4-Point Correlations of Dusty Fluid MHD Turbulent Flow in a 1st order Chemical-Reaction

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GJSFR-F Classification : FOR Code : MSC 2010: 00A69

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I. INTRODUCTION

Chemical reaction as used in chemistry, chemical engineering, physics, fluid mechanics, heat and mass transport. The mathematical models that describe chemical reaction kinetics provide chemists and chemical engineers with tools to better understand and describe chemical processes such as food decomposition, stratospheric ozone decomposition, the complex chemistry of biological systems and MHD turbulence. In recent year, the motion of dusty viscous fluids has developed rapidly. The motion of dusty fluid occurs in the movement of dust–laden air, in problems of fluidization, in the use of dust in a gas cooling system and in the sedimentation problem of tidal rivers. The behavior of dust particles in a turbulent flow depends on the concentrations of the particles and the size of the particles with respect to the scale of turbulent fluid. Kishore and Golsefid [1, 1988] obtained and expression for the effect of Coriolis force on acceleration covariance in MHD turbulent flow of a dusty incompressible fluid. Kumar and Patel [2, 1974] derived expressions the first order reactant in homogeneous turbulence before the final period of decay. Kumar and Patel [3, 1975] also studied the first order reactant in homogeneous turbulence before the final period for the case of multi-point and multi-time. Chandrasekhar [4, 1951] obtained the invariant theory of isotropic turbulence in magneto-hydrodynamics. Corrsin [5, 1951] established on the spectrum of isotropic temperature fluctuations in isotropic turbulence. Bkar PK et al.,[6,2012] calculated for the first-order reactant in homogeneous dusty fluid turbulence prior to the ultimate phase of decay for four-point correlation in a rotating system. Sarker et al., [7, 2012] discussed the homogeneous dusty fluid turbulence in a first-order reactant for the case of multi point and multi time prior to the final period of decay. Bkar Pk et al., [8, 2013] also established the homogeneous turbulence in a first-order reactant for the case of multi point and multi time prior to the final period of decay in a rotating system. Bkar Pk et al.,[9, 2014] further enlarge the previous problem for the first-order reactant of homogeneous dusty fluid turbulence prior to the final period of decay in a rotating system for the case of multi-point and multi-time at four-point

For first order chemical reaction, most of the author has been discussed their problems in two and three point correlation and some author has been done in a porous moving plate. Bkar PK et al., has been investigated their problems for MHD turbulence with the present of dust particles, rotating systems, dust particles in rotating systems and first order chemical reaction for point correlation.

To the best of author’s knowledge, the interaction between dusty fluid MHD turbulence and first order chemical reaction at four point correlations has received little attention. Hence in our present paper we have studied the decay of dusty fluid MHD turbulence in a first order chemical reaction for four-point correlation. The expressions for the fluctuation of velocity components and concentration have been obtained and effects of chemical reactions have been computed numerically and discussed in detail. Finally we have obtained the decay of dusty fluid of magnetic energy fluctuation of concentration undergoing a first order chemical reaction for four-point correlation in the form

\[
\frac{\langle h^2 \rangle}{2} = \left( A T_0^{-2} + B T_0^{-5} \right) \exp(-R T_0) + \left( C T^{-2} + D T^{-5} \right) \exp(-R + M T_0^2)
\]

where \( R \) is the chemical reaction, \( M \) is the dust particle parameter, \( \langle h^2 \rangle \) denotes the total energy that is, mean square of the magnetic field fluctuation, \( t \) is the time, and \( A, B, C, D, t_0 \) and \( t_1 \) are arbitrary constants determined by the initial conditions.

II. Two-Point Correlation and Spectral Equations-

First we discussed two and three point correlations with spectral equations in briefly next calculated our main problem elaborately. Induction equation at the point \( P \) and the corresponding equation for the point \( P' \) in the magnetic are given by
\[
\frac{\partial h_i}{\partial t} + u_k \frac{\partial h_i}{\partial x_k} - h_k \frac{\partial u_i}{\partial x_k} = \left( \frac{\nu}{p_M} \right) \frac{\partial^2 h_i}{\partial x_k \partial x_k},
\]

\[
\frac{\partial h'_i}{\partial t} + u'_k \frac{\partial h'_i}{\partial x'_k} - h'_k \frac{\partial u'_i}{\partial x'_k} = \left( \frac{\nu}{p_M} \right) \frac{\partial^2 h'_i}{\partial x'_k \partial x'_k}.
\]

Multiplying equation (1) by \( h'_j \) (2) by \( h_i \), adding and taking ensemble average and using

\[
\frac{\partial}{\partial r_k} = -\frac{\partial}{\partial x_k} = \frac{\partial}{\partial x'_k},
\]

with the relations

\[
\langle u_i h'_i \rangle = \langle -u'_i h_i \rangle, \langle u'_i h'_i \rangle = \langle -u_i h'_i \rangle
\]

we get

\[
\frac{\partial}{\partial t} \langle h_i h'_j \rangle + 2[\frac{\partial}{\partial r_k} \langle u'_k h_i h'_j \rangle - \frac{\partial}{\partial r'_k} \langle u_k h_i h'_j \rangle] = 2\left( \frac{\nu}{p_M} \right) \frac{\partial^2}{\partial r_k \partial r'_k} \langle h_i h'_j \rangle,
\]

Interchanging the points \( p \) and \( p' \) with indices \( i \) and \( j \), then taking contraction of the indices \( i \) and \( j \), we get the spectral equation corresponding to two point correlation is

