] which are not of good consistent with the observational data [14]. On the other hand CG is an interesting fluid explaining the acceleration of the universe. The extension of the CG model is proposed by [4, 8, 34] which is called Generalized Chaplygin Gas (GCG). However, observational data ruled out such proposal. Then GCG was extended to Modified Chaplygin Gas (MCG) [13]. Further extension of CG model called Modified Cosmic Chaplygin Gas (MCCG) was proposed by [24, 26]. Also, various CG model were studied from the holographic point of view [27, 30, 31]. The MCG and MCCG include only barotropic fluid with linear EoS while it is possible to extend them including quadratic barotropic EoS of the form [1, 10, 21]

$$p = p_0 + \omega_1 \rho + \omega_2 \rho^2,$$

where p_0, ω_1 and ω_2 are constants.
If, we set $p_0 = \omega_2 = 0$ to recover linear barotropic EoS.

Pourhassan and Kahya [15, 16, 25], Khurshudyan et al. [18, 19, 20] and Sadeghi et al. [28] introduced Extended Chaplygin Gas (ECG) with EoS of the form

$$p = \sum_n (A_n \rho^n) - \frac{B}{\rho^\alpha}, \tag{1}$$

where A, B and α are positive constants.
It reduces to MCG EoS for $n = 1$ with $(A_0 = 0)$ and recover barotropic fluid with quadratic EoS by setting $n = 2$. Also, higher n may recover higher order barotropic fluid which is a motivation to suggest ECG.

Pourhassan and Kahya [25], used numerical method to investigate the behaviour of some cosmological parameter such as scale factor, Hubble expansion parameter, energy density and deceleration parameter in the framework of ECG EoS. Pourhassan and Kahya [15], studied the ECG as a candidate of inflation and predicted the values of gas parameters for physically viable cosmological model. Pourhassan and Kahya [16], also studied cosmological model where the universe is dominated by ECG. Sadeghi et al. [28] studied holographic dark energy density and interacting ECG energy density in the Einstein gravity and analyzed tensor to scalar ratio and observed that it is a good agreement with BICEP2 data [6, 7].

Another approach in quantum gravity, namely holographic principle [32] is employed to understand dark energy problem. According to the principle: *all information inside any spatial region can be observed, instead of its volume, on its boundary surface.*

Based on the validity of the effective local quantum field theory, a short distance (UV) cutoff Λ is related to the long distance (IR) cutoff L due to the limit set by the formation of black hole [11]. Applying the UV-IR relationship constraints the total vaccum energy in a box of volume L^3, where the total vaccum energy cannot be greater than the mass of a black hole with the same size. This upper limit for vaccum energy density is given by

$$\rho_\Lambda \leq M_P^2 L^{-2},$$

where $M_p^2 = 1/8\pi G$ is the Plank mass and L is an IR cutoff.
Saturating the inequality, we obtain the holographic dark energy density,

$$\rho_\Lambda = 3c^2 M_P^2 L^{-2}, \tag{2}$$

where c is a free dimensionless constant and the numeric coefficient is chosen for convenience.

In this paper we suggest a correspondence between holographic dark energy scenario and ECG as a candidate of dark energy in Friedmann-Robertson-Walker (FRW) universe and reconstruct the potential and dynamics of the scalar field which describe the ECG cosmology. The paper is organized as follows: In section II, we review FRW cosmology and give some useful equation to study the cosmological parameters by considering holographic dark energy density. In section III, we consider the ECG EoS and discuss the various cases for n and α and obtained the scalar potential and kinetic energy term. Finally, we summerize our results and concluding remarks are given in section IV.

2. FRW cosmology and Holographic dark energy model

We consider the FRW universe of the form

$$ds^2 = -dt^2 + a^2(t)\left(\frac{dr^2}{1-kr^2} + r^2 d\Omega^2\right), \tag{3}$$

where k denotes the curvature of space $k = 0, 1, -1$ for flat, closed and open universe respectively.

Einstein's field equations are

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \kappa T_{\mu\nu}, \tag{4}$$

where $G_{\mu\nu}$ is the Einstein tensor, $R_{\mu\nu}$ is the Ricci tensor, R is the Ricci scalar, $\kappa = 8\pi G$ and $T_{\mu\nu}$ is the energy momentum tensor given by

$$T_{\mu\nu} = (\rho + p)u_\mu u_\nu + pg_{\mu\nu}, \tag{5}$$

where ρ is energy density and p is the pressure.
The Field equations (4) with the help of line element (3) are given by

$$3\left(\frac{\dot{a}^2 + k}{a^2}\right) = 8\pi G\rho,$$

and

$$\frac{2\ddot{a}}{a} + \frac{\dot{a}^2 + k}{a^2} = -8\pi Gp. \tag{6}$$

The first Friedmann equation is given by

$$H^2 + \frac{k}{a^2} = \frac{\rho}{3M_p^2}. \tag{7}$$

In future, we use $p = p_m + p_\Lambda$ and consider $p_m = 0$.
Therefore, $p = p_\Lambda$ and $\rho = \rho_m + \rho_\Lambda$,
where ρ_m and ρ_Λ is energy density of matter and dark energy respectively and p_m and p_Λ is pressure of matter and dark energy respectively.
The conservation equation is given by

$$\dot{\rho_\Lambda} + 3H(\rho_\Lambda + p_\Lambda) = 0, \tag{8}$$

by using the equation of state for perfect fluid of the form

$$p_\Lambda = \omega_\Lambda \rho_\Lambda, \tag{9}$$

above conservation equation (8) becomes

$$\dot{\rho_\Lambda} + 3H(1 + \omega_\Lambda)\rho_\Lambda = 0. \tag{10}$$

Define

$$\Omega_m = \frac{\rho_m}{\rho_{cr}} = \frac{\rho_m}{3M_p^2 H^2},$$

$$\Omega_\Lambda = \frac{\rho_\Lambda}{\rho_{cr}} = \frac{\rho_\Lambda}{3M_p^2 H^2}, \Omega_k = \frac{k}{a^2 H^2}. \tag{11}$$

In non-flat universe, we are choosing holographic dark energy density as given by Eq. (2).
L is defined in the following form [30]:

$$L = ar(t), \tag{12}$$

where a is the scale factor and $r(t)$ is relevant to the future event horizon of the universe and can be obtained from the following equation

$$\int_0^{r(t)} \frac{dr}{\sqrt{1-kr^2}} = \int_t^{\infty} \frac{dt}{a} = \frac{R_h}{a}, \tag{13}$$

where R_h is event horizon given by

$$R_h = a\int_t^{\infty} \frac{dt}{a} = a\int_a^{\infty} \frac{da}{Ha^2}. \tag{14}$$

We get the value of $r(t)$ as

$$r(t) = \frac{1}{\sqrt{k}} sin[\sqrt{k}R_h/a]. \tag{15}$$

Hence from (12) we get the value of L as

$$L = \frac{a(t)sinn[\sqrt{|k|}R_h(t)/a(t)]}{\sqrt{|k|}}. \tag{16}$$

Using Eqs. (2) and (11) we get

$$HL = \frac{c}{\sqrt{\Omega_\Lambda}}. \tag{17}$$

Eqs. (16) and (17) yield

$$\dot{L} = \frac{c}{\sqrt{\Omega_\Lambda}} - \frac{1}{\sqrt{|k|}} cosn(\sqrt{|k|}R_h/a). \tag{18}$$

By using the definition of holographic energy density and eqs. (17) and (18) we get,

$$\dot{\rho_\Lambda} = -2H\left(1 - \frac{\sqrt{\Omega_\Lambda}}{c}\frac{1}{\sqrt{|k|}} cosn(\sqrt{|k|}R_h/a)\right)\rho_\Lambda. \tag{19}$$

Substituting this relation into Eq. (10) we obtain the EoS parameter as

$$\omega_\Lambda = -\left[\frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}} cosn(\sqrt{|k|}R_h/a)\right]. \tag{20}$$

We have plotted the evolution of EoS parameter ω_Λ for holographic dark energy with respect to scale factor a in fig. 1. We see that the EoS parameter ω_Λ is $-0.91 \le \omega_\Lambda \le -0.90$ as $a \to 1$ for the value of $\Omega_\Lambda = 0.75$. Similarly for $\Omega_\Lambda = 0.73$,

ω_Λ ranges from $-0.90 \leq \omega_\Lambda \leq -0.89$ and $\Omega_\Lambda = 0.69$, ω_Λ ranges from $-0.88 \leq \omega_\Lambda \leq -0.87$.

