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Solution of Problems Arising due Global Warming and Climate Change in the Modelling Process

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Abstract: In this paper we have discussed about how to control of Global Warming caused by carbon dioxide. We describe two models for the removal of CO_2 causing global warming. First is Removal of carbon-dioxide from the atmosphere by using liquid droplets and particulate matters and second is by using liquid droplets, particulate matters and green belts of. We used equilibrium method for remove carbon dioxide from atmosphere.
Keywords: Mathematical modeling, Equilibrium, Global warming, Removal of co_2

I. INTRODUCTION

During past several years scientists and ecologists have found that the temperature of the environment is slowly increasing due to emission of global warming gases such as CO_2, CH_4, etc., Carbon dioxide is the main contributor to the global warming. In this an ecological type nonlinear mathematical model is proposed and analyzed for the removal of a global warming gas CO_2 from the regional atmosphere by externally introduced liquid species. As global warming gas interacts with externally introduced liquid droplets, secondary species (such as particulate matters) is formed and removed from the atmosphere due to gravity reducing the concentration of global warming gas CO_2 from the regional atmosphere. In recent years some studies have been conducted for removing air pollutants and particulate matters from the atmosphere by rain but this concept has not been used for decreasing global warming gases from the atmosphere. We apply this concept to model the phenomenon of removing carbon dioxide from the near earth atmosphere by introducing external species and planting green belts around the sources of emission[3].

II. FORMATION

1) *Case I:* Removal of CO_2 by externally introduced liquid droplets and particulate matters in the upper atmosphere in a region [6]. The problem is governed by the following nonlinear ordinary differential equations,

C : The concentration of CO_2 in the atmosphere

C_i : The concentration of externally introduced liquid species

C_p : The concentration of particulate matters

Q : The rate of introduction of CO_2 into the regional atmosphere

$$\frac{dC}{dt} = Q - \alpha_0 C - \alpha_1 CC_i - \alpha_2 CC_p$$

$$\frac{dc_i}{dt} = \lambda C - \lambda_0 C_i - \lambda_1 CC_i$$

$$\frac{dc_p}{dt} = rC - r_0 C_p - \lambda_2 CC_p$$

With $C(0) > 0, C_i(0) > 0, C_p(0) > 0$

The symbols are described below

$\alpha 1 \sim \lambda 1$, $\alpha 2 \sim \lambda 2$, Rates of interaction (depletion rates) of CO_2 with and C, respectively.

λ, Rate of introduction of liquid species in the regional atmosphere.

r, Rate of introduction of particulate matters in the regional atmosphere

α_0, λ_0, r_0, Natural depletion rate coefficients of C, C_i and Cp respectively

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2) *Case II:* Removal of CO_2 from the near earth atmosphere by introducing a liquid species as well as by planting green belt near the sources of emission[6].

Let
C, The concentration of CO_2 in the atmosphere
C_i , The concentration of externally introduced liquid species
C_p, The concentration of particulate matters
B is the density of biomass
Q, The rate of introduction of CO_2 into the regional atmosphere
The problem is governed by the following nonlinear ordinary differential equations,

$$\frac{dc}{dt} = Q - \alpha_0 C - \lambda_1 CC_i - \lambda_2 BC$$

$$\frac{dc_i}{dt} = \lambda C - \lambda_0 C_i - \lambda_1 CC_i$$

$$\frac{dB}{dt} = rB - \frac{r_0 B^2}{K} + \lambda_2 BC$$

With C(0) > 0, $C_i > 0$, B > 0
The symbols are described below
λ_1, λ_2, Rates of interaction (depletion rates) of CO_2 with and C, respectively
λ, Rate of introduction of liquid species in the regional atmosphere
r, Rate of introduction of particulate matters in the regional atmosphere

