

Effects of Viscous and Darcy Dissipation on Pressure-Driven Flow and Heat Transfer between Porous Plates

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ABSTRACT

This paper investigates pressure-driven flow and heat transfer between porous plates, with particular emphasis on the effects of viscous and Darcy dissipation. A mathematical model comprising coupled momentum and energy equations is formulated for fluid flow between porous plates, with injection at the hot plate and suction at the cold plate. The governing equations are nondimensionalized and solved analytically subject to the prescribed boundary conditions. The analysis focuses on the effects of the suction/injection parameter, Darcy number, pressure driven parameter, viscous dissipation parameter which is expressed as Eckert number and Prandtl number on the velocity and temperature distributions, skin friction, and rate of heat transfer. The results reveal that, increase in the pressure driven parameter lead to enhancement in the fluid velocity and temperature. Increases the Darcy number enhance the fluid velocity and temperature profiles. The results further demonstrate that, viscous and Darcy dissipation contributes to the thermal behavior of the fluid and therefore plays important roles in pressure-driven transport through porous media. This research provides theoretical insight into the coupled effects of porous-medium resistance, suction/injection, pressure driving, and dissipative mechanisms on flow and heat transfer between porous plates.

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INTRODUCTION

The study of heat transfer and fluid flow in porous media is important in engineering systems such as filtration channels, thermal energy storage devices, heat exchangers and groundwater-related processes. In such systems, the conversion of mechanical energy into thermal energy through viscous dissipation and the loss of energy associated with porous resistance can significantly influence the velocity and temperature fields. Viscous dissipation represents the generation of internal energy as a result of fluid friction, whereas Darcy dissipation accounts for energy loss associated with resistance offered by the porous matrix. The Brinkman extension of Darcy flow provides a useful framework for incorporating viscous diffusion into porous-media models and for examining the combined influence of viscous effects, porous resistance and convective transport. Previous analyses have shown that dissipation may substantially modify temperature distributions and heat-transfer rates, including the Nusselt number, with the magnitude and direction of the effect depending on the flow configuration, boundary conditions and intensity of through-flow (Barletta and Mulone, 2020).

Earlier studies have primarily considered dissipation effects within natural or free-convection configurations. Aina et al. (2021) examined viscous and Joule dissipation in fully developed natural-convection flow through a vertical micro-channel in the presence of Lorentz forces, considering velocity slip and temperature-jump conditions. Their perturbation-series analysis showed that increasing the Hartmann number reduced the influence of both viscous and Joule dissipation on velocity, temperature, skin friction and heat-transfer rate, while the effects of the Hartmann, Knudsen, fluid-wall interaction and buoyancy parameters

were particularly pronounced under symmetric heating. Aina and Daramola (2022) subsequently investigated viscous dissipation in free-convection flow through a vertical permeable micro-channel with suction/injection, velocity slip and temperature-jump conditions. Their work demonstrated the importance of boundary and flow-control conditions in determining the hydrodynamic and thermal responses of permeable channels. Munira et al. (2022) also considered MHD natural-convection flow with heat generation and viscous dissipation, further demonstrating the relevance of internal heat-generation mechanisms in buoyancy-driven systems.

The literature has also expanded to mixed-convection and stability problems, where buoyancy interacts with externally imposed flow and porous resistance. Ahmad (2023) highlighted the complex interaction between buoyancy, external forcing, suction/injection and dissipative effects in porous channels, with heat transfer depending on the balance between Brinkman and Darcy effects, through-flow conditions and fluid properties. Ajibade et al. (2023) specifically investigated the combined effects of viscous and Darcy dissipation on mixed-convection flow in an annulus partially filled with porous material, showing the continuing importance of both dissipation mechanisms in mixed-convection porous systems. Brandão (2023) considered stability in Darcy-Bénard and related porous-layer problems and reported that viscous and Darcy dissipation can influence the onset and development of disturbances, while through-flow and magnetic effects further modify the stability characteristics. These studies indicate that dissipation cannot be treated independently of the dominant flow mechanism and porous resistance when predicting thermal and hydrodynamic behaviour.