The spectral equation corresponding to the two point correlation equation taking contraction of the indices is

\[
\frac{\partial}{\partial t} \langle \phi, \phi'(-\hat{k}) \rangle + \frac{2\nu}{p_M} k^2 \langle \phi, \phi'(-\hat{k}) \rangle = 2ik_1[\{\alpha, \phi, \phi'(-\hat{k})\} - \{\alpha, \phi, \phi'(-\hat{k})\}]
\]

where,

\[
\langle h_i h'_j \rangle = \int_{-\infty}^{\infty} \langle \phi, \phi'(-\hat{k}) \rangle \exp[i(k.\hat{r})] \, d\hat{k}
\]

\[
\langle u_i h'_j \rangle = \int_{-\infty}^{\infty} \langle \alpha, \phi, \phi'(-\hat{k}) \rangle \exp[i(k.\hat{r})] \, d\hat{k}
\]

and \( \langle u'_i h'_j \rangle = \langle u_i h_i \rangle = \int_{-\infty}^{\infty} \langle \alpha, \phi, \phi'(-\hat{k}) \rangle \exp[i(k.\hat{r})] \, d\hat{k} \).

### III. Three-Point Correlation and Spectral Equations

We take momentum equation of MHD turbulence at the point \( p \), and the induction equations in the magnetic field at the and \( p'' \) as

\[
\frac{\partial u_i}{\partial t} + u_k \frac{\partial u_i}{\partial x_k} - h_k \frac{\partial u_i}{\partial x_k} = -\frac{\partial W}{\partial x_k} + \nu \frac{\partial^2 u_i}{\partial x_k \partial x_k},
\]

\[
\frac{\partial h'_i}{\partial t} + u'_k \frac{\partial h'_i}{\partial x'_k} - h'_k \frac{\partial u'_i}{\partial x'_k} = \left( \frac{\nu}{p_M} \right) \frac{\partial^2 h'_i}{\partial x'_k \partial x'_k},
\]
\[ \frac{\partial h''}{\partial t} + u'_k \frac{\partial h''}{\partial x'_k} - h'' \frac{\partial u''}{\partial x'_k} = \left( \frac{\nu}{\rho M} \right) \frac{\partial^2 h''}{\partial x'_k \partial x'_k}. \]  

(9)

We multiplying equation (7) by \( h' h'' \), (8) by \( u' h'' \), and (9) by \( u'_h h'' \), then adding and taking ensemble average and using

\[ \frac{\partial}{\partial x'_k} = \frac{\partial}{\partial x'_k}, \quad \frac{\partial}{\partial r'_{k'}} = \frac{\partial}{\partial r'_{k'}} = -\left( \frac{\partial}{\partial r_k} + \frac{\partial}{\partial r'_{k'}} \right) \]

and interchanging of points \( p' \) and \( p'' \), in the subscript \( i \) and \( j \), with the relations

\[ \langle u_i u'_i h'' h' \rangle = \langle u_i u'_i h' h'' \rangle \] and \( \langle u_i u'_i h h'' \rangle = \langle u_i u'_i h h'' \rangle \).

After simplifying the obtained results and then using Fourier transforms as

\[ \langle u_i h'_i (\hat{r}) h''_i (\hat{r}') \rangle = \int \int \langle \phi_i \beta'_i (\hat{k}) \beta''_i (\hat{k}') \rangle \exp[i(\hat{k}_r + \hat{k}'_r) \hat{k}'] \, dk d\hat{k}', \]  

(10)

\[ \langle u_i u'_i (\hat{r}) h''_i (\hat{r}') \rangle = \int \int \langle \phi_i \beta'_i (\hat{k}) \beta''_i (\hat{k}') \rangle \exp[i(\hat{k}_r + \hat{k}'_r) \hat{k}'] \, dk d\hat{k}', \]  

(11)

\[ \langle u_i u'_i (\hat{r}) h'_i (\hat{r}) h''_i (\hat{r}') \rangle = \int \int \langle \phi_i \beta_1 (\hat{k}) \beta'_i (\hat{k}') \rangle \exp[i(\hat{k}_r + \hat{k}'_r) \hat{k}'] \, dk d\hat{k}', \]  

(12)

\[ \langle u_i h'_i (\hat{r}) h''_i (\hat{r}') \rangle = \int \int \langle \phi_i \beta'_i (\hat{k}) \beta''_i (\hat{k}') \rangle \exp[i(\hat{k}_r + \hat{k}'_r) \hat{k}'] \, dk d\hat{k}', \]  

(13)

\[ \langle u_i h_i (\hat{r}) h'_i (\hat{r}) h''_i (\hat{r}') \rangle = \int \int \langle \phi_i \beta_i (\hat{k}) \beta'_i (\hat{k}') \rangle \exp[i(\hat{k}_r + \hat{k}'_r) \hat{k}'] \, dk d\hat{k}', \]  

(14)

\[ \langle w h'_i (\hat{r}) h''_i (\hat{r}') \rangle = \int \int \langle \beta'_i (\hat{k}) \beta''_i (\hat{k}') \rangle \exp[i(\hat{k}_r + \hat{k}'_r) \hat{k}'] \, dk d\hat{k}'. \]  

(15)

we get

\[ \frac{\partial}{\partial t} \left( \phi_1 \beta'_1 \beta''_1 \right) + \frac{\nu}{\rho M} \left[ (1 + p_M) (k^2 + k'^2) + 2 p_M k k' + R \right] \left( \phi_1 \beta'_1 \beta''_1 \right) = \]

\[ i(k_k + k'_k)(\phi_1 \beta'_1 \beta''_1) - i(k_k + k'_k)(\beta_i \beta_k \beta'_i \beta''_j) - i(k_k + k'_k)(\phi_1 \beta'_1 \beta''_j) \]

\[ + (k_k + k'_k)(\phi_1 \beta'_1 \beta''_j) + i(k_k + k'_k)(\gamma \beta'_1 \beta''_j) \]