III. NUMERICAL SOLUTION BY EQUILIBRIUM METHOD

A. *Case 1: Numerical Solution Of Removal Of Co2 By Externally Introduced Liquid Droplets And Particulate Matters In The Upper Atmosphere In A Region*

$$\frac{dC}{dt} = Q - \alpha_0 C - \alpha_1 CC_i - \alpha_2 CC_p \tag{1}$$

$$\frac{dc_i}{dt} = \lambda C - \lambda_0 C_i - \lambda_1 CC_i \tag{2}$$

$$\frac{dc_p}{dt} = rC - r_0 C_p - \lambda_2 CC_p \tag{3}$$

It is noted here that, for very large value of δ, $\frac{dC}{dt}$ may become negative. This implies that, if the interaction rate coefficient δ is very large, the global warming gas CO_2 would be removed almost completely from the regional atmosphere[5].
The region of attraction for all solution of model system (1) – (3) initiating in the positive octant is given by the set,

$$\Omega = \left\{ \left(C, A, C_p\right) \in R_+^3 : 0 \le C \le \frac{Q}{\delta_o}, 0 \le A \le \frac{\lambda}{\lambda_o}\frac{Q}{\delta_o}, 0 \le C_p \le \frac{\theta}{\theta_o}\frac{\lambda}{\lambda_o}\left(\frac{Q}{\delta_o}\right)^2 \right\} \tag{4}$$

1) *Equilibrium and Stability Analysis:* The model system (1) – (3) has only one non-trivial equilibrium $E^*(C^*, C_i^*, C_p^*)$ In the following, we prove the existence of $E^*(C^*, C_i^*, C_p^*)$, where C^*, C_i^* and C_p^* are positive solutions of the following system of algebraic equations,

$$C_i = \frac{\lambda C}{\lambda_0 + \lambda_1 C} = f(\mathrm{C}) \tag{5}$$

$$C_p = \frac{rC}{r_0 + \lambda_2 C} = g(\mathrm{C})$$

(6)

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Here $F(C) = Q - \alpha_0 C - \alpha_1 C f(C) - \alpha_2 C g(C) = 0$

This implies that there exist a root of F(C) = 0 (say C^*) in $0 \le C \le \dfrac{Q}{\delta_o}$

For the uniqueness of the root, we have,

$$F'(C) = Q - \alpha_0 C - \alpha_1 C f'(C) - \alpha_1 f(C) - \alpha_2 C g'(C) - \alpha_2 C g'(C) < 0$$

In the following, we check the variations of dependent variables with respect to relevant parameters, from equations (5) and (6) we have,

$$\left(\alpha_0\lambda_1 + \alpha_0\lambda_2 + \alpha_1\lambda + \alpha_2 r\right)C^2 + \left(\alpha_0\lambda_0 + \alpha_0 r_0 - Q\lambda_1 - Q\lambda_2\right)C - Q\left(\lambda_0 + r_0\right) = 0$$

(7)

From (7) we get C*

$$C^* = \frac{-\left(\alpha_0\lambda_0 + \alpha_0 r_0 - Q\lambda_1 - Q\lambda_2\right) + \sqrt{\left(\alpha_0\lambda_0 + \alpha_0 r_0 - Q\lambda_1 - Q\lambda_2\right)^2 + 4\left(\alpha_0\lambda_1 + \alpha_0\lambda_2 + \alpha_1\lambda + \alpha_2 r\right)Q\left(\lambda_0 + r_0\right)}}{2\left(\alpha_0\lambda_1 + \alpha_0\lambda_2 + \alpha_1\lambda + \alpha_2 r\right)}$$

2) Variation of C_i with Q

Differentiating (5) with respect to 'Q', we get,

$$\frac{dC_i}{dC} = \frac{\lambda\lambda_0}{(\lambda_0 + \lambda_1 C)^2}$$

Since $\dfrac{dC}{dQ}$ >0 therefore from $\dfrac{dC_i}{dQ} = \dfrac{dC_i}{dC}\dfrac{dC}{dQ}$ we have $\dfrac{dC_i}{dQ}$ >0

This implies that, if the rate of emission of global warming gas CO_2 increases, the requirement of externally introduced liquid species also increase.