Subsequent natural-convection studies have further confirmed the influence of the combined dissipation mechanisms under different thermal conditions. Daramola et al. (2024) examined steady natural-convection flow in a vertical tube partially filled with porous material under asymmetric thermal boundary conditions and reported that increasing the Brinkman number enhanced both the temperature and velocity profiles. Abdullah (2024) investigated viscous dissipation and periodic heat flux in MHD free-convection flow between vertical parallel plates with heat generation, incorporating magnetic-field, buoyancy, Prandtl-number and Eckert-number effects. These investigations demonstrate that changes in thermal boundary conditions and additional physical mechanisms can substantially alter the influence of viscous dissipation. More recently, Pažanin and Suárez-Grau (2026) studied Darcy–Brinkman flow in a thin porous medium with viscous dissipation and non-homogeneous thermal boundary conditions. Their findings showed that viscous dissipation significantly affects the temperature distribution, while non-homogeneous boundary conditions produce corresponding changes in heat-transfer characteristics. Collectively, these studies establish a strong foundation for understanding dissipative effects, but their principal emphasis remains on natural/free-convection, MHD, micro-channel, tube, annular or thin-porous-medium configurations rather than the specific pressure-driven porous-plate arrangement considered here. A related body of work has examined forced or pressure-driven convection and the role of suction/injection as a flow-control mechanism. Suction and injection across parallel porous plates can modify velocity gradients, boundary-layer development, temperature distributions and heat-transfer rates. Studies of forced convection in porous channels indicate that asymmetrical heating, magnetic effects, radiation, Joule heating and other boundary or material conditions can alter wall heat flux and the thermal boundary layer (Falieh and Shehab, 2024). Entropy-generation studies likewise identify viscous and Darcy-related dissipation as important sources of irreversibility in suction/injection and mixed-convection systems, with implications for the design of porous heat-transfer devices (Panya, 2023). However, these studies introduce several additional physical mechanisms and geometrical conditions, making it difficult to isolate the combined effects of viscous and Darcy dissipation in a comparatively simple pressure-driven flow between porous parallel plates. The literature provided for this study therefore points to a need for a focused model that treats the pressure gradient, porous resistance, viscous

dissipation and Darcy dissipation together while retaining suction/injection and thermal transport as explicit parameters. Despite the progress made by previous natural, mixed and forced-convection studies, a specific gap remains in the treatment of pressure-driven flow and heat transfer between porous parallel plates when viscous and Darcy dissipations are considered simultaneously. Existing studies have addressed these mechanisms separately or within different configurations such as vertical micro-channels, porous tubes, partially porous annuli, MHD channels, stability problems and thin porous media (Aina et al., 2021; Aina and Daramola, 2022; Ajibade et al., 2023; Daramola et al., 2024; Abdullah, 2024; Pažanin and Suárez-Grau, 2026). Consequently, the coupled response of velocity and temperature fields to viscous dissipation, Darcy dissipation, suction/injection and Prandtl-number variation in a pressure-driven porous-plate configuration is not sufficiently developed in the literature reviewed here. Addressing this gap, the present study develops theoretical solutions for pressure-driven flow and heat transfer between porous plates and systematically examines the effects of viscous dissipation, Darcy dissipation, suction/injection and the Prandtl number on the resulting flow and thermal characteristics. The novelty of the study lies in bringing these mechanisms together within a single pressure-driven porous-plate framework, thereby providing a more direct assessment of their combined influence without relying on the additional physical complexities used in many earlier studies. The study contributes by establishing the governing analytical framework, identifying how the selected dimensionless parameters modify velocity and temperature distributions, and providing results that can improve understanding of porous-channel heat-transfer processes relevant to engineering applications.

MATHEMATICAL ANALYSIS

Pressure-driven flow and heat transfer between porous plates in the presence of viscous and Darcy dissipation with constant suction having suction velocity V_0' is considered. The geometry of the problem is shown in Figure 1, where x' axis is taken vertically upward along the plates and the y' axis normal to it. The distance between the plates is b . Fluid is being injected into the flow region through the hot porous plate and in order to conserve the mass of the fluid in the porous plate, fluid is being sucked out of the porous plate at the same rate through the cold porous plate.

