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Blow-up and Extinction Phenomenon for the Generalized Burgers Equation

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Abstract: In this paper, the author consider conditions of that initial boundary value to study the dynamic behavior for Generalized Burgers equation, and give these system for that new conditions of blow-up, and Extinction Phenomenon of these equation with in rich using engineering. Such as, these theories and method can be used in other similar systems, they have a wide range of applications. Finale, some numerical simulations are carried out to support these new results. The authors extend dynamic behavior and the critical value to continuum more previous work [3, 9, 13] for in-depth achieve for apply value.

Keywords: Blow-up and extinction, boundary value problems, generalized burgers equation, nonlinear source.

1. INTRODUCTION AND PRELIMINARIES

Like Burgers equation and Schrodinger equation is one of the most modern science universal equation, as describe the nonlinear wave equation of the corresponding effect of the disperse-on and interaction model, in material mechanics and fluid mechanics are apply value in physics area, and also continuous stochastic process in the actual problem in many fields, such as, these theories and method can be used in other similar systems, they have a wide range of applications. Johannes Burgers first by using of bellow nonlinear equation in year 1948 for the

$$u_t + uu_x = \gamma u_{xx} \tag{1.1}$$

where $\gamma > 0$ denote the fluid flow, let us describe that interaction between the convection and the effective sense of flow for the nonlinear source model.

Recently, its dynamic time senior behaviour and its analytical solution and numerical solution were investigated to study.

If the burgers equation was nonlinear equation in the following of initial boundary value problem

$$\begin{aligned} & u_t + uu_x = \nu u_{xx}, a < x < b, t > 0 \\ & u(x,t) = \phi(x), a < x < b, \\ & u(a,t) = u(b,t) = 0, t > 0 \end{aligned} \tag{1.2}$$

which $\gamma > 0$ as the viscosity coefficient, $\phi(x)$ for a given function. Batman gave out stable of solution. Many problems are based on the Burges equation basic models to extension and application [1], meanwhile Burger equation and Navier-Stoke equation can be thought of as the approximate equation [2], make it in the nonlinear wave, gas dynamics, the shock wave and continuous stochastic process has a broad application space, etc. (see [11-15]) AIkis S. Tersenov study in the following of initial boundary value problem

$$u_t + g(t,x,u) \cdot \nabla u = \varepsilon \Delta u + \lambda f(u) \tag{1.3}$$

formulate a condition guaranteeing the absence of the blow-up of a solution and discuss the optimality of this condition [3]. In particular, functions $f(u) = |u|^{p-1} u$, $p \ge 0$ and $f(u) = e^u$ satisfy this condition. Eq. (1.3) with $f(u) = u^p$ arises in many application (see [4-7]). Eq. (1.1) with $g(x,t,u) \equiv 0$ and it is well known that if $f(u)$ is super-linear the Phenomenon of the solution blowing up, and extinction may occur (see [8-10]).

Concerning the preventive effect of the linear gradient term $(au^q + b)u_{x_1}$. $(i.e. q = 0$ or $a \equiv 0)$ see [11]. Due to the fact that parameter ε is often small we will consider the helpful influence of the diffusing term $\varepsilon \Delta u$ and $\varepsilon \Delta^2 u$ (in extinction); concerning the preventive effect of linear and nonlinear diffusion, see [8, 12].

2. THE EXTINCTION PHENOMENON THE BURGERS EQUATION

Let Ω be a bounded domain of R^n having sufficiently smooth boundary $\partial\Omega, n$ be outer normal direction and $(x,t) \in \Omega \times [0, +\infty)$ that $\Delta u = \sum_{i=1}^{n} \partial^2 / \partial x_i^2, \Delta^2 = \Delta(\Delta)$, $\Delta^3 = \Delta(\Delta^2), \cdots$.

