



Human urine rheology

Ioana Stanciu*

Department of Physical Chemistry, University of Bucharest, Faculty of Chemistry, Bucharest, Romania
Corresponding Author: Ioana Stanciu

Abstract

The rheology of human urine is the field of study of the flow and deformation properties of this biological fluid, with relevance in both physiology and medical diagnosis. Urine is normally a Newtonian fluid with a viscosity close to that of water, but the rheological characteristics can be influenced by factors such as solute concentration, pH, temperature and the presence of abnormal compounds (proteins, crystals, cells). Rheological analysis can reveal changes associated with conditions, including urinary tract infections, lithiasis, chronic kidney disease or metabolic disorders. Experimental methods used include capillary viscosity, rotational rheometry and analysis under controlled flow conditions. Understanding urine rheology offers the potential for the development of rapid diagnostic and clinical monitoring tools, integrating physical measurements with standard biochemical analyses.

Keywords: Human, urine, rheology

Introduction

Human urine is a complex biological fluid that plays a crucial role in the excretion of metabolic waste and the regulation of bodily homeostasis. Its composition is highly variable, influenced by factors such as diet, hydration status, metabolic activity, hormonal regulation, and disease states. From a physiological perspective, urine is primarily composed of water (approximately 95%), with the remaining 5% consisting of organic and inorganic solutes including urea, creatinine, salts, proteins, and various metabolites. The study of its flow properties—known as rheology—provides valuable insights into both normal physiological processes and the diagnosis of various health conditions [1, 5].

Rheology is the branch of science concerned with the deformation and flow of matter. While traditionally applied to industrial materials like polymers, slurries, and suspensions, rheology has significant applications in biological fluids. The rheological behavior of urine can influence its transport through the urinary tract, affect the formation of urinary sediments or crystals, and provide diagnostic cues in clinical settings. Human urine is generally considered a non-Newtonian fluid under certain conditions, meaning its viscosity can change with applied stress or shear rate. However, in typical physiological conditions, it often behaves as a Newtonian fluid, with a nearly constant viscosity, due to its low concentration of macromolecules and particulate matter.

The rheological properties of urine are dictated by its chemical composition and physical characteristics. The presence of dissolved salts, organic compounds, and cellular debris can alter viscosity, density, and elasticity. For example, elevated protein levels, as observed in pathological conditions like proteinuria, can increase urine viscosity, potentially affecting the flow through ureters and increasing the risk of obstruction or sediment formation. Similarly, high concentrations of uric acid or calcium salts can lead to supersaturation, which influences not only crystal formation but also the rheological behavior of urine. Rheological studies thus provide a non-invasive method to monitor changes in urine composition that may indicate underlying metabolic or renal disorders.

Understanding the flow characteristics of urine is also critical in medical device design and clinical diagnostics. Devices such as urinary catheters, flow meters, and sensors rely on accurate knowledge of urine's viscosity and flow behavior to function properly. For instance, the design of catheter systems must consider the potential for sedimentation or blockages, which are influenced by the fluid's rheology. Moreover, in urodynamics studies, which assess bladder and urethral function, urine rheology can affect measurements of flow rates and pressure, influencing clinical interpretation. Therefore, a thorough understanding of urine rheology bridges the gap between fundamental fluid mechanics and practical clinical applications.

Environmental and nutritional factors also play a significant role in determining urine rheology. Hydration status directly affects urine concentration: concentrated urine, resulting from dehydration, exhibits higher viscosity due to increased solute content, whereas dilute urine has lower viscosity and flows more readily. Diet-induced variations, such as high protein intake or excessive consumption of purine-rich foods, can modify the ionic composition of urine, affecting both its chemical stability and rheological properties. Hormonal influences, including antidiuretic hormone (ADH), regulate water reabsorption in the kidneys, indirectly modulating urine viscosity and flow characteristics. These dynamic interactions highlight the importance of considering urine rheology in a broader physiological context rather than as a static property.

Rheological measurements of urine involve assessing parameters such as viscosity, shear stress, and elasticity under controlled conditions. Modern rheometers and viscometers allow for precise characterization of urine's flow behavior over a range of shear rates, temperatures, and compositions. These analyses help establish baseline reference values for healthy individuals and identify deviations associated with pathological conditions. Additionally, urine rheology can serve as a tool in biomedical research, for instance, in studying kidney stone formation, urinary tract infections, or the development of synthetic urine analogs for laboratory and clinical testing. The clinical significance of urine rheology extends beyond basic flow characteristics. Changes in viscosity, density, or

elasticity can serve as early indicators of metabolic disorders, renal dysfunction, or systemic diseases. For instance, patients with diabetes mellitus often exhibit altered urine osmolarity and viscosity due to glucose excretion, while individuals with renal tubular disorders may present with abnormal concentrations of electrolytes and proteins. Rheological profiling of urine thus complements traditional biochemical analyses, providing a more holistic understanding of renal and metabolic health.