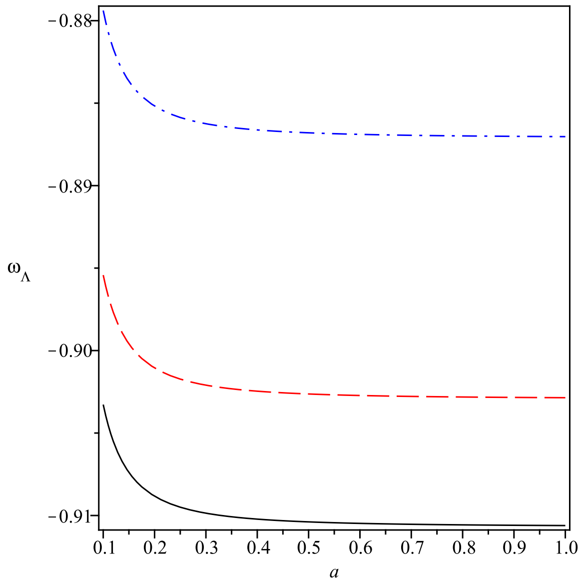

FIGURE 1. EoS parameter versus scale factor for $\Omega_\Lambda = 0.69$ (blue), $\Omega_\Lambda = 0.73$ (red), $\Omega_\Lambda = 0.75$ (black).

3. Extended Chaplygin gas model

In this section, we find out the energy density ρ_Λ from conservation eq. (8) by using the ECG EoS (1). We assume that the origin of dark energy is a scalar field ϕ [3], i.e., $\rho_\Lambda = \rho_\phi$ and then we compare the energy density of ECG with holographic dark energy. We find the EoS parameter (ω_Λ) by using ECG EoS and then compare it with the EoS parameter obtained from holographic dark energy Eq. (20) for calculating the value of arbitrary constants. Finally, we find the terms representing scalar potential and kinetic energy.

In the following part, we consider some special cases and find special solutions.

Case I: $n = 1$ and $\alpha = arbitrary$

In this case EoS (1) becomes

$$p = A\rho_\Lambda - \frac{B}{\rho_\Lambda^\alpha}. \tag{21}$$

Inserting the EoS (21) into the relativistic energy conservation equation (8), leads to a density evolving as

$$\rho_\Lambda = \left[\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}\right]^{\frac{1}{1+\alpha}}. \tag{22}$$

where C is the constant of integration.

The energy density and pressure of the scalar field model can be expressed as

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi), \tag{23}$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi). \tag{24}$$

By using $\rho_\Lambda = \rho_\phi$, we get

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) = \rho_\Lambda = \left[\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}\right]^{\frac{1}{1+\alpha}}, \tag{25}$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) = A\rho_\Lambda - \frac{B}{\rho_\Lambda^\alpha} = \frac{A\left[\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}\right] - B}{\left[\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}\right]^{\frac{\alpha}{1+\alpha}}}. \tag{26}$$

Then, one can easily derive the scalar potential and kinetic energy terms as

$$V(\phi) = \frac{(1-A)\left[\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}\right] + B}{2\left[\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}\right]^{\frac{\alpha}{1+\alpha}}}, \tag{27}$$

$$\dot{\phi}^2 = \frac{\frac{(1+A)C}{a^{3(1+\alpha)(1+A)}}}{\left[\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}\right]^{\frac{\alpha}{1+\alpha}}}. \tag{28}$$

If we establish the correspondance between the holographic dark energy and ECG energy density, then by equating Eqs. (2) and (22)

$$3c^2M_P^2L^{-2} = \left[\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}\right]^{\frac{1}{1+\alpha}},$$

we get

$$C = a^{3(1+\alpha)(1+A)}\left[(3c^2M_p^2L^{-2})^{(1+\alpha)} - \frac{B}{1+A}\right]. \tag{29}$$

By using Eq. (9) with the help of Eqs. (21) and (22) we get the EoS parameter as

$$\omega_\Lambda = \frac{p_\Lambda}{\rho_\Lambda} = A - \frac{B}{\rho_\Lambda^{(1+\alpha)}} = A - \frac{B}{\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}}. \tag{30}$$

Now, using the EoS parameter of holographic dark energy, i.e., by using Eq. (20) we get

$$A - \frac{B}{\frac{B}{1+A} + \frac{C}{a^{3(1+\alpha)(1+A)}}} = -\left[\frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right].$$

Substituting the value of C in the above equation we get the following value of B

$$B = (3c^2M_p^2L^{-2})^{(1+\alpha)}\left[A + \frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right]. \tag{31}$$

Substituting the value of B in Eq. (28) we get the value of C as

$$C = \frac{(3c^2M_p^2L^{-2}a^{3(1+A)})^{(1+\alpha)}}{1+A}\left[\frac{2}{3} - \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right]. \tag{32}$$

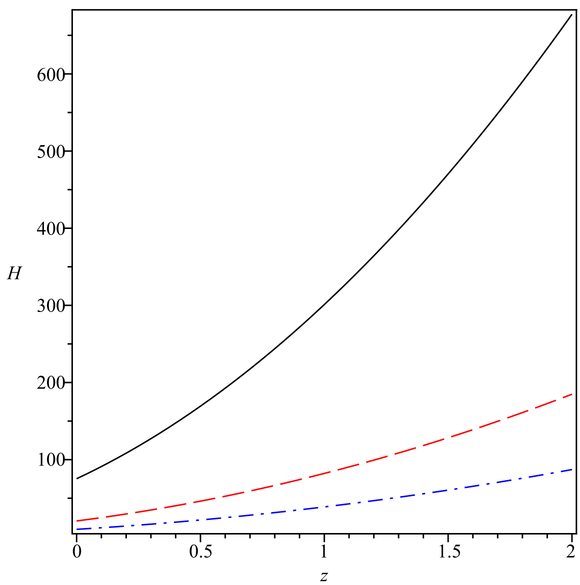

FIGURE 2. Hubble parameter versus red shift for A = 1/3, B = 1, n = 1, $\alpha = 0.1$ (black), $\alpha = 0.5$ (red), $\alpha = 0.9$ (blue).

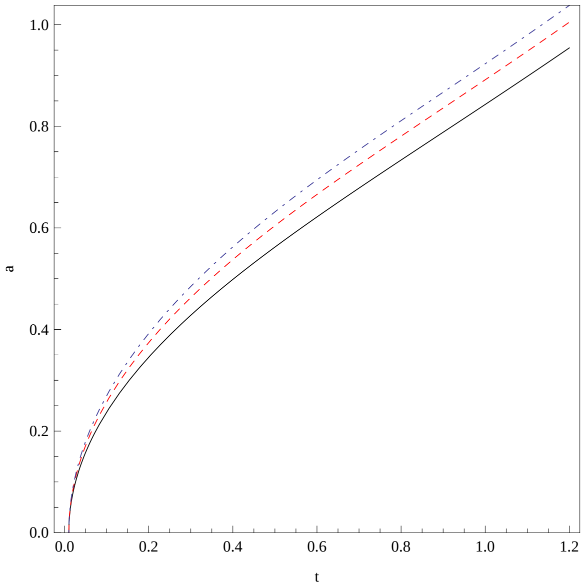

FIGURE 3. Scale factor versus time for A = 1/3, B = 1, n = 1, α = 0.1 (black), α = 0.5 (red), α = 0.9 (blue).

