RHEOLOGY OF SCREEN PRINTING INK

A Thesis

Submitted to the College of Engineering of Al-Nahrain University in partial Fulfillment of the Requirements for The Degree of Master of Science in

Chemical Engineering.

By

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CERTIFICATION

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Abstract

Rheological studies on printing inks(adhesion type inks) were carried out of various alkyd resin concentration. Several properties of ink are investigated such as viscosity ,shear rate and shear stress. The effect of time and concentraton of alkyd resin on the viscosity is also studied and discussed at 25 c⁰. The percentages of alkyd resin considered were 31.7, 28 and 24.5 wt% for time range of 0–35 sec using Rheology international R1:I:M viscometer at different values of speed and spindles size . It is found that the printing ink viscosity decreases clearly with time and increases with alkyd resin concentration. Equation for the Rheological behavior of screen printing ink was predicted, which is the power law .

It was found from n values that the screen printing ink behaves as a non-Newtonian pseudoplastic behavior, also the area of thixotropy was calculated which represents the cracking energy of the molecular bounds and reconstructing it which known as hystersis loop.

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NOMENOCLATURE

n	Power Law flow index
t	$Time(s^{-1})$
Т	Temperature(c°)
U	Flow velocity(m/sec)
$ au_{ij}$	Shear stress tensor(N/m ²)
ρ	Density (kg/m^3)
UI	Velocity vector
Р	Pressure(pa)
$ au_{ m R}$	Shear stress at r=R
Ν	rpm
А	$Area(m^2)$
F	Force of liquid (N)
A,B,C	Constant of equ(4-27 to 4-29)
ω	Angular velocity (sec ⁻¹)
Ω	Angular velocity of bounding surface (sec ⁻¹)
R	Radius(m)
h	Height (m)
g	Gravity acceleration
π	22/7
Z	Height at any point of liquid(m)
Τ	Torque consistency variable in disc and plate(N.m)
Т	Total torque
$\omega(z)$	Angular velocity function of height

wt%	Weight percent	
θ	Angular displacement (sec)	
k	Consistency index	
9	Shear rate(sec ⁻¹)	
τ	Shear stress(N/m)	
μ	Viscosity (pois)	

Subscriptions:

cal	Calculated value
i	Component i
j	Component j



CHAPTER ON



INTRODUCTION

Generally printing inks are important, where it is used in wide fields such as printing of books, newspapers, credit cards and journals. Also printing inks are used to provide information about the produced goods [5].

There are different types of printing inks dependent according to the purpose of use, the type of the equipment or press that used in products of the ink, the raw materials and the nature of the surface to be written on i.e.(papers ,metallic or non metallic ,cards and plastic), printing press (letterpress, gravure, Lithography, screen saver) [33].

There are many substances used in producing the screen printing ink such as alkyd resin ,pigment, linseed oil, castor oil, thinner, Toluene, drier. The alkyd resin is the basic component to produce the ink ,where it is used as vehicle and binder to the dye ,at the same time it behaves as a thickener substance ,where it increase the viscosity of the ink.As for the rest of the substances they help for much adhesion on the wanted surface and exceeds the drying process in lesser time [32].

Researches concerning the study of printing inks are limited in the literature

Rheology is with the science of the deformation and flow behavior of matter under applied force [17]. It is concerned with the response of materials to mechanical force, that response may be irreversible flow, reversible elastic deformation, or a combination of both. An understanding of rheology and the

ability to measure rheological properties is necessary before rheology can be controlled, and control is essential for the manufacture and handling of many materials, i.e. (cosmetics, plastics, paint, inks) [33].

The aim of the present work: -

1-Studing the relations between shear rate and viscosity to know the type of ink Newtonian or non-Newtonian behavior.

2-Studing the rheological properties (shear rate, shear stress) of Screen Printing ink.

3-Determine the values of (n) from plots of shear stress (τ) versus shear $\stackrel{\circ}{\text{Rate}(\nu)}$ on log-log scale .

4-Determine the area (hystersis loop) an indication of the amount of thixotropy.

5-Studing the effect of time and alkyd resin concentration on the viscosity behavior of ink.



CHAPTER TWO

LITERATURE SURVEY

2-1 Historicaly of Ink

Historicaly, writing ink was first prepared and used by the Chinese and the Egyptians as early as 2600 BC. early inks were Probably.composed of carbonaceous materials such as lamp black or soot mixed with animal glue or vegetable oil vehicles. Reference is also made to the Chinese Invention of solid ink, black and pellets similar to India ink as it is known today, which had its origin during the period 220-419AD.Writing –ink Formulation became a highly developed art under The Chinese, who printed from hand-cut blocks in the 11^{th} century AD, 400 years before Gutenberg introduced movable type in Europe. The number of printing ink Manufacturing establishments in the United States is approximately 700.This includes some 100 captive ink Plants.The value of the total Printing-ink production in the United States was approximately $\$10^6$ [32].

2-2 Printing Inks

Printing ink is a mixture of coloring matter dispersed or dissolved in a vehicle or carrier. The colorants used are generally pigments, and dyes, or combinations of these materials. The vehicle is the liquid that holds the particles of pigment and carries them to the paper [15]. used acts as a carrier for the colorant during the printing operation, and in most cases, serves to bind the colorant to the substrate. Printing inks are applied in thin films on many substrates such as paper, paperboard, metal sheets and metallic foil,

plastic films, molded plastic articles, textiles and glass, It is generally conceded that there are four classes of printing inks, which vary considerably in physical appearance, composition, method of application, and drying mechanism. They are letterpress and lithographic (litho) inks, which are commonly called oil inks or paste inks, usually of pasty consistency, and flexographic (flexo), rotogravure (gravure), screen saver inks which are referred to as solvent or liquid inks.

Four properties of inks are of cardinal importance-drying, printability which is largely a function of the rheology of the ink, color, and use properties. Use properties are those considerations that determine how printed substrate function throughout all processing and usage of the printing ink from the time of printing throughout the useful life of the printed product [32].

There are four main printing processes: relief or letterpress, intaglio or gravure, planographic or lithography, and stencil or screen printing [34].

<u>SCREEN PRINTING INK:</u>

These inks, often known in the past as Silk-Screen inks, are printed on the substrate by being forced through a screen Stencil by means of a squeegee. Screen printing inks are dispersions of Pigments in vehicle [32].

Silk -Screen inks used for high-grade stencil printing greeting cards board, paper posters, ceramics, and plastic [40].

2-3 General Composition of Printing Inks: Ink is made of six main ingredients:-

2-3-1 Pigment:

There are two Kinds of materials used to impart color to the "vehicle" portion of a printing ink.

A- pigments are insoluble colored materials, which are dispersed in the vehicle [28].

B- dyes are colored materials which are soluble in the solvents used in the manufacturing of printing inks [26].

Carbon black:- Carbon black is an important member of the family of industrial carbons. Its various uses depend on chemical composition and pigment properties.

This printed page was made with ink containing a pigment grade of carbon black [30].

Methods of manufacturing carbon Black involved the partial combustion of organic materials such as oils, waxes and woods [41].

The three most important properties used to identify and classify carbon black are surface area, structure, and tinting strength [15].

2-3-2 Resin:

Resin provides the hardness and gloss of the film. Both these properties increase with the increasing of resin content, but the durability decreases such as alkyd resin [27]. Both natural and articicial resins are used in the manufacturing of printing ink. Alkyd resin is used widely for economical aspect [21].

Alkyd resin:- Alkyd resins have been defined as the reaction product of polyhydric alcohol's and polybasic acids. This definition includes polyester resins of which alkyds are a particular type [33].

The characteristics of alkyd resin are rapid drying, good adhesion, flexibility mare resistance, and durability [29].

<u>2-3-3 Toluene (C₆H₅CH₃):</u>

Toluene is the most extensively used diluent for cellulose nitrate lacquers. Toluene is a solvents for a large number of resin and is miscible with drying oils and most other solvents [2].

<u>2-3-4 Oils</u>:

Oils used in the paint and inks industry are derived mainly from vegetable and, to a much lesser extent, from animal sources. They are esterse of glycerol and fatty acids, non-volatile, and unstable at high temperature [38]. These oils vary in properties according to the nature of the fatty acid combined with the glycerol, i.e.they may be saturated or unsaturated. In the latter case, the oil possesses the valuable property of setting slowly to a solid and adherent film when spread on a surface and exposed to air. This film formation is an irreversible process and the film is insoluble in white spirit. This process is known as"drying" [27]. Drying oils are available in a variety of viscosities for use in paints, ink [11] and varnishes the part of the ink in which the other materials such as pigments, dries, and solvent are dissolved or suspended [35].