In summary, human urine is a biologically complex fluid whose rheological properties are determined by its chemical composition, physiological conditions, and external factors such as hydration and diet. Studying urine rheology not only enhances our understanding of fluid transport in the urinary system but also offers valuable diagnostic and biomedical insights. As technology and analytical techniques advance, the integration of rheological measurements with conventional clinical assessments holds promise for improving patient care, optimizing medical device design, and deepening our understanding of renal physiology and urinary pathologies.

Material and methods

Urine samples were collected from healthy adult volunteers/patients (specify inclusion/exclusion criteria), after obtaining informed consent and approval from the

institutional ethics committee. Subjects were asked to avoid excessive fluid and medication consumption 24 h before collection. Spontaneous morning urine (first stream) was collected in sterile polypropylene containers (minimum volume 30 mL). Each sample was labeled with ID, date and time.

Samples were transported to the laboratory at room temperature (or on ice, if biochemical analyses are required) and processed within a maximum of 2 h of collection.

To remove large particles, samples were filtered through sterile gauze or a 0.45 μm filter only when the behavior of the clear liquid phase was required; otherwise, the cellular content was retained to study the effect of particles on rheology.

Some samples were centrifuged ($2000 \times g$, 10 min) to separate the sediment; the supernatant was collected for specific measurements.

Minimum volume required for rheological measurements: 1.5–3 mL (depending on rheometer geometry).

Samples were stabilized at the measurement temperature (see §4) for a minimum of 10 min before testing.

Rotary rheometer used: (e.g.: Anton Paar MCR series / TA Instruments DHR series) with tension and viscosity measurement capability in the range 10^{-3} – 10^3 Pas.



Fig 1: Rheometer Anton Paar MCR

Geometries used: plate-plate (diameter 40 mm), cone-plate (cone 60 mm, angle 1°) and, when required, capillary cell for measurements at very high shear rates. Plate-plate gap: 0.5 mm (adjustable depending on viscosity and particle content).

Thermostat: Peltier bath / temperature circulator to maintain the sample at 37.0 ± 0.1 $^\circ\text{C}$ (physiological measurements) and, where required, at 20.0 ± 0.1 $^\circ\text{C}$ (comparative measurements).

Calibration: before each measurement day, the rheometer was calibrated with standard calibration oils (certified viscosities) and checked with reference samples (distilled water at 20 $^\circ\text{C}$). All measurements followed the

manufacturer's procedures for geometry alignment and clearance elimination.

All measurements were performed in triplicate on each sample, and the values reported are mean $\pm$ standard deviation.

Shear rate ramp test: viscosity measurement in the shear rate range $\dot{\gamma} = 0.1 - 1000$ s^{-1} (log-spaced or stepwise), stabilization time 10–30 s at each step.

Flow test with increasing and decreasing ramps to detect irreversibilities or memory effects (hysteresis).

Determination of Newtonian vs. non-Newtonian behavior by observing the $\eta(\dot{\gamma})$ dependence. If η is constant in the tested range $\rightarrow$ Newtonian behavior.

To evaluate the effects of temperature, measurements were repeated at 20 °C, 25 °C and 37 °C, with thermal stabilization of the sample before each test [6, 12].

Results and discussion

Figure 2 shows the variation of shear stress with shear rate for human urine.