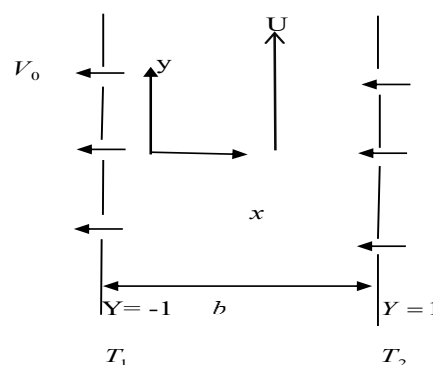


Figure 1: Flow configuration and coordinate system

As stated earlier, our emphasis in this paper is to investigate the combined effects of the viscous and Darcy dissipation and suction/injection on pressure-driven flow and heat transfer

between porous plates. Let be the velocity of the fluid along x -axis, is the velocity vector. The dimensional momentum and energy equation are:

$$\mu \frac{d^2 u^t}{dy^2} + \rho V_0 \frac{du^t}{dy} - \frac{\mu}{K} u + \frac{dp}{dx} = 0 \quad (1)$$

$$K \frac{d^2 T^t}{dy^2} + \rho C_p V_0 \frac{dT^t}{dy} + \mu \left[\frac{du^t}{dy} \right]^2 + \frac{\mu}{K} u^2 + \frac{\alpha B_0^2}{K} V_0^2 = 0 \quad (2)$$

Using the following non-dimensional quantities;

$$Pr = \frac{v}{\alpha}, S = \frac{V_0 b}{v}, Da = \frac{K}{b^2} y = \frac{y'}{b}, U = \frac{vu'}{g\beta b^2(T_1 - T_0)}, Re = \frac{U_0 b}{v} \quad (3)$$

Where:

U = dimensional velocity (m/s)

y = dimensional coordinate (m)

T = temperature coordinate (K)

K = permeability of the porous Medium (m^2)

V_0 = suction/injection velocity (m/s)

μ = dynamic viscosity

K = thermal conductivity

ρ = fluid density

C_p = specific heat at constant pressure

Therefore, using equation (3) in the equation (1) and (2), we have the governing equations in dimensionless form:

$$\frac{d^2 U}{dY^2} + \frac{S}{Pr} \frac{dU}{dY} - \frac{U}{Da} + \frac{P}{Pr} = 0 \quad (4)$$

$$\frac{d^2 \theta}{dY^2} + S Pr \frac{d\theta}{dY} + E_c Pr \left[\left(\frac{dU}{dY} \right)^2 + \frac{B}{Da} U^2 + \frac{B}{Da} C \frac{S^2}{Re^2} \right] = 0 \quad (5)$$

With the boundary conditions in non-dimensional form as

$$U(Y) = 0 \quad \theta(Y) = 0 \quad \text{at } Y = -1 \quad (6)$$

$$U(Y) = 0 \quad \theta(Y) = 1 \quad \text{at } Y = 1 \quad (7)$$

The solutions of the non-dimensional governing equations (4)–(5), subject to the boundary conditions (6)–(7), are:

$$U(Y) = \exp\left(\frac{-S}{2\gamma} Y\right) [C_1 \cosh(\delta Y) + C_2 \sinh(\delta Y)] + P Da \quad (8)$$

$$\theta(Y) = \frac{C_3}{S Pr} + C_4 \exp(-S Pr Y) + \frac{A_{21} \exp(A_{17} Y)}{(A_{17} - S Pr)} + \frac{A_{22} \exp(A_{18} Y)}{(A_{18} + S Pr)} + \frac{A_{23} \exp(A_{19} Y)}{(A_{19} + S Pr)} + \frac{A_{24} \exp(A_{20} Y)}{(A_{20} + S Pr)} - \frac{A_{12} \exp\left(\frac{-SY}{\gamma}\right)}{S\left(S Pr - \frac{S}{\gamma}\right)} + \frac{A_{14} + A_{10}}{(S Pr)^2} [S Pr \cdot Y - 1] \quad (9)$$

