

# Peristaltic Transport of a Nanofluid in Circular Tube

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**ABSTRACT:** In this work, we investigated the peristaltic flow of a Jeffery nanofluid in a circular tube. The governing equations of the model involves partial differential equation solved using Homotopy Perturbation Method. The flow pattern is discussed for axial velocity and pressure rise per wave length for various governing non-dimensional parameters that are involved in the nanofluid model. The results obtained in our model are compared with the earlier work as a particular case and found to be in good agreement.

**KEYWORDS:** Nanofluid, Homotopy Perturbation Method, Peristaltic flow.

## I. INTRODUCTION

Peristaltic transport is a form of fluid transport induced by a progressive wave of contraction and expansion along the length of a distensible tube containing fluid. The mechanism of peristaltic transport has been exploited for industrial applications like sanitary fluid transport, blood pumps in heart-lung machine and transport of corrosive fluids where the contact of fluid with the machinery parts is prohibited. The problem of the mechanism of peristaltic transport has attracted the attention of many investigators since the first investigation of Latham [1]. Following this experimental work, Burns and Parkes [2] studied the peristaltic motion of a viscous fluid through a pipe and channel by considering sinusoidal variations at the walls. Shapiro et al [3] analyzed the peristaltic transport with long wavelength and low Reynolds number assumption. Srivastava and Srivastava [4] presented a review of the literature on peristalsis up to 1983 by arranging according to the geometry, the fluid model, the Reynolds number, the amplitude ratio and the wave shape. The significant contributions to the subject between the years 1984 and 1994 were well referenced by Srivastava and Saxena [5].

In the last decades, the study of nanofluid is an important area which has attracted the attention of many investigators. Nanofluids has many applications of heat transfer, computing technology, high power X-rays medicine and material synthesis and lasers optical devices. Miniature devices have many severe problems. These devices require high cooling. Large devices such as transportation trucks with their new energy technology such as fuel cells also require more efficient cooling systems with greater cooling capacities. Therefore, high cooling performance is the need of the hour. The conventional heat transfer fluids such as water, oil and ethylene glycol mixture that are used for cooling purpose have poor thermal conductivity. The low thermal conductivity of such fluids is the main drawback in the development of energy efficient heat transfer fluids which are used in several industrial applications. To improve the heat transfer efficiency, various techniques have been developed. Maxwell [6] was successful in obtaining enhancement of thermophysical properties of base fluids by suspension of solid particles. The term 'nanofluid' was first coined by Choi [7]. Observed enhanced thermal conductivity of the base fluid. Nanofluids are engineered colloidal suspensions of nanoparticles in a base fluid. Nanoparticles used in nanofluids - metals (Al, Cu), oxides (Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub> and CuO), carbides (SiC), nitrides (AlN, SiN) or nonmetals (Graphite, carbon nanotubes). Small concentration nanofluid and Newtonian behavior of the base fluid enhances the thermal conductivity. The rise in viscosity was nominal, so pressure drop was increased only marginally.

In the cancer treatment, magnetic nanoparticles are injected into the blood vessel nearest to the cancer's tissues. The dynamic of these nanoparticles occurs under the action of the peristaltic waves generated on the flexible walls of the blood vessel. Studying such nanofluid flow under this action is, therefore, useful in treating tissues of the cancer.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 13, July 2017