Taking contraction of the indices \( i \) and \( j \), we get spectral equations corresponding to the three-point correlation equations

\[ \frac{\partial}{\partial t} \left( \phi_1 \beta'_1 \beta''_1 \right) + \frac{\nu}{\rho M} \left[ (1 + p_M) (k^2 + k'^2) + 2 p_M k k' + R \right] \left( \phi_1 \beta'_1 \beta''_1 \right) = \]

\[ i(k_k + k'_k)(\phi_1 \beta'_1 \beta''_1) - i(k_k + k'_k)(\beta_i \beta_k \beta'_i \beta''_j) - i(k_k + k'_k)(\phi_1 \beta'_1 \beta''_j) \]

\[ + (k_k + k'_k)(\phi_1 \beta'_1 \beta''_j) + i(k_k + k'_k)(\gamma \beta'_1 \beta''_j) \]  

(16)

\[ - (\gamma \beta'_1 \beta''_j) = \frac{(k_k k_k + k'_k k'_k + k_k k'_k + k'_k k'_k)}{(k_k^2 + k'_k^2 + 2k_k k'_k)} \left( \phi_1 \beta'_1 \beta''_1 - \beta_i \beta_k \beta'_i \beta''_j \right) \]  

(17)
To find the four point correlation equation, following Deissler’s [17] we take the momentum equation of dusty fluid MHD turbulence in a first order chemical reaction at the point \( p \) and the induction equation of magnetic field fluctuation at \( p''', p'''' \) as

\[
\frac{\partial u_i}{\partial t} + u_k \frac{\partial u_i}{\partial x_k} - h_k \frac{\partial h_i}{\partial x_k} = -\frac{\partial w}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_k \partial x_k} - Ru_i + f(u_i - v_i)
\]

\[
\frac{\partial h_i'}{\partial t} + u_k \frac{\partial h_i'}{\partial x_k} - h_k' \frac{\partial u_i'}{\partial x_k} = \frac{\nu}{p_M} \frac{\partial^2 h_i'}{\partial x_k \partial x_k}
\]

\[
\frac{\partial h_i''}{\partial t} + u_k \frac{\partial h_i''}{\partial x_k} - h_k'' \frac{\partial u_i''}{\partial x_k} = \frac{\nu}{p_M} \frac{\partial^2 h_i''}{\partial x_k \partial x_k}
\]

\[
\frac{\partial h_i'''}{\partial t} + u_k \frac{\partial h_i'''}{\partial x_k} - h_k''' \frac{\partial u_i'''}{\partial x_k} = \frac{\nu}{p_M} \frac{\partial^2 h_i'''}{\partial x_k \partial x_k}
\]

where \( w = \frac{P + \frac{1}{2} \langle h^2 \rangle}{\rho} \) is the total MHD pressure, \( p(\hat{x}, t) \) is the hydrodynamic pressure, \( \rho \) is the fluid density, \( v = \frac{\nu}{\lambda} \) is the Magnetic Prandtl number, \( \Omega \) is the angular velocity components, \( m = \frac{4}{3} \pi R^3 \rho \), is the mass of a single spherical dust particle of radius \( R \) and \( \rho \), constant density of the material in dust particles, \( R \) is the first order chemical reaction \( f = \frac{KN}{\rho} \), is the dimensions of frequency, \( K \) is the Stock’s drug resistance, \( N \) is the constant number density of dust particle. \( v \), is the kinematics viscosity, \( \lambda \) is the magnetic diffusivity, \( h_i(x, t) \) is the magnetic field fluctuation, \( u_i(x, t) \) is the turbulent velocity, \( v_i \), dust velocity component, \( t \) is the time, \( x_k \) is the space co-ordinate and repeated subscripts are summed from 1 to 3.

Multiplying equation (18) by \( h_i h_j'^2 \) (19) by \( u_i h_j''^2 \) (20) by \( u_i h_j'''^2 \) (21) by \( u_i h_j''''^2 \) and adding the four equations, we than taking the angular bracket \( \langle \cdots \rangle \) or \( \langle \cdots \cdots \rangle \), we get

\[
\frac{\partial}{\partial t} \langle u_i h_j'^2 h_j''^2 \rangle + \frac{\partial}{\partial x_k} \langle u_i u_k h_j'^2 h_j''^2 \rangle - \frac{\partial}{\partial x_k} \langle h_j h_j'^2 h_j''^2 \rangle + \\
\frac{\partial}{\partial x_k} \langle u_i u_k h_j' h_j'''^2 \rangle - \frac{\partial}{\partial x_k} \langle u_i u_k h_j' h_j''''^2 \rangle + \frac{\partial}{\partial x_k} \langle u_i u_k h_j' h_j''''^2 \rangle - \\
\frac{\partial}{\partial x_k} \langle u_i u_k h_j' h_j''''^2 \rangle + \frac{\partial}{\partial x_k} \langle u_i u_k h_j' h_j''''^2 \rangle - \frac{\partial}{\partial x_k} \langle u_i u_k h_j' h_j''''^2 \rangle - \\
- \frac{\partial}{\partial x_k} \langle w h_j'^2 h_j''^2 \rangle + \frac{\partial^2}{\partial x_k \partial x_k} \langle u_i h_j'^2 h_j''^2 \rangle + \frac{\nu}{p_M} \frac{\partial^2}{\partial x_k \partial x_k} \langle u_i h_j'^2 h_j''^2 \rangle + \\
\frac{\partial^2}{\partial x_k \partial x_k} \langle u_i h_j'^2 h_j''^2 \rangle + \frac{\partial^2}{\partial x_k \partial x_k} \langle u_i h_j'^2 h_j''^2 \rangle - Ru_i h_j'^2 h_j''^2 \rangle
\]

