Soy-Based Flexographic Ink for Linerboard Printing

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SOY-BASED FLEXOGRAPHIC INK FOR LINERBOARD PRINTING

by

Rahul Pingale

A thesis submitted to the Graduate College
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Thesis Committee:

Alexandra Pekarovicova, Ph.D., Chair
Paul Dan Fleming, Ph.D.
Veronika Husovska, Ph.D.
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SOY- BASED FLEXOGRAPHIC INK FOR LINERBOARD PRINTING

Rahul Pingale, M.S.E.

Western Michigan University, 2018

Many printing inks use volatile solvents in the formulation, which are hazardous to the environment from emission of VOC’s and at the same time, synthetic resins in these inks are not biodegradable. These problems with the fluctuating and rising price of petroleum are main reasons to look for new resources for making more environmentally friendly printing inks. The majority of the commercially available water based inks are formulated based on using acrylic resins, synthetic colorants, solvents/water and additives, which are the common main components for formulating printing inks. In this research, soy proteins were tested for their suitability to partially or fully replace acrylic emulsion resins in water based packaging inks. The first step was formulating a water based ink based on fully acrylic solution and emulsion resins and the next step was formulating soy polymer using ProSoy7475 Protein powder to replace emulsion acrylic polymers as resins. The letdown portion of the ink was formulated with soy polymers, adding them in increments 20-40-60 up to 100% replacement of the corresponding acrylic emulsion portions of fluid packaging ink. A cyan process color ink was formulated, and its printability, rheology, and end use properties such as rub resistance, gloss, and adhesion were tested and compared to fully acrylic formulations. It was found that the soy polymer did not affect the final color of packaging ink, measured as Delta E (ΔE). Delta E (ΔE) (CMC2:1) for all soy formulations were less than 1.5, when the fully acrylic formulation was used as a standard.
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CHAPTER I

INTRODUCTION

“The demand by print customers for printed products that have minimal environmental impact is growing at an extremely rapid pace,” said Michael Makin, president and CEO of Printing Industries of America, (PIA) [1]. A company's environmental friendliness is very important these days, because of the growing number of inquiries from customers. The Sustainable Green Printing (SGP) Partnership was founded in June 2007 and it was established by three founding printing organizations-PIA/GATF, Specialty Graphic Imaging Association (SGIA), and Flexographic Technical Association (FTA) [2]. Their mission is “To encourage and promote participation in the worldwide movement to reduce environmental impact and increase social responsibility of the print and graphic communications industry through sustainable green printing practices” [3]. The SGP would like to see more use of environmentally friendly materials from the printing and graphic communications industry.

The corrugation packaging market is growing rapidly in developed countries, especially in the U.S. It will experience an annual growth rate of 5.6 percent according to study done by The Freedonia Group, which was reported by the Packaging outlook online publication published in 2018 [4]. Corrugated packaging aims to use coatings made of biodegradable polymers, but it only makes sense to print on them with biodegradable inks. Water-based (WB) inks represent an exciting trend in the flexographic packaging industry, because of their environmentally benign nature; significant growth in their usage is taking place [5].
In the case of flexo water-based inks, usually petroleum-based acrylic polymers are used. Also, acrylic polymers are employed in a variety of applications, such as the automotive, medical device, paint, and adhesive industries. Often times, the ink industry has to compete with other industries for acrylic polymers, making it an expensive and time consuming process. There is a lack of information about soy polymer use in water based flexographic ink [6]. In order to truly be “green” or environmentally friendly, it is important to replace ink resins made of fossil raw materials in the inks with environmentally friendly resins produced from renewable resources. The focus of this research was to investigate whether WB inks made using renewable and/or biodegradable resins produced from renewable resources, namely soy protein, could be comparable to, and thus substitute for conventional acrylic resins (produced from petroleum feedstock), when printed on Kraft paper or board, which is mainly used in corrugated packaging printing [3].

The focus will be on inks for linerboards, because linerboard is a substrate used essentially with 100% water based ink formulations, and the linerboard packaging sector is growing exponentially [7]. The first step will be to formulate water based ink based on fully acrylic solution and emulsion polymers as resins. Next, letdown portion of the ink formulation will be replaced with soy polymers, doing it in increments 20-40-60 up to 100% replacement of the corresponding acrylic emulsion resin. The formulated cyan process color ink will be tested for printability, rheology, and end use properties such as rub resistance, gloss, and adhesion. This will help to achieve the formulation of a truly environmentally friendly flexographic water based ink, while eliminating emission of VOCs.
1.1. Overview of Flexography Process

In the U.S., packaging is most often printed using the flexographic (flexo) printing process, because it is less expensive than gravure, which is another major package printing process. Flexography is more versatile than other printing processes, meaning that it is able to print virtually on every substrate. Also, because of its flexible plate image carrier, it is more forgiving than gravure or lithography concerning substrate smoothness. Flexography is mainly used for packaging applications, such as corrugated containers, flexible pouches, films, paperboard printing, etc. This process is nothing but modified version of letterpress printing, which also uses raised surface as an image area. Flexo plates, whether molded from rubber, or imaged to photopolymer, are generally made from flexible materials. The working principle of flexo is illustrated in Figure 1 [8].

![Flexographic printing process](image)

**Figure 1. Flexographic printing process [9]**

In the simplest and most common form, the flexography process consists of four components [9,10]:

1. Fountain Roll/Chambered Doctor Blade Inking System,

2. Ink-metering (Anilox) roll,
3. Plate cylinder,

4. Impression cylinder.

The fountain roll rotates in an ink reservoir. Its main purpose is to pick-up and to deliver a relatively heavy flow of ink from the fountain pan (or enclosed doctor blade chamber) to the anilox roll, which is usually ceramic and equipped with tiny engraved cells shown in Figure 2. The number of cells varies from 80 to 2000 cells per linear inch, depending on resolution. Screen rulings mostly depend upon substrate type. More porous substrates absorb more ink, and in that case lower line count anilox is used to deliver more ink [11].