We consider Burgers equation with higher-order term as follows

$$u_t + g(t,x,u)\cdot\nabla u = \varepsilon\Delta^2 u + \lambda f(u), Q_T = (0,T)\times\Omega, \Omega\in R^n \quad (2.1)$$

$$\partial\nabla^{(i)}u(x,t)/\partial n = 0, (x,t)\in(0,\infty)\times\partial\Omega, (i=1,2), \quad (2.2)$$

$$\beta u(x,t) + \alpha\partial u(x,t)/\partial n = 0, (x,t)\in(0,\infty)\times\partial\Omega, \quad (2.3)$$

$$u(x,0) = u_0(x), x\in\Omega, t>0 \quad (2.4)$$

where

$$g(x,t,u) = a_1(x,t)u^q + a_2(x,t)u^p + b(x,t),$$

$$f(u) = c_1u^q + c_2u^p + c_3u.$$

Definition2.1: If there is $T_0\in(0,\infty)$ for solution $u(x,t)$ of problem (2.1)-(2.4) satisfy:

$$u(x,t)\neq 0, (x,t)\in[0,T_0)\times\Omega,\ u(x,t)\equiv 0, (x,t)\in[T_0,\infty]\times\Omega.$$

Then the problem (2.1)-(2.4) with solution $u(x,t)$ be called extinction in finite time.

We will give the theorem to extend some results [9], we have the following results as lemma.

Lemma 2.2[10] If $u(t,x)\in W_0^{1,2}(\Omega)\cap L^{1+q}(\Omega)$, then for $\forall\varepsilon>0$, exists $C_\varepsilon>0$, such that holds inequality:

$$\|u(\cdot,t)\|_2^k \le C_\varepsilon\|u(\cdot,t)\|_{1+q}^{1+q} + \varepsilon\|\nabla u(\cdot,t)\|_2^2, \quad (2.5)$$

where, $k = \dfrac{2N(1-\gamma)+4(1+\gamma)}{4+N(1-\gamma)}, N=n, \|\cdot\|_l$ implies norm of space $L^l(\Omega)$, $l\ge 1$.

Proof. From Gagliardo-Nirenberg inequality [9], and Holder inequality that we easy get the conclusion.

Theorem 2.3 Assume that $\alpha = \min|a_1(t,x)|>0$, $\alpha_1 = \min|a_2(t,x)|>0$, there exists $\varepsilon>0, \lambda\le-\max(a_1,a_2)$ and satisfies following inequality:

$$a_1\int_\Omega u^{q+1}\nabla u(x,t)dx + a_2\int_\Omega u^{p+1}\nabla u(x,t)dx - \varepsilon\int_\Omega(\Delta u)^2dx$$
$$\le \max(a_1,a_2)\int_\Omega u(x,t)^{\max\{q,p\}+1}dx + \varepsilon\int_\Omega(\nabla u(x,t))^2dx, \quad (2.6)$$

then $\forall u_0(x)\in(L^2(\Omega)\cap L^2(\partial\Omega), L^4(\partial\Omega)), u_0(x)\equiv 0.$

The solution $u(x,t)$ of problem (2.1)-(2.4) will be with extinction in finite time, and with follow decay estimate:

$$\int_\Omega u^2(x,t)dx \le \left(\left(\int_\Omega u_0^2(x)dx\right)^{\frac{(2-k)}{2}} - C^*(\varepsilon_1,\lambda)\left(\frac{2-k}{2}\right)\right)^{\frac{2}{(2-k)}},$$

$$t\in[0,T_0),\ \int_\Omega u^2(x,t)dx = 0,\ t\in[T_0,\infty) \quad (2.7)$$

Proof. By $u(x,t)$ multiplies the both side of (2.1) and integrating on Ω for x. To combine Green's formula and boundary conditions we have:

$$\frac{1}{2}\left(\int_\Omega u^2(x,t)dx\right)_t + a_1\int_\Omega u^{q+1}\nabla u(x,t)dx + a_2\int_\Omega u^{p+1}\nabla u(x,t)dx$$

$$= \int_\Omega(\Delta u)^2dx + \lambda\int_\Omega u^{\gamma+1}(x,t)dx, \quad (2.8)$$