\[
+f\left[u_i h_j'^2 h_j''^2 - \langle u_i h_j'^2 h_j''^2 \rangle\right]
\]

\[
(22)
\]
Using the transformations,
\[
\frac{\partial}{\partial x_k} = \frac{\partial}{\partial r_i}, \quad \frac{\partial}{\partial x_k} = \frac{\partial}{\partial r_i}, \quad \frac{\partial}{\partial x_k} = \frac{\partial}{\partial r_i} + \frac{\partial}{\partial r_i} + \frac{\partial}{\partial r_i}
\]
and Fourier transforms
\[
\langle u, u' h_i(r) h_j(r') h_m^n(r) \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left( \phi_i \gamma_j(r) \gamma_m^n(r) \right) \exp\left( ik \cdot \hat{r} + \hat{k} \cdot \hat{r}' + \hat{k}^n \cdot \hat{r}'' \right) dkdk'dk'^*,
\]
\[\text{(23)}\]
\[
\langle u, u' h_i(r) h_j(r') h_m^n(r) \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left( \phi_i \gamma_j(r) \gamma_m^n(r) \right) \exp\left( ik \cdot \hat{r} + \hat{k} \cdot \hat{r}' + \hat{k}^n \cdot \hat{r}'' \right) dkdk'dk'^*,
\]
\[\text{(24)}\]
\[
\langle u, u' h_i(r) h_j(r') h_m^n(r) \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left( \phi_i \gamma_j(r) \gamma_m^n(r) \right) \exp\left( ik \cdot \hat{r} + \hat{k} \cdot \hat{r}' + \hat{k}^n \cdot \hat{r}'' \right) dkdk'dk'^*,
\]
\[\text{(25)}\]
\[
\langle u, u' h_i(r) h_j(r') h_m^n(r) \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left( \phi_i \gamma_j(r) \gamma_m^n(r) \right) \exp\left( ik \cdot \hat{r} + \hat{k} \cdot \hat{r}' + \hat{k}^n \cdot \hat{r}'' \right) dkdk'dk'^*,
\]
\[\text{(26)}\]
\[
\langle u, u' h_i(r) h_j(r') h_m^n(r) \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left( \phi_i \gamma_j(r) \gamma_m^n(r) \right) \exp\left( ik \cdot \hat{r} + \hat{k} \cdot \hat{r}' + \hat{k}^n \cdot \hat{r}'' \right) dkdk'dk'^*,
\]
\[\text{(27)}\]
\[
\langle u, u' h_i(r) h_j(r') h_m^n(r) \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left( \phi_i \gamma_j(r) \gamma_m^n(r) \right) \exp\left( ik \cdot \hat{r} + \hat{k} \cdot \hat{r}' + \hat{k}^n \cdot \hat{r}'' \right) dkdk'dk'^*,
\]
\[\text{(28)}\]
\[
\langle w, h_i(r) h_j(r') h_m^n(r) \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left( \gamma_i(r) \gamma_j(r') \gamma_m^n(r) \right) \exp\left( ik \cdot \hat{r} + \hat{k} \cdot \hat{r}' + \hat{k}^n \cdot \hat{r}'' \right) dkdk'dk'^*,
\]
\[\text{(29)}\]
\[
\langle v, h_i(r) h_j(r') h_m^n(r) \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left( \Omega_i(r) \gamma_j(r') \gamma_m^n(r) \right) \exp\left( ik \cdot \hat{r} + \hat{k} \cdot \hat{r}' + \hat{k}^n \cdot \hat{r}'' \right) dkdk'dk'^*,
\]
\[\text{(30)}\]
\[
\langle u, u' h_i h_j h_m^n \rangle = \langle u, u' h_i h_j h_m^n \rangle,
\]
\[\text{(31)}\]
with the fact
\[
\langle u, u' h_i h_j h_m^n \rangle = \langle u, u' h_i h_j h_m^n \rangle,
\]
\[\text{(32)}\]
\[
\langle u, u' h_i h_j h_m^n \rangle = \langle u, u' h_i h_j h_m^n \rangle,
\]
\[\text{(33)}\]
\[
\langle u, u' h_i h_j h_m^n \rangle = \langle u, u' h_i h_j h_m^n \rangle,
\]
\[\text{(34)}\]
\[
\langle u, u' h_i h_j h_m^n \rangle = \langle u, u' h_i h_j h_m^n \rangle,
\]
\[\text{(35)}\]
and by taking contraction of the indices \(i\) and \(j\), \(i\) and \(m\), we obtained four-point correlation equation as
\[
\frac{\partial}{\partial t} \left( \phi_i \gamma_j(r) \gamma_m^n \right) + \frac{V}{P_M} \left[(1 + P_M) (k^2 + k'^2 + k^n^2) + 2 P_M k k' \right]
\]
\[\text{(36)}\]
\[
+ 2 P_M k k'' + 2 P_M k k'' \right) \left( \phi_i \gamma_j(r) \gamma_m^n \right) + (R - f) \left( \phi_i \gamma_j(r) \gamma_m^n \right)
\]
\[\text{(37)}\]
\[
+ f \left( \Omega_i(r) \gamma_j(r') \gamma_m^n \right) = i(k_k + k_k' + k_k^*) \left( \phi_i \gamma_j(r) \gamma_m^n \right)
\]
\[\text{(38)}\]
\[
- i(k_k + k_k' + k_k^*) \left( \gamma_i(r) \gamma_j(r') \gamma_m^n \right) - i(k_k + k_k' + k_k^*) \left( \Omega_i(r) \gamma_j(r') \gamma_m^n \right)
\]
If we take the derivative with respect to $x_i$ of equation (18) and multiplying by $q_{n}q_{m}$, using time averages and writing the equation in terms of the independent variables $\hat{r}, \hat{r}', \hat{r}''$, we have

$$-(\frac{\partial \gamma_{r,n}}{\partial \gamma_{r,m}}) =$$

$$\frac{(k_jk_k + k_i'k_i + k_ik_i' + k_ik_i'' + k_i''k_i' + k_i''k_i + k_i'k_i' + k_ik_i' + k_i'k_i'' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + k_i''k_i' + k_i'k_i' + k_i''k_i'' + g\)}

Equation (32) and (33) are the spectral equation corresponding to the four-point correlation equation.