Two types of oils are used mainly in producing printing inks. Linseed oil drying oil and Castor oil non drying oil.

Linseed oil is produced from the seeds of the common flax plant. Linum usitatissimum [45].

Castor oil is derived from the plant Ricinus communis is non drying oil but can be converted to dehydrated castor oil which produces superior alkyd resins [9].

2-3-5 Driers:

Catalyst the conversion (by oxidation and polymerization) of the oil to the solid state. They are usually added to the component of printing ink in very small quantities as solutions of naphthenates or octoates of lead, cobalt, calcium, and sometimes manganese [1].

When film of drying oil is exposed to the air it sets gradually, and ultimately" dries" to a tough elastic film. Whereas the original oil is soluble in solvents, the dried film is not soluble in these solvent and is therefore quite different in nature from the original oil. It is this drying process which enables one coat of ink to be applied over another [18].

Straight drying oils, such as linseed, drirs very slowly, some two to three days being required for raw linseed oil. So that we added on these driers(cobalt, calcium, manganese and lead) so as to haste the drying process in less time [31].

Cobalt naphthenate is used as drying material. Since in the production of printing ink production the quantity of drier depend up on the type of printing ink and also depends upon the storage period and storage conditions [31] .IT was necessary to incorporate this material in each ink for a definite time prior to each initial test, and the use of volatile solvent had to be avoided; an oleic acid solution of the naphthenate is used [7].

2-3-6 Thinners:

Thinner is added for the sole purpose of reducing the oil/resin complex to a suitable consistence for application. They should evaporate completely from the applied film [22].

2-4 Rheological Properties of Printing Inks

2-4-1 Viscosity

Viscosity is defined as the resistance of liquid to flow [36]. When a fluid starts to flow under the action of a force shearing stress arises everywhere in that fluid that tends to oppose the motion [20]. Viscosity is resistance to flow .If ink flows or pours readily; it has a low viscosity. If it refuses to pour at all, it has high viscosity .Screen inks usually have a relatively high viscosity [12]. The viscosity of ink can be characterized using cone and plate rheometer or disk, to obtain shear-viscosity relationship [39]. Viscosity is important for ink quality: ink is made up of color pigment, resin, and solvent. Evaporation of solvent in printing operations increases percent solids, causing changes in color and solid concentration this leads to increasing viscosity [14].

Viscosity can be defined as the ratio of shear stress to shear rate. [36] as shown in equation (2-1)

Viscosity =
$$\frac{\text{Shear stress}}{\text{Shear rate}}$$

$$\mu = \frac{\tau}{\gamma} \left[\frac{\text{Dyne-sec}}{\text{cm}^2} \right] = \text{Poise} \qquad (2-1)$$

Shear stress: Stress is defined as force per unit area, and is distributed continuously throughout any continuous medium, which is subjected to external forces.

Shear rate: is defined as the differential change in velocity divided by the distance.

Viscosity is more easily measured than some of the properties that affect it, making it a valuable tool for material characterization. Having identified a particular rheological behavior in a material.

Viscosity depends on the followings.

A-Shear rateB-TimeC-Physical / Chemical PropertiesFor ink, Risen, Pigment, etc

A-Shear rate: Most of the fluids display'shear thinning'that is the viscosity decreasing with the increasing of shear rate. The viscosity is often the most important property for engineering calculation [42].

Viscosity is measurement at several shear rates to detect rheological behavior that may have an effect on processing [43].

B-Time: The time elapsed under conditions of shear obviously affects thixotropic materials, but changes in viscosity of many materials can occur over the time .The viscosity decreasing with the increasing of time [4].

C-Physical / Chemical Properties: The composition of a material is a determining factor of its viscosity. When this composition is altered, either by changing the proportions of the component substances, or by the addition of other materials, a change in viscosity is very likely. For example; the addition of a solvent to printing inks will lower the viscosity [19].

2-4-2 FLOW CURVES

The measured viscosity of a fluid can be seen to behave in one of four ways when sheared, namely:

A-Viscosity remains constant no matter what the shear rate is Newtonian behavior.

B-Viscosity decreases, as shear rate is increases Pseudoplastic (Shear thinning behavior).

C-Viscosity increases, as shear rate is increases Dilatant (Shear thickening behavior).

D-Viscosity appears to be infinite unit when a certain shear stress is achieved (Bingham plastic) [6].

Since it is the relationship of shear stress to shear rate that are strictly related to flow, we can directly show the flow characteristics of a material by plotting shear stress varsus shear rate, graphs of this type is called a flow curve .see fig. (2-1).



Figure 2-1: show the flow curves and viscosity curves of the four behavoirs.

2-4-3 Power law- (or Ostwald model)

Many non-Newtonian materials undergo simple increase or decrease in viscosity as the shear rate is increased. If the viscosity decreases as the shear rate is increased, the material is said to be pseudo plastic (shear thinning). The opposite effect is known as dilatant (shear thickening).

The power law is good for describing a materials flow under a small range of shear rates. Most materials deviate from this simple relationship over a sufficiently wide shear rate range.

$$\tau = k^*$$
 (2-2)

Where 'n' is often referred to the power law index of the material. If n is less than one, the material is pseudo plastic, if n is more than one then material is dilatant, if n equal one then Newtonian [44].

2-5 Newtonian and Non-Newtonian fluids

2-5-1 Newtonian fluid:

This is the simplest type of fluid where the materials viscosity is constant and independent of the shear rate as shown in equation(2-3). Newtonian liquids are so called because they follow the law of viscosity as defined by Sir Isaac Newton [24].

Shear Stress = Shear rate* viscosity

 $\tau = \mathop{\circ}_{\gamma} \mathop{*}_{\mu} \mu \tag{2-3}$

(μ Const)



Figure 2-2: Water.Oil and dilute polymer solutions are some examples of Newtonian materials.

2-5-2 Non-Newtonian fluids:

Non-Newtonian fluid is defined as one in which the relationship between the shear stress and shear rate is non-linear as shown in fig (2-3). The viscosity of such fluids will therefor change as the shear rate is varied. This measured viscosity is called the "apparent viscosity".

There are several types of non-Newtonian flow behaviors, characterized by the way fluids viscosity changes in response to variations in shear rate as shown in equation (2-4) [10].

$$\tau = \mu(\overset{\circ}{_{\boldsymbol{v}}})\overset{\circ}{_{\boldsymbol{v}}} \tag{2-4}$$





Figure 2-3: The Relation shipe between viscosity and shear rate. There are three classes of fluids which will be treated as follows:

- A-Time-independent
- B- Time-dependent
- C-Relation between time-dependent and time-independent fluid

A-Time-independent non-Newtonian fluid

Fluid of the first type whose properties are independent of time may be described by a rheological equation of the form

$$_{\gamma}^{\circ}=f(\tau) \qquad (2-5)$$

This equation (2-5) implies that the rate of shear at any point in the fluid is a simple function of the shear stress at that point.

This fluid may conveniently be subdivided into three distinct types depending on the nature of the function in equation (2-5). These types are:-

1-Bingham plastics

2-Pseudoplastic fluid

3-Dilatant fluids

And typical flow curves for these three fluids are shown in Fig. (2-4) and compared with the linear relation typical of Newtonian fluid [44].



Figure 2-4: Flow curves for various types of time-independent non-Newtonian fluid .

1-Bingham plastics: Bingham plastic is characterized by a flow curve, which is a straight line having an intercept τ_y on the shear-stress axis. The yield stresses the magnitude of the stress, which must be exceeded before flow starts [42].

2-Pseudo-plastic (shear-thinning): This type of fluid will display a decreasing viscosity with an increasing shear rate, as show in Figure (1-4), probably the

most common of the non-Newtonian fluid, pseudo-plastic include inks, paints, and etc [43].

The ratio of shear stress to shear rate which is, termed the viscosity, The logarithmic plot of shear stress and shear rate for these materials is often found to be linear over many decades of shear rate, with a slope between zero and unity. As result, an empirical functional relation known as the'power law's widely used to characterize fluids of this type. This relation, which was originally, proposed by de waele (1923) and Ostwald (1925), as shown in equation (2-2).

$$\tau = k^* \quad (2-2)$$

k and n are constants

If n < 1 for pseudo-plastic the viscosity function decreases as the rate of shear increases. This type of behaviour is characteristic of high polymers, polymer solution and many suspensions. One physical interpretation of this phenomenon is that with increasing rates of shear the molecules (or the structure) are progressively aligned. Instead of the random intermingled state, which exists when the fluid is at rest, the major axes are brought into line with the direction of flow and the viscosity decreases [25].

