ABSTRACT
This document gives information about contents of fountain solution and their functions. It also describes the major performance attributes of the fountain solution.

KEYWORDS
Dampening solution, pH, Hardness, Conductivity

I. INTRODUCTION
Lithography works on the principle that oil and water do not mix with each other. The image areas on the printing surface i.e. plate must be oleophilic as well as hydrophobic. At the same time, the non-image areas on the plate must be oleophobic & hydrophilic. On the press, during printing the operator strives to achieve optimum ink-water balance. Ideally the ink should have about 15% water accepting capacity i.e. water in ink emulsification. The fountain solution keeps the non-image areas on the plate hydrophilic as well as oleophobic. Its ingredients other than water also perform various functions. The ingredient such as iso propyl alcohol also poses environmental problems; hence it has to be dealt very carefully.

II. FUNCTIONS AND COMMON INGREDIENTS OF FOUNTAIN SOLUTION
Fountain solution is primarily required to maintain the hydrophilic nature of non-image areas i.e. the desensitization of non-image areas so that they would not accept ink during printing. We can observe on any lithographic printing machine that if we turn down the water then ink starts to print in the non-image, if we turn up the water only then the ink leaves the image. A printer tries to achieve the balance between ink and water during printing. Each surface is carrying a thin film of primarily the intended material. Notice that even though the two surfaces are very different, both can accept ink or water.

- Supply a Film of Fountain solution
- Desensitizing the non image areas
- Cleaning
- Spreading of solution
- Lubrication
- Maintaining proper emulsification

The following are the major ingredients used in fountain solutions along with water:
- Water soluble gums.
- A pH buffer system.
- Desensitizing salts.
- Acids or their salts.
- Wetting agents (also called surfactants).
- Solvents.
- Non-piling or lubricating additives.
- Emulsion control agents.
- Viscosity builders.
- Biocides (fungus, bacteria, and mold control agents).
- Defoamers.
- Dyes.

Use of gum for desensitization of the plate non-image areas - When the plates are manufactured, the aluminium surface is treated to be both durable and hydrophilic. As the plate wears and is constantly exposed to ink and dirt, this treatment must be renewed. Gum Arabic is commonly used as a desensitizer. This is the dried sap of the acacia tree that grows in parts of Africa. This gum is water soluble and has a high affinity for aluminium metal. It bonds best at pH near four. Other water soluble polymers such as larch gum, starches, Carboxy Methyl Cellulose (CMC) have also found use as plate desensitizers. After each application of fountain solution, a small amount of gum adheres to the plate surface particularly non image areas; providing a protective film. When the machine is stopped for any length of time, it is very important that this gum film is adequate to protect the plate from oxidation or handling.

Desensitizing salts:
Several inorganic salts aggressively react with aluminium metal to form hydrophilic compounds.
These salts contain strong polar bonds which attract water. Examples are silicates (SiO4) and phosphates (PO4); both contain oxygen atoms (O); these polar oxygen atoms will stick up from the plate surface and draw water. Plates are often treated during manufacturing with these same salts following the anodizing to impart a durable, corrosion-resistant surface.

**Use of acids, solvents, and wetting agents**

These act as cleaners and tend to remove any accumulated oily debris from the plate surface. If left to build up, this debris will attract ink and cause sensitivity. Acids, like phosphoric, are used for metal cleaning. A very thin layer of metal is dissolved off the plate exposing a fresh surface. The sequence of events during a press shutdown and restart - The thin film of fountain solution dries on the plate. Ink may get on the non image areas after shutdown if the press is inclined. During restart, fountain solution is applied by the water form roller wetting the non image areas. The dried gum film should dissolve and lift off any ink or dirt. The desensitizing ingredients will reestablish the hydrophilic layer on the non image areas, and the plate will be printing clean. A failure at any point will slow the restart and cause more spoilage. There must be a thick film of gum from the evaporating fountain solution. The gum film must be readily soluble when the water returns. The wetting agents should help remove any oily debris. The desensitizing salts must reestablish the hydrophilic surface which will strongly attract water. A Uniform Film of solution must be applied. At the instant the water form roller and the plate split, the ratio of wettest to driest areas must be a minimum across the plate.