3) Variation of C with λ

Differentiating (7) with respect to λ, we get,

$$\frac{dC}{d\lambda} = \frac{-\alpha_1 C^3}{Q(\lambda_0 + r_0) + \left(\alpha_0\lambda_1 + \alpha_0\lambda_2 + \alpha_1\lambda + \alpha_2 r\right)C^2} < 0$$

This implies that the concentration of carbon dioxide decreases as the rate of introduction of external liquid species increase.

From the above analysis, it is shown that, if the rate of emission of global warming gas CO_2 increases in the regional atmosphere, more amounts of liquid species is required for its removal. Further, as the rate of externally introduced liquid species increases, the concentration of carbon dioxide decreases.

To check the feasibility of our analysis regarding the existence of E∗, we conduct some Simulations of model (1) – (3) by choosing the following set of parameters.

Q=1, α_0=0.2, α_1=0.6, α_2=0.6, r=0.8, r_0=0.7 λ=0.4, λ_0=0.1, λ_1=0.3, λ_2=0.1

The equilibrium E∗ is calculated as,

$$C^* = 1.1612, C_i^* = 1.03595, C_p^* = 1.13826$$

B. *Case 2: Numerical Solution Of Removal Of Co2 From The Near Earth Atmosphere By Introducing A Liquid Species As Well As By Planting Green Belt Near The Sources Of Emissions*

$$\frac{dC}{dt} = Q - \alpha_0 C - \lambda_1 C C_i - \lambda_2 B C$$

(8)

$$\frac{dC_i}{dt} = \lambda C - \lambda_0 C_i - \lambda_1 C C_i$$

(9)

$$\frac{dB}{dt} = rB - \frac{r_0 B^2}{K} + \lambda_2 BC$$

(10)

$$\frac{dC_p}{dt} = \theta C C_i - \theta_0 C_p$$

(11)

With $C(0) > 0, C_p(0) > 0, C_i(0) > 0, \mathrm{B} > 0$

The region of attraction for all solution of model system (8) – (11) initiating in the positive octant is given by the set,

$$\Omega = \left\{ \left(C, C_i, B, C_p\right) : 0 \le C \le \frac{Q}{\alpha_0}, 0 \le C_i \le \frac{q}{\lambda_0}, 0 \le B \le B_m, 0 \le C_p \le C_m \right\}$$

Where $B_m = \dfrac{K}{r_0}\left(r + \lambda_2 \dfrac{Q}{\alpha_0}\right)$ and $C_m = \dfrac{\theta q Q}{\theta_0 \lambda_0 \alpha_0}$

The model (8) – (11) has two nonnegative equilibrium, namely $\overline{E}(\overline{\mathrm{C}}, \overline{\mathrm{C}}_{\mathrm{i}}, 0, \overline{\mathrm{C}}_{\mathrm{p}})$ and $\mathrm{E}^*(\mathrm{C}^*, \mathrm{C}_i^*, \mathrm{B}^*, \mathrm{C}_p^*)$, These are obtained by solving the algebraic equations:

$$Q - \alpha_0 C - \lambda_1 C C_i - \lambda_2 B C = 0$$

(12)

$$\lambda C - \lambda_0 C_i - \lambda_1 C C_i = 0$$

(13)

$$rB - \frac{r_0 B^2}{K} + \lambda_2 BC = 0$$

(14)

$$B = 0 \text{ And } B = \frac{K}{r_0}\left(r + \lambda_2 C\right)$$

$$\theta C C_i - \theta_0 C_p = 0$$

(15)

From these values we get to equilibrium corresponding to each B as shown in the following.