Where:

$$\delta = \sqrt{\left(\frac{S}{2\gamma}\right)^2 + \frac{1}{\gamma Da}}; C_1 = \frac{-P Da \cosh\left(\frac{S}{2\gamma}\right)}{\cosh(S)}; C_2 = \frac{P Da \sinh\left(\frac{S}{2\gamma}\right)}{\sinh(S)}; C_3 = S Pr \left[\frac{-(A_{26} + 1) \exp S Pr - A_{25} \exp(-S Pr)}{2 \sinh(S Pr)} \right]; C_4 = \frac{A_{25} - A_{26} - 1}{2 \sinh(S Pr)};$$

where $A_1, A_2, \dots, A_{27}$ are constants given in Appendix.

Skin Friction

The dimensionless skin frictions are:

$$\frac{dU}{dY} = \exp\left(\frac{-S}{2\gamma} Y\right) [A_1 \sinh(\delta Y)] + A_2 \cosh(\delta Y)$$

$$\left. \frac{dU}{dY} \right|_{Y=-1} = \exp\left(\frac{S}{2\gamma}\right) [A_1 \sinh(-\delta)] + A_2 \cosh(-\delta)$$

$$\left. \frac{dU}{dY} \right|_{Y=1} = \exp\left(\frac{-S}{2\gamma}\right) [A_1 \sinh(\delta)] + A_2 \cosh(\delta)$$

The Rates of Heat Transfer on the Porous Plates are:

$$\frac{d\theta}{dY} = -S Pr C_4 \exp(-S Pr Y) + \frac{A_{17} A_{21} \exp(A_{17} Y)}{(A_{17} + S Pr)} + \frac{A_{18} A_{22} \exp(A_{18} Y)}{(A_{18} + S Pr)} + \frac{A_{19} A_{23} \exp(A_{19} Y)}{(A_{19} + S Pr)} + \frac{A_{20} A_{24} \exp(A_{20} Y)}{(A_{20} + S Pr)} + \frac{A_{12} \exp(-SY)}{S Pr - \frac{S}{\gamma}} +$$

$$\frac{A_{14} + A_{10}}{S Pr} \left. \frac{dU}{dY} \right|_{Y=-1} = -S Pr C_4 \exp(S Pr) + A_{29}$$

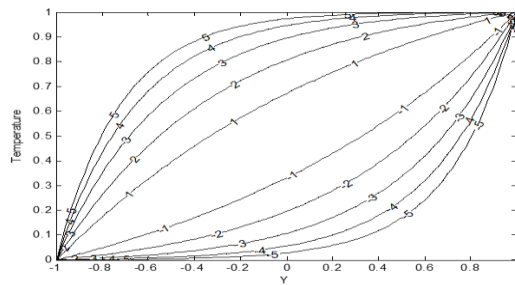
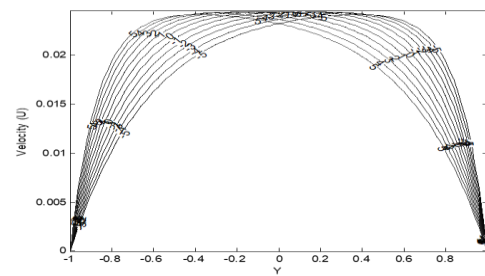
$$\left. \frac{dU}{dY} \right|_{Y=1} = -S Pr C_4 \exp(-S Pr) + A_{30}$$

RESULTS AND DISCUSSION

To study the effects of different flow parameters like viscous dissipation parameter, Darcy dissipation parameter suction/injection parameter (S) on flow formation, temperature, the skin friction and rate of heat transfer are investigated and presented in Figures 2–9.