By (2.8) and (2.6) we have

$$\frac{1}{2}\frac{d}{dt}\left(\int_\Omega u^2(x,t)dx\right)$$
$$\le -2\max(a_1,a_2)\int_\Omega u(x,t)^{\max\{q,p\}+\gamma+2}dx - \varepsilon\int_\Omega(\nabla u)^2dx,$$

Utilize lemma 2.2, we obtain

$k = \dfrac{2(2-n)\max\{q,p\}+5\gamma+8}{4-n(\max\{q,p\}+\gamma)}$ select suiting parameter $C^*(\varepsilon_1,\lambda)$, we obtain that bellow inequality:

$$\frac{1}{2}\frac{d}{dt}\left(\int_\Omega u^2dx\right) \le -C^*(\varepsilon_1,\lambda)\left(\int_\Omega u^k(t,x)dx\right)^k.$$

By integral above inequality for t and notice initial condition $u(t,x) = u_0(x)$. It is (2.7). Therefore, the solution of (2.1)-(2.4) is extinction in finite time, and has the result of estimates that completes the proof of Theorem 2.3.

3. THE BLOW-UP PHENOMENON FOR THE BURGERS EQUATION

Consider the following equation of [3]

$$u_t + g(t,x,u)\cdot\nabla u = \varepsilon\Delta u + \lambda f(u)$$

in $Q_T = (0,T)\times\Omega, \Omega\in R^n$ (3.1)

Coupled with initial and boundary conditions

$u(0,x) = \phi(x)$ for

$$(x,t)\in\Gamma_T = \partial\bar{Q}_T\setminus\{(x,T): x\in\Omega\}. \quad (3.2)$$

Here $\varepsilon>0$ and λ are constants,

$$g = (g_1,g_2,\cdots,g_n), g_i = g_i(t,x,u), i=1,2,\cdots,n.$$

Assume that $g_1 = a_1(x,t)u^q + b(x,t)$ and $\min_{\bar{Q}_T}|a(x,t)| = a_0 > 0,$

where $a,b\in C^0(\overline{Q}_T)$ and the positive constants q,p are such that $y^q\in R$ for any $y\in R$. If the solution is nonnegative the last assumption is unnecessary. Concerning the nonlinear source $f(u)$ we assume that

$$|f(\xi)|\le f(\eta)\ \text{ for all } \xi \text{ and } \eta \text{ such that } |\xi|\le\eta. \tag{3.3}$$

Let us formulate our result. Denote $b_1=\min_{Q_T}|b(x,t)|$

$m=\max_{\Gamma_T}|u|$, here Γ_T is the parabolic boundary of Q_T *i.e.* $\Gamma_T=\partial\overline{Q}_T\setminus\{(x,T):x\in\Omega\}$. Without loss of generality suppose that the domain Ω is lying in the strip $-l_1<x_1<l_1$. We will prove the global (*i.e.* for arbitrary $T>0$) classical solvability of problem (3.1), (3.2) under the following assumption:

There exists a constant $M\ge m$ such that

$$2l_1|\lambda|f(2M)+b_1M\le a_0M^{q+1}. \tag{3.4}$$

Lemma 3.1[3] Assume that

$\phi\in C^0(\Gamma_T),\ g_i(t,x,u)\in C^1(Q_T\times(-2M,2M))$,

$f(u)\in C^1(-2M,2M)$.

If condition (3.3) and (3.4) are satisfied then for an arbitrary $T>0$, there exists a unique classical solution of problem (3.1), (3.2) such that

$$|u(t,x)|\le 2M. \tag{3.5}$$

Moreover, consider dynamic action in large time with compound term of generalized Burgers equation. Consider the auxiliary equation

$$u_t+\left(a_1(x,t)u^q+a_2(x,t)u^p+b(x,t)\right)\cdot\nabla u$$
$$=e\Delta u+\lambda u\left(u^{q_1}-u^{p_1}+1\right),\qquad \text{in}(0,T)\times\Omega.$$

We study the most typical case: we omit subscript 1 in x_1 and l_1:

$$u_t+\left(a_1(x,t)u^q+a_2(x,t)u^p+b(x,t)u\right)u_x$$
$$=eu_{xx}+\lambda u\left(u^{q_1}-u^{p_1}+1\right),\qquad in(0,T)\times(-l,l). \tag{3.6}$$

Coupled with initial and boundary conditions

$u(x)=\phi(x)$ for

$$(x,t)\in\partial\left((0,T)\times(-l,l)\right)\setminus\{(x,T):x\in(-l,l)\}. \tag{3.7}$$

where $a_1,a_2,b\in C^0\overline{(0,T)\times(-l,l)}$ and the positive constants q_1,p_1 are such that $y^{q_1},y^{p_1}\in R$ for any $y\in R$.