3-Dilatant (shear thickening) fluid: Dilatant fluid is similar to pseudo-plastics but the viscosity for these materials increases with the increasing of rates of shear. Osborne Reynolds (1885) originally discussed this type of behaviour in connection with concentrated suspensions of solids. He suggested that when these concentrated suspensions are at rest, the voidage is at a minimum and the liquid is only sufficient to fill the voids. When these materials are sheared at low rates, the liquid lubricates the motion of one particle past another and the stresses are consequently small. At higher rates of shear the dense packing of the particles is broken up and the material expands or'dilates'sliightly and the voidage increases. There is now insufficient liquid in the new structure to lubricate the flow of the particles moving past each other and the applied stresses have to be much greater. The formation of this structure causes the viscosity to increase rapidly with the increasing of rates of shear [42]. see Fig. (2-4).

B-Time-dependent non-Newtonian fluids.

Included are those materials for which shear stress changes with the duration of shear. Excluded are changes, which might be produced through mechanical breaking or destruction of particles or molecular bond [23].

These fluids may conveniently be subdivided into three distinct types.

1-Thixotropic fluid-breakdown of structure by shear.

2-Rheopectic fluids-formation of structure by shear.

3-Viscoelastic fluids.

1-Thixotropic fluids: Thixotropic fluids possess a structure the breakdown of which is a function of time under shear [37].

Thixotropic is a rheological phenomenon of tremendous industrial importance. It is a time-dependent characteristic of some non-Newtonian fluids. Another non-Newtonian phenomenon, pseudoplastic, in that a thixotropic fluid has the characteristic of rebuilding its structure and consequently regaining its viscosity as a function of time. That is, in a thixotropic fluid, the viscosity is not only dependent on the shear rate but also the time period through which the fluid is being sheared [13].

As the structure breaks down with constant shear rate, shear stress decreases. This structure can rebuild itself if not prevented from doing so by externally applied forces. The shear diagram of a thixotropic fluid as obtained with a rotational viscometer is given in fig (2-5). The area within loop DAD is an indication of the amount of thixotropic. If the shear rate is held constant point A has been reached on the up curve, the shear stress will decreases along path AB until point C is reached.beyond which no further breakdown can occur for that shear rate. If shear rate is then decreased the down curves CD is followed. Any number of intermediate down curves, such as BD, is possible. Examples of such fluids are mayonnaise, paints, and inks [37].



Figure 2- 5: The shear rate diagram of thixotropic fluid.

2-Rheopectic fluids: Rheopectic materials will set up or build up, increase in apparent viscosity very rapidly upon being rhythmically shaken or tapped. Examples of these materials are Benton sols, vanadium pentoxide sol [37]. in thixotropy the a decreasing viscosity as function of both shear rate and time is observed; however, the critical difference between the two is that, in a

rheopectic sample, the viscosity builds faster than it decreases initially. Thus, for one shear rate, tow values of viscosity are recorded: one value for the up curve and a different value for down curve [8]. as shown in fig. (2-5).

3-Viscoelastic fluid: this fluid exhibits elastic recovery from deformations, which occur during flow [37].

C- The relation between time-dependent and time-independent fluids:

Thixotropic is rather like pseudoplasticity in which the time required for the alignment of particles is not negligible. This time effect for 'pseudoplastic material's not observable in the apparatus normally used for the testing of these fluid. The difference then is only a matter of degree.

In the same way rheopectic fluids are superficially similar to their timeindependent counterparts (dilatant fluids) in which the time for structure build-up isinsignificantly small [3].

2-6 Measurement of shear rate

The measurement quantities are angular velocity (Ω) as a function of torque (T) includes determination of shear.stress, shear rate relations, also determination of apparent viscosity (η) of these solution. There are several types of viscometers [10].

The viscometer used in this study is of (Disc and Plate) the disc is rotating member. The shear rate is determined from the angular velocity (Ω). The flow field is described in terms of the cylindrical coordinates shown in fig. (2-6).



Figure 2-6: Viscometer Disc and Plate

The flow field is described is terms of the cylindrical coordinates shown in Fig 2-6, for which the tensor velocity components are:

$$U^{1} = \frac{d\theta}{dt} = w(z)$$
 $U^{2} = U^{3} = 0$ (2-6)

And the corresponding physical components are:

 $U_{\theta} = r\omega(z)$ $U_{z} = U_{r} = 0$ (2-7)

Where $\omega(\mathbf{r})$ is the angular velocity

Where
$$\stackrel{\circ}{\gamma} = r \, dw/dz.$$
 (2-8)

The compound momentum equations of motion are [4].

r Comp.:-

$$\rho \left[\frac{\partial U_{r}}{\partial t} + U_{r} \cdot \frac{\partial U_{r}}{\partial r} + \frac{U_{\theta}}{r} \cdot \frac{\partial U_{r}}{\partial \theta} - \frac{U_{\theta}^{2}}{r} + U_{z} \cdot \frac{\partial U_{r}}{\partial z} \right] = -\frac{\partial P}{\partial r} - \frac{\partial P}{\partial r} - \frac{1}{r} \cdot \frac{\partial P}{\partial r} - \frac{1}{r} \cdot \frac{\partial P}{\partial \theta} - \frac{\tau_{\theta\theta}}{r} + \frac{\partial T_{rz}}{\partial z} + \rho \cdot g_{r}$$
(2-9)

θ Comp.:-

$$\rho \left[\frac{\partial U_{\theta}}{\partial t} + U_{r} \cdot \frac{\partial U_{\theta}}{\partial r} + \frac{U_{\theta}}{r} \cdot \frac{\partial U_{\theta}}{\partial \theta} + \frac{Ur \cdot U_{\theta}}{r} + U_{z} \cdot \frac{\partial U_{\theta}}{\partial z} \right] = -\frac{1}{r} \frac{\partial P}{\partial \theta} - \frac{1}{r^{2} \cdot \frac{\partial P}{\partial r}} \left[\frac{(2 + 10)}{r^{2} \cdot \frac{\partial}{\partial r}} (r^{2} \cdot \tau_{r\theta}) + \frac{1}{r} \cdot \frac{\partial \tau_{\theta\theta}}{\partial \theta} + \frac{\partial \tau_{\thetaz}}{\partial z} \right] + \rho \cdot g_{\theta}$$

$$(2-10)$$

Z Comp. -

$$\rho \left[\frac{\partial U_z}{\partial t} + U_r \cdot \frac{\partial U_z}{\partial r} + \frac{U_{\theta}}{r} \cdot \frac{\partial U_z}{\partial \theta} + U_z \cdot \frac{\partial U_z}{\partial z} \right] = - \frac{\partial P}{\partial z} - \left[\frac{1}{r} \cdot \frac{\partial}{\partial r} (r \cdot \tau_{rz}) + \frac{1}{r} \cdot \frac{\partial \tau_{\theta z}}{\partial \theta} + \frac{\partial \tau_{zz}}{\partial z} \right] + \rho \cdot g_z$$
(2-11)

$$z^{3} = r \text{ comp:}$$

 $-\frac{\rho U^{2} \theta}{r} = -\frac{\partial p}{\partial r}$ (2-12)

 $z^1 = \theta$ comp:

$$0 = \frac{\partial \tau_{\theta z}}{\partial z}$$
(2-13)

 $z^2 = z$ comp:

$$0 = -\frac{\partial P}{\partial z} + \frac{1}{r} \cdot \frac{\partial \tau_{\theta z}}{\partial \theta} + \rho g_z \qquad (2-14)$$

Integration of Eq. (2-8) with respect to z gives:

$$\omega = \frac{\stackrel{\circ}{\gamma} z}{r} + e_1^0 \qquad (2-15)$$

The constant of integration, c_1 , must be zero since w = 0 at z = 0, so that the shear rate is given by

$${\stackrel{\circ}{\nu}} = {\stackrel{\circ}{\nu}}(r) = \frac{\omega r}{Z}$$
 or ${\stackrel{\circ}{\nu}}(r) = \frac{\Omega r}{h}$ (2-16)

Where we have used the condition that $\omega = \Omega$ at z = h. Thus ,the shear rate at any point within the system may be determined directly from the angular velocity of the disc and the dimensions of the apparatus.

