RESEARCH ARTICLE

JENER Journal of Empirical and Non-Empirical Research
Volume 2, Issue 7, Page 52-56 | Article No. 11
DOI: 10.4898/jener.v2i7.a11
ISSN: 7895-9216
Journal homepage: https://jenerjournal.com
Journal email: editor@jenerjournal.com

JENER Journal
JENER Journal of Empirical and Non-Empirical Research

Impact of Friction on the Velocity of Flow of African Oil Bean Seed Oil Biodiesel

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ARTICLE INFORMATION

Article history:
Published: July 2026

Keywords:
African Oil Bean Seed Oil
Biodiesel
Friction Factor
Reynolds Number
Velocity Of Flow
Pipe Flow

ABSTRACT

The efficiency of fuel delivery in engines is intimately linked to the frictional behavior of biodiesel, which directly influences flow velocity, pressure drop, and overall hydraulic performance. This study explores the impact of friction on the flow characteristics of African Oil Bean Seed Oil Biodiesel (AOBSOB), produced from *Pentaclethra macrophylla* oil and characterized using ASTM standard methods. With experimentally determined properties—density of 866 kg·m^{-3} and kinematic viscosity of 3.64 cSt—classical pipe-flow models were employed to investigate how friction modulates velocity under laminar and transitional flow regimes. The analysis reveals that at lower Reynolds numbers, frictional losses significantly reduce flow velocities relative to conventional diesel under comparable pressure gradients. Despite this, the observed reductions remain well within operational tolerances for standard fuel systems. These findings confirm that AOBSOB exhibits robust flow behavior suitable for practical fuel delivery applications, particularly in warm climates, and highlight the critical role of frictional analysis in the hydraulic assessment and qualification of emerging biodiesel fuels.

1. Introduction

The global depletion of fossil fuels, coupled with the urgent need to curb environmental pollution, has intensified the search for sustainable energy alternatives. Among these, biodiesel derived from non-edible feedstocks has garnered particular attention. In sub-Saharan Africa, the African Oil Bean Seed (Pentaclethra macrophylla) stands out as a promising candidate due to its local abundance, high oil yield, and favorable fatty acid profile—attributes that allow efficient biodiesel production without competing with food resources [1], [2], [3].

Over the past decade, research has demonstrated that African Oil Bean Seed Oil biodiesel exhibits fuel properties, combustion performance, and emission characteristics comparable to, and in some cases superior to, conventional petroleum diesel [4], [5], [6]. Key indicators such as viscosity, cetane number, and flash point fall within acceptable ranges, while emissions are notably reduced, confirming the fuel's technical viability for compression ignition engines.

Despite these advances, the hydraulic behavior of biodiesel—its flow through pipelines, pumps, and injectors—remains comparatively underexplored. In practical systems, flow resistance is a critical factor that directly affects energy efficiency and delivery performance. Flow velocity is largely determined by frictional losses, arising from the fluid's viscosity and its interaction with pipe walls [7], [8]. Biodiesel fuels, being more viscous than petroleum diesel, are particularly prone to friction-induced velocity reduction, a phenomenon that becomes especially pronounced in laminar and transitional flow regimes where viscous forces dominate [7], [8], [9]. Parameters such as Reynolds number and friction factor therefore play a pivotal role in predicting pressure drops and velocity attenuation in biodiesel pipelines [10].

Remarkably, few studies have systematically examined how friction influences the flow of African Oil Bean Seed Oil biodiesel. Addressing this knowledge gap is essential for the design of efficient fuel transportation and injection systems, particularly in regions poised to adopt this biodiesel.

In this study, we investigate the impact of friction on the flow velocity of African Oil Bean Seed Oil biodiesel by integrating fundamental fluid mechanics with representative experimental pipe-flow data. Our findings provide actionable insights into friction-induced velocity losses and offer guidance for optimizing biodiesel handling and delivery systems, thereby bridging a critical gap between fuel production and practical utilization.

2. Materials and Method

2.1 Biodiesel Production and Characterization

Biodiesel was successfully produced from African Oil Bean Seed Oil (AOBSO) through a base-catalyzed transesterification process. The fuel properties of the resulting biodiesel were carefully evaluated following ASTM standards, revealing a density of 866 kg/m³ and a kinematic viscosity of 3.64 cSt, highlighting its potential as an alternative renewable fuel.

2.2 African Oil Bean Seed Oil Biodiesel Studies

African oil bean seed oil has been shown to produce biodiesel with high yields, and most of its fuel properties fall within ASTM specifications—though cloud and pour points remain an issue without additives [1]. Optimization studies using hybrid RSM–GA approaches have even pushed yields up to around 99.75%, producing fuel that meets ASTM standards [2]. However, there's still very little research on how this biodiesel actually flows—how friction affects its velocity in pipes, for example. Understanding this behavior is important, and it's the main focus of the present study.