Mekheimer and Abdelmaboud [8] found that the  $42 \square -45^\circ$  C. On the other hand, in this application the drug may be placed on the magnetic nanoparticles and is injected near the tumor. Then, the drug is absorbed by the tumor through a high gradient magnetic field, which is concentrated near the tumor center [9]. Therefore, the interaction of nanoparticles in peristaltic flows has now been receiving attentions of many researchers. Akram et al. [10] investigated the influence of peristaltic transport on Jeffrey nanofluid in an asymmetric channel. Also, Ebid and Aly [11] studied the peristaltic nanofluids flow in a channel with flexible walls and slip condition. This study was considered as an application to the cancer treatment. Furthermore, many investigators studied the interaction between nanoparticles and mild stenosis. Ellahi et al. [12] investigated the blood flow of nanofluid with stenosis and permeable walls. Also, the problem of blood flow in the nano-Prandtl fluid of tapered stenosed artery has been discussed by Nadeem et al. [13]. The interaction of nanoparticles in peristaltic flows has now been receiving attentions of many researchers. Sheu L.J, et al [14] investigated linear stability of convection in a viscoelastic nanofluid layer. To our knowledge much work has not been considered to study the nanofluid in Biomechanics. Therefore, here we are making an attempt to study the characteristic of fluid flow for a peristaltic transport of a Jeffrey nanofluid flow in a circular tube.

## II. MATHEMATICAL FORMULATION

In this model, we consider a two-dimensional, axis symmetric, unsteady Jeffrey nanofluid through a vertical circular tube. The outer tube is trapped and has a sinusoidal wave travelling down its wall. The cylindrical coordinates  $(r, \theta, z)$  is consider for the model, in which, the  $z$ -axis is considered along the vertical circular tube. All the physical quantities are not varying with respect to  $\theta$ -direction. The acceleration due to gravity  $g$  is taken along the  $z$ -axis as shown in the below Fig.1. The governing equations for the physical model are given below.

The prototype of Jeffrey fluid is taken in the form of

$$S = \frac{\mu}{1 + \lambda_1} (A + \lambda_2 A) \tag{1}$$

where  $S$  is the stress deviator,  $\mu$  is dynamic viscosity,  $\lambda_1$  is the ratio of the relaxation time to retardation one,  $\lambda_2$  is the retardation time,  $A = (\varphi + \varphi^T)$  is the rate of strain tensor,  $\varphi = \nabla V$ . The velocity field of the fluid flow is taken in the form of  $V = (u, 0, w)$ . Since the base fluid is Newtonian and incompressible, the continuity equation for the flow will take the form

$$\nabla \cdot V = 0$$

The Navier-Stokes equation for the momentum equation is

$$\rho \left( \frac{\partial V}{\partial t} + V(\nabla \cdot V) \right) = -\nabla p + \nabla \cdot S + \rho \bar{g} \tag{2}$$

where  $p$  is the pressure.

The density for the nanofluid as discussed in [11].

$$\rho = C\rho_p + (1 - C)\rho_f (1 - B_f(T - T_0)) \tag{3}$$

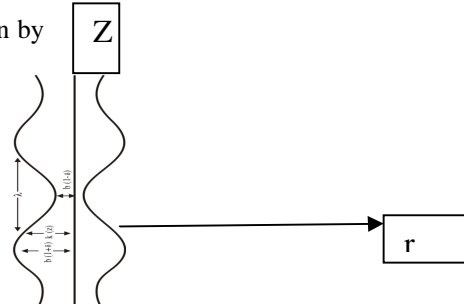
where  $C$  is the nanoparticle volume fraction of the nanofluid,  $\rho_p$  is the density of the nanoparticles,  $\rho_f$  is the density of the fluid.  $B_f$  is the volumetric expansion coefficient of the nanofluid and  $T$  is the temperature.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 13, July 2017

By following [10], the equation of energy is given by



**Fig1:Physical configuration of the problem**

By following [10], the equation of energy is given by

$$(\rho C_f) \left( \frac{\partial T}{\partial t} + V \cdot \nabla T \right) = K \nabla^2 T + (\rho C_p) \left( D_B \nabla C \cdot \nabla T + \frac{D_T}{T_0} \nabla T \cdot \nabla T \right) \quad (4)$$

where T is the temperature, K is thermal conductivity,  $c_f$  is the specific heat of the base fluid,  $C_p$  is specific heat of nanofluid particle,  $D_B$  is the Brownian diffusion coefficient and  $D_T$  is the thermal diffusion coefficient.

