

Electrophoretic displays (EPD)

Display device is an output device for displaying information as visible or palpable such as Braille screen for blinds. Color or black and white images can be displayed by different devices that take electrical signals as an input and produce images on the screen. Among the display devices, Electronic Display or E-paper are a range of technologies on the screen that create an image similar to the effect of the ink on the paper. It is very similar to the paper so that it has used even the same color material in the printing industry. Electrophoretic Displays perform in active or passive modes. In this case, passive displays keep their image without the need to power consumption and the active displays use an electric current to display the image [1]. These display devices only reflect the ambient light like the ordinary papers and unlike the typical screens which have light. Many of these papers can show the fixed texts and images without the use of electricity indefinitely. Reading the electronic papers is easier than normal screens owing to the constantly changing the images, greater viewing angles and reflection of the ambient light instead of illumination of the screen. The writings of a good E-paper are not fade in the sunlight. The contrast ratio of the electronic papers that are presented up to the 2008 is similar to the newspaper, although this ratio is a little better in the newer electronic papers. Of course, the electronic paper should not be confused with the digital paper that is a screen to create handwritten digital documents using a digital pen. Hence, much attention is focused on the "electronic papers" in the EPD displays technology nowadays [2, 6]. Figure 1-1 shows one example of electronic paper [7].

In the past decades, much attention is focused on the Electrophoretic displays (EPDs) instead of ordinary paper due to the low cost, low weight, low power consumption and its safety. EPDs are of reflective displays that act based on the

migration of charged suspension particles in the dielectric fluid towards the oppositely charged electrode and this is called electrophoresis phenomenon [2, 7, and 9].

The so-called electrophoresis refers to the movement of suspended charged particles in the suspension fluid under the influence of an electric field. Whenever the electric field between the electrodes used in a cell, the particles migrate according to the electrical charge and the suspension fluid remains stable [2, 10].

In displays based on the electrophoretic inks, the suspension fluid and particles in the capsules or microcapsules immigrate under the influence of the applied electric field [11, 12].

In general, electrophoretic displays containing color suspensions or dispersed charged particles in a dielectric media that create Color Contrasting in a cell consisting of two conductive electrodes with transparent and parallel plates that have been placed with a specified distance of about Micron.

Since 1960, the electrophoretic displays (EPDs) are developed as a sort of reflective display. Their images can be repeatedly electrically written or erased. This technology has several advantages such as wide viewing angle and high contrast ratios that are similar to the printed papers. The EPDs is the first and most basic choice to make electronic papers. However, their serious problems that limited the technology industry are the ability to ensure image quality and longevity of particle clustering, agglomeration and aggregation.

E-ink technology is usually called bistable. Bistable concept is that the image on the E-Ink screen remains even after a power outage. In practice, this means that the display only consumes power when a change occurs in the screen. For example, when reading a book with an E-reader, power is consumed only when turning the

page, but when you're studying a page, the screen does not consume any power [13, 14]. This is especially very important when the reader goes to sleep, because in this mode only one image is displayed. However, in a typical Liquid Crystal Display (LCD), regardless of whether the new image should be displayed or not, the page must be retrieved continuously 30 times per second. This feature significantly reduces the power consumption in the E-Ink displays and precisely for this reason the reader devices have tremendous battery life.

Figure 1-2 shows the electrophoretic display of white particles microcapsule with negative charge in a blue color fluid that was displayed for the first time in 1997.

1.1.1 Differences of Reflective and Emissive Displays

The E-Ink displays are also called reflective displays. In a LCD or emissive display, a light shines from a light source behind the sheet to the viewer eyes. However, in an E-Ink display, no light spun off from behind the sheet but the ambient light is reflected from the display to the viewer eyes. Like any other reflective surface, the greater the ambient light the brighter the display will be.

This feature is actually an imitation of the ordinary paper and ink and that is exactly why E-Ink users acknowledge that when long term study with these displays, eyes do not feel tired as the LCD displays. On the other hand, the backlight can consume up to the 40 percent of the battery charge in the electronic devices. Thus, removal of the backlight in the E-Ink displays dramatically increases the battery charge life compared to the older LCD displays. Figure 1-3 shows the image comparison of the E-Ink and LCD displays.