![Figure 2. Anilox roller](image)

The flexographic printing process depends upon a precise, controlled transfer of a liquid ink, varnish or coating. An anilox roll is a chrome or ceramic plated metering roll designed to consistently supply an uniform and measurable volume of ink from the fountain roller onto the image carrier/plate cylinder (sometimes paired with a doctor blade to further wipe excess ink from the roll). Thus, the anilox roll is an extremely important component of the flexographic process, having the ability to effectively change the print outcome through ink receptivity and its releasing capabilities; the volume of ink that is transferred is extremely important in the reproduction of halftones and process colors. The number of cells on an anilox roll is denoted as “lpi” (lines per inch), and it determines the amount of ink that will transfer onto the plate cylinder. These cells are
usually mechanically or laser engraved and are categorized into 5 types of cell structure: trihelical, pyramid, quadrangular, hexagonal, hexagonal Channel (See Figure 3).

The higher the anilox lpi count means larger amount of cells, lesser amount of deposited ink and more controlled ink supply. Line screen or lpi is the major component to understand when specifying an anilox roll, since a lpi is chosen in direct correlation to anilox volume. Anilox roll volume is the capacity of the engraved surface in a square inch, expressed in Billion Cubic Microns (BCM). Higher volume translates to a higher solid ink density, more color, or a heavier coating thickness. Lower volumes apply thinner ink films directly associated with higher print quality and process efficiency.

The anilox roll (Figure.2) supplies a fine film of ink to the printing plate. That’s why the fountain and anilox rolls are set to rotate against one another with the least amount of pressure required to form a pond behind the nip. The anilox roll is often used with a reverse angle doctor blade to wipe excess ink from the roll. The chambered inking system [9] is commonly used on narrow web flexo presses to print more consistently, precisely and without facing issues related to solvent evaporation, and rheological instability.
The steel plate cylinder with mounted flexo plate is installed between the anilox roll and the impression cylinder. Printing plates (Figure 4) are attached to the plate cylinder with special double-sided tape called stickyback. The raised surface of the printing plate picks up ink from the anilox and transfers it to the substrate. The impression cylinder, which is located at the opposite side of the substrate against the plate cylinder, supports the substrate and creates the printing nip.
1.2. Flexography Packaging Inks

Inks are colored suspensions designed to reproduce colorful images on printing surfaces. The majority of printing inks consist of colorant, either pigment, which is insoluble in its vehicle, or a dye, which is soluble in its vehicle [15]. Flexo inks can be formulated to meet specific needs, according to the press configuration and surface of the substrate. These inks are fluid and quickly drying. Flexo packaging inks can be categorized based on their chemical make-up as one of the following major types [15]:

1. Water based (WB),
2. Solvent-based,
3. Energy curable (UV/EB) inks.

All these inks are comprised of colorants and vehicles. Colorants, which can be pigments or dyes, give ink its color. Pigments may be divided according to their chemical nature into inorganic or organic pigments, or according to their function, such as conventional process color pigments (yellow, magenta, cyan, and black), spot color pigments, special effect pigments, metallic, and functional, such as conductive, or semi conductive [16]. Resins contribute to an ink's printability, rheology/viscosity (flow), adhesion and stability. Solvents are, basically, carrier agents that transport ink from the fountain to drum to substrate. Finally, additives bring some special properties to ink formulation. They can enhance gloss, opacity, and can improve heat, moisture, fade and rub resistance [9].

**Pigments:** Responsible for what we see on a printed page, i.e. ink color, which is the most expensive ingredient and contributes to about 50% of the ink cost. Pigments are solid particulate materials that either absorb or scatter light. They have to be milled in order to disperse them into resin and keep them in the dispersion. Pigments have a crystalline structure and must be evenly
distributed in order to produce good quality print. Pigments can be classified as organic pigments, inorganic pigments, metallic, fluorescent, pearlescent, etc., all of which are insoluble in the vehicle, whereas dyestuffs are soluble in the vehicle. When referring to a pigment, it is often done so by either their formula number, or their color index name.

![Figure 5. Types of pigments][17]

Pigments are used frequently in many of the printing applications, whereas dyestuffs are more common in water-based inks such as those found in pens. Although more recently, there have been inks that make use of both a dye and a pigment. An example of a dye is eosin, which is commonly used in red fountain pens. Two inorganic pigments are titanium dioxide, used in white inks, and carbon black which is used to make black inks. Organic pigments are used for colored inks; examples are phthalocyanine pigments that give green and blue inks, and azo pigments for red and yellow inks. Over the past several decades health and environmental concerns have led to the reduction of the use of inorganic color pigments as they typically contain toxic heavy metals [18].
Resins: Responsible for binding the pigments and contribute to the gloss and adhesion of the ink. Synthetic resins for fluid inks such as water based flexo or gravure inks are acrylic resins. Alkyd resins, on the other hand, are used in formulating litho inks. An example of a natural resin is rosin, which is made of abietic acid, and it is the one that is obtained from pine trees, or as a by-product of kraft pulping. Rosin is major raw material for formulation of solvent based publication gravure inks. Other common rosin derivatives are known as fumarics.

The vehicle, also called a binder or a varnish, allows for the colorant to disperse and stay in a printable form, such that the colorant can reach the substrate or the surface, and affix itself to it. The vehicles are typically resins that will remain on the substrate or surface along with the colorant, sometimes with the additives, that are also considered to be part of the vehicle. Resins are mostly polymeric materials with some examples of synthetic resins being epoxy resins, polyamide resins, or acrylic resins.

Solvents: Responsible for keeping the ink in liquid form, keep resin or polymer dissolved, regulate ink viscosity, and they are also a huge factor in ink safety. Solvents represent usually less than 40% of ink weight. The solvent is used to dissolve the binder of the ink, and also to change the viscosity of the ink. Examples of solvents are xylene, toluene, mineral oil, alcohols, esters, ketones, and water. Many of the ink formulations dry by heat, where the solvent is removed by the evaporation from the ink. Some inks, such as in UV-curable ones, do not contain solvent, but liquid monomers, which polymerize and become a solid part of the ink.

Additives: A number of additives exist in the ink industry. Some are present in many different chemistries of inks, such as waxes, others are very specific for particular chemistries of the inks, such as defoamers, found solely in water based inks. They help carry, stabilize, and enhance the final product. Additives are typically the smallest percentage of the composition of the ink, present
in inks in less than 5% of their formulation. They are used to adjust the properties of the ink or add a property to the ink, thus increasing its performance. An ink may contain additives such as waxes, plasticizers, de-foaming agents, thixotropic promoters, optical brighteners, anti-skinning agents, adhesion promoters, and driers.