The equation of nano particle volume fraction in the nanofluid [14] is given by

$$\frac{\partial C}{\partial t} + V \cdot \nabla C = D_B \nabla^2 C + \frac{D_T}{T_0} \nabla^2 T \quad (5)$$

The appropriate boundary conditions to the flow are

$$u = \frac{\partial k}{\partial t}, w = -c, \text{ at } r = k \quad (5a) \quad \left( \frac{\partial w}{\partial r} \right) = 0 \quad \text{at } r = 0$$

$$\left( \frac{\partial \theta}{\partial r} \right) = 0 \quad \left( \frac{\partial \sigma}{\partial r} \right) = 0 \quad \text{at } r = 0$$

$$\theta = 0 \quad \sigma = 0 \quad \text{at } r = k$$

The geometry of the peristaltic wave is considered to be in the form

$$k = b \left[ 1 + \delta \cos \frac{2\pi}{\lambda} (z - ct) \right] \quad (5b)$$

here b is the radius of the undisturbed tube,  $\delta$  is the amplitude of the wave,  $\lambda$  is the wave length, c is the velocity of wave.

We will use the moving co-ordinate system (r,z) travelling with the wave as

$$r = R, \quad Z = z - ct \quad (6)$$

The Non-dimensional parameters are

$$\bar{r} = \frac{r}{a}, \quad \bar{z} = \frac{z}{a}, \quad \bar{u} = \frac{u}{a}, \quad \bar{w} = \frac{w}{a}, \quad \bar{t} = \frac{t}{a}, \quad p = \frac{\mu c p}{a}, \quad T = T_0 + (T_1 - T_0)\theta, \quad C = C_0 + (C_1 - C_0)\sigma \quad (6a)$$

$$G_r = \frac{g \alpha a}{\rho \gamma c} (T_0 - T_1) \text{ Grashof number}; \quad B_r = \frac{g \alpha a^2}{\rho \gamma c} (C_0 - C_1) \text{ Local nanoparticle grashof number};$$

$$N_b = \frac{D_B \tau}{\alpha} (C_0 - C_1) \text{ Brownian motion parameter}; \quad Nt = \frac{D_T \tau}{T_0 \alpha} (T_0 - T_1) \text{ Thermophoresis parameter.}$$

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 13, July 2017

Introducing the non dimensional variables (6a) into (5) and (5a) under the assumption of long wave length and low Reynold's approximation the governing equations reduces to ( after removing bars)

$$\frac{1}{r} \frac{\partial(rw)}{\partial r} + \frac{\partial u}{\partial z} = 0 \tag{7}$$

$$-\frac{\partial p}{\partial r} = 0 \tag{8}$$

$$\frac{\partial p}{\partial z} = \frac{\mu}{1 + \lambda_1} \left[ \frac{1}{r} \frac{\partial w}{\partial r} + \frac{\partial^2 w}{\partial r^2} \right] + G_r \theta + B_r \sigma \tag{9}$$

$$\frac{\partial^2 \theta}{\partial r^2} + \frac{1}{r} \frac{\partial \theta}{\partial r} + N_b \left( \frac{\partial \theta}{\partial r} \right) \left( \frac{\partial \sigma}{\partial r} \right) + N_t \left( \frac{\partial \theta}{\partial r} \right)^2 = 0 \tag{10}$$

$$N_b \frac{\partial}{\partial r} \left( r \frac{\partial \sigma}{\partial r} \right) + N_t \frac{\partial}{\partial r} \left( r \frac{\partial \theta}{\partial r} \right) = 0 \tag{11}$$

Non-dimensional boundary conditions are

$$u = \frac{\partial k}{\partial t}, \quad w = -c, \quad \theta = 0, \quad \sigma = 0 \quad \text{at } r = k; \quad \left( \frac{\partial w}{\partial r} \right) = 0 \quad \text{at } r = 0 \quad \left( \frac{\partial \theta}{\partial r} \right) = 0 \quad \left( \frac{\partial \sigma}{\partial r} \right) = 0 \quad \text{at } r = 0 \tag{12}$$

where  $T_0$  and  $T_1$  is the uniform temperature maintained at the center of the channel and at the boundary of the tube.  $C_0$  and  $C_1$  is the concentration maintained at the center of the channel and at the boundary of the tube.

