CHAPTER – 2

REVIEW OF LITERATURE

OVERVIEW:

The chapter included the scholar works performed till today in the field of formulation as well as application of pH-responsive polymers for hygiene; and microencapsulation of the same polymers. As per the research title, the chapter is divided into three major sections hygiene textiles, pH-responsive polymers, and microencapsulation. Further, the chapter deals with the combination of three major sections with each other and their application to textiles. The chapter also includes the objectives of the proposed research study.

2.1 Hygiene Textiles

Hygiene textiles comprise equally throwaway and the matters which cannot be dispose that are primarily used by females, such as tampons, towels, incontinence products, panty shields, sanitary napkins, diapers, wipes, antimicrobial textiles, and so on. They are classified on the basis of their application (figure 2.1) (DeMarinis et al., 2018). Durable or disposable cloth type products are included in this type of absorbents. The second one is hygienic, comfortable and multi-layered. These absorbents have majorly two layers: internal film is permeable, and it possess a high quality of wicking properties which can hold liquid, while the exterior film consisting waterproof material. So, keeping skin dry they can absorb more fluid. Currently, scholars are concentrated on reusable and ultrathin diaper. These reusable diapers are fully flushable and compostable for comforting to adults and babies both. Superabsorbent chemicals are the main reason for helping in manufacturing ultrathin diaper, which is comfortable and functional(Luchese et al., 2021).

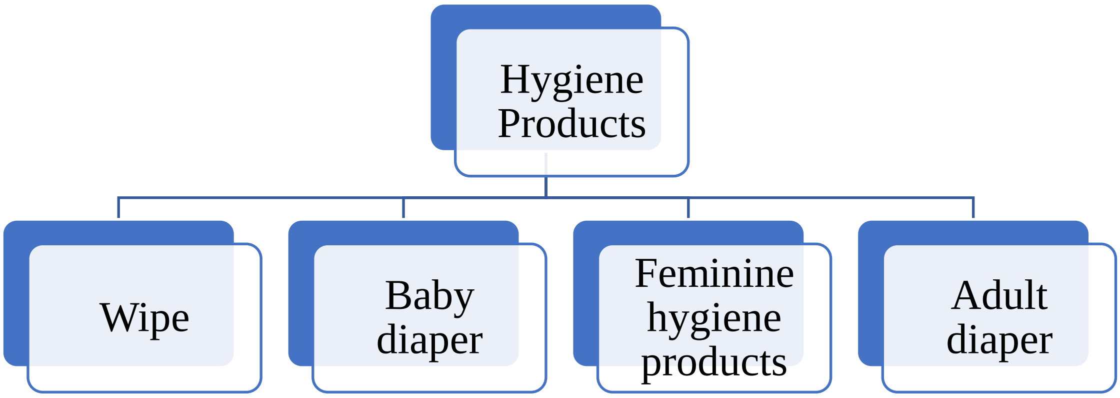


Figure 2.1: Classification of hygiene textiles on the bases of application

2.1.1 Female Hygiene

Overall health and well-being are majorly concerned with better hygiene, and it is more specific for women. Women are participating for caring of their bodies and maintaining hygiene, including menstruation management and vaginal health preservation.

Globally, in daily life practices, women utilised numerous intimate hygiene products for cleansing purposes. These routine practices are inclined by many variables, like individual wish, social ethics, sacred opinions, and guidance from healthcare experts. In many regions, the lack of knowledge regarding the vaginal area and its effect on personal hygiene practices, have on the biological and physiological stability of the vulvar region, despite the fact that in attendance of a noteworthy figure of works on the vaginal environment. Precisely, the scarcity of available medical material concerning intimate womanly sanitation about external topical washes and its role in lessening unfriendly indications and endorsing total intimate well-being (Y. Chen et al., 2017).

According to C. et al., 2016, appropriate hygiene meaningly diminishes the risk of contracting illnesses and contaminations, gets rid of unpleasant odours, and significantly progresses the quality of lifespan and self-assurance of womenfolk. Adolescence marks the commencement of period, which is a component of the generative cycle that occurs after teenage years. Menstruation is a regular incidence, contempt the fact which it is linked to a diversity of happenings and opinions that might result in adverse effects on one's health. During menstruation, a noteworthy number of females experience a change of distresses, with but not limited to abdominal aching, annoyances, joint distress, and mastalgia. In a woman's life, being cultivated about menstrual sanitation is an important component of health edification. Several factors, including as the physiology of menstruation, psychology, and pathology are connected to females' well-being; also, they have the potential to cause a number of conditions that cannot be cured. Tegegne & Sisay, 2014 state that as a consequence of this, it presents a substantial problem with regard to the mortality and morbidity rates encountered by the female demographic.

The term "menstrual hygiene" meaning is a specific type of medical treatment which is mandatory for females during their once-a-month catamenial sequence. Unhealthy hygiene practices throughout period can prime to momentous diseases, including contaminations of the generative tract and urinary region, among other potential complications. The incorrect care of menstrual hygiene can lead to an contamination of the generative territory, which is a quiet widespread which can have a negative influence on the survives of affected womankind. In addition to microbial vaginitis and urinary tract infections, venereal infections affect around 10% of women per annum (C. et al., 2016; P. S, 2014). Genital infections range from bacterial vaginitis to urinary tract infections. Having a poor hygiene routine and being pregnant are both risk factors for developing a vaginal infection. When sanitary napkins are used inaccurately, it can lead to difficulties in the menstruation zones, such as unpredicted body fluid loss and discomfort. The vast widely held of females replace their permeable substantial during the nocturnal, but only a small percentage of females change their napkins at night-time due to unwarranted flow of blood. The numeral of hygienic naperies that a woman uses is directly proportional to the amount of menstrual flow that she experiences (Girigoswami et al., 2024).

2.1.2 Importance of Feminine Hygiene

Hygiene maintenance involves cleansing the external genitals with vaginal wash during menstruation, followed by hand-washing with cleanser. The external genitalia are often cleansed post-toilet use, yielding favourable results. Approximately 1.61% of womenfolk revealed inadequate cleansing practices. Cleansing establishes an aspect of individual sanitation, with nearly 50% of individuals employing aquatic for cleansing, while a minority utilized soap and water, and some opted the same for vaginal rinse. Throughout the catamenial sequence, it is essential that one has to maintain appropriate hygiene by changing sanitary napkins every 3–4 hours as the action of cure contamination and avoid unpleasant odours, itching, and rashes. The external genitalia regulate hygiene and pH through the body's discharge mechanisms. For intravaginal cleaning, use of soaps or other harsh cleansers is prohibited since they can disturb the pH equilibrium. Females should utilize solitary aquatic and vaginal rinses, as they do not affect the pH balance. Approximately 51% of young woman are aware of menses and its administration. Merely 33% of females employed products which works as an absorbent at the time of menstruation. The discarding of old hygienic naperies is crucial as they pollute the air and contributes to environment pollution through the incineration of napkins (Y. Chen et al., 2017; Girigoswami et al., 2024). However, females have understanding regarding the disposal of hygienic pads as catamenial absorbents, and countless of those materials employ household cloth. The lack of knowledge and scarcity of financial resources affect the pad usage and so, the partial acceptance of sanitary napkins is there only. Cotton hygienic materials are cremated in countryside regions due to the availability of empty space. Furthermore, in metropolitan regions, individuals dispose of soiled hygienic pads in drainage systems as the household waste, potentially barricading the drainage assembly. Used sanitary pads are disposed of in unoccupied areas, allowing germs to flourish, which can harm our pets and upset the earth's microbiota (Tegegne & Sisay, 2014). The study analyzed the design, period, and magnitude of catamenial current, revealing that 82% of girls experienced regular menstruation, 65% had modest blood current, and 18% exhibited an irregular catamenial sequence (Deshpande et al., 2018)

2.1.3 Functioning of the vulvovaginal zone

Primary warrior against the contamination of the genital tract is the vulva. Vulvar bacterial development and species equilibrium are recurrently inclined by augmented moistness, perspiration, menstruation, and hormonal instabilities, which can lead to unpleasant odour and vulvovaginal infection. Contaminants frequently gather in the vulvar crinkles. Vulvar skin is additional vulnerable to interesting mediators than forearm membrane due to its frictional assets, obstruction, and enhanced hydration, which distinguish it from other skin spots in terms of hydration, abrasion, porousness, and visually apparent annoyance (Eisner et al., 1990; Farage, 2005; Farage M & Maibach H, 2016). It is probable that the vulvar vestibule, which is not keratinized, is further porous than keratinized epidermis. Venereal membrane is distinctive in which it is protected by a slim layer stratum corneum that encompasses numerous hair cavities, which enables the diffusion of the skin by microbial and supplementary substances. The vagina is a fibromuscular channel that extends from the exterior introductory in the vulva to the cervix uteri (WAKASHIN, 2007). Non-keratinized epithelial liner enclosing the uteri with primarily soft muscles' composition. The facing is thick till the climacteric, and the folds are kept humid by watery concealed from the vaginal barrier and secretion which comes from the vestibular and cervical secretory organ (Table 2.1).

Maintaining the microbiota ratio is expected to be vital for general vulvovaginal health, even if human beings' understanding of the bacteriological greasepaint of the peripheral vulvar zone is still evolving. Research has indicated that the typical vulvar flora includes intertriginous skin germs as well as vaginal, urethral, and intestinal microbes. According to numerous studies of healthy women, the vulva's microbiota is varied, with no solitary types shared by all womankind (Brown et al., 2007). These species may include lactobacilli, streptococci, diphtheroids, staphylococci, micrococci, yeasts, gram-negative poles, and types of fecal source. The growth of exogenic pathogens that reason urinary tract and vaginal contagions may also be impacted by vulvar flora (Y. Chen et al., 2017; Crowley et al., 1974).

Table 2.1: Physiological characteristics of the vagina

Tissue Structure	The fibromuscular canal is lined with a laminated squamous epithelium which is not keratinized and is primarily poised of smooth muscle.
pH	Premenarche suggest 7.0 pH Reproductive age suggest 3.8 – 4.4 pH Menopause without hormone therapy suggest 6.5 – 7.0 pH Menopause with hormone therapy 4.5 – 5.0 pH
Microflora	*Candida albicans, Lactobacillus spp., Megaspaera spp., Leptotrochia spp., Staphylococcus aureus, Atopobium vaginae,* and/or *Gardnerella vaginalis*

There is a better considerate of the configuration of the microbiota related to vagina. In the past, it was believed that non-sporing *bacillus* known as *Lactobacillus* produces lactic acid, and it was Gram-positive; was the principal bacteria in a healthy vagina. *Lactobacillus* is accountable for generating a sour situation with a pH array of 3.0 – 4.0. Through rivalry for epithelial cell receptors and over the inhibition of development through the cohort of disinfectant complexes in association with distinctive mass fortifications (such as intermittent hormonal cycling that promotes carbohydrate release and continuous exuviating of epithelial cells which carries bacteria), these *Lactobacilli* play a role in preventing the colonization of the vagina by other bacteria, including pathogens. This helps to preserve a well vaginal ecology. Though, the configuration of well vaginal flora is extra diverse than was first imagined. In some hale and hearty womankind, *Lactobacilli* are replaced by other bacteria as it is not present and which produce lactic acid (Huang et al., 2014). These bacteria include *Leptotrichia spp, Megasphaera spp.,* and/or *Atopobium vaginae.* There are instances in which women of generative age who remain symptomless are settled by possibly pathogenic classes, such as *Gardnerella vaginalis, Staphylococcus aureus*, and *Candida albicans*. As a result, the characterization of a strong versus a morbid vaginal microbiome is a complicated one (Drell et al., 2013).

