CHAPTER II

LITERATURE REVIEWS AND THEORETICAL CONSIDERATIONS

2.1 Natural rubber (Para rubber)

2.1.1 Natural rubber of latex

The fresh latex used commercially is obtained from the tree known botanically as Hevea brasiliensis. It is a milky white or slightly yellowish opaque liquid and contains a range of particles in an ambient serum (C-serum) with pH 6.9 approximately and varying viscosity. The chemical and physical characteristics of latex are influenced by clones of rubber, age of rubber, tapping intensity, soil characteristics and season of tapping.

Fresh latex can be separated into three main fractions by ultracentrifugation:

(1). the lighter top rubber phase with a small layer of the Free-Wyssling complexes below it.

(2). the C-serum phase.

(3). the more dense bottom fraction consisting of mostly lutoids and small amounts of other non-rubber particles (Cook and Sekhar, 1953 ; Moir, 1959).

The latex consists of rubber hydrocarbons which makes up 30-45 % of the whole volume. These particles are spherical or pear shaped with diameters ranging from 5 ^{o}A to 3 μm (Gomez, 1974). Each particle is stable due to a negatively charged surface which consists of protein and lipid component (Smith, 1953 ; Ho et al., 1976). The

rubber, contained within the particles, is non-water-soluble and predominantly cis-1,4-polyisoprene. Next group of particles are the lutoid with makes up to 10-20 % of the latex volume, of which the surface of particle is negatively charged, and contains fluid (B-serum) at pH 5.5. The B-serum are positive charges (Tata and Edwin, 1970). These particles are osmotically sensitive and are 2 μm to 5 μm in diameter. The last group of particles are Frey-Wyssling complexes with 4 μm to 6 μm in diameter. These particles are bright orange color due to the carotenoid inclusions within the complex (Dickenson, 1969 and 1965 ; Tata and Edwin, 1970) and causes the yellow color of some lattices.

Table 2.1 Composition of latex (Fong, 1992)

Composition	per cent
Rubber hydrocarbons	36.0
Water	58.5
Proteinous substances	1.4
Neutral lipids	1.0
Phospholipids	0.6
Ash	0.5
Inositols and carbohydrates	1.6
Other nitrogen compounds	0.3

The total protein content of fresh latex is approximately 1-1.5 % of which about 20 % is absorbed on the rubber particles and a similar proportion is associated with the bottom fraction. The remainder is dissolved in the serum fraction. Proteins influence in stress-strain and modulus of the vulcanised rubber.

The composition of rubber is an unsaturated hydrocarbon of varying high molecular weight, having the formula $(C_5H_8)_n$ where n is about 10,000 and C_5H_8 is the monomer isoprene. The arrangement of isoprene is cis (Figure 2.1), hence the chemical name of natural rubber is cis-polyisoprene.

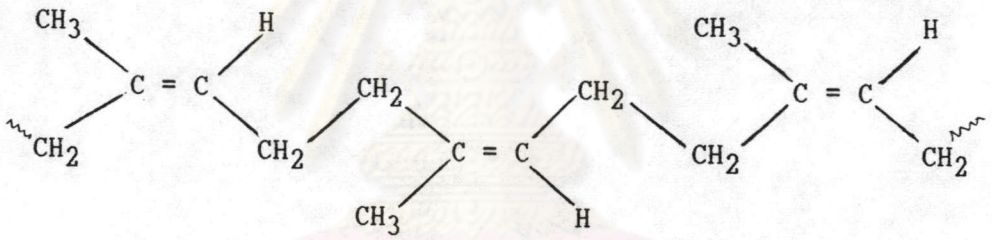

Figure 2.1 The chemical structure of Hevea rubber

Molecular weight (Mw) and molecular weight distribution (MWD) are inherent properties of the polymer mass. The range of molecular weight of Hevea rubber always falls between 3×10^4 and 10^7, and the high molecular weight peak appears at $1\text{-}1.25 \times 10^6$ and the low molecular weight peak at $1\text{-}2 \times 10^5$, there are great variations in the average molecular weight between rubber of different clone. (Table 2.2)

Table 2.2 Average molecular weight (Mw), number average molecular weight (Mn), Mooney viscosity and molecular weight distribution of some clonal rubber. (Subramaniam, 1975)

Clone	Mw x 10^{-6} (from GPC)	Mn x 10^{-5} (from GPC)	Mooney viscosity ML(1+4 min) 100 ^{0}C	Type of MWD * curve
RRIM 600	1.93	2.58	72	2
PB 28/59	2.15	5.20	87	3
PB 5/51	2.18	5.21	94	3
GT 1	1.85	2.65	79	2

(* See Figure 2.2)

Similarly, the molecular weight distribution also varies widely with the ratio of Mw/Mn range from 2.5 to 10, and a typical value for a low molecular weight is nine. There are three different types of MWD as shown in Figure 2.2.