**Use of surfactants to reduce dynamic surface tension**

Any surfactants that are in the fountain solution must be capable of acting very quickly. This is called good “Dynamic Surface Tension Reduction”. When a water film is split (at the nips, for example) these surfactant molecules react by travelling (migrating) to a water surface. To be effective, the molecules must line up with their hydrophilic ends pointed towards the surface. They have no effect while inside the body of the liquid. The strength and concentration of the surfactant controls how much the surface tension will be reduced, but of greater importance the “migration speed of the molecules” controls how quickly the reduction or rapid wetting will occur on press. Surfactants are wetting agents that lower the surface tension of a liquid, allowing easier spreading, and lower the interfacial tension between two liquids. The term surfactant is a blend of “Surface active agent”. Surfactants are usually organic compounds that are amphiphatic, meaning they contain both hydrophobic groups (their “tails”) and hydrophilic groups (their “heads”). Therefore, they are typically sparingly soluble in both organic solvents and water. Surfactants reduce the surface tension of water by adsorbing at the air-water interface. They also reduce the interfacial tension between oil and water by adsorbing at the liquid-liquid interface. A surfactant can be classified by the presence of formally charged groups in its head.

A non-ionic surfactant has no charge groups in its head. The head of an ionic surfactant carries a net charge. If the charge is negative, the surfactant is more specifically called anionic; if the charge is positive, it is called cationic. If a surfactant contains a head with two oppositely charged groups, it is termed zwitterionic. E.g. Sodium dodecyl sulphate (SDS) – CH3(CH2)11OSO3Na

**Purpose of using Alcohol**

- Alcohol is a very good wetting agent, it improves dampening flow.
- Alcohol evaporates from the ink rollers quickly, leaving no residue.
- The evaporation helps cool the ink train.
- The viscosity of water & thus of fountain solution increases as IPA is added (up to about 25% alcohol concentration by volume).
- Alcohol is used at high percentages compared to other fountain ingredients.
- Alcohol gives only medium surface tension, but, because the molecules are small, its dynamic properties are exceptionally good. It gives very fast surface tension reduction.

**Drawbacks of Alcohol**

- IPA can cause starvation (ghosting), since the emulsifying of the dampening solution in the ink is made more difficult.
- IPA encourages blank runs, in particular in the presence of very hard water, since IPA reduces the solubility of calcium salts.
- Too much IPA can breakdown the adhesive agent in the printing ink, dissolves the protective covering of metal pigments, and reduce luster.
• IPA can attack the paper coating, which can lead to build-up on the rubber blanket.
• IPA belongs to that category of volatile organic compounds (VOC), which damage the atmosphere.

Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA) regulations (such as those calling for the reduction of volatile organic compounds) are limiting, if not eliminating, the use of alcohol in dampening solutions.

Many such disadvantages of alcohol like cost, toxicity, flammability, and need for adequate ventilation in surroundings; are causing alcohol substitutes2 to be used. These substitutes include derivatives of glycol and glycol ethers, frequently in combination with ethylene glycol. These substitutes can either completely replace isopropanol or they can be added as a supplement to it, reducing the total isopropanol concentration. The advantages of these substitutes include a lower volatility, which cuts down on toxic emissions; their effectiveness at lower concentrations than alcohol (5% or less); increased print quality, including less ink and water necessary for good color printing, sharper halftone dots and reduced dot gain; and their lack of odor improves workplace conditions. However, their disadvantages include increased piling of paper debris on the blanket; increased amounts of dampening solution transferred to the blanket; inability to mix directly with concentrated amounts of gum; increase of ink drying time; press problems such as roller stripping; and incompatibility with non-paper substrates, such as plastic, film, or other nonabsorbent surfaces. They also increase the tendency for the metering roller (in continuous-flow dampening systems) to become ink-receptive. The use of 1:32 gum etch can help eliminate the problem. Another metering-roller problem of banding (the formation of light and dark bands on the roller which cause streaks on the plate and print), happens when using alcohol substitutes on a hard roller (durometer A of 25:30). The use of a lower-durometer roller (18:22) will reduce the problem, as will using a metering roller with a slightly grained surface, which allows more water to be carried by the roller. The low volatility of alcohol substitutes (which can be lower than that of water) can also result in an increase in substitute concentration over the course of a print run as the water evaporates then the only preventive measure is to replace the fountain solution at least once a week. Some alcohol substitutes also increase the tendency for foaming. Another roller problem is caused by the deposit of salts (a white solid material) on the metering roller, typically a problem when the press is idle for about 8 hours. The metering roller needs to be cleaned and desensitized. Alcohol substitutes also have no effect on fountain solution viscosity, which requires higher roller speeds in continuous-flow dampening systems. Refrigerating the solution, however, can help increase the viscosity.