1.1.2 Advantages and Disadvantages of Electrophoretic Displays

It can be said as advantages of these displays that this group of displays are based on the reflection of the ambient light without the need to backlight. The display can

even be observed in the direct sunlight and wide viewing angles. This makes the display easier to read and also the consumption of the power is very low owing to the inactivity of this group which are very suitable for E-book and E-reader. In contrast the advantages mentioned, the image update time for this type of display is long and it makes the quick view impossible.

1.2 Microcapsules

Encapsulation being raised as a technology to place the solid, liquid and gas materials in the small capsules. Encapsulation is divided into the three categories of capsule off (the particles size less than 1 micron), micro capsule off (the particles size between 1 and 1000 micron) and macro capsule off (the particles size more than 1000 micron) based on the coated particles size. Among these three groups, microcapsule is with more applications. Microcapsule off is a process where small particles and droplets have useful features in the form of small capsules.

Small particles that are formed from the material in the microcapsules as the core (internal phase) in front of the uniform wall named shell (coating or membrane). Microcapsule off is prepared in different ways with respect to the desired physical and chemical properties. Material place not only the properties such as optical, magnetic, electrical properties, etc. in themselves, but also they can react under the influence of various stimuli.

The purpose of microcapsule off is to enhance sustainability of the particle against the material accumulation and improve its properties. So, the core-shell microcapsules present clear promise of the preparation of new 'smart' material to offer in the applications of the smart microstructures and microsystems [17]. Many of the responsive microcapsules to environmental stimuli such as temperature changes [1-3], pH [4-6], light [18], an external electric field [4, 5], the magnetic field

[5], sound [12], redox conditions [21], ionic strength [22] and other stimulants have been reported. The attention to these smart microcapsules is also continuing.

In general, most microcapsules are formed only from the single-phase liquid or solid material [1, 4]. On the other hand, the microcapsules containing multiphase materials, especially suspensions made from organic material and particles, have been less studied. Encapsulated capsules containing suspension are of different single-phase material because the compatibility of all components should be considered.

1.2.1 Methods of Nano / Micro-Particles Production

Methods of producing nano / micro-particles particularly E-Ink can be divided into four groups:

1. Desolvation
2. Coacervation
3. Emulsification
4. Electrospray

1.1.2.1 Desolvation

In preparing the electrophoresis microcapsule, the method of desolvation is called in situ polymerization method that is one of the most important methods of E-Ink synthesis that uses a desolvation agent to produce nano particles. The nanoparticles produced by this method can be separated using centrifugal force. Among the important parameters examined in this method can be referred to the effect of particle properties and structure, different fluids on the electrophoretic movement of colored particles, the level of different actives on the microcapsules structure and stirring rate in the encapsulation process [24].

Microcapsules shell in situ polymerization method is usually Aminoplasts such as melamine- formaldehyde [5-9], urea-formaldehyde [10, 11], urea- melamine-formaldehyde [30] or resorcinol- modified melamine- formaldehyde polymers [31]. Situ polymerization process has attracted the industrial, scientific and more research attention in recent years [15-20].

1.2.1.2 Coacervation

This method is similar to the Desolvation method with the difference that the mixture of water-soluble solvent (like acetone or ethanol) is used. This solution provides the ability to create a product with little accumulation. The difference of this technique with Desolvation one is in a variety of parameters that affect the properties of nanoparticles. These parameters are the primary E-Ink solution concentration, temperature, pH, the shaping concentration of transverse bonds, and molar ratio of E-Ink to the solvent and the addition rate of organic solvent.

1.2.1.3 Emulsification

The various methods in this group include dispersions, emulsions and micro emulsions. The purpose of emulsification is mixing an aqueous phase and an oil phase that is stable with the aid of emulsifier. In the particle production method by the aid of emulsification, the aqueous solvent evaporates after making the emulsion. In this method, particles create in the range of 100-50 nm. This is a complicated and time-consuming procedure in which there is a need to control parameters such as monomer combination, reaction conditions and the type of emulsifier.

Among other disadvantages of this method in the production of nanoparticles is the use of organic solvents, separation and its toxicity. Some polymer particles containing colored oil-soluble material with mini-emulsion polymerization methods have been developed [5, 7]. However, the color of these particles can be spontaneously faded due to the influence of dye into the fluid [5, 6].

1.2.1.4 Electrospray

Electrospray is a well-known method that has many applications such as the manufacture of inorganic nanoparticles, deposition of the thin layer films, deposition of nanoparticles, nano production and microcapsule off and so on [36 and 37].