### III. SOLUTION OF THE PROBLEM

The solution of the coupled equations (10) and (11) have been solved using homotopy perturbation method

$$H(q, \theta) = (1 - q)[L(\theta) - L(\theta_0)] + qL(\theta) + qN_b \frac{\partial \sigma}{\partial r} \frac{\partial \theta}{\partial r} + N_t q \left( \frac{\partial \theta}{\partial r} \right)^2 \tag{13}$$

Where  $L = \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial}{\partial r} \right)$   $q$  is the embedding parameter which has the range  $0 \leq q \leq 1$ .

$$\theta(r, z) = \theta_0 + q\theta_1 + q^2\theta_2 + q^3\theta_3 \tag{13a}$$

$$\sigma(r, z) = \sigma_0 + q\sigma_1 + q^2\sigma_2 + q^3\sigma_3$$

The initial solution is assumed which will satisfy the initial boundary condition of the problem and is taken in the form of

$$\theta_0 = \left( \frac{r^2 - k^2}{4} \right) \sigma_0 = - \left( \frac{r^2 - k^2}{4} \right) \tag{13b}$$

The expression for  $\theta$  (temperature) and  $\sigma$  (concentration) are using (13a) and (13b) in 13 under boundary condition 12 are obtained as follows:

$$\theta = a_{11}(r^4 - k^4) + a_{12}(r^6 - k^6) + a_{13}(r^4 - k^4) + a_{14}(r^8 - k^8);$$

$$\sigma = a_{15}(r^2 - k^2) + a_{16}(r^4 - k^4) + a_{17}(r^6 - k^6)$$

The radial and axial velocity components  $u$  and  $w$  are obtained by solving the equations (8) and (7) along with the boundary conditions (12). The analytical expression for  $u$  and  $w$  are as follows

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 13, July 2017

$$u = \frac{1}{r} \left( \frac{-k^3 k' p}{4} + \frac{p'}{4} \left( \frac{k^4}{4} - \frac{k^4}{2} \right) - 3k^7 a_{18} - 4a_{19} k^9 - 5k^{11} a_{21} - k k' k^2 + \left( \frac{k^4}{4} - \frac{k^4}{2} \right) a_{29} - 2k^6 a_{25} \right)$$

$$w = -c + \frac{P}{4} (r^2 - k^2) + a_{18} (r^6 - k^6) + a_{19} (r^8 - k^8) + a_{21} (r^{10} - k^{10}) + a_{29} (r^2 - k^2) + a_{25} (r^4 - k^4)$$

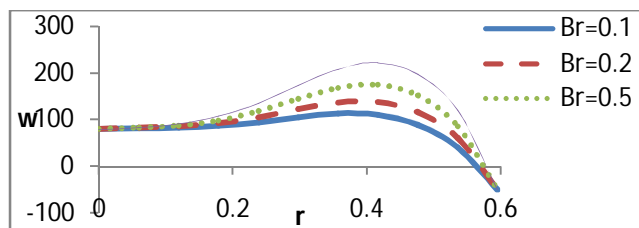
where the constants are mentioned in the Appendix column.

The volumetric flow rate is given by  $Q = 2\pi \int_0^k r w \, dr$

Pressure rise per wavelength is given by  $\Delta p = \int_0^1 \frac{dp}{dz} \, dz$  and numerical computation are carried out using numerical integration.