**Reducer:** The purpose is to produce a clear glossy film over the printed material, mostly used in litho inks, such as tung seed oil.

**Waxes:** Provide chemical resistance and increase rub resistance. Waxes are often melted into the solvent being used, they may be synthetic or natural. Polyethylene waxes are example of synthetic waxes. Carnauba or bee wax are natural ones.[19].

### 1.3. Water-Based Inks

A water-based ink is an ink that has either the pigments or the dyes as a colorant. Predominantly, pigments are employed in a colloidal suspension with polymeric resins of different molecular weight, and water as a solvent. Although the main solvent in water-based inks is water, there can also be other co-solvents present. These co-solvents typically are VOC’s, such as isopropyl or normal propyl alcohol, however, they have to be present in amounts less than 5% in ink formulations.
Water-based inks have been in existence since around 2500 B.C. The first water based inks were black writing inks that were typically carbon in water suspensions that were stabilized by either egg albumin or a natural gum [19]. Even though water-based inks have existed for over 4500 years; they were used very little up until the late 1960’s. Water-based inks used to have inherent problems, and thus were ignored as a viable option to other solvent based inks for some time. In the 1970’s a crude oil shortage, combined with a new awareness of the damaging effects that the solvents in ink could have both on humans and the environment, new laws were put into effect forcing the ink industry to seek an alternative in the form of water-based inks [21]. The goal of using water-based inks is to completely remove hazardous chemicals from ink, not just reduce the VOC’s that are present.

1.3.1. Properties Used to Classify Inks

To determine what ink needs to be used for a particular process or application, properties examined are: viscosity, ink tack, or ability to adhere to surfaces, size of the particles, the color or
color strength, drying time, rub resistance, and gloss. Determining whether or not a specific ink can be used for a given application may also depend on the solvent that might remain in the ink film, odor that the ink may transfer to the substrate or release, bleeding of the colorant, heat resistance, cold resistance, heat seal or any number of other properties [22].

1.3.2. Properties of Water-Based Inks

The main properties of interest with water based inks are viscosity, surface tension, stability of the colloidal dispersion, size and shape of the colorant particles, shear stability, bleeding, foamability, scrubbing resistance, water resistance, boiling point temperature, and the pH and viscosity. Water-based inks are formulated for their specific application and properties or characteristics. That is the type of printing process they are to be used in, the substrate or surface they are to be printed on, the environment that the ink will be exposed to, the texture of the ink, the color of the ink, etc. [22]

The flow of a fluid has four categories, Newtonian, non-Newtonian (pseudo plastic), dilatant, and thixotropic [19]. Flow of the liquid, where viscosity remains constant as shear force is applied, is called Newtonian flow. Water exhibits Newtonian flow, whereas liquid decreasing in viscosity with an increase in shear is an example of Non-Newtonian flow or pseudo plastic flow. When both the viscosity and shear increase together, a Dilatant flow is observed. Thixotropic flow is characterized by decrease in viscosity with an increase in shear, which is similar to pseudo plastic flow with the exception that thixotropic flow applies in the time domain. Thixotropic flow behavior is observed mainly in water-based inks. Thus, the viscosity of the ink will decrease when a shear force is applied, and when the shear force is removed, the viscosity will return to its previous value [22].
Surface tension of an ink affects properties such as the foaming of an ink, and wettability. The wettability of an ink is the ink tendency to spread at a substrate or surface. The best situation for the coating of a substrate occurs when the surface energy of the substrate is much greater than surface tension of the liquid that will be coating the substrate. This is a problem for water-based inks, as water has a very high surface tension of 72 mN/m, when most solvent based inks have a surface tension between 20-35 mN/m, so the surface tension of the water-based ink will be higher than that of most substrates that it will be printed on [22].

To solve this problem, typically a surfactant will be added, or the surface of the substrate will be modified through cleaning or another process, such as corona treatment. Surfactants are so called “surface active” molecules that contain both a hydrophilic and a hydrophobic portion of the molecule. The addition of a surfactant to a water-based ink will have the result of drastically lowering the surface tension of the ink due to the orientation effects at interfaces, caused by the orientation of hydrophilic and hydrophobic portions of the surfactant molecule. The addition of the surfactant has the effect of lowering the surface tension, but it also accelerates the formation of foam in the ink. To prevent this, it is necessary to add an anti-foaming agent such as hydrophobic solids, or fatty acids. The colloidal stability of the ink is necessary for achieving quality printing, as well as to ensure a long shelf-life of the ink. Without stabilizing the colloidal system of the ink, the pigment would settle within a short time making the ink useless.

To stabilize water-based inks, there are two methods the addition of surfactants, and the addition of polymers, and in some cases the colloidal system is stabilized by both. The addition of surfactant and/or polymer to the water-based ink will result in the surfactant and/or polymer adsorbing at the solid (pigment)/liquid interface. The adsorbed surfactant and/or polymer will form coating on the pigment of various compositions and thicknesses which will result in a net repulsion
of the pigment particles with in the ink causing its stabilization. The drawback of using a surfactant and/or polymer to stabilize the colloidal system will be the negative effects seen on the applicability of the ink, especially for printed electronics and in graphic printing in affecting its color strength [22].

In regards to the inks color strength, colorfastness, colloidal stability, viscosity, as well as many other properties the size and shape of the colorant particles are important. When pigments are used to color the ink, it is necessary to choose the size and shape of the particles to meet the crucial requirements of the ink. The smaller the particles, the easier it will be for the dispersion to stabilize, and also the smaller the particles are, the brighter, saturated, or more pronounced the color that’s why the size of the particles of the pigment is important for colloidal stability. A change in the pH or temperature of the ink will result in a change in the surface tension of the ink, the viscosity of the ink, as well as the colloidal stability of the ink, all of which are unwanted. The temperature and pH of water-based inks must be monitored throughout the printing process, as even a small change in either direction can cause poor printing due to the change in the properties of the ink [22]. The boiling point or heat of evaporation of the ink is an important factor in that dictates the amount of time and the temperature needed to dry or cure the ink. One of the difficulties of water based inks is due to water having a high heat of vaporization.