A relation between $\phi(\hat{r}^0, \hat{r}')$ and $\phi(\hat{r}'', \hat{r}'')$ can be obtained by letting $\hat{r}''=0$ in equation (23) and comparing the result with equation (11), we get

$$\langle \phi(\hat{r}, \hat{r}') \rangle(\hat{k}) = \int_0^{(\hat{r}, \hat{r}')}(\hat{k})d\hat{r}'$$

The relation between $\alpha_i \phi(\hat{k})$ and $\beta_i \phi(\hat{k})$ is obtained by letting $\hat{r}''=0$ in equation (17) and comparing the result with equation (5), then

$$\langle \alpha_i \phi(\hat{k}) \rangle(\hat{k}) = \int_0^{\hat{k}}(\hat{r}, \hat{r}')d\hat{r}'$$

V. Solution Neglecting Quintuple Correlations

Using $\int(\eta_{r,n}r_{m})=L(\eta_{r}r_{m})$, 1-L=s, and neglecting all the terms on the right side of equation (32), then integrating between $t_1$ and $t$, we get

$$\langle \phi(\hat{r}, \hat{r}'') \rangle(\hat{k}) =$$

$$\langle \phi(\hat{r}, \hat{r}') \rangle(\hat{k})_1 \exp\left(-\frac{V}{P_M}(k^2 + k'^2 + k''^2 + 2kk' + 2kk'' + 2kk') - R + ft\right)$$

For small values of $k, k'$ and $k''$, $\langle \phi(\hat{r}, \hat{r}') \rangle(\hat{k})_1$ is the value of $\langle \phi(\hat{r}, \hat{r}') \rangle(\hat{k})$ at $t=t_1$. Substituting of equations (17), (33),(34) (35),(36) in equation (16) and integrating with respect to $k^n, k^m, k^r$ and farther integrating with respect to time, and in order to simplify calculations, we will assume that $[\alpha]_1=0$ and the integration is performed, then substituting the obtained equation in equation (4) and setting $H=2\pi k^2 \phi(\hat{k})$, we obtain

$$\frac{\partial H}{\partial t} + \left(\frac{2\pi k^2}{P_M}\right)H = G$$

where,

$$G = k^2 \int_{-\infty}^{\infty} 2\pi \hat{a}\left[k_i \phi(\hat{r}, \hat{r}')(\hat{k}, \hat{k}') - \frac{\partial \gamma_{r,n}}{\partial \gamma_{r,m}}(R + ft)\right]_0 \cdot \exp\left(-\frac{R}{s}\right)\left(t - t_0\right)$$
\[
\exp\left[-\frac{V}{P_M} (t - t_0)\left\{ (1 + P_M)(k^2 + k'^2) + 2P_M kk' \right\}\right]dk' \\
+ k^2 \int_{-\infty}^{\infty} \frac{2P_M \pi^\frac{5}{2}}{\nu} i\left[b(\hat{k} \hat{k'}) - b(-\hat{k}, -\hat{k'})\right] \exp\{- R(t - t_1)\} \\
+ \omega^{-1} \exp[-\omega^2\left\{ (1 + 2P_M)\frac{k^2}{1 + P_M} \right\} + \frac{2P_M kk'}{1 + P_M}(k'^2 + k^2)] \\
+ k \exp\left[ - \omega^2 \left( (1 + P_M)(k^2 + k'^2) + 2P_M kk' \right) \right] \int_0^\infty \exp(x^2)dx \exp(\xi_0) (k^2 - k'^2) \right\} \right] \\
- \omega^{-1} \exp[-\omega^2\left\{ (1 + 2P_M)\frac{k^2}{1 + P_M} \right\} + \frac{2P_M kk'}{1 + P_M}(k'^2 + k^2)] \\
+ k' \exp\left[ - \omega^2 \left( (1 + P_M)(k^2 + k'^2) + 2P_M kk' \right) \right] \int_0^\infty \exp(x^2)dx \exp(\xi_0) (k^2 - k'^2) \right\} \right] (38)
\]

where \( G \) is the energy transfer function and \( H \) is the magnetic energy spectrum function. In order to make further calculations, an assumption must be made for the forms of the bracketed quantities with the subscripts 0 and 1 in equation (38) which depends on the initial conditions.

\[
(2\pi)^2 \left\{ \left\langle k_0^2 \phi_k \beta'_k(\hat{k}, \hat{k'}) \right\rangle - \left\langle k_0^2 \phi_k \beta'_k(-\hat{k}, -\hat{k'}) \right\rangle \right\} = -\xi_0 (k^2 - k'^2) \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} (39)
\]

where \( \xi_0 \) is a constant depending on the initial conditions for the other bracketed quantities in equation (38), we get

\[
\frac{4P_M \pi^\frac{5}{2}}{\nu} \left[ b(\hat{k} \hat{k'}) - b(-\hat{k}, -\hat{k'})\right] = \frac{4P_M \pi^\frac{5}{2}}{\nu} \left[ c(\hat{k} \hat{k'}) - c(-\hat{k}, -\hat{k'})\right] = -2\xi_0 (k^4 - k'^4) \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} (40)
\]