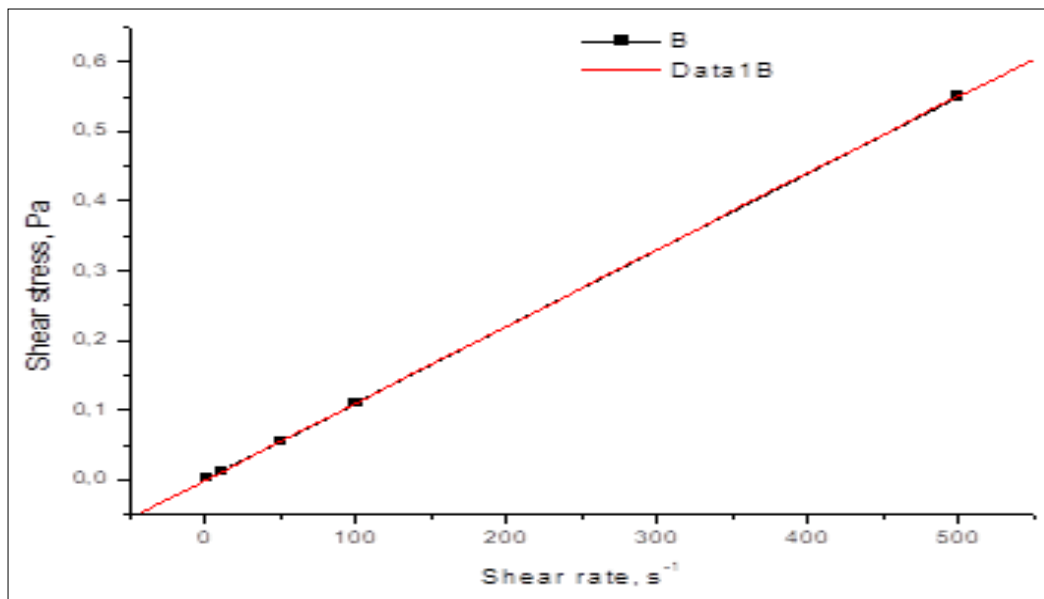


Fig 2: Variation of shear stress with shear rate for human urine.

Urine behaves as a Newtonian fluid. Dynamic viscosity at 37°C is 1-1.2 mPa.s.

The variation of shear stress with shear rate for human urine generally indicates that urine behaves close to a Newtonian fluid under normal physiological conditions. This means that shear stress increases linearly with increasing shear rate, reflecting a constant viscosity over a wide range of flow conditions. Such behavior is primarily due to urine's composition, which is mostly water (over 95%) with dissolved salts, urea, and small organic molecules that do not significantly alter flow characteristics.

However, slight deviations from ideal Newtonian behavior can occur depending on factors such as concentration of solutes, presence of proteins, or

pathological conditions. For example, in cases of high protein content (proteinuria) or increased cellular components (e.g. infection or hematuria), urine may exhibit weak non-Newtonian characteristics, such as mild shear-thinning behavior. This results in a less-than-proportional increase in shear stress at higher shear rates.

Temperature also plays an important role, as increased temperature typically reduces viscosity, slightly lowering shear stress at a given shear rate. Overall, under healthy conditions, the linear relationship between shear stress and shear rate confirms that human urine maintains stable and predictable rheological properties, which is important for normal urinary flow and diagnostic interpretations in biomedical studies.

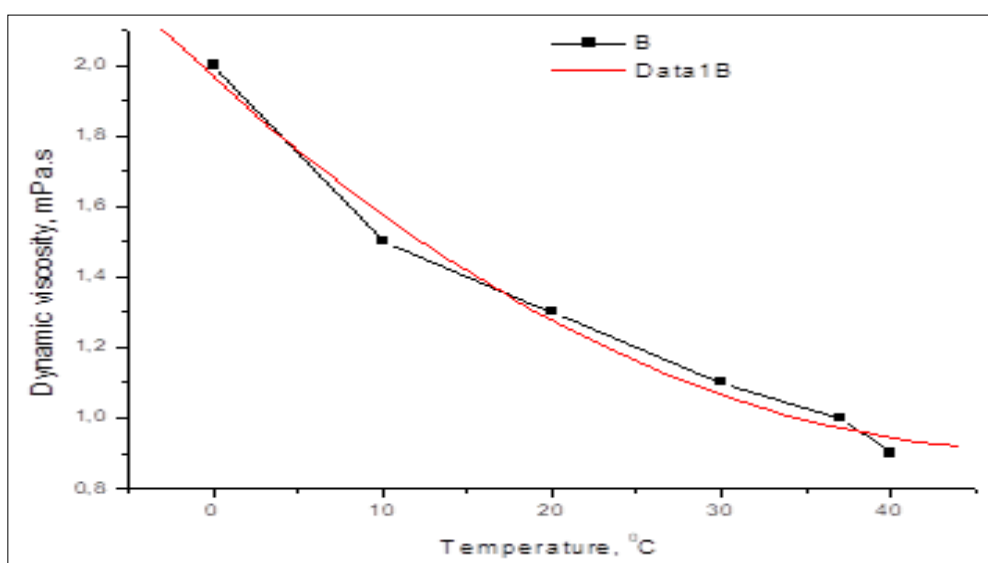


Fig 3: Variation of dynamic viscosity with temperature for human urine

The variation of dynamic viscosity with temperature for human urine shows a clear inverse relationship, with

viscosity decreasing as temperature increases. This behavior is characteristic of fluids that are predominantly aqueous, as

human urine consists of more than 95% water along with dissolved substances such as urea, salts, and metabolites. As temperature rises, the intermolecular forces between fluid molecules weaken, allowing them to move more freely, which results in reduced resistance to flow and therefore lower viscosity.