Water has a higher heat of evaporation as compared to other solvents that are used in ink industry. The time and the temperature necessary to dry or cure the water based ink is increased greatly as compared to solvent based ones. Through the use of additives, many of the properties of the ink can be changed. Typically, water-based inks are not water resistant or able to dry or cure quickly, this can be changed though by adding waxes to increase the inks water resistance
properties. Fine tuning of addition of ammonia and amines into water based inks takes care of ink resolubility, or their water resistance.

**Advantages and Disadvantages of Water-Based Ink**

Due to the many problems associated with water-based inks, they were not widely used or accepted until the 1980’s. They were used only on porous surfaces such as paper or paperboard that required only minimal quality and detail in the prints. The use of water-based inks by printing companies required them to purchase new equipment and adopt new printing practices. Water-based inks require increased drying capacity, they could only be used on certain materials and not on metals or plastics [23]. Water-based inks have many issues like they would dry on the printing equipment such as the rollers or screens, they had poor print quality, poor blocking resistance, poor water resistance, poor abrasion resistance, and a number of other disadvantages.

The physical properties of water-based inks have greatly improved through the discovery of better emulsion acrylic polymers and copolymers, additives like high molecular weight resins, waxes, surfactants, and other materials. Although in the past, there were many disadvantages to using water-based inks when compared to the other solvent based inks, they now offer better performance, lower printing costs, and are a less damaging alternative to both people and the environment [22].

**1.3.3. Applications**

Water-based inks can now be readily applied to most materials even plastics and foils, through the use of surface preparation techniques such as corona treatment. Water-based inks excel in printing applications involving paper, cardboard, and textiles, are even used to print on foils, plastics, and food packaging. Through the development of new additives and printing processes,
water-based inks can now be used in the majority of printing processes, although not for offset lithography, and on most materials and for many different applications.

1.3.4. Manufacturing of Water-Based Inks

Manufacturing of water based inks is a simple mixing process where the pigments, additives, and vehicles are produced separately. Pigments have too large particles to be directly used in manufacturing inks. The pigments have to be ground or milled to particles sizes between 5μm to 100nm depending on what color strength, coating thickness, and dispersion properties are needed. Grinding is aided by grind resins, in the case of water based inks that would be solution resins with molecular weight no more than 15,000. Wetting agents or surfactants are also added as milling/wetting additives. With the high speed mixer, the pigments are mixed with the letdown resins in solvent or solvents which in the case of water-based inks is going to be either mostly water or all water. Let down resin in the case of water based ink would be emulsion resin with molecular weight of about 200,000, depending on ink final application. Emulsion resin will impart film forming properties of the ink. To stabilize the colloidal dispersion, the surfactant and/or polymer are added and allow for even distribution of the pigment. To complete the ink making process for ready to use inks, the additives are then added to the mixer to achieve the desired properties [22].

1.3.5. Formulations of Water-Based Ink

Colorant, vehicle, solvent, and additives are used in formulation of water based inks. To achieve the desired properties of the ink; different pigments, additives, and vehicles are used in different combinations and amounts. For water-based printing inks, they will typically have a composition of 60% water/other solvents, 20% resin, 15% colorant, and 5% additives. The vehicle is referred to all of the ink components except the colorant. Traditionally, acrylic chemistry is used
in grinding (dispersion) of pigments and let-down emulsion polymers adding up to finish the formulation of water based ink. In the case of flexo water-based inks, usually petroleum-based acrylic polymers are used. Also, acrylic polymers are used in a variety of applications, such as the automotive, medical device, paint, and adhesive industries. Often times, the ink industry has to compete with other industries for acrylic polymers, making it an expensive and time consuming process. They do not biodegrade, which is unacceptable from sustainability point of view. Thus, there is need to look for application of biodegradable polymers for water based inks, and one of the possible solutions seems to be utilization of soy protein.

1.4. What is a Soybean?

The soybean is a legume low in saturated fat with no cholesterol in it. It was introduced to the U.S. in 1765 and used for both food and industrial applications. The soybean is comprised of eight vital amino acids and it is known to be a good source of fiber, iron, calcium, zinc, and vitamins. Soybeans include about 40% protein and 20% oil. They are also known to contain three natural surfactants: soy protein, soy lecithin, and soy saponin. Soy proteins are obtained through the extraction of soybean oil. They form the byproduct that remains after the removal of the hulls and oil from the flake [24, 25].
Soybean oil is known as a vegetable, non-toxic oil that is widely used in cooking and food products, such as mayonnaise. It originates from renewable sources; it is available at a reasonable price, so it can be a good candidate for ink manufacture. Technology is known for production of vegetable-oil-based printing ink vehicles with favorable commercial characteristics. The inks that are formulated with these vehicles are used for lithographic newsprint applications [27]. A slightly reduced amount of pigment content, due to the light vehicle color based on the soy oil, is the reason that soy oil inks can be a competitively priced alternative to petroleum-based inks [28]. Soybean oil is mixed with resins, pigments and waxes to formulate soy oil-based for cold set litho ink. Worldwide, there are about ten thousand newspaper printers that use soy oil ink. Increasing demand for this kind of ink takes place in the U.S., Asia, Europe and Australia [29, 30]. As mentioned above, the increased consumption of soy ink reduces environmental pollutions, because of the low amount of volatile organic compounds (VOC) present in soy inks. As we know, every specific printing process requires a different kind of ink, so researchers are seeking to make the
best quality soy ink for each type of printing process. Since soybean oil readily mixes with pigments, soy ink results in deeper and brighter colors, thus overall better litho print quality. The removal of soy-based inks is easier than petroleum-based ink in deinking processes. This results in less damage to the paper fibers, which is recycled and reused [31].

The soy ink is more stable during printing, which leads to less waste in comparison to conventional petroleum-based inks. There are also several disadvantages to using soy inks, such as longer drying times in comparison to conventional petroleum-based litho printing inks (especially for coated papers). This difference can cause some lateral print problems such as smudging and bleeding, which makes them unsuitable for food packaging and ballpoint pen inks [31].