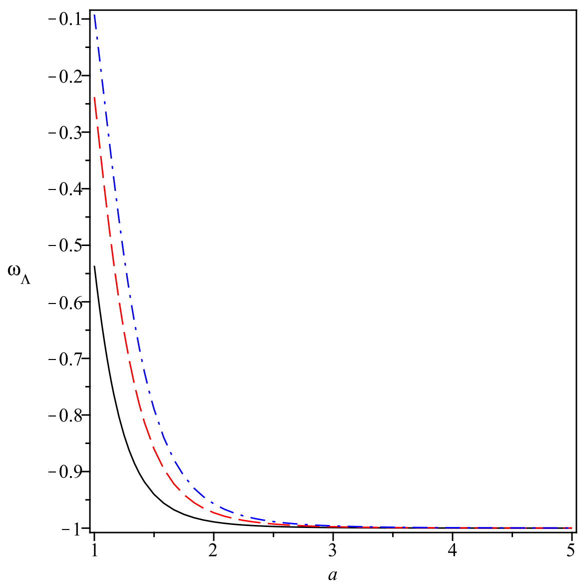

FIGURE 4. EoS parameter versus scale factor for A = 1/3, B = 1, n = 1, α = 0.5, C = 0.4 (black), C = 1 (red), C = 1.6 (blue).

In Figs. 2 and 3 we fix A and B and observe the behaviour of Hubble parameter H in terms of red shift z which is quite close to the observations [33]. Also we observe that as α increases value of scale factor increases. Fig. 4 shows the variation of EoS parameter ω_Λ and it is observed that EoS parameter approaches -1.

Case II: $n = -\alpha$

In this case EoS (1) becomes

$$p = -\frac{(B-A)}{\rho_\Lambda^\alpha}, \tag{33}$$

where $(B-A) > 0$.
Inserting the EoS (33) into the relativistic energy conservation equation (8), leads to a density evolving as

$$\rho_\Lambda = \left[B - A + \frac{C}{a^{3(1+\alpha)}}\right]^{\frac{1}{1+\alpha}}. \tag{34}$$

Proceeding in the similar way as discussed in case I energy density and pressure of the scalar field model are given in Eqs. (23) and (24) and assuming that the origin of dark energy is a scalar field ϕ, we get

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) = \rho_\Lambda = \left[B - A + Ca^{-3(1+\alpha)}\right]^{\frac{1}{1+\alpha}}, \tag{35}$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) = -\frac{(B-A)}{\rho_\Lambda^\alpha} = -\frac{(B-A)}{\left[B - A + Ca^{-3(1+\alpha)}\right]^{\frac{\alpha}{1+\alpha}}}. \tag{36}$$

Then, one can easily derive the scalar potential and kinetic energy term as

$$V(\phi) = \frac{2(B-A) + Ca^{-3(1+\alpha)}}{2\left[(B-A) + Ca^{-3(1+\alpha)}\right]^{\frac{\alpha}{1+\alpha}}}, \tag{37}$$

$$\dot{\phi}^2 = \frac{Ca^{-3(1+\alpha)}}{\left[(B-A) + Ca^{-3(1+\alpha)}\right]^{\frac{\alpha}{1+\alpha}}}. \tag{38}$$

If we establish the correspondance between the holographic dark energy and ECG energy density, then using Eqs. (2) and (34)

$$3c^2 M_P^2 L^{-2} = \left[B - A + Ca^{-3(1+\alpha)}\right]^{\frac{1}{1+\alpha}},$$

we get

$$C = a^{3(1+\alpha)}\left[(3c^2M_p^2L^{-2})^{(1+\alpha)} - (B-A)\right]. \tag{39}$$

By using Eq. (9) with the help of Eqs. (33) and (34) we get the EoS parameter as

$$\omega_\Lambda = \frac{p_\Lambda}{\rho_\Lambda} = -\frac{B-A}{\rho_\Lambda^{(1+\alpha)}} = -\frac{B-A}{B-A+Ca^{-3(1+\alpha)}}. \tag{40}$$

Now, using the EoS parameter of holographic dark energy, i.e., by using Eq. (20) we get

$$-\frac{B-A}{B-A+Ca^{-3(1+\alpha)}} = -\left[\frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right].$$

Substituting the value of C in the above equation we get the following value of B

$$B = A + (3c^2M_p^2L^{-2})^{1+\alpha}\left[\frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right]. \tag{41}$$

Substituting the value of B in eq. (39) we get the value of C as

$$C = (3c^2M_p^2L^{-2}a^3)^{1+\alpha}\left[\frac{2}{3} - \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right]. \tag{42}$$

Hubble parameter H in terms of red shift is plotted in Fig. 5 and it is observed that it is atmost according to the observations. In Fig. 6 by fixing A and B it is noted that as C increases value of scale factor a increases. Fig. 7 shows the variation of EoS parameter ω_Λ and it is observed that EoS parameter approaches -1.

Case III: $\alpha = -1$

In this case EoS (1) becomes

$$p = A\rho_\Lambda^n - \frac{B}{\rho_\Lambda^{-1}} = A\rho_\Lambda^n - B\rho_\Lambda = \rho_\Lambda(A\rho_\Lambda^{n-1} - B). \tag{43}$$

Inserting the EoS (43) into the relativistic energy conservation equation (8), leads to a density evolving as

$$\rho_\Lambda = \left[\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right]^{\frac{1}{1-n}}. \tag{44}$$

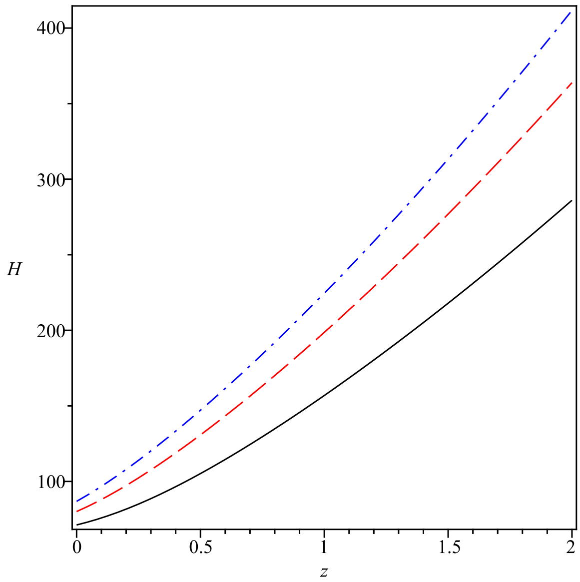

FIGURE 5. Hubble parameter versus red shift for A = 1/3, B = 1, n = $-\alpha$, $\alpha = 0.9$, C = 0.4 (black), C = 1 (red), C = 1.6 (blue).

