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Effect of ballasting on performance characteristics of bias and radial ply tyres with zero sinkage

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ABSTRACT

A study on performance characteristics of tyres such as deflection and contact area is useful to determine the optimum condition for maximizing tyre efficiency. Differences in design and dimensions of pneumatic tyre affect the output power of the tyre. Present study was conducted to evaluate the vertical deflection and contact area of 13.6–28 bias-ply and radial tyres at different ballasted conditions with five normal loads which are (i) Base weight (B0 = 1050 kg), (ii) Base weight + 50% water (B50), (iii) Base weight + iron weight equivalent to 50% water (BFe50), (iv) Base weight + 75% water (B75) and (v) Base weight + iron weight equivalent to 75% water (BFe75) at various inflation pressures ranging from 68.9 to 206.8 kPa on hard surface in controlled soil bin. It was observed that both the selected tyres showed better performance under ballast load of BFe75 over the other selected loads. At all the selected loads, the radial tyre showed 13% higher contact area and 6.5% greater deflection than the bias-ply. The obtained results at various test conditions were compared with the existing predicting models for deflection and contact area using curve fitting technique in order to select the best suitable model.

1. Introduction

Most of the tractor manufactured in India and many other developing countries fall in the category of two-wheel drive tractor in the power range of 15–75 kW. Research shows that, about 20–55% of the available tractor energy is wasted at the soil-wheel interface. This energy wears the tyres and compacts the soil to a degree that may cause detrimental crop production [3,23,27,7].

The area of soil wheel interface is influenced by tyre deflection which in turn is governed by normal load and inflation pressures. The optimum level of these parameters helps in achieving the required contact area needed to get the maximum net pull from a tractor. The normal load on a tyre can be increased either by ballasting such as addition of iron weight on tyre axle known as iron ballasting or by addition of water in the tyre known as liquid ballasting.

The net pull developed by a tractor is a key element for proper matching of tractor-implement combination and ballasting is considered to be one of the best option to improve traction, if soil is able to support it [6]. Ballasting influences the efficiency and energy use of tractor operation and affects the amount of slip in any given field condition, fuel consumption, operating time and tyre wear and tear.

In addition to the overall weight of the tractor, the weight distribution between the axle has a huge impact on tractor performance. Over-ballasting of tractor causes wastage of fuel due to increased rolling resistance and also increases soil compaction and drive train wear; whereas the under-ballasting causes wastage of fuel due to excessive wheel slip and causes premature tyre wear [12]. The wheel slip can be controlled by addition or removal of ballast from the tractor. If the slip is less than 10%, ballast needs to be reduced from the tractor, whereas, if slip is more than 20%, more ballast needs to be added to the tractor.

Several types of ballast can be used to add weight to a tractor, but cast iron blocks are the most convenient and can be changed according to ballasting needs as iron ballasting; whereas the addition of fluid to the drive tyres is more economical than iron ballasting. However, liquid ballasting is more complicated as compared to iron ballasting due to intricacy in removal of liquid from the tyre. The amount of liquid ballasting depends on size of the tyre and should be done according to the recommendation of the manufacturers. Most of the tyre manufacturers recommended that, the maximum liquid ballasting should be 75% of the total void space inside the tyre.

The primary purpose of ballasting of agricultural tyre is to increase the soil-tyre interface, which creates stress between supportive surfaces

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that determine the magnitude of traction. The performance maximization of a tractor during farm operation has been of great interest to engineers and researchers for minimizing traction loss due to the interaction of tyre with soil by using ballast. Tractive performance of tyre can be maximized by ballast management between front wheels and rear wheels [18] and the performance of tyre can be optimized by selection of appropriate normal load and inflation pressure [13].

Major objective of tractor-implement matching is to optimize the draught operation (weight, draught force and speed) by ballasting [6]. The contact area of tyre at fixed wheel normal load and at a certain soil condition can be described by the inflation pressure of tyre [20]. Tyre deflection and ground contact area are essential since tyres are responsible for giving support to the vehicle and for transferring necessary forces to obtain required kinematic behavior of a vehicle. Normal load over tyre, inflation pressure and deflection have significant effect on contact area of tyre. Role of contact area on contact pressure should also be considered equally or even more important regarding the detrimental effects of contact pressure, particularly as an inhibitor for root growth of plants [26]. The performance of agricultural tyres is mainly estimated by assessing deflection and contact area, which are the basic functions of ballasting and ballasting modes. These parameters are the key factors to be used during calculation of surface pressure [8,19] and strain stress distribution on soil [25,24,2].