The vaginal microflora's composition varies due to inner aspects such as time of life, alteration in hormones during menstruation, pregnancy and menarche; and contaminations, as well as exterior factors including sanitation performs, sensual activity, use of antibiotic, and treatment for replacement of hormone. Numerous lessons designate dissimilarities in typical vaginal flora according to society, with *Lactobacillus spp*. predominating in 80.2% and 89.7% of Asiatic and Grey womankind, correspondingly, while only 59.6% and 61.9% of Hispanic American and Dark womankind exhibit this dominance, individually. None the less, these inequalities might be moderately accredited to variations in cleanliness manners between different cultural clusters (Lewis et al., 2017). Scholar's research evaluated the simple pregnancies, full-term, revealing limited multiplicity of the microbiome of the vagina (dominated by two classes: *Lactobacillus iners* and *crispatus*) and significant steadiness during growth. The skin microbiome of an individual seems to be influenced by the manner of delivery (cesarean versus vaginal), perhaps affecting immunological development and having long-term consequences for microbial diversity (Walther-António et al., 2014).

Disrupting the vaginal microclimate can affect the invulnerable response and wall characteristics of the humanoid vaginal epithelia, leading to the growth and development of generative sicknesses.

During the menstrual cycle, vulvar pH typically ranges from 3.8 to 4.2, falling between the skin's estimated 4.7 pH (Lambers et al., 2006) and the vagina's average pH of 3.5 (O'Hanlon et al., 2013). Endogenic aspects (e.g., moisture, perspiration, vaginal liberation, menses, urine and fecal infection, bodily foldaway, inheritances, and time of life) and exogenic influences (e.g., cleanser, shampoos, beautifying goods, oils and spermatocides, obstruction with close-fitting wear or hygienic cloths, shaving and hairlessness goods) can all have an impact on vulvar pH. Long aeration affects the skin at vulvar, and it is confirmed by research to extremely inferior the subject's pH. Entire lactate composition affects the vaginal pH, as there is a major presence of lactic acid in the vaginal mucosa zone, and it generated estrogen which is regulated by the metabolism of anaerobiotic glucose. Extracellular glucose is converted into lactic acid with the help of *Lactobacillus* microbes and accompanying classes. So, the addition of production of lactic acid will result in vaginal pH which is generated from the bacterial flora and the vaginal mucosa, albeit microbial metabolism has the extent effect on the vaginal metabolism. Vaginal pH appears that differ through civilization. A scholar's effort found that hale and hearty reproductive-life of age Latino American (pH 5.0 ± 0.59), Dark (pH 4.7 ± 1.04) womankind had lower vaginal pH than Grey (pH 4.2 ± 0.3) and Asiatic (pH 4.4 ± 0.59) womankind (Y. Chen et al., 2017; Girigoswami et al., 2024; Linhares et al., 2011). This is due to the development of pervasiveness of non-Lactobacillus microbial societies in these two ethnic groups.

It is distinctive and well for a female to create a vaginal liberation beginning a decided time or before earlier adolescence and ongoing until after climacteric. This discharge is composed of microbes and peel off epithelial cells that marsh off of the vaginal fortifications, collected with secretion and watery (blood plasma) which is produced with the action of cervix and vagina. During the menstrual cycle, the following changes occur in terms of both quantity and texture: When estrogen stages are short at the beginning and end of the catamenial sequence, vaginal discharge is viscous, gummy, and intimidating to spermatozoa. As estrogen levels increase preceding to ovulation, vaginal discharge becomes increasingly transparent, watery, and stretchy. This phase of the menstrual sequence occurs when estrogen heights are short (Eschenbach et al., 2000; Girigoswami et al., 2024; Spence & Melville, 2007).

The intrinsic defense mechanisms that defend in contradiction of vulvovaginal contaminations contain the typical vaginal flora, the naturally vaginal pH is acidic, and the vaginal evacuation. Natural bacteria interact with foreign pathogens for adherence to the vaginal mucosa and contribute to maintaining an acidic pH. They combat diseases by synthesizing antimicrobial agents, like bacteriocin. Vaginal secretions received from five females demonstrated in vitro effectiveness towards those who are not resident's microbial species, including Escherichia coli as Group A and B with *Streptococcus*. Defense in contrast to Group B *Streptococcus* is predominantly significant for expectant females as it frequently takes possession of the vagina through the gastric section, growing the jeopardy of untimely delivery, neonate meningitis and possible infant mortality (Hantoushzadeh et al., 2014). This additionally can lead to asymptomatic bacteriuria, infections of the urinary system, upper reproductive tract bacterial infections, and maternal endometrial cancer.

Research of pregnant women revealed that raised vaginal pH, presence in low quantity of an acute vaginal contagion, was significantly associated with premature birth, resulting in obstetric complications. A substantial population-driven study indicates that elevated vaginal pH is associated with an additional danger of contamination from various human papillomavirus (HPV) variants and inferior squamous intraepithelial lesions (Clarke et al., 2012).

Post-menopause, the decrease in hormone levels of estrogen contributes to a boosted vaginal pH, which is connected with a greater vulnerability to pathogenic microbes. Vulvar imperfections in the skin are more frequent throughout menopause. Lactic acid in the vagina is an indispensable component that assists in local immune system response, supports vaginal well-being, and reduces the development of microbes that cause a condition called bacterial vaginosis. The vaginal epithelium functions as a further line of safety, promptly modifying and maintaining numerous compounds that fight bacteria, especially lactoferrin and lysozyme (Patton et al., 2000; Witkin, 2015). Newfangled studies have also shown that several components, such as nitric oxide, β-defensins, the complement system, surfactant protein A, and Toll-like receptors, show a noteworthy part in the feminine venereal tract's idiosyncratic and adaptive resistance (Y. Chen et al., 2017)

2.1.4 Practices for Feminine Hygiene

A multitude of variable factors influences feminine hygiene behaviours, encompassing personal quality, social context, and factors in the environment. Despite its widespread use among women, covering the vagina has no recognised health advantages and can disrupt natural immune system functions by affecting the conventional vaginal flora, hence increasing susceptibility to infectious diseases. Vaginal douching is associated with a heightened risk of inflammatory pelvic conditions, endometriosis, and infection that is sexually transmitted (Cottrell, 2010; Klebanoff et al., 2010). Conversely, periodic vulva cleaning is recommended to prevent the buildup of vaginal liberation, perspiration, fecal matter, and urine, which may lead to unpleasant physique aroma. While vulvar purging may be beneficial in conjunction with health practices, it is not designed to treat infections. Nonetheless, multiple personal goods used for cleaning and odor control may alter the pH that exists in the vulvovaginal region, disrupting the configuration of the regular vulvovaginal microbiota essential for contamination prevention (Fashemi et al., 2013).

Researchers describe feminine hygiene behaviors as akin to the delicate art of as grooming and the tender care of one’s body. Nurturing your body is like tending to a garden, where cleansing and removing waste is akin to pulling out weeds to allow the flowers to bloom freely. Precise womanly sanitation practices encompass genitourinary cleanliness, bidet utilization, urinary sanitation, and vaginal irrigation. Discussions occurred regarding the methods of conveying personal hygiene practices for women and girls, the significance of sanitation, and disposal of waste; however, there was no mention of menstrual waste management (Czerwinski, 2019). Girigoswami et al., 2024 provided a wide-ranging valuation of the elementary performs of female hygiene as well as personal practices of genital care, such as bathing, douching, and using tampons. Researcher stated that deodorant sprays are needless if the vaginal area can be thoroughly cleaned with soap and water. The use of inner hygienic fortification was recommended only during usual menstruation, with hands cleansed before and after tampon supplement. Tampons should not be introduced while a woman is not menstruation to avert infections (Czerwinski, 1996).

Disparities in feminine hygiene procedures stem from cultural and psychological biases. Research shows that Afro-Caribbean migrants are more likely to use an antibiotic or showers with bubbles to wash their vulva than white women. This supports the idea that methodical cleanliness is important for good health. Some traditional Jewish women take symbolic baths (mikveh) after giving birth or menstruation to achieve ceremonial purity. Muslims advocate full cleansing (ghusl) as a way to cleanse after sexual activity or the menstrual cycle. In South Africa and Mozambique, some females clean the vaginal interiors with a solution of vinegar, saltwater solutions, or lemon juice to eradicate vaginal release and supposedly discourse sexually communicated infections (Hull et al., 2011).

Despite their widespread use, outdated diaper liners (i.e., individuals that provide non-breathable backing) can significantly alter the vulvar microenvironment by increasing epidermal warmth, exterior moisture, and pH (RUNEMAN et al., 2003).

Widespread pubic hair removal, conventionally accomplished for social and spiritual determinations, has gradually expanded acceptance for appealing motives. Hair removal can persuade microtrauma to the skin, enabling the broadcasting of infectious agents in the pubic region (Rowen et al., 2016). Severe outcomes may include vulvovaginal discomfort, infection, and the transmission of infections that are transmitted sexually (e.g., snail contagiosum and HSV). A current research investigation on genital hair elimination revealed that over half of women experienced total eradication of genital hair, with most encountering one or more complications as a result (DeMaria et al., 2014). Hair on the pubic region assists as a protective fence for the vulvovaginal zone, and its broad elimination may increase the likelihood of infections; however, additional investigation is necessary to validate this association (Castronovo et al., 2012; DeMaria et al., 2014).

2.1.5 Management of Hygiene during Period

The administration of menstrual in adolescent girls and women (ages 18–45) involves the utilization of hygienic materials throughout the catamenial cycle to captivate or contain blood, which should be rehabilitated as frequently as essential throughout the menstrual cycle. Water and soap can be acquired for personal hygiene as needed, and there are facilities for getting rid of spent menstrual items. Proper menstrual hygiene management is essential for females, since inadequate cleanliness during menstruation can result in bacterial infections and numerous diseases transmitted through sexual activity, potentially leading to serious complications such as cancer of the cervical region (Deshpande et al., 2018). In less affluent societies, women and girls may encounter challenges in obtaining potable water for sanitation and suitable private areas for replacing their absorbing objects during menstrual. A significant proportion of girls primarily relies on two categories of absorbing material items: textile pads and industrially produced pads. Many choose a pleated fabric that is utilized in their undergarments. This fabric choice is typically utilized in lower-quality areas and provides the benefit of being reusable. Additionally, alternatives such as newspapers, foliage, bathroom tissue, and cotton wool have been used by several women, as the expense of economically manufactured pads can be excessive (Crofts & Fisher, 2012).

2.1.6 Various absorbents utilized during menses

Throughout cycles of catamenia females have to keep sanitation. They utilize commercially viable goods that includes feminine hygiene products, menstrual cups, and tampons, each of which are easily obtainable from retail outlets (figure 2.2). The absorbent constituents can be soft, hygienic, durable, and essential for health defense. Care and well-being are the primary incentives for women to use sanitary napkins. Women in both urban and rural surroundings employ several types of porous constituents as an absorbent materials like logs dirt, grass dirt, and ashes throughout their menstrual cycles. Recyclable fabric pads are chiefly utilized in pastoral areas, while marketable hygienic pads are favored in city settings (Kaur et al., 2018).