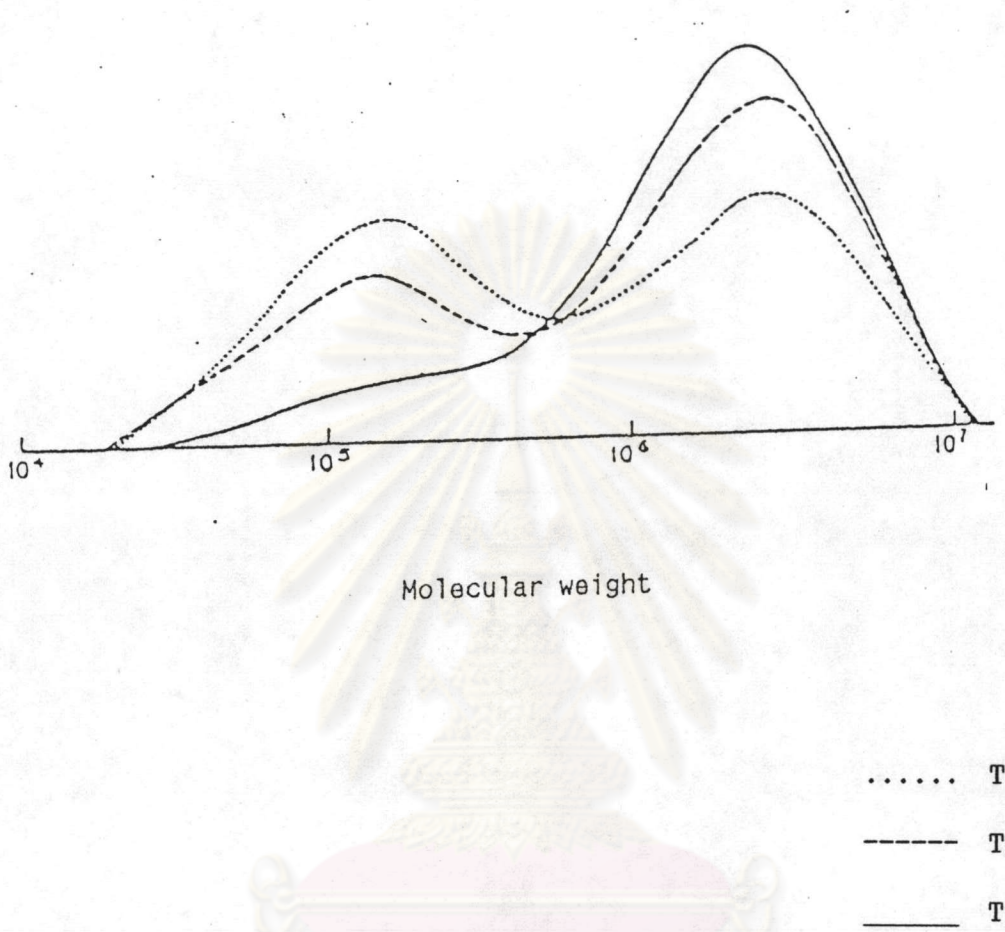

Figure 2.2 Types of molecular weight distribution curves of natural rubber (Subramamium, 1980)

Type 1 : Distinctly bimodal distribution where peaks are of nearly the same height.

Type 2 : Distinctly bimodal distribution where the peaks in the low molecular weight region is small.

Type 3 : A skewed unimodal distribution with a 'shoulder' or 'plateau' in the low molecular weight region.

2.1.2 Rubber particle stabilization

The rubber particle is stabilized because the surface of particle is surrounded by a layer of proteins absorbed which carry negative charges, and proteins are hydrophillic substances. Then there is an envelope of water molecules surrounding the rubber particle. These water molecules, acting as a sheath, prevent direct contact between particles. Stability of natural rubber has two aspects, mechanical and chemical stability. Mechanical stability is the capacity of latex to withstand mechanical agitator, transportation and processing, whereas chemical stability is concerned with the property of latex to maintain the colloidal characteristics. Chemical destability agent are acid, matallic, organic solvents etc. The stability of latex can be increased by adding the external chemical agent which are classified as ionic (anionic, cationic and amphoteric) and nonionic.