The aim of this technology like encapsulation chemical methods is active protection of nuclear material from the external environment. It is a technique that can produce small particles from the fluids with certain viscosity under the electric field by applying high voltage to the nozzle and collector plate and creation of a strong field in the direction of gravity. In this method, the droplet size distribution is controlled by electric field voltage.

Use a conductive fluid of electrical current causes that the outer surface of the liquid has been pulled in the nozzle opening by the certain force towards the collector plate by the control of the created electric field and finally the droplet is produced by overcoming of this force on the surface tension and tearing the fluid level [37].

In this way, it is possible to produce mono-dispersed particles. Figure 4 shows the microcapsules formation through the electrospray with coaxial needle [38].

In this way, solution or melt (often a polymer) enters into a conductive nozzle that is connected to the electrical potential of direct current in the size of kV. With the charged of the fluid, its particles are accelerated and thrown from the tip of the hanging drops to the opposite electrode that is negative charge or ground electrode.

The desired product is nano particle depending on the type of the fluid and the process conditions. Chemical composition, physical properties of solution, liquid flow rate, nozzle diameter, the distance between the nozzle and the collector substrate, the potential difference are considered the key operational parameters that affect the diameter of particles and their properties [39].

In the production of core-shell micro-particles, two or more capillary tubes are connected to the uniform electrical potential that the effective material and lining polymer are flowing in the internal and external capillary tubes, respectively. The coaxial liquids strip emitted from the tip of the needle or nozzle is converted to the capsule or multi-layered drop [40].

So, the selection of micro capsule off method affects the particles size and their distribution. Although the chemical synthesis methods may be used to place the dye in the polymers, in many cases obtaining a pure product is difficult due to the concurrent reaction between monomers and the separation of the phase. These methods need to control various parameters such as the composition of monomers, reaction conditions, the type of emulsifier, etc. in addition to the time-consuming and complication [41].

1.3 Electronic ink (E- Ink) or Electrophoretic Ink

E-ink is actually a direct result of the integration of chemistry, physics and electronics. Ink-E composition for electrophoretic display containing electrophoresis particles such as charged colored material, the dielectric dispersion environment, and load control agent [3, 5]. In order to control the particle load, usually the load control auxiliary materials are used that led to the emergence of positive or negative loads on the particle surface [43].

1.3.1 Effective Parameters in the Image Quality in the EPD Display with E-Ink

The electrophoretic particles properties are key factor in determining the image quality. The increase of the image quality requires very small particle size with a narrow size distribution, large surface charge to precise create and control the images, high contrast ratio, quicker response to the applied voltage, transparency used in the shell, light stability and stable dispersion of ink and the other parameters. As a result, a lot of research are conducted on modified particles, surface morphology, and surface charges and special stability.

As mentioned above, the spatial stability of electrophoretic particles is an important factor in determining image quality that is specified from the measurement of the zeta potential. In fact, zeta potential is a factor to potential stability of colloidal systems. If all the particles in suspension have a positive or negative charge, the particles tend to repel each other and show no tendency to integration. The tendency of particles with similar charge to repel each other directly related to the zeta potential. Generally, stable and unstable border of the suspension can be determined by zeta potential. Suspensions containing particles with zeta potential greater than 30 mV or less than -30 mV are stable.

1.3.2 The Formation Mechanism of the Image on the EPD Display Containing E- ink

When an electric field is applied across an electrolyte, charged particles suspended in the electrolyte are attracted to the oppositely charged electrode. At this time, the forces resist against this movement and opposed with the movement of charged particles.

When the movement force of particles and the counter-movement force of particles are in competition with each other, the particles moving at a constant speed in the electrolyte. The speed of particles in an electric field is called electrophoretic

mobility. Now that, the electronic ink is formed of millions of tiny microcapsules. For example, in black and white displays, microcapsules containing positively charged white particles and negatively charged black particles suspended in a transparent liquid.

When this suspension is under the positive or negative electric field between two electrodes, the white or black particles are moved to the top of the microcapsule depending on the applied field and are exposed to the viewer. So that, that point of the screen seems white or black.

1.3.3 Electrophoretic Display Components Containing E-Ink Microcapsules

An EPD display is formed of various components to show an image with better quality. Figure 6-1 and table 1-1 show an overview of electrophoretic display containing white and black E-Ink microcapsule and its components in the electric field, respectively.

Nowadays, although the products of the black and white microencapsulated electrophoretic displays have been commercially successful, but now they cannot meet the needs of the display market. For this reason, many recent studies have focused on the preparation of colored microcapsules.