2.1.6.1 Reusable and washable cloth pads

Cotton sanitary pads are environmentally friendly. It strongly suggests that the absorbent pads be disposed of hygienically and dried in sunlight. Utilizing solar heat to dry the cloth pads, which serves as an effective disinfection, renders these pads reusable. Moreover, they are readily available, economical, provide a substantial fluid retention ability, provide convenience, and offer inherent benefits. It is imperative to store the cotton pads in a hygienic and moisture-free environment to avert contamination and ensure their reusability (Kaur et al., 2018). Women are employing over 11,000 items for personal hygiene. The utilization of reusable pads helps reduce incidental waste. Likewise, they do not include somewhat damaging components, producing the throwaway cloth pads suitable for both individuals and the environment. Textile pads are constructed from permeable and breathable fabrics which allow ventilation. The ecological cotton pads reduce annoyance and perspiration. The usage of cotton pads significantly reduces the likelihood of yeast-related infections (Attia et al., 2023).

2.1.6.2 Commercial sanitary pads

The marketed sanitary napkins are not environmentally friendly because their composition does not support 100% cotton as a natural fiber and may contain some pesticides. The commercial napkins are easily obtained from pharmacies, numerous stores, or online, and their cost is relatively higher than that of the easily accessible cloth napkins, which are also reusable (Girigoswami et al., 2024; Kaur et al., 2018).


(a)

(b)

(c)

(d)

Figure 2.2: Types of absorbents used during menstruation (a) Reuseable and washable pads made by cloth, (b) Marketable sanitary pads, (c) Tampons, and (d) Menstrual cups

2.1.6.3 Tampons

One generous of permeable material that proposes inner fortification is tampon. Before the catamenial current greeneries the body, it is absorbed by a soft substance that is acquaint with the vagina. Natural resources like cotton, wool, hemp, or bamboo are used to make the reusable tampons. They are highly costly, ineffectively biodegradable, and not environmentally friendly (Billon et al., 2020). Examples of resources that fascinate blood are menstrual cups, tampons, and sponges. Currently, only a minor proportion of women and teenage girls are conscious of the roles of tampons. Added important preventive component in actual life is inadequate demand, which is caused by high values. Despite the widespread availability of tampons, women refrain from using them due to reports from adolescent girls indicating that the insertion process is troublesome, uncomfortable, or prone to obstruction. Numerous ladies exhibit apprehension regarding the impact of insertion devices on productivity and well-being, which is conventionally regrettable (Crofts & Fisher, 2012).

2.1.6.4 Menstrual cups

Menstrual cups are mainly composed of rubber, silicone, and latex which aid in the introduction of the cup into the vagina. The vessels are designed to acquire blood from menstruation and possess a capacity ranging from 10 to 38 milliliters. The cup must be drained per 4 to 12 hours. There are dual types of menstruation cups based on blood current: a vaginal cup, often bell-shaped and inserted into the female reproductive tract, and a cervical vessel, positioned around the cervical area. They are reusable and environmentally friendly. Menstrual cups are suggested for one user and are reasonably priced. They can also be thrown away. The main advantage of menstrual cups is that they have no negative effects on vaginal flora; however, some womenfolk have vaginal wound or experienced severe pain, onset of the urinary tract contagions as well as rashes, or allergies. The main drawbacks are uncomfortable clothing and menstrual blood leakage. Safety risks linked with these cups comprise contrary events such as contaminations, alterations to vaginal bacteria, genital scratching, harmful shock syndrome, infestations in the hormonal, urination, or gastrointestinal systems, and safety issues related to inferior or affordable absorbent materials (van Eijk et al., 2019).

2.1.7 Disease allied with inappropriate utilization of sanitary pads/napkins

In the event that menstrual hygiene practices are neglected, they can lead to a number of vaginal diseases, including generative tract contaminations, toxic shock syndrome, and other conditions. This is a serious problematic situation which can have adverse influence on individual health. Poor genital hygiene can have a harmful effect on the well-being of the adolescent or even cause severe damage. To a large extent, the young women are impromptu and insensible of menarche since menstruation is not well-versed by them and have received incorrect information about it. It is possible that menstrual hygiene will lead to an unhealthy life if it is not handled or practiced in a safe manner. This will result in a number of negative outcomes, including emotional anguish, genitourinary zone contaminations, generative tract infections, cervical tumor, feelings of guilt, scent problems, and even dropping out of school. The diseases are listed as below:

1) Menstrual toxic shock syndrome (mTTS)
2) Reproductive tract infection (RTI)

3) Polycystic ovary syndrome

2.2 pH-responsive polymers

Polymers' external features can be altered to modify their biological, physical, and chemical assets or circumstances, thus enhancing product bio-compatibility Consequently, scholars are increasingly attracted to the arena of stimuli-responsive polymers. These polymers react as per their chemical and physical modifications in their surrounding surroundings. They are proficient at detecting any minor change in their environment and adjust their behaviors accordingly. pH, solvent, ionic strength of salt, temperature, magnetic field, illumination, and electric field constitute atmospheric variable quantity. There are trio which encompass ecological stimuli: 1) Physical, 2) Chemical, and 3) Biological. All three types of stimuli are suggested in Figure 2.3

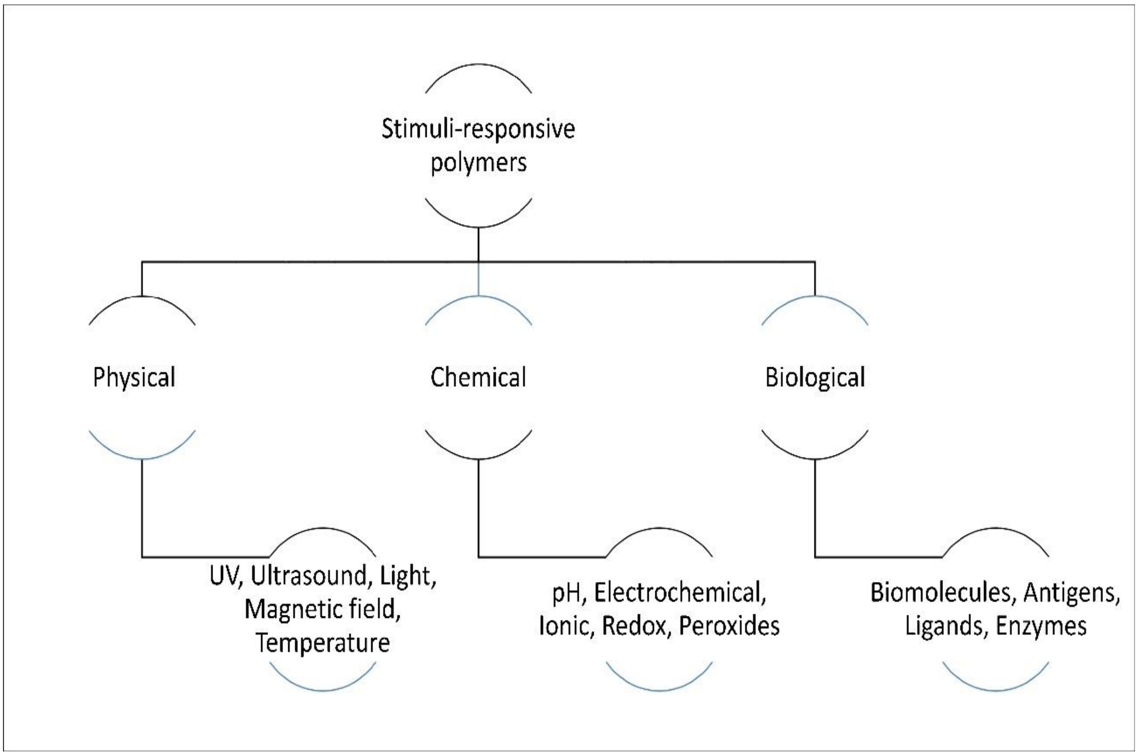


Figure 2.3: Classification according to Stimuli

Polyelectrolytes respond to fluctuations in the environment by either receiving or releasing protons, hence altering their weakly acidic or basic in nature composition. These specific polyelectrolytes are recognized as pH-responsive polymers (Dai et al., 2008; Na et al., 2004). The physical and chemical features of pH-sensitive materials can be modified by differing the charge amount on the foundation of polymer. pH-dependent polymers can be generated by a number of polymerization techniques are readily employed, which includes reversible addition-fragmentation chain transfer (RAFT) polymerization, emulsion polymerization, group transfer polymerization, atom transfer radical polymerization (ATRP), and regulated or conventional radical polymerization. Different constructions such as block polymers, homo polymers, nano- and microparticles, hydrogels (HGs), and microgels are employed as pH-responsive polymers (Gregory & Stenzel, 2012). Owing to their sensitive smart properties, these polymers possess prospective uses in the petroleum, covering, medicinal, and healthcare sectors (Chuang et al., 2009).

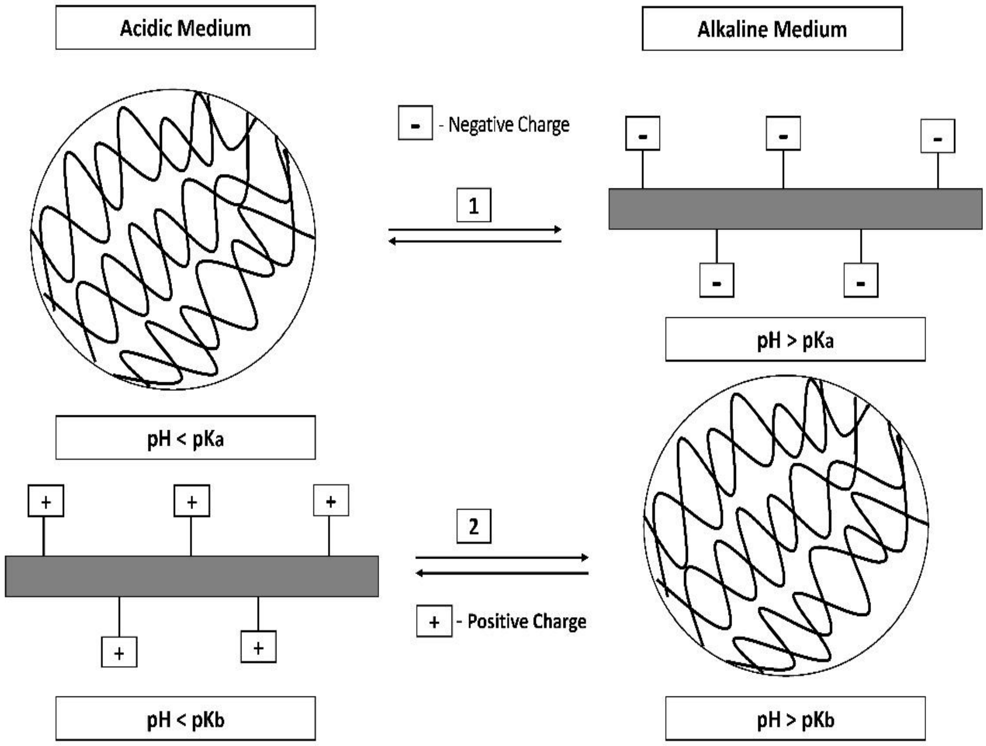


Figure 2.4: Polymer state reliant on the ionization

In aqueous or hydrophilic chemicals, pH-sensitive polymers generate polymeric ions. These polymers swell upon ionization in a hydrophilic fluid or liquid as the polymer strand hinders the charges. When pH-sensitive polymers cannot ionize, the polymers remain coiled. Consequently, hydrodynamic interface potential and electrical resistance among ions influence the way the polymers perform. As an outcome, these specialized polymers suggest structural variations occurring with modest ambient pH fluctuations