The shear stress may be determined from the expression for the total torque (T) on the disc. Torque is the product of force times the lever arm at which it is measured, it must be balanced by the moment due to the shear force developed within the fluid:

$$_{\rm T} = \int_{0}^{\rm R} r \tau_{\theta_z} \ 2\pi r \ dr = 2\pi \int_{0}^{\rm R} r^2 \tau \ dr \qquad (2-17)$$

Using equation (2-16) to change variables from r to equation (2-17) becomes

$$T = 2\pi \left[\frac{h}{\Omega}\right]^3 \int_0^{\Omega R/h} \tau_{\gamma}^{\circ 2} d_{\gamma}^{\circ}$$
(2-18)

Which can also be written:

$$\mathbf{T} = \frac{4}{{}^{\circ}3} \int_{0}^{\mathbf{v}\mathbf{R}} \tau_{\mathbf{v}}^{\circ 2} d_{\mathbf{v}}^{\circ} \qquad (2-19)$$

Where

$$\mathbf{T} = \frac{2\mathrm{T}}{\pi\mathrm{R}^3} \tag{2-20}$$

And

Is the shear rate evaluated at r = R

The relation between number of revolution per mint (N) and angular velocity (Ω) [16] is given in

$$\Omega = \frac{2.\pi}{60} . N \tag{2-22}$$

$$\Omega = 0.1047 \text{N}$$
 (2-23)

For a Newtonian fluid:

$$\tau = \mu \frac{\circ}{\nu}$$
 or $\tau_{\theta z} = \mu \frac{du_{\theta}}{dz}$ (2-24)

Where

 $U_{\theta} = r\omega$

From equation (2-12)

$$0 = \frac{\partial \tau_{\theta z}}{\partial z} = \frac{d^2 u_{\theta}}{dz^2}$$

And applying the boundary conditions:

(1)
$$U_{\theta} = 0$$
 at $z = 0$

(2)
$$U_{\theta} = r\Omega$$
 at $z = h$

gives the velocity distribution:

$$u_{\theta=} \frac{r\Omega z}{h}$$
 (2-25)

The shear stress is therefore:

$$\tau_{\theta z} = \mu \frac{du_{\theta}}{dz} = \mu \frac{r\Omega}{h} = \tau(r)$$
(2-26)

Now equation (2-17) gives the torque on the disc

$$T = 2\pi \int_0^R r^2 \tau \, dr = \frac{2\pi\mu\Omega}{h} \int_0^R r^3 \, dr = \frac{\pi\mu\Omega R^4}{h}$$
(2-27)

$$\tau_{\rm R} = \frac{\mu \Omega R}{h} = \frac{2T}{\pi R^3} = \mathbf{T}$$
(2-28)

So that



HAPTER THREE

EXPERMENTAL WORK

<u>3-1 The Composition of Screen Printing Ink</u>

The viscosity of three samples of screen printing ink had been studied with different alkyd resin concentrations .

The raw materials were purchased from the market ,and used to prepare the three samples in the petrochemical industries office-ministry of sciences and technology .Table 3-1 shows the composition of the samples .

material	Sample1	Sample 2	Sample 3
	(wt%)	(wt%)	(wt%)
Alkyd resin	31.7	28	24.5
Pigment	25	26.2	27.6
Linseed oil	14.4	15.1	15.9
Castor oil	9.6	10.1	10.6
Thinner	19.2	20.2	21.3
Drier	<1	<1	<1

Table 3-1: The composition of the screen printing inks

The alkyd resin of different weight percentage were taken, but for (pigment, linseed oil, castor oil, thinner, drier) the weight percent were being constant, because the alkyd resin is the most effect resin in the screen printing ink solution.

Mixing process was taken after shaking; then heated the samples were to $25c^{\circ}$ in water bath (memmert type).

Viscosity measurements were completed immediately, after preparing the mixture to avoid deposit formation or vaporizing of light ends. All the viscosity measurements were carried out at atmospheric pressure.

3.2 Viscosity measurement

Viscosity of each ink sample was measured at different shear rate. At each Shear rate eight different times measurements where taken (0, 5, 10, 15, 20, 25, 30,35) sec with a rheology international viscometer (Model R: I: M) were taken, shown in Fig. (3-1).

The viscometer was placed in a water bath (memmert type), which was capable of maintaining at temperature with in \pm 0.1 c of the selected temperature.

The viscometer rotates a sensing element and measures the torque necessary to overcome the viscous resistance to the induced movement. This is accomplished by driving the immersed element, which is called a spindle, through a berylium copper spring via the pivot point assembly. The percentage torque wind-up of the spring due to the viscosity of the fluid is displayed as engineering units, "E". The electronic circuitry of the viscometer converts the measured torque into viscosity units, and displays it in cPs, P, KP.

The viscometer is able to measure over a numbered of ranges since the viscosity is proportional to the torque wind-up of the spring; the torque wind-

up is proportional to the spindle speed, and is related to the spindle size and shape. For a material of a given viscosity the drag will be greater as the spindle size and/or rotational speed increases. The minimum viscosity range is obtained by using the smallest spindle at the slowest speed.

Autozero is an important element of preparing the instrument for operation. It is initiated by pressing the autozreo switch on the front panel after powerup, after spindle changes or when the user requires. It must be completed with a clean spindle attached, and the spindle runs in air. The value achieved will be added or subtracted from all subsequent readings (unit the next autozero or power down) to give a correct centipoises reading. This ensures instrument accuracy over time.

With the spindle immersed in the fluid under test, the instrument will continuously display (as selected) percentage torque wind-up in engineering units ("E") or viscosity in cps, p, Kp. To freeze the display and hold a reading; press the "Hold" switch. The spindle continues to rotate but the display holds the last reading.

The speed and spindle selected are displayed at the commencement of rotation, or after a speed/spindle change to allow the user check settings.

It is essential that the correct spindle is selected otherwise centipoises or the engineering unit conversions will be meaningless. The R1: 1:M is calibratted to bureau of standards values on the basis of the Instruments used, with its guard legs attached in a 600 ml low from griffin beaker. If the instruments are used in a larger container the ranges over which M1 and M2 spindles measure will be slightly increased. This effect is negligible with spindles M3 to M7.

The M7 spindle has a narrow "negk" on its shaft rather than the groove found on the other spindle should be immersed in fluid so that half of this "Neck" is covered.


Figure 3-1:Rheology Iinternational Viscometer



RESULT AND DISCUSSION

4.1 Effect of Shear Rate on the Viscosity and Relation with Shear Stress of Screen Printing Ink:

The viscosity of three different samples of Screen printing ink is determined at each alkyd resin concentration and its relation with shear rate is conducted .Shear rate is estimated from Eq.(2-16),and the angular velocity (Ω) is estimated from Eq.(2-23) from (N). Table 4-1 lists values of shear rate($\hat{\gamma}$) at different angular velocity values .The viscosity is measured at various time intervals range 0-35 sec .

Tables 4-2 to 4-4 show the variation of viscosity with shear rate. It is clear that the viscosity varies with shear rate indicating that the ink is non-newtonian fluid.

It is noticeable from Figs 4-1 to 4-3 the viscosity is defined as the resistance of flow decreases with the increasing shear rate, because this increase of shear rate breaks down the structure of the inks.

From Tables 4-2 to 4-4 (which is represented graphically in Figs 4-1 to 4-3 one can conclude that the printing ink is non-Newtonian material and the viscosity decreases with shear rate increase at alkyd resin concentration (31.7,28,24.5 wt%) this behavior is known as (pseudoplastic).

h = 6.2 cm the height of liquid R = 2.35 cm the radius of disc

h and R the constant but the Ω the variable with speed
rpm (N) =
$$0.1047 \Omega$$
 (2-23)

 $\Omega(\sec^{-1}) \quad \gamma^{0}(\sec^{-1})$ N 1.2564 0.4762 12 2.094 0.7936 20 1.1905 30 3.141 5.235 1.9842 50 60 6.282 2.381 100 10.47 3.9684

Table :4-1 The value of shear rate with angular velocity

Table 4-	- 2:	Viscosity	of alkyd	resin	31	.7wt %	with	shear	rate at	different	time.
			/								

Shear		Viscosity(p)									
Rate											
(sec ⁻¹)	0(sec)	5(sec)	10(sec)	15(sec)	20(sec)	25(sec)	30(sec)	35(sec)			
0.47621	7.211	6.83	6.63	6.48	6.34	6.27	6.15	6			
0.7936	7.11	6.75	6.69	6.5	6.42	6.4	6.37	6.32			
1.1905	6.82	6.77	6.71	6.7	6.66	6.65	6.62	6.63			
1.9842	4.329	4.329	4.329	4.329	4.329	4.329	4.33	4.329			
2.381	3.695	3.695	3.695	3.695	3.695	3.695	3.7	3.695			
3.9684	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29			

Shear Rate (sec ⁻¹)		Viscosity(p)										
	0(sec)	5(sec)	10(sec)	15(sec)	20(sec)	25(sec)	30(sec)	35(sec)				
0.7936	5.201	5.011	4.803	4.612	4.564	4.53	4.5	4.48				
1.1905	5.081	4.99	4.932	4.901	4.872	4.85	4.82	4.812				
1.9842	3.804	3.764	3.741	3.73	3.723	3.718	3.71	3.711				
2.381	3.682	3.642	3.578	3.56	3.547	3.536	3.53	3.547				
3.9684	2.689	2.679	2.675	2.66	2.664	2.66	2.65	2.645				