1.3.4 Tri-Color Electrophoretic Particles for Chromatic Display (CEPD)

Full-colored display can be realized by dividing each of the image elements in the black and white electrophoretic displays and placing horizontal colored filters as RGB (red, green, blue) and CMY (blue, red, yellow) arrays [20] . However, the colored filter absorbs large amounts of reflected light, which leads to low contrast and brightness. Figure 1-7 shows a view of the process.

Recently, the studies have focused on the preparation of the tri-color electrophoretic particles for color displays (CEPD). The encapsulated dye and modified pigment are used for the synthesis of electrophoretic particles. Preparation of colored ink are obtained through the placement of colored material into the polymers such as polystyrene, poly (N vinyl pyrrolidone), poly (methyl Methacrylate) and some other copolymers [5, 6]. However, some weaknesses such as low visibility and poor light stability limit the use of dyes in the CEPD.

In comparison, organic pigments with ultra-light resistance, better stability and higher color strength are suitable for CEPD [46]. Various methods are used for the preparation of applied dyes in the CEPD. Figure 1-8 and 1-9 show an example of two and three pigments systems schematically.

1.3.5 Some of the Applications of Electronic Ink (E-ink)

The encapsulated electrophoretic inks are very common in EPD applications. The following are some of these applications. Figure 1-9 shows a few examples of its applications.

- Electronic books, E-newspapers, E-magazines and documents
- Wireless devices displays: remote control, game controller, clock
- Industrial displays such as temperature display
- Symptoms related to sales and promotions in stores

Although Electrophoretic display is expanded, there are still many problems in displaying images with high contrast ratio, high resolution and manufacture cost.

Chapter Two

1.2 Review of the Literature

According to the raised advantages and applications about the electrophoretic ink displays, many companies and research centers allocate their research to the examining the EPD display material and the other related technologies. In this section the results and achievements obtained in the preparation of black, white and color E-Ink and EPD will be discussed.

Electrophoretic displays based on electrophoresis theory was first introduced by Ota in 1972 [49]. Comiskey et al (1997) present the concept of the electrophoretic ink based on electrophoretic materials as separately in the form of microcapsules. This solves not only the congestion problems and the accumulation of particles with larger scale than the size of the capsule, but also causes microcapsules remain stable in the display [50].

Today, the micro-capsulated EPDS is becoming one of the most attractive applications in the preparation of electronic paper. Because electronic ink can be printed on an appropriate context to achieve flexible display [51]. In 1997, a hardware company began its research in the MIT laboratory on the electronic paper display technology and in 2001 an Electronic reader called Kindle Amazon (Fig.2-1) entered the market [52].

As can be seen in Figure 2-2, this technology is based on the white particles with positive charge and black particles with negative charge and deposition of these particles based on the transparent fluid. The particles are oriented due to the charge in the electric field. This means that in a negative electric field, black pigments transferred to the top and the surface will be seen as a black background and vice versa this phenomena also occurs for white pigment.

Barrett Comiskey et al (1998) report the E-Ink microcapsules with white particles dispersed in a blue fluid that was prepared with the in situ polymerization method of urea and formaldehyde. Titanium dioxide was used with a specific gravity of 4.2 for reflection and high color purity as a white particle.

In order to reduce the specific gravity and surface modification of particles to response to the applied electric field, the polyethylene was used as a coating on titanium dioxide. In this study, the response time was reported 0.1 second. As shown in Figure 2-3 (a), when microencapsulated electrophoretic particle is placed between two electrodes with opposite charges, the charged particles are oriented by applying a current and have orientation towards an electrode with opposite charge. In this case, when viewer look from above to the particle, he sees a white background with negative charge in the vicinity of positive electrode.

Also, part (b) shows the photomicrograph of the real examples of the electrophoretic microcapsules build-in the electric field [11].

In 2002, the Boston, Massachusetts E-Ink Company showed a prototype of the full-colored E-Ink display for the first time at the "Society for Information Display (SID)". In general, today's leading readers exclusively use an electrophoretic display technology from a company named E-Ink affiliated with the Massachusetts Institute of Technology, MIT.

H.L.Guo et al (2004) introduced an encapsulated electrophoretic ink. In this study, the Scarlett pigment was used for its brightness, small size and low density (Figure 2-4) [55].