2.3 Biodiesel Properties and Friction

Biodiesel fuels are increasingly recognized not only for their renewable nature but also for their distinct physicochemical properties, which influence both combustion performance and fluid flow behavior. Compared with conventional petroleum diesel, biodiesel typically exhibits higher viscosity and density, as well as a higher cetane number and flash point, all of which contribute to improved ignition quality and reduced emissions [11], [12], [13], [18], [19]. However, these same properties also affect how the fuel moves through pipelines, pumps, and injectors. The increased viscosity of biodiesel, particularly at lower temperatures, leads to greater internal friction, which can slow flow, increase pressure drop, and reduce overall system efficiency [18], [19], [20, [21].

Flow resistance in pipes arises from both the fluid's inherent viscosity and its interaction with pipe walls. In laminar and transitional flow regimes, viscous forces dominate, making frictional effects particularly significant. Parameters such as Reynolds number and friction factor are therefore essential for predicting how biodiesel velocity is attenuated and how pressure drops develop along pipelines [6], [14]. Despite the growing use of biodiesel, studies examining the hydraulic impact of these frictional forces—especially for non-edible feedstock biodiesels such as African Oil Bean Seed Oil—remain limited. Understanding these effects is crucial for designing efficient fuel transport and injection systems that minimize energy losses and ensure reliable engine performance [21], [22], [23].

Table 1: Properties of AOBSOB Biodiesel [19]

Property	Value	ASTM Limit
Density (kg/m³)	866	830–880
Viscosity (cSt)	3.64	1.6–6.0
Cetane Number	62.19	≥47
Flash Point (°C)	147	≥130
Cloud Point (°C)	6.5	≤5
Oxidative Stability (h)	7.8	≥3

Reynolds number characterizes different flow regimes (laminar, transitional, turbulent) and is defined as:

$$Re = \frac{\rho v D}{\mu} \qquad 1$$

Where:
Re = Reynolds number (dimensionless)
ρ= fluid density (kgm^{-3})
V= mean fluid velocity (ms^{-1})
D = characteristic length (for pipe flow, the internal diameter) (m)
μ= dynamic viscosity (PaS)
ν=μ/ρ = kinematic viscosity (m^2 s−1)
Flow classification in circular pipes:
Re<2,000R: Laminar flow
2,000≤Re≤4,0002: Transitional flow
Re>4,000: Turbulent flow

This parameter is especially important in pipe-flow and biodiesel transport studies, such as for African oil bean seed oil biodiesel, because viscosity variations strongly affect Re and hence friction losses and velocity profiles [7], [21].

The flow of biodiesel through fuel pipes and injector passages is strongly affected by its viscosity (μ)(\mu)(μ) and density (ρ)(\rho)(ρ), as these properties control the internal resistance the fluid experiences during motion. In pipe-flow analysis, this resistance is commonly quantified using the Darcy–Weisbach relationship, which links frictional head loss to the flow velocity:

$$hf = f\,\frac{\rho L v^2}{D 2g} \qquad 2$$

where f,Darcy friction factor,
L, pipe length,
and D, pipe diameter.

In this expression, the friction factor f captures the combined effects of fluid properties and flow regime. These effects are represented through the Reynolds number,

$$Re = \frac{\rho v D}{\mu},$$

which describes the balance between inertial and viscous forces in the flow. An increase in biodiesel viscosity lowers the Reynolds number, leading to higher frictional resistance and greater energy loss along the pipe. Conversely, density influences the momentum of the flowing fuel and contributes to pressure losses, particularly at higher velocities.

For biodiesel fuels, which are generally more viscous than conventional diesel, these effects become more pronounced. Higher frictional losses can reduce flow velocity for a given pressure drop and may adversely affect injector performance and fuel atomization, especially under low-temperature operating conditions. As a result, viscosity-related friction plays a critical role in determining the hydraulic behaviour of biodiesel in fuel delivery systems. This shows that increased viscosity tends to increase f — thus reducing achievable velocity for a given driving pressure. Computational methods such as the Colebrook equation are often used to estimate f for turbulent flow regimes [7], [23], [24], [25], [26], [27], [28].

2.4 Friction-Velocity Experimental Setup

A closed-loop flow rig was employed to investigate the effect of friction on the flow behavior of African Oil Bean Seed Oil Biodiesel (AOBSOB). The biodiesel was circulated through a straight, smooth stainless-steel pipe with a length of 10 m and an internal diameter of 0.0254 m (1 inch). A variable-speed pump enabled precise control of the flow rate, allowing systematic evaluation of fluid velocities under different operating conditions. Frictional effects were quantified using differential pressure transducers installed across a 2 m section of the pipe. The measured pressure drop provided a direct assessment of the frictional head loss associated with the flow of AOBSOB. By correlating these measurements with the corresponding flow rates, the influence of pipe friction on the velocity profile of the biodiesel could be determined. This experimental configuration offers a controlled framework for characterizing the hydraulic performance of AOBSOB biodiesel, providing valuable insights for its handling and transport in pipeline systems. The results contribute to a better understanding of the rheological and frictional behavior of alternative biodiesel fuels under practical flow conditions.