To increase the stability of latex for this study, chemical stabilizing agent (ammonia solution and Triton X-100) was added. Ammonia, which has been used as a preservative is an alkali, not particularly harmful, has no effect on rubber, no deposits and can easily be deammoniated. It increases the pH of latex then inhibits bacteria growth, sequesters some metallic ions and deactivates the carbohydrates which act as an enzymatic substates forming fatty acid anions, resulting in the increasing of stability. Triton X-100 (Iso-octyl phenoxypolyethoxyethanol, Nonidet P-40) is nonionic detergent which has the capacity to solubilize proteins and also stabilize the colloidal state of rubber particles (John et al, 1977).

2.1.3 Coagulation of latex using steam

Latex can be auto-coagulated and complete coagulation in about 48 hours by the action of bacterial and yeasts on indigenous substrates and produced acid (John 1966a and 1966b). There is disadvantage to rubber process due to time-consuming. Coagulation of field latex with acid must take 2-4 hours to yield complete coagulation. To reduce coagulation time, the coagulation of latex using steam was investigated. John and Sin (1974) have experimented a method of coagulation latex with steam. They found that complete coagulation (clear serum separating from the coagulum) was obtained by steaming with 1 kg/cm^2 pressure maintained for 10 minutes at a depth of latex up to 4 cm. and range of DRC in 5 - 40 %. The yielded of rubber from steam coagulation was about 2 % higher than that from acid coagulation.

2.2 Solid natural rubber

2.2.1 Gel content

Hevea rubber contain a gel which is insoluble in rubber solvent ; depending on clone of rubber. This phase consists of microgel and macrogel, which cause an increased in the bulk viscosity of the rubber. Microgel (about 1-47 %) causes crosslinking between rubber molecules within the rubber particles (Freeman, 1954), while the macrogel (about 2-17.5 %) is associated with storage hardening of dry rubber (Wood, 1952). Freeman has shown that rubbers with high microgel content and macrogel content have higher bulk viscosity, but bulk viscosity is independent on macrogel content at level lower than 5 %.

2.2.2 Storage hardening

The increase in the bulk viscosity or the arise of stiffening in rubber during manufacture, shipping and storage is known as storage hardening and the viscosity can rise by 10-40 Mooney unit. The reaction of hardening occurs due to the crosslinking between rubber molecules in main rubber chain (as indicated by the increase in Mooney viscosity) involving the aldehyde or carbonyl group in the rubber molecules (Bloomfield, 1951 ; Sekhal, 1961 and 1962) and aldehyde group in the non-rubber phase, including some amino acid (Subramaniam, 1975 ; Sekhar, 1962 ; Gregory and Tan, 1976). The variation of viscosity is due to many factors, clonal rubber, average molecular weight, microgel and gel content and non-rubber constituents.

There are advantages to control the viscosity in consumer's factory by easier milling , pre-mastication saving, consistency of compound vulcanization and stock storage. The inhibition hardening is produced by adding mono-functional amines or carbonyl condensing reagent. Chin (1969) reported that hydroxylamine hydrochloride at 0.15 p.h.r. was suitable to stabilized viscosity due to availability, low cost, compatibility with latex. It functions by blocking the crosslinking sites in the rubber molecules and this restricts the rise in viscosity of rubber.

For production, the rubber can be divided into three arbitrary ranges among with Mooney viscosity, soft (with a ML 1+4' of less than 50), medium (with a ML 1+4' between 50 and 75) and hard (with a ML 1+4' of higher than 75). It is advantageous to produce rubber with different viscosity range for different CV grade.

2.2.3 Discoloration of natural rubber

The color of latex is a clonal characteristic. The rubber clone, PB 28/59 has yellow latex but RRIM 600 have white latex. The color of rubber latex is due to non-rubber constituents, carotenoid pigments which is the cause of yellow color of some lattices (Nadarajah and Karunaratne, 1971). These were many factors causing discoloration of latex and rubber e.g. season, tapping, rubber processing, chemical etc. The enzymatic action was one of the factor which caused the discoloration. Spence (1908) has reported that oxidizing enzymes, namely oxidase and peroxidases in latex. These enzymes catalyse the action of oxygen and peroxides on certain of its ingredients. Through their activity, coagulated rubber when exposed to the air, developed a greyish or purplish color. The color substance does not affect the properties of the rubber, but the discoloration is objectionable in the manufacture of light color rubber. This type of discoloration was prevented by adding of sodium metabisulphite at 0.05 p.h.r..