The modified pigment suspension is prepared in the tetra chlorethylene and microcapsule was obtained with in situ polymerization method with urea and formaldehyde shell material.

It was shown that the presence of polyethylene in the surface modification of pigment leads to increase the spread and stability of the particle and also causes the particles tend to the negative electrode.

In this study, the response time was 3.2 seconds. As can be seen in Figure 2-5a, when the microcapsules are placed under zero electric field, pigments are randomly placed inside the capsule, but quickly respond to the direct electric field of $E=120\text{V/mm}$ (Fig. 2-5b) and are inclined towards the negative pole and vice versa they are pushed back in the reverse electric field (Fig. 2-5c) [55].

J.P. Wang and his colleagues use the blue phthalocyanine (PB15:3) BGS due to its high brightness and low price as blue particles in the preparation of E-Ink. The modified particles in the tetrachlorethylene are prepared as core material and finally the urea-formaldehyde microcapsules are produced with in situ polymerization method as E-Ink. It was observed that E-ink microcapsules prepared in this paper has a uniform particle size, smooth surface, good transparency and high mechanical strength that helps the characteristics of blue electronic ink (Fig. 2-6) [56].

The results showed that the powders modified with Octadecylamine (ODA) show greater affinity to the tetrachlorethylene until the dispersing extent increased four times to the unmodified particle. It also concluded that increased active level of Span80 not only increases the dispersion of the PB15:3 in the tetrachlorethylene but also prevents the particles absorption on the capsules walls more than 0.062 mM. (Fig. 2-7) [56].

Huilin Guo et al (2004) prepare the microcapsules containing charged particles responsive to the electric field with the urea-formaldehyde in situ polymerization method. The suspension was prepared from the green phthalocyanine pigment (PPG) and tetrachlorethylene. Figure 2-8 shows a diagram of the preparation of

microcapsules containing tetrachlorethylene and PPG particles. In order to study the accumulation of particles in the microcapsule process, the ability to disperse particles in tetrachlorethylene, the effect of different Emulsifiers on the microcapsule off and the application of the synthetic microcapsules in the E-Ink were investigated [17]. The process of PPG particles dispersion in the tetrachlorethylene was shown in the Fig. 2-9. The particles in the case of unmodified and modified were investigated with 2, 5 and 8 weight percentages of Octadecylamine.

In this study, the dispersion and fat friendly range of the PPG particles are improved due to the surface modification of the particles with Octadecylamine. The contact angle between the modified PPG particles and tetrachlorethylene is increased and the modified PPG particles with 2% Octadecylamine have the best tendency to the tetrachlorethylene.

The surface tension between C_2Cl_4 and water with urea-formaldehyde pre-polymer was reduced from 43 to 35 mN/m which indicates that the polymer has certain surface activity. Therefore, the water-soluble emulsifiers have a significant impact on the micro encapsulated time because they can be absorbed on the surface of the inner phase and prevent the precipitation of urea-formaldehyde resin. The results of scanning electron microscopy (SEM) and cross-sectional surface show relatively smooth microcapsules with an average thickness of about 4.5 micron. [17]. (Fig. 2-10 shows the SEM images of external and cross-sectional surface of microcapsules).

In this study, the microcapsules were prepared with stirrer speed of 600 and 1000 rpm. As shown in the Fig. 2-11, microcapsules have an average size of 11 and 155 micron. At the end to show mobility of particles in an electric field, an electric current is established, the particles move in the capsules to the positive electrode

with a response time of several hundred milliseconds and are inclined to the positive electrode [17].

In a study by Yan Xin Hu et al (2012), the organic pigment of P.R.2 (F2R) was used as colored electrophoretic particles (Fig. 2-12). Surface modification to enhance surface charge and stability of the dispersions was carried out in an organic environment. The result was that the addition of dispersing agents to the dielectric environment alter the size and shape of the particles as well as intensify the electric surface charge [57].

According to the results, SEM images, particles size distribution of raw material and modified with ODA that is shown in Figure 2-13, particles size distribution was 100 to 1500 nm in the case of pre-modification while this extension in the modified particles was reduced to 80 to 220 nm. In this study, the average size was 105 nm and a very narrow distribution of dispersion index was 0.068 [57].

Various modifiers such as sodium dodecyl sulfate (SDS), Cetrimonium Bromide (CTAB), CH-6 and Disperse 655 (D-655) were tested. According to the results and Fig. 2-14, the best of them is commercial dispersant 655 (D-655). The sedimentation rate of the prepared particles in the tetrachlorethylene was less than 5% in 12 days [57].