Remembering, \( dk' = 2\pi k'^2 d(\cos \theta)dk' \) and \( kk' = kk' \cos \theta, \theta \) is the angle between \( \hat{k} \) and \( \hat{k}' \) and carrying out the integration with respect to \( \theta \), we get

\[
G = \frac{4P_M \pi^\frac{5}{2}}{\nu} \left[ b(\hat{k} \hat{k'}) - b(-\hat{k}, -\hat{k'})\right] = \frac{4P_M \pi^\frac{5}{2}}{\nu} \left[ c(\hat{k} \hat{k'}) - c(-\hat{k}, -\hat{k'})\right] = -2\xi_0 (k^4 - k'^4) \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} \right\} (40)
\]
+ \omega^{-1} \exp[-\omega^2 \left( k^2 - \frac{2p_M k k'}{(1+p_M)} + \left(1+2p_M\right) k'^2 \right)]

- \omega^{-1} \exp[-\omega^2 \left( k^2 + \frac{2p_M k k'}{(1+p_M)} + \left(1+2p_M\right) k'^2 \right)]

- \omega^{-1} \exp[-\omega^2 \left( k^2 + 2p_M k k' \right)]

+ \left\{ k \exp[-\omega^2 ((1+p_M)(k^2 + k'^2) - 2p_M k k')] \right\}^{\omega k/2} \exp(x^2) dx

+ \left\{ k' \exp[-\omega^2 ((1+p_M)(k^2 + k'^2) - 2p_M k k')] \right\}^{\omega k'/2} \exp(x^2) dx \right\}^{\omega k'/2} \exp(x^2) dx \right\} \right] \right\}^{\omega k'/2} \exp(x^2) dx \right\}

(41)

Here, \omega = \left( \frac{\nu(t-t_1)(1+p_M)}{p_M} \right)^{1/2}.

Integrating equation (41) with respect to k', we have

G = G_\beta + G_\gamma \exp\left\{ - (R - f_s) (t-t_1) \right\}

(42)

where,

G_\beta = - \frac{1}{\nu^2 (t-t_0)^2 (1+p_M)^2} \exp\left\{ - \frac{\nu(t-t_0)(1+2p_M) k^2}{p_M (1+p_M)} \right\}

\left[ \frac{15p_M k^4}{4\nu^2 (t-t_0)^2 (1+p_M)} + \left\{ \frac{5p_M^2}{(1+p_M)^2 \nu (t-t_0)} - \frac{3}{2\nu (t-t_0)} \right\} k^6 + \frac{p_M}{1+p_M} \left\{ \frac{p_M^2}{(1+p_M)^2} - 1 \right\} k^8 \right]

and

G_\gamma = G_{\gamma_1} + G_{\gamma_2} + G_{\gamma_3} + G_{\gamma_4}

G_{\gamma_1} = \frac{\xi_1 \sqrt{\pi} p_M^5}{8\nu^2 (t-t_0)^2 (1+p_M)} \exp\left\{ - \frac{\nu(t-t_0)(1+2p_M - p_M^2)}{p_M (1+p_M)} \right\} k^2

\left[ \frac{90p_M k^6}{\nu^4 (t-t_1)^4 (1+p_M)} + \left\{ \frac{4p_M}{\nu^2 (t-t_1)^2 (1+p_M)} + \frac{2p_M^2}{\nu^2 (t-t_1)^2 (1+p_M)^2} - \frac{1}{\nu^2 (t-t_1)^3} \right\} k^4 \right.

\left. + \left\{ \frac{64p_M^2}{\nu(t-t_1)(1+p_M)} + \frac{10p_M^3}{\nu^2 (t-t_1)^2 (1+p_M)^2} - \frac{40}{\nu(t-t_1)} \right\} k^{10} \right)

+ \left\{ \frac{p_M}{1+p_M} - \frac{p_M}{1+p_M} \right\} \right\} k^{12}
\[ G_{r_2} = \frac{\xi \sqrt{\pi p^5} (1 + p_M)^4}{8\nu^2 (t-t_i)^2 (1 + 2p_M)^9/2} \exp\left(-\nu(t-t_i)(1 + p_M)(1 + 2p_M - 2p^2_M)\right)k^2 \]

\[ \left\{ \frac{90p_M (1 + p_M)k^6}{\nu^2 (t-t_i)^2 (1 + 2p_M)^2} + \frac{120p_M (1 + p_M)}{\nu^2 (t-t_i)^2 (1 + 2p_M)^2} + \frac{2p^2_M (1 + p_M)^2}{\nu^2 (t-t_i)^2 (1 + 2p_M)^2} - \frac{1}{\nu^2 (t-t_i)^2} \right\}k^8 \]

\[ + \left\{ \frac{64p^2_M (1 + p_M)^2}{\nu^2 (t-t_i)^2 (1 + 2p_M)^2} - \frac{40}{\nu^2 (t-t_i)^2 (1 + 2p_M)^2} + \frac{10p^3_M (1 + p_M)^3}{\nu^2 (t-t_i)^2 (1 + 2p_M)^2} \right\}k^{10} \]

\[ + \left\{ \frac{8p^3_M (1 + p_M)}{1 + 2p_M} \left( \frac{p_M (1 + p_M)}{1 + 2p_M} \right) \right\}k^{12} \]

\[ G_{r_3} = \frac{\xi \sqrt{\pi p^5} p^{15/2} M^{3/2}}{8\nu^2 (t-t_i)^2 (1 + p_M)^8} \exp\left(-\nu(t-t_i)(1 + p_M)(1 + 2p_M - 2p^2_M)\right)k^2 \]