Table 4-3: Viscosity of alkyd resin 28 wt % with shear rate at different time

Table 4- 4: Viscosity of alkyd resin 24.5.wt % with shear rate at different time

Shear		Viscosity(p)									
Rate(sec ⁻¹)											
	0(sec)	5(sec)	10(sec)	15(sec)	20(sec)	25(sec)	30(sec)	35(sec)			
0.7936	3.669	3.59	3.461	3.43	3.4	3.377	3.36	3.34			
1.1905	3.34	3.21	3.16	3.13	3.117	3.108	3.09	3.093			
1.9842	3.279	3.199	3.15	3.11	3.08	3.05	3.03	3.02			
2.381	3.09	3.069	3.061	3.046	3.036	3.03	3.02	3			
3.9684	3.08	2.83	2.78	2.73	2.71	2.67	2.661	2.651			



Fig(4-1) :-Effect of shear rate(sec⁻¹) on the viscosity(p) of various time(sec) at alkyd resin 31.7wt%



Fig(4-2) :-Effect of shear rate(sec⁻¹) on the viscosity(p) of various time(sec) at alkyd resin 28wt%



Fig(4-3) :-Effect of shear rate(sec⁻¹) on the viscosity(p) of various time(sec) at alkyd resin 24.5wt%.

Used the Equ(2-4), it was can supose measurement shear stress expresental to plote the relation between shear rate and shear stress to given resulte more apresetion to the fluid Non-Newtonian

$$\tau_1 = \mu(\breve{\gamma})\breve{\gamma}$$
(2-4)

It is noticeable from Eq.(2-4) when shear rate increases the shear stress increases as shown in the Tables 4-5 to 4-7 and Figs. 4-4 to 4-6 the increase of shear rate will increase the shear stress at each alkyd resin concentration (31.7,28,24.5wt%) and different time intervals (0-35)sec this behavior indicate that the ink is non-Newtonian because the relation between shear rate and shear stress is not linear indicating that the ink posses pseudoplastic properties.

Shear Rate(sec ⁻¹)		Shear Stress(pa)									
Male(see)		5(600)	10(600)	15(600)	20(600)	25(600)	30(600)	35(600)			
	0(300)	5(360)	10(300)	13(300)	20(300)	20(300)	50(300)	55(360)			
0.4762	3.433	3.252	3.1572	3.0858	3.019	2.99	2.9286	2.857			
0.7936	5.642	5.3568	5.3091	5.1584	5.095	5.08	5.0552	5.016			
1.1905	8.119	8.0596	7.988	7.9763	7.929	7.92	7.8811	7.893			
1.9842	8.59	8.5896	8.5896	8.5896	8.59	8.59	8.5896	8.59			
2.381	8.797	8.7977	8.7977	8.7977	8.798	8.8	8.7977	8.798			
3.9684	9.088	9.0876	9.0876	9.0876	9.088	9.09	9.0876	9.088			

Table 4-5:Shear stress of alkyd resin 31.7wt % with shear rate at different time

Table 4-6:Shear stress of alkyd resin 28 wt % with shear rate at different time

Shear	Shear Stress(pa)									
Rate(sec ⁻¹)	0(sec)	5(sec)	10(sec)	15(sec)	20(sec)	25(sec)	30(sec)	35(sec)		
0.7936	4.127	3.9767	3.8117	3.66	3.622	3.6	3.571	3.557		
1.1905	6.049	5.9405	5.8715	5.8346	5.835	5.77	5.7382	5.726		
1.9842	7.558	7.4685	7.4228	7.401	7.387	7.38	7.3653	7.363		
2.381	8.767	8.6716	8.5192	8.4811	8.445	8.42	8.3954	8.445		
3.9684	10.67	10.631	10.615	10.588	10.57	10.6	10.532	10.5		

Shear								
Rate(sec ⁻¹)			1	1				1
naio(see)	0(sec)	5(sec)	10(sec)	15(sec)	20(sec)	25(sec)	30(sec)	35(sec)
0.7936	2.9117	2.849	2.7466	2.722	2.698	2.6799	2.6664	2.6506
1.1905	3.9762	3.8215	3.761	3.726	3.7107	3.7000	3.6786	3.682
1.9842	6.5061	6.347	6.250	6.1708	6.1113	6.0518	6.0121	5.9922
2.381	7.3603	7.3103	7.2913	7.255	7.2317	7.217	7.1936	7.146
3.9684	12.222	11.230	10.793	10.833	10.753	10.595	10.559	10.519

Table 4-7:Shear stress of alkyd resin 24.5wt % with shear rate at different time



Fig(4-4) :- Shear stress(pa) of alkyd resin 31.7wt% versus shear rate(sec⁻¹) at different time(sec).



Fig(4-5) :- Shear stress(pa) of alkyd resin 28wt% versus shear rate(sec⁻¹) at different time(sec).



Fig(4-6):- Shear stress(pa) of alkyd resin 24.5wt% versus shear rate(sec⁻¹) at different time(sec).

4.2 Power law index

The Power law is good to describe the Rheological properties of the printing ink. This type of ink is non-Newtonian. The shear stress is variable with shear rate, and this behavior indicates that the ink posses pseudoplastic or dilatant.

The logarithmic plot of shear stress and shear rate for screen printing ink is often found to be linear with a slope between zero and unity the empirical functional A plot of shear rate with shear stress at each alkyd resin concentration and different time, in log-log scale is given in Figs. 4-7 to 4-22 to find the slope (n) and intercept (k) from equation (2-2).

$$\tau = k^* \stackrel{\circ}{\gamma}^n \tag{2-2}$$

It is noticeable from Tables 4-8 to 4-9 the n < 1 at alkyd resin concentration (31.7,28,24.5 wt%) this behavior indicates that the ink is non-newtonian and posses pseudoplastic properties.

Tables 4-8 to 4-9 show the values of k and n at each alkyd resin concentration and different time.

time(sec)	Alkyd resin 31.7wt%					
	n	k				
0	0.444544	1.77365				
5	0.474986	1.74393				
10	0.488101	1.73136				
15	0.502198	1.71749				
20	0.512976	1.70696				
25	0.517748	1.70264				
30	0.526007	1.69495				
35	0.536492	1.68605				

Table 4-8: The value of n(slope) with k(intercept) at different time

time(sec)	Alkyd i	resin 28wt%
	n	k
0	0.57773	1.62357
5	0.596773	1.5963
10	0.617227	1.56865
15	0.637508	1.5456
20	0.641041	1.53989
25	0.646342	1.53214
30	0.649601	1.52449
35	0.651532	1.52449

Table 4-9: The value of n(slope) with k(intercept) at different time



Fig(4-7) :-Shear stress(pa) versus shear rate(sec⁻¹) on (log - log)at time 0(sec) and alkyd resin 31.7wt%.



Fig(4-8) :-Shear stress(pa) versus shear rate(sec⁻¹) on (log - log)at time 5(sec) and alkyd resin 31.7wt%.





Fig(4-10) :-Shear stress(pa) versus shear rate(sec⁻¹) on (log $-\log$)at time 15(sec) and alkyd resin 31.7wt%



20(sec) and alkyd resin 31.7wt%



Fig(4-12) :-Shear stress(pa) versus shear rate(sec) on (log – log)a 25(sec) and alkyd resin 31.7wt%.



Fig(4-13) :-Shear stress(pa)versus shear rate(sec⁻¹)on (log- log)at time 30(sec)and alkyd resin 31.7wt%



Fig(4-14) :-Shear stress(pa) versus shear rate(sec⁻¹) on $(\log - \log)$ at time 35(sec) and alkyd resin 31.7wt%.



Fig(4-15) :-Shear stress(pa) versus shear rate(sec⁻¹) on $(\log - \log)$ at time 0(sec) and alkyd resin 28wt%



Fig(4-16) :-Shear stress(pa) versus shear rate(sec⁻¹) on $(\log - \log)$ at time 5(sec) and alkyd resin 28wt%



Fig(4-17) :-Shear stress(pa) versus shear rate(sec⁻¹) on $(\log - \log)$ at time 10(sec) and alkyd resin 28wt%



Fig(4-18) :-Shear stress(pa) versus shear rate(sec⁻¹) on $(\log - \log)$ at time 15(sec) and alkyd resin 28wt%



Fig(4-19) :-Shear stress(pa) versus shear rate(sec⁻¹) on (log $-\log$)at time 20(sec) and alkyd resin 28wt%



Fig(4-20) :-Shear stress(pa) versus shear rate(sec⁻¹) on $(\log - \log)$ at time 25(sec) and alkyd resin 28wt%



Fig(4-21) :-Shear stress(pa) versus shear rate(sec⁻¹)on (log -log)at time 30(sec) and alkyd resin 28wt%



35(sec) and alkyd resin 28wt%

4.3 Thixotropic Effect

Thixotropy is one of the important Rheological properties of printing ink which represents the change of viscosity with the time ,therefor, we get the relation between shear rate and shear stress with time .The plot has two curves up and down curves. The up curve shows that the viscosity decreases gradually with the increasing shear rate, that leads to increase shear stress . The down curve indicates that the shear rate decreases again to zero that means viscosity decreases and begins to increase, that leads to decrease the shear stress. Fig. 4-23 indicates the that the ink is thixotropic as evidenced by previous studies for other ink types [37].

