CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

Transportation system is the backbone of modern civilization. From animal drawn carts to airplane, wheel is the key component. In the modern era, we can not imagine wheel without tire. Hence role of tire for road as well as air transport is very important. Ever since it was invented by John Boyd Dunlop in 1888, pneumatic tires have gained immense importance in modern civilization. A modern pneumatic radial tire is made up with composite materials where besides rubber that is the main constituent, fabric and steel are also used. The use of rubber in tires is because of its unique viscoelastic characteristics due to which it can not only absorb substantial amount of energy but also provide cushioning effect. The major limitation of rubber is that it cannot be used alone; several other chemicals and pigments need to be added to make it useful. Rubber has to be cross-linked with sulphur and accelerators to get elasticity and dimensional stability. The organic and/or inorganic materials called fillers are added to reinforce rubber for the improvement of its mechanical properties. Antioxidants and antiozonenants are added to protect rubber from oxidative and thermo-mechanical degradation.

Fillers are among the most important ingredients used in rubber compound formulation. Carbon black continues to be the most important reinforcing filler in the rubber industry followed by silica. About 5 million metric tons of carbon black is globally consumed each year while ~250,000 tons of the different silica grades are used each year. Incorporation of fillers improves mechanical and fracture properties of rubber; but at the same time it influences the hysteresis loss. The major reason of hysteresis loss in rubber is due to filler-filler interaction that is influenced by the nature of filler, its quantity and the polymeric material used.

Rolling resistance is the force acting in the opposite direction to the driving force and to over come this, a good amount of fuel is burnt. The energy consumed by the tire is converted into heat. ***Glaeser (2005) of Federal Highway Research Institute, Germany*** reports that at a constant speed of 100 km/h a passenger car needs ~50% of its fuel to overcome rolling resistance and the rest of the fuel is used to overcome air drag and in all driving conditions an average of 25% of the fuel consumption of a passenger car is due to rolling resistance (75% air drag and acceleration). He also reported that at a constant speed of 80 km/h a truck needs ~40% of its fuel to overcome rolling resistance. Energy efficient tires having 20% less rolling resistance in comparison to conventional tires reduces the fuel consumption of a car by ~5%. Improvement of 10 % rolling resistance will lead to ≈ 2 g/km less CO_2 emission.

Tire rolling resistance is greatly influenced by viscoelastic behaviour (hysteresis loss) of rubber. Approximate 90% of tire rolling loss may be attributed to hysteresis loss of rubber components. The different rubber components in a tire have their own contribution for tire rolling resistance; tread rubber alone is responsible for 39% of total tire rolling resistance (Willet 1973, 1974). In the past 20 years considerable attention has been paid to reduction of tire rolling resistance in order to reduce fuel consumption and environmental pollution, but lower rolling resistance with higher traction and better abrasion resistance are contradictory requirements from a single tire tread compound for passenger car tire.

The development of silica/silane and solution styrene butadiene rubber based passenger car tread provided a balanced approach to reduce of rolling resistance without sacrificing traction and tread wear. By using this technology tire industry has been able to cut down rolling resistance by almost 20% (Bridgestone 2002) without sacrificing traction.

Tire hysteresis loss is primary reason for tire rolling resistance which is greatly influenced by nature and volume of filler present in the compound. Carbon black has been the main filler since 1905 and only recently in the past two decades it has been partially substituted by silica. Investigation of reinforcing mechanism, filler-filler interaction and filler-polymer interactions of different fillers such as carbon black, silica and/or nanoclay are the key to understanding the role of fillers on viscoelastic properties of rubber for the reduction of tire rolling resistance.

New generation fillers like organoclay; (organic layer silicate-OLS) is gaining potential to substitute conventional fillers because of its extremely high reinforcing capability. A small quantity of nanoclay due to its very high surface area offers reinforcement similar to that by 40-50 phr of conventional fillers like carbon black and silica. As the total amount of filler is much lower in case of nanocomposite, there is a possibility of reduction of hysteresis losses. Therefore, nanocomposite based tread compounds are likely to be future candidates for low rolling resistance tires. Modified nanoclay are very interesting and potential materials for rubber reinforcement because a very small quantity (3-4 %) gives very good mechanical properties and lowers hysteresis losses too if it is well dispersed in rubber. The exfoliation of organic layer silicate (organoclay) in rubber matrix is a difficult task and reinforcement depends on the extent of intercalation and exfoliation of clay in the rubber matrix, hence success of clay is largely depends on its dispersion.

