# AUTOMATING THE LATEX FRACTIONATION PROCESS IN THE CREPE RUBBER INDUSTRY

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree
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# Declaration

I hereby declare this thesis/dissertation is my own work and this does not include any content previously submitted for a Degree or Diploma in any other University or Institute of higher learning without acknowledgement and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future work (such as articles or books).

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Name of the Candidate: V.H Athukorala

Registration No: 178675 B

The above candidate has carried out research for the Master's thesis/dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of the Supervisor 1: Prof. A.G.B.P Jayasekara

Signature: Date:

Name of the Supervisor 2: Dr. H.H.M.P Rathnayake

Signature: Date:

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# Abstract

Sri Lanka is the largest manufacturer and exporter of natural Crepe rubber which is one of the purest forms of natural rubber manufactured. Crepe rubber should be manufactured in clean hygienic and controlled conditions in order to maintain its pale color and hardness in the final product. Since the inception of the Rubber industry in Sri Lanka in 1876, there hasn't been much of a development in the manufacturing processes. We still rely on the mechanisms that the British introduced in the colonial era. The initial stage of manufacturing is called rubber fractionation, a process that is specific to crepe rubber production which is done to remove the impurities in the natural rubber latex. This process includes dry rubber content measurement, standardization (dilution to the standard) of the latex, addition of sodium bisulphite/metabisulphite and agitation for around 2 hours. These are high labor-intensive tasks and when closely observed many inefficiencies and health hazards for those who are involved could be identified. Also, the labor shortages have been a major bottleneck in the crepe rubber manufacturing process.

The objectives of the project are increasing the efficiency and output yield by reducing the process time and wastage of latex and also minimizing the human involvement in the fractionation process hence reducing the health hazards faced by the employees involved. To achieve these objectives firstly, a more efficient and reliable dry rubber content measurement method that enables high precision standardization and chemical dosing are proposed as an alternative to the current measurement using the metrolac. Then an automated solution is proposed through a working demonstration of a prototype to perform the current manual tasks of standardization, chemical dosing, agitation and determining the process end. The prototype enabled the entire fractionation process to be performed in much lesser times than the observed processes in the manufacturing facilities with higher accuracies in standardization and chemical dosing. Hence suggested improvements are proved viable to be implemented in the manufacturing facilities which will give the manufacturers a high output yield, reduce rubber wastages and enable compliance with export standards in the final crepe sheets. The ultimate goal of this study is to make a contribution to the development of the Crepe rubber industry in Sri Lanka.



**Keywords**: Crepe rubber, Dry rubber content, Fractionation

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# List of Abbreviations

| Abbreviation | Description |
|---|---|
| BS | British Standard |
| DRC | Dry Rubber Content |
| ISO | International Organization for Standardization |
| LDRC | Laboratory measured dry rubber content using ISO/BS method |
| MDRC | Metrolac measured dry rubber content |
| Metro_E | Standard existing metrolac ready-reckoner chart |
| Metro_N | Temperature corrected metrolac ready-reckoner chart |
| RRISL | Rubber research institute of Sri Lanka |
| RSS | Ribbed smoked sheet rubber |
| TS | Total Solid |
| TSR | Technically specified natural rubber |

# 1. INTRODUCTION

## 1.1 Crepe Rubber Industry

The inception of the rubber plantation industry in Sri Lanka was in 1876 which started with the planting of 1,919 rubber plantlets during the colonial era. Since then the industry grew and added a significant contribution to the global rubber industry and currently, Sri Lanka is the 7th largest rubber manufacturer in the world [1].
Latex crepe rubber is one of the purest forms of natural rubber currently manufactured and traded in the rubber industry and it is produced by coagulating natural field rubber latex. Sri Lanka is the world's leading producer and exporter of premium latex crepe rubber. This rubber type is also known as pale crepe because of its white colour. Crepe rubber is an essential raw material for dry rubber-based products, in particular non-black applications, pharmaceutical and surgical appliances of rubber and rubber products in contact with food [2]. Figure 1 shows the outer appearance of finished crepe rubber sheets.

Figure 1 : Outer appearance of Crepe rubber Sheets

Sri Lankan Crepe Rubber is exported both in the raw & value-added form. Higher quality in Crepe rubber when compared with other types of rubber has given a considerable demand in the international market regardless of the high price it carries. The final product is graded based on its color and strength. From annual rubber production in 2018, crepe rubber production was nearly 14.5 million kilograms in the forms of sole crepe, scrap crepe, and latex c crepe. This accounted for around 12% of the total rubber production in the country [3]. Crepe rubber exportation leads the natural raw rubber exports in Sri Lanka whilst Technically Specified Natural Rubber (TSR) along with RSS Rubber are the other main contributors. The average export value share of crepe rubber is 66% while RSS rubber had a share of 19% between 2014 and 2019 [4].

### 1.1.1 Types of Crepe Rubber

Subject to the density, thickness, and amount of contamination, crepe rubber is categorized into many grades. To name a few Latex Crepe No.1X, Latex Crepe No.1, Latex Crepe No.2, Latex Crepe No.3, Latex Crepe No.4, Scrap Crepe (Brown) No.1, Scrap Crepe (Brown) No.2, Scrap Crepe (Brown) No.3, Scrap Crepe, (Brown) No.4, Flat Bark and Skim Crepe [2].

### 1.1.2 Important Stages in Crepe Rubber Manufacturing

Crepe rubber is manufactured under clean, hygienic, and carefully controlled conditions in order to obtain its quality in the final product. The manufacturing takes around 2-3 days to complete a batch of sheets [2]. Figure 2 illustrates a block diagram of the crepe rubber manufacturing process.

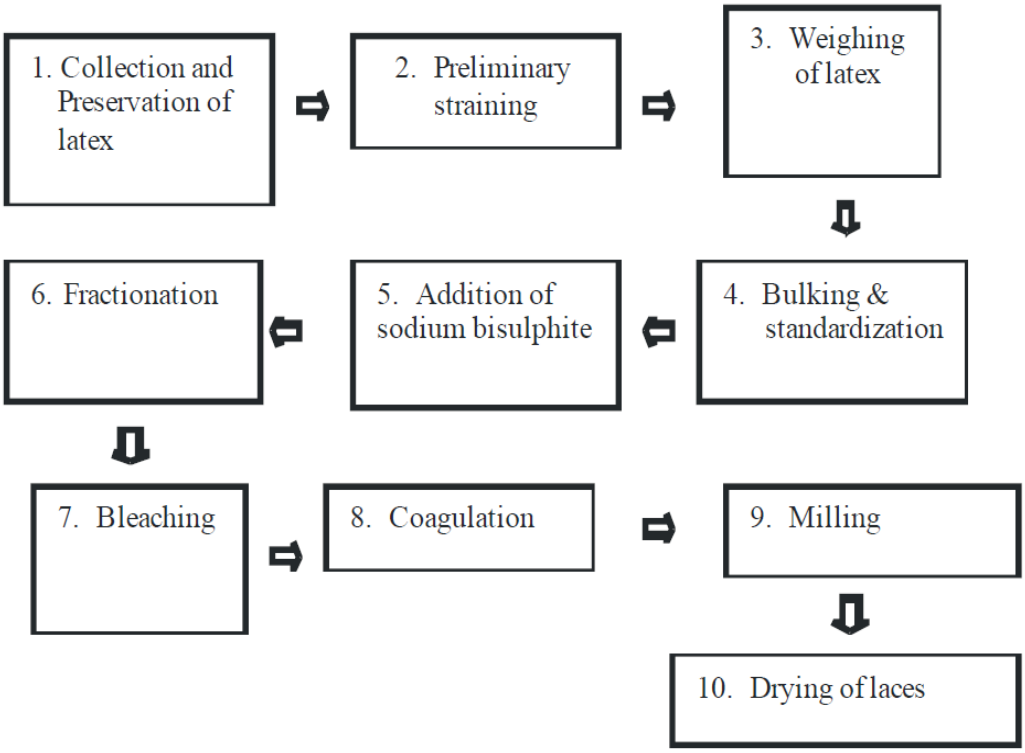


Figure 2 : Crepe rubber manufacturing process *[2]*

### 1.1.3 Declining Production Volume for Natural Crepe rubber

Despite the consistently high demand for natural crepe in the international market, the production volume is on a decline in Sri Lanka. As per industry expert insights, labor shortages, high wage rates (compared to other agro-industrials), decreasing plantation lands, low productivity and increase in the cost of production are identified as the main reasons for the decline [5]. Figure 3 indicates a gradual decline in the latex crepe rubber production volumes (in metric tonnes) in Sri Lanka from the year 1980 to 2018.

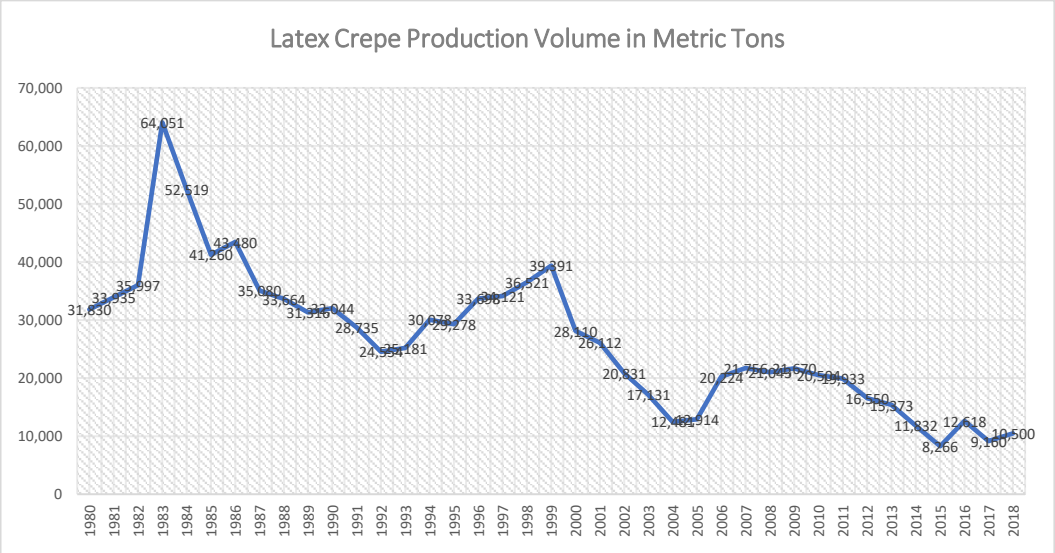


Figure 3: Latex Crepe production in Sri Lanka from 1980-2018 *[6]*

## 1.2 Fractionation Process

Fractionation is a process carried out to remove the non-rubber constitutes from the field latex. This is the initial process once the latex is transported to the factory from the collection centers to remove the Impurities from the natural latex before further processing. The fractionation process includes steps 4 – 6 in Figure 2.
The process recommended by the RRISL is summarized in Figure 4 and is described in detail in the next chapter.