The up curve is determined by increasing the shear rate at a constant rate to maximum rate viscosity decreases with the time increases. The down curve is then started when the shear rate were held at rate max and shear rate begins decreasing again to zero or unit viscosity increases with the time increases.

This methods is used for the quantitative characterization of thixotropic material on the basis of the shape and area of hystersis loop.

The area between two curves represents hystersis loop the structure break down and go back to origin. Table 4-10 and Fig. 4-23 show the variation of shear stress with shear rate of two curves at alkyd resin concentration (28wt%) and different time.

Table 4-10: The two curves of shear stress of alkyd resin 56wt% with shear rate at different time

Shear rate(sec ⁻¹)		shear stresses (pa)										
	0(sec)	5(sec)	10(sec)	15(sec)	20(sec)	25(sec)	30(sec)	35(sec)				
1.1905	528	5.25	5.23	5.17	5.15	5.12	5.11	5.09				
1.9842	11.171	10.16	10.14	9.98	9.95	9.93	9.2	9.01				
2.381	11.462	11.462	11.462	11.462	11.462	11.462	11.462	11.462				
39684	11.484	11.484	11.484	11.484	11.484	11.484	11.484	11.484				
39684	11.484	11.484	11.484	11.484	11.484	11.4846	11.484	11.484				
2.381	11.46	11.46	11.46	11.46	11.46	11.46	11.46	11.46				
1.9842	10.15	10.11	9.88	9.86	9.72	9.53	9.22	9.01				
1.1905	4.68	4.66	4.605	4.59	4.57	4.522	4.50	4.48				



Fig(4-23) :- Shear stress(pa) versus shear rate(sec⁻¹) (up and down curves) at different time(sec) at alkyd resin 28wt%

The area between up and down curves calculate by integration under the curves show Table 4-11.

Shear rate	τ _{up} (pa)	τ _{down} (pa)		
(sec ⁻¹)				
0	-69.097	-7.62654		
5	-35.6550445	-1.2970875		
10	-7.081578	3.87277		
15	16.6233995	7.8830325		
20	35.459888	10.7337		
25	49.4278875	12.4247725		
30	58.527398	12.95625		
35	62.7584195	12.3281325		

Table 4-11: The value of shear stress the up and down curves with the shear rate

Area of thixotropic = $\int \tau_{up} (\mathring{\gamma}) d\mathring{\gamma} - \int \tau_{down} (\mathring{\gamma}) d\mathring{\gamma}$

= 64.79386331- 27.07910719

=37.7147561 (Pa)

4.4 Effect of Concentration on the Viscosity of Printing Ink

The viscosity of the three different samples of printing ink increases when the concentration of alkyd resin increases because viscosity is defined as the resistance of flow i.e. the value of the viscosity measurement at alkyd resin concentration (31.7wt%) greater than the value of viscosity measurement to the same type of ink at alkyd resin (28,24.5 wt%) because when the alkyd resin concentration increases in a mixture that leads to decrease the flow of mixture. Show Tables 4-12 to 4-19 and Figs. 4-24 to 4-31 indicated that the viscosity decreases with the increase shear rate at constant time.

It is noticeable from Figs 4-24 to 4-31 the viscosity structure at height shear rate breaks down, normally, more than that at low shear rate.

Table 4-12: Viscosity of concentration alkyd resin at time (0) and different shear rates

Concentration of alkyd wt%	Viscosity(p)							
	0.7936(sec ⁻¹)	1.1905(sec ⁻¹)	1.9842(sec ⁻¹)	2.381(sec ⁻¹)				
24.5	3.66	3.34	3.279	3.09				
28	5.201	5.081	3.804	3.682				
31.7	7.11	6.82	4.329	3.695				

Concentration of alkyd wt%	Viscosity(p)					
	0.7936(sec ⁻¹) 1.1905(sec ⁻¹) 1.9842(sec ⁻¹) 2.381(sec ⁻¹)					
24.5	3.59	3.21	3.199	3.066		
28	5.011	4.99	3.764	3.642		
31.7	6.75	6.77	4.329	3.695		

Table 4-13: Viscosity of concentration alkyd resin at time (5) and different shear rates

Table 4-14: Viscosity of concentration alkyd resin at time (10) and different shear rates

Concentration of alkyd wt%	Viscosity(p)					
	0.7936(sec ⁻¹) 1.1905(sec ⁻¹) 1.9842(sec ⁻¹) 2.381(sec ⁻¹)					
24.5	3.461	3.16	3.153	3.061		
28	4.932	4.932	3.741	3.578		
31.7	6.71	6.71	4.329	3.695		

Table 4-15: Viscosity of concentration alkyd resin at time (15) and different shear rates

Concentration of alkyd wt%	Viscosity(p)						
	0.7936(sec ⁻¹)	0.7936(sec ⁻¹) 1.1905(sec ⁻¹) 1.9842(sec ⁻¹) 2.381(sec ⁻¹)					
24.5	3.43	3.132	3.11	3.046			
28	3.901	3.901	3.73	3.562			
31.7	6.7	6.7	4.329	3.695			

Concentration of alkyd wt%	Viscosity(p)				
	0.7936(sec ⁻¹) 1.1905(sec ⁻¹) 1.9842(sec ⁻¹) 2.381(sec ⁻¹)				
24.5	3.4	3.117	3.08	3.036	
28	4.564	4.872	3.723	3.547	
31.7	6.42	6.66	4.329	3.695	

Table 4-16: Viscosity of concentration alkyd resin at time (20) and different shear rates

Table 4-17: Viscosity of concentration alkyd resin at time (25) and different shear rates

Concentration of alkyd wt%	Viscosity(p)				
	0.7936(sec ⁻¹) 1.1905(sec ⁻¹) 1.9842(sec ⁻¹) 2.381(sec ⁻¹)				
24.5	3.37	3.108	3.05	3.03	
28	4.53	4.85	3.718	3.536	
31.7	6.4	6.65	4.329	3.695	

Table 4-18: Viscosity of concentration alkyd resin at time (30) and different shear rates

Concentration of alkyd wt%	Viscosity(p) 0.7936(sec ⁻¹) 1.1905(sec ⁻¹) 1.9842(sec ⁻¹) 2.381(sec ⁻¹)				
24.5	3.357	3.096	3.03	3.019	
28	4.501	4.821	3.712	3.526	
31.7	6.37	6.62	4.329	3.695	

Concentration of alkyd wt%	Viscosity(p)					
	0.7936(sec ⁻¹) 1.1905(sec ⁻¹) 1.9842(sec ⁻¹) 2.381(sec ⁻¹)					
24.5	3.34	3.093	3.02	3		
28	4.48	4.812	3.11	3.547		
31.7	6.32	6.63	4.329	3.695		

Table 4-19: Viscosity of concentration alkyd resin at time (35) and different shear rates



Fig(4-24) :-Effect of alkyd resin concentration(wt%) on the viscosity(p) for various shear rates(sec⁻¹) at time 0(sec).



Fig(4-25) :-Effect of alkyd resin concentration(wt%) on the viscosity(p) for various shear rates(sec⁻¹) at time 5(sec).



Fig(4-26) :-Effect of alkyd resin concentration(wt%) on the viscosity(p) for various shear rates(sec⁻¹) at time 10(sec).



Fig(4-27) :-Effect of alkyd resin concentration(wt%) on the viscosity(p) for various shear rates(sec⁻¹) at time 15(sec).



Fig(4-28) :-Effect of alkyd resin concentration(wt%) on the viscosity(p) for various shear rates(sec⁻¹) at time 20(sec).



Fig(4-29) :-Effect of alkyd resin concentration(wt%) on the viscosity(p) for various shear rates(sec⁻¹) at time 25(sec).



Fig(4-30) :-Effect of alkyd resin concentration(wt%) on the viscosity(p) for various shear rates(sec⁻¹) at time 30(sec)



Fig(4-31) :-Effect of alkyd resin concentration(wt%) on the viscosity(p) forvarious shear rates(sec⁻¹) at time 35(sec).