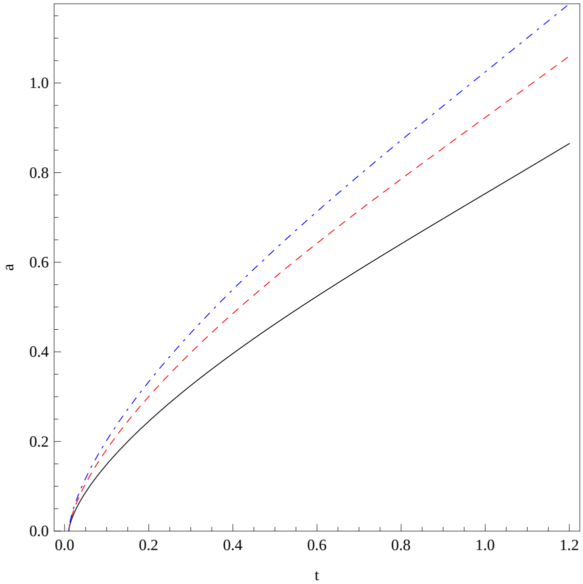

FIGURE 6. Scale factor versus time for A = 1/3, B = 1, n = $-\alpha$, $\alpha = 0.5$, C = 0.4 (black), C = 1 (red), C = 1.6 (blue).

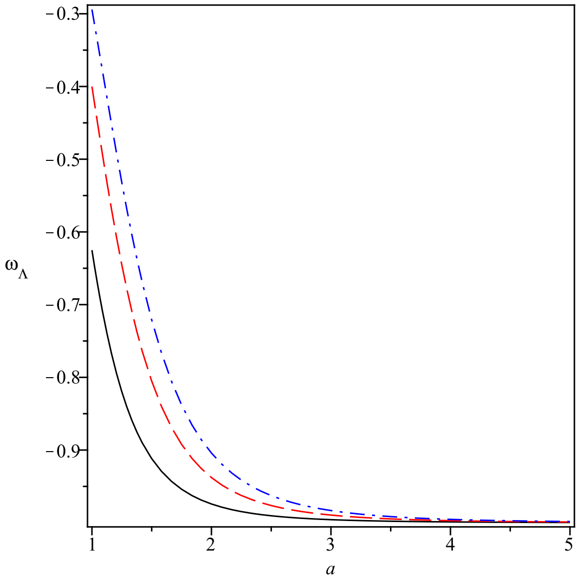

FIGURE 7. EoS parameter versus scale factor for A = 1/3, B = 1, n = $-\alpha$, α = 0.5, C = 0.4 (black), C = 1 (red), C = 1.6 (blue).

Here, again by using $\rho_\Lambda = \rho_\phi$ we get

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) = \rho_\Lambda = \left[\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right]^{\frac{1}{1-n}}, \tag{45}$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) = \rho_\Lambda(A\rho_\Lambda^{n-1} - B)$$

$$= \left[\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right]^{\frac{1}{1-n}} \left[\frac{A}{\left(\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right)} - B\right]. \tag{46}$$

Then, one can easily derive the scalar potential and kinetic energy terms as

$$V(\phi) = \frac{1}{2}\left[\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right]^{\frac{1}{1-n}} \left[B - \frac{A}{\left(\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right)} + 1\right], \tag{47}$$

$$\dot{\phi}^2 = \left[\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right]^{\frac{1}{1-n}} \left[1 + \frac{A}{\left(\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right)} - B\right]. \tag{48}$$

If we establish the correspondance between the holographic dark energy and ECG energy density, then using Eqs. (2) and (44) we have

$$3c^2M_P^2L^{-2} = \left[\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right]^{\frac{1}{1-n}},$$

we get

$$C = a^{3(B-1)(n-1)}\left[-(3c^2M_p^2L^{-2})^{(1-n)} + \frac{A}{B-1}\right]. \tag{49}$$

By using Eq. (9) with the help of Eqs. (43) and (44) we get the EoS parameter as

$$\omega_\Lambda = \frac{p_\Lambda}{\rho_\Lambda} = A\rho_\Lambda^{n-1} - B = \frac{A}{\left(\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right)} - B. \tag{50}$$

Now, using the EoS parameter of holographic dark energy, i.e., by using Eq. (20) we get

$$\frac{A}{\left(\frac{A}{B-1} - \frac{C}{a^{3(B-1)(n-1)}}\right)} - B = -\left[\frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right].$$

Substituting the value of C in the above equation we get the following value of A

$$A = (3c^2M_p^2L^{-2})^{(1-n)}\left[B - \frac{1}{3} - \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right]. \tag{51}$$

Substituting the value of A in Eq. (49) we get the value of C as

$$C = \frac{(3c^2M_p^2L^{-2}a^{-3(B-1)})^{(1-n)}}{B-1}\left[\frac{2}{3} - \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right]. \tag{52}$$

In Figs. 8 and 9 we fix A and B and observe that variation of Hubble parameter H in terms of red shift z and scale factor a versus t. We observe that a decreases as n increases. Fig. 10 shows the variation of EoS parameter ω_Λ.

Case IV: $n = 2, \alpha = 1/2$

In this case EoS (1) becomes

$$p = A_1\rho_\Lambda + A_2\rho_\Lambda^2 - \frac{B}{\rho_\Lambda^{1/2}}.$$

Taking $A_1 = A_2 = A$ we get

$$p = A\rho_\Lambda + A\rho_\Lambda^2 - \frac{B}{\sqrt{\rho_\Lambda}} = (1+\rho_\Lambda)A\rho_\Lambda - \frac{B}{\sqrt{\rho_\Lambda}}. \tag{53}$$

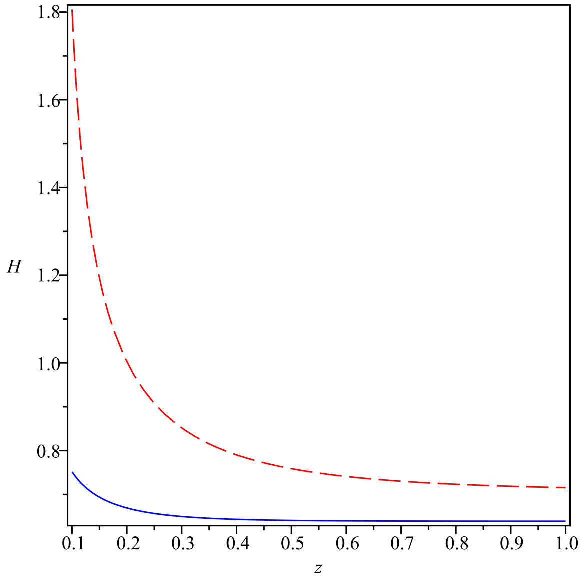

FIGURE 8. Hubble parameter versus red shift for A = 1/3, B = 3, α = -1, n = 2 (red), n = 3 (blue).

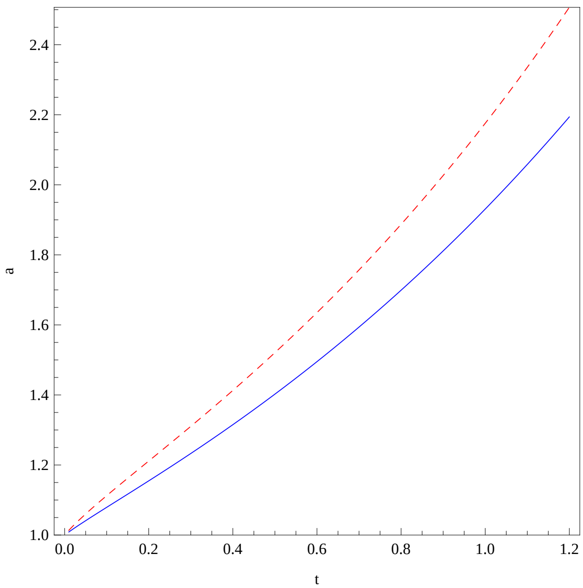

FIGURE 9. Scale factor versus time for A = 1/3, B = 3, α = -1, n = 2 (red), n = 3 (blue).