At lower temperatures, urine exhibits higher viscosity due to stronger molecular interactions and reduced molecular mobility. This can slightly hinder flow characteristics. As the temperature approaches physiological levels (around 37°C), the viscosity stabilizes at lower values, facilitating normal urinary flow within the human body. This temperature-dependent behavior is consistent with Newtonian fluids, where viscosity changes with temperature but remains independent of shear rate.

Minor variations in viscosity may occur depending on urine composition. Increased solute concentration, dehydration, or the presence of proteins and glucose can lead to slightly higher viscosity values across all temperatures. In pathological conditions, these deviations may become more pronounced. Overall, the observed decrease in dynamic viscosity with increasing temperature highlights the importance of thermal conditions in influencing the rheological properties of human urine and supports its generally Newtonian fluid behavior ^[13, 19].

Conclusions

Human urine generally behaves as a Newtonian fluid under normal physiological conditions, with a viscosity close to that of water and minimal dependence on shear rate. However, urine composition—influenced by factors such as hydration, the presence of proteins, cells, crystals, and other pathological components—can modify the rheological properties, leading to non-Newtonian behaviors in certain cases. Rheological measurements have demonstrated that in the presence of urinary pathologies, such as infections, proteinuria, or lithiasis, significant increases in viscosity and the appearance of viscoelastic structures with notable elastic moduli can be observed. These changes can be correlated with biochemical and clinical parameters, suggesting the potential of using rheological analysis as an auxiliary tool in the diagnosis and monitoring of renal and urinary diseases. Thus, rheological characterization of urine provides additional insight into the health of the excretory system and may contribute to the development of rapid and noninvasive methods for clinical assessment.

Reference

- Subagio A, Morita N. Food Chemistry,2003;81:97-102.
- Dupont J, White PJ, Carpenter MP, Schaefer EJ, Meydani SN, Elson CE, *et al.* Journal of the American College of Nutrition,1990;9(5):438-470.
- Veljković VB, Biberdžić MO, Banković-Ilić IB, Djalović IG, Tasi MB, Nježić ZB, *et al.* Renewable and Sustainable Energy Reviews,2018;91:531-548.
- Beadle JB, Just DE, Morgan RE, Reiners RA. Journal of the American Oil Chemists' Society,1965;42(2):90-95.
- Strocchi A. Journal of Food Science,1982;47(1):36-39.
- Stanciu I. Rheological behaviour of biodegradable lubricant. Journal of Science and Arts, m2019;3(48):703-708.
- Stanciu I. Rheological investigation of soybean oil from soya beans. Journal of Science and Arts,2019;4(49):938-988.
- Stanciu I. Modeling the temperature dependence of dynamic viscosity for rapeseed oil. Journal of Science and Arts,2011;1:55-58.
- Meneghetti SMP, Meneghetti MR, Wolf CR, Silva EC, Lima GE, Coimbra MDA, *et al.* Journal of the American Oil Chemists' Society,2006;83(9):819-822.
- Stanciu I. Journal of Science and Arts,2018;18(2):453-458.
- Sheibani A, Ghotbaddini-Bahraman NASER, Sadeghi FATEMEH. Oriental Journal of Chemistry,2014;30(3):1205-1209.
- Stanciu I. Some methods for determining the viscosity index of hydraulic oil. Indian Journal of Science & Technology,2023;16(4):254-258.
- Stanciu I. Rheological behavior of corn oil at different viscosity and shear rate. Oriental Journal of Chemistry,2023;39(2):335-339.
- Stanciu I. Rheological characteristics of corn oil used in biodegradable lubricant. Oriental Journal of Chemistry,2023;39(3):592-595.
- Stanciu I. Effect of temperature on rheology of corn (Zea mays) oil. Oriental Journal of Chemistry,2023;39(4):1068-1070.
- Stanciu I. Study Rheological Behavior of Rapeseed oils Compared to Mineral oil. Oriental Journal of Chemistry,2021;37(1):247-249.
- Stanciu I. Influence of Temperature on the Rheological Behavior of Orange Honey. Oriental Journal of Chemistry,2021;37(2):440-443.
- Ribot F, Toledano P, Sanchez C. Inorg Chim Acta,1991;185(2):239-245.
- Catterick J, Thornton P. Adv Inorg Chem and Radio Chem. In: Emeleus HJ, Sharpe AG, editors. Vol. 20. Academic, 1977.