4.5 Effect of Time on the Viscosity of Printing Ink

The viscosity for three different samples of printing ink is behaving (Non-Netonian) because the viscosity is not constant (changing with the shear rate and time) the viscosity drops with the increasing of time at range (0-35)sec at each shear rate and temperature 25c° .Which is defined as (thixotropic property) . As shown in the Tables 4-20 to 4-22 and Figs 4-32 to 4-34that the viscosity decreases with the increase of time at each shear rate.

It is noticeable from figs 4-32 to 4-34, that viscosity decreases with the increasing of time and shear rate until it is constant or nearly constant because of the combine shear rate and time effect, that occurs during a series of

measurements for viscosity with time also the viscosity decreases because the shear rate break down the structure during shearing.

Time			Viscor	sity(D)				
(sec)		v iscosity(F)						
	0.4762(sec ⁻¹)	0.7936(sec ⁻¹)	1.1905(sec ⁻¹)	1.9842(sec ⁻¹)	2.381(sec ⁻¹)	3.9684(sec ⁻¹)		
0	7.21	7.11	6.82	4.329	3.695	2.29		
5	6.83	6.75	6.77	4.329	3.695	2.29		
10	6.63	6.69	6.71	4.329	3.695	2.29		
15	6.48	6.5	6.7	4.329	3.695	2.29		
20	6.34	6.42	6.66	4.329	3.695	2.29		
25	6.27	6.4	6.65	4.329	3.695	2.29		
30	6.15	6.37	6.62	4.329	3.695	2.29		
35	6	6.32	6.63	4.329	3.695	2.29		

Table 4-20: Viscosity of printing ink with time at alkyd concentration of 31.7wt% and different shear rates

Table 4-21: Viscosity of printing ink with time at alkyd concentration of 28wt% and different shear rates

Time	Viscosity(p)					
(sec)						
	0.7936(sec ⁻¹)	1.1905(sec ⁻¹)	1.9842(sec ⁻¹)	2.381(sec ⁻¹)	3.9684(sec ⁻¹)	
0	5.201	5.081	3.804	3.682	2.689	
5	5.011	4.99	3.764	3.642	2.679	
10	4.803	4.932	3.741	3.578	2.675	
15	4.612	4.901	3.73	3.562	2.668	
20	4.564	4.872	3.723	3.547	2.663	
25	4.53	4.85	3.718	3.536	2.66	
30	4.501	4.821	3.712	3.526	2.654	
35	4.482	4.813	3.711	3.547	2.645	

Time (sec)	Viscosity(p)					
	0.7936(sec ⁻¹)	1.1905(sec ⁻¹)	1.9842(sec ⁻¹)	2.381(sec ⁻¹)	3.9684(sec ⁻¹)	
0	3.669	3.34	3.279	3.09	3.08	
5	3.59	3.21	3.199	3.0669	2.83	
10	3.461	3.16	3.153	3.061	2.78	
15	3.43	3.132	3.11	3.046	2.73	
20	3.4	3.117	3.08	3.036	2.71	
25	3.377	3.108	3.05	3.03	2.67	
30	3.357	3.096	3.03	3.019	2.661	
35	3.34	3.093	3.02	3	2.651	

Table 4-22: Viscosity of printing ink with time at alkyd concentration of 24.5wt% and different shear rates



Fig (4-32): - Effect of time (sec) on the viscosity (p) for various shears rates (sec⁻¹) at alkyd resin 31.7wt%



Fig (4-33): - Effect of time (sec) on the viscosity (p) for various shears rates (sec⁻¹) at alkyd resin 28wt%



Fig (4-34): - Effect of time (sec) on the viscosity (p) for various shears rates (sec⁻¹) at alkyd resin 24.5wt%

<u>4.6 Shear stress – Shear rate Correlations</u>

The computer was used to find the right functions by using graphic program. These functions are used to find the values of shear stress calculations and compare it with the values of shear stress calculations from Equ(2-4). These functions were taken from fig.4-4 to 4-6, the functions which were concluding a accordingly were from a nonlinear least square fitting . From these functions we have got constants at each time for different alkyd resin concentrations as shown in the tables 4-23 to 4-25.

Table 4-23: The value of constant of Equ. (4-1) at alkyd resin concentration (31.7wt%).

Alkyd resin (31.7wt%)				
Time (sec)	Α	В	С	
0	1.83244	5.28703	-0.88292	
5	1.48746	5.53185	-0.92267	
10	1.35866	5.61823	-0.9362	
15	1.20297	5.72964	-0.95437	
20	1.09603	5.8012	-0.96554	
25	1.05286	5.83336	-0.97094	
30	0.97895	5.88484	-0.97923	
35	0.88817	5.96134	-0.99299	

Alkyd resin (28wt%)					
Time (sec)	Α	В	C		
0	1.28228	4.2775	-0.47414		
5	1.10938	4.27868	-0. 4968		
10	0.96943	4.29271	-0.47069		
15	0.74603	4.44178	-0.49613		
20	0.71996	4.44662	-0.49712		
25	0.66669	4.46341	-0.49867		
30	0.62775	4.47776	-0.50132		
35	5.78573	4.49366	-0.50132		

Table 4-24: The value of constant of Equ (4-1) at alkyd resin concentration (28wt%).

Table 4-25: The value of constant of Equ (4-1) at alkyd resin concentration (24.5wt%).

Alkyd resin (24.5wt%)			
Time (sec)	Α	В	С
0	0.649485	2.81535	0.02476
5	0.236392	3.29218	- 0.131164
10	- 0.044574	3.57109	- 0.21104
15	- 0.0057034	3.473285	- 0.18623
20	- 0.0231269	3.49087	- 0.1895
25	- 0.0652368	3.51387	- 0.207556
30	- 0.0660083	3.49321	- 0.204526
35	- 0.0476068	3.48206	- 0.200521
Sub the constant of equation (4-1) to calculate the (τ_{cal2}) at each time and alkyd resin concentration at any value of shear rate as shown in tables (4-26) to (4-28).

$$\tau_{cal2} = \mathbf{A} + \mathbf{B}\mathbf{\mathring{\gamma}} + \mathbf{C}\mathbf{\mathring{\gamma}}^2 \tag{4-1}$$

Table 4-26:Comparison between shear stress calculated value from equ(2-4)and (4-1)for screen printing ink at alkyd resin concentration (31.7 wt%)

Shear	Shear	Time(sec)								Error%		
rate	stress	0	5	10	15	20	25	30	35	total		
	τ 2	4.15	3.91	3.82	3.72	3.54	3.61	3.56	3.50			
0.40	τ 1	3.43	3.25	3.16	3.09	3.02	2.99	2.93	2.86			
0.48	Error%	20.88	20.31	21.05	20.39	17.40	20.93	21.54	22.56	2.063		
	τ2	5.47	5.30	5.23	5.15	4.93	5.07	5.03	4.99			
	τ ₁	5.64	5.36	5.31	5.16	5.09	5.08	5.06	5.02			
0.79	Error%	3.02	1.13	1.53	0.18	3.18	0.16	0.45	0.43	1.26		
	τ 2	6.88	6.77	6.72	6.67	6.40	6.62	6.60	6.58			
	τ ₁	8.12	8.06	7.99	7.98	7.93	7.92	7.88	7.89			
1.19	Error%	15.32	16.06	15.87	16.36	19.33	16.36	16.29	16.66	1.653		
	τ2	8.85	8.83	8.82	8.81	8.41	8.80	8.80	8.81			
	τ ₁	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59			
1.98	Error%	3.00	2.81	2.69	2.62	2.11	2.50	2.45	2.53	2.59		
	τ2	9.42	9.43	9.43	9.43	8.96	9.44	9.44	9.45			
	τ ₁	8.80	8.80	8.80	8.80	8.80	8.80	8.80	8.80			
2.38	Error%	7.03	7.16	7.17	7.24	1.83	7.27	7.29	7.45	6.56		
	τ 2	8.91	8.91	8.91	8.91	8.12	8.91	8.91	8.91			
	τ ₁	9.09	9.09	9.09	9.09	9.09	9.09	9.09	9.09			
3.97	Error%	1.96	1.96	1.95	1.94	10.67	1.94	1.94	1.98	3.04		
Average absolute error %							8.44					