(Kocak et al., 2017; SCHMALJOHANN, 2006). The pH-sensitive polymer framework comprises moderately basic (-NH_3) or acidic (-COOH) members which either give away or receive hydrogen in reaction with the fluctuations in the pH of environment. (Figure 2.4). For particulars, polyacrylic acid, that transforms at the pH more compared to the pKa which is possess, is the measurements –COOH group – with the value of 4.25 as a dissociation constant, which is the reason of the enlargement of PAA happened because of the existence of static repellent effect. Catalytic polymers which demonstrate the identical contrary activities with the response to the PAA enlargement responses. Lowering the pH can generate individuals to become ionized. As a conclusion, pH-sensitive polymers indicate able to reverse activities in shifting.

pH-responsive polymers are based on synthetic and natural polymers with viscoelastic characteristics and structure. The properties like chain conformation, surface activity, and solubility change with the surrounding pH (SCHMALJOHANN, 2006). pH-responsive block copolymers undergo modifications such as gelation, vesicle formation, swelling, and micellization by self-assembly processes (Kocak et al., 2017; Wei et al., 2017). pH-sensitive polymers are containing weak basic and weak acidic functional entity in their mainstay as the main active group. The ionic chain entity possesses the ionization degree, and it is suggesting a presentation of such a polyacid and a polybase. When pH > pKa, expanded state of the polyacid, while at pH > pKb, the collapsing of the polybase. Same as when pH < pKa, polyacid collapses, and while pH < pKb, polybase expands. Swelling and deswelling are the majorly described behaviours of such polyacids and polybases. These polymers are generally water-insoluble and soluble in water, when they are neutral and charges respectively. This happens due to the neutrality conversion of ionizable groups, the disappearance of static charges, and the domination of aquaphobic communication. So, the assortment of pH-responsive polymers is founded on the pKa value. The transition of such polymers also depends on the acidic material (pKa) and basic material (pKb) can be changed by modifying the aquaphobic and static interaction (Nafee et al., 2008; Stayton & Hoffman, 2008).

pH-responsive polymers (PRPs) are widely classified into two zones, viz. natural (Table 2.2) or synthetic (Figure 2.5 and 2.6)

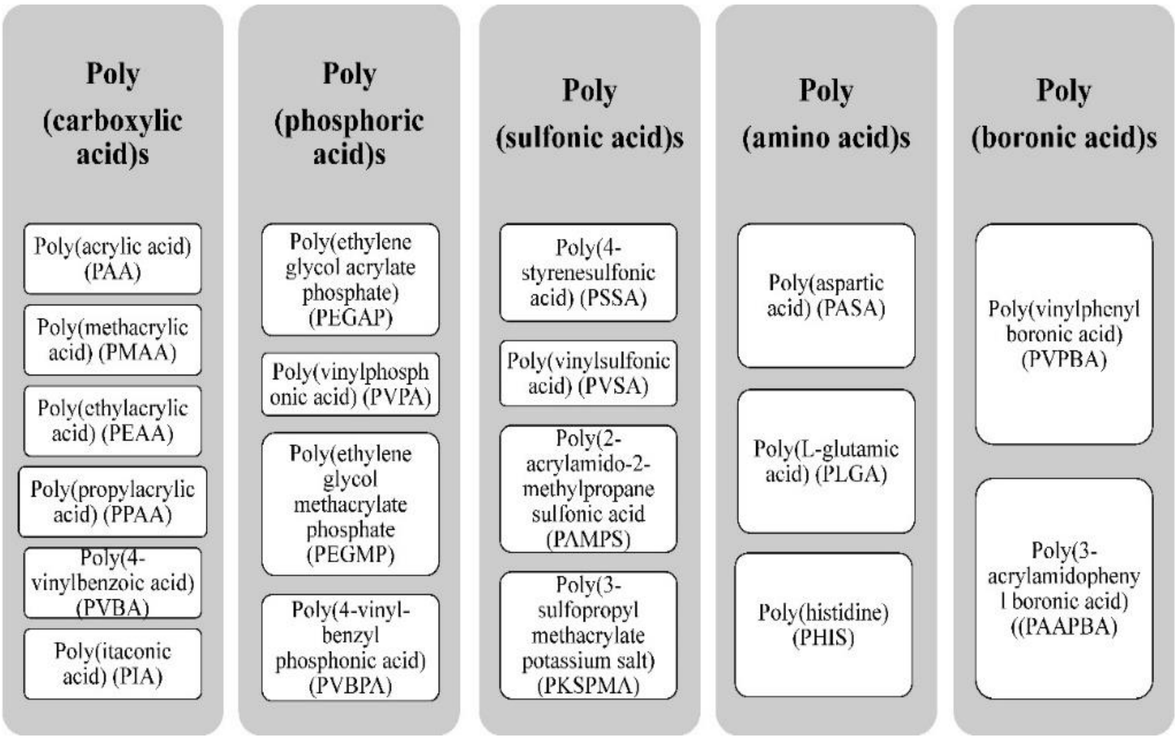


Figure2.5: Polyanions pH-sensitive polymers

(Koetting et al., 2015; Ofridam et al., 2021)

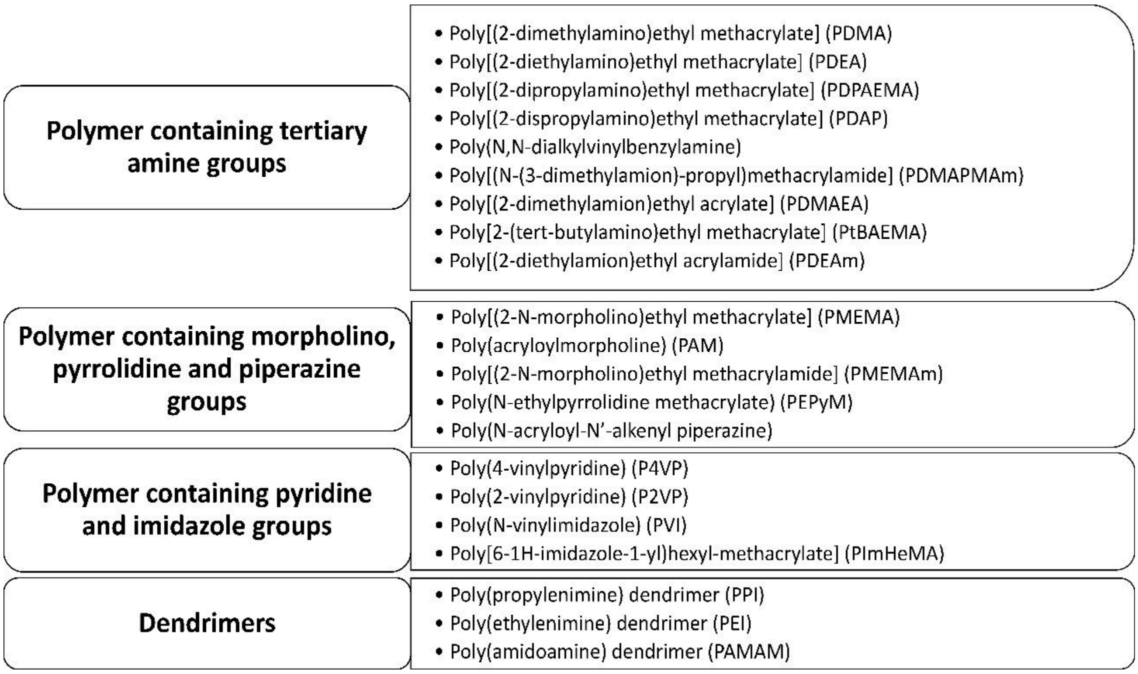
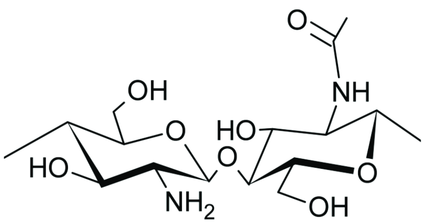
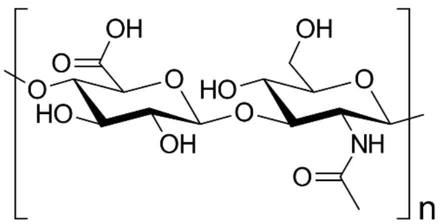
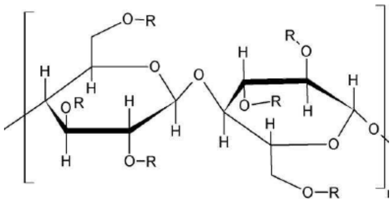
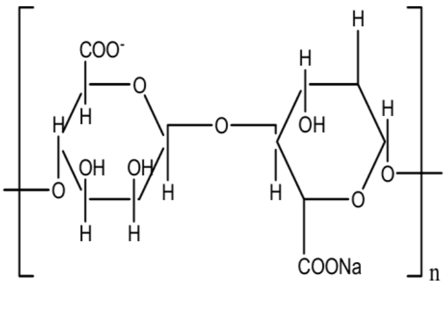


Figure 2.6: Polycations pH-sensitive polymers

(Koetting et al., 2015; Ofridam et al., 2021)

Table 2.2: pH-responsive polymer (Natural)

Nature Polymer	Description	Sources (Year)
Chitosan 	• Chitosan is a randomly distributed glucosamine (2-acetamido-2-deoxy-β-D-glucopyranose) and N-acetyl glucosamine (2-acetamido-2-deoxy-β-D-glucopyranose) polysaccharide • It is applied in food, wastewater treatment, medical fields, agriculture • At higher pH, it is insoluble ad at low pH it dissolves freely	(Ezati & Rhim, 2020; Gaware et al., 2019; Heras-Mozos et al., 2022; Jing et al., 2022; Obireddy & Lai, 2022; Rinaudo, 2006; Yao et al., 1994)
Hyaluronic acid (HA) 	• HA is a composite of N-acetyle-D-glucosamine disaccharide and D-gulcuronic acid • It behaves as anionic polyelectrolyte at pH = 7 • pK_a of HA lies between 3 and 4 • Insulin can be protected against acidic pH of stomach	(L. Han et al., 2012; S. M. Han et al., 2022; Kamaly et al., 2016; Miyazaki et al., 2018; H.

	with the help of pH-responsive HA nanoparticles • It is also utilized as cell surface producer for cancer related treatment	Wang et al., 2022)
Carboxymethylcellulose (CMC) 	• CMC is the derivative of an anionic cellulose • When pK_a is more than 4.3, CMC ionizes • Hydrogel for controlling the release of entities is prepared using modified CMC • Utilised in drug delivery, food, tissue engineering, and agriculture	(Bazban-Shotorbani et al., 2017; Chang et al., 2011; H. Liu et al., 2017; Z. Liu et al., 2022; Y. Wang et al., 2022)
Alginate 	• Alginate is the example of a polysaccharide. • Applied in medicine, food, and pharmaceuticals • It is a β-D-mannuronic (M) and α-L-guluronic acid (G) based block copolymer • pK_a of alginate lies between 3 and 4 • It is pH-responsive as the monomers existence which have carboxylic acid, and are present in its both monomers	(A. W. Chan et al., 2009; D'Ayala et al., 2008; Draget et al., 2002; Ghauri et al., 2022; Ju et al., 2001; Khushbu & Jindal, 2022; Reyes-

	• It converts in to gel or swell mildly in the existence of bivalent cations • It remains in encapsulated forms with shrinking with low pH	Ortega, 2014; Shalaby & Burg, 2003)

2.2.1 Synthesis of pH-sensitive Polymers

This section discusses polymerisation strategies for synthesising pH-sensitive polymers, such as controlled radical polymerisation (ATRP), group transfer polymerisation (GTP), reversible addition-fragmentation chain transfer (RAFT), and emulsion polymerisation. The polymers manufactured by applying the aforementioned processes can be micro- or nanostructures, microgels, block copolymers, HGs, and homo or copolymers. Novel 3D materials with convertible hydrophilic surfaces have received a proportion of attention for their application in oil/water segregation. Melamine foam (MF) when imbedded with a poly (2-dimethylaminoethyl methacrylate) to form pH-responsvie polymer via chain transfer free radical polymerization, the polymer prepares is excellent responsive against pH (Ma et al., 2022). Nanostructure of UCNPs@SiO2@PAzo/MAA is prepared using monofunctional 6-(4-methoxy-4′-oxygen-azobenzene) hexyl methacrylate (Azo) which act as a light-sensitive monomer and the monomer methacrylic acid (MAA) which functions as pH-sensitive entity (X. Wang et al., 2022).