2.3 Deproteinized natural rubber

The removal of protein from natural rubber has been well-known. The absorbed proteins were known to adversely affect the dynamic properties of rubber (Smith, 1974). Then low protein rubber improved the technology and dynamic properties. The rubber with low protein content has been known as Deproteinised Natural Rubber (DPNR) or sometimes Low Nitrogen Natural Rubber (LNNR).

There were two methods which have been successful for removal of proteins from latex, chemical hydrolysis (alkaline hydrolysis) and enzymatic hydrolysis. Chemical hydrolysis, the protein can be removed

by soaking the coagulum rubber in NaOH solution for 24 hours (Yapa, 1977), but it adversely affects the oxidative resistance. For enzymatic hydrolysis, the proteolytic enzymes have been used such as Alcalase, Bacterial Protease Novo (BPN), Esperase, Papain, Bromelain or pineapple juice, Superase and Trypsin. These enzymes breakdown the naturally occurring proteins into water soluble products (peptides and amino acids) that was washed away during manufacture of raw rubber.

The basic steps in the manufacture of low protein rubber by enzymatic hydrolysis are,

(1) latex (either field or concentrated, with or without a surfactant or with little or substantial dilution with water) is treated with enzyme.

(2) the treated rubber is left for breakdown of protein.

(3) the digested rubber is coagulated by the enzyme itself such as papain and pineapple juice or by adding acid, then the coagulum can be processed into any form of rubber desired, block rubber, crepe rubber or sheet rubber.

For enzyme digestion, the most popular enzymes used in commercial manufacture of low protein rubber are papain in Sri Lanka and superase in Malaysia. Papain treatment latex can be done on field latex hence comparatively less expensive and do not required additional acid for coagulation, whereas the ammoniated latex/superase treatment required additional acid for coagulation of latex, hence more expensive.

2.3.1 The development of DPNR

In 1955, Firestone Plantations used alkali treatment to break down the protein in spontaneous coagulation of skim latex. The

coagulum was then milled to a crumb and soaked in a solution of lime followed by sodium hydroxide solution. This method can reduce nitrogen content for about 35 %.

In 1971, John produced latex rubber with less protein. He obtained a rubber with about 30 % less nitrogen than acid coagulated rubber by treating field latex with di-octyl sodium sulphosuccinate and an anionic surfactant at neutral pH.

In 1975, Yapa has a preparation of low nitrogen content constant viscosity rubber. The chemicals such as hydroxylamine sulphate, hydroxylamine hydrochloride, semicarbozide hydrochloride were used to stabilized viscosity. In the experiment, he started from field latex which was diluted (1:1) with water and papain (0.05 % on volume) was added as a suspension in water followed by stabilized chemical solution (0.08 % on volume). The latex was left overnight for the enzyme to act on the latex proteins. He found that papain and hydroxylamine were suitable for the manufacture of low nitrogen CV-rubber and reduced nitrogen content for about 40 %. In the other method, the coagulum papain treatment was soaked in stabilized chemical.

In 1977, Chang, Lau and Nambiar had a preparation of viscosity stabilized DPNR from clarified field latex. The clarified latex was added with 10 % solution of sodium metabisulphite (0.05 p.h.r.) and hydroxylamine neutral sulphate (0.15 p.h.r.) followed by adding 10 % solution of potassium naphthenate and 2.5 % solution of the enzyme alcalase or superase. The enzymolysis was carried out in a tank with a slow-speed stirrer for at least 24 hours. Then the treated latex was diluted to 3 % total solids and coagulated with 2 % mixture of equal

parts by weight of phosphoric and sulphuric acids. The nitrogen content was 0.12 %.

In 1977, John, Nadarajah and Chan prepared DPNR by papain treatment and surface active agent, Nonidet P-40.

In 1977, Yapa had prepared DPNR and CV-DPNR by difference proteolytic enzymes. Field latex was diluted to 1:1 with water and papain was added (0.05 % w/v). In the case of BPN, TPN or superase, enzyme concentration (0.1 w/v) were used. Latex was coagulated on leaving overnight and the coagulum was granulated and soaked for 24 hours in a solution of 1 % NaOH. Rubber was then removed from the alkali solution and washed in running water and soaked in fresh water overnight with several change of water. Next the rubber was soaked in solution of 1 % oxalic acid overnight and washed with water. For CV-DPNR, hydroxylamine hydrochloride was added before enzyme treatment. He found that papain is the best enzyme to remove proteins and alkali treatment after enzyme treatment reduced protein higher than the only enzyme treatment.