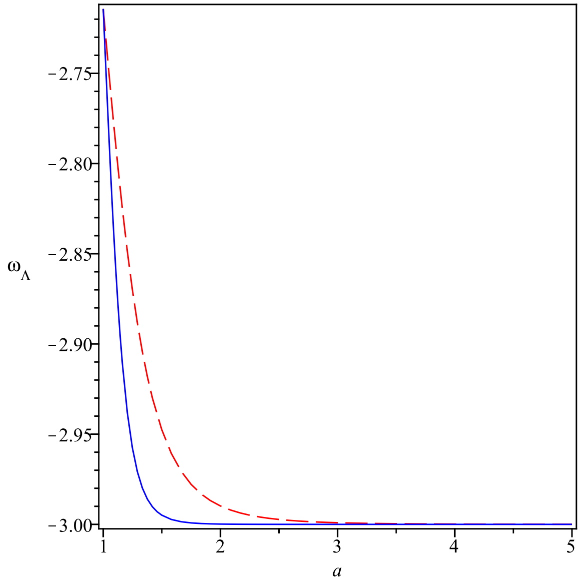

FIGURE 10. EoS parameter versus scale factor for A = 1/3, B = 3, α = -1, n = 2 (red), n = 3 (blue).

Inserting the EoS (53) into the relativistic energy conservation equation (8), leads to a density evolving as

$$\rho_\Lambda = U_1, \tag{54}$$

where $U_1 = a^{-9}\left(Xa^{9/2} + a^{\frac{-A}{2}(15X^2+9)}\right)^2$,
where X is the root of $AX^5 + (1+A)X^3 - B = 0$.
Again, by using $\rho_\Lambda = \rho_\phi$ we get

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) = \rho_\Lambda = U_1, \tag{55}$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) = (1+\rho_\Lambda)A\rho_\Lambda - \frac{B}{\sqrt{\rho_\Lambda}} = AU_1(1+U_1) - \frac{B}{\sqrt{U_1}}. \tag{56}$$

Then, one can easily derive the scalar potential and kinetic energy term as

$$V(\phi) = \frac{U_1}{2}[1 - A(1+U_1)] + \frac{1}{2}\frac{B}{\sqrt{U_1}}, \tag{57}$$

$$\dot{\phi}^2 = U_1[1 + A(1+U_1)] - \frac{B}{\sqrt{U_1}}. \tag{58}$$

If we establish the correspondance between the holographic dark energy and ECG energy density, then using Eqs. (2) and (54)

$$3c^2M_P^2L^{-2} = U_1,$$

we get

(59) $$A = \frac{-2}{15X^2+9}\frac{log((3c^2M_p^2L^{-2}a^9)^{1/2} - Xa^{9/2})}{loga}.$$

By using Eq. (9) with the help of Eqs. (53) and (54) we get the EoS parameter as

(60) $$\omega_\Lambda = \frac{p_\Lambda}{\rho_\Lambda} = (1+\rho_\Lambda)A - \frac{B}{\rho_\Lambda^{3/2}} = A(1+U_1) - \frac{B}{U_1^{3/2}}.$$

Now, using the EoS parameter of holographic dark energy, i.e., by using Eq. (20) we get

$$A(1+U_1) - \frac{B}{U_1^{3/2}} = -\left[\frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right].$$

Substituting the value of A in the above equation we get the following value of B

(61)
$$B = (3c^2M_p^2L^{-2})^{3/2}\left[A(1+3c^2M_p^2L^{-2}) + \frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right].$$

Fig. 11 shows the variation of EoS parameter ω_Λ and it is observed that EoS parameter approaches -1.

Case V: $n = 3, \alpha = 1/2$

In this case EoS (1) becomes

$$p = A_1\rho_\Lambda + A_2\rho_\Lambda^2 + A_3\rho_\Lambda^3 - \frac{B}{\rho_\Lambda^{1/2}}.$$

Taking $A_1 = A_2 = A_3 = A$ we get

(62) $$p = A\rho_\Lambda + A\rho_\Lambda^2 + A\rho_\Lambda^3 - \frac{B}{\sqrt{\rho_\Lambda}} = (1+\rho_\Lambda+\rho_\Lambda^2)A\rho_\Lambda - \frac{B}{\sqrt{\rho_\Lambda}}.$$

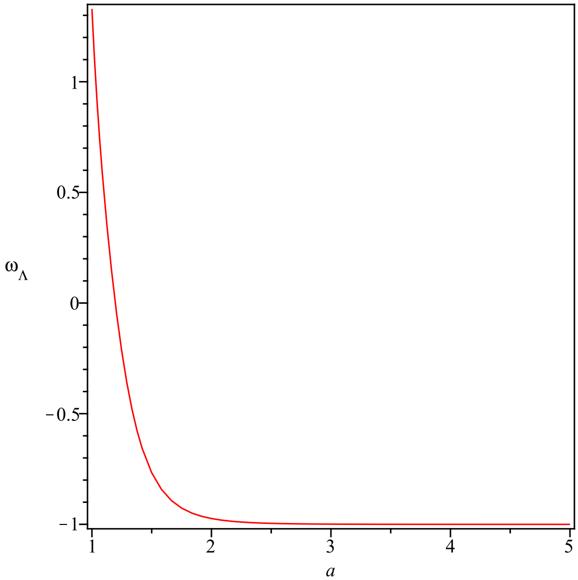

FIGURE 11. EoS parameter versus scale factor for A = 1/3, B = 3, α = 0.5, n = 2.

Inserting the EoS (62) into the relativistic energy conservation equation (8), leads to a density evolving as

$$\rho_\Lambda = U_2, \tag{63}$$

where $U_2 = a^{-9}\left(Ya^{9/2} + a^{\frac{-A}{2}(21Y^4+15Y^2+9)}\right)^2$,
where Y is the root of $AY^7 + AY^5 + (1+A)Y^3 - B = 0$.
Again, by using $\rho_\Lambda = \rho_\phi$ we get

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) = \rho_\Lambda = U_2, \tag{64}$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) = (1+\rho_\Lambda+\rho_\Lambda^2)A\rho_\Lambda - \frac{B}{\sqrt{\rho_\Lambda}} = [1+U_2+U_2^2]AU_2 - \frac{B}{\sqrt{U_2}}. \tag{65}$$

Then, one can easily derive the scalar potential and kinetic energy terms as

$$V(\phi) = \frac{U_2}{2}[1 - A(1+U_2+U_2^2)] + \frac{1}{2}\frac{B}{\sqrt{U_2}}, \tag{66}$$

$$\dot{\phi}^2 = U_2[1 + A(1+U_2+U_2^2)] - \frac{B}{\sqrt{U_2}}. \tag{67}$$

If we establish the correspondance between the holographic dark energy and ECG energy density, then using Eqs. (2) and (63)

$$3c^2M_P^2L^{-2} = U_2,$$

we get

$$A = \frac{-2}{21Y^4 + 15Y^2 + 9}\frac{log((3c^2M_p^2L^{-2}a^9)^{1/2} - Ya^{9/2})}{loga}. \tag{68}$$

By using Eq. (9) with the help of Eqs. (62) and (63) we get the EoS parameter as

$$\omega_\Lambda = \frac{p_\Lambda}{\rho_\Lambda} = (1 + \rho_\Lambda + \rho_\Lambda^2)A - \frac{B}{\rho_\Lambda^{3/2}}$$

$$= A(1 + U_2 + U_2^2) - \frac{B}{U_2^{3/2}}. \tag{69}$$

Now, using the EoS parameter of holographic dark energy, i.e., by using Eq. (20) we get

$$A(1 + U_2 + U_2^2) - \frac{B}{U_2^{3/2}} = -\left[\frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right].$$

Substituting the value of A in the above equation we get the following value of B

$$B = (3c^2M_p^2L^{-2})^{3/2}X_1, \tag{70}$$

where $X_1 = A(1 + 3c^2M_p^2L^{-2} + (3c^2M_p^2L^{-2})^2) + \frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)$. Hubble parameter H in terms of red shift is plotted in Fig. 12 for $n = 2$ and 3, i.e., for quadratic and cubic EoS and it is noted that these cases are very different from the observations. Scale factor in terms of time for $n = 2$ and 3 is shown in Fig. 13.