\[ \left\{ \frac{90p_M k^7}{\nu^2 (t-t_i)^2 (1 + p_M)^2} + \frac{120p_M}{\nu^2 (t-t_i)^2 (1 + p_M)^2} + \frac{60p^2_M}{\nu^2 (t-t_i)^2 (1 + p_M)^2} - \frac{30}{\nu^2 (t-t_i)^2} \right\}k^9 \]

\[ + \left\{ \frac{64p^2_M}{\nu^2 (t-t_i)^2 (1 + p_M)^2} + \frac{10p^3_M}{\nu^2 (t-t_i)^2 (1 + p_M)^2} - \frac{40(1 + p_M)^2}{\nu^2 (t-t_i)^2 (1 + p_M)^2} \right\}k^{11} + \left\{ p^2_M - p_M (1 + p_M)^2 \right\}k^{13} \]

\[ \int_0^\infty G \, dk = 0 \quad (43) \]

In equation (42), the quantity \( G_{r_\beta} \) represents the transfer function arising due to consideration of magnetic field at 3 and \( G_{r} \) for four-point correlation equation in a chemical reaction. Integration of equation (42) over all wave numbers shows that

Since \( G \) is a measure of transfer of energy and the numbers must be zero it satisfies the conditions of continuity and homogeneity, from (37),

\[ H = \exp\left[-\frac{2\nu k^2 (t-t_0)}{p_M}\right] \int G \exp\left[-\frac{2\nu k^2 (t-t_0)}{p_M}\right] dt + J(k) \exp\left[-\frac{2\nu k^2 (t-t_0)}{p_M}\right], \]
where, $J(k) = \frac{N_0 k^2}{\pi}$ is a constant of integration and can be obtained as by Corrsin [5]. Therefore we obtain,

$$H = \frac{N_0 k^2}{\pi} \exp\left[\frac{-2v k^2(t-t_0)}{p_m}\right] + \exp\left[\frac{-2v k^2(t-t_0)}{p_m}\right]\left[G_\beta + (G_{n_1} + G_{n_2} + G_{n_3} + G_{n_4})\right]$$

$$\exp\left[-(R - fs)(t-t_1)\right] \exp\left[\frac{-2v k^2(t-t_0)}{p_m}\right]dt$$

(44)

From equation (42), we get

$$H = H_1 + H_2 \exp\left[-(R - fs)(t-t_1)\right]$$

(45)

In equation (45) $H_1$ and $H_2$ magnetic energy spectrum arising from consideration of the three and four-point correlation equations in a first order chemical reaction respectively. Equation (45) can be integrated over all wave numbers to give the total magnetic turbulent energy.

$$\langle h^2 \rangle = \frac{N_0 P_M^3 \chi^3 (t-t_0)^{3/2}}{8\sqrt{2\pi}} + \xi_0 \chi^2 (t-t_0)^{-5/2} \exp[-R(t-t_0)]$$

$$+ \left[\xi_1 \chi^2 (t-t_1)^{17/2} + \xi_2 \chi^2 (t-t_1)^{19/2}\right] \exp[-(R - fs)(t-t_1)]$$

(46)

This represents the equation of the decay of dusty fluid MHD turbulence in a first order chemical reaction for four point correlation.

$$Q = \frac{\pi p^6 M}{(1 + P_m)(1 + 2 P_m)^{3/2}}$$

$$\left\{ \frac{9}{16} \frac{5P_m(7P_m - 6)}{(1 + 2P_m)} - \frac{35P_m(3p^2 - 2p^2) + 8p^2(3p^2 - 2p^2) + 3}{8(1 + 2p^2)^2} + \ldots \right\}$$

here,

$$L_1 = Q_2 + Q_4 + Q_6 + Q_7, L_2 = Q_1 + Q_3 + Q_5$$ and $Q^s$ values

$$Q_1 = -\frac{\pi P^6 M}{(1 + P_m)^{5/2}(1 + 2P_m - p^2_p)^{7/2}}$$

$$\left[ \frac{15.9}{2^6} + \frac{15.7(15 - 6p^2_m + 21p^2) + 15.7(15 - 6p^2_m + 36p^2_m - 6p^3_m + 61p^4_m)}{2^{10}(1 + 2P_m - p^2_p)^2} \right]$$

$$+ \frac{11.9.7(1 + p^2_m)(15 - 30p^2_m + 180p^2_m - 30p^3_m + 305p^4_m)}{2^{11}(1 + 2P_m - p^2_p)^2} + \ldots$$

$$Q_2 = -\frac{\pi P^{21/2} M}{(1 + P_m)^{3/2}(1 + 2P_m - p^2_p)^{9/2}}$$

\[
Q_3 = -\frac{\pi p^{19/2} (1 + p_M)^{1/2}}{(1 + 2p_M)^2 (1 + 2p_M - p^M)} \left[ \frac{15.7}{2^8} + \frac{15.9.7(14p^2_M - 18 - 40p_M)}{2^9(1 + 2p_M - p^2_M)} + \frac{15.11.9.7(14p^4_M - 56p^3_M - 12p^2_M - 40p_M - 18)}{2^{10}(1 + 2p_M - p^3_M)^2} \right] \ldots
\]

\[
Q_4 = -\frac{\pi p^{21/2} (1 + p_M)^{1/2}}{(1 + p_M)^{1/2} (1 + 2p_M)(1 + 2p_M - p^2_M)^{9/2}} \left[ \frac{25.7.3}{2^5} + \frac{15.9.7(-40p_M - 48p^2_M + 64p^3_M + 52p^4_M)}{2^9(1 + p^2_M)^2(1 + 2p_M - p^3_M)} + \frac{15.11.9.7(-40p_M - 89p^2_M + 51p^3_M + 124p^4_M + 40p^5_M + 36p^6_M + 60p^7_M)}{2^{10}(1 + p^3_M)(1 + 2p_M - p^7_M)^2} \right] \ldots
\]