Figure 2 and 3 displays the impact of suction/injection parameter on fluid velocity and temperature distribution. From the Figures, it is interesting to note that with suction on

the cold plate of the porous plate with simultaneous injection on the hot plate of the porous plate increases, the fluid velocity and temperature is enhanced. Physically speaking, this is as a result of heated fluid particles being introduced into the micro-porous plate by injection through the hot wall while cold fluid particles are removed from the porous plate by suction through the cold wall. Thus, strengthening the convection current within the porous plate leading to enhancement in the fluid velocity

Figure 2: Variation of temperature with S Figure 3: Variation of velocity with S

Figures 4 and 5 present the influence of the Darcy number on the fluid velocity and temperature. It is evident from these figures that, as the Darcy number increases, the velocity profile and temperature profile increases. Physically

Speaking, when the Darcy number is high, the porous medium behaves more like a transparent fluid region, whereas a low Darcy number makes the porous region act like a solid material with significant resistance.

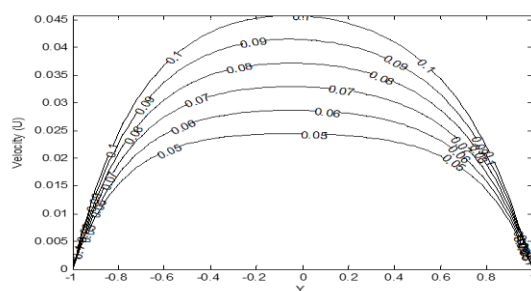
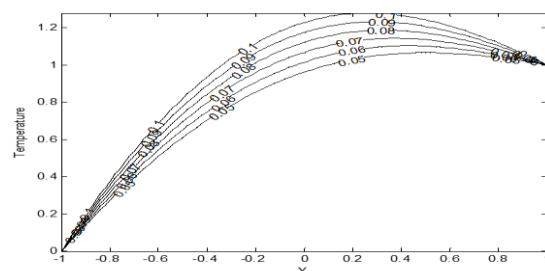
Figure 4: Variation of velocity with Da Figure 5: Variation of temperature with Da

Figure 6 and 7 illustrate the impact of pressure-driven parameter on the fluid velocity and temperature. It is evident

that increase in the pressure-driven parameter lead to enhancement in the fluid velocity and temperature.

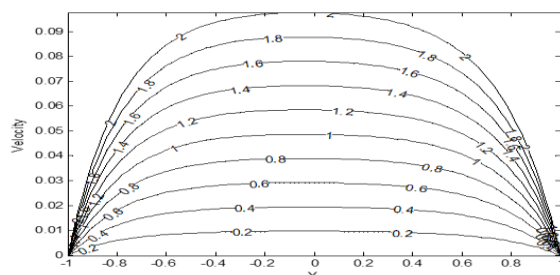
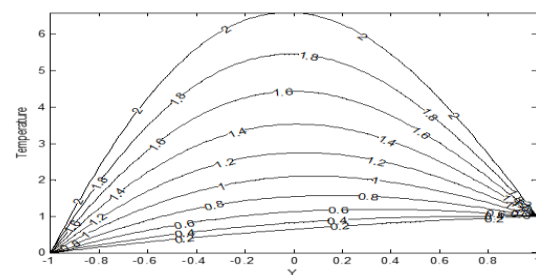
Figure 6: Variation of velocity with P Figure 7: Variation of temperature with P

Figure 8 illustrates the influence of the Eckert number Ec on the temperature. It is evident from the Figure 8 that increase

in Eckert number lead to enhancement in then temperature.

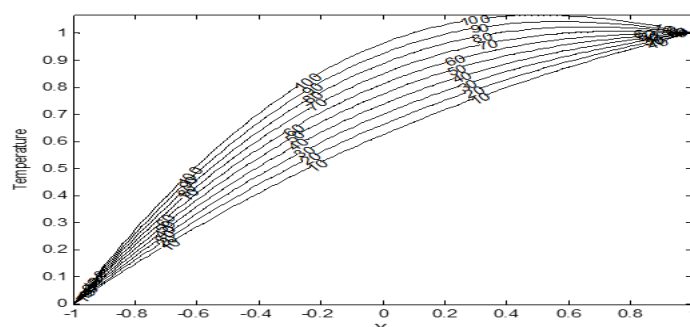
Figure 8: Variation of temperature with Ec

Figure 9 show the impact of Prandtl number on the temperature profile. An increase in the Prandtl number leads

to increase in the temperature as seen in Figure 9.