Case VI: $n = arbitrary$, $\alpha = 1/2$

In this case, EoS (1) becomes

$$p = A_1\rho_\Lambda + A_2\rho_\Lambda^2 + ... + A_n\rho_\Lambda^n - \frac{B}{\rho_\Lambda^{1/2}}.$$

Taking $A_1 = A_2 = ... = A_n = A$ we get

$$p = A\rho_\Lambda + A\rho_\Lambda^2 + ... + A\rho_\Lambda^n - \frac{B}{\sqrt{\rho_\Lambda}} = (1 + \rho_\Lambda + ... + \rho_\Lambda^{n-1})A\rho_\Lambda - \frac{B}{\sqrt{\rho_\Lambda}}. \tag{71}$$

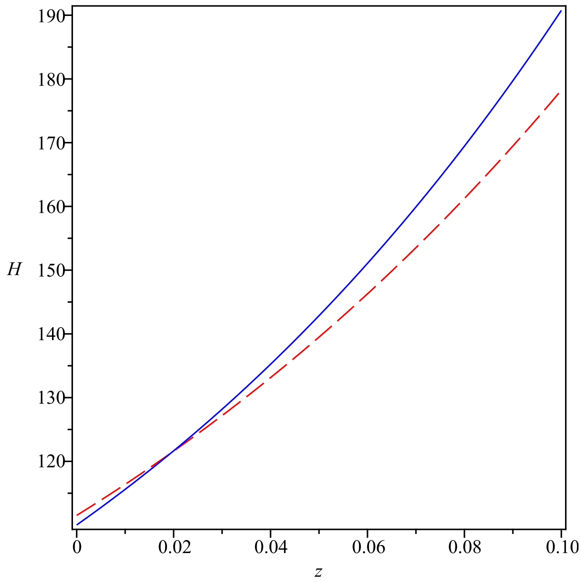

FIGURE 12. Hubble parameter versus red shift for A = 1/3, B = 1, α = 0.5, n = 2 (red), n = 3 (blue).

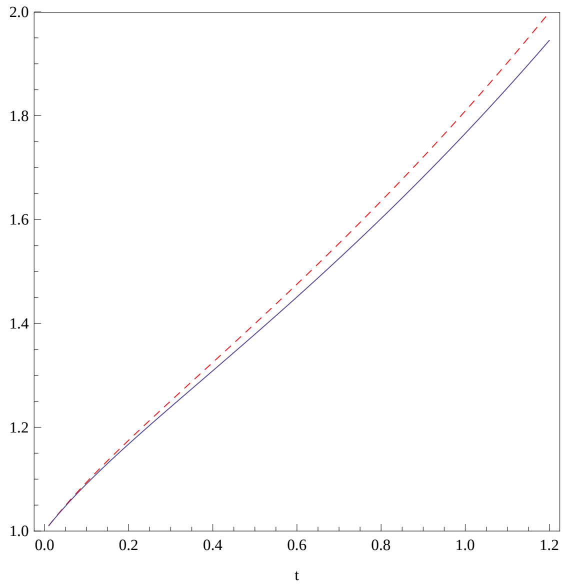

FIGURE 13. Scale factor versus time for A = 1/3, B = 1, α = 0.5, n = 2 (red), n = 3 (blue).

Inserting the EoS (71) into the relativistic energy conservation equation (8), leads to a density evolving as

$$\rho_\Lambda = U_3, \tag{72}$$

where $U_3 = a^{-9}\left(Za^{9/2} + a^{\frac{-A}{2}(9+\sum 6(n-1)Z^{2(n-1)})}\right)^2$,
where Z is the root of $A\sum Z^{2n+1} + (1+A)Z^3 - B = 0$.

By using the expression

$$\Omega = \frac{\rho}{3H_0^2},$$

where H_0 is the Hubble parameter today.
$H(z)$ for this case can be obtained in the form of below equation.

$$\Omega(z) = \Omega_0[1 - c + c(1+z)^l]^2, \tag{73}$$

where c and l are constants related to Z, A and B [25].
Again, by using $\rho_\Lambda = \rho_\phi$ we get

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) = \rho_\Lambda = U_3, \tag{74}$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) = (1 + \rho_\Lambda + ... + \rho_\Lambda^{n-1})A\rho_\Lambda - \frac{B}{\sqrt{\rho_\Lambda}}$$

$$= (1 + U_3 + U_3^2 ... + U_3^{n-1})AU_3 - \frac{B}{\sqrt{U_3}}. \tag{75}$$

Then, one can easily derive the scalar potential and kinetic energy term as

$$V(\phi) = \frac{U_3}{2}[1 - A(1 + U_3 + U_3^2 ... + U_3^{n-1})] + \frac{1}{2}\frac{B}{\sqrt{U_3}}, \tag{76}$$

$$\dot{\phi}^2 = U_3[1 + A(1 + U_3 + U_3^2 ... + U_3^{n-1})] - \frac{B}{\sqrt{U_3}}. \tag{77}$$

If we establish the correspondance between the holographic dark energy and ECG energy density, then using Eqs. (2) and (72)

$$3c^2M_P^2L^{-2} = U_3,$$

we get

$$A = \frac{-2}{9 + \sum 6(n-1)Z^{2(n-1)}} \frac{log((3c^2M_p^2L^{-2}a^9)^{1/2} - Za^{9/2})}{loga}. \tag{78}$$

By using Eq. (9) with the help of Eqs. (71) and (72) we get the EoS parameter as

(79) $\omega_\Lambda = \dfrac{p_\Lambda}{\rho_\Lambda} = (1+\rho_\Lambda+...+\rho_\Lambda^{n-1})A - \dfrac{B}{\rho_\Lambda^{3/2}} = A(1+U_3+...+U_3^{n-1})A - \dfrac{B}{U_3^{3/2}}.$

Now, using the EoS parameter of holographic dark energy, i.e., by using Eq. (20) we get

$$A(1+U_3+...+U_3^{n-1})A - \frac{B}{U_3^{3/2}} = -\left[\frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right].$$

Substituting the value of A in the above equation we get the following value of B

$$B = (3c^2M_p^2L^{-2})^{3/2}X_2, \tag{80}$$

where $X_2 = A(1+3c^2M_p^2L^{-2}+...+(3c^2M_p^2L^{-2})^{n-1})+\frac{1}{3}+\frac{2\sqrt{\Omega_\Lambda}}{3c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a).$

Hubble parameter H is plotted in Fig. 14 by fixing c and taking different values of l.