Soy proteins exist in three major forms: soy flours, soy protein concentrates and soy protein isolates. Soy flour is made by grinding the soybean and contains about 50-59% protein. Soy protein concentrate is made by removing the aqueous liquid part of the soybean and it contains approximately 65-72% protein. Soy protein isolate is made from defatted soy flour by removing water-soluble carbohydrates of the bean. It is the most refined form of soy proteins and contains 90% protein [24, 25]. Soy protein has been popular since 1936 due to its great functional properties. It is used in a variety of foods, such as salad dressings, frozen desserts, breads, and breakfast cereals; also, it can be used as a natural polymeric emulsifier, foaming agent, and texture-enhancer. The other industrial products that use soy protein include adhesives, asphalts, resins, cleaning materials, cosmetics, inks, paints, plastics, polyesters and textile fibers [31]. The basic application of industrial-grade protein is as a binder in paper coating. Proteins are built by condensation reaction of amino acid monomers and create peptide bonds. Water molecules are released as a result of condensation reaction between amino acids (Figure 8) [32].
Soy protein has a complex 3-D shape and contains 19 different amino acids, which are held together in a coiled structure by peptide bonds. Figure 9 and Figure 10 show the structure of amino acids and proteins.
Proteins contain positive and negative functional groups, which enable them to achieve an isoelectric point. Amino, carboxyl, hydroxyl, phenyl and sulfhydryl groups are main building blocks of soy protein [32].

Soy protein is mainly used in paper coatings. However, its use in the printing industry is in its beginnings. There is not known a commercial production of water based inks based on soy protein for flexography printing, and therefore, it is the topic of this work [35, 36]. The soy based product used in this research is chemically and a thermo-mechanically processed polymer designed to be a functional, consistent and cost saving binder for water based ink. It is environmentally friendly, non-hazardous and renewable. It can be let down into any ink as a solution or dispersed as a powder into pigment prior to dispersion. The advantages were reported as superior heat resistance, ink scuff resistance in preprint corrugated board, improved slide angle, excellent ink solubility, longer press run, enhanced print quality, easier press cleanups, controlled amphoteric charge density, proper interaction with color pigments, good ink transfer properties and good color strength.
Acrylic solution and emulsion polymers and their various copolymers are widely used in water based ink formulations. Water-based flexo inks are formulated with various acrylic polymers and copolymers serving as solution and emulsion resins to grind and disperse pigments and create ink films, and impart necessary properties such as rheology, adhesion, or rub resistance. The printing industry sometimes feels shortages of these acrylic polymers, with associated higher prices. The aim of this project is to determine if a particular soy protein (ProSoy 7475) can be used to partially replace acrylic resins (AC0073) in water-based flexo inks, mainly in the letdown portion of the ink, thus replacing primarily emulsion resins, responsible for film forming, to create more environmentally friendly inks, with the goal not only to reduce environmental pollution, but also to create an ink with better sustainability and printability.
CHAPTER III
EXPERIMENTAL

In PHASE 1; Commercial acrylic water based ink formulation was carried out. Such acrylic ink, which is used in flexography process, was formulated using PB15-44 (Cyan pigment dispersion) and its print parameters such as optical density, CIE L*a*b* color values, rub resistance, water drop test, foam test, pH stability & viscosity were studied.

In PHASE 2; soy vehicle formulation was carried out. Target was to prepare SOY vehicle formulation using ProSoy 7475 Protein powder and compare its pH & viscosity with the commercial acrylic ink vehicle (AC0073) provided by American Inks & Technology, ltd.

In PHASE 3; Soy vehicle (ProSoy7475) was blended into commercial acrylic ink formulation in the increments of 0-20-40-60-80 wt. % up to 100% soy vehicle. Acrylic vehicle AC0073 was employed and results of both PHASE 1 & PHASE 3 were compared.

3.1. Materials

Soy Protein (ProSoy 7475) was provided from ARRO company. A cyan Pigment dispersion was obtained from American Inks & Technology Ltd. Company, under the commercial name “PB15-44” Other materials that were used in this research were also provided by same company. Table 1 gives the physical and chemical properties of ProSoy 7475. Table 2 gives the physical and chemical properties of pigment dispersions.
Table 1. Physical and chemical properties of ProSoy 7475 powder

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Appearance</td>
<td>Off White to Tan Granular Powder</td>
</tr>
<tr>
<td>Solution Color</td>
<td>Opaque Light Brown</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>672 Kg/m$^3$</td>
</tr>
<tr>
<td>Moisture</td>
<td>15% Max.</td>
</tr>
<tr>
<td>Solution Solids</td>
<td>20%</td>
</tr>
<tr>
<td>Particle size</td>
<td>&lt;5% (325 Mesh)</td>
</tr>
</tbody>
</table>

Table 2. Physical and chemical properties of pigment dispersion (PB15-44)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Blue Liquid</td>
</tr>
<tr>
<td>pH</td>
<td>8-10</td>
</tr>
<tr>
<td>Solubility in Water</td>
<td>Miscible</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.11</td>
</tr>
<tr>
<td>Viscosity (cP)</td>
<td>15-25</td>
</tr>
</tbody>
</table>

Other Material such as IPA, Defoamer (FC-613), Acrylic Varnish (AC0073), Wax, Ammonia (NH4OH) are used.

3.2. Instrumentation

After formulating the inks, they were analyzed for various printability properties such as: optical density, pH & Viscosity, Rub/Scuff Resistance, CIE L*a*b* values. The optical density and CIE L*a*b* values of the print were measured with an Spectrodensitometer eXact and Spectrodensitometer X-Rite 530 (Figure 11). CIE L*a*b* values define a 3-dimensional color space in which values of L*, a*, and b* are designed at right angles to one another to form a three-dimensional coordinate system. Equal distances in the space roughly denote equal color
differences. Value L* signifies lightness, value a* signifies the redness/greenness axis, and value b* signifies the yellowness/blueness axis [37].

![Spectro-densitometer X-Rite (eXact)](image)

**Figure 11. Spectro-densitometer X-Rite (eXact)**

The Flexo Anilox hand proofer includes the housing, a rubber transfer roll and a spring-adjustable mechanically engraved anilox roll, (with a Path Width of 4-3/4”) shown in Figure 12. The hand Proofer gives you more options — for testing on polyethylene, cellophane, glassine, metallic foils, plastic films, paper and paperboard. In addition, what you see on the proof is what you’ll print on press. Since proofer rolls are available in a full range of screens to duplicate your press requirements, you can make any changes in ink or screen before you get to the pressroom!