Under the based of corresponding condition and combine lemma 3.1, we will prove the global classical solvability of problem (3.6), (3.7) under the following assumption: there exists a constant $M\ge m$ Such that

$$2^{p_1+1}l|\lambda|M^{p_1}+b_1M\le(a_1+a_2)M^{\min\{q,p\}+1}. \tag{3.8}$$

We will supply the following theorem:

Theorem 3.2 Assume that $\phi\in C^0(\Gamma_T)$,

$\left(a_1u^q+a_2u^p+b\right)\in C^1\left((0,T)\times(-l,l)\times(-2M,2M)\right)$,

$\left(u^{q_1+1}-u^{p_1+1}+u\right)\in C^1(-2M,2M)$. If condition (3.3) and (3.8) are satisfied then for an arbitrary $T>0$, there exists a unique classical solution of problem (3.6), (3.7) such that

$$|u(x,t)|\le 2M. \tag{3.9}$$

where $\Gamma_T=\partial\overline{(0,T)\times(-l,l)}\setminus\{(x,T):x\in\Omega\}$, $M=\max\{M_1,M_2\}$.

Proof. Let $a_1(x,t)=a_1,a_2(x,t)=a_2,b(x,t)=b$,

$f(u)=\lambda u\left(u^{q_1}-u^{p_1}+1\right)$,

$$u_t+\left(a_1u^q+a_2u^p+b\right)u_x=eu_{xx}+\lambda\left(u^{q_1+1}-u^{p_1+1}+u\right) \text{ in } (0,T)\times(-l,l). \tag{3.10}$$

We assume here is that u^{p_1+1} and u^{q_1+1} are defined, otherwise we take $|u|^{p_1}u$ and $|u|^{q_1}u$. It is known that there exists a global solution of problem (3.10), and (3.7) without smallness restrictions on initial data for $p_1\le q+1,\phi\ge 0$,

$p=q$, (or $p_1\le\min\{q,p\}q+1,\phi\ge 0$, when $p\ne q$) and zero boundary conditions, moreover if $p_1>q+1$, when

$p=q$; (or $p\ne q$, $p_1>\max\{q,p\}q+1$), then a finite blow up occurs if the initial data is sufficiently large. Let us apply our Lemma3.1 to Eq. (3.9).

If we consider two case (i) and (ii):

(i) $p_1<q+1$, when $p=q$, then condition (3.8) is always fulfilled with

$$M_1=\max\left\{m_1,\left(\sup\left\{2^{p_1+1}|\lambda|l,b_1\right\}/|a_1+a_2|\right)^{\frac{1}{q+1-p_1}}\right\},$$

$p_1<q+1,(p=q)$.

(ii) $p_1<\min\{q,p\}+1$, when $p\ne q$; Similar case (i) there with

$$M_2 = \left\{ \max \left\{ m, \left(\frac{\sup \left\{ 2^{p_1+1} |\lambda| l, b_1 \right\}}{|a_1 + a_2|} \right)^{\frac{1}{\gamma}} \right\} \right\},$$

$p_1 < \min\{q, p\} + 1, (p \neq q)$

$\gamma = (\min\{q, p\} + 1 - \max\{1, p_1\})$.

Combine the two case, and as a consequence for arbitrary data there exists a global solution satisfying the estimate $|u| \le 2\max\{M_1, M_2\}$.