Existence of $\overline{E}(\overline{\mathrm{C}}, \overline{\mathrm{C}}_{\mathrm{i}}, 0, \overline{\mathrm{C}}_{\mathrm{p}})$

For $\overline{E}(\overline{\mathrm{C}}, \overline{\mathrm{C}}_{\mathrm{i}}, 0, \overline{\mathrm{C}}_{\mathrm{p}})$, the value of $\overline{\mathrm{C}}$ is given by the following algebraic equation

From (13) we have, $\overline{C_i} = \dfrac{\lambda \overline{C}}{\lambda_0 + \lambda_1 \overline{C}}$

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Insert the value of $\overline{C_i}$ in equation (12) we have,

$$(\lambda_1\lambda + \alpha_0\lambda_1)\overline{C}^2 + (\alpha_0\lambda_0 - \lambda_1 Q)\overline{C} - Q\lambda_0 = 0 \qquad (16)$$

Equation (16) has two roots, one is positive and the other is negative. The positive solution of is

$$\overline{C} = \frac{-(\alpha_0\lambda_0 - \lambda_1 Q) + \sqrt{(\alpha_0\lambda_0 - \lambda_1 Q)^2 - 4(\lambda_1\lambda + \alpha_0\lambda_1)Q\lambda_0}}{2(\lambda_1\lambda + \alpha_0\lambda_1)}$$

Using $\overline{C}$, the other equilibrium values are

$$\overline{C_i} = \frac{\lambda\overline{C}}{\lambda_0 + \lambda_1\overline{C}} \text{ and } \overline{C_p} = \frac{\theta\overline{C}\overline{C_i}}{\theta_0}$$

Existence of $E^*(C^*, C_i^*, B^*, C_p^*)$

For $E^*(C^*, C_i^*, B^*, C_p^*)$, the value of C^* is given by the algebraic equation

$$aC^2 + bC - c = 0 \qquad (17)$$

$$\left(\alpha_0\lambda_1 + \lambda\lambda_1 + \lambda_2^2\frac{K}{r_0}\right)C^2 + \left(\alpha_0\lambda_0 + \lambda_2\frac{rK}{r_0} - Q\lambda_1\right)C - Q\lambda_0 = 0$$

1) Variation of C^* with respect to λ_1 and λ_2

From (17), it can easily be shown that $\frac{dC^*}{d\lambda_1} < 0$ and $\frac{dC^*}{d\lambda_2} < 0$. These conditions show that the Steady state concentration of carbon dioxide (C^*) decreases with its interaction with the external Species with concentration C_i and density B of leafy trees.

Further, from equation (17), we have

$$C^* = \frac{-\left(\frac{\alpha_0\lambda_0}{\lambda_1} + \frac{\lambda_2 rK}{\lambda_1 r_0} - Q\right) + \sqrt{\left(\frac{\alpha_0\lambda_0}{\lambda_1} + \frac{\lambda_2 rK}{\lambda_1 r_0} - Q\right)^2 + 4\left(\alpha_0 + \lambda + \frac{\lambda_2^2 K}{\lambda_1 r_0}\right)Q\lambda_0}}{2\left(\alpha_0 + \lambda + \frac{\lambda_2^2 K}{\lambda_1 r_0}\right)}$$

Thus we have, $\lim_{\lambda_1\to\infty} C^* = 0$

Again, from (17), we have

$$C^* = \frac{-\left(\frac{\alpha_0\lambda_0}{\lambda_2} + \frac{rK}{r_0} - \frac{Q\lambda_1}{\lambda_2}\right) + \sqrt{\left(\frac{\alpha_0\lambda_0}{\lambda_2} + \frac{rK}{r_0} - \frac{Q\lambda_1}{\lambda_2}\right)^2 + 4\left(\frac{\alpha_0\lambda_0}{\lambda_2} + \frac{\lambda\lambda_1}{\lambda_2} + \frac{\lambda_2 K}{r_0}\right)Q\lambda_0}}{2\left(\frac{\alpha_0\lambda_0}{\lambda_2} + \frac{\lambda\lambda_1}{\lambda_2} + \frac{\lambda_2 K}{r_0}\right)}$$

Thus we have, $\lim_{\lambda_2\to\infty} C^* = 0$

2) Numerical Simulation

To check the feasibility of our analysis regarding the existence of E^*, we conduct some Simulations of model (8) – (11) by choosing the following set of parameters.