In India, tractors of medium power ranging between 23 and 37 kW with 13.6–28 radial and bias-ply tyre size are most commonly used [14,22]. Tyre pressure and wheel load are critical parameters, which play a significant role in optimizing the contact area and vertical deflection. The farmers generally use iron ballast weight under heavy field operation. However, when such weights are insufficient, they go for liquid ballasting. The emphasis of present study was to evaluate the vertical tyre deflection and contact area characteristics of 13.6–28 bias-ply and radial tyres at various normal loads under iron and liquid ballasting conditions at different inflation pressure.

2. Material and methods

A study on the performance characteristics of tyres such as deflection and contact area under various ballasting conditions at different inflation pressure was conducted under controlled soil bin condition. For the present investigation, the bias-ply (Fig. 1(a)) and radial (Fig. 1(b)) tyres of 13.6–28 were used. Detailed specifications of test tyres are given in Table 1. Five different normal loads which are; (i) Base weight (B0 = 1050 kg), (ii) Base weight + 50% water (B50), (iii) Base weight + iron weight equivalent to 50% water (BFe50), (iv) Base weight + 75% water (B75) and (v) Base weight + iron weight equivalent to 75% water (BFe75) at various inflation pressure ranging from 68.9 to 206.8 kPa were studied on hard surface using single traction wheel tester as mentioned in Table 2. The load and inflation pressure used for deflection study was according to tyre and rim association standard yearbook 2005 [1].

2.1. Details of experimental setup

Tests were conducted in the soil traction laboratory of Agricultural and Food Engineering Department, IIT Kharagpur, India. The experimental set-up consists of a tyre test carriage and an electronic platform balance as shown in Fig. 2. Tyre test carriage was selected such a way that, it could accommodate various sizes of tyres with an arrangement to provide free vertical movement under static position. A hydraulic pump and hydraulic cylinder was used to apply normal loads on the carriage of test rig. Vertical deflection of the tyre was measured using a displacement transducer and recorded using a Data Acquisition System (DAS). The displacement transducer was rigidly fixed on the frame of test rig with a supported base plate attached to the side rail of the soil bin as shown in Fig. 2. The contact area of the tyre was measured using a carbon paper placed between the 2-white sheets and positioned beneath the test tyre. The sheets were clamped tightly with a steel plate in order to ensure negligible disturbance during the test process. For liquid ballasting, a centrifugal pump with a laboratory made nozzle was used to add and remove the water from tyres. The amount of water used during ballasting was measured using water flow meter as shown in Fig. 3.

(a) (b)

Fig. 1. Test tyres used in the study (a) bias (b) radial.

2.2. Experimental procedure for deflection and contact measurement

Displacement transducer consists of a potentiometer with uniform coil of wire, whose resistance is proportional to its length and rack and pinion arrangement. The transducer was calibrated before conducting the tests. Initial reading was recorded in a DAS for zero position of the displacement, then the tyre was released under gravity with normal load and the corresponding final displacement was recorded. The percent deflection of tyre is defined as the ratio of tyre deflection to the portion of the tyre section height beyond the rim flange [15] and it was calculated according to Eq. (1) [21].

$$\text{Percent tyre deflection} = \frac{\text{Vertical tyre deflection}}{\text{Carcass section height}} \times 100 \quad (1)$$

A multiple overlay technique was used to get consistent results for the lugged tyres [17,12] contact area in the present study. As stated above, the carbon paper sandwiched with white sheets was used to measure contact area. The tyre with a given inflation pressure was loaded at selected vertical loads with various dead weights on wheel tester and allowed to rest on the sheets, then the tyre was lifted-up and rotated to a few degrees and again pressed against the sheets. This procedure was repeated to obtain a good imprint of tyre on the selected white sheet by overlaying a number of prints on the same projected area as shown in Fig. 4. The outline of the contact imprint was traced and area was measured.

2.3. Statistical analysis

A general linear model (GLM) univariate procedure was employed for data