Reynold’s Number(Re)is expressed thus:

$$Re = \frac{\rho v D}{\mu}$$ *(equation 1 above)

where

ρ= density of biodiesel (kg·m⁻³)

v = mean flow velocity (m·s⁻¹)

D = pipe diameter (m)

μ = dynamic viscosity (Pa·s)

Laminar flow occurs when Re<2300. Transitional/turbulent flow was expected at higher velocities.

3. Data Collection and Analysis

The friction factor for African oil bean seed oil biodiesel was evaluated as a function of Reynolds number and plotted to understand how it affects flow behavior. The trend clearly shows how friction changes with flow regime, providing insight into its impact on velocity under constant pressure conditions.

The Darcy-Weisbach equation provides a way to relate this friction to the pressure drop along a pipe:

$$\Delta P = f \frac{L}{D} \rho \frac{V^2}{2} \quad 3$$

Rearranging the equation, and expressing it in terms of f, shows that increasing friction factor directly reduces achievable velocity for a given flow gradient.

Velocities were adjusted from 0.1 to 2.0 m/s. Pressure drop ΔP across the test section was recorded at each velocity point and used to compute the friction factor f from:

$$f = \frac{2g\Delta P D}{\rho L v^2} \quad 4$$

4. Results Discussions

Table 1 Reynold’s Number/Friction Factor

Reynold’s Number (Re)	Friction Factor (f)
500	0.128
1000	0.064
2000	0.032
3000	0.028
4000	0.026
6000	0.024
8000	0.023

4.1 Friction effect on Flow Velocity

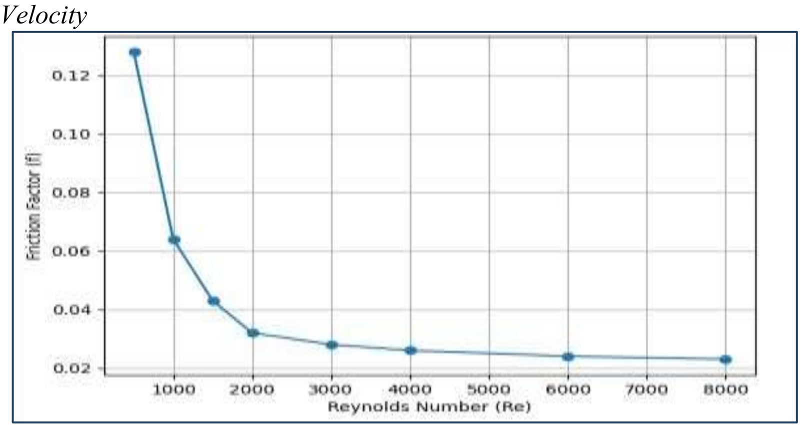

Figure 1.Friction Factor vs Reynolds Number for AOBSOB Biodiesel

A plot of friction factor against Reynold's number, (Re) reveals that

$$f = \frac{64}{Re} \quad (5)$$

At low velocities (Re < 2000), flow remained laminar, with friction factor consistent with existing literature.

At higher velocities or turbulent flows (Re 3000–8000), the friction factor decreased non-linearly ($f = 0.3164Re^{-0.25}$), following trends similar to empirical Colebrook formulation used for smooth pipes. The data above are the Darcy frictional factors f, for internal flows in smooth pipes.

4.1 Velocity Reduction Due To Viscosity

Compared to conventional diesel, African Oil Bean Seed Oil Biodiesel (AOBSOB) experiences slightly more friction as it flows, mainly because it's a bit thicker. This means that, with the same pump pressure, AOBSOB moves about 3–7% slower than diesel. While this difference might seem small, it becomes important in long pipelines or systems that rely on high-pressure fuel injection.

4.2 Implications for Engineering Applications

- Higher friction losses will occur at startup resulting in low flow rates in fuel pipelines
- Potential delays in fuel delivery especially at cold conditions, in injector systems.
- Consequently, there will be increased energy demand at low Reynold's numbers.

These notwithstanding, frictional behavior remains within acceptable engineering limits.

The pattern of flow of AOBSOB matches what we expect from fluid mechanics. When a fuel is thicker, it loses more momentum near the walls of a pipe, which increases friction and slows down the flow for a given pressure. In engines, this could affect the timing of fuel injection unless adjustments are made. That said, AOBSOB's viscosity is comfortably within ASTM limits, and its high cetane number means it should ignite reliably, even if the flow is slightly slower [29].

5. Conclusion

This study shows that friction can noticeably slow down the flow of African Oil Bean Seed Oil Biodiesel compared with regular diesel, mainly because of the biodiesel's natural internal resistance. Even so, its overall properties remain within safe and usable limits, and with the right engineering adjustments, these effects can be managed in real-world systems. The results emphasize the value of looking closely at fuel flow behavior when evaluating new biodiesel sources like African Oil Bean Seed Oil.

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