Q=1, K=20, λ=0.5, α_0=0.6, θ=0.3, θ_0=0.25, r=0.6, r_0=0.6, λ_0=0.3, λ_1=0.1, λ_2=0.05

It is found that under the above set of parameters, equilibrium values of components of $E^*(C^*, C_i^*, B^*, C_p^*)$ as follows,

$$C^* = 0.2651, C_i^* = 0.4060, B^* = 20.4418, C_p^* = 0.1292$$

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IV. FIGURE AND TABLES

A. For case-1

Table 1: Variation of C_i with different value of Q for any time t.

Q	1	2	3	4	5
C_i	1.036	1.1316	1.1765	1.2036	1.2222

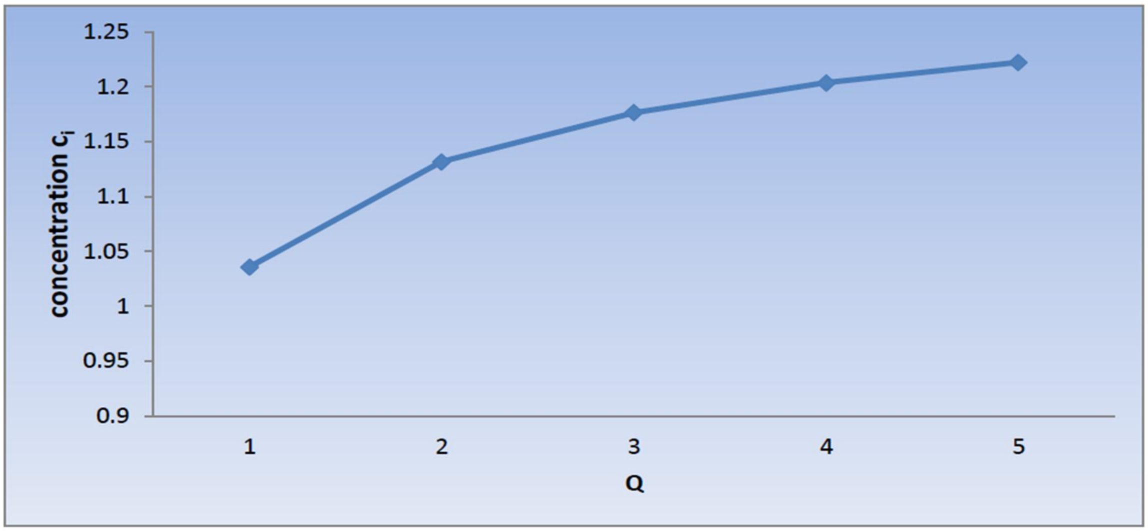
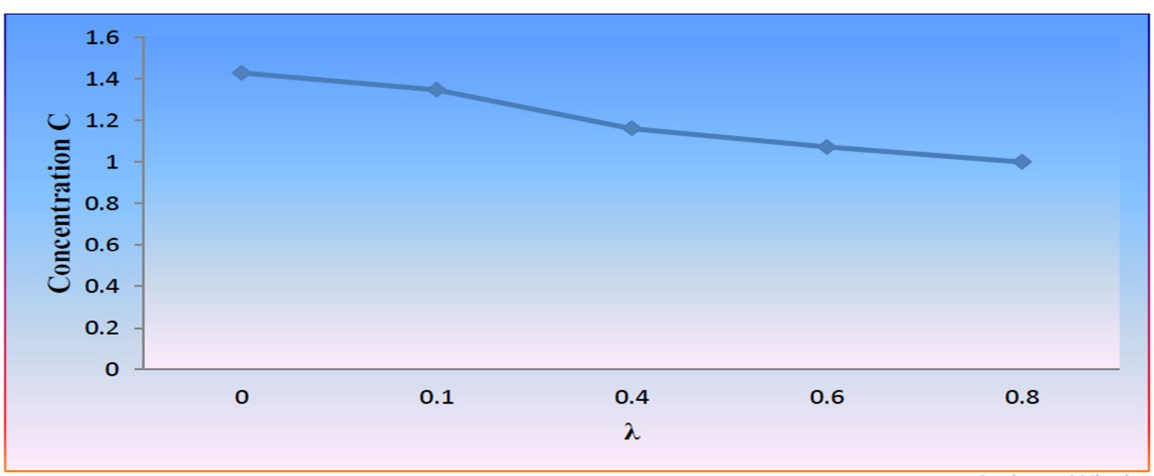