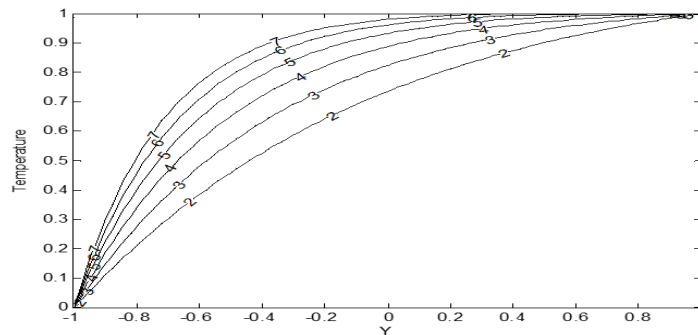
Figure 9: Variation of temperature with Pr

Figure 10 and 11 illustrate the influences of the suction/injection parameter (s) and Darcy dissipation parameter (Da) on the skin friction at $Y = -1$ and $Y = 1$, respectively. It is

observed that, an increase in the suction/Injection parameter as well as Darcy dissipation parameter lead to an increase in the skin friction at the plates.

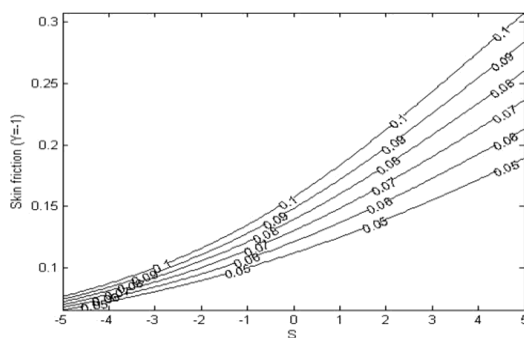
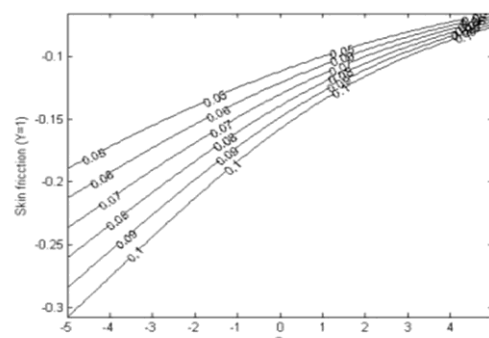
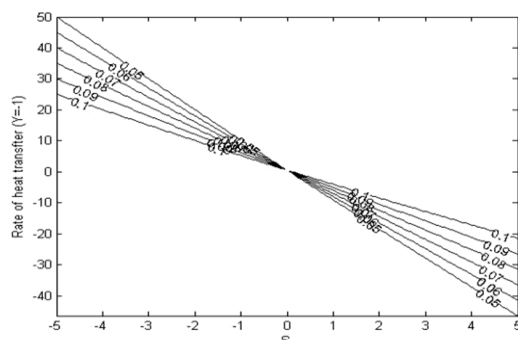
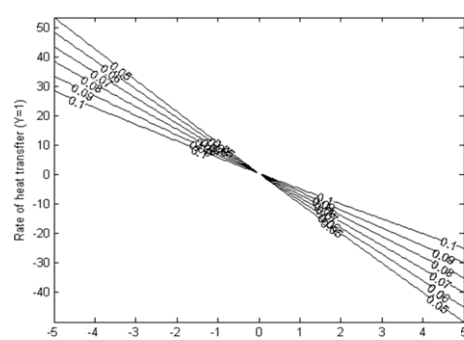
Figure 10: Variation of skin friction at ($Y = -1$)Figure 11: Variation of skin friction at ($Y = 1$)

Figure 12 and 13 depicts the effects of the suction/injection parameter (s) as well as Darcy dissipation parameter (Da) on the rate of heat transfer at $Y = -1$ and $Y = 1$, respectively. It is seen that

an increase in the Darcy dissipation as well as suction/injection significantly increase the rate of heat transfer at the plates.

