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A Study on the Behaviour of Non-Newtonian Fluid

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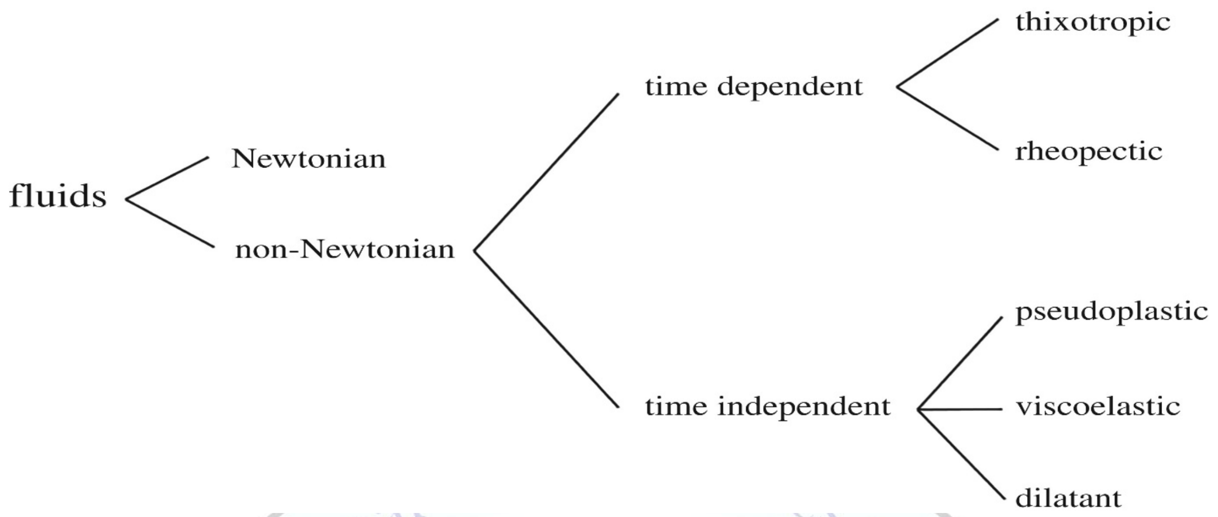
Abstract:

This paper aims at studying the behaviour of fluids, Non- Newtonian in nature and in this exercise characteristics of such fluids and their different types have been discussed. Investigation into the nature and effect pertaining to shear stress including shear strain under different conditions has been made. Definition of fluids has been derived that fluids deviating from Newtonian fluids are known to be Non-Newtonian fluids meaning that these are the fluids which do not obey the law of viscosities. The properties of several types of Non-Newtonian fluids which have enhanced their value in the field of engineering, technology and industrial fields are considered. The purpose of this study is to know the importance of fluid behaviour, its wide spread contribution and application.

Key words: *Non-Newtonian Fluid, Viscosity, Stress, Strain.*

Introduction:

A fluid which does not follow the law of viscosity is known to be Non- Newtonian fluid. According to this law there exists proportional relationship between shear stress and shear strain at constant temperature as well as pressure where viscosity is the constant of proportionality. Temperature brings about decrease in viscosity but pressure increases it. No linear relationship is shown by shear stress with respect to shear strain so far as Non-Newtonian fluids are concerned. Viscosity, the Constant of proportionality may change under the influence of stress or applied force. For this reason Non- Newtonian fluids display different behaviour and as such are **comparatively more useful than Newtonian fluids in their application**. For example some such fluids are slurries, colloidal suspensions, blood, banana puree, plastics and industrial polymer. A number of mathematical models like, Jeffry model, micro-polar model, Bingham model and Power law model are very useful in describing the flow of these fluids. In the present paper it is stresses to the study various kinds of behaviour of Non- Newtonian fluids, their importance and application.



Definitions:

Viscosity:

It is the amount of resistance offered to the flow of a fluid due to internal friction of the following fluid. It depends upon its molecular built up. High viscosity high friction and slow motion or flow and low viscosity low friction and faster rate of flow.

Non-Newtonian Fluid:

A fluid which disobeys law of viscosity and shear stress in this case does not bear a linear relationship to shear strain. Viscosity, may undergo change under the influence of applied force or stress.

Non-Newtonian fluid Behaviour:

To study the fluid behaviour pertaining to Non-Newtonian fluids concept of Newtonian fluid behaviour should be clear. In the case of Newtonian fluids the viscosity will not undergo any change as long as temperature and pressure are constant, that means viscosity remains constant. While In the case of Non-Newtonian fluids viscosity is the apparent viscosity i.e. local shear stress divided by local shear strain ($\frac{local\ shear\ stress}{local\ shear\ strain\ rate}$) at a particular point at a given temperature and pressure is not constant. It depends upon flow conditions. In this case the flow curve does not pass through the origin.