![Flexo anilox hand proofer with 200 lpi anilox resolution](image)

**Figure 12. Flexo anilox hand proofer with 200 lpi anilox resolution**
3.3. Experimental Procedures

3.3.1. Phase 1: Acrylic Ink Formulation

Acrylic water based ink formulation proceeds as per the guideline shown in the Table 3. A commercial water based acrylic ink for flexo ink was formulated as per the formula weight used in commercial ink formulation by using acrylic vehicle AC0073 (Table 3). pH & Viscosity noted as pH - 9.1 & Viscosity was measured as efflux time - on Zahn cup 2 with controlled temperature at 76⁰ Celsius, efflux time was 25 seconds.

Table 3. Flexo commercial water based ink formulation

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight in gm</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigment Dispersion PB-15-44</td>
<td>43.50</td>
<td>Provides Color</td>
</tr>
<tr>
<td>H₂O (DI water)</td>
<td>07.00</td>
<td>Carries Pigment to the Substrate</td>
</tr>
<tr>
<td>Acrylic Varnish (AC 0073)</td>
<td>48.10</td>
<td>Holds pigment on substrate</td>
</tr>
<tr>
<td>WAX (AIT-PE-35)</td>
<td>01.00</td>
<td>Provides elasticity</td>
</tr>
<tr>
<td>Defoamer (FC-613)</td>
<td>00.40</td>
<td>Controls foaming issues</td>
</tr>
<tr>
<td>Total weight</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>
3.3.2. Phase 2: Soy Vehicle Formulation

In the second phase of the project, soy vehicle formulation experiment was carried out using Soy Protein powder (ProSoy 7475) and final formulation was characterized. The commercial vehicle (AC0073) was used as a target in the Phase 3 as a commercial acrylic varnish. Preparation of a ProSoy 7475 water based solution: There are four key variables affecting the rate or degree of ProSoy solubility. Increased rate or degree of solubilization is observed with increasing levels of the following variable: temperature, pH, shear rate and time. Solids level can be adjusted as desired. A solids limitation will be reached due to increased solution viscosity with higher solids. A solids level of ~20% for ProSoy 7475 is a good starting point. Higher or lower solids can be evaluated as desired.

Table 4. Soy vehicle formulation

<table>
<thead>
<tr>
<th>Material</th>
<th>Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>80</td>
</tr>
<tr>
<td>ProSoy</td>
<td>15</td>
</tr>
<tr>
<td>Amine (For pH Adjustment)</td>
<td>0.4 to 1.0</td>
</tr>
<tr>
<td>Isopropyl Alcohol</td>
<td>4</td>
</tr>
<tr>
<td>Biocides</td>
<td>As Needed</td>
</tr>
<tr>
<td>Antifoam</td>
<td>As Needed</td>
</tr>
</tbody>
</table>

The water was heated to desired cooking temperature, which is typically, 60° to 76° Celsius. Then, ammonia water 27% concentration was added in the formulation under agitation (typical pH range of final solution should be 9.0 to 10.5). ProSoy was added under good agitation such that the powder is immediately pulled below the surface and wet out. Agitation with a vortex
messenger was maintained for 40 minutes at the desired cooking temperature (60°C). Other formulation ingredients were added under agitation to the protein solution.

**Table 5. Soy vehicle formulation trials (formula weight in gm)**

<table>
<thead>
<tr>
<th>Vehicle Formulation using ProSoy 7475 @ 76°C Celsius</th>
<th>Standard</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProSoy 7475</td>
<td>15</td>
<td>25</td>
<td>15.4</td>
<td>15.6</td>
</tr>
<tr>
<td>Water (DI Water)</td>
<td>80</td>
<td>67.4</td>
<td>80</td>
<td>78.45</td>
</tr>
<tr>
<td>Ammonia (27%)</td>
<td>0.6</td>
<td>0.6</td>
<td>0.4</td>
<td>1.6</td>
</tr>
<tr>
<td>IPA</td>
<td>4</td>
<td>6.6</td>
<td>4</td>
<td>4.1</td>
</tr>
<tr>
<td>Defoamer (FC-613)</td>
<td>0.4</td>
<td>0.4</td>
<td>0.2</td>
<td>0.25</td>
</tr>
<tr>
<td>Total Weight (gm)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

To minimize the variations; pH & viscosity were maintained the same as for mixing the acrylic vehicle AC0073. Soy varnish was formulated by using ProSoy 7475 protein powder as per technical data sheet (MSDS & SDS) provided by ARRO and according to Table 5. After four trials; final water based vehicle formulation using ProSoy 7475 Protein was developed and it is given in the Table 5. These formulations were observed for over a time duration of about twenty days for pH & viscosity stabilization.
3.3.3. Phase 3: Increments of Soy Vehicle (ProSoy 7475) Addition Into The Acrylic Vehicle (AC0073) Using Commercial Acrylic Water Based Ink Formulation

Letdown portion of the ink formulation was replaced with soy polymers (ProSoy 7475), doing it in increments of 20-40-60 up to 100% (Table 6) replacement of the acrylic emulsion resin (AC0073). Formulated cyan process color ink was tested for printability, rheology, and end use properties such as rub resistance, and adhesion.

Table 6. Acrylic water based ink formulation (formula weight in gm)

<table>
<thead>
<tr>
<th>Material</th>
<th>Standard</th>
<th>Ink 1</th>
<th>Ink 2</th>
<th>Ink 3</th>
<th>Ink 4</th>
<th>Ink 5</th>
<th>Ink 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB-15-44</td>
<td>43.5</td>
<td>43.5</td>
<td>43.5</td>
<td>43.5</td>
<td>43.5</td>
<td>43.5</td>
<td>43.5</td>
</tr>
<tr>
<td>H₂O (DI water)</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Varnish (AC 0073):(ProSoy 7475)</td>
<td>48.1</td>
<td>100:0</td>
<td>20:80</td>
<td>40:60</td>
<td>60:40</td>
<td>80:20</td>
<td>0:100</td>
</tr>
<tr>
<td>WAX (AIT-PE-35)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Defoamer (FC-613)</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Total weight</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
CHAPTER IV
RESULTS AND DISCUSSION

4.1. pH and Viscosity

Water based inks may change in viscosity over the time, which may be caused by change in pH. Thus, settling means an increase in viscosity and a decrease in pH over time, depending upon types of resins and pigments used. Here, the time duration was taken from day one to day sixty to check the pH and viscosity for acrylic ink and soy vehicle ink. As shows in Figure 13, the pH value of acrylic ink value ranges from 8.9 to 9.1 and the viscosity ranges from 25 to 26 s measured as efflux time on Zahn #2 cup. Whereas in the soy vehicle increments pH value are different for different increments of soy vehicle percentages. Example may be as follows: for 20% soy addition, pH changed from 9.1 to 9.2, at 40% soy vehicle addition pH varied from 8.9 to 9.1, at 60% soy vehicle pH changed from 8.8 to 9.0, at 80% soy addition pH was found in range from 8.7 to 9.0 and at 100% soy vehicle measured pH varied from 8.9 to 9.1. When compared pH difference between acrylic ink vehicle and soy vehicle, ink pH is almost negligible and within the expected range.