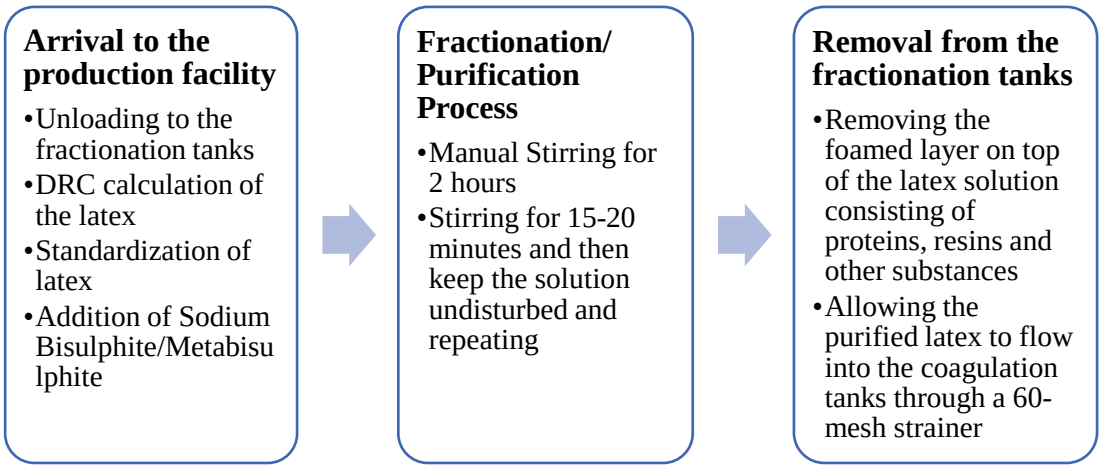


Figure 4 : Rubber fractionation Process *[7]*

### 1.2.1 Importance of Fractionation Process

Fractionation is a specific process that is only followed in crepe manufacturing in order to remove non-rubber constitutes from natural latex [2]. It improves the purity of the rubber by;

1. Making the latex free from yellow pigments
2. Preventing the tendency of the latex to undergo enzymatic discolouration
3. Making the latex free from amines, phenols, or other composites which can discolor the final pale crepe

Figure 5: Froth that start forming on top of the latex (This contains non-rubber constituents including carotenoids and other pigments in the field latex)

### 1.2.2 Issues in the fractionation Process

**High labour dependency**

Due to the inefficiencies and high labour dependency in the production process, the manufacturers often fail to meet the demand requirements and export standards [1]. A main problem in the current process is the significant health hazards involved in the initial stage mainly due to the exposure to harmful chemicals. Due to this reason, the laborers are disinclined to work in the industry, and this has been the bottleneck in the production process as per the leading rubber manufacturers in the country.

**Health Risks faced by laborers involved**

The inhalation and exposure of ammonia, Sulphur for prolonged periods can cause irritation in the respiratory system, eye injury, conjunctivitis; skin irritation/ulcer,

sensitization dermatitis and can even cause cancer in the skin and respiratory system. Figure 6 and Figure 7 illustrate the possible health risks and an instance an employee is in direct contact with rubber latex mixed with many chemicals such as sodium bisulfite, formic acid, and bleaching agents.

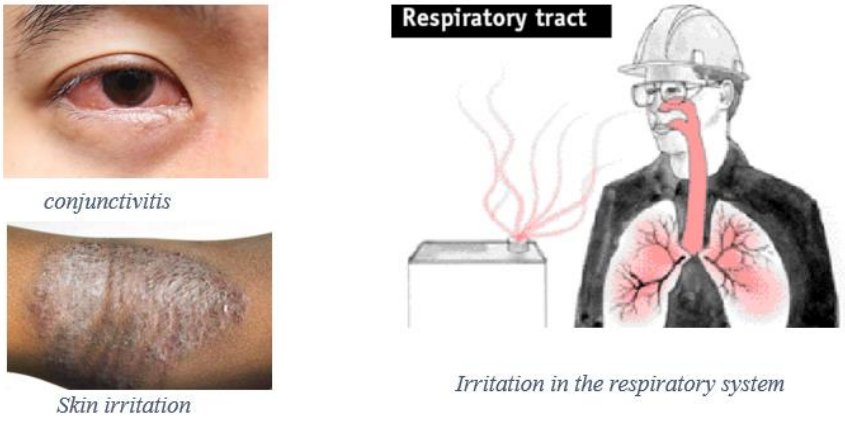


Figure 6: Health complications due to exposure to harmful chemicals

Figure 7: Laborers in direct contact with chemicals

## 1.3 Aim and Research Objectives

This project aims to overcome the issues discussed above in the fractionation process and thereby contribute positively to the declining crepe rubber industry.

### 1.3.1 Research Objectives

To Improve the current fractionation process by researching new methods in:

- Accurate Dry Rubber content measurement
- Accurate detection of the process completion
- Automating the process

And thereby,

- Achieve precise standardization and chemical dosing
- Increase the quality of the processed sheets while minimizing wastages
- Minimize labour dependency for the process thereby preventing the health risks faced by the laborers
- Reduce the fractionation process time

## 1.4 Chapter Outline

### 1.4.1 Introduction

The first chapter discusses the foundation and basis of this research and the related industry gap that is investigated and addressed. The research problem will also be highlighted. The study will identify the effects of the research problem and investigate the ways to mitigate the issue by exploring distinctive proof. The objectives of the research study will be clearly mentioned in Chapter 1.

### 1.4.2 Review of Literature

This chapter investigates and cites well-known studies done regarding the focused process of fractionation and related aspects. Firstly, the current and existing production procedures are analyzed in-depth to identify the room for improvement. The significance of this chapter is to explore what different approaches are used in the rubber industry and related industries to identify the critical parameters in crepe rubber manufacturing. The viability of using such approaches in the existing rubber manufacturing facilities is then discussed.

### 1.4.3 Improving the fractionation process of the crepe rubber manufacturing

The approaches and the particular implementations used to achieve the research objectives are being discussed in this chapter. The conceptual framework will be disclosed and the research methodology in detail will be discussed. The construction

of the prototype environment to perform the automated and improved fraction process is being discussed as well. This chapter also presents the observations acquired through the methodology. The observations and results are then interpreted and discussed.

### 1.4.4 Summary and Recommendations

The fourth and final chapter will summarize the results and findings presented and interpretations are provided by the authors. Authors give their recommendations based on the results and observations of the prototype simulation and the actual process. Recommendations to solve the research problem are finally discussed. Whether the research objectives were achieved or not will be justified and limitations and further scope for the research will be given.

# 2. REVIEW OF LITERATURE

## 2.1 Status of Research on Crepe Rubber Production improvement

While most of the research and the development has been done to improve the Quality of latex and the Plant Science and the genetic aspects of rubber comparatively less attention is given to improving the manufacturing methods and the technologies used in the production processes. The Rubber Development Department of Sri Lanka and the Rubber research institute of Sri Lanka (RRISL) have been focused on the enhancement of the Plantation Sector and implementing regulations under Ordinances and Acts of rubber plantation.
The fractionation process followed in the facilities is being practiced since the British introduced the industry to Sri Lanka.

## 2.2 Fractionation Process

As mentioned before fractionation is a specific process for crepe rubber manufacturing which is done to make the latex free from yellow discolouration, and enzymatic discolouration and preserve the strength of the crepe in the final product.
The recommended procedure by the RRISL to be followed is illustrated in the flowchart in Figure 8:

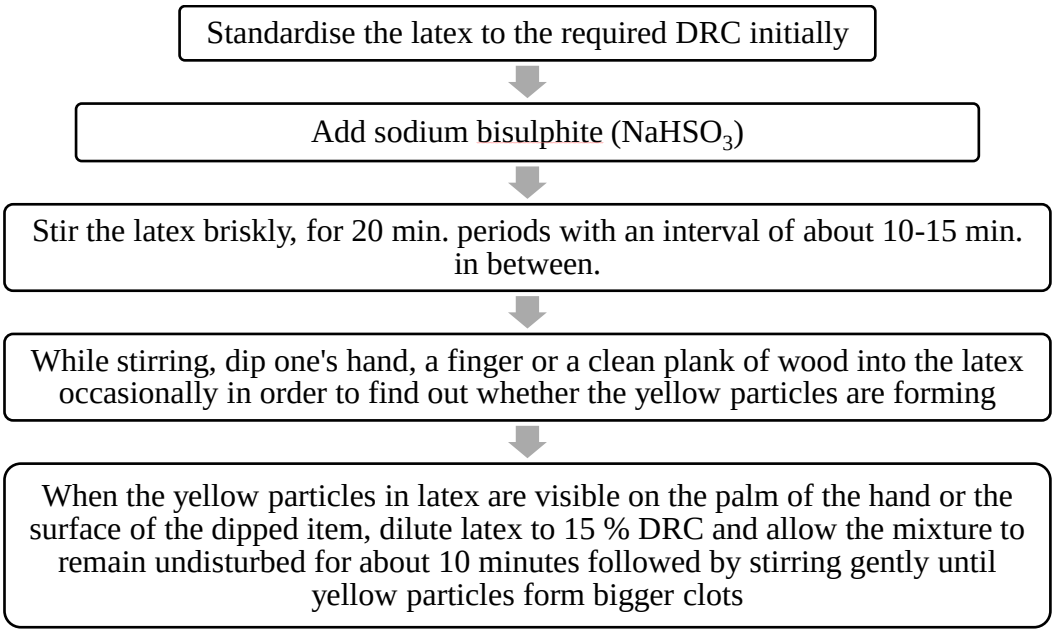


Figure 8: Recommended steps for fractionation. Adapted from *[7]*

### 2.2.1 Standardization of DRC

Based on the required grade quality of rubber the field latex is diluted. This is done after calculating DRC in the field latex,

### 2.2.2 Addition of Sodium Bisulphite/Metabisulphite

Once the fresh latex is unloaded into the fractioning tanks, diluted sodium bisulphite or sodium metabisulphite is mixed as soon as possible as a freshly prepared solution to the latex to prevent enzymatic discolouration in the pale crepe rubber [2]. The chemical needs to be mixed with the latex at the ratio of 5g/kg of dry rubber (maximum) and it should be in the form of a diluted solution. Exceeding the recommended dosage of the chemical causes delays in the drying process and as a result, could cause discolouration of the pale crepe sheets. An instance where a laborer annually adds the chemical to a bulking tank is shown in Figure 9.

Figure 9: Laborers adding Sodium Bisulphite to the diluted field latex

### 2.2.3 Agitation

The recommended agitation method is to stir up the latex briskly for 20-minute periods with intervals of about 10-15 minutes in-between. While stirring, dip a finger or a clean plank of wood into the latex intermittently to check whether the yellow fragments are forming. When such yellow fragments/flakes in latex are visible on the exterior of the dipped item let the latex solution remain undisturbed for about 10 minutes followed by stirring gently till yellow fragments form bigger clots [6]. Figure 10 shows the manual agitation process being performed by the laborers using wooden flaps.

Figure 10: Agitation of the Latex

## 2.3 DRC Measurement

Rubber latex is accumulated by regular excision of a thin shaving of the bark of the Hevea tree. The value of the fresh latex is determined by the volume, as well as the dry rubber content (DRC) present in the fresh latex [8].

The DRC of fresh field latex varies depending on many factors. The DRC is high at the initial opening of the tapping cut and in following tappings, it drops until reaching an equilibrium. Also, the DRC is high in very dry weather and is very low after prolonged rain or flooding. Severe and rigorous tapping procedures and the use of stimulants usually decrease the DRC. [7, pp. 33-58]. DRC of the field latex usually varies in the range of 20-45% as weight fraction and it depends on several factors such as season, climate and weather condition, tapping system, clone, soil condition, etc… The effect of the regional climate, age of the tree, and seasonal changes in tree physiology on the accuracy of DRC reading via a Metrolac reading are found to be not substantial [9].

### 2.3.1 Importance of determining the DRC in field latex

1. For standardization of latex

   The RRISL Recommends certain DRC levels in the field latex prior to coagulation based on certain export standards

   If a fraction is taken for use, latex should be diluted to a standard DRC of 21% (W/W) in the bulking tank.

   If a fraction is disposed, latex should be diluted to a standard DRC of 15% (W/W) in the bulking tank. [2]

2. Determining the Sodium Bisulphite quantity to be added in the fractionation process

   The recommended dosage is 5g per 1 kg of dry rubber (maximum) and in the form of a diluted solution. [2]

### 2.3.2 Current Method of DRC Measurement

A field latex sample is diluted to 1 : 2 with water before taking the density measurement. A glass hydrometer called the metrolac which is calibrated to measure absolute densities in the range of 0.9 - 1 $gcm^{-3}$ with high sensitivity is used on a diluted fresh latex sample. The density varies corresponding to the amount of rubber present in the latex solution, and the apparatus is graduated to provide a reading of the rubber content of latex in grams per liter. A metrolac and the sample DRC measuring apparatus are shown in Figure 11.

Figure 11 : Metrolac used for the DRC measurement

The reading from the metrolac is then compared with the standard metrolac chart (Shown in Table 1: Standard Metrolac Chart for DRC measurement. Adapted from that is recommended by the RRISL to obtain the DRC of the latex. The earliest ready-reckoner chart for the Metrolac/ latexometer was introduced in the early 20$^{th}$ century and later on, with several revisions, the current ready-reckoner chart has been established. To evade the temperature variations, the existing ready reckoner in Table 1 values are standardized at 29ºC [8].