In order to show good contrast in an electrophoretic display, the red particles are used with white electrophoretic particles in which the response time is reported 200 milliseconds, respectively (Figure 2-15) [57].

Sun Wha Oh (2009) reported a communication that charged ink nano particles of the three organic dyes are obtained through encapsulate of these three dyes with styrene dispersions polymerization and 4-vinyl pyridine (poly (styrene-4 VP).

Poly Styrene polymer particles- 4 VP containing three acidic red 8, yellow 76 and blue 25 dyes using two surfactants sodium dodecyl sulfate (SDS) were used as anionic dispersing agent and acetyl tri methyl ammonium bromide (CTAB) of the cationic agent. It was shown that with increasing the concentration in both type of the active surface from 1 to 5% by weight, the particles size was reduced from 1.5 micrometer to 800nm. Also, with increasing the concentration, the number of effective charge sites is increased on the ink particles that leads to increase the particle electric mobility. Figure 2-16 shows the electric movement rate of positively charged particles of three different dyes [43].

Xianwei Meng et al (2010) synthesized the spherical Carbon–Iron Oxide Microspheres' Black Pigments (CIOMBs). This black pigment was prepared through the Pyrolysis of aqueous solutions ultrasonic spray containing ferrous chloride ($FeCl_2$) and glucose. Figure 2-17 shows the image of synthesized pigment particles in the different concentrations of $FeCl_2$. It was observed that with increasing $FeCl_2$, the surface of particles becomes rough due to the particles oxidation through the iron ion [58].

Since the poor dispersion of electrophoretic particles limits the applications in the EPDs, the spherical carbon particles obtained by dehydration of the polysaccharides water soluble under hydrothermal conditions showed an excellent ability of dispersion. Based on Figure 2-18, many functional groups on the surface CIOMBs (such as: OH, COH, CH₂, etc.) leads to excellent dispersion in different solvents. So CIOMBs in polar solvents (such as water, methanol and ethanol) and non-polar solvents such as tetra chlorethylene are dispersed as well [58].

Despite extensive studies, preparation of tri-color electrophoretic particles RGB with high surface charge, very good dispersion stability and good light stability are also

required for Chromatic Electrophoretic Display (CEPD). Wenlong Qin et al (2012) modify the three-colored pigments of RGB through the in situ polymerization, styrene-acrylate copolymer solution. The chemical structure of three red, yellow and green pigments are shown in Figure 2-19 [59].

In this study, different acrylates containing Stearyl Methacrylate (SMA), dimethyl amino ethyl Meta acrylate (DMA) and ethyl glycol di Meta acrylate (EGDMA) were used as monomer (Fig. 2-20).

In this study, Ethylene Glycol Dimethacrylate (EGDMA) causes the crosslinking copolymer on the pigment surface. This leads to prevent the accumulation of particles and their stability in the tetrachlorethylene nonpolar environment (TCE) that is one of the key parameters in EPDs. Figure 2-21 shows the sustainability comparison of pigments suspensions with/ without surface modifiers after 24 h in TCE [59].

It was shown that small amounts of EGDMA leads to increase the zeta potential and mobility of modified colored particles with P (SMA-DMA-St) and also the reduction of average size of the particles according to the table 2-1 is 1.2 times the original size [59].

Also in this study, response time of pigments in CEPD sample device made by this group was reported about 0.7 ~ 1 which needs to be further improved. In addition, RGB E-Ink light stability is very important in CEPD performance.

In order to evaluate this parameter, EPD prototype was exposed to the Xenon lamp radiation (500W), 14 times the light intensity of sunlight at noon. It is concluded that after 36 hours exposure to the light, the RGB reflection remains stable that is desired for stability of CEPD equipment performance [59].

Chunli Yang et al (2014) modify the titanium dioxide particles with Vinyl Triethoxysilane (VTES) with Sol-Gel method through flow groups' graft on the TiO_2 particles surface. TiO_2 Particles have excellent image in the dark surroundings for contrast and are widely used as white electrophoretic particles in the manufacture of E-Ink. However, since this particle has high density, van der Waals attraction overcomes and leads to aggregation, quick sedimentation and slow response to the electric field.