Viscosity of acrylic ink ranges from 25mPa to 27mPa, whereas viscosity of soy vehicle ink depending on soy vehicle percentages, and ranges from 26mPa to 28mPa. It was noticed that the viscosity of acrylic ink is almost constant over time, whereas viscosity of soy vehicle ink showed little increase with soy vehicle addition and time.
Figure 13. pH and viscosity (acrylic ink vs increments of ProSoy7475)

4.2. Optical Density

Optical density refers to a computed number representing the ability of a transmissive material to block light, or the ability of a reflective surface to absorb light. The more light is blocked or absorbed, the higher is the density. Here, optical density was measured with an X-Rite 530 spectrodensitometer. The instrument was calibrated before taking the density measurement. The optical density of acrylic ink at 100% tone was ranged from 1.26 to 1.29, whereas optical density of soy vehicle increments ranged from 1.24 to 1.27 at the same tone step. This difference
was very minimal or it can be said there was no significant difference in acrylic resin based ink and soy vehicle based ink at 100% tone step (Figure 14).

![Image](image.png)

**Figure 14. Optical density (acrylic ink vs increments of ProSoy 7475) at 100% tone step (percent mean the amount of soy polymer in ink let down portion)**

### 4.3. CIE L*a*b* color measurement

A CIE L*a*b* color space is a color-opponent space with dimensions L* for lightness and a* and b* for the color-opponent dimensions of red-green and yellow-blue, based on nonlinearly compressed (e.g. CIE XYZ) coordinates. The terminology originates from the three dimensions of the Hunter 1948 color space, which are L*, a*, and b*. There are a few popular ways of mathematically comparing colors, most notably CIE76. CMC 1:c is another such method that was devised in 1984 by the Colour Measurement Committee of the Society of Dyers and Colourists based on the Lch color model. This method incorporates thresholds that allow the users to weight the difference based on the ratio of lightness to chroma that is applicable to the task at hand. The most common ratios are 2:1 for “acceptability” and 1:1 to the threshold of “imperceptability”. The ΔE (CMC2:1) values were calculated by taking CIE L* a* b* values of the standard Cyan color on the substrates. When acrylic ink color coordinates CIE L*a*b* and soy CIE L*a*b* were
compared on 100% cyan tone step, the difference in L*a*b* values were very minimal or there was almost no difference noticed (Figure 15).

**Figure 15. CIE L*a*b* (Acrylic ink vs increments of ProSoy 7475) measurement on 100% cyan tone step**

### 4.4. Delta E (ΔE) Color Difference

Delta E (ΔE) is defined as the difference between two colors in a CIE L*a*b* color space. As the values determined are based on a mathematical formula, it is important what is the type of color formula taken into account when comparing the values. In the Color Verifier alone, there are three different formulas to choose from, each producing different results [38].

Delta E (CMC) The color difference method of the Color Measurement Committee (the CMC) is a model using two parameters l and c, typically expressed as CMC(l:c). Commonly used values for acceptability are CMC(2:1) and for perceptibility are CMC(1:1). The CIE L*a*b* formula used in the proofing market calculates the Euclidian distance, that is purely the distance between two points in a three-dimensional color space. The actual position of the points themselves
is irrelevant. Higher ΔE values mean that the colors are further away from the original color values and vice versa. The color difference, or ΔE, between a sample color (L2, a2, b2) and a reference color (L1, a1, b1) can be calculated using the formula for $\Delta E_{CMC}$ as follows (“CIE L*a*b Color Scale”) as in Equation 1:[38]

$$\Delta E_{CMC} = \sqrt{\left(\frac{L_2 - L_1}{L_1}\right)^2 + \left(\frac{C_2 - C_1}{c S_C}\right)^2 + \left(\frac{H_2 - H_1}{S_H}\right)^2}$$

$S_L = \begin{cases} 0.511 & L_1 < 16 \\ 0.040975 L_1 & L_1 \geq 16 \end{cases}$

$S_C = \frac{0.0638C_1^a}{1 + 0.0131C_1^a} + 0.638$

$S_H = S_C(FT + 1 - F)$

$F = \sqrt{\frac{C_1^a}{C_1^a + 1900}}$

$T = \begin{cases} 0.56 + |0.2 \cos(h_1 + 168^\circ)| & 164^\circ \leq h_1 \leq 345^\circ \\ 0.36 + |0.4 \cos(h_1 + 35^\circ)| & \text{otherwise} \end{cases}$

Equation: (1)

![Delta E - Acrylic Ink Vs Soy increments inks](image)

**Figure 16. ΔE (acrylic ink vs increments of ProSoy7475) at 100% cyan tone step**

The calculated ΔE for acrylic ink and soy varnish ink was within the range of ΔE=1 (Figure 16-21), which is below the acceptable color difference of ΔE 2 in the printing industry [38]. It was observed that the increments of soy varnish up to 100% result in color change below ΔE=1 that
states the difference cannot be identified by human eye. The soy varnish is causing ink to reflect more blue, thus the highest shift towards the blue side is observed in 100% soy vehicle cyan ink.

**Color Comparison for CIE L* a* b* & Delta E Values**

Figure 17-21 shows color comparison for acrylic ink at 100% cyan tone step versus increments of soy vehicle introduced into it. This comparison was done by using ColorCert software where in settings used in it was as follows: Color space = CIE L* a* b*, Method = \( \Delta E_{\text{cmc}} (2:1) \), Illumination = D50, Observer = 2\(^0\) and Filter = no filter.