### IV. NUMERICAL DISCUSSIONS

The analytical expression for axial velocity  $w$ , radial velocity  $u$ , temperature  $\theta$  and the concentration  $\sigma$  have been obtained for the peristaltic transport of a nanofluid in circular tube by using homotopy perturbation method. The numerical computations are carried out for axial velocity, radial velocity, temperature and concentration have been shown graphically for various parameters involved in the physical problem such as Brownian motion parameter  $N_b$ , thermophoresis parameter  $N_t$ , Grashof number  $G_r$ , pressure rise per wavelength  $\nabla P$  and frictional force at the wall have been tabulated for the above controlling parameters. In the **Fig.2**, it is observed that as the local nanoparticle Grashof number  $Br$  increases the axial velocity increases due to reduction in the viscosity of the base fluid. The velocity will be having its maximum in the vicinity of  $0.3 \leq r \leq 0.5$  Since the boundaries of the physical model is a peristaltic flow maximum driving force can be seen in the middle of the vertical tube. **Fig. 3**, depicts the variation of the axial velocity for various values of Grashof number  $Gr$ . It is observed that the axial velocity decreases as Grashof number  $Gr$  increases in magnitude. Here, the velocity of the fluid will be more near the entrance of the tube and gradually slows down as it goes near the end of tube and also due to the thinning of the viscosity of the nanofluid. Similar effect can be seen in the case of negative Grashof number and the magnitude of the velocity may be decreases in this case of analysis. In **Fig.4**, we observe the variation of concentration for various values of Brownian motion parameter  $N_b$ . Concentration increases with increase in  $N_b$  due to increase in the density of the nanofluid. In **Fig.5**, we observe the variation of concentration for various values of thermophoresis parameter  $N_t$ . The magnitude of concentration decreases with increase in  $N_t$  parameter due to transfer of the fluid is fast due to density diminishes. An opposite behavior of the variation of temperature for various values of thermophoresis parameter  $N_t$  is observed in **Fig.7** due to density variation of the nanofluid. The pressure rise  $\nabla p$  versus mean flow rate  $Q$  for different values  $N_t$ ,  $N_b$ ,  $B_r$  and  $G_r$  is tabulated in the Tables 1 and 2. It is observed that pressure gradient of the nanofluid flow decreases with increase  $N_t$  and increase with the volumetric flow rate  $Q$ . In the case of the Brownian motion of the parameter, pressure gradient enhances the fluid flow but decreases the volumetric flow rate  $Q$ .

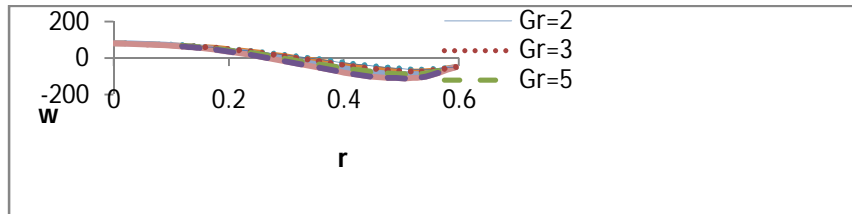


**Fig. 2:** Variation of axial velocity  $w$  versus  $r$  for various values of  $B_r$ ,  $G_r=5$ ,  $N_b=0.4$ ,  $N_t=4$ .

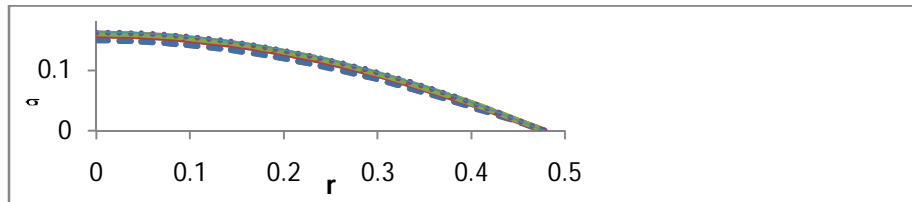
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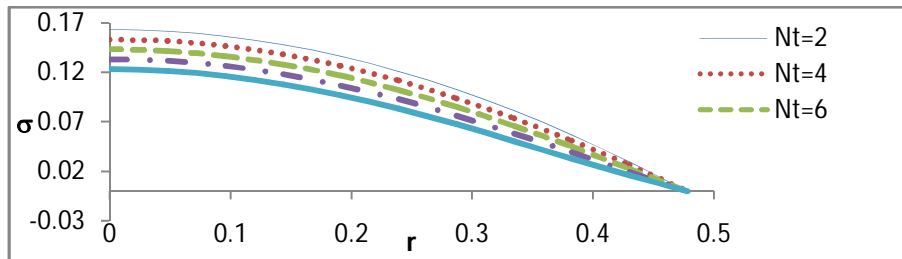
Vol. 6, Special Issue 13, July 2017