2.2.1.1 Emulsion polymerisation

Emulsion polymerization can extensively employ to produce vinyl-based pH-sensitive polymers. This approach produces latexes via radical chain polymerization, resulting in a narrow particle size distribution. This polymerization necessitates monomer(s), liquid, a liquid-soluble catalyst, and a solvent or surfactant. The primary disadvantage of this procedure is the elimination of the surfactant employed in polymerization, which may be the reason for generation the lates coagulation or flocculation. This technique is subdivided into mini-emulsion and micro-emulsion polymerization. Poly(4-vinylpyridine) and pH-responsive nanostructures have been produced via a surfactant-free approach grounded in soft microgels (Pickering emulsion) (Atta et al., 2019), which has the stimuli-sensitive characteristics of a micro structure and is capable of being sustained by Mickering emulsions. In the mixture of divinylbenzene as an agent utilised for cross-linking, 2-(tert-butylamino)ethyl methacrylate is polymerised applying emulsion polymerization and a macromonomer poly(ethylene glycol) methacrylate (PEGMA) which is kept with monoethoxy gave the stabilised latex around 10% showing 9 pH at 70°C (Morse et al., 2012).

2.2.1.2 Group Transfer Polymerisation (GTP)

Methacrylates are predominantly produced using this approach. Michael's incorporation of ending silyl ketene acetal and monomer involved the introduction of the monomer with the attachment the silyl group, resulting in the formation of an entirely novel terminal group. This approach employed the use of catalyst a salt of carboxylic acid and an accelerator 1-methoxy-1-(trimethoxysiloxy)-2-methylpro-1-ene (MTS). In the solution of tetrahydrofuran Copolymerization of ethylene glycol dimethacrylate with N, N-dimethylaminoethylmethacrylate(DMAEMA), allowing for the regulation of molecular weight distribution and primary chain by GTP to synthesize block copolymers (Perumal et al., 2022). Formulation of the block copolymer can also occur via the incorporation of a new monomer, as chain development. ceases following the aforementioned steps (Ofridam et al., 2021).

2.2.1.3 Reversible Addition-Fragmentation Chain Transfer (RAFT) Polymerisation

In the past ten years, reversible addition–fragmentation chain transfer (RAFT) polymerization has emerged as a potent method for synthesizing precisely specified copolymer structures. Dissolved in water, stimuli-sensitive section, star, and graft copolymers are particularly important for the targeted administration of analytical and medicinal substances. RAFT polymerization is frequently conducted straight in aquatic at room temperature, eliminating the necessity for protective group chemistry (Smith et al., 2010). This polymerisation includes the manufacturing of polymers via the reaction of monomer, radical motivator, and chain transmission. This is the synthesizing of macromolecular structure with a low polydispersity index. In the technique, the initiator generates radicals, radicals propagate the polymeric chain. RAFT agent helps to keep radicals in the polymeric chain at the last location of the chain end, which helps in the termination of the chain also. The pH-sensitive micelles with the core of poly(hexafluorobutyl acrylate) (PHFBA) and shell of poly (2-(dimethylamino) ethyl methacrylate) (PDMAEMA) which is amphiphilic block copolymer can be formulated by reversible addition-fragmentation chain transfer polymerization tempted flat pack (J. Zhou et al., 2020). Amphiphilic block copolymers founded benzaldehyde-containing *para*-formyl phenyl methacrylate (pFPMA), oligo(ethylene glycol) methacrylate (OEGMA) and pH-sensitve monomer 2-(diisopropyl)aminoethyl methacrylate (DPA) can also be formulated utilising reversible addition-fragmentation chain transfer (RAFT) polymerization (Smyth et al., 2020). 2-(dimethylamino) ethyl methacrylate (DMAEMA), disulfide diacrylate (DSDA) and 2-propyl acrylic acid (PAA) are utilised to create a new pH-sensitive hyperbranched polymers (HBPs) containing fluorescently labeled folate through the RAFT co-polymerization. The reaction was facilitated by 4-cyano-4-((dodecylthio)carbonothioyl)thio)pentanoic acid (CDCTPA) which works as the RAFT agent, with the application of bioconjugation approach for post-functionalization (Blackburn et al., 2019). Benzoate class RAFT agent is applied for polymerisation of N-isopropylacrylamide/methacrylic acid. The resulting penta block terpolymer has a core-shell-corona assembly and exhibits strong thermo- and pH-responsive properties (Ahmadkhani et al., 2017). Two varieties of star polymers, featuring a poly(acrylic acid) (PAA) block positioned either externally or internally on an arm chain, were produced using RAFT polymerisation with the conjunction of hydrophilic poly(2-hydroxyethyl acrylate) (PHEA) (Kitajima et al., 2022).

2.2.1.4 Atom Transfer Radical Polymerisation (ATRP)

This technique is precise/alive radical polymerisation, in which various acrylic and vinyl monomers are polymerised with mild conditions. As an initiator alkyl halide ia applied and as a catalyst transition metal in a lower oxidation is utilised in the ATRP technique. In this technique, formed radicals grow, and are reversibly deactivated by generating dormant sites. By reactivation the same dormant sites, the polymer chain can grow again. Photoinduced atom transfer radical polymerization is employed to produce star like block copolymers with the fraction amount of -(dimethylamino)ethyl]amine (Me6TREN) and $CuBr_2$ complex, and the yield is showing low dispersity and controlled molecular weight (He et al., 2021). When PyMCIBMA monomer is polymerised with reversible addition–fragmentation chain transfer (RAFT), it works to create homopolymer of poly(PyMCIBMA) containing Cl in each and every repeating unit as an ATRP initiating group (R. Chen et al., 2022).

Examples of the above techniques suggested in Table 2.3.

Table 2.3: Formulation of pH-sensitive polymers

Polymerisation technique	Description	Sources (Year)
Emulsion polymerisation	• Core-shell NPs which possesses a core material as poly(methylmethacrylate) (PMMA) and a shell material as P(MMA-co-EA) • PMAA and PDMAEMA based system • Mini emulsion utilised for formulation of PAA NPs • Initiator is used in this technique for preparing polymer by utilising micro emulsion is water insoluble	(Atta et al., 2019; Jiang et al., 2010; Tan et al., 2005, 2006; Tan & Tam, 2008; X. Wang et al., 2004)
Group Transfer Polymerisation (GTP)	• Ethylene glycol dimethacrylate (EGDMA) and N,N-dimethylamino ethyl methacrylate (DMAEMA) copolymer in tetrahydrofuran (THF) • Crosslinked polymer with numerous molecular weights can be formulate with the catalyst tetrabutylammonium bibenzoate	(Yamasaki & Patrickios, 2003; C. Zhu et al., 2010a)
Reversible Addition-Fragmentation Chain Transfer (RAFT) Polymerisation	• PDMSEMSs can be manufactured which is reducible • For the microcapsule-based drug delivery, core-shell structure can be	(Ahmadkhani et al., 2017; Blackburn et al., 2019; Y.

	generated with the weak acidic charge by RAFT • For drug delivery, a core poly(BA) and a shell poly(PEG-A) were grafted through RAFT agent	Chan et al., 2006; Kitajima et al., 2022; Lansalot et al., 2002; Smith et al., 2010; Smyth et al., 2020; Zhou et al., 2020b)
Atom Transfer Radical Polymerisation (ATRP)	• t-butyl methacrylate or propyl methacrylate and polyethylene glycol-based copolymer was formulated by ATRP • For solid tumor, Pluronic P85 and PAA block copolymers were formulated for drug delivery system	(R. Chen et al., 2022; He et al., 2021; Satturwar et al., 2007; Tian et al., 2007)

2.2.2 Structures of pH-sensitive Polymers

Usually labelled pH-responsive polymers’ assemblies are: NPs, and HGs, linear homopolymer or copolymer, star, dendritic polymers, polymer brushes, grafted copolymer, and block copolymer. (Figure 2.7).

2.2.2.1 Linear copolymers

Amphiphilic copolymers like homopolymers and random copolymers are examples of liner copolymers. Their structure comprises two, three or more monomers (Rodríguez-Hernández & Lecommandoux, 2005). Soluble and insoluble segments present in the polymers directly affect the micelle configuration. These types are polymers self-assembled in solution by generating micelle configuration. pH-sensitive copolymers have a huge amount of collections in the backbone as well as at the end which can be ionized (J. K. Kim et al., 2010). This assembly is affected by various factors like pH, temperature, characteristics of solvent, salt, and polymer concentration. Their structure changes their forms in spherical, flower, worm, and hollow with the change in pH (Sanjuan & Tran, 2008).

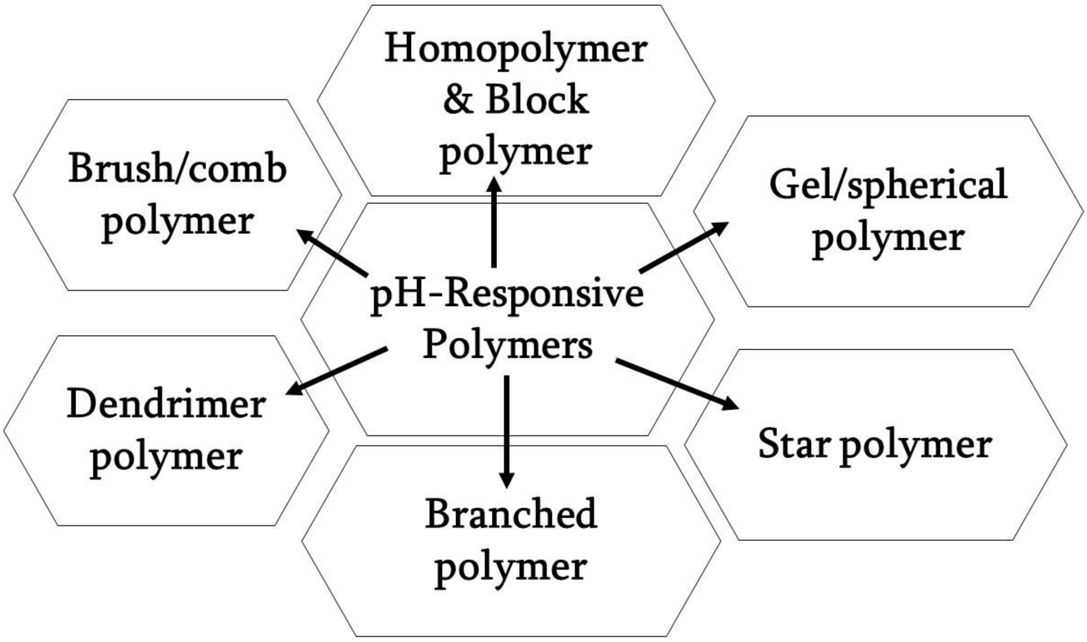


Figure 2.7: Structures of pH-sensitive polymers

2.2.2.2 Star Polymers

Dendritic and highly branching copolymers, as well as grafted polymers, are examples of star polymers whose micelle shape changes in response to variations in pH (Sanjuan & Tran, 2008). For administering medications and coverings, this particular kind of polymer is often employed. These polymers exhibit excellent solubility, altered thermal characteristics, and melt viscosities.