First, acrylic ink at 100% cyan tone step was measured and set it as a standard and compared with 20%-40%-60%-80% & 100% increments of soy vehicle (ProSoy 7475) in acrylic ink as shown in Figure 17-21.
Figure 17. Ink 1 (acrylic) vs ink 2 with acrylic : soy varnish (80:20) comparison at 100% cyan tone step
Figure 18. Ink 1 (acrylic) vs ink 3 with acrylic:soy (60:40) comparison at 100% cyan tone step
**Figure 19.** Ink 1 (acrylic) versus ink 4 with acrylic :soy varnish (40:60) comparison at 100% cyan tone step
Figure 20. Ink 1 (acrylic) versus ink 5 acrylic : soy varnish (20:80) comparison at 100 % cyan tone step
Figure 21. Ink 1 (acrylic) versus ink 6 acrylic : soy varnish (0:100) comparison at 100% cyan tone step

Figure 22 shows the slight decrease in solids levels of inks when the increments of soy vehicle are introduced into the acrylic ink vehicle. This could be caused by higher hygroscopicity of soy protein than acrylic polymer, but probably solids content could be adjusted more accurately.
after additional attempts. In Figure 23, the interactions of light with the particles in ink film suggest that the angle of reflected light changes depending on the solid levels in the ink samples, explaining the reason for the color shift in ink samples that was observed in Figures 17-21 [39]. The reason would be related to the wavelength dependence of the refractive index of the acrylic vehicle versus the samples containing the increments of the soy vehicle. Refractive index may be also changing with different vehicle and causing the shift towards the blue region.

![Solid levels of inks in percentage (%)](image)

**Figure 22. Solid levels of inks (%) (Ink 1 to Ink 6)**
An ink rub tester evaluates the rubbing or scuffing resistance of printed surfaces by simulating abrasion damage typical in the field. For rub resistance Sutherland rub tester is used. Printed strip of 2x7 in was used for test with load of 4lb weight block and 60 cycles. The grading was done from poor to excellent rub resistance on the scale of 0 to 5, respectively. As shown in Figure 24, acrylic ink showed 5 means excellent rub resistance property as compared to 20%, 40% and 60% increments of soy vehicle to acrylic ink whereas, 80% and 100% soy vehicle ink also exhibited excellent rub resistance similar to 100% acrylic ink (Figure 24). There is no particular explanation for this, except it could be possible that soy and acrylic vehicle did not bond as strongly as acrylic polymers alone or soy polymer alone could. Thus, lower compatibility between the acrylic and soy polymer may occur. Also, it is possible that some draw-downs were less uniform, leading to these results.
Figure 24. Rub resistance (acrylic ink vs increments of ProSoy 7475)

### 4.6. Water Drop Test

Water drop test was carried out to check the ink interaction with the water on substrate over time both on 100% acrylic ink and 100% increment soy vehicle ink. Time duration for test was ranged from 10 seconds to 120 seconds with the time gap of 10 seconds till 60 seconds and after that tested for 120 seconds. The results were graded the same way as rub resistance test on scale from 0 to 5 (Figure 25).
Figure 25. Water drop test (acrylic ink vs increments of ProSoy7475)

Acrylic ink showed excellent water resistance at water drop test for all time durations tested. Ink containing 100% soy vehicle showed at 60 seconds and 120 seconds worse results as compared to acrylic ink.

4.7. 3M Tape Adhesion Test

The tape adhesion test according to the ASTM F2252-03 standard only requires 0.75-1.0” wide 3M #610 tape for tape adhesion testing for water-based inks. To perform the test, the 3M #610 tape was used. The tape was applied over the printed surface and removed by pulling it away from ink film surface. If the ink sticks onto the tape and gets peeled off, the tape adhesion test failed.

Acrylic ink showed excellent result for 3M tape test. Inks with 20% and 40% soy vehicle increments showed also excellent tape adhesion. Inks with 60-100% soy vehicle had slightly
poorer performance. They exhibited lower adhesion than acrylic ink, and their performance dropped down to level 4 (Figure 26).

![3M-Tape Test - (Scale 0-5)](image)

*Figure 26. Tape test (acrylic ink vs increments of ProSoy7475)*

4.7. Vehicle Foam Test

Water-based inks use to have a problem of ink foaming. Ink foaming problem always results in machine downtime and increase in materials wastage. Ink foam problem is never completely removed but can get minimized both at manufacturer’s end as well as at operator’s end. For this test, acrylic vehicle and soy vehicle were separately formulated where in each formulation all ingredients were cut down with 50% addition of DI water. DI water is added along with 0.001% Defoamer (FC-613). Both the samples were shaken for 10 seconds and observed, and time was calculated for settling down the foam. As shown in the Figure 27, acrylic vehicle took almost 80 seconds to settle down the foam, whereas soy vehicle took only 20 seconds to settle down. From the test is obvious that soy vehicle foams less than acrylic one.
Figure 27. Vehicle foam test (acrylic vs soy)
CHAPTER V
CONCLUSION

Water based inks for flexography are employing acrylic solution and emulsion polymers and various copolymers with styrene, butadiene, and many other copolymers. Their performance is reliable and very good, the problem is, that these resins are used in many other fields and sometimes it is not easy to have sufficient supply of them for ink industries. Another problem is that acrylic resins are not biodegradable. The focus of this research was to investigate whether inks made from renewable and/or biodegradable materials such as soy protein could be suitable for use in flexographic water-based ink formulations for printing on liner board.

The experimental findings showed that the increments of soy vehicle in the acrylic ink as compared to the 100% acrylic ink have performed similarly as the 100% acrylic ink. The color comparison between the target acrylic ink and the increments of soy ink samples in terms of color difference was found below $\Delta E=1$, which is in accord with the $\Delta E$ standards used in the graphic and printing industry. The results suggest that soy vehicle can be used to replace acrylic vehicle in water-based flexo inks. This helps to achieve the formulation of a truly environmentally friendly water-based ink, which also helps to reduce the emission of VOCs.

The suggested future work for this research would be to conduct further test for all process color pigment dispersion using ProSoy 7475 vehicle in water-based ink formulations. The print parameters on different substrates can be analyzed. The rheology curves of the samples containing the increments of soy vehicle should be analyzed using a dynamic stress rheometer and compared to commercial flexo inks in order to assess the printability and runnability performance. The
formulations in this research would also be tested on the commercial flexo press to investigate ink performance and find out if large scale results match the results found in laboratory.
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