Refrigeration of dampening solution has other benefits also. Hot-weather scumming (tinting), is caused by the accumulation of ink in non-image areas of the plate, and is caused by the particles of ink pigment bleeding into the dampening solution, a tendency that increases with temperature. Keeping the temperature of the fountain solution low can reduce this problem. Refrigeration also helps ensure that the fountain solution stays at a constant temperature. As viscosity decreases with increasing temperature, keeping the solution at a constant temperature keeps the viscosity constant, eliminating the need for frequent adjustments of the metering nip in continuous-flow dampening systems. Refrigeration also reduces the evaporation of alcohol in alcohol-based fountain solutions, which helps prolong the fountain solution and cuts down on the concentration of the health-hazards of evaporated alcohol in the pressroom air. However, refrigeration is not without its problems such as when the warm press and fountain pan cause condensation of water drops on the bottom of the pan containing cold fountain solution. These drops can drip onto the paper, damaging it. Cold fountain solutions can also increase the ink tack, increasing the problems as picking, splitting, and tearing of the paper.

Alkaline fountain solution

In order to reduce the cost of acidic fountain concentrates alkaline solutions are used with pH range of 8 to 11. These solutions are particularly used in newspaper printing where the paper is not of much quality & durability of the printed product is not the issue. But neutral and alkaline solutions are not unable to provide the properties required for use with latest sophisticated presses. E.g. performance improvement of the cleansing and wetting capabilities of fountain solutions. The neutral and alkaline solutions do not cleanse the
plate fast and effective enough to accommodate the increasing speeds of latest presses. In fact, some of today's newer systems will not function correctly at a pH greater than 4.0. Secondly, although alkaline based solutions were suitable for use with older generation inks based on mineral oils, they are generally incompatible with newer generation inks comprising vegetable oils, such as soy, linseed, and rapeseed. When a vegetable oil and alkali are mixed, the resultant chemical reaction produces a water soluble soap, which adversely affects the equipment's performance and resultant quality of the printed material. They also have the problem of bad odour, algae formation. Hence their use is limited.

Non-aqueous fountain solution composition - US Patent 6187081

The composition is prepared by dry blending 2-25% by weight of a film forming agent, 2.5-25% by weight of an acid, 2.5-50% by weight of an acid salt combination, 0.5-1.5% by weight of a biocide, 0-10% by weight of a sequestrant, 0-25% by weight of a corrosion inhibitor, 0-10% by weight of a humectants, and 0-5% by weight of an anti-foaming agent. It is provided in solid or powder form & is added to water at appropriate levels for use as a dampening or fountain solution in lithographic printing systems.

Film forming agent (sodium carboxyl methyl cellulose) - Creates a hydrophilic film over the non-image areas of the plate, thereby shielding such non-image areas from the subsequently applied ink.

The acid and acid salt combination (Citric acid and sodium citrate as the acid and acid salt, respectively) achieves the desired pH value in the composition.

Biocide (Sodium benzoate) preserves the composition during storage and in use by impeding the growth of and destroying any fungus or microorganisms that may be present in the composition.