In 1978, Yapa et al prepared DPNR from skim latex. Skim latex was creamed with sodium alginate and ammonium oleate for 24 hours. The creamed latex was diluted 1:1 with water and mixed with fresh latex 1 : 1 and diluted with water 1 : 1 again. The mixed latex was coagulated with papain (0.08 w/v).

In 1980, Yapa et al. prepared DPNR from field latex by pineapple juice (PAJ) treatment. In this method, field latex was diluted with water (1:1) and added pineapple juice or bromelain. The rubber was left overnight for coagulation.

In 1992, Visessanguan prepared CV-DPNR from fresh latex and concentrated latex by enzyme treatment. Processing of DPNR from fresh latex, latex was added with 0.9 p.h.r. of Triton X-100 and then diluted to 25 % DRC at pH 7-8 with water, ammonia solution and chemicals (hydroxylamine hydrochloride and sodium metabisulfite). The latex was treated with papain 0.3 p.h.r. with shaking at 50 ^{o}C for 2 hours and then was coagulated with steam. The nitrogen reduction was 70-75 %. For concentrated latex 60 %, ammonia was evaporated from latex and the latex was diluted to 25 % DRC with water and chemicals. The latex was adjusted to pH 8-9 and treated with alcalase 0.3 p.h.r. in shaker at 50 ^{o}C for 10 hours. The treated latex was diluted to 5 % DRC and coagulated with 2 % mixture of sulfuric and phosphoric acids. The coagulum was dipped in 2 % thiourea solution. In this method, nitrogen can be reduced by about 70-75 %.

The low nitrogen content rubbers produced by differect method were summarized in Table 2.3.

Table 2.3 Developments in manufacture of low nitrogen rubber

Method of manufacture	Reference
Skim latex/NaOH	Firestone Co., 1955
Skim latex/sodium sulfosuccinate/calcium chloride	John and Sin, 1973
Field latex/papain	Nadarajah et al, 1973
Latex concentrate/superase	Chin and Smith, 1974
Skim latex/NaOH/oxalic	Ong, 1974
Skim/trypsin	Ong, 1974
Field latex/papain/$NH_2OH.HCl$	Yapa, 1975
Clarified latex/superase	Chang et al, 1977
Clarified field latex/superase/Hydroxylamine neutral sulphate	Chang et al, 1977
Field latex/alkali	Yapa, 1977
Field latex/BPN/alkali/$NH_2OH.HCl$	Yapa, 1977
Field latex/papain/alkali	Yapa, 1977
Field latex/papain/alkali/$NH_2OH.HCl$	Yapa, 1977
Field latex/superase/alkali/$NH_2OH.HCl$	Yapa, 1977
Skim latex/papain	Yapa et al, 1978
Field latex/pineapple juice	Yapa et al, 1980
Field latex/papain	Yapa, 1984
Field latex/pineapple juice	Yapa, 1984
Field latex/papain	Visessanguan, 1992

2.3.2 Properties of DPNR

The properties of DPNR produced at the Rubber Research Institute of Malaysia (RRIM) since 1977 were given in Table 2.4. The nitrogen and ash values should be below 0.15 % weight.

Table 2.4 Specifications of DPNR

Properties	DPNR from latex concentrate	DPNR from clarified field latex	Proposed specifications
Dirt (%wt)	0.006	0.005	No test value > 0.015
Nitrogen (%wt)	0.066	0.12	No sample > 0.12 on test
Ash (%wt)	0.052	0.13	No sample > 0.15 on test
Volitile matter (%wt)	0.28	0.25	No value > 0.5
Initial plasticity (P_0)	39	32	–
Plasticity Retention Index (PRI)	66	85	60 (min)
ΔP ($P_H - P_0$)	–	7	No value > 9 on test
Mooney viscosity	–	51	45–55 55–65

Although latex contains less non-rubber ingredients, but it influences on the properties of rubber. The dynamic performance of rubber is of great importance. The variation in the dynamic and related properties of rubber is associated with non-rubber content, particularly proteinaceous material. The proteins are known to

adversely affect the dynamic properties of rubber as they have polar and hydrophilic characteristics (Smith, 1974). Removal of proteinaceous material improves the dynamic and technological properties, particularly the heat-build up (Knight and Tan, 1975). The improved heat performance of low protein rubber makes it highly advantageous in tyre manufacture especially in heavy duty tyre such as air craft, where the heat-build up is very high. The other advantageous of DPNR are low affinity for water due to removal of naturally occuring hydrophilic substance, enchanced resistance, reduced creep, superior fatigue lift, uniformity in cure behaviour (Bernard, 1973), light color and resistance to mold growth. The treated rubber can be stored for long time (Anandan and Longanathan, 1984). For this reason, it has many advantages in the field of engineering applications. A number of people are in contact with latex and latex products. There is a report that proteins in Hevea latex has been suggested as a possible allergic (Leynadier et al., 1989 ; Turjanmaa et al., 1988). The DPNR was suitable for medical applications.