2.2.2.3 Hydrogels (HGs)

The cross-linked insoluble structures which are highly hydrophilic are known as hydrogels (Hoffman, 2012). Bases in their dry weight, hydrogels can absorb 10 to 20% more up to thousands of times. These gels contain acidic/basic groups with acid/base linkage where at low pH, the acidic entity is hydrogenated, and ate high pH, basic entity is dehydrogenated (De et al., 2002). When pKa value is less than pH suggested, anionic hydrogels ionised in solution (pH > pKa), and gel starts to swell. Whereas, the dissociation constant value is higher than the pH (pH < pKa), cationic clusters are ionised, and the gel will start to swell (Gupta et al., 2002).

2.2.2.4 pH-sensitive brush and comb copolymers

Brush and comb copolymers are chains in which hairy-like structures are grafted on a surface. Brushes are anchored by physical absorption or by chemical covalent formation to the polymer surfaces. As pH changes, modifications or changes are clearly exhibited in surface energy or state (T. Chen et al., 2010; Sanjuan & Tran, 2008).

2.3 Microencapsulation

Microcapsules, microparticles, or microspheres are made by small packaging is known as microencapsulation, which possesses one or more active components. Also, it can be defined as the process in which lightweight capsules are utilized for coating small components or particles (Niamah et al., 2021). These small components are solid particles, liquid droplets or gas molecules. This technique utilized for protecting the active components or chemicals or ingredients from harmful environment like evaporation, acidity, moisture, alkalinity or heat. (S. Y. Cheng et al., 2008). Microencapsulation supports in decreasing the responsiveness of the ingredient which is being condensed and stops loss or evaporation of the encapsulated part. It also, prepare the encapsulated material which is easy to handle, easy to apply and easy to store. So, this technique can be utilized for masking the taste, activity, and odor of encapsulated components (Calderón-Oliver & Ponce-Alquicira, 2022).

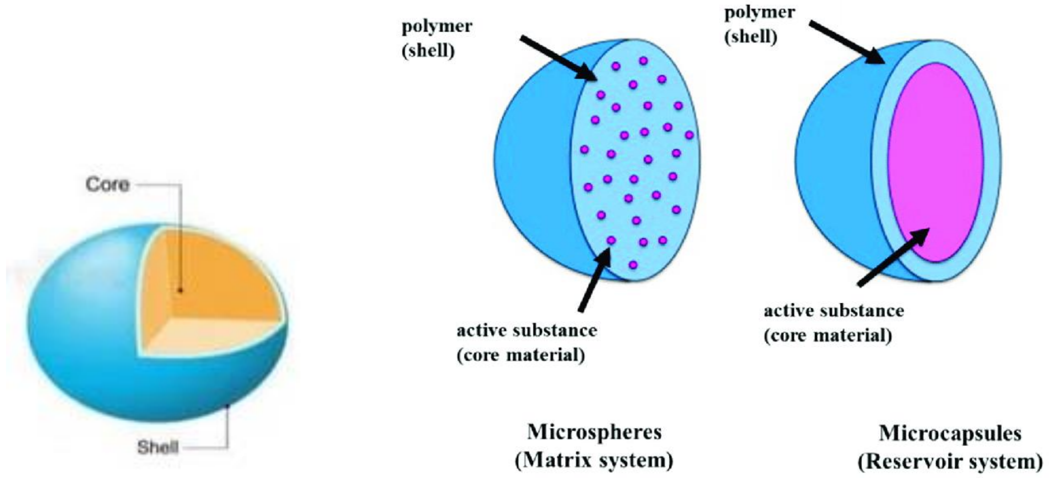


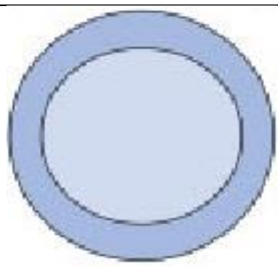
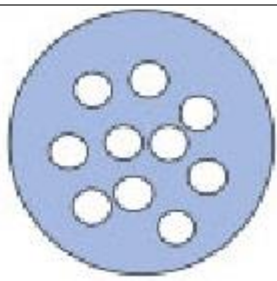
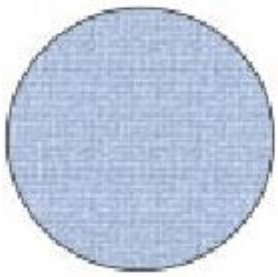
Figure 2.8: Morphology of microcapsules

Microcapsules is self-possessed of binary portions: one is known as the core and another one is the shell (figure 2.8). The core as a central portion encompasses a lively substance, while the shell as an exterior portion protects the core which may affected by the peripheral atmospheric conditions permanently or temporarily (Urbas et al., 2017).

2.3.1 Classification of microcapsules

Table 2.4 suggests various classes of microcapsules with their characteristics and diagrammatic representation (H. Cho et al., 2020).

Table 2.4: Classification of Microcapsules

Types of microcapsules	Characteristics	Representation
Mononuclear	It is mono hollow section present in the shell	 
Polynuclear	Various diverse size sections present in the shell	 
Matrix	Shell entrenched the active species	 

2.3.2 Methods of microencapsulation

Microcapsules can be prepared or manufactured by utilizing various techniques. Physical attributes, solubility, shell permeability, release rate of the core, and thickness of the shell are the factors responsible for choosing the proper microencapsulation technique. The techniques are divided in three major groups, viz. chemical, physicochemical, physical. Further distribution of techniques included in three major groups are classified in the table 2.5 (Abdel-Aziz et al., 2022; Boh Podgornik et al., 2021).

Table 2.5: Microencapsulation methods used in textiles

Chemical	Physicochemical	Physical
In situ polymerisation Pre condensate or monomer accepts the aquatic states of the emulsion	**Simple coacervation** Phase is separated by desolvation agent	**Spray drying** In heating assembly, core and shell emulsions are sprayed
Interfacial polymerisation Dissolution of 1st monomer in water and other dissolves in hydrophobic solvent	**Complex coacervation** Aquatic phase or precipitates are separated via phase separation	**Solvent evaporation** Removing a solvent from a solution to create a film or capsule wall
Phtopolymerisation Uses light to transform a liquid resin into a solid material	**Molecular inclusion** One compound encloses another compound within its cavity	

2.3.3 Techniques for the core release

Success of microencapsulation process can be measured on the release of core material when it requires, and till that it must be protected. Releasing of the core component possesses the various mechanisms for releasing which cover pH, dissolution, degradation, pressure, change in temperature and diffusion (figure 2.9). The characteristics of core component and the shell components are responsible for deciding the mechanisms (Choudhury et al., 2021).

2.3.4 Application methods of microcapsules on textiles

Introduction of the microcapsules to the textiles is performed mechanically from polymer stage to fabric stage. The application of the microcapsules performed at various stages and in the various forms in different textile processing techniques.

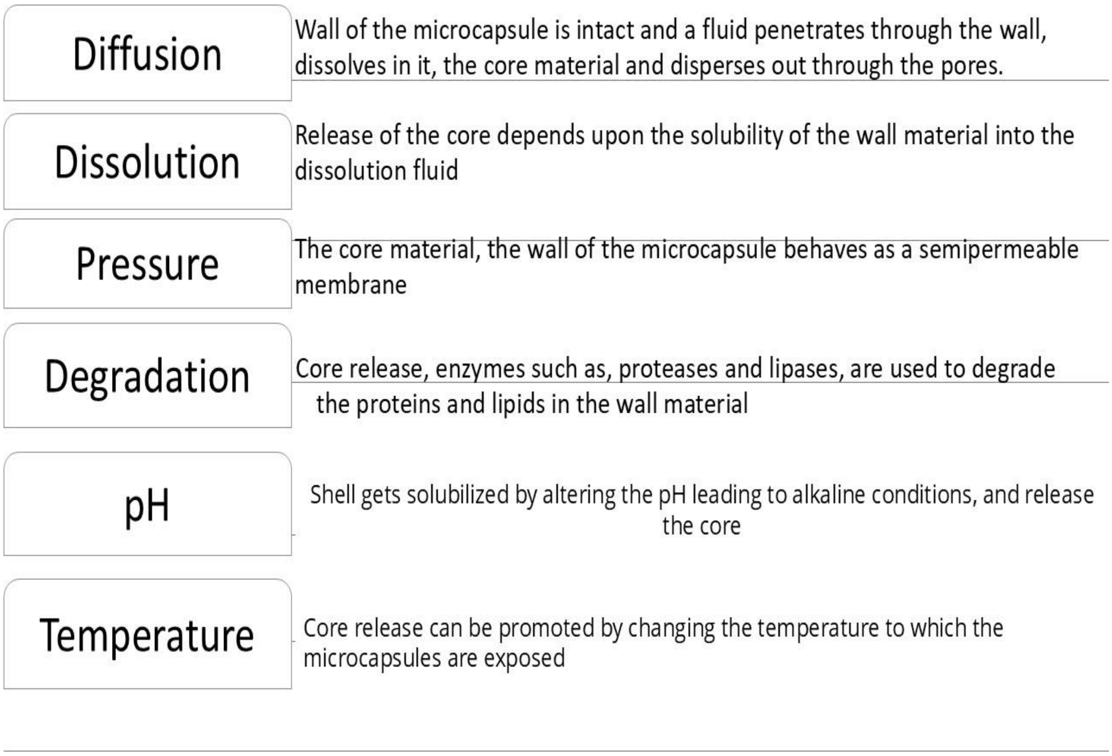


Figure 2.9: Methods for control release of the core

1) Polymer: When synthetic fibres are manufactured, microcapsules has been added during the spinning process (Choudhury et al., 2021).
2) During Padding: The fabric is dipped in the prepared microcapsules assembly, and then allowed to pass through the cushioning rollers for removing the excess liquid (Kert et al., 2021).
3) Immersion: The textile material is treated in the microcapsule's assembly only, and not padded from the adjusted rollers (Kert et al., 2021; W. Li et al., 2014).
4) Printing: Printing paste is prepared using binder and microcapsules, and then applied to the fabric by utilizing different printing methods (Trojanowska et al., 2017).
5) Coating: Fabric is coated with the homogenous mixture of the capsules (Trojanowska et al., 2017).
6) Spraying: Spray nozzle sprays the microcapsules on the textile material in a close compartment, and then treated with the high temperature which helps in stabilizing the microcapsules on the textile (Tulshyan & Dedhia, 2021).

2.3.5 Microcapsules application on textiles

Functional finishes for the textiles are recently demanded majorly by textile market, as well as by consumers also. The functionality depends on the end uses of the textile materials, viz, flame retardant, antimicrobial, wrinkle free, water resistant, oil resistant, UV resistant, medical textiles etc. Microencapsulation is one of the methods used for obtaining or receiving permanent or temporary functionality on the textile materials. Ultimately, its finishing only. Table 2.6 discusses the various ingredients utilized for preparing functional textile with microencapsulation technique (Abdel-Aziz et al., 2022; Boh Podgornik et al., 2021; Tulshyan & Dedhia, 2021).