Table 2: Variation of C with different value of λ for any time t.

λ	0	0.1	0.4	0.6	0.8
C	1.428	1.346	1.161	1.072	0.999



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B. For case-2

Table 3: Variation of C with different value of λ_1 for any time t.

λ_1	0.01	0.1	0.2	0.4	0.5
C	0.2513	0.2651	0.2815	0.317	0.336

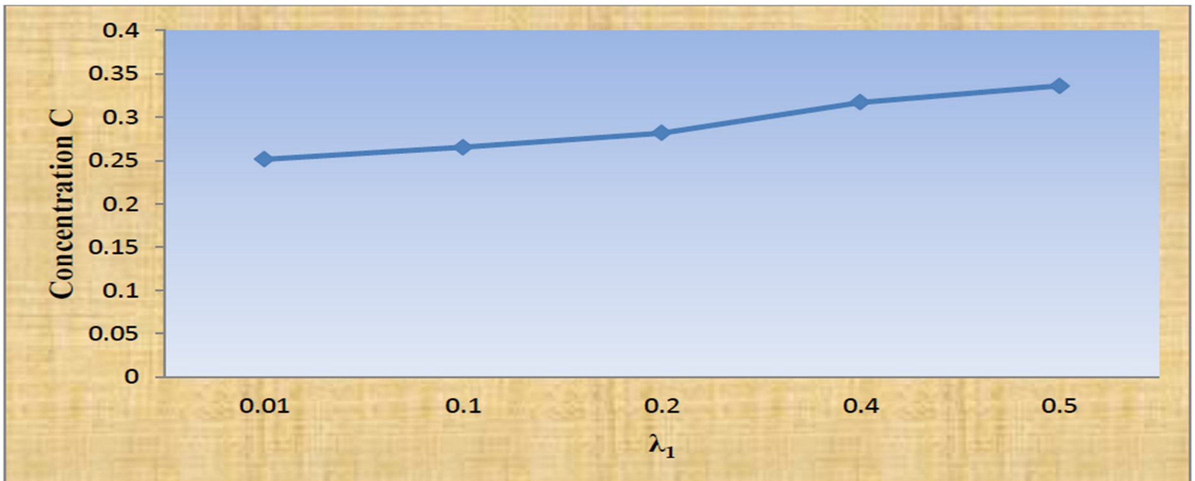
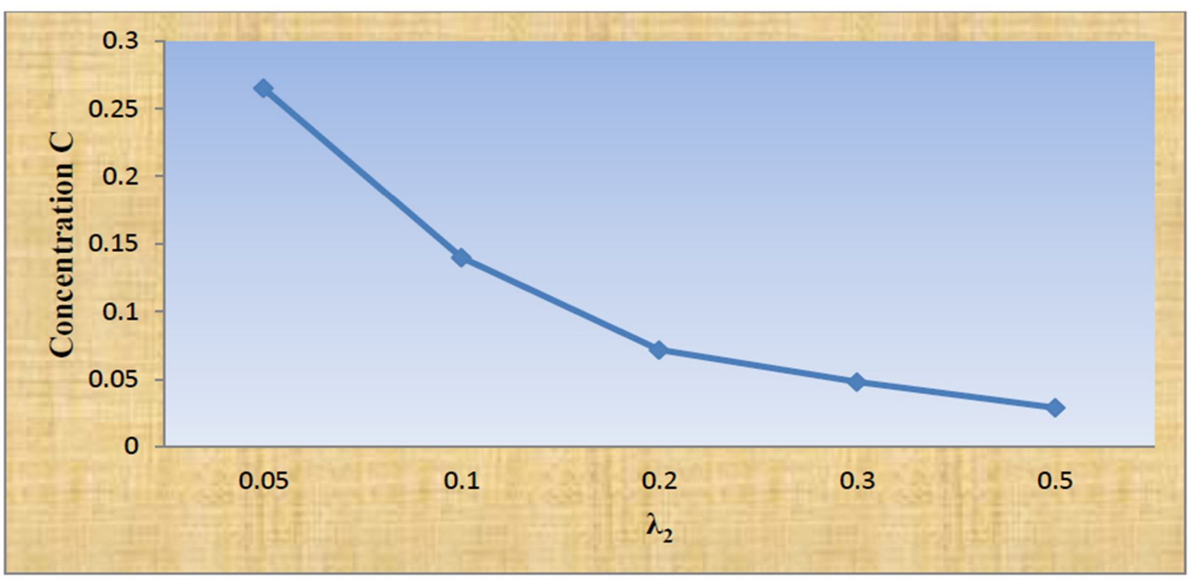