2.4 Theoretical considerations

2.4.1 Enzyme-catalysed reaction

Enzyme are proteins with large number of amino acid residues linked together in a specific sequence. The protein does not normally exist as an extended polypeptide, but is coiled or folded. The reaction by enzyme occurs in the area of catalytic active which is called active site. Enzyme required the presence of a small amounts of chemical agents to start the catalysed reaction. These chemicals

are called co-factor (metal ions, more complex organic molecules or proteins). The purpose of co-factor is usually to supply a specific chemical function that is not possible with the enzyme alone. The difference between enzyme and inorganic catalysts are;

(1) the rate of an enzyme-catalysed reaction is usually faster than the same reaction catalysed by non-biological catalyses.

(2) enzyme are very specific and one enzyme will usually catalyse only one particular type of reaction under very limited chemical and physical condition.

(3) there existed a vast number of enzymes each catalysing a specific reaction which frequently form links in a metabolic pathway.

The enzyme-catalysed reaction involves two steps;

(1) the reversible, rapid combination of enzyme (E) and substrate (S) to form a complex (ES).

(2) the breakdown of ES to give product (P) and regenerate free enzyme. The kinetic model is given as

$$E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES \xrightarrow{k_2} E + P$$

Effect on the rate of enzyme-catalysed reaction

pH Some effect of reaction on changing in pH due to changing in the ionisation of group involved in the catalytic mechanism may completely disrupt the mechanism, changing in the groups involved in the bonding site may reduce the affinity of the enzyme for the

substrate and hence lead to reduction in catalysis, changing in the state of ionisation of group in the substrate may due alter its affinity for the enzyme, changing in the ionisation of other groups in the enzyme may cause minor or even major and changing in the three-dimensional structure of the enzyme causing disruption of the active site.

Temperature The variation in the rate of a chemical reaction can be discribed by the Arrhenius equation (Stauffer, 1989). The frequency with which molecules in homogeneous solution collide depends upon their concentration (collision frequency = Z[E][S] where Z was a constant normalizing to unit time and unit volume). Formation of a reaction product [ES] depended upon the probability (p) that the colliding molecules had the proper orientation (substrate must contract that part of enzyme which comprised the active site) and also upon the presence of sufficient energy to enable the reaction to occur. This minimum energy was called the activation energy, E_a. From the Maxwell -Boltzman law the fraction of collisions which entail at least this much energy was proportional to exp $(-E_a/RT)$. The rate at which ES formed by collision of E and S was:

$$\text{rate} = k_1[E][S]$$

and

$$\text{rate of productive collisions} = pZ[E][S] \exp(-E_a/RT)$$

so by comparison, the Arrhenius equation arrived

$$k_1 = pZ \exp(-E_a/RT)$$

This may be linearized by taking logs, substituting the more usual k_o for the constants pZ, and noting that k was the specific reaction rate constant for any rate.

$$\ln k = \ln k_o - (E_a/R)(1/T)$$

The plot of ln k versus 1/T was (usually) linear with a slope of $-E_a/R$ (Figure 2.3).