Table 2.6: Functional textiles and ingredient used for preparing them

Ingredients used in microcapsules	Functional textiles
Dyes and pigments	Permanently coloured textiles
Thermochromic dyes	Colour changing textiles
Photochromic dyes	
Electrochromic dyes	
Fire retardant	Flame resistant
Phase change materials	Textile for thermal control
UV absorbers	UV protecting textiles
Superhydrophobic	Technical textiles
Sound-absorbing	
Biosensors	
Acaricides	Insecticidal textiles
Insecticides	
Mosquito repellent	Insect repellent textiles
Moth repellent	
Essential oil	Fragranced textiles
Perfumes	
Aromas	
Natural antimicrobials	Antimicrobial textiles
Antibiotics	Medical textiles

Disinfectants	
Wound-healing agents	
Essential oils	Cosmetotextiles
Vitamins	
Hydrating agents	
Combine three or more ingredients	Multifunctional textiles

2.4 Microencapsulated pH-responsive polymers (PCM) for textiles

Phase change materials which can change their responses according to their surrounding stimuli have captured attention now a days. Stimuli like temperature, pH, light, and ultrasound etc. Specifically, pH-responsive PCM has attracted research scholars. On the bases of delivery and controlled release properties, microcapsule modifications have been widely studied for application on textiles (D. Sun et al., 2018). Recent environment condition, green and clean chemistry is must for scientific and technological development. Melamine-formaldehyde, phenol-formaldehyde resins are mostly used to prepare microcapsules which are applied on textiles, and those are hazardous due to formaldehyde, a toxic substance (Sharkawy et al., 2017; Zhao et al., 2020). Numerous approaches have been considered for preparation of microcapsules which can be applied in pharmaceuticals and engineering; and those are advantageous due to their preparation environment, particle sizes, and shell component (Read et al., 2020; Z. Zhang et al., 2019).

Smart fabric which can respond with pH alteration can be processed through several techniques, like combining colour changing fibre to form the fabric, colour changing dye application on textiles, coating with colour changing dyes and pigments. pH-responsive dye or turmeric can be applied to the cotton to prepare colour changing textiles. pH-responsive dye can be mixed with polymer solution and those micro capsulated fibres can be utilised for preparing colour changing fabric with pH difference. Dyes containing the azobenzene functional group and vinyl sulfoxide polymer dyes which are water-based might be synthesized through an epoxy material as the foundation. This epoxy resin transitions to the red spectrum when the pH becomes acidic, indicating a change in colour and that is conversion to red from yellow. This pH-sensitive polymer dye can be employed to formulate microspheres to manufacture color-changing intelligent textiles (Jia et al., 2023).

Smart hydrophilic materials are being developed which starts to swell and/or de-swell, when pH and/or temperature alters. These materials, mentioned as thermo-sensitive, intelligent, or smart microgels, stimuli-responsive, consist of microencapsulated polymeric structures. Their applications include sportswear, medicinal, and cosmetic textiles (Mohamed & Hassabo, 2021).

pH of human skin provides information about the health, and so the monitoring of pH drawn attraction of the scholars. Dermatitis and fungal infection skin diseases change the pH of skin. Dehydration due to exercise, heatstroke can also be identified by measuring the pH of skin. Healthy skin suggests the pH range of 4.2-5.6, whereas dry skin suggested a little basic pH. For wound healing, pH of skin most helpful, as undamaged skin shows weakly acidic conditions, while damaged skin suggest the pH more than 7 due to biochemical reaction associated with blood clotting (Mani et al., 2020; Oh et al., 2018).

A smart device is mounted on the skin for detection and response to the physiological situation of the skin for data diagnosis. Recently, pH responsive electrodes or organic dyes are utilised for measuring the pH. Compare to electrode, pH responsive dyes used in wearable sensors generates issue related to tuning, and for that it requires complex modification for analysis. Aside from the growing utilization of soft elastomers and textiles for wearable chemical sensing, the inherent rigidity of most substrates limits the mobility of sensors on the body. Current improvements in the domain of protein-based materials have enabled the creation of macro-sized pH-responsive films, patches, and coatings that exhibit both mechanical flexibility and responsiveness (Saldanha et al., 2020). Tabel 2.7 suggests some examples of pH-responsive polymers which had been micro encapsulated and applied on textile for specific purpose.

Table 2.7: pH-sensitive polymers which can be micro encapsulated

pH-sensitive polymer	Sources (Year)	Types
• Methyl methacrylate and methacrylic acid copolymer	(Alotaibi et al., 2019)	**Tablet**

• For overflowing publication at the mark position to improve the effectiveness chitosan and alginate base nano-sized complex	(Li et al., 2022)	
• Hydroxypropyl methylcellulose • Ethyl cellulose/ Methacrylic acid	(Joshi & Mohamed, 2014; Sung et al., 2012)	
• Cellulose acetate phthalate	(Chandran et al., 2008)	
• Cellulose acetate phthalate-co-poly(methacrylic acid)	(Shah et al., 2019)	
• Poly-acrylic resin and Methacrylic acid/ethyl cellulose based NPs	(Cui et al., 2020)	**Coated pellets**
• Poly-acrylic resin and Methacrylic acid/ethyl cellulose and hydroxypropyl cellulose based NPs	(Kadam & Gattani, 2010)	
• Hydroxypropyl methylcellulose phthalate	(Yu et al., 2015)	**Microcapsules**
• Poly-acrylic resin and ethyl cellulose/methacrylic acid	(Naha et al., 2008; Wu et al., 2012)	
• Methyl methacrylate/Gelatine and methacrylic acid copolymer	(Mastiholimath et al., 2007)	
• Sodium alginate/Methyl cellulose	(Y. Zhou et al., 2020)	
• Ethyl cellulose/Methacrylic acid	(M. Obeidat & Price, 2006)	
• Acrylic acid/Sodium alginate	(Jelvehgari et al., 2010)	**Hydrogel**
• N,N – dimethyl amino ethyl methacrylate (DMAEMA)	(Agrawal et al., 2017; Jalil	

• Methacrylic acid (MAAc)	et al., 2017; S. Sun et al., 2015)	
• Ph-responsive hydrogel based on guar gum (GG)/kappa-carrageenan (KC)/poly(vinyl alcohol) (PVA)	(Farooq et al., 2022)	
• Methyl methacrylate, methacrylic acid and and PLGA based copolymer	(Abou Taleb, 2013)	**Nanoparticles**
• 2-(dimethylamino)ethyl methacrylate (DMAEMA), N-vinylcaprolactam (NVCL), and polyethylene glycol diacrylate (PEGDA).	(Du et al., 2022)	
• Chitosan	(Cetin et al., 2010)	
• Poly(2-isobutyl-acrylic acid)	(L. Liu et al., 2018)	**Microgel**
• Polyacrylic resin/ethyl cellulose	(C. Li et al., 2019)	**Solid lipid nanoparticles (SLN's)**
• Carboxymethyl chitosan (CM-CMCS)/Chitosan	(Feng et al., 2013)	**Nanoparticles**
• Polymethacrylic acid (PMAAc)	(Shalviri et al., 2012)	
• Acid-labile Schiff's base connection, PEG-DOX-cur prodrug	(Y. Zhang et al., 2016)	
• NPs coated with chitosan	(Montha et al., 2016; Sadighian et al., 2014;	

	Unsoy et al., 2014)	
• Chitosan	(Vivek et al., 2013)	
• Poly(glutamic acid) (mPEG-b-PLGA)-block-methoxy poly(ethylene glycol)	(Ahmad et al., 2018)	
• Orthoester linkage of (PGE-pH-PBLG)	(Thambi et al., 2011)	**Polymeric micelles**
• (HPMA)-benzoic-imine bonds	(Xu et al., 2016)	
• (HPMA)-hydrazone bonds	(Chytil et al., 2018; Z. Zhou et al., 2014)	
• Poly(L-histidine)	(John et al., 2017)	
• Hydrazine linker poly(lactic acid)-poly(ethylene glycol)	(H. Li et al., 2015)	
• Copolymer of poly(methacrylic acid) and poly(ethylene oxide)	(J. O. Kim et al., 2009)	
• Polycaprolactone-b-poly(acrylic acid)	(H. Liu, Chen, et al., 2019)	
• Poly(β-amino ester)methyl ether poly(ethylene glycol)	(Min et al., 2010)	
• PEG and polyaspartic acid	(Hamaguchi et al., 2005)	

• Poly[2-(methacryloyoxy)ethyl phosphorylcoline]-poly[2-(dispropylamino)ethyl methacrylate]	(Licciardi et al., 2008)	
• PHIS -b-PHEMA	(Johnson et al., 2012)	
• PEYM -b-PEG, orthoester side chains	(Tang et al., 2011)	
• Poly(methacrylic acid)	(Qu et al., 2019)	**Nanogel**
• Poly(n-isopropyl acrylamide-methacrylic acid-hydroxy ethyl methacrylate)	(Shim & Kwon, 2012)	
• Chitosan (cationic amino polysaccharides)	(Lee et al., 2011)	**DNA carrier**
• Poly(aspartame hydrazinedoxorubician)-poly(ethylene glycol)-	(Nishiyama et al., 2005)	**nanocarriers**
• PEI as branched or liner • Dendrimer of polyamidoamine • Poly(β-aminoester)	(Park et al., 2012)	**Gene transfection**
• PLL side chains and poly(N,N’-diethylamino ethyl methacrylate)	(Ho et al., 2011)	**DNA carrier**
• Polyethylenimine (PEI)	(Godbey et al., 1999)	**Proton sponge effect**
• Poly(L-lysine)	(Zakeri et al., 2018)	**High charge density**
• PMMA and PEI nanoparticles	(J. Zhu et al., 2005)	**Better diffusion**

• Poly[2-(diethylamino)-ethyl methacrylate] (PDEA)	(Manganiello et al., 2012; C. Zhu et al., 2010b)	**Gene delivery**
• poly[2-(methacryloyoxy)ethyl phosphorylcoline] and poly(ethylene glycol)	(Chim et al., 2005; H. Y. Cho et al., 2011; Yue et al., 2012)	**nonviral vectors**
• N,N'-dimethylacrylamide, sucrose particles and Sulfadimethoxine	(S. Il Kang & Bae, 2003)	**Hydrogel**
• Poly(2-glucose-oxyethyl acrylate)-block-poly(ethylene oxide)	(Chiappetta & Sosnik, 2007)	**Micelle**
• Poly(ethylene glycol) acrylate with Fe (II, III) oxide and 2-hydroxy methacrylate	(J. Gonçalves et al., 2019; H. Li et al., 2016)	**Hydrogel**
• Poly(acrylic acid) or poly(diallyl dimethyl ammonium chloride) with Poly(N-isopropylacrylamide)	(X. Li et al., 2017; Shang & Theato, 2018)	**Actuator and sensor**
• Sodium alginate with PDMA-AM and PDMA	(Y. Cheng et al., 2018)	**Environmental sensor**
• Poly(AAm-co-AAc)	(Zarzar et al., 2011)	**Hydrogel**

2.5 Application of microencapsulation in hygiene textiles

In recent trend, modern textile products are mainly processed or treated with microcapsules, and so it gains more attention. Microcapsules are applied to materials for the preparation of skincare goods, fragrance, insect repellents, sensors, flame-resistant items, and antibacterial substances (Y. Zhou et al., 2017). So, the product with new valuable characteristics can be produce with the ease of microencapsulation technique. In the arena of purposeful resources, for improving the efficiency of the specific functionality microcapsules are utilised for finishing, and it also increase the cost, but still attracted science and industry as well (L. Liu et al., 2016).

The microcapsules can be adjusted with goods during various phases of manufacturing of the resources. The morphology of the microcapsules similarly differs on the basis of manufacturing.