Now, putting the value of constants in the respective equations of scalar potential and kinetic energy for all the cases we get their values as

$$V(\phi) = 2c^2M_p^2L^{-2}\left[1 + \frac{\sqrt{\Omega_\Lambda}}{2c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right]. \tag{81}$$

Using Eq. (17) we get

$$V(\phi) = 2H^2M_p^2\Omega_\Lambda\left[1 + \frac{\sqrt{\Omega_\Lambda}}{2c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right]. \tag{82}$$

$$\dot{\phi} = \frac{cM_p}{L}\sqrt{2\left(1 - \frac{\sqrt{\Omega_\Lambda}}{c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right)}. \tag{83}$$

Consider $x \equiv lna$, we get

$$\dot{\phi} = \phi' H. \tag{84}$$

Using Eqs. (17) and (83) we get

$$\phi' = M_p\sqrt{2\Omega_\Lambda\left(1 - \frac{\sqrt{\Omega_\Lambda}}{c}\frac{1}{\sqrt{|k|}}cosn(\sqrt{|k|}R_h/a)\right)}. \tag{85}$$

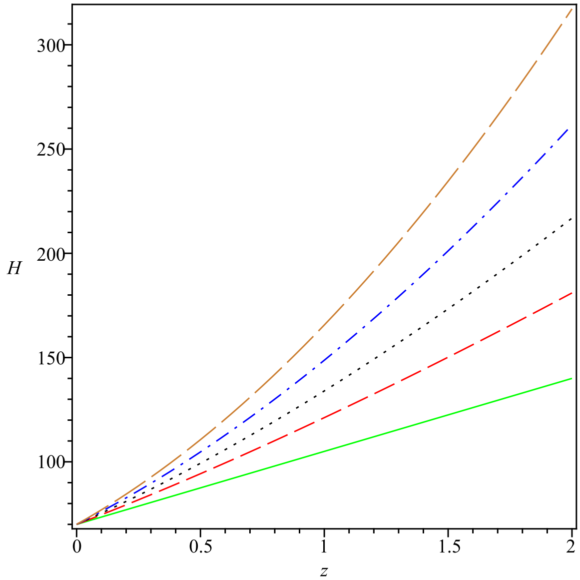

FIGURE 14. Hubble parameter versus red shift in the case of arbitrary n and α, c = 0.5, l = 1 (green), l = 1.3 (red), l = 1.5 (black), l = 1.7 (blue), l = 1.9 (gold).

The Evolutionary form of the field is obtained as

$$\phi(a) - \phi(a_0) =$$

$$\int_0^{lna} M_p \sqrt{2\Omega_\Lambda \left(1 - \frac{\sqrt{\Omega_\Lambda}}{c} \frac{1}{\sqrt{|k|}} cosn(\sqrt{|k|}R_h/a)\right)} dx. \tag{86}$$

where a_0 is the present time value of scale factor.
Behaviour of $V(\phi)$ and $\phi(a)$ is shown in Figs. 15 and 16 respectively where both $V(\phi)$ and $\phi(a)$ goes up as scale factor increases.

4. Conclusion

In this work, we consider an extended model of CG proposed by Pourhassan and Kahya [25], as dark energy which recovers barotropic fluid with quadratic EoS. Amongst the different candidates to play the role of dark energy, the CG has

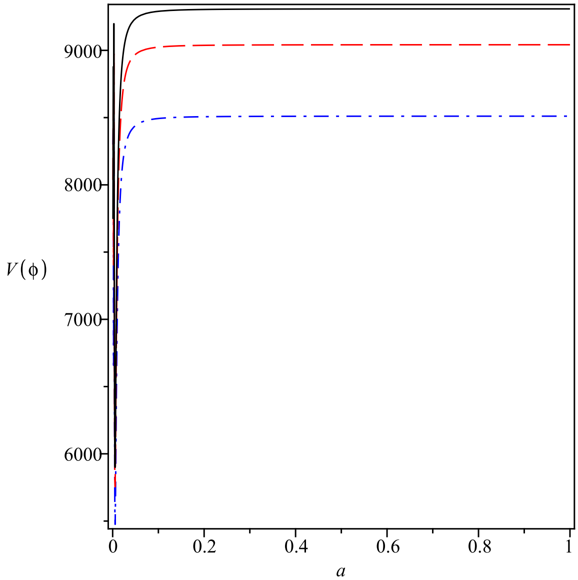

FIGURE 15. $V(\phi)$ versus a for $\Omega_\Lambda = 0.69$ (blue), $\Omega_\Lambda = 0.73$ (red), $\Omega_\Lambda = 0.75$ (black).

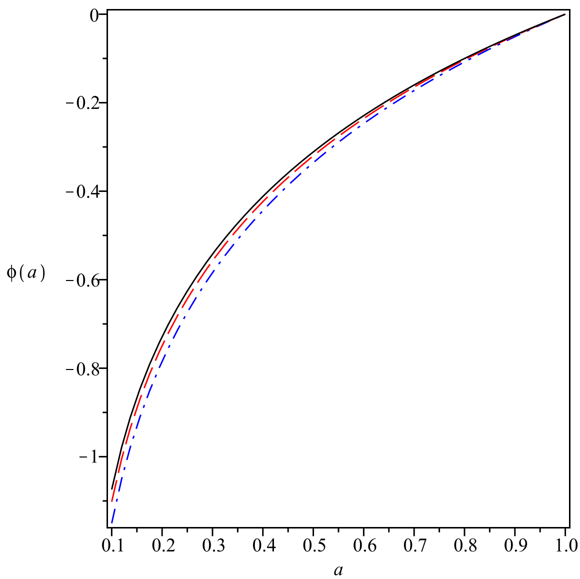

FIGURE 16. ϕ versus a for $\Omega_\Lambda = 0.69$ (blue), $\Omega_\Lambda = 0.73$ (red), $\Omega_\Lambda = 0.75$ (black).

emerged as a possible unification of dark matter and dark energy, since it's cosmological evolution is similar to an initial dust like matter and cosmological constant for late times [30]. Inspired by the fact that the CG possesses negative pressure, Gorini et al. [14] have undertaken the simple task of studying FRW cosmological model filled with this type of fluid.

In the first part of the paper we consider the holographic dark energy density of the form (2) and by using the field equations we have obtained the EoS parameter ω_Λ. The evolution of ω_Λ for holographic dark energy versus scale factor is discussed in Fig. 1. It is seen that the EoS parameter ω_Λ is $-0.91 \leq \omega_\Lambda \leq -0.90$ as $a \to 1$ for the value of $\Omega_\Lambda = 0.75$. Similarly for $\Omega_\Lambda = 0.73$, ω_Λ ranges from $-0.90 \leq \omega_\Lambda \leq -0.89$ and $\Omega_\Lambda = 0.69$, ω_Λ ranges from $-0.88 \leq \omega_\Lambda \leq -0.87$.

In the second part of the manuscript we have associated the holographic dark energy in FRW universe with scalar field which describe the ECG cosmology. The ECG is actually a scalar field which acts like dust or cosmological constant depending upon the period of the universe and the kind of parameters. We obtained the evolution of the scale factor, Hubble expansion parameter H and time dependent dark energy density ρ_Λ and also found the effect of n in cosmological parameter.

For the case $n = 1$ (linear barotropic fluid), EoS of ECG reduces to EoS of MCG and found that the evolution of scale factor is faster than the case $n = 2$ (quadratic barotropic fluid). We also found that the Hubble parameter is decreasing with n.

In the Figs. 2 and 3 it is observed that for $A = 1/3$ and $B = 1$ the behaviour of Hubble parameter in terms of red shift is quite close to observations [33].

For the case $n = -\alpha$, we have obtained the time dependent scale factor by using the numerical methods. In Figs. 5 and 6 if we fix A and B it is seen that scale factor a increases with time. Also, Hubble parameter H in terms of red shift is quite close to the observations for various values of C. From the Figs. 4, 7 and 11, it is clear that EoS parameter ω_Λ approaches -1 as scale factor increases.

Fig. 8 shows the evolution of Hubble parameter versus red shift for the case $\alpha = -1$. It is observed that initially H is increasing and then it is constant as red shift increases. The evolution of scale factor a versus time t is plotted in Fig. 9 and evolution of EoS parameter ω_Λ versus scale factor is plotted in Fig. 10. This case is dual to first case if we take $A \to -B$ and $n \to -\alpha$.

The evolution of Hubble parameter H versus red shift for the case $n = 2, 3$ and $\alpha = 1/2$ are plotted in Fig. 12. We noted that it is far from observations in any time. For the case $n = arbitrary$, from Fig. 14 we get a good fit that is in agreement with the observational data [22, 36]. From Figs. 15 and 16, it is observed that both $V(\phi)$ and $\phi(a)$ increases as scale factor increases.