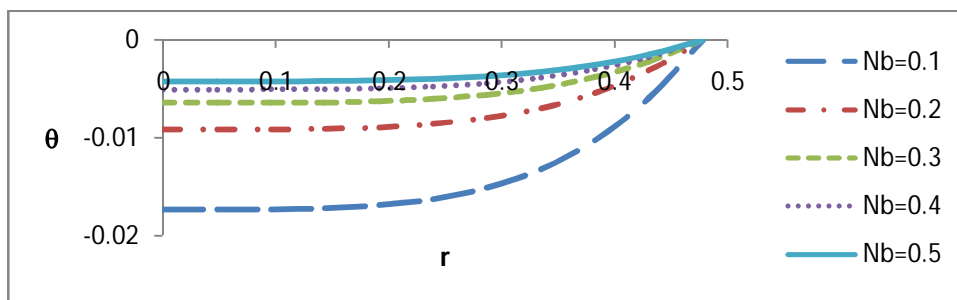
**Fig. 3:** Variation of axial velocity  $w$  versus  $r$  for various values of  $G_r$ ,  $Br=0.2$ ,  $Nb=0.4$ ,  $Nt=4$



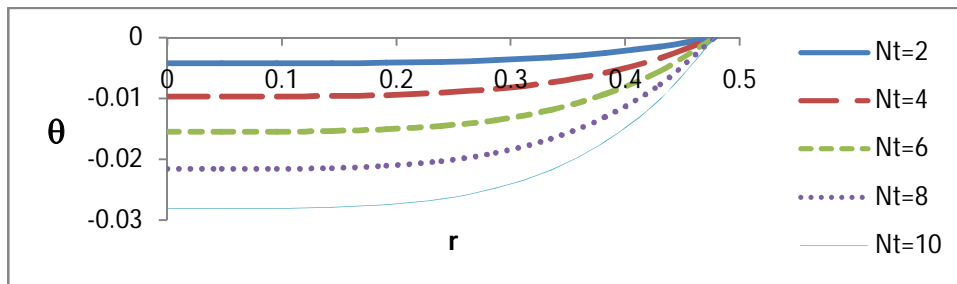
**Fig. 4:** Variation of concentration  $\sigma$  versus  $r$  for various values of  $N_b$ ,  $Nt=2$ .