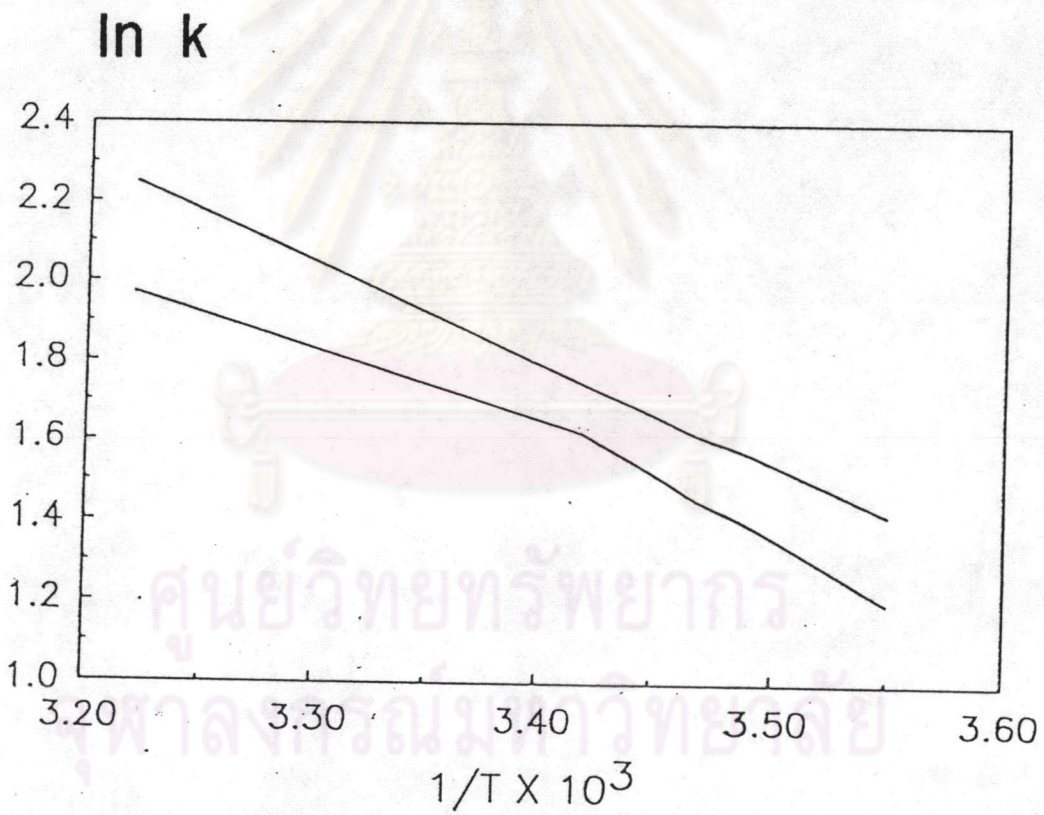

Figure 2.3 Arrhenius plot

The Arrhenius plot is generally linear over the temperature range of interest, occasionally plots are found which bend in the middle. This is often due to a change in the rate-limiting step of sequential reaction. From the Arrhenius equation, it can be seen that an increase in temperature will obviously lead to an increase in the rate of reaction by the rate constant, k. When the rate of an enzyme-catalysed reaction, it appeared to exhibit a maximum and at higher temperature the rate of reaction fell rapidly (from Arrhenius plot, the plot broke sharply, giving a positive slope on the left side). This maximum is not predicted by Arrhenenius equation so there must be another process involved which has a negative temperature. This process is denaturation of enzyme. The denaturation of the enzyme by temperature is due to (Roberts);

(1) A reversible structure change may take place in the enzyme, the change can alter the conformation of the active site and hence change the energy requirements for the catalytic step.

(2) The rate limiting step in a consecutive or sequential system involving two or more enzymes may alter as the temperature changes because of different enthalpies of activation for the individual enzyme-catalysed steps in the overall mechanism.

(3) An enzyme may undergo reversible dimerisation or polymerisation into other action form, the reaction catalysed by the latter may have completely different entropies and enthalpies of activation.

2.4.2 Enhancement of deproteinization by agitation

In a suspension system, the particles are dispersed in a solution. The actions of impeller are, (1) to disperse the particles

and enzyme, and (2) to circulate the suspension around the tank for the heat transfer from the jacket.

An agitated tank presents a very complex fluid mechanical system. For any particular design of agitator, there exists a region where turbulence is most intense. In this region especially, mechanical energy is transmitted and transformed into kinetic energy in the eddies. It follows that an impeller may be characterised by its ability in creating a highly turbulent zone. Compared with the average level of turbulence in the vessel, $\bar{e}$, the maximum level of turbulence developed, e, can be described by a turbulence intensity factor (Tasakorn, 1977) :

$$\theta = e/\bar{e}$$

The average power input per unit mass e is given by

$$e = P/\rho V$$

where P is the power input to the liquid

V is the volume of the liquid

With the same impeller/tank geometry, the turbulence intensity factor in a baffled vessel may, to a first approximation, be regarded as constant characteristic only of the type and geometry of the impeller. In the case of unbaffled vessels, however, the turbulence intensity factor is affected by the agitation condition. Owing to the formation of the forced vortex. The head developed as the impeller

speed is increased may interfere with the formation of vortices behind the blades and the turbulent field. It has therefore been proposed that the empirical expression,

$$\theta = aRe^{b}$$

where $Re = \rho NL^2/\mu$

may be applied to unbaffled vessels. The constants a and b are characteristic properties of the impeller and tank geometry only. The turbulence intensity factor for a paddle in an unbaffled vessel ($10^3 < Re < 10^5$) may be calculated using a = 1.1, and b = 0.55.