Table 1: Standard Metrolac Chart for DRC measurement. Adapted from *[7]*

**The standard metrolac chart**

(Dilution: 1 part of latex to 2 parts of water)

| METROLAC READING → | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Volume of Latex (Litres) ↓ | ↓ Weight of rubber in kilograms | | | | | | | | | | |
| 1 | 0.20 | 0.22 | 0.24 | 0.26 | 0.28 | 0.30 | 0.32 | 0.34 | 0.36 | 0.38 | 0.40 |
| 2 | 0.40 | 0.44 | 0.48 | 0.52 | 0.56 | 0.60 | 0.64 | 0.68 | 0.72 | 0.76 | 0.80 |
| 3 | 0.60 | 0.66 | 0.72 | 0.78 | 0.84 | 0.90 | 0.96 | 1.02 | 1.08 | 1.14 | 1.20 |
| 4 | 0.80 | 0.88 | 0.96 | 1.04 | 1.12 | 1.20 | 1.28 | 1.36 | 1.44 | 1.52 | 1.60 |
| 5 | 1.00 | 1.10 | 1.20 | 1.30 | 1.40 | 1.50 | 1.60 | 1.70 | 1.80 | 1.90 | 2.00 |
| 6 | 1.20 | 1.32 | 1.44 | 1.56 | 1.68 | 1.80 | 1.92 | 2.04 | 2.16 | 2.28 | 2.40 |
| 7 | 1.40 | 1.54 | 1.68 | 1.82 | 1.96 | 2.10 | 2.24 | 2.38 | 2.52 | 2.66 | 2.80 |
| 8 | 1.60 | 1.76 | 1.92 | 2.08 | 2.24 | 2.40 | 2.56 | 2.72 | 2.88 | 3.04 | 3.20 |
| 9 | 1.80 | 1.98 | 2.16 | 2.34 | 2.52 | 2.70 | 2.88 | 3.06 | 3.24 | 3.42 | 3.60 |
| 10 | 2.00 | 2.20 | 2.40 | 2.60 | 2.80 | 3.00 | 3.20 | 3.40 | 3.60 | 3.80 | 4.00 |
| 11 | 2.20 | 2.42 | 2.64 | 2.86 | 3.08 | 3.30 | 3.52 | 3.74 | 3.96 | 4.18 | 4.40 |
| 12 | 2.40 | 2.64 | 2.88 | 3.12 | 3.36 | 3.60 | 3.84 | 4.08 | 4.32 | 4.56 | 4.80 |
| 13 | 5.20 | 5.72 | 6.24 | 6.76 | 7.28 | 7.80 | 8.32 | 8.84 | 9.36 | 9.88 | 10.40 |
| 14 | 2.80 | 3.08 | 3.36 | 3.64 | 3.92 | 4.20 | 4.48 | 4.76 | 5.04 | 5.32 | 5.60 |
| 15 | 3.00 | 3.30 | 3.60 | 3.90 | 4.20 | 4.50 | 4.80 | 5.10 | 5.40 | 5.70 | 6.00 |
| 16 | 3.20 | 3.52 | 3.84 | 4.16 | 4.48 | 4.80 | 5.12 | 5.44 | 5.76 | 6.08 | 6.40 |
| 17 | 3.40 | 3.74 | 4.08 | 4.42 | 4.76 | 5.10 | 5.44 | 5.78 | 6.12 | 6.46 | 6.80 |
| 18 | 3.60 | 3.96 | 4.32 | 4.68 | 5.04 | 5.40 | 5.76 | 6.12 | 6.48 | 6.84 | 7.20 |
| 19 | 3.80 | 4.18 | 4.56 | 4.94 | 5.32 | 5.70 | 6.08 | 6.46 | 6.84 | 7.22 | 7.60 |
| 20 | 4.00 | 4.40 | 4.80 | 5.20 | 5.60 | 6.00 | 6.40 | 6.80 | 7.20 | 7.60 | 8.00 |
| 21 | 4.20 | 4.62 | 5.04 | 5.46 | 5.88 | 6.30 | 6.72 | 7.14 | 7.56 | 7.98 | 8.40 |
| 22 | 4.40 | 4.84 | 5.28 | 5.72 | 6.16 | 6.60 | 7.04 | 7.48 | 7.92 | 8.36 | 8.80 |
| 23 | 4.60 | 5.06 | 5.52 | 5.98 | 6.44 | 6.90 | 7.36 | 7.82 | 8.28 | 8.74 | 9.20 |
| 24 | 4.80 | 5.28 | 5.76 | 6.24 | 6.72 | 7.20 | 7.68 | 8.16 | 8.64 | 9.12 | 9.60 |
| 25 | 5.00 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 8.00 | 8.50 | 9.00 | 9.50 | 10.00 |
| 26 | 5.20 | 5.72 | 6.24 | 6.76 | 7.28 | 7.80 | 8.32 | 8.84 | 9.36 | 9.88 | 10.40 |
| 27 | 5.40 | 5.94 | 6.48 | 7.02 | 7.56 | 8.10 | 8.64 | 9.18 | 9.72 | 10.26 | 10.80 |
| 28 | 5.60 | 6.16 | 6.72 | 7.28 | 7.84 | 8.40 | 8.96 | 9.52 | 10.08 | 10.64 | 11.20 |
| 29 | 5.80 | 6.38 | 6.96 | 7.54 | 8.12 | 8.70 | 9.28 | 9.86 | 10.44 | 11.02 | 11.60 |
| 30 | 6.00 | 6.60 | 7.20 | 7.80 | 8.40 | 9.00 | 9.60 | 10.20 | 10.80 | 11.40 | 12.00 |

**Issues with using the metrolac**

The latex sample needs to be diluted at first before the density could be measured. This is done because the metrolac cannot be used on natural latex due to the high viscosity. Dilution needs to be done as 1:2 water. Measurement errors could occur as the sample is usually around 50 ml and a small volume error could lead to a significant error on the DRC.

The practical difficulty in using the instrument such as the foam on the surface of the latex disrupting the reading and the angle at which the reading is done will impact the results as shown in Figure 12.

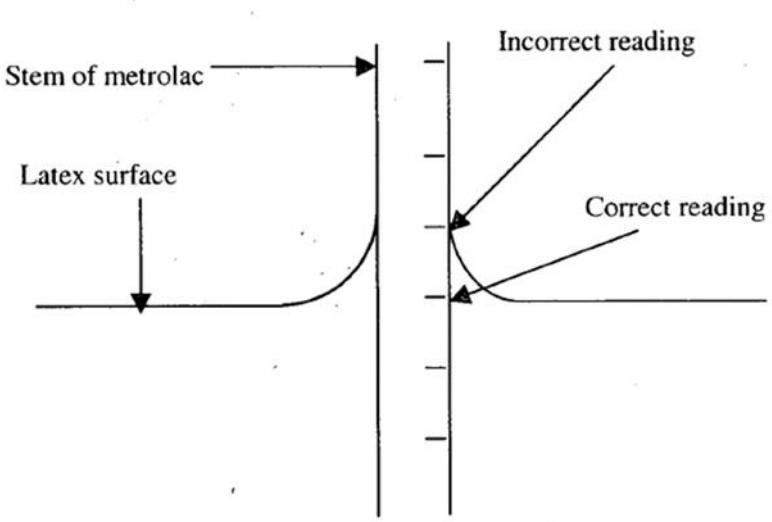


Figure 12 : Taking the metrolac reading. Adapted from *[7]*

Also, the addition of contaminants such as plant sap, and soapy water has a likelihood of making the latex more viscous and affects the free movement of the Metrolac giving an inaccurate reading [9].

### 2.3.3 Effect on temperature for DRC

The standard metrolac chart (Table 1) is based on a temperature of 29 °C. However, in real manufacturing conditions, the temperature of the latex water mixture prepared for the determination of Metrolac reading varies widely due to factors like;

- The environmental temperature: Especially in non-conventional rubber plantation areas (i.e. Badulla and Nuwaraeliya districts in up-country areas and Ampara and Moneragala districts in the low-country intermediate zone), temperature variations from 17 ºC to 32 ºC in the diluted latex samples is observed. Even in established rubber plantation areas, temperature variations as such may occur under extreme climate and weather conditions [8].
- The temperature of the field latex arrived at the factory
- The temperature of the water used to dilute the latex
- Sodium Sulphite is added as an anticoagulant at the latex collection centers. It will react with the acids that cause the coagulation of rubber. [7]

  This is an exothermic reaction hence the temperature in the solution will be slightly increased.

$$2\,NaHSO_3 + O_2 \rightarrow 2\,NaHSO_4 + Heat$$

Hence the latex reaching the factory could be warmer than the environmental temperature.

The temperature of the measured sample latex will affect the DRC reading since the density temperature are inversely related. The metrolac bases the density of the sample for the reading and hence the effect of temperature on the DRC measurement was looked upon.

**Temperature corrected ready-reckoner chart**

A study has been carried out by Kudaligama et al. for a 'Temperature corrected ready-reckoner chart for determination of dry rubber content in Hevea latex using the metrolac' which illustrates the DRC variations with varying temperatures [8].
The methodology and conclusion of the study were as follows:

*Methodology*

Around 400 fresh natural latex samples were collected from rubber estates Dartonfield in Kalutara District, Sanquhar in Nuwaraeliya District, and Keppetigala in Kurunegala district. Metrolac reading requires one fold of fresh latex to be mixed with two folds of clean water for the estimation of DRC estimation. The 1:2 diluted latex mixture's temperature was measured when taking the Metrolac reading.
Furthermore, 140 latex samples were measured for the Metrolac reading by artificially altering the temperature of diluted latex solutions using hot/cold water for dilution. The actual DRC of was determined by the standard ISO/BS laboratory method for each sample. The temperatures of these 140 latex water mixtures (mixed in 2:1) were altered using a hot water or an ice bath and a Metrolac reading was carried out at each degree of Celcius from 15°C to 35°C.

*Results, Discussion, and Conclusion*

A metrolac reading vs Temperature Adjusted DRC chart was obtained.
The DRC content opposed to the metrolac reading in the standard metrolac chart recommended by the RRISL is calibrated for 29 °C. Hence this chart can be used for DRC measurement in different temperatures. Table 2 :Temperature corrected DRC estimation chart with metrolac by Kudeligama et al. Adapted from Temperature corrected DRC estimation chart with metrolac developed by Kudeligama et al [8].

Table 2 :Temperature corrected DRC estimation chart with metrolac by Kudeligama et al. Adapted from *[8]*

TEMPERATURE* (°C)

| METROLAC READING | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.20 | 0.19 | 0.18 | 0.17 | 0.17 | 0.16 | 0.15 | 50 |
| 60 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.20 | 0.19 | 0.19 | 0.18 | 0.17 | 60 |
| 70 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.21 | 0.20 | 0.19 | 70 |
| 80 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.23 | 0.22 | 0.21 | 80 |
| 90 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.24 | 0.23 | 90 |
| 100 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 100 |
| 110 | 0.46 | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 110 |
| 120 | 0.48 | 0.47 | 0.46 | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 120 |
| 130 | 0.50 | 0.49 | 0.48 | 0.47 | 0.46 | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 130 |
| 140 | 0.52 | 0.51 | 0.50 | 0.49 | 0.48 | 0.47 | 0.46 | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 140 |
| 150 | 0.54 | 0.53 | 0.52 | 0.51 | 0.50 | 0.49 | 0.48 | 0.47 | 0.46 | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 150 |

(Dilution: 1 part of latex to 2 parts of water
*Temperature of 1:2 diluted latex water mixture at the time of Metrolac reading)

In order to examine the accuracy of the new chart for the estimation of DRC, two series of latex sample sets were investigated, that is to study the practicality of measuring the DRC of latex with the Metrolac under natural conditions and modified conditions. Under natural and adjusted conditions the new ready-reckoner chart showed an accuracy level of 84% on average ($r^2 = 0.84$) in the estimation of dry rubber content whilst the average accuracy of the existing chart was below 50% ($r^2 = 0.49$) [8]. However, there is no evidence that any of the crepe rubber manufacturing facilities in Sri Lanka uses a temperature-corrected ready-reckoner chart for DRC estimation.