It is needed that while defining Non- Newtonian behaviour the range of shear rate is to be ascertained under which a particular fluid behaviour, Rheology is to be considered as the Apparent viscosity, here depends upon shear rate. Same fluid will show different value of apparent viscosity for different range of shear rate. Sometime increasing viscosity is shown and sometime decreasing. In this case

Some Non-Newtonian Fluids:

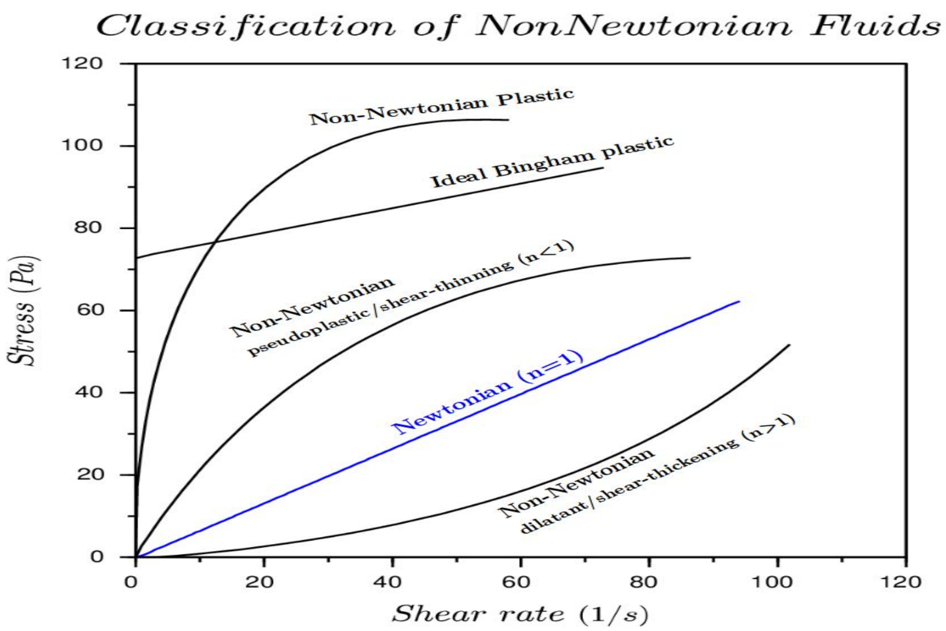
Here is a mention of some such fluids and these are sticky in nature and under particular range of shear rate, exhibit Non- Newtonian characteristics.

Food stuffs like vegetable and fruit purees, Sauces, Jams, Dairy Products, Blood, Saliva, Paints, Polishes, Varnishes, Crude Oil, Personal care products, Cosmetics, Pharmaceutical Products, Pastes,	Lubricating Oils and Greases, Bitumen, Cement Paste, slurries, Printing colour, Ink, Mineral Suspension Polymers, Wet Beach Sand, Drilling Mud, Waxy Crude Oil.

There is a certain range of shear rate which is very important to decide the behaviour of Non-Newtonian material since the behaviour changes depend on range of shear rate. Hence a particular or specified range of shear rate is required for a particular application.

For example:

1. Pipe flow-Pumping, blood flow 10^0-10^3 Sec^{-1}
2. Food 10^3 -10^2 Sec^{-1}
3. Paper Industry 10^3 -10^4 Sec^{-1}
4. Gasoline Engine Lubricating 10^3 -10^2 Sec^{-1}
5. Polymers 10^0 -10^2 Sec^{-1}
6. Painting and coating 10^{-1} -10^1 Sec^{-1}
   (Draining under gravity)
7. Medicine , Paints 10^6 -10^4 Sec^{-1}



Viscoelastic Fluids:

Such fluids acquire original shape completely or partially when the acting force or stress is released/ withdrawn.

Viscoelastic Fluid Behaviour:

Non-Newtonian fluids show viscoelastic fluid behaviour. Elastically deformed perfect solid comes to its original state when the stress is withdrawn. Soap solutions, polymer melts and synovial fluids show viscoelastic behaviour under specific shear rates. Viscoelastic materials possess the quality to store and regain shear energy but pure viscous fluids san it. We have observed that apparent viscosity ($\frac{local\ shear\ stress}{local\ shear\ strain\ rate}$) depends on shear rate. So the apparent viscosity changes when shear rate changes. Duration of shearing also has its effect. Sometimes with the increase in duration of shearing the viscosity may increase but the apparent viscosity may show increase or decrease at different occasions. Such fluids behave as fluids as well as elastic solids. Hook's law of elasticity is followed. Related equation is given by

$$\gamma' = \frac{\tau}{\pi} + \frac{r'}{K}$$

Time Independent:

In such fluids viscosity does not depend on time. Dependence isexhibited on shear stress as well as shear strain..linear relation between the two is given by

$\tau = (y')$ where τ denotes shear stress andγ' shear strain.

Shear Thinning in Pseudo plastic fluids:

Most of the fluids which deviate in behaviour from Newtonian fluids behave as shear thinning fluids. Shear rate increase decreases their apparent viscosity. Temporary viscosity loss occurs in their case and are known as **pseudo plastic** also. The more shearing the lesser viscous the fluid becomes**. Paint** can be quoted as an example. It is found to be very viscous when taken out of the cane or taken with the brush. Since the shear rate is small and when it is applied on the wall it is under layer shear rate and becomes less viscous.