Shear	Shear	Time(sec)							Error%	
rate	stress									total
		0	5	10	15	20	25	30	35	-
	τ 2	4.38	4.19	4.08	3.96	3.94	3.89	3.87	3.84	
0.70	τ ₁	4.13	3.98	3.81	3.66	3.62	3.60	3.57	3.56	7 49
0.15	Error%	6.10	5.42	7.03	8.16	8.69	8.34	8.22	8.00	1.45
	τ 2	5.70	5.50	5.41	5.33	5.31	5.27	5.25	5.25	
1 10	τ ₁	6.05	5.94	5.87	5.83	5.83	5.77	5.74	5.73	8.03
1.19	Error%	5.72	7.43	7.81	8.63	9.01	8.66	8.54	8.39	0.05
	τ2	7.90	7.64	7.63	7.61	7.59	7.56	7.54	7.56	
1 98	τ ₁	7.56	7.47	7.42	7.40	7.39	7.38	7.37	7.36	2 84
1.50	Error%	4.57	2.34	2.84	2.77	2.69	2.47	2.36	2.68	2.04
	τ2	8.78	8.48	8.52	8.51	8.49	8.47	8.45	8.47	
2.38	τ ₁	8.77	8.67	8.52	8.48	8.45	8.42	8.40	8.45	0 59
	Error%	0.14	2.20	0.03	0.33	0.52	0.60	0.62	0.30	
	τ2	10.79	10.27	10.59	10.56	10.54	10.53	10.50	10.47	
3.97	τ ₁	10.67	10.63	10.62	10.59	10.57	10.56	10.53	10.50	0.77
	Error%	1.12	3.44	0.22	0.26	0.29	0.28	0.28	0.25	
Average absolute error %						3.94				

Table 4-27:Comparison between shear stress calculated value from equ(2-4) and (4-1)for screen printing ink at alkyd resin concentration (28 wt%)

Shear	Shear	Time(sec)								Error%	
rate	stress	0	5	10	15	20	25	30	35	total	
	τ 2	2.90	2.77	2.66	2.63	2.61	2.59	2.58	2.59		
0.79	τ ₁	2.91	2.85	2.75	2.72	2.70	2.68	2.67	2.65	2.74	
	Error%	0.42	2.90	3.28	3.25	3.19	3.26	3.34	2.31		
	τ 2	4.04	3.97	3.91	3.87	3.84	3.82	3.80	3.81		
1.19	τ ₁	3.98	3.82	3.76	3.73	3.71	3.70	3.68	3.68	3.35	
	Error%	1.51	3.88	3.90	3.74	3.49	3.35	3.38	3.57		
	τ₂	6.33	6.25	6.21	6.15	6.12	6.09	6.06	6.07		
1.98	τ ₁	6.51	6.35	6.25	6.17	6.11	6.05	6.01	5.99	0.99	
	Error%	2.66	1.49	0.64	0.29	0.10	0.63	0.80	1.33		
	τ 2	7.50	7.33	7.26	7.21	7.17	7.13	7.09	7.11		
2.38	τ ₁	7.36	7.31	7.29	7.26	7.23	7.22	7.19	7.15	0.90	
	Error%	1.85	0.33	0.37	0.61	0.86	1.25	1.38	0.52		
	τ 2	12.21	11.24	10.80	10.84	10.77	10.61	10.58	10.61		
3.97	τ ₁	12.22	11.23	10.79	10.83	10.75	10.60	10.56	10.52	0.21	
	Error%	0.08	0.05	0.10	0.11	0.12	0.15	0.16	0.89		
Average absolute error %						1.64					

Table 4-28: Comparison between shear stress calculated value from equ(2-4)and (4-1)for screen printing ink at alkyd resin concentration (24.5 wt%)



CONCLSUSINS AND RECOMMENDATIONS

5.1 Conclusion

From the results of the present work, the following conclusions are obtained: -

1- The viscosity changes with the shear rate this behavior indicates that the screen printing ink is non-Newtonian.

$$\tau = \mu (\overset{\circ}{\nu})^{\overset{\circ}{\nu}}$$

2- The viscosity decreases with the increase of shear rate (pseudoplastic behavior) at different alkyd resin concentrations (33,28,24.5wt%)

3- Describing the rheological properties of screen printing ink the flow under the shear rate .From this relation ship

$$\tau = k^* \overset{\circ n}{\nu}$$

at alkyd resin concentration of (31.7,28,24.5 wt %) the behavior of the viscosity is found to the pseudoplastic (n is lest than one) the type of screen printing ink is Non-Newtonian, because n is not equal one.

4-The viscosity increases with increase the alkyd resin concentration of the ink such that the value of viscosity at alkyd resin 31.7wt% is greater than when the value of alkyd resin (28, 24.5 wt%) at different times and shear rate.

5- The viscosity decreases with the increase of time at different alkyd resin concentrations of the screen printing ink, indicating that ink is thixotropic.

5.2 Recommendations

The following recommendations are suggested for future work:-1-A rheological study on screen printing ink at a wide range of concentrations of alkyd resin.

2-Studying the effect of temperature on the rheological properties of ink solution.

3-Studying the rheological properties of different types of ink.

4- Studying the rheological properties by device measurement more than 100 rpm

5-Usied the Equ(2-4), it was can supose measurement shear stress experimental to plote the relation between shear rate and shear stress to given resulte more apresetion to the fluid Non-Newtonian.

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APPENDIX

Sample of Calculation

Example: Alkyd resin concentration is (28 wt%) at time 0(sec) :

A- Estimate the power law index printing ink

Power law index estimated from Eq.(2-2) $\tau = \mu \gamma^{n}$ (2-2)

 $\log \tau = n \log \vartheta + \log \mu$

The experiment date (shear rate and shear stress) at time o (sec) taken from table (4-7)

Plot shear stress with shear rate of (log–log) scale from fig.(4-23) to give the intercept (μ) = 1.62357 and slope (n) = 0.57773 n: power law index

B-Estimate the shear stress calculation(τ_{cal})

The constants of equation are taken from table (4-26) by using graphic fitting program are

$$\tau_{cal} = A + B^{?} + C^{?2}$$

$$\tau_{cal} = 1.28228 + 4.2775^{*}(3.97) - 0.47414^{*}(3.97)^{2}$$

 $\tau_{cal(2)} = 10.79 \text{ pa}$

shear stress experimental($\tau_{cal(1)}$) at time 0(sec) and shear rate 3.97(sec⁻¹) equal 10.67

$$: - \tau_{cal(1)} = \tau_{cal(2)}$$

C- Estimate the average absolute error %(AAE)

$$\operatorname{Error}^{\bullet} = \operatorname{ABS} \left| \frac{\tau_1 - \tau_2}{\tau_1} \right| * 100$$

$$\text{Error}\% = \text{ABS}|\frac{10.67 - 10.79}{10.67}| *100$$

$$Error\% = 1.1246$$

$$AAE\% = \frac{\Sigma \text{ Error\%}}{\text{no.}} = 3.94$$

no. is the number of error.

لقد أجريت دراسة ريولوجية لاحبار الطباعة (نوع حبر اللواصق) حيث تمت الدراسة على هذا النوع من الحبر بتراكيز مختلفة للالكيد . تضمنت الدراسة ،دراسة خواص هذا النوع من الحبر مثل معدل سرعة القص (shear.rate) و إجهاد القص (shear.Stress) واللزوجة (viscosity). كما تمت دراسة تأثير تغير الزمن والتراكيز (النسبة الوزنية للالكيد) على اللزوجة عند درجة حرارة "cos

لقد اجريت قياسات اللزوجة على حبر اللواصق بتراكيز مختلفة للالكيد هي

(% 31.7, 28, 24.5 wt) عند زمن يتراوح بين (٠-٣٥) باستخدام جهاز اللزوجة (% Rheology international RI:I:M) الذي يتضمن قيم مختلفة من السرع و أحجام مختلفة من (SPINDLES) ،وجد ان اللزوجة لحبر اللواصق ينخفض بشكل ملحوظ مع مرور الزمن و تزداد بزيادة تركيز للالكيد. كما تم التنبؤ بمعادلة لمعرفة التصرف الريولوجي لحبر اللواصق و هي معادلة تعرف بقانون القوة (LAW)

وقد تبين من خلال حساب قيم (n) أن هذا الحبر يتصرف بسيدوبلاستك

non-newtonian pseudoplastic behavior

أضافه لذلك تمم حساب مساحة التكسوتروبيك (area of thixotropy)التي تمثل طاقة (hystersis loop) التي تمثل طاقة تكسير الأواصر بين الجزيئات واعادة بنائه وهذا ما يعرف ب

. . .

رسالة مقدمة الى كلية الهندسة في جامعة النهرين كجزء من متطلبات نيل درجة ماجستير علوم في الهندسة الكيمياوية

> من قبل منى عبد الصاحب الحمدي بكالوريوس هندسة كيمياوية ٢٠٠١

حزيران ٢٠٠٤

ربيع الثاني ٢٤٢٥