\[
Q_5 = -\frac{\pi p^{19/2} (1 + p_M)^{19/2} (1 + 2p_M)^{9/2}}{1 + p_M)^{19/2} (1 + 2p_M)^{9/2}} \left\{ \frac{45.7.5.3}{2^{10}} + \frac{9.7.5.3(20p^2_M - 70p_M - 5)}{2^{10}(1 + 2p_M)} + \frac{11.9.7.5.3(20p^4_M - 40p^3_M + 160p^2_M - 60p_M - 5)}{2^{11}(1 + 2p_M)^2} \right\} \ldots
\]

\[
Q_6 = -\frac{\pi p^{21/2} (1 + p_M)^{11/2}}{(1 + p_M)^{15/2} (1 + 2p_M)^{11/2}} \left\{ \frac{15.9.7.5.3}{2^5} + \frac{11.9.7.5.3(24p^2_M - 200p_M + 20)}{2^{11}(1 + 2p_M)} \right\} \ldots
\]

\[
Q_7 = -\frac{\pi p^9 (1 + p_M)^{23/2}}{(1 + p_M)^{23/2} (1 + 2p_M)^{7/2}} \left\{ \frac{9.7.5.3}{2^{11}} - 7.5.3(4231710 + 16938180p_M + 25381440p^2_M + 1689480p^3_M + 4213440p^4_M)}{2^{13}(1 + 2p_M)} \right\} \ldots
\]

Equation (46) can be written as

\[
\frac{\langle h^2 \rangle}{2} = \left( AT_0^{1/2} + BT_0^{5/2} \right) \exp(-RT_0) + \left( CT^{1/2} + DT^{1/2} \right) \exp\left(\frac{1}{2}(R + M)T\right). \quad (47)
\]
Where, \( T_0 = (t - t_0) \) and \( T = (t - t_0) \).

This is the equation of 4-point correlations of dusty fluid MHD turbulence in a first order chemical reaction.

**VI. RESULTS AND DISCUSSION**

The first term of right hand side of equation (47) corresponds to the energy of magnetic field fluctuation of two-point correlation; the second term represents magnetic energy for the three-point correlation; the third and fourth term represents magnetic energy for four-point correlation. For large times, the second term in the equation becomes negligible, leaving the \(-3/2\) power decay law for the ending phase.

If Chemical reaction and dust particles are absent then equation (47) is of the form

\[
\frac{\langle h^2 \rangle}{2} = AT_0^{-3} + BT_0^{-5} + CT_0^{-15} + DT_0^{-17}. \tag{48}
\]

this is the energy decay of MHD turbulence for four-point correlation. If \( \xi_1 = 0 \) then the equation (47) becomes

\[
\frac{\langle h^2 \rangle}{2} = (AT_0^{-3} + BT_0^{-5})\exp(-RT_0) \tag{49}
\]

This was obtained earlier by Islam and Sarker [18] for 3-point correlation.

This study shows that the terms associated with the higher-order correlation’s die out faster than those associated with the lower order ones. Here three and four-point correlations between fluctuating quantities have been considered and the quintuple correlations are neglected in comparison to the third and fourth order correlations. If the quadruple and quintuple correlations were not neglected, equation (46) contains more terms in negative higher power of \((t - t_0)\) and \((t - t_0)\) would be added to equation (47). In the Figures \( h_1, h_2, h_3, h_4 \) and \( h_5 \) represents the energy decay curves in a first order chemical reaction of equation (47) at \( t_0 = t = 0.5, 1, 1.5, 2, \) and 2.5 respectively.

**Figure 1:** Decomposing curves for \( M = 0.5, R = 0.50 \).

**Figure 2:** Energy decay curves of equation (47) if \( M = 0.5, R = 2 \).
Figure 3: Decomposing curves of equation
\[ M=0.5, \ R=1 \]

Figure 4: Energy decay curves of equation.
\[ (47) \text{ if } M=0.5, \ R=0.5 \]

Figure 5: Decomposing curves of equation
\[ (48) \text{ if } M=0.5, \ R=0 \]

Figure 6: Energy decay curves of equation
\[ (47) \text{ if } M=3, \ R=0.5 \]

Figure 7: Energy decay curves of equation
\[ (47) \text{ if } M=2, \ R=0.5 \]

Figure 8: Decay curves of equation
\[ (47) \text{ if } M=1, \ R=0.5 \]
In the Figures $h1$, $h2$, $h3$, $h4$ and $h5$ represents the energy decay curves in a first order chemical reaction of equation (47) at $t_0=t_1=0.5$, 1, 1.5, 2, and 2.5 respectively. From the Figures (1-5) we observed that if $M=0.5$ energy decay increases for the decreases of the values $R$ and maximum if the chemical reaction is absent. If $M=3, 2, 1, 0$ then the decay of energy decreases slowly at the point where $R=0.5$ that are indicated in the Figures (6-9). From Figure: 10 we see that energy decay very rapidly in the clean fluid.

VII. Conclusion

We conclude that if the concentration selected in the chemical reactant of dusty fluid MHD turbulent flow of the first order at four point correlations, then the result is that the decaying of the concentration fluctuation is much more slow and the slower rate of decay is governed by $\exp[-(R-M)T]$. In the case of clean combination, the decay of concentration fluctuation is much more rapid and the faster rate of decay is due to absent of chemical reaction and dust particles.

References Références Referencias

7. M.S.Alam Sarker, M.A.Bkar PK and M.A.K.Azad. Homogeneous dusty fluid turbulence in a first order reactant for the case of multi point and multi time...


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