Ketchup In this case viscosity decreases when shear stress increases. Initially when you try to take out the fluid, the flow is difficult due to slow rate of deformation but shaking the inverted bottle the result is sudden gush of fluid which is due to lower viscosity.

Another such fluids can be taken to be blood. Shear thinning affects the blood flow in the body due to the decrease in viscosity due to increased shear strain rate. Ball point pen ink, polymer melt, synovial fluid, fabric conditioner and lubricating grease fall under this category.

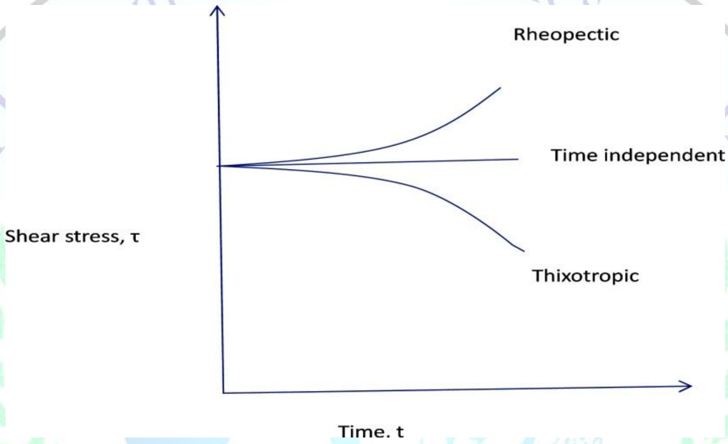
Bingham Plastic Fluids:

In Plastic fluids the shear thinning is considered to be at the extreme or certain fluids yield stress is needed for the fluid flow to begin. All such fluids can be termed as Bingham plastic fluids.

For example pastes, creams do not flow out of the tube even if it is turned upside down through stress due to gravity is there, on clinching the tube in hand pressing it, the paste flows out. This is because the fluid requires finite yield stress before it begins to flow.

Dilatant or Shear Thickening Fluids.

Such fluids show increase in viscosity when there is increase in shear rate. Starch suspensions, Gum solutions and wet sand are considered as shear thickening or Dilatant fluids. In such fluids more and more shearing will make the fluid more viscous. We can extend the example of quicksand which is a thick mixture of sand in water. It is easy to move through it in case we walk slowly but if we try to rush through it our movement is resisted and we are held up.



A house built on some clay, under the jolt of Earthquake, will face destruction. This is due to sudden stress applied on the material which liquefies it resulting into loss to the building.

Time Dependent Fluids:

These are known as complex Non- Newtonian fluids which show shear thinning behaviour at low shear rates and thickening behaviour at high shear rate. In their case the apparent viscosity does not depend only on shear rate but duration of shear rate also. To identify this behaviour the shear rate is increased in a steady manner from 0 to some specific higher value and then decreased at the same rate to 0 value. If in this process the two curves so obtained carve a hysteresis loop then there exists time dependent property/ behaviour. If overlapping of curves occurs then time dependent behaviour is not there. Large enclosed area of the curve shows stronger time dependent behaviour. Red mud suspension and Cement paste are the examples.

Rheopectic Fluids:

In the case of fluids where the shear strain rate depends on time, increasing shear stress is needed so that shear strain rate is kept constant. Such fluids are known as Rheopectic. Printer ink, Gypseum paste and synovial fluids are the examples of these fluids. When shaken for long time the fluid thickens due to increase in viscosity. Long duration of shearing force takes the viscosity to higher value. It may be considered as time dependent dilatant behaviour.

Thixotropic Fluid:

Its name comes from Greek word, 'Thixis' stands for shaking and 'trepo' for change. Certain fluids like Gel cannot flow unless external force is applied or is stressed. Apparent viscosity of a material decrease with the time of shearing. Example of such fluids is drilling fluid, waxy crude oil, red mud suspensions, protein solutions and cement paste.

Importance and Application of Non-Newtonian Fluid Behaviour:

Since Newtonian behaviour in many cases does not come up to the expectations and therefore Non-Newtonian behaviour, which is more complex in nature has to be modelled. Particularly in the processing pertaining to plastic and chemical industries such situations are faced. In mining industry, too, in dealing with muds and slurries Non-Newtonian behaviour is employed. It is also applied for lubrication and in bio-medical flows. Simulation of such flow is, therefore, of great importance to industry.

It is very difficult to offer any prediction in such liquid behaviours which are highly non-linear. Computer aided analysis and also designed software can have appreciable impact on these industries and is seen particularly in injection moulding of thermoplastics, due to availability of sophisticated computer packages. Introduction of new models in addition to solution techniques much progress has been made.

Conclusion:

In this article various types of Non- Newtonian characteristics/ behaviours have been considered and studied. Different behaviour shown by several materials has been discussed and highlighted. Need of shear stress and shear strain rate required to increase or decrease the viscosity, apparent viscosity for shear thinning or shear thickening has been studied including shear rates required for certain applications and mentioned qualitative explanations of each type of behaviour of Non- Newtonian fluids for furthering the study.

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