Table 4: Variation of C with different value of λ_2 for any time t.

λ_2	0.05	0.1	0.2	0.3	0.5
C	0.2651	0.13996	0.0717	0.0481	0.0291



V. CONCLUSION

In this chapter, we have modeled the phenomenon of removal of a global warming gas CO2 by externally introduced liquid species. It is assumed that the model system consists of three nonlinearly dependent variables namely, the concentration of global warming gas CO2, the concentration externally introduced liquid species and the concentration of particulate matters formed due to interaction of carbon dioxide with liquid species. The proposed model is analyzed using stability theory of ordinary differential equations and numerical simulations. It is shown, analytically and numerically, that the concentration of global warming gas CO2 decreases as the concentration of externally introduced liquid species increases and if the rate of introduction of liquid species is very high, the carbon dioxide would be removed completely from the atmosphere. It has also been shown that the concentration of CO2 decreases as the interaction rate coefficient Q of CO_2 with liquid species increases. The analyses suggest that the equilibrium level of global warming gas can be reduced from the atmosphere by introducing suitable external species.

The removal of global warming gas such as carbon dioxide from the atmosphere is a very important problem to be solved by scientists. In this chapter a modeling study has been conducted to reduce carbon dioxide from the near earth atmosphere by introducing external species such as liquid drops or appropriate particulate matters which can react with carbon dioxide and removed it by gravity. Carbon dioxide can also be removed by growing leafy trees in the greenbelts surrounding the sources of emission, which use it during photosynthesis. Thus, the phenomenon has been assumed to be governed by four dependent variables, namely, the concentrations of carbon dioxide, the externally introduced species, the cumulative biomass density λ_1 and λ_2 of trees in the green belts and the concentration of the resulting particulate matters. The rate of introduction of the external species in to the atmosphere has been assumed to be proportional to concentration of carbon dioxide in the regional atmosphere. The cumulative biomass density of plants has been assumed to follow a logistic model with constant intrinsic growth rate and constant carrying capacity. The model analysis has shown that the concentration of carbon dioxide can be decreased considerably and it can almost be eliminated if the rate of introduction of external species as well as cumulative biomass density in the greenbelt is very large.