**Fig. 5:** Variation of concentration  $\sigma$  versus  $r$  for various values of  $N_t$ ,  $N_b=0.5$ .



**Fig. 6** Variation of temperature  $\theta$  versus  $r$  for various values of  $N_b, N_t=2$



**Fig. 7** Variation of temperature  $\theta$  versus  $r$  for various values of  $N_t, N_b=0.5$

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 13, July 2017

Q	Table 1: Pressure rise $\nabla p$ versus volumetric flow rate Q.						Table 2 : Pressure rise $\nabla p$ versus volumetric flow rate Q.					
	$N_b=0.5, G_r=5, B_r=0.2$			$N_b=4, G_r=5, B_r=0.2$			$N_b=0.5, N_r=4, B_r=0.2$			$N_b=0.5, N_r=4, B_r=0.2$		
	$N_t=2$	$N_t=6$	$N_t=7$	$N_b=0.1$	$N_b=0.5$	$N_b=0.6$	$G_r=2$	$G_r=6$	$G_r=10$	$B_r=0.1$	$B_r=0.3$	$B_r=0.5$
1	74.57945	73.97673	73.37401	75.00692	74.4042	73.80148	74.51456	73.91184	73.30912	74.53508	73.93236	73.32964
2	74.82687	74.22416	73.62144	74.74143	74.13871	73.536	74.55782	73.9551	73.35238	74.51456	73.91184	73.30912
3	75.35542	74.7527	74.14998	74.65214	74.04943	73.44671	74.60108	73.99836	73.39564	74.49404	73.89132	73.2886
4	76.32201	75.7193	75.11658	74.60696	74.00424	73.40152	74.64434	74.04162	73.4389	74.47352	73.8708	73.26808
5	77.88359	77.28087	76.67815	74.57945	73.97673	73.37401	74.6876	74.08488	73.48217	74.453	73.85028	73.24756

## V. APPENDIX

$$\frac{dp}{dz} = \frac{-8Q}{(1 + \lambda_1)k^4} - \frac{8c}{k^2} - 6a_{18}k^4 - a_{19}k^6(9.6) - a_{21}k^8(6.6656) - a_{29} - a_{25}k^2(5.328)$$

$$a_1 = N_b - N_t \quad a_2 = 1 - \frac{N_t}{N_b} \quad a_3 = \frac{N_t}{N_b} \quad a_4 = \frac{N_b b_1}{2} - \frac{N_b a_1 a_2}{32} + \frac{N_b a_3}{32} + \frac{N_t a_1}{16} - N_t b_1$$

$$a_5 = \frac{N_b b_2}{2} - \frac{N_b a_1^2}{16^2} - N_t b_2 \quad a_6 = \frac{N_b a_2}{4} - \frac{N_b a_3}{4} - \frac{N_t}{4} \quad a_7 = \frac{N_t}{4} - \frac{N_t^2}{2N_b} + \frac{a_2 N_t}{4}$$

$$a_8 = -\frac{a_1 N_t}{32} + \frac{a_1 N_t^2}{16} \quad a_9 = \frac{N_b}{64} + \frac{a_2}{64} - \frac{N_t}{32} \quad a_{10} = \frac{a_1}{1152} - \frac{N_t a_1}{576} \quad a_{11} = \frac{a_1}{64} - a_9 \quad a_{12} = \frac{a_4}{36} + a_{10} \quad a_{13} = \frac{a_6}{16}$$

$$a_{14} = \frac{a_5}{64} \quad a_{15} = \frac{a_2}{4} + \frac{N_t}{4N_b} - 1 \quad a_{16} = \frac{a_3}{64} + \frac{a_7}{16} \quad a_{17} = \frac{a_8}{36} \quad a_{18} = -G_r \frac{a_{11}}{36} - B_r \frac{a_{16}}{36} \quad a_{19} = -\frac{a_{12}}{64} G_r - \frac{a_{17}}{64} B_r$$

$$a_{21} = -\frac{a_{14}}{100} G_r \quad a_{22} = -\frac{a_{11}}{4} G_r \quad a_{23} = -\frac{a_{12}}{4} G_r \quad a_{24} = -\frac{a_{13}}{36} G_r \quad a_{25} = -\frac{a_{15}}{16} B_r \quad a_{26} = -\frac{a_{15}}{4} B_r \quad a_{27} = -\frac{a_{16}}{4} B_r$$

$$a_{28} = -\frac{a_{17}}{4} B_r \quad a_{29} = a_{22}k^4 + a_{23}k^6 + a_{24}k^7 + a_{26}k^2 + a_{27}k^4 + a_{28}k^6$$

$$p' = \frac{32Q}{\pi k^3} - \frac{16c}{k} - 24a_{18}k^3 - 57.6a_{19}k^5 - 45.808a_{20}k^6 - 53.3248a_{21}k^7 - a_{29} - a_{25}k(10.656)$$

$$Q = 2\pi \left( \frac{-ck^2}{2} - \frac{p}{16}k^4 - a_{18} \right)$$

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