Therefore, extensive research has been done on surface modification. In this study, the results of the whole FTIR are confirmed the new peaks in $560,670cm^{-1}$ wavelengths due to the stretching vibrations and also two peaks with $1.020,1.120cm^{-1}$ wavelengths which represents the stretching vibrations of Si-O bonds in VTES [60]. So, it was shown that VTES was grafted as well on the TiO_2 surface (Fig.2-22).

Modified particles size is reported in the range of 100-200 nm with very narrow distribution. Figure 2-23 shows the stability characteristics of dispersion and suspension before and after the nanoparticles surface modification [60].

In a study Hongli Liu and his colleagues presented the electrophoretic microcapsules using Isopar L as dispersion medium with mass method between gelatin and acacia that its features are non-toxic, low concentration of aromatics and low evaporation.

The effect of weight ratio of capsule material to the nuclear material, PH value, dispersion time and speed were investigated on the microcapsules properties. In this study, the ratio of capsule material to the nuclear material is 1:4 and capsules walls with PH=8.5 in temperature of $45^{\circ}C$ and dispersion time and speed are reported 20 min and 800 mpr, respectively. Figure 2-24 shows that the higher the ratio of nuclear material to the capsule material, the lower the particles size followed by the increase

of microcapsules efficiency up to 70%. Here, the best picture with the size of 30 to 60 micrometer have been reported [61].

Also, with increasing agitation speed, the particle size is reduced (Figure 2-25).

Figure 2-26 shows that in PH=8.5, the microcapsule efficiency is 83.88%. The low efficiency in low PH implies that some of the amino groups of gelatin still exists as NH^{3+} . Hence, it cannot be cross link with Formyl group while some parts of gelatin are destroyed in high PH [61].

Clock display panels made from microcapsules in electric field with direct current of 5-volt show clear images of white context with black background and vice versa (Figure 2-27) [61].

Some of the problems of the two-phase microcapsules are stability and respond to an electric field, prevent the extruded nuclear material as egression from oil phase to the aqueous phase in the encapsulation process and particles absorption on the inner surfaces of capsule shell.

In a study published in 2008, the effect of polyethylene membrane on the Benzidine Yellow Pigment was studied which aims at its Pregnant and prevent the accumulation of yellow pigment particles due to the creation of a spatial barrier around it. According to the results of investigating the particles size and their response behavior in an electric field, the electric movement of these particles are modified and finally dispersed urea-formaldehyde microcapsules in cyclohexane as E-Ink are reported 10 times more than unmodified particles [24].

The application of nanospheres is in painting, ink, food, electronic displays, textile and medicine. Kuanjun Fang et al (2014) introduced an easy method for preparation of colored poly (styrene-acrylic) nanospheres. This method was performed easily in

contrast to previous methods in which the preparation of uniform colored nanospheres with high color purity was very difficult.

In this study, the Emulsifier-Free Emulsion Polymerization was performed to synthesize copolymer spherical nanoparticles (AA-St), so that the effect of the active surface was removed. Spherical nanoparticles dispersions were prepared with three solution disperse dyes including blue 56, red 60 and yellow 64, so that each of the dyes are gradually entered to the copolymer spherical nanoparticles (AA-St) due to the heat and then fixed dyes in the spherical nanoparticles are obtained with increasing heat and sedimentation, washing and dyeing. The process is shown in the Fig. 2-28 [19].

According to the images obtained by transmission electron microscopy, the average size of spherical nanoparticles after dyeing for each three dye is 23nm [19].

Xiao-Meng Liua et al (2014) caused a new innovation in preparation of electrophoretic ink using electro spray method to preparation of E-ink. They prepared electrophoretic ink microcapsules with the narrow size distribution and the white and red particles mean of about 100 and 200 micrometer using Coaxial Jet of figure 2-30 [62].

The results showed that by adjusting the flow velocity of the shell fluids, nuclear and gas which are the important factors in this method, the microcapsules size and shell thickness can be controlled. Fig. 2-31 a shows the alteration of the microcapsule diameter and shell thickness versus different flows speed of 2 to 10 mL/h.

It was observed that by increasing the flow rate of the core, the shell thickness is reduced and the microcapsule size is increased. In the Fig. 2-31 b, with increasing continuous flow rate, the shell thickness and size are increased [62].

In this study, orthogonal test was used through three factors and three orthogonal experiments levels. Three factors of core flow rate, shell and gas are separately used in three different levels. In this study the optimum values are reported 4,6,25ml/h and coating Ratio was 90%. Fig. 2-32 shows the charged particle movement of red pigment in the electric field [62].