Figure 12: Variation of heat transfer at ($Y = -1$)Figure 13: Variation of heat transfer at ($Y = 1$)

CONCLUSION

The current study investigated the effects of viscous and Darcy dissipation on pressure-driven flow and heat transfer between porous plates. The solution of velocity and temperature is obtained in terms of suction/injection parameter Darcy number and Prandtl number. The main findings are summarized as follows:

As the Darcy number increases, the velocity profile and temperature increases while increase in the pressure-driven parameter lead to enhancement in the fluid velocity and temperature. Also, it is interesting to note that with suction on the cold plate of the porous plate with simultaneous injection

on the hot plate of the porous plate ($S > 0$) increases, the fluid velocity and temperature is enhanced. In addition, the effect of suction/injection on the skin friction can be useful in mechanical engineering for modelling a system. It can be easily obtained a suitable value of suction/injection for which the value of the skin friction will be optimum.

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Appendix

$$A_1 = SC_1 - \frac{S}{2\gamma} C_2$$

$$A_2 = SC_2 - \frac{S}{2\gamma} C_1$$

$$A_3 = A_1^2 + \frac{B}{Da} C_2^2$$

$$A_4 = A_2^2 + \frac{B}{Da} C_1^2$$

$$A_5 = A_1 A_2 - \frac{B}{Da} C_1 C_2$$

$$A_6 = P^2 B D a$$

$$A_7 = 2BP$$

$$A_8 = \frac{A_3 + A_4}{2}$$

$$A_9 = \frac{A_4 - A_3}{2}$$

$$A_{10} = -E Pr \left[\frac{B}{Da} C \frac{S^2}{Re^2} \right]$$

$$A_{11} = -E Pr A_8$$

$$A_{12} = -E Pr A_9$$

$$A_{13} = -E Pr A_5$$

$$A_{14} = -E Pr A_6$$

$$A_{15} = -E Pr A_7 C_1$$

$$A_{16} = -E Pr A_7 C_2$$

$$A_{17} = 2S - \frac{S}{\gamma}$$

$$A_{18} = -\left(2\sigma + \frac{S}{\gamma}\right)$$

$$A_{19} = S - \frac{S}{2\gamma}$$

$$A_{20} = -\left(S + \frac{S}{2\gamma}\right)$$

$$A_{21} = \frac{A_{11} + A_{13}}{2A_{17}}$$

$$A_{22} = \frac{A_{11} - A_{13}}{2A_{18}}$$

$$A_{23} = \frac{A_{15} + A_{16}}{2A_{19}}$$

$$A_{24} = \frac{A_{15} - A_{16}}{2A_{20}}$$

$$A_{25} = \frac{C_3}{SP_r} + C_4 \exp(SP_r)$$

$$A_{26} = \frac{C_3}{SP_r} + C_4 \exp(-SP_r)$$

$$A_{27} = \frac{A_{17} A_{21} \exp(-A_{17})}{A_{19} + SP_r} + \frac{A_{18} A_{22} \exp(-A_{18})}{A_{20} + SP_r} + \frac{A_{12} \exp(S)}{SP_r - \frac{S}{\gamma}} + \frac{A_{10} + A_{14}}{SP_r}$$

$$A_{28} = \frac{A_{17} A_{21} \exp(A_{17})}{A_{19} + SP_r} + \frac{A_{18} A_{22} \exp(A_{18})}{A_{20} + SP_r} + \frac{A_{19} A_{23} \exp(A_{19})}{A_{19} + SP_r} + \frac{A_{20} A_{24} \exp(A_{20})}{A_{20} + SP_r} + \frac{A_{12} \exp(-S)}{SP_r - \frac{S}{\gamma}} + \frac{A_{10} + A_{14}}{SP_r}$$

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