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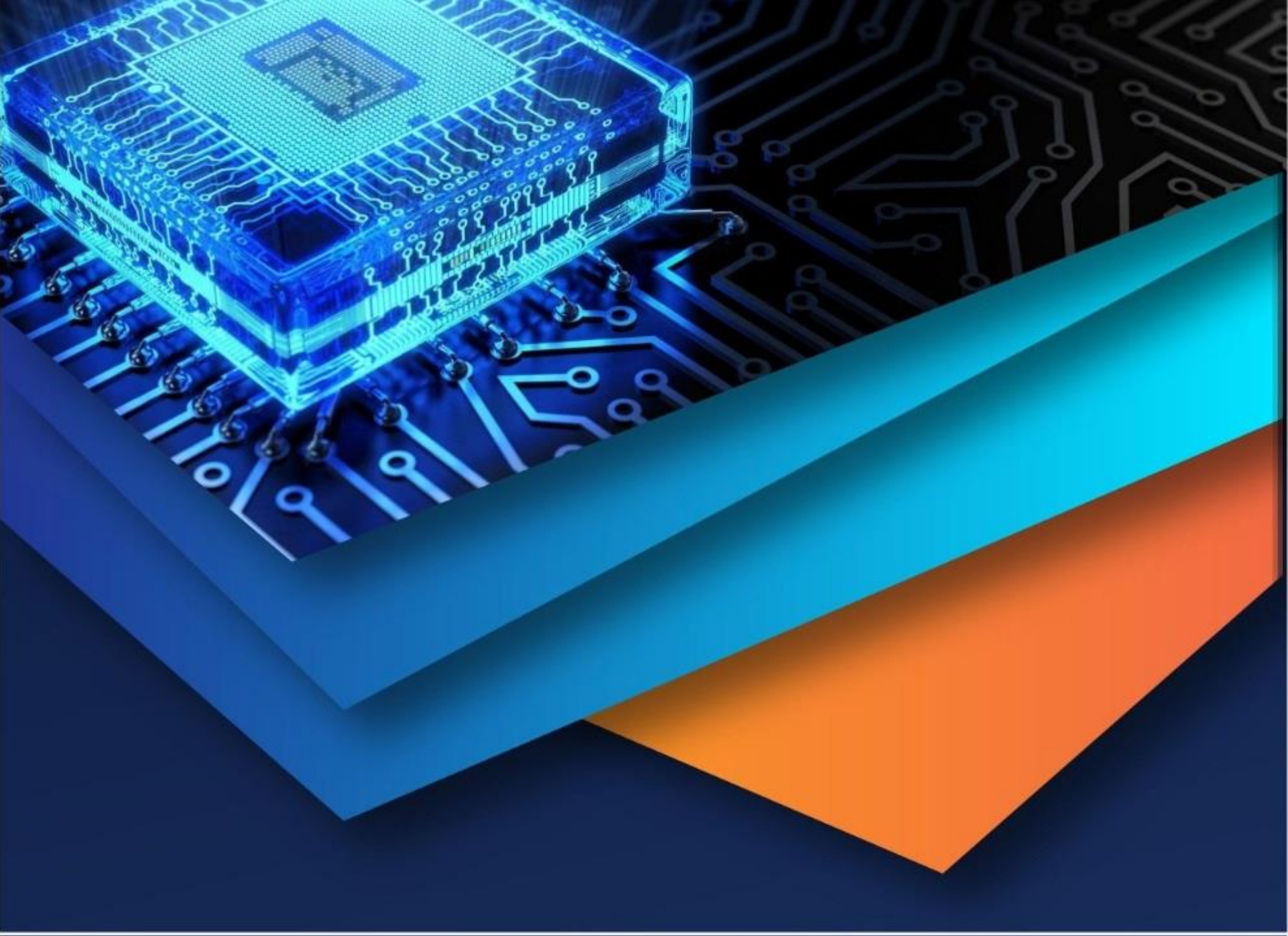

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