Sequestrant (sodium salt of ethylene diamine tetra acetic acid) counteracts the effects of dissolved calcium and other interfering agents introduced to the fountain solution with the addition of water. Without the introduction of the sequestrant, the calcium and other interfering agents tend to react with ingredients in the ink and fountain solution to create scale and sludge in the offset printing system.

Corrosion inhibitor (Sodium nitrate and sodium phosphate) protects the printing plate, press and associated components from corrosion.

Humectant (polyethylene glycol of high molecular weight) prevents the printing plate from drying too rapidly and to maintain the properties of the film formers.

Anti-foaming agent (dry silica based defoamer) prevents the formation of foam after the composition is mixed with water.

III. MAJOR VARIABLES TO BE MONITORED IN FOUNTAIN SOLUTION

Following are some variables which need to be monitored for optimum performance of fountain solution.

**Water Hardness**

Water is the most important ingredient of fountain solution and it is the ingredient present in highest percentage. A printer uses tap water as the source material for the fountain solution. This water found in nature is not clean; rather it contains numerous gasses and minerals. If the proportions of these salts are exceeding certain tolerance, the fountain solution ingredients may have to be modified to achieve desired results. The hardness of the water must be calculated before any additives are introduced, since hardness is no longer easily determined in a prepared dampening solution. Test-strips are useful in performing a simple determination of the total water hardness.

The proportion of lime in the water can cause the following problems during printing

- The inking rollers run blank (calcification)
- Deposits on the rubber blanket
- Impact on the pH-Balance
- Fluctuation in the pH-Balance

If the proportion of chloride, sulphate, or nitrate is too high, it will lead to corrosion.

Ideally, the dampening solution should possess a water hardness of 8° dH to 12° dH. 1° dH = 10 mg of CaO per litre of water = 17.8 ppm CaO per litre of water.

There are three stable substitutes for tap water: De-ionized, Distilled & reverse osmosis water.

De-ionization or the demineralization process: A complex chemical process that uses two ion exchange resins to remove minerals from water.

The cost of this method is considerably less than the cost of producing distilled water. Distilled water: Produced in a laboratory by boiling
ordinary tap water in water still. The steam that rises from the boiling water is almost free of the mineral matter present in the tap water. Some fountain solutions do not work well with distilled water. Reverse Osmosis water: The best method of water purification. In this process the water is filtered through a membrane to remove most of the positive and negative ions, un-ionized dissolved solids (sugars), suspended matter, and bacteria leaving only pure water. Pure water has an electrical conductivity of close to 0 micromhos / cm (µmhos or µSiemen per cm). As the amount of dissolved solids in water increases, so does its electrical conductivity, in direct proportion to the concentration of total dissolved solids. Soft water has a conductivity of 0 to 225 µmhos / cm, hard water having a conductivity greater than 450 µmhos / cm. Average water straight from tap may have a conductivity of 200 µmhos or greater. In order for a dampening solution to be effective and trouble-free, its conductivity must fluctuate by no more than ±50 µmhos. Conductivity fluctuations of at least 200 µmhos are a sign that water purification is necessary. A relationship exists among concentration of the solution, the pH, and the electrical conductivity, all of which need to be in balance when mixing an effective fountain solution. In countries using the SI system, the printing industry measures conductivity in microSiemens or µS / cm. The numerical values are identical to µmhos.

Conductivity
It describes how electricity is conducted through a liquid; impurities in the dampening solution allow conductivity to increase. Conductivity varies depending on the water and additives. The temperature and the concentration of alcohol also influences conductivity. By increasing Iso Propyl Alcohol (IPA), conductivity declines. Conductivity should be determined using a “freshly prepared dampening solution”, so that this measure can then serve as a standard when the dampening solution is later exchanged. When the conductivity in the dampening solution has climbed by approx. 1000 µS/cm, this should be taken as a signal that it is time to change the dampening solution.