Rubber particles consist of long length of the polyisoprene chain and non-rubber such as proteins and lipid. The proteins are adhered on the rubber particle or between the polyisoprene chain. The proteins adhered to the rubber particles is easily removed by papain because it is on the surface of the particles. But the proteins between the polymer chain is difficult to remove due to the slow diffusion of papain into the interior of the particles (Figure 2.4).

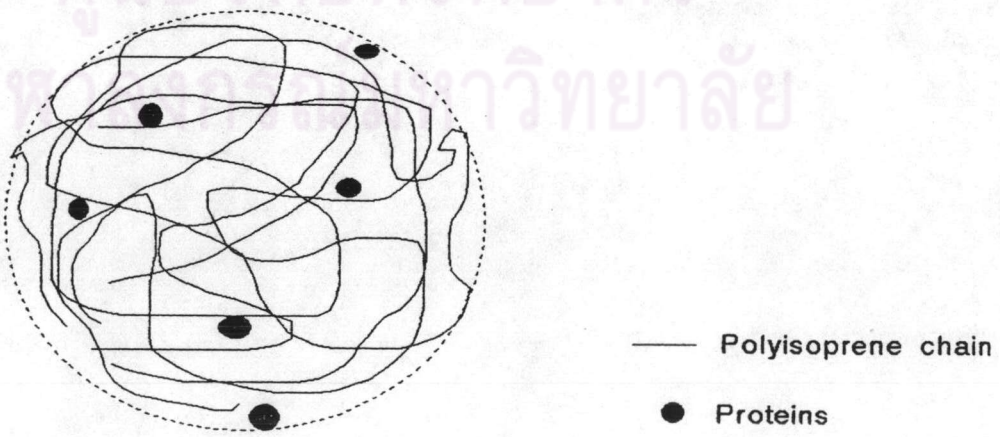

Figure 2.4 Rubber particle

In agitation tank operating at high Reynolds number, turbulence is generated. Under the condition of extremely high energy input, the energy containing eddies with similar size range as latex particles will transmit kinetic energy to the particles. As a result, the polymer chain will move and proteins will be exposed to the enzyme. Reaction will be enhanced (Figure 2.5).

Higher value of turbulence intensity factor indicates smaller sizes of energy containing eddies. Therefore, the removal of proteins will be greatest at a certain value of Θ.

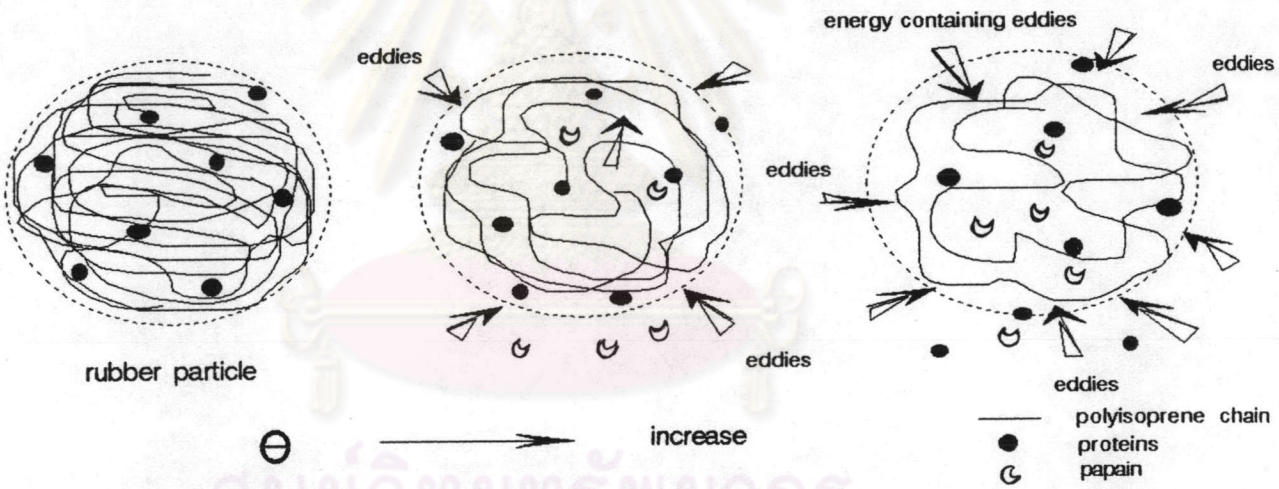

Figure 2.5 Effect of Θ on deproteinization