We established a correspondence between holographic dark energy and ECG model and also reconstructed the potential and dynamics of holographic scalar field. We surely come to know that the potential $V(\phi)$ and dynamics of the scalar field ϕ are same in all the cases of ECG. The analogous results for standard Chaplygin gas EoS is earlier discussed by Setare [30].

5. Acknowledgments

This work is supported by Fund for Improvement of Science and Technology Infrastructure (FIST) Level-I program of DST, New Delhi, Grant No. SR/FST/MSI-114/2016 and also supported by Special Assistance Programme (SAP-DRS Phase-II) - UGC sanction F. No. 510/11/DRS-II/2018 (SAP-I) dated 09-04-2018.

References

[1] Ananda K. N. and Bruni M., Cosmological dynamics and dark energy with a quadratic equation of state: Anisotropic models, large-scale perturbations, and cosmological singularities, Physical Review D, Vol. 74, Number 2, 023523 (2006).

[2] Armendariz-Picon C., Mukhanov V. and Steinhardt P. J., Dynamical Solution to the Problem of a Small Cosmological Constant and Late-Time Cosmic Acceleration, Physical Review Letters, Vol. 85, Number 21, 4438 (2000).

[3] Barrow J. D., Graduated inflationary universes, Physics Letters B, Vol. 235, Number 1, 40 (1990).

[4] Bazeia D., Galileo invariant system and the motion of relativistic d-branes, Physical Review D, Vol. 59, Number 8, 085007 (1999).

[5] Bento M. C., Bertolami O. and Sen A. A., Generalized Chaplygin Gas, Accelerated Expansion and Dark Energy-Matter Unification, Physical Review D, Vol. 66, Number 4, 043507 (2002).

[6] BICEP2 Collaboration (P. A. R. Ade et al.), Detection of B-Mode Polarization at Degree Angular Scales by BICEP2, Physical Review Letters, Vol. 112, Number 24, 241101 (2014).

[7] BICEP2 Collaboration (P. A. R. Ade et al.), BICEP2 II: Experiment and Three-Year Data Set, The Astrophysical Journal, Vol. 792, Number 1, 62 (2014).

[8] Bilic N., Tupper G. B. and Viollier R. D., Unification of Dark Matter and Dark Energy: the Inhomogeneous Chaplygin Gas, Physics Letters B, Vol. 535, Number 1, 17 (2002).

[9] Chaplygin S., On gas jets, Moscow University Mathematics Bulletin, Vol. 21, 1 (1904).

[10] Chavanis P. H., A cosmological model describing the early inflation, the intermediate decelerating expansion, and the late accelerating expansion by a quadratic equation of state, Universe, Vol. 1, Number 3, 357 (2015).

[11] Cohen A. G., Kaplan D. B. and Nelson A. E., Effective Field Theory, Black Holes, and the Cosmological Constant, Physical Review Letters, Vol. 82, Number 25, 4971 (1999).

[12] Copeland E. J., Sami M. and Tsujikawa S., Dynamics of dark energy, International Journal of Modern Physics D, Vol. 15, Number 11, 1753 (2006).

[13] Debnath U., Banerjee A. and Chakraborty S., Role of Modified Chaplygin Gas in Accelerated Universe, Classical Quantum Gravity, Vol. 21, Number 23, 5609 (2004).

[14] Gorini V., Kamenshchik A., Moschella U. and Pasquier V., The Chaplygin Gas as a Model for Dark Energy, Proceedings of the 10th Marcel Grossmann Meeting, 840, (2003).

[15] Kahya E. O. and Pourhassan B., Observational constraints on the extended Chaplygin gas inflation, Astrophysics Space Science, Vol. 353, Number 2, 677 (2014).

[16] Kahya E. O. and Pourhassan B., The universe dominated by the extended Chaplygin gas, Modern Physics Letters A, Vol. 30, Number 13, 150070 (2015).

[17] Kamenshchik A., Moschella U. and Pasquier V., An alternative to quintessence, Physics Letters, Vol. 511, Number 2, 265 (2001).

[18] Khurshudyan M. , Interaction between Generalized Varying Chaplygin gas and Tachyonic Fluid, arXiv: 1301.1021.

[19] Khurshudyan M. , Sadeghi J., Hakobyan M., Farahani H. and Myrzakulov R., Interaction between modified Chaplygin gas and ghost dark energy in the presence of extra dimensions, The European Physical Journal Plus, Vol. 129, Number 6, 119 (2014).

[20] Khurshudyan M. , Kahya E. O., Pourhassan B., Myrzakulov R. and Pasqua A., Higher order corrections of the extended Chaplygin gas cosmology with varying G and Λ, European Physical Journal C, Vol. 75, Number 2, 43 (2015).

[21] Linder E. V. and Scherrer R. J., Aetherizing Lambda: Barotropic fluids as dark energy, Physical Review D, Vol. 80, Number 2, 023008 (2009).

[22] Ma C. and Zhang T. J., Power of observational Hubble parameter data: A figure of merit exploration, The Astrophysical Journal, Vol. 730, Number 2, 74 (2011).

[23] Nobbenhuis S., Categorizing Different Approaches to the Cosmological Constant Problem, Foundations of Physics, Vol. 36, Number 5, 613 (2006).

[24] Pourhassan B., Viscous Modified Cosmic Chaplygin Gas Cosmology, International Journal of Modern Physics D, Vol. 22, Number 9, 1350061 (2013).

[25] Pourhassan B. and Kahya E. O., FRW cosmology with the extended Chaplygin gas, Advances in High Energy Physics, Vol. 2014, 231452 (2014).

[26] Sadeghi J. and Farahani H., Interaction between viscous varying modified cosmic Chaplygin gas and Tachyonic fluid, Astrophysics Space Science , Vol. 347, Number 1, 209 (2013).

[27] Sadeghi J., Pourhassan B. and Moghaddam Z. Abbaspour, Interacting Entropy-Corrected Holographic Dark Energy and IR Cut-Off Length, International Journal of Theoretical Physics, Vol. 53, Number 1, 125 (2014).

[28] Sadeghi J., Farahani H. and Pourhassan B., Interacting holographic extended Chaplygin gas and phantom cosmology in the light of BICEP2, European Physical Journal C, Vol. 130, Number 4, 84 (2015).

[29] Sen A., Remarks on Tachyon Driven Cosmology, Physica Scripta, Vol. T117, 70 (2005).

[30] Setare M. R., Holographic Chaplygin gas model, Physics Letters B, Vol. 648, Number 5, 329 (2007).

[31] Setare M. R., Interacting holographic generalized Chaplygin gas model, Physics Letters B, Vol. 654, Number 1, 1 (2007).

[32] Susskind L., The World as a Hologram, Journal of Mathematical Physics, Vol. 36, Number 11, 6377 (1995).

[33] Thakur P., Ghose S. and Paul B. C., Modified Chaplygin Gas and Constraints on its B parameter from CDM and UDME Cosmological models, Monthly Notices of the Royal Astronomical Society, Vol. 397, Number 4, 1935 (2009).

[34] Xu L., Wang Y. and Noh H., Modified Chaplygin gas as a unified dark matter and dark energy model and cosmic constraints, European Physical Journal C , Vol. 72, Number 3, 1931 (2012).

[35] Yoo J. and Watanabe Y., Theoretical Models of Dark Energy, International Journal of Modern Physics D, Vol. 21, Number 12, 1230002 (2012).

[36] Zhang T. J., Ma C. and Lan T., Constraints on the Dark Side of the Universe and Observational Hubble Parameter Data, Advances in Astronomy, Vol. 2010, 184284 (2010).