pH
Ideally, the dampening solution should possess a pH-Balance of 4.8 to 5.5. Higher pH readings may cause scumming and toning, whereas pH readings of less than 4.0 may retard or inactivate ink drying by locking up the catalytic dryers in the ink. Buffers are chemicals that are used in fountain concentrates to help stabilize the pH level of the mixed solution. Buffers reduce the tendency of pH to drift (becoming more acidic or alkaline) due to the introduction of contaminants such as paper coatings, inks, wash-up solutions, and any other contaminant. Fountain solutions are buffered to maintain low pH because the gums used to desensitize and protect the plate non-image area lose effectiveness as pH rises. Fountain solution additives are buffered, in order for the most part to neutralize external influences. A pH-Balance measure does not tell about the quality of the dampening solution it only shows, whether an additive is present or not. In order to decide the quality of the dampening solution, its conductivity should also be determined.

Acidic buffer solutions (pH less than 7)
Weak acid and one of its salts e.g. Acetic acid and Sodium acetate in solution.

Alkaline buffer solutions (pH greater than 7)
Weak base and one of its salts e.g. ammonia solution & ammonium chloride solution. If these were mixed in equal molar proportions, the pH would be 9.25.

Emulsifiers
A stable emulsion consisting of two pure liquids cannot be prepared; to achieve stability, a third component, an emulsifying agent, must be present. Generally, the introduction of an emulsifying agent will lower the interfacial tension of the two phases. A large number of emulsifying agents are known; they can be classified broadly into several groups. The largest group is that of the soaps, detergents, and other compounds whose basic structure is a paraffin chain terminating in a polar group.

Surface Tension and its significance in lithographic offset
Surface tension is an effect within the surface layer of a liquid that causes the layer to behave as an elastic sheet. It is the effect that allows insects (such as the water strider) to walk on water, and causes capillary action. Surface tension is caused by the attraction between the molecules of the liquid, due to various intermolecular forces. In the bulk of the liquid each molecule is pulled equally in all directions by neighbouring liquid molecules, resulting in a net force of zero. At the surface of
the liquid, the molecules are pulled inwards by other molecules deeper inside the liquid, but there are no liquid molecules on the outside to balance these forces. (There may also be a small outward attraction caused by air molecules, but as air is much less dense than the liquid, this force is negligible.) All of the molecules at the surface are therefore subject to an inward force of molecular attraction which can be balanced only by the resistance of the liquid to compression. Thus the liquid squeezes itself together until it has the locally lowest surface area possible. Surface tension, measured in newtons per meter (N/m), is represented by the symbol γ and is defined as the force along a line of unit length perpendicular to the surface, or work done per unit area. The surface tension of ideal fountain solution is about 34 dynes / cm. In offset lithography, ink travels from the ink supply fountain, transferring from roller to roller, until it reaches the plate and finally the blanket from which it is printed to the substrate. This occurs as conventional ink with a surface tension in the range of 30-32 dynes / cm, and UV ink 34-35 dynes / cm readily covers both higher dyne rubber and copper rollers. The interaction concerning fountain solution is that the surface tension of water at 73 dynes is lowered to be about 35 dynes due to the addition of alcohol or substitute. Because this is below the dyne level of copper, water (fountain solution) would eventually wet out these rollers. When this happens ink would not be able to wet out the water wet copper and we would have a condition called “stripping”. Continuing, let’s consider the plate next. When fountain solution reaches the plate it readily wets out the much higher (as much as 400 dyne / cm) non-image area while adjacent it is repelled by the lower dyne image area where it beads. When ink arrives from the form roller, it comes under pressure along with the non-image area fountain solution in the nip. At the backside of the nip, the layer of ink and fountain solution split at the weakest point which is within the thin film fountain solution. This process leaves a very thin film of fountain solution on the non-image plate area (0.5 to 1 micron thick), and also a layer on the ink form roller, where it beads up since the 35 dyne fountain solution will not wet the lower dyne ink. While there will be some beads of fountain solution on the image area when the inked form roller hits it, they are pushed aside as the 30-32 dyne ink covers the higher dyne plate image area. Then, where the nip opens, the ink film splits as it now contains the weakest point in the absence of fountain solution so that some of the ink remains on the roller and some transfers to the plate image area. Most critical is what happens to the beads of fountain solution that are left on the ink forms after contact with the plate non-image area. These beads come under pressure in the nip between the form and vibrator rollers. This squeeze forces the fountain solution droplets into the ink, emulsifying it. These tiny droplets on the surface of the ink help replace fountain solution on the plate’s non-image area. Ideally, the fountain solution being added exactly equals that which is being removed by the plate. When the form-vibrator nip pressure (stripe too wide or form roller too hard) is excessive, fountain solution beads are made so small that they will not transfer back to the plate. Seen as scumming, fountain solution build-up ruins ink properties. Opposite, when the pressure is too little (stripe too narrow), large beads of fountain solution will be forced onto the ink film halting ink transfer which will result in a light print and piling on the rollers. Scumming can also result from too high a fountain solution substitute level, which can produce beads that are so small that they build up in the ink. Further, high fountain solution salts as measured by conductivity or high pH, can also produce scumming. 