Next, consider another two case with inverse form:

(i) Suppose that $p_1 > q+1$, $p = q$. Condition (3.8) becomes a smallness restriction. In fact, rewrite (3.8) in the form

$\exists M_1 \ge m_1$ such that

$$M_1^{p_1-q-1} \le \frac{a_1 + a_2}{\max\left\{2^{p_1+1} l|\lambda|, b_1\right\}}, p = q$$

Obviously, if

$$m_1 \le \left(\frac{a_1 + a_2}{\max\left\{2^{p_1+1} l|\lambda|, b_1\right\}} \right)^{\frac{1}{p_1-q-1}}, p = q$$

then (3.8) is fulfilled with $M_1 = m_1$ and there exists a global solution such that $|u| \le 2m_1$.

(ii) Let that $p_1 > \max\{q, p\}q + 1$, when $p \ne q$. Similar case (i) there $\exists M_2 \ge m_2$ that is

$$m_2 \le \left((a_1 + a_2)/\max\left\{2^{p_1+1} l|\lambda|, b_1\right\}\right)^{\frac{1}{\gamma_1}}, p \ne q,$$

$$\gamma_1 = \frac{1}{\max\{1, p_1\} - \min\{q, p\} - 1}.$$

Then (3.8) is fulfilled with $M_2 = m_2$ and there exists a global solution such that $|u| \le 2m_1$.

Now, consider the two critical case.

Case (i) $p_1 = q+1$, when $p = q$:

$$u_t + \left((a_1 + a_2)u^q + b\right)u_x = eu_{xx} + \lambda(u^{q+1} - u). \quad (3.11)$$

For the function $v = ue^{-\mu x}$ with $\mu = \lambda / (a_1 + a_2)$, we have

$$v_t + \left((a_1 + a_2)v^q e^{q\mu x} + bve^{\mu x} - 2\mu e\right)v_x = ev_{xx} + (\varepsilon\mu^2 + c)v. \quad (3.12)$$

$v = \phi e^{-\mu x}$ for

$(x, t) \in \Gamma_T = \{t = 0, |x| \le l\} \cup \{0 < t \le T, x = \pm l\}$

Case (ii) $p_1 = \min\{q, p\} + 1$, when $p \ne q$;

$$u_t + \left((a_1 + a_2)u^{\max\{1,p_1\} - \min\{q,p\} - 1} + b\right)u_x = eu_{xx} + \lambda\left(u^{\max\{1,p_1\} - \min\{q,p\}} - u\right) \quad (3.13)$$

Similar case (i), we have

$$v_t + \left((a_1 + a_2)\left(ve^{\mu x}\right)^{\gamma} + bve^{\mu x} - 2\mu e\right)v_x = eu_{xx} + (\varepsilon\mu^2 + c)v, \gamma = \max\{1, p_1\} - \min\{q, p\} - 1 \quad (3.14)$$

$v = \phi e^{-\mu x}$ for

$(x, t) \in \Gamma_T = \{t = 0, |x| \le l\} \cup \{0 < t \le T, x = \pm l\}$

Condition (3.8) for Eq. (3.12) take the form $\exists M_1 \ge m_1 e^{|\mu| l}$ such that

$$4l|\lambda|(\varepsilon\mu^2 + c)M_1 + 2\varepsilon|\mu|M_1 \le (a_1 + a_2)e^{-q|\mu|l} M_1^{q+1}$$

Obviously this condition fulfilled with

$$M_1 = \max\left\{ m_1, \left(\frac{\sup\left\{4l|\lambda|(\varepsilon|\mu|^2 + c), 2\varepsilon|\mu|\right\}}{a_1 + a_2} \right)^{\frac{1}{q}} \right\} e^{|\mu| l},$$

$\mu = \lambda / (a_1 + a_2)$ and the estimate $|u(x,t)| \le 2M_1$ is obtained. As a consequence the theorem guarantees the global solvability of problem (3.11), (3.7) and the solution satisfies the estimate $|u(x,t)| \le 2M_1 e^{\mu x}$.