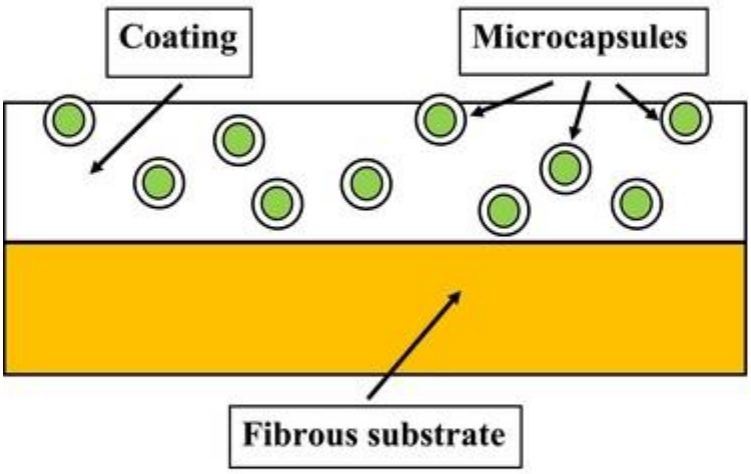


Figure 2.10: Microcapsules: example of application

Generally, when the core is surrounded with the shell, is known as mononuclear microcapsules, which is broadly applied for textile materials, and those are for cosmetic, medical, and color changes. These The mononuclear microcapsules are applied on the textile by finishing operations (figure 2.10). Mostly, they are applied by padding, coating or spraying on the textile substrates like wovens, knit wears or nonwovens. Thermoplastic binders have been used to linked the microcapsules with the fabric surface or in situ of the fibre, and the examples of binders are silicone-type, polyurethane, starch, resin of acrylic, or other materials (Bezerra et al., 2016; Petrulis & Petrulyte, 2019).

The basic types of microcapsules systematic sphere-shaped and asymmetrical shape are applied on textile also, and those are differed in their morphology in shell thickness, diameter, and other properties. So, characteristic proportion and sphericity aspect are used for showing the dimension of microcapsules, and it has been recorded with size distribution data (Nazir et al., 2019). Nanocapsule denotation is given for the smallest microencapsulated product with the diameter less than 0.2 μm, while some products have the size about 0.05 μm, and the biggest size of material which was microencapsulated is 1000 μm (H. Liu, Wang, et al., 2019).

The thickness of shell wall prepared with melamine-formaldehyde is about 330 nm and the diameter of the microcapsules if about 34–346 μm. The same values have been observed in the case of crystalline titanium dioxide (TiO_2) with the 90-200nm shell thickness (Chai et al., 2015).

Most important in the case of microencapsulation is the choice of shell component, as it affects the stability of the microcapsules. Generally, single layer of shell is utilized to protect core and also the same layer works as release controller. Double-walled microcapsules also formulated with two-layer shell, and in these types of microcapsules, they are bound to the textile via thermoplastic layer. Complex microcapsules with three layers are also applied for thermal regulating textile materials (Choe et al., 2023; S. Zhang et al., 2022). The selection of shell and core materials for microencapsulation which can be applied on the textiles are encompassed in table 2.8

Table 2.8: Ingredient utilized for microcapsules

Shell	Core	Textile	References (Year)
Gelatin	Vitamin C	Cosmetic textiles	(Yuen, 2009)
PBA	*n*-hexadecane	100 % cotton 50/50% P/C blend	(Alay et al., 2011)
Dodecane	BSA + l-Cysteine (l-Cys)	Wound dressing	(Gouveia, 2012)
Ethyl cellulose biopolymer	*Citrus aurantifolia*	Antibacterial cosmetotextiles	(Julaeha et al., 2023)
Maltodextrin	*Citrus latifolia* essential oil	Antimicrobial textiles	(Van et al., 2024)
Chitosan/alginate	lime peel essential	Antimicrobial textiles	(Indriyani et al., 2024)

Chitosan	Epigallocatechin	Sanitary products	(H. Zhang et al., 2023)
Gum acacia	Coleus aromaticus	Mosquito repellent cotton	(Boominathan et al., 2022)
Polyvinyl pyrrolidone	Cholesteric liquid crystals	Intelligent fiber	(Guan et al., 2018)
Arabic gum	Moxa oil	Antibacterial textiles	(L. Li et al., 2013)
Chitosan	Quercetin	Sanitary napkin	(Dou et al., 2024)
N, N′-Methylene-bis (acrylamide)	*Citrus aurantium L*	Salt resistance Antibacterial Nonirritant	(P. Zhou et al., 2023)
Cellulose grafted with chitosan	Polypropylene	Sanitary Products	(Y. Wang et al., 2021)
Polyphenol	Nano-reinforced chitosan	Antioxidant	(Khanzada et al., 2024)

2.6 Application of pH-responsive polymers (super absorbent polymers – SAPs) in hygiene textiles

Polyacrylic acid, polyacryl amide, polyacrylonitriles and associated salt counterparts are cross linked for producing pH-responsive superabsorbent polymers (SAPs) (J. Chen et al., 2022). These polymers can absorb several hundred times their own weight in water, making them applicable across various industries, including hygiene items, sewage treatment, architecture, and agribusiness (Bashari et al., 2018; Oladosu et al., 2022; S. V. S et al., 2023). They also alter their state in response to differences in their pH of immediate environment. These substances are produced through the polymerization of acrylic acid or its substitutes, including acrylates of potassium or sodium, followed by cross-linking the resultant polymer with a organic cross-linker to create a three-dimensional structure composed of polymer chains (J. Chen et al., 2022). Raw materials for such polymerisation are easily available, and so manufacturing cost for the same is lower or effective. Moreover, these pH-responsive polymers in nature they are biocompatible and therefore they are harmless for practice in therapeutic and individual care products. Fundamental limitations of these polymers are that they can free residual monomers and cross-linker in very minor amount (Sonkaya et al., 2021). Disposal of the products which have been coated with pH-responsive polymers are problematic, as they are not biodegradable and involve in increasing environmental pollution.

Due to hydrophilic characteristic of pH-responsive SAPs, they attract commercial application in hygiene, wound dressing, agriculture, construction, etc. these SAPs are utilized in diapers, biocosmetic, and sanitary napkins, the products of sanitary and cosmetics industries (Bachra et al., 2020). Table 2.9 discuss the pH-responsive polymers and their application textile for achieving hygienic properties.

Table 2.9: pH-responsive polymers with their application textiles

Textile product	**pH-responsive entities**	**Hygienic property achieved**	**Sources (Year)**
Polypropylene	Poly (dimethylaminoethyl methacrylate) (PDMAEMA)	Reversible wettability	(T.-T. Li et al., 2022)
Polyester	PRBN based on 2-(perfluorobutyl)ethyl methacrylate (PBMA) and 2-Diethylaminoethyl methacrylate (DEAEMA), 2,2,3,4,4,4-hexafluorobutyl methacrylate (HFBMA)	Super wettable	(Jia et al., 2020)
Cotton	Carboxymethyl cellulose – co – acrylic acid and acrylamide	Biocompatible hydrogel	(Mondal & Rahman, 2024)
Cotton	Chitosan	Antibacterial hydrogel	(Trad et al., 2018)
Cotton	Starch – co – acrylic acid and acrylamide	Wettability Biodegradability	(Teli & Mallick, 2018)

Polypropylene	Carboxy methyl cellulose and cellulose	Antimicrobial Super absorbent	(Shibly et al., 2021)
Tempons	AgNPs/Chitosan/ Polyvinyl alcohol/ Polyethylene glycol	Wettability Antibacterial	(Bayat Tork et al., 2016)
Cotton Polypropylene	Cellulose – chitosan	Super absorbent	(Alam & Christopher, 2018)
Cotton Polypropylene	Sodium carboxymethyl cellulose (NaCMC) and starch	Super absorbent	(G et al., 2020)
Cotton	sericin/poly(N-isopropylacrylamide)/ poly (ethylene oxide)	Antibacterial	(J. Li et al., 2021)
Polyester	Poly(dimethyl amino methyl styrene-*co*-1H,1H,2H,2H-perfluorodecyl acrylate) (P(DMAMS-*co*-PFDA), PDP)	Antifouling Antiviral Antibacterial	(Song et al., 2021)
Polypropylene	sodium 12-methacrylamidododecanoate (NaMmD) and sodium 2-(acrylamido)-2-methylpropanesulfonate (NaAMPS) copolymer	Absorbent	(Teramoto et al., 2014)
Cotton	Chitosan Genipin	Biomaterial based smart textiles	(Miras et al., 2021)
Nanofiber	chitosan/poly(vinyl alcohol)/glycerol	Wound healing	(M. M. Gonçalves et al., 2022)

Cotton	Sodium carboxymethyl cellulose (CMC)–hydroxyethyl cellulose (HEC)	Mechanical strength Super absorbent	(J. Kang & Yun, 2022)
Disposable hygiene product	Silica particles and bentonite reinforced with carboxymethyl guar gum	Swelling Super absorbent	(Bachra et al., 2022)

2.7 The objective of the study

2.7.1 Research gap and motivation

The literature review predominantly examines thermo-responsive phase transition polymers. The research has focused on cotton and nonwoven materials, examining the impact of hydrogels, thermo-responsive polymers, and to a lesser extent, pH-sensitive polymers. They are commonly employed in biosensors, gene delivery systems, and medications. Polyelectrolytes pH-sensitive hydrogels with variable power operated by increasing their network mesh sizes, a phenomenon induced by the repulsive forces arising from the protonation or ionization of the polymers. Chitosan as a cationic polyelectrolyte operates efficiently in the stomach with the acidic pH.

Diapers available in the market for feminine vaginal use or for infants exhibit greater absorption; however, they still do not adequately address pH-related features. However, some are also thermo-responsive. Consequently, discomfort, rashes, and pH imbalance occur in females and infants.

The examination of fragmentation and the design of pH-sensitive polymers, utilizing microencapsulation techniques in textiles, may address the aforementioned issues. Additional experimental procedures and characterization of the pH-responsive materials are essential for the individual investigation.

The literature indicates that the polymers or hydrogels employed in textile applications are exclusively thermo-responsive materials. Furthermore, pH-responsive polymers are exclusively utilized for drug or gene administration, rather than for surface application on textiles. Particularly for feminine and infant hygiene products.

This project aims to develop a pH-responsive polymer suitable for microencapsulation in hydrogels, intended for use in textiles designed for hygiene products for women and infants. Additionally, to evaluate the produced product against traditional alternatives available in the market.

2.7.2 Objectives

1. Synthesis of pH-responsive polymers by diverse combinations of monomers.
2. Experimental investigation of the pH-responsive characteristics and characterization of the synthesized polymer.
3. Formulate microencapsulated phase change materials pH-responsive polymer employing either synthetic or natural polymers.
4. Apply the produced polymer to the fabrics used in the production of female and infant hygiene products.
5. Examine the characteristics of the product completed with the formulated polymer. Quality assessment of identical textiles for commercial use.

2.7.3 Methodology

1. Characterization of synthesized pH-responsive microencapsulated phase change material.
2. Examine the absorption capacity and pH sensitivity of the identical substance.
3. Implement the material as a surface embellishment on textiles through cushioning application.
4. To establish optimum conditions for the application and adhesion of the same material on textile hygiene products.
5. The data acquired from the experimental activities are analyzed and discussed.
6. Formulate the principle, mechanism, and functionality of the synthesized substance under various parameters and juxtapose it with empirical evidence.
7. Compare and corroborate the preparation and implementation methodology with empirical findings.

2.7.4 Anticipated results/ Rational for the work

- pH-responsive microencapsulated phase change material can regulate pH upon application to the diaper.

- The diaper may regulate pH levels, enhancing comfort for both the female and the infant when applied to the baby's diaper.
- Novel products and procedures may be devised for the fabrication of materials suitable for hygiene textiles.
- The created product may rival commercially existing products serving the same purpose in the market.

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