Rollers for dampening system

For the IPA free and/or low IPA offset printing, the surface energy of rollers should be higher than that of water. Besides, a high percentage of this surface energy should be of a polar nature, in order that the polarity of water is used for the dampening process. A certain degree of roughness and micro-surface-pores are desirable, since the water transport is better than on polished smooth surfaces. Within the technical operation rollers with hard-chromium plated surfaces were tested. The layer thicknesses are between 100 µm and 500 µm depending on the range of use. A layer thickness of 150 µm to 200 µm has proved to be most advantageous from the economic and technical point of view. 

IV. PRECIPITATION OF CALCIUM CARBONATE

The coated paper contains clay and CaCO3. While clay is essentially inert, calcium carbonate, CaCO3, is an alkaline substance. In water,
solubility equilibrium is achieved at a pH of 8.0 or slightly higher, and a small amount dissolves creating doubly charged calcium cations, Ca++. If the aqueous medium is acidic, the acid and the carbonate neutralize each other and, provided concentrations are not unreasonably high, the reaction continues until either the pH rises to the equilibrium level or the carbonate is consumed. The calcium salts of many inorganic and organic substances are sparingly soluble, and solubility may decrease as pH rises. It may result in precipitation when carbonate in the paper meets the acidic fountain solution. There is insufficient time to achieve equilibrium under the dynamic conditions of the press. The availability of carbonate inside the sheet is limited and most reaction products rapidly leave with the paper as it passes through the press. However, a small amount of fountain solution does travel back from the press nip and spreads throughout the distribution system, potentially at elevated pH and/or dissolved calcium content. One expected result of high levels of dissolved calcium and/or high pH is the precipitation of minute essentially invisible deposits onto press surfaces. These can be inorganic salts, such as citrate or phosphate, or organic from the gum Arabic or synthetic gum replacements. Even light deposits are capable of disrupting the delicate hydrophilic - hydrophobic balance of plate and roller surfaces on which the lithographic process depends. In the plate image area, deposits cause "blinding" in which specific areas become less receptive to ink. Diminished density produces irregular solids or halftones and, ultimately, ink may be totally rejected. Sensitivity of the non-image area to ink may increase, resulting in toning or scumming. This may be especially evident on start-up or with deeply grained plates that tend to carry a lot of water. Deposits on roller surfaces, called "glazing", alter their hydrophobic-hydrophilic nature. Fountain rollers may start to carry ink and those in the inking system may become de-sensitized, disrupting the ink feed. Precipitates are difficult to remove and don't respond to the customary, organically-based, washes. Carbonates and many calcium compounds are soluble in dilute acetic acid, so this can be a solution. Significant amounts of calcium can enter the lithographic system as hardness of the water used to dilute the fountain concentrate and in the Lithol Rubine 4B pigment found in magenta inks. Calcium precipitations are frequently experienced more severely, on the magenta unit. It is well known, but worth repeating here, that proper treatment of the water used to make down the fountain solution concentrate is often the key to avoiding calcium issues. Several systems are available, including water softening, reverse osmosis, de-ionization.

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