### 2.3.4 Consequences of misestimating the DRC

There are severe effects on the productivity and the quality of the final crepe sheets from miscalculations of DRC. Such consequences are summarized in Table 3.

Table 3 : Consequences of misestimating the DRC

| **Consequences of overestimating the DRC** | **Consequences of underestimating the DRC** |
|---|---|
| ▪ The latex is over-diluted when standardizing<br><br>This will result in reduced strength in the final sheets and result in failure to meet export standards [2] | ▪ The latex is not diluted enough when standardizing<br><br>More dry rubber will be available in the final products resulting in a lower output yield<br>Harder coagulum leads to increased energy consumption during the milling process [2] |

| | |
|---|---|
| ▪ Sodium Bisulphite is overdosed<br><br>This will result in longer drying periods thus resulting in discoloration of the pale crepe [2] | ▪ Sodium Bisulphite is underdosed [2]<br><br>The fractionation will take longer Amines or other compounds could remain in the latex which will result in discoloration of the sheets later in the process [2] |

### 2.3.5 Other existing/researched methods for DRC Measuring

There have been many methods available and researched to measure the DRC in natural latex since it is one of the most important measurements required in any rubber manufacturing process. Some of the methods available and researched for DRC measurement are briefly discussed in Table 4.

Table 4: Methods of calculating the DRC

| | **Method** | **Procedure** | **Findings/Conclusion** |
|---|---|---|---|
| 1 | ISO/BS Method | Employ an ordinary air-circulating oven for drying by heating the latex to 70 °C for around 6 - 8 hours. | Natural latex is dried until only the Total Solid (TS) content is remaining and then the weight is measured |
| 2 | A rapid and accurate method for determining the dry rubber content and total solid content of NR latex [10] | Using a microwave oven instead of a conventional airflow oven and heating the solution to 70 °C | The DRC and TS content of latex could be determined in 10 and 25 minutes respectively with the same accuracy as the BS or ISO techniques where the time taken for the test is over 6 hours with the conventional oven. |
| 3. | Measurement of Dry Rubber Content in Latex Using Microwave Technique [11] | This experiment performs an experimental analysis on the dielectric properties of natural rubber latex as a function of the DRC | The study concludes by showing a relation between moisture content and the dielectric constant. |
| 4 | A simple optical sensor for the | A laser beam transmitted through a thin column of | A linear relationship is observed between the |

| | | | |
|---|---|---|---|
| | measurement of dry rubber content in natural rubber latex [12] | latex is imaged from an image sensor and the image is processed to compute the strength of scattering | DRC of the latex and the full width at half of the maximum of the laser beam intensity profile. |
| 5 | Quantifying Dry Rubber Content in Latex Solution Using an Ultrasonic Pulse [13] | Experiment is performed on a set of latex solutions in cylindrical tubes that are of different lengths. The ultrasonic pulse transverse longitudinally across the tubes that are fully contained with the rubber latex solutions. Ultrasonic speeds and spatial attenuations for different dry rubber contents were then obtained. | The results revealed that the ultrasonic speed and spatial attenuation are linearly proportional to the amount of dry rubber content present in the latex solutions. |

The methods discussed in Table 4 are not feasible to be used in a crepe rubber manufacturing facility due to the requirement of sophisticated technical equipment and expertise and high time requirement. What is required in a facility is a nearly spontaneous calculation that requires minimal cost incurrence and technical expertise.

## 2.4 Room for Improvement and Research Gaps Identified

### 2.4.1 Estimating the DRC in a more accurate manner

Due to the shortcomings in the current method used for measuring the DRC (mentioned earlier in this chapter), a more accurate method of DRC method needs be developed to be used in the industry.

### 2.4.2 Reliably determining the end of the Fractionation process

A reliable method needs to be developed to determine the fractionation process that is not subjective to a judgement of an individual.

### 2.4.3 Minimizing Human Involvement in the Process

Due to the significant health hazards involved in the fractionation process and the procedures carried out that are subject to human error the human involvement should be prevented wherever is possible. It is vital to prevent prolonged exposure to chemicals by the laborers.

# 3. IMPROVING THE FRACTIONATION PROCESS OF THE CREPE RUBBER MANUFACTURING

This chapter consists of the research methodology which evaluates more efficient and accurate methods to determine the DRC and process completion. Also, the implementation of an automated solution to minimize human involvement is proposed via a prototype demonstration. The data obtained are presented, analysed, and interpreted in this chapter as well.

## 3.1 Measuring the Dry Rubber Content

Even though several accurate methods are available for the determination of the dry rubber content in natural rubber latex, the Metrolac is widely used in Sri Lanka due to its convenience in field use [8]. However, due to the shortcomings and inaccuracies of using the metrolac with the standard chart as discussed in the previous chapter, a new reliable measurement method was evaluated.

### 3.1.1 Evaluating Effect of Temperature on DRC

The environmental temperature variation was analyzed in Eladuwa, Dodangoda, Sri Lanka where one of the crepe rubber manufacturing factories of study is located. The average monthly temperatures varied from 24 °C to 32 °C in a period of 1-year as shown in Figure 13 [14].

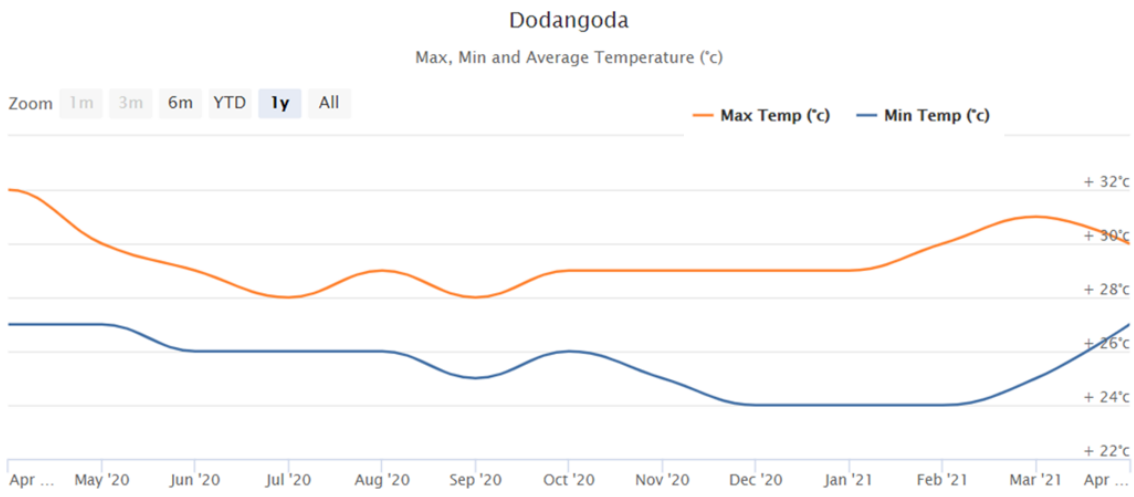


Figure 13: Variation of environmental temperature near the manufacturing facility of study *[14]*

12 Sample sets within a period of 3 weeks were also tested for the environmental temperature and the diluted latex temperature and the observed data are given in Table 5 and Table 6.

Table 5: Temperature variations in sample field latex sets

| Sample | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Environmental temperature measured (°C) | 28 | 29 | 28 | 29 | 33 | 30 | 30 | 29 | 28 | 26 | 27 | 27 |
| Temperature of the sample latex (°C) | 26 | 26 | 28 | 30 | 32 | 30 | 30 | 29 | 28 | 24 | 26 | 25 |

Table 6: Time taken for the fractionation process

| Sample | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature of the sample latex (°C) | 26 | 26 | 28 | 30 | 32 | 30 | 30 | 29 | 28 | 24 | 26 | 25 |
| Natural Latex Volume (Liters) (Measured at the collecting centers) | 487.6 | 390 | 428.4 | 443.3 | 433 | 520.7 | 486.4 | 505.4 | 528 | 477 | 506 | 514 |
| **Process Time* (Minutes)** | **138** | **132** | **130** | **125** | **120** | **128** | **125** | **122** | **127** | **148** | **135** | **134** |

Environmental temperature depended on the time of the day, climate and weather and the latex sample temperature did not have a clear relationship with the environmental temperature. The measured latex temperatures varied from 24 °C to 32 °C.
The samples with lower temperatures tended to have a long fractionation process time. Hence it was evident that the sample temperature had an impact on the process time and should be measured for each instance when measuring the DRC.

### 3.1.2 Evaluating the error when using the standard chart at the extreme temperatures measured

The results of the study conducted by Kudaligama, et al. were used as the base to calculate the error in different temperatures.
The error in DRC calculation can be calculated using the following formula:

$$The\ error\ \% = \frac{|DRC\ reading\ at\ 29℃ - DRC\ reading\ at\ actual\ temperature|}{DRC\ reading\ at\ actual\ temperature} * 100$$

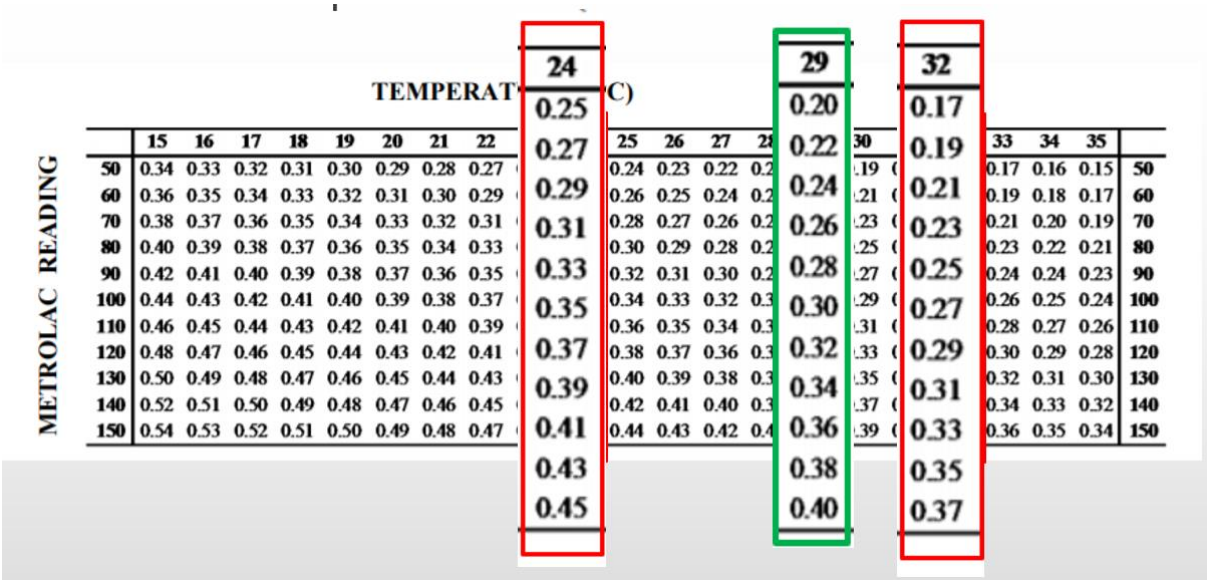


Figure 14: Evaluating the error when using the standard chart at the extreme temperatures measured

For temperatures above 29 °C

The DRC will be overestimated.

Example - At 32 °C there is a 0.03 Kg (30g) difference in the measurement of DRC content per diluted liter of the latex.

The fractionation tanks range from 100 to 1000 liters of total volume. So, the total error in reading using the standard metrolac chart could be 3 -30 kg of solid dry dubber.

Assuming the metrolac reading to 100 in a tank with 100 liters of diluted latex the DRC will be read as 30 Kgs where the actual content is 27 Kg.

$$\text{The error \%} = \frac{|30-27|}{27} * 100 = 11.11\%$$

For temperatures below 29 °C

The DRC will be underestimated.

Example - At 24 °C there is a 0.05 Kg (50g) difference in the measurement of DRC content per diluted liter of the latex.

Assuming the metrolac reading to 100 in a tank with 100 liters of diluted latex the DRC will be read as 30 Kgs where the actual content is 35 Kg.

$$\text{The error \%} = \frac{|30-35|}{35} * 100 = 14.28\%$$

Figure 15 shows DRC measurement error percentages at different temperatures. This is the temperature range that was observed in the Eladuwa rubber facility. For lower temperatures in non-traditional rubber plantation areas, the error will be higher.

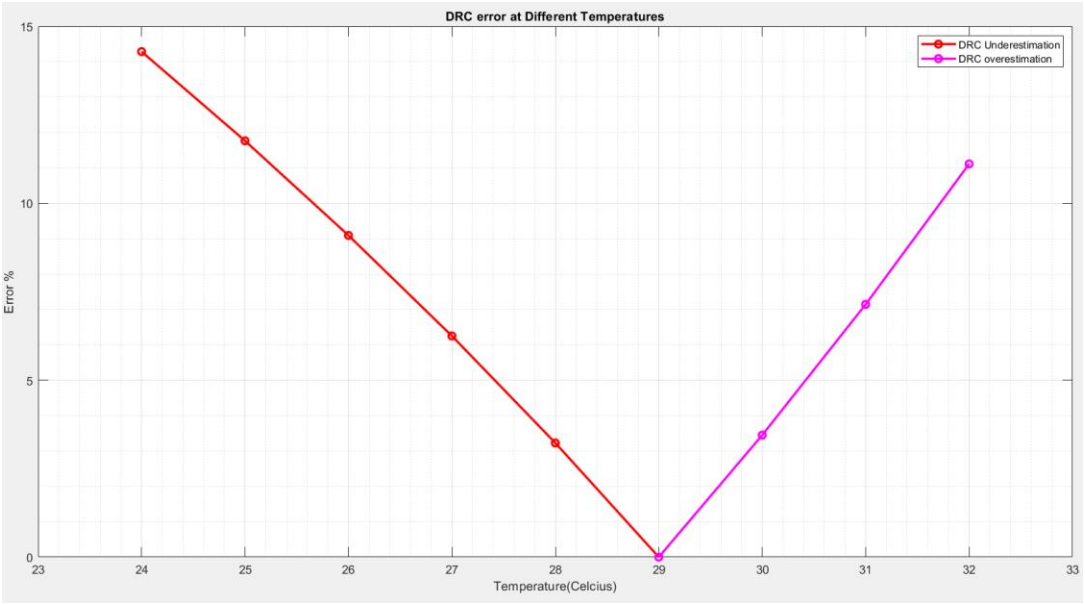


Figure 15: DRC error at different temperatures (when using the standard chart)

Given the considerable error component with varying temperatures, it is evident that the temperature should be taken into account if the DRC is measured by means of latex density. Hence the standard metrolac chart needs to be corrected for temperature.

### 3.1.3 The proposed method to measure DRC

The absolute density of a field latex sample can be measured through a weight–volume measurement. This is done to overcome the practical issue when using the metrolac.

1. A Sample Natural latex volume ($v$) is measured
2. The weight difference ($W$) with the addition of Natural Latex to the prototype tank is measured
3. Absolute Density was then measured:
   Density reading ($\rho$) = $W/v$
4. Measured absolute densities were compared with the metrolac used in the industry
   Rubber latex was first diluted with water in a 1:2 ratio before taking the measurements.
   Then the diluted latex samples were added with more water (to increase density) and acetone (to decrease density) and the corresponding metrolac reading and absolute densities were mapped as shown in Table 7.

Table 7: Mapping the absolute density with Metrolac reading

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Absolute Density ($gcm^{-3}$) | 0.9897 | 0.9894 | 0.9892 | 0.9889 | 0.9887 | 0.9884 | 0.9881 | 0.9879 | 0.9876 | 0.9875 | 0.987 |
| Metrolac Value | 75 | 80 | 85 | 90 | 95 | 100 | 105 | 110 | 115 | 120 | 125 |
| DRC (From standard chart) | | | | | | 0.30 | | | 0.33 | | |

5. The corresponding densities of the undiluted latex were then mapped as shown in Table 8 and Table 9.

Table 8: Corresponding undiluted latex density

| | | |
|---|---|---|
| Density in diluted latex ($gcm^{-3}$) | 0.9884 | 0.9876 |
| Absolute density in Field latex ($gcm^{-3}$) | 0.9732 | 0.9709 |
| DRC (From standard chart) (w/w) | 0.30 | 0.33 |

Undiluted field latex densities were extrapolated using the absolute densities of natural rubber particles and water at 29°C. The compared measured values were accurate (Error <1%) for DRC values of 0.3 and 0.33.

*Density of water at 29°C - 0.996 $gcm^{-3}$* [15] *Solid Dry Rubber at 29°C - 0.92 $gcm^{-3}$* [16]

Table 9: Mapping the absolute densities of field latex, diluted latex, DRC, and metrolac reading

| Absolute Density of field Latex | Absolute Density of diluted Latex | DRC | Metrolac value |
|---|---|---|---|
| 0.9808 | 0.9909 | 0.20 | 50 |
| 0.9800 | 0.9907 | 0.21 | 55 |
| 0.9793 | 0.9904 | 0.22 | 60 |
| 0.9785 | 0.9902 | 0.23 | 65 |
| 0.9778 | 0.9899 | 0.24 | 70 |
| 0.9770 | 0.9897 | 0.25 | 75 |
| 0.9762 | 0.9894 | 0.26 | 80 |
| 0.9755 | 0.9892 | 0.27 | 85 |
| 0.9747 | 0.9889 | 0.28 | 90 |
| 0.9740 | 0.9887 | 0.29 | 95 |
| 0.9732 | 0.9884 | 0.30 | 100 |

| | | | |
|---|---|---|---|
| 0.9724 | 0.9881 | 0.31 | 105 |
| 0.9717 | 0.9879 | 0.32 | 110 |
| 0.9709 | 0.9876 | 0.33 | 115 |
| 0.9702 | 0.9874 | 0.34 | 120 |
| 0.9694 | 0.9871 | 0.35 | 125 |
| 0.9686 | 0.9869 | 0.36 | 130 |
| 0.9679 | 0.9866 | 0.37 | 135 |
| 0.9671 | 0.9864 | 0.38 | 140 |
| 0.9664 | 0.9861 | 0.39 | 145 |
| 0.9656 | 0.9859 | 0.40 | 150 |

Table 10: Derived DRC reference chart with temperature adjustments

| | | **Latex Temperature °C** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** |
| **Absolute Density (gcm-3) of Field (Undiluted) Latex** | **0.9808** | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.20 | 0.19 | 0.18 | 0.17 | 0.17 | 0.16 | 0.15 |
| | **0.9800** | 0.3 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.2 | 0.19 | 0.18 | 0.18 | 0.17 | 0.16 |
| | **0.9793** | 0.31 | 0.3 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.20 | 0.19 | 0.19 | 0.18 | 0.17 |
| | **0.9785** | 0.32 | 0.31 | 0.3 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.2 | 0.2 | 0.19 | 0.18 |
| | **0.9778** | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.21 | 0.2 | 0.19 |
| | **0.9770** | 0.34 | 0.33 | 0.32 | 0.31 | 0.3 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.22 | 0.21 | 0.20 |
| | **0.9762** | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.23 | 0.22 | 0.21 |
| | **0.9755** | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.3 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 | 0.23 | 0.22 |
| | **0.9747** | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.24 | 0.23 |
| | **0.9740** | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.3 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 | 0.23 |
| | **0.9732** | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 | 0.24 |
| | **0.9724** | 0.4 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.3 | 0.29 | 0.28 | 0.27 | 0.26 | 0.25 |
| | **0.9717** | 0.41 | 0.4 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.26 |
| | **0.9709** | 0.42 | 0.41 | 0.4 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.3 | 0.29 | 0.28 | 0.27 |
| | **0.9702** | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.3 | 0.29 | 0.28 |
| | **0.9694** | 0.44 | 0.43 | 0.42 | 0.41 | 0.4 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.3 | 0.29 |
| | **0.9686** | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 |
| | **0.9679** | 0.46 | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.4 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.31 |
| | **0.9671** | 0.47 | 0.46 | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 |
| | **0.9664** | 0.48 | 0.47 | 0.46 | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.4 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 |
| | **0.9656** | 0.49 | 0.48 | 0.47 | 0.46 | 0.45 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 | 0.34 |
| | | DRC per 1 liter of natural latex (in kg) | | | | | | | | | | | | | | | |

Table 10 can be used to determine the DRC value at a given temperature (ranging from 20 -35 °C) when the absolute density of the field latex is measured accurately.
The obtained DRC value can then be based for the dilution (standardization) and chemical dosing (addition of sodium bisulphite).

*Diluting the latex*

Water volume to be added:

If the fraction disposed

$$V_1 = v(\frac{DRC}{0.15} - 1)$$ $v$ : Latex Volume

If the fraction is taken for use

$$V_1 = v(\frac{DRC}{0.21} - 1)$$ $v$ : Latex Volume

*Chemical dosing*

The maximum quantity of sodium bisulphite needed is 5 g per 1 kg of dry rubber (Handbook of rubber – Processing technology) ;
Hence the required Sodium Bisulphite amount (m) is:

$$m = DRC \times 0.005$$

**Assumptions when Interpolating and Extrapolating the Values**

1. The calculations are based on the standard metrolac chart
2. Values of the deviated temperatures are based on the study of Kudaligama et al [8]
3. Natural Latex was assumed to only contain solid rubber particles and water. (In reality, they add to up 96%)
4. The effect of Anticoagulant added at collection centers on density is disregarded (There is no proof of an effect on the estimation of dry rubber content with the Metrolac recorded with the use of preservers if used within the recommended amounts [9] )
5. Latex is assumed to be undiluted and uncoagulated

### 3.1.4 Comparing the temperature corrected DRC measurement chart with the laboratory method.

As mentioned before the temperature corrected DRC – Metrolac chart has proven to have an accuracy level of 84% (when compared to LDRC) on average in the estimation of the DRC over the standard metrolac chart with an average accuracy of the existing chart of 49% (Figure 16). However, for high dry rubber contents, the accuracy veered to be low with both standard and new charts.

The correlation of dry rubber content percentage approximated with the Metrolac using existing standard (Metro_E) and new (Metro_N) ready-reckoner charts with percentage DRC assessed in the laboratory under a) natural environment and b) artificially induced temperatures are illustrated in Figure 16.

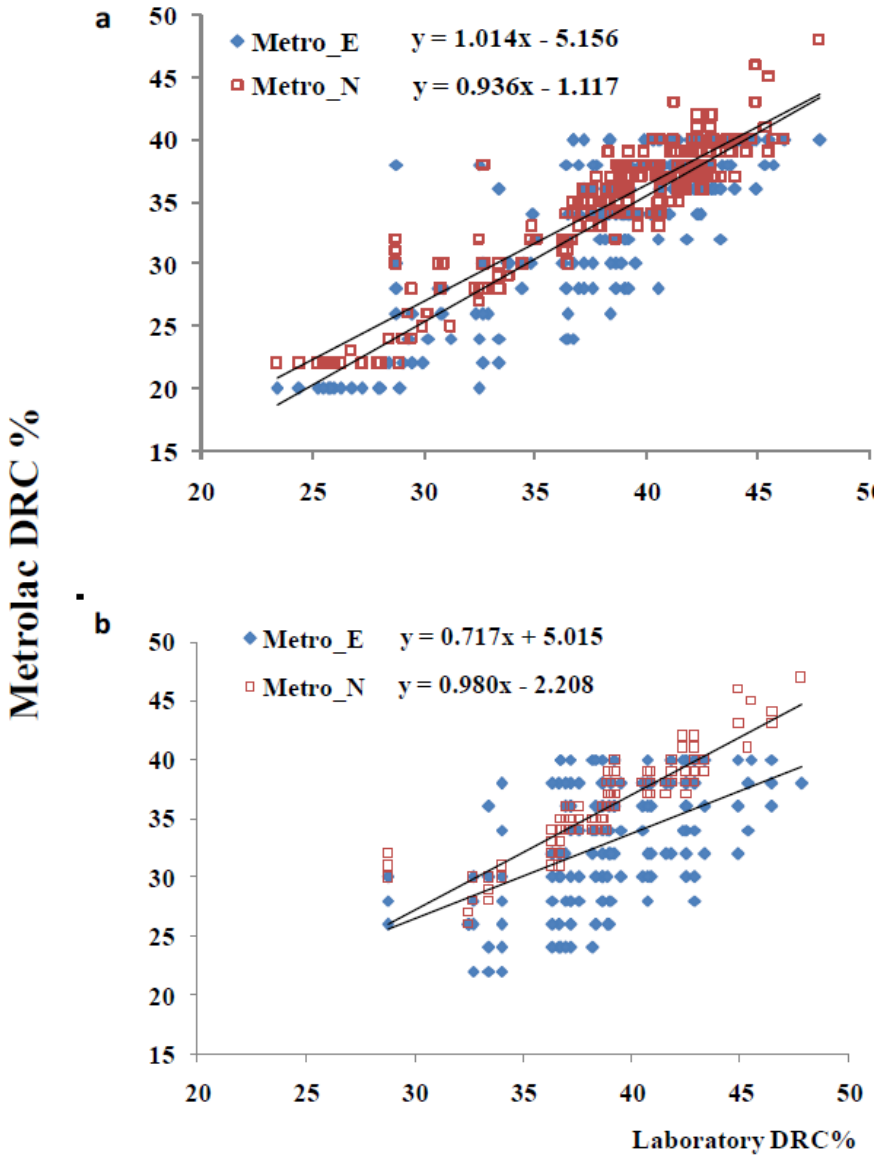


Figure 16: Comparing results of the DRC estimations with Metro_E and Metro_N. Adapted from *[8]*

It was impossible to detect a specific pattern in the studied deviation of the approximated Metrolac dry rubber content (MDRC) from Laboratory measured dry rubber content using ISO/BS method (LDRC) in the samples that were tested under both environmental and artificially induced temperatures. Under environmental conditions, the observed variations in MDRC from LDRC were between -12.69% and 9.25% when using the Metro_E whereas the variation of the estimated values with the Metro_N was between -7.56% and 5.31%. In those latex samples in which

temperatures were artificially stimulated the detected variations in MDRC from LDRC were between -14.89% and 4.00% with the Metro_E whilst this variation was limited to values between -6.48% and 3.25% with the use of Metro_N (Table 2) [8].
The variations observed in the DRC percentage estimated with the Metrolac with the use of Metro_E and Metro_N ready-reckoner charts and the DRC percentage measured in the laboratory under a) natural environment and b) artificially induced temperatures are illustrated in Figure 17.

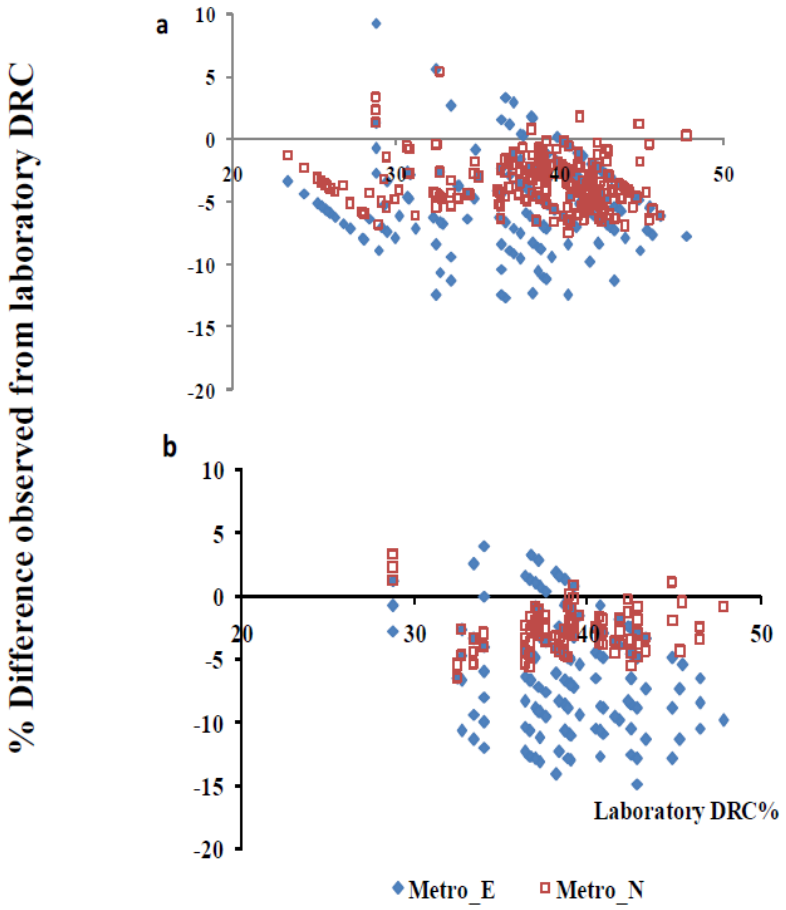


Figure 17: The variances observed in the Dry rubber content % estimated with the Metrolac with the use of Metro_E and Metro_N charts and the % DRC measured in the research laboratory, Adapted from *[8]*

At lower temperatures than the standard temperature (29ºC), the dry rubber contents measured with the Metro_E were underestimated, and the variations observed between MDRC and LDRC were larger.
As anticipated, this variation grows to be slighter at around 29ºC and then results in overestimation of DRC for temperatures above 29 ºC. Deviation of temperature from 1ºC in the latex solution used for weighing resulted in a 0.91% difference in the DRC estimated with the standard metrolac chart [8].
Due to the temperature correction, such variation was not detected with the new ready-reckoner chart (Table 2). The discrepancy observed in the DRC percentage estimated with Metrolac with the existing standard (Metro_E) and new (Metro_N) ready-

reckoner charts and the temperature of weighing solution under a) natural environment and b) artificially induced temperatures are shown in Figure 18.

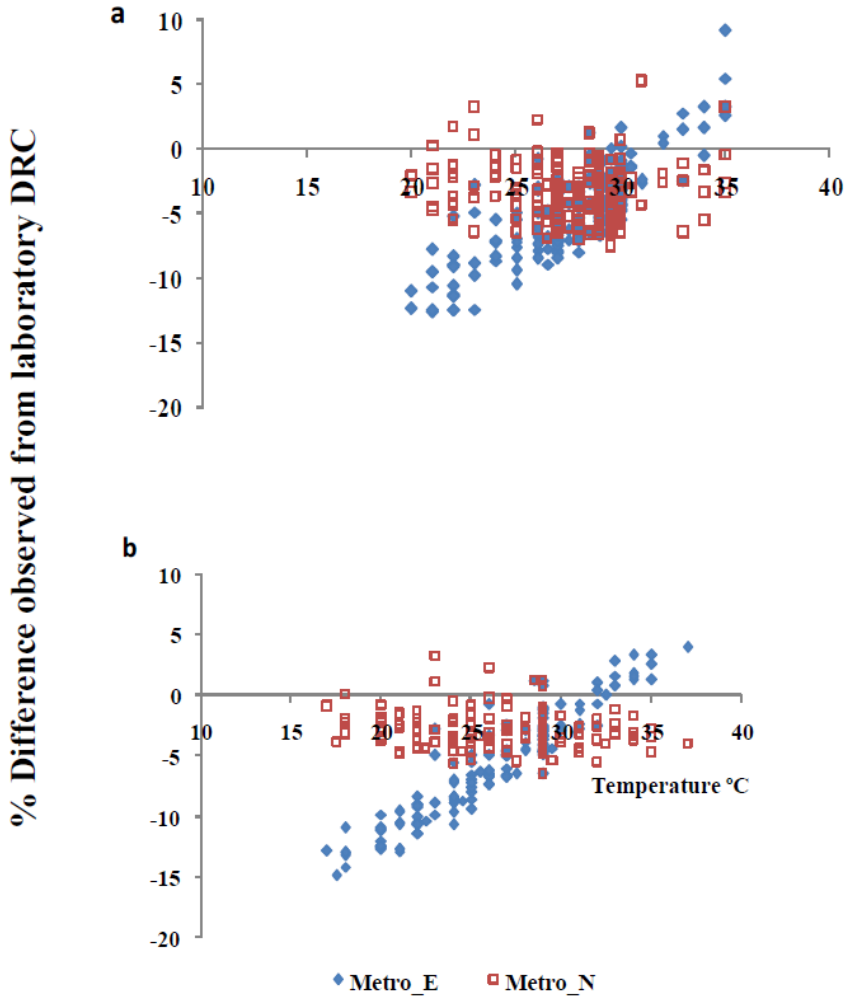


Figure 18: Variance detected in the DRC percentage estimated with Metrolac with the use of existing and new temperature corrected charts and the temperature of latex solution. Adapted from *[8]*

## 3.2 Determining the completion of fractionation

The current method to determine the process end is through a visual inspection. Once the froth starts forming on top of the latex (as shown in Figure 19) the fractionation process generally is deemed to be enough. This practice, however, makes the judgment subjective to a human error and based on the experience and knowledge of the inspector. Hence the need for a more reliable way to determine the process end was sought.

Figure 19: Determining the completion of fractionation

In order to determine a reliable way to determine the process end, few physical parameters were observed in the latex solution during the fractionation process. The pH variation proved to be a viable parameter to rely on to determine the process end.
The pH level of a solution is a measure of its hydrogen ion concentration (pH = -log[H+])
Fresh latex is a neutral, slightly weak alkaline tendency, pH value of 7 to 7.2 [15]. Small amounts of sodium bisulfite is added at the collection centers to prevent coagulation which leads to a slight decrease in pH in the latex received at the factory. The pH variation was observed during the process which is illustrated in Figure 20 and Figure 21.

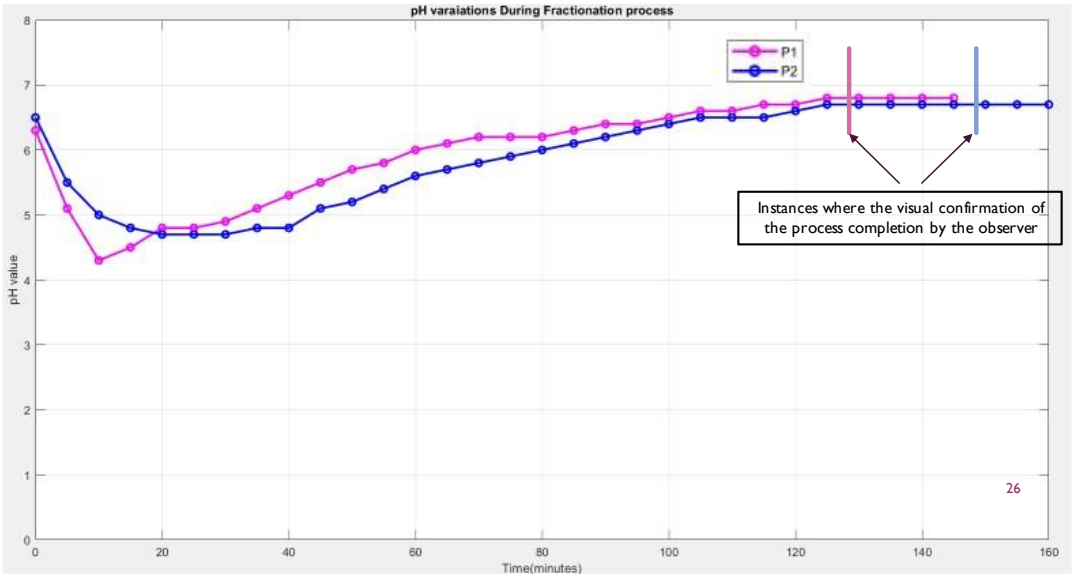


Figure 20: pH variation during the fractionation process 1

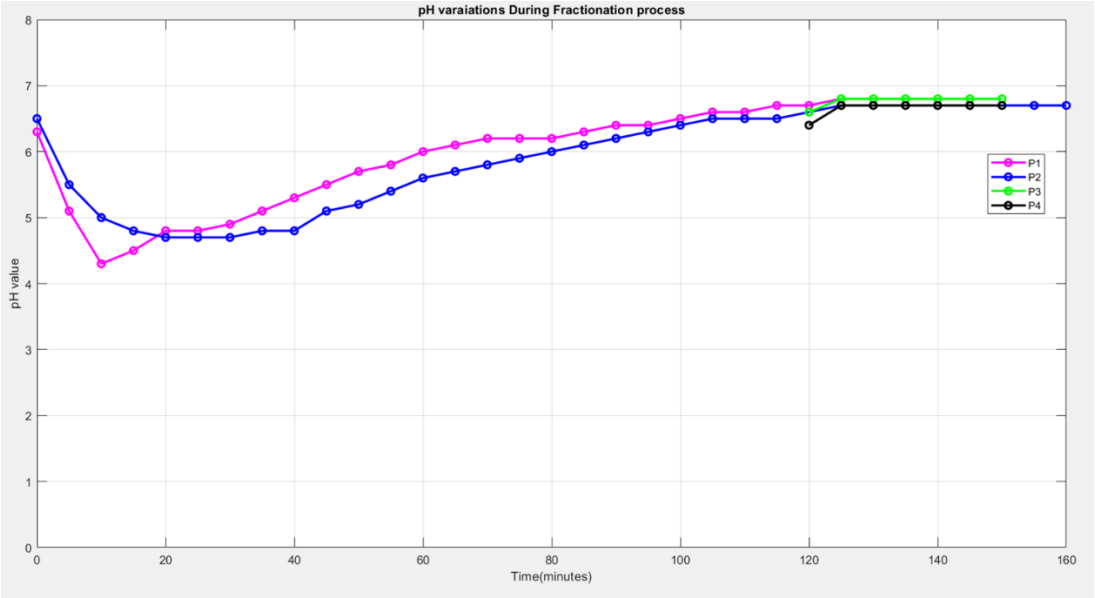


Figure 21: pH variation during the fractionation process 2

Two entire processes (P1 & P2) and two processes towards the end (P3 & P4) were continuously monitored for pH variation at the factory. The corresponding paraments of the latex used are shown in Table 11.

Table 11: Recorded process times for the processes observed

| Process | Recorded process time (minutes) as confirmed by visual inspection | Time taken for pH level to be stable (minutes) |
|---|---|---|
| P1 | 127 | 125 |
| P2 | 148 | 140 |
| P3 | 135 | 125 |
| P4 | 134 | 125 |

### 3.2.1 Fractionation Process in a Prototype Environment

A prototype tank was used to analyze the fractionation process.
Samples were initially tested for DRC and pH variations were recorded during the process which is presented in Table 12.

Table 12: Parameters of the samples tested in the prototype tank

| **Sample** | Volume (Liters) | Initial pH | Absolute Density ($g/cm^3$) | Temperature °C | DRC* | Rubber Weight (kg) | NaHSO4 added (g) |
|---|---|---|---|---|---|---|---|
| S1 | 10 | 6.7 | 0.9874 | 30 | 0.33 | 3.26 | 16.3 |
| S2 | 10 | 6.8 | 0.9889 | 27 | 0.3 | 2.97 | 14.8 |
| S3 | 8.3 | 6.8 | 0.9889 | 27 | 0.3 | 2.46 | 12.3 |
| S4 | 10 | 6.8 | 0.9889 | 27 | 0.3 | 2.97 | 14.8 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| S5 | 10 | 7 | 0.9724 | 29 | 0.31 | 3.01 | 15.1 |
| S6 | 10 | 6.8 | 0.9710 | 28 | 0.34 | 3.30 | 16.5 |

*DRC was obtained from the constructed temperature corrected density chart (Table 10)

Figure 22: Apparatus for testing samples for DRC measurement

## 3.3 The automated solution to perform the fractionation process

One of the primary objectives of this study is to present an automated solution to perform the fractionation process. The main functions of the automated solution are chemical dosing, agitation, and determining the process end.
The operation process of the automated solution is shown in Figure 23.

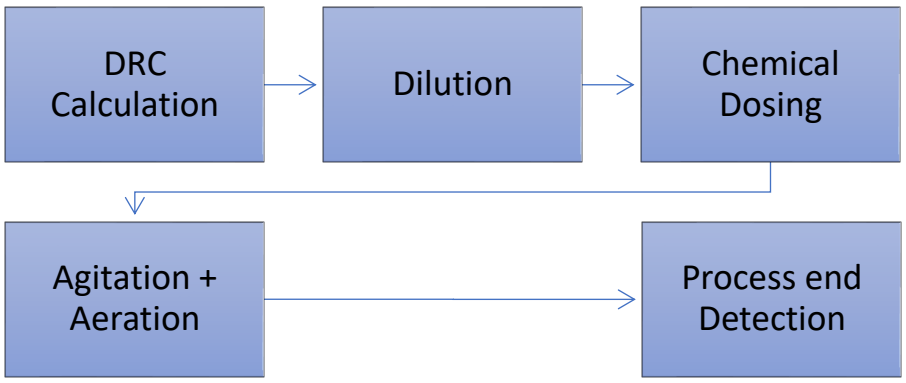


Figure 23: The operation process of the automated solution

### 3.3.1 Control Process

The control process of the automated solution is illustrated in Figure 24.

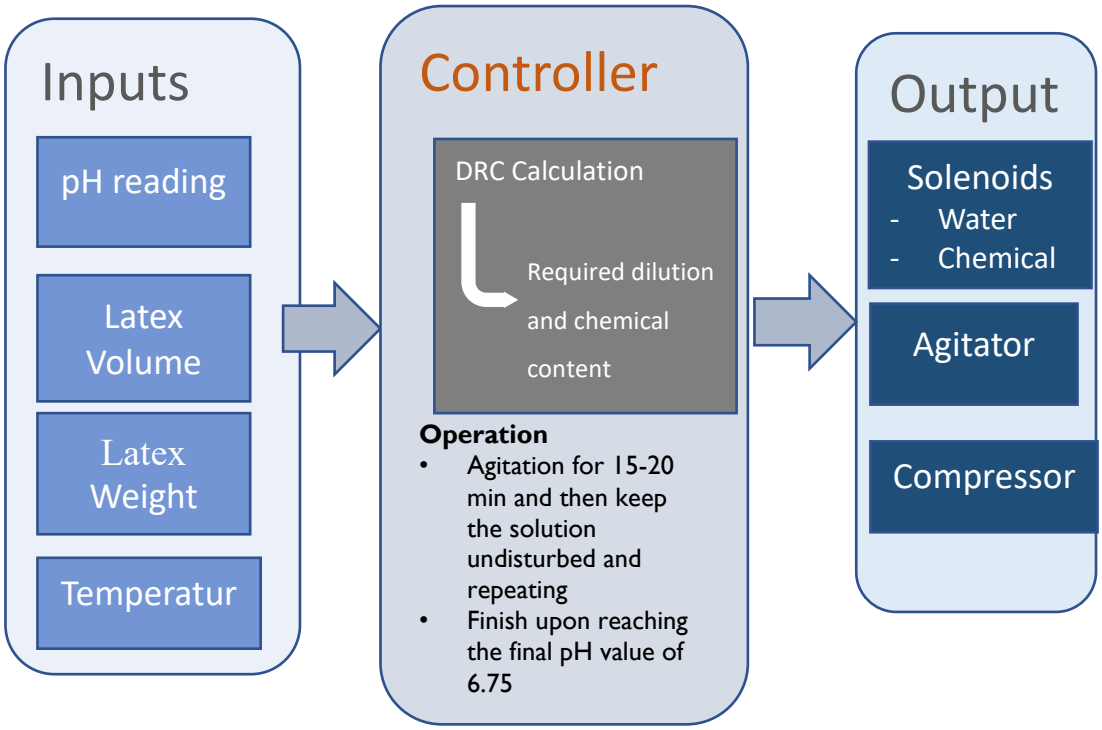


Figure 24: Control Process of the automated solution

### 3.3.2 Sensors and Actuators used

The following sensors and actuators were used for the automated prototype for the fractionation process.

**DRC calculation**

DRC is calculated by means of an absolute density calculation.
Volume was measured manually as in the actual production process the rubber volume is measured at collection centers.
To measure the weight of the latex two 25 kg load cells are mounted at the tank bottom along with 24-bit analog to digital converters were used as shown in Figure 25.

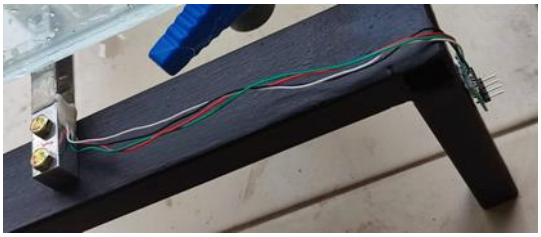

Figure 25: Load cells and ADCs

**Temperature measurement**

A temperature sensor probe (DS18b20) shown in Figure 26 was used to measure the initial sample temperature to accompany the density reading.

Figure 26: Temperature sensor probe (DS18b20)

**Chemical dosing and Dilution**

A pipeline carrying liquid rubber is directed to the tank through a small reservoir. A Hall Effect fluid flow meter is inserted into the pipeline and an electronically controlled solenoid valve is used to control the liquid flow as shown in Figure 27. Once the flow meter reads the required amount of volume the solenoid is set to close.

Figure 27: Flow meter and Electronic Solenoids

**Mechanical agitation and aeration**

The manual agitation procedure is replaced by a mechanical agitator and a compressed air supply to the latex solution. Here a sprinkler made out of PVC is used. Also a sealed pneumatic rotary joint is used to supply a compressed airflow while the sprinkler is rotating in order to speed up the process. After the pH value settles at a predetermined value the sprinkler stops automatically and is lifted using a pneumatic cylinder.
The Compressed air flow from the compressor is controlled by a 2/1 pneumatic solenoid to open/close the air inlet to the rotary joint. Also, another 5/2 pneumatic solenoid is used to supply the airflow to the pneumatic cylinder. The apparatus and setup are shown in Figure 28.

DC geared Motor

Air Compressor

Pneumatic cylinder

Figure 28: Apparatus for mechanical agitation and aeration

**pH monitoring**

A pH sensing regulator sensor module monitoring control meter tester along with a BNC pH electrode probe for Arduino (shown in Figure 29) was used for continuous monitoring and recording of the pH variation in the processes at the factory as well as in the prototype.

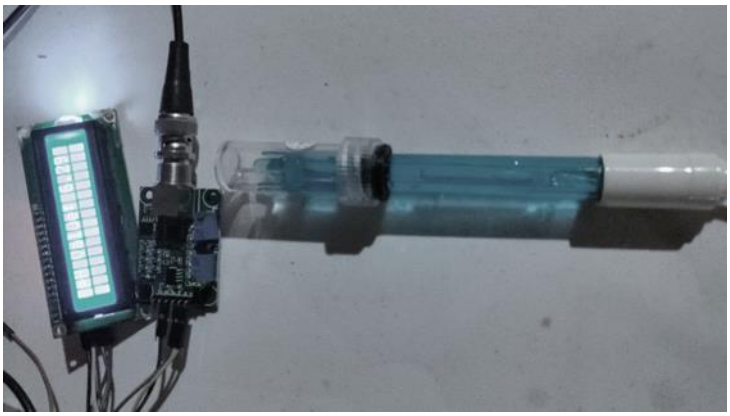

Figure 29: pH sensing apparatus

**Controller**

24,12 and 9V 5A power supplies were used to power electrical components and a pneumatic compressor is used to supply compressed air required for the sprinkler and to control all the pneumatic components.
An Arduino mega is used as the controller of the operation. The control board is shown in Figure 30.

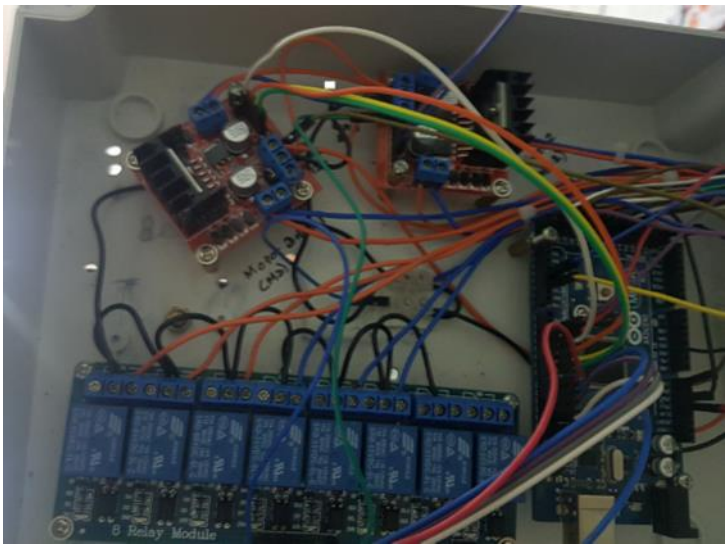


Figure 30: Control board

## 3.4 Observations on pH variation

The pH variations of the observed processes in the prototype tank are illustrated in Figure 31.

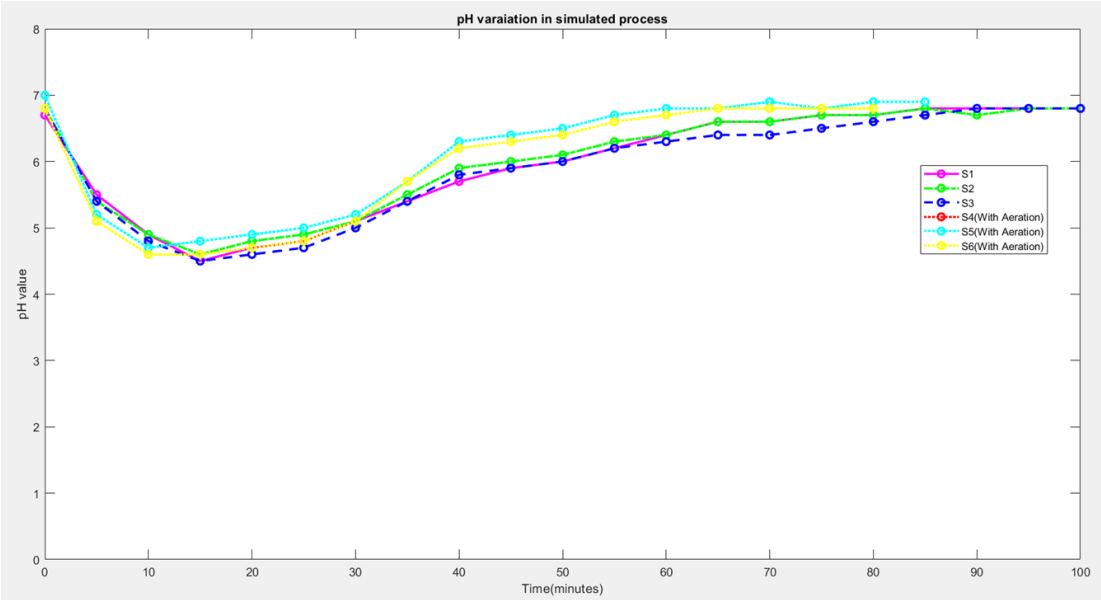


Figure 31: pH variation in the prototype simulated processes

All pH variations (in the real process and prototype simulated process) are contrasted and shown in Figure 32. The pH variation pattern in the real and simulated processes were similar.

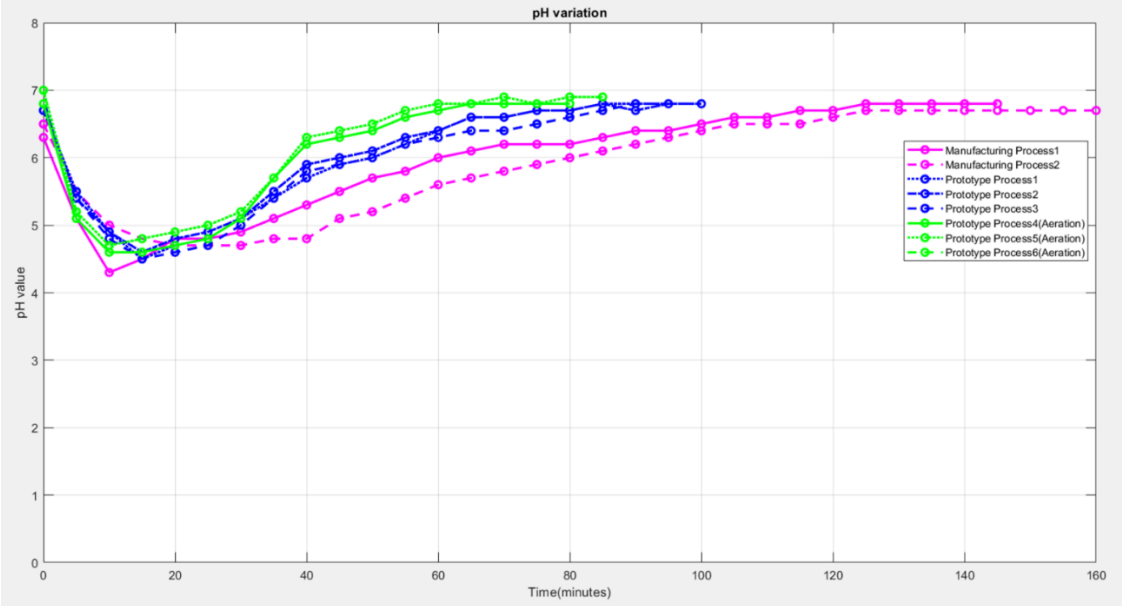


Figure 32: pH variation in all processes

Observations on pH variation during the fractionation processes

1. Initial pH was in the range of 6.8 - 7 in the rubber latex that arrived at the factory
2. pH value dropped with the addition of sodium bisuphite

3. pH variation pattern in the prototype was similar to the two processes observed at the factory
4. At the process end, the pH settled at 6.7- 6.8 in every process observed (at the factory and prototype)
5. Three samples were tested with aeration and manual agitation (S4, S5, and S6)
6. Two identical samples were tested with aeration and manual agitation (S3 and S4)
7. The sample with aeration settled sooner compared to the agitated samples

Based on the observations it was evident that the pH variation can be used as an indicator to determine the end of the fractionation process.

# 4. SUMMARY AND CONCLUSIONS

## 4.1 Suggested Improvements to the current process

Based on the experiments and results the following improvements can be suggested for the crepe rubber fractionation process.

### 4.1.1 Replace the metrolac with volume - weight measurement system

- A field latex sample can be tested for the DRC using a setup similar to the prototype.
- This prevents the errors of measurement when using the metrolac that were discussed in the review of the literature.

### 4.1.2 Accompany the density measurement with a temperature measurement and using the temperature corrected DRC estimation chart

- Given the effect of temperature variation on the DRC measurement, it is vital to take the latex temperature into account when determining the DRC via any means of a density measurement.
- Hence a temperature reading should be taken in every sample that is measured for DRC and the temperature corrected chart should be referred to estimate the DRC.

### 4.1.3 Automated chemical dosing & dilution

- Once the DRC is accurately calculated the dilution and chemical dosing can be done in the automated solution with greater accuracy.
- This eliminates the measurement errors that could occur when dilution and chemical dosing is done manually.

### 4.1.4 Using a Mechanical agitator along with aeration

- Using motorized agitation to replace manual agitation will eliminate the requirement for human involvement in the process.
- The motorized agitation can be programmed in a way that follows the recommended procedure of agitation (15 minutes of agitation and similar gaps to rest the solution in between)
- Aeration can be used along with mechanical agitation to further reduce the process time and proper fractionation.

### 4.1.5 pH monitoring to determine the process end

- A similar pH monitoring system as in the prototype tank can be used in the bulking tank in the actual manufacturing process.
- An industrial-grade pH sensor or two needs to be used for continuous pH monitoring in each of the bulking tanks.

## 4.2 Industrial Implementation

- The prototype can be scaled up for implementation in the rubber manufacturing facility.
- Instead of the Arduino compatible lightweight sensors and actuators, industrial-grade equipment can be introduced.

### 4.2.1 The estimated cost of implementation

The estimated cost of implementation as estimated on 15th February 2022 is as per the table below.

Table 13: Estimated cost of implementation

| **Sample Testing** | **Estimated Cost as at 15.02.2022** |
|---|---|
| Industrial Temperature Sensor | Rs. 12000 |
| Solenoid ball valves (2) | Rs. 16000 |
| 1W-2W DC geared motor | Rs. 12000 |
| PLC | Rs. 24000 |
| Flow meters (2) | Rs. 12000 |
| HMI | Rs. 15000 |
| Industrial grade load cells (2) | Rs. 12000 |
| pH sensor | Rs. 15000 |
| Sprinkler Fabrication | Rs. 10000 |
| Chemical reservoir and water reservoir construction | Rs. 40000 |
| Modifications to the tank and installation | Rs. 10000 |
| **Total** | **Rs 178,000** |

It is difficult to predict the payback period due to the ambiguity in calculating factors like :

- Reduced rubber wastage
- Reduced production interruptions

- Reduced Employee Engagement
- Reduced chemical wastage

## 4.3 Benefits for the manufacturer due to the Suggested Improvements

### 4.3.1 Superior quality in the crepe sheets

- Accurate standardization leads to achieving the required quality and meeting the export standards for all latex crepe types.
- This reduces the risk of quality check fails that lead to non-compliance with export standards thus resulting in rejections.

### 4.3.2 Prevention of the health hazards faced by the laborers

- The implementation of the suggested improvements minimizes the requirement for human involvement in the fractionation process.
- This prevents laborers from contacting chemicals and prolonged exposure to Sulfur dioxide and other gases.
- It provides a solution for a pressing issue in the industry.

### 4.3.3 Increase in output yield

- Accurate standardization results in reduced rubber wastages due to DRC underestimation.

### 4.3.4 Reliably determining the end of the process

- The pH value monitoring system proved to be a reliable way of determining the end of the process.
- This can be implemented to replace the current practice of determining the process on based visual inspection eliminating the need for experienced employees to be involved as well as preventing the decisions to be subjective to persons.

### 4.3.5 Production cost savings

- Reduced production interruptions due to the minimal dependency on laborers for the fractionation process.
- Reduced employee engagement results in a cutback in wages thus saving a considerable amount for each production batch.

### 4.3.6 Reduced process time

- The processing time can be minimized to the mechanized agitation and aeration as tested in the prototype environment.
- The efficiency will not depend on the laborer involved.
- Determining the process end by continuous pH level monitoring also reduces the processing time.

## 4.4 Research Contribution

As for the research contributions the improvement suggestions discussed under 4.1 can be highlighted. These improvements are suggested based on the critical analysis of the literature and the experiments performed in this study. The following can be identified as key contributions from this study.

- Accurate DRC measurement technique to be used in manufacturing Crepe rubber
- Reliable method to determine fractionation process end
- Automating the manual tasks to minimize human involvement (Thus prevent health hazards and increase efficiency) – Demonstrated through a prototype implementation of the process. Industrial implementation also discussed under 4.2.

## 4.5 Limitations to the study

- The tested latex samples were from one particular crepe rubber manufacturing facility located in Eladowa, Dodangoda.
- Also, the fractionation processes were observed in only three manufacturing facilities located in Dodangoda and Paddukka.
- The procedures followed in facilities all over the country were assumed to be similar as this was the information received by the experts involved in the industry and as per the recommended methods to follow under the handbook of crepe rubber and advisory circular published on the manufacturing process by the RRISL.
- The DRC measurement method proposed is still based on the density of the latex to measure the DRC. Hence routine errors such as incorrect straining, and the addition of anticoagulants at collection centers could also lead to providing inconsistent values in DRC measurement and they would not be resolved from the proposed solutions.
- Due to the large volume of latex that arrived at the factory an apparatus was not used to remeasure the latex volume once it is received at the facility. The

volume was measured as per the recorded values from the latex collection centers.

## 4.6 Further Improvements

- Integrated data collecting and analyzing system.

A data acquisition and recording system can be added to the model in the actual implementation in order to record the production volumes, Chemical usage, and waste levels. These data can help the management of the facility in the decision-making process and forecasting. The data analyzed will assist the administration greatly.

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