Temperature Dependency of Water Viscosity

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The dependency of dynamic viscosity of water, the commonly encountered liquid in engineering, on temperature was first observed experimentally by the French hydraulic engineer Pierre-Louis-Georges Du Buat (1734 - 1809) [1 - see endnotes] and reported in his two volume book *Principes d'hyraulique* (1786) [2]. This was the first time, to my knowledge, the temperature dependency of viscosity was studied.

Du Buat was a gifted experimenter and he devised a method for measuring the pressure distribution over a surface of an obstacle by arranging many holes on the surface of a body, with only one open at a time; the pressure in the hole being easily measured by a manometer. As we may notice, this method is in use even today. Du Buat showed the existence of *negative* pressures (negative, when compared with the pressure of the undisturbed flow) in the rear of solid obstacles in a flow field.

He was also the first person to experimentally discover the *no-slip* condition between a fluid *wetting* a solid wall, which we recognize today as the Du Buat - Stokes boundary condition [4].¡span¿¡/span¿ Among other things, Du Buat also contributed to the study of solid motion in a fluid with the concept of "virtual mass". An account of Du Buat's experimental deeds and its historical niche in the evolution of fluid mechanics, are well discussed by Nemenyi (1962). Here we focus (see Table 1) on his pipe flow experiments. One of his principal objectives is to get an *idee de la fluidite* of different liquids having different properties. His experiment involves a horizontal test pipe connecting a reservoir in one end and open to atmosphere on the other end, the discharge being collected in another reservoir.

For the flow of different liquids, the pressure load, in inches of liquid column,

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Du Buat's experimental results supporting his suspicion of whether different liquids affected by their properties (viscosity) *still* come out of a pipe, at the *same* speed.

Experiments on the movement of different liquids, at different degrees of temperatures, and at different heads, inside glass pipes (...that have served the previous experiments.)					
Exp. No.	Name of the Liquid	Temperature over ice point	Pressure Head (load) at the start of the pipe	Height (of discharge) at the exit per minute	Speed per second
		°C	inches	inches	inches
...	...	...	...	...	...
44	saline water	3	2.0833	5.1666	12.7823
45	saline water	11	2.0833	5.222	13.9197
...	...	...	...	...	...
52	rain water	30	15.2916	6.9166	35.980
53	rain water	36	15.2916	7.0833	36.847
54	rain water	56	15.2916	7.2013	37.461
...	....	...	...	...	...

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Fig. 1.

at one end and the discharge per minute in the other end in inches of rise of the liquid are measured. With the results of these experiments, among other things, he was able to show that the properties of liquids (not named explicitly as viscosity, we are still in 1786) do affect their discharge out of a pipe maintained across a pressure drop.

More than half a century later, Hagen (1839) and Poiseuille [5] (1840) carried out independently pipe flow experiments, which as we know, led to the now famous Hagen-Poiseuille relation between pressure-drop and fluid speed for duct flow. Poiseuille in the introduction of his article acknowledges Du Buat, Girard [6] and Navier to have investigated the problem before him.

Later on, Helmholtz (1860) reduced Poiseuille's data in the form,

$$\mu = \frac{0.01779}{1 + 0.03368T + 0.00022099T^2} \tag{1}$$

a palatable formula for the viscosity variation of water with temperature (T), in C. G. S. units (see page 575, Lamb (1932) for further details). The most recent one for water at atmospheric pressure is suggested by Kestin and Wakeham (1988).

While the viscosity of liquids like water decreases with increase in temperature, for gases (including air) it would increase with increase in temperature.

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Endnotes

(1) not to be confused with Arsene Dupuit, another French hydraulic engineer who contributed to the understanding of flow through porous media.

(2) here we use the 2^{nd} edition, which contains more experimental results than the 1^{st} edition of 1779. The final edition of the book came in 1816, as a three volume set.

(3) only selected (for temperature variation) data, from page 9, vol. II, Du Buat (1786), is shown - translation from French is mine.

(4) It is worth reminding here that the no-slip condition for a viscous fluid, although correctly taken into account in his study, was never stated by Newton explicitly, even while proposing his hypothesis on the concept of viscosity.

(5) Jean L. M. Poiseuille (1799 - 1869) (pronounced *Pwah-zu-yuh* - read *zu* as zoo) and his experiments are well discussed in many secondary sources, such as Tokaty (1971).

(6) Girard had concluded earlier in 1813, through experiments, that the laws of water flow in long and short pipes are different; that in a sufficiently long pipe, p, the pressure per square unit area of cross section and velocity v, change so that the ratio $dp/4lv$ remains a constant. Notice this conclusion of $dp/4lv = A$, a constant, is in agreement with the experimental results of Du Buat in Table 1.

References

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(5) Nemenyi, P. F., 1962 The Main Concepts and Ideas of Fluid Dynamics in their Historical Development. Archives for History of Exact Sciences, 2, 52-86.

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(7) Tokaty, G. A., 1971 A History and Philosophy of Fluid Mechanics. Dover Pub. Inc., New York

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