Similar case (i) there $\exists M_2, M > 0$, we have $M_2 \ge m_2 e^{|\mu| l}$ and $\exists M \ge me^{|\mu| l}$ such that

$$4l|\lambda|(\varepsilon\mu^2 + c)M_2 + 2\varepsilon|\mu|M_2 \le (a_1 + a_2)e^{-(\max\{q,p\}+1)|\mu|l} M_2^{\max\{q,p\}+1}.$$

Obviously this condition fulfilled with

$$M_2 = \max\left\{ m_2, \left(\frac{\sup\left\{4l|\lambda|(\varepsilon|\mu|^2 + c), 2\varepsilon|\mu|\right\}}{a_1 + a_2} \right)^{\gamma_2} \right\} e^{|\mu| l}$$

$\mu = \lambda / (a_1 + a_2), \gamma_2 = (\max\{q, p\} + 1)^{-1}$

and the estimate $|u(x,t)| \le 2M_2$ is obtained. As a consequence the Theorem guarantees the global solvability of

Table 1. Aking the parameters of Burger-Eq. (3.6).

a_1	a_2	b_1	p_1	q_1	q_2	p	e	λ	c
0.2	**0.8**	**1**	**1**	**1**	**1**	**4**	**0.1**	**0.9**	**0.9**

Table 2. Taking the parameters of Burger-Eq. (3.6).

a_1	a_2	b_1	p_1	q_1	q_2	p	e	λ	c
0.2	**0.8**	**1**	**1**	**2**	**1**	**2**	**0.4**	**0.9**	**0.9**

problem (3.13), (3.7) and the solution satisfies the estimate $\left|u\left(x,t\right)\right| \le 2M_2 e^{\mu x}$.

By (i) and (ii), we obtain estimate

$$\left|u\left(x,t\right)\right| \le 2\left\{M_1, M_2\right\}e^{\mu x}, \mu = \lambda / \left(a_1 + a_2\right).$$

We complete this proof of theorem.

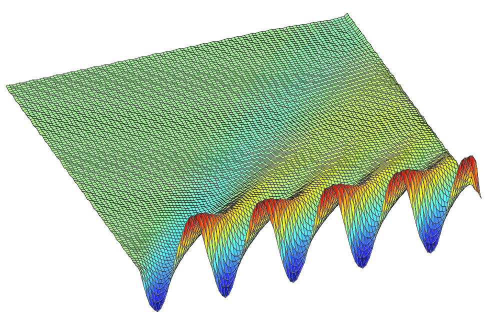

Fig. (1). The solution found by numerical integration of Burger-Eq. (3.6) description taking the parameters in Table **1**.

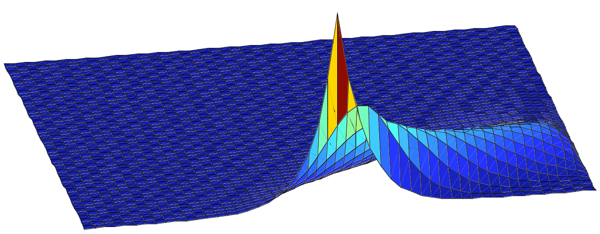

Fig. (2). The solution found by numerical integration of Burger-Eq. (3.6) description taking the parameters in Table **2**.

4. NUMERICAL SIMULATIONS

In order to illustrate our theoretical analysis, numerical simulations are also included in aid of MATLAB 7.0. Most of parameters are taking follow with from Tables **1** and **2**.

According to case Table **1**:

Figure description taking the parameters (See Table **1**).

Under (3.7), we can show the trend of dynamics behaveour of Burger-Eq. (3.6) with taking the parameters in Table **1** (See Fig. **1**).

Figure description taking the parameters (See Table **2**).

Under (3.7), we can show the trend of dynamics behaveour of Burger-Eq. (3.6) with taking the parameters in Table **1** (See Fig. **2**).

According to case Table **2**.

CONCLUSION

This article mainly studies the general dynamics behaviour of Burger-equation of blasting and Extinguishing phenomenon, to discuss these case through certain parameters values. Such equations always exhibit a rich phenomenology attracts many attention in engineering mechanics, material mechanics and fluid mechanics with application value. The authors extend dynamic behaviour and the critical value to continuum more previous work [3, 9, 13-15] for in-depth achieve for apply value.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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