Increased vehicle population world wide especially in the emerging economics like Brazil, Russia, India and China, (BRIC) has increased fuel consumption and creating more pollutant and hence demands a renewed focus to the tire rolling resistance. Scientists and engineers are continuously working with materials and design to bring down tire rolling resistance.

The hysteresis loss of rubber can be measured by dynamic mechanical analysis in the laboratory, but measurement of its effect on tire during developmental stage is a big challenge. Finite element (FE) simulation technique is being used to predict the rolling resistance of tire in the design stage, but there are limitations too, all simulation methods use linear viscoelastic model of rubber but in reality rubber exhibits non linear viscoelastic behaviour therefore the real challenge is the non-linear viscoelastic analysis of rubber to predict the tire rolling resistance with greater precision. Hence there is scope to study the role of fillers especially organoclay on the viscoelastic properties of rubber for the reduction of hysteresis losses i.e. rolling resistance of tire and develop a suitable simulation technique to study the rolling resistance of nanocomposite based tire tread in the design stage itself.

1.2 RESEARCH OBJECTIVE

The primary objective of this study was to develop low rolling resistance passenger car radial (PCR) and truck bus radial (TBR) tire tread compounds based on nanocomposites so as to improve the fuel efficiency and reduce carbon emission. To achieve the said objective, understanding the influence of various fillers especially organoclay and combination of organoclay and conventional fillers on rubber viscoelastic properties (hysteresis properties) is of utmost importance. The properties of nanocomposites largely depend on intercalation and exfoliation of organoclay in the rubber matrix. The investigation on the influence of compatibilizer and different mixing techniques on the clay dispersion was another important aspect of this study.

The final objective was to predict the tire rolling resistance using nanocomposite based tread compounds and compare with the commercially used standard tire tread compounds based on conventional fillers like carbon black (CB) and silica. Linear viscoelastic simulation of rubber using commercial finite element software requires complex material properties and is computationally expensive. To predict tire rolling resistance accurately requires non linear viscoelastic material properties and finite element software to compute the energy loss in tire. Suitable commercial software is not available that can perform non linear viscoelastic simulation; hence a software was developed to predict rolling resistance that can very well accommodate non linear viscoelastic properties of rubber.

1.3 OUTLINE OF THE THESIS

In this investigation the major focus was given into main three areas (a) preparation and characterization of styrene butadiene rubber/Polybutadiene-organoclay nanocomposites for passenger car radial tire (PCR) tread application (b) preparation and characterization of natural rubber/Polybutadiene-organoclay nanocomposites for truck bus radial (TBR) tire tread application and (c) investigations on the rolling resistance of nanocomposite based tread compounds using finite element simulation.

The thesis is presented in eight Chapters, ***Chapter 1:*** Introduction deals with the ideas presented above. ***Chapter 2:*** presents the Literature Survey and Scope of present investigation. ***Chapter 3:*** Materials and Methods describe Experimental methods, Analytical techniques and Materials. In ***Chapter 4:*** Development and characterization of SBR/BR nanocomposites for passenger car radial (PCR) tire tread application is elaborated. ***Chapter 5*** covers Preparation and characterization of NR/BR nanocomposites for truck bus radial (TBR) tire tread application. In ***Chapter 6*** Tire finite element simulation methods, development of rolling resistance software, *"RR Code"*, temperature equation and tire temperature distribution are elaborated. In ***Chapter 7*** Investigations on the rolling resistance of nanocomposite based tread compounds using FE simulation is described. The simulated results are compared with experimental data for commercial tires. ***Chapter 8*** describes summarizes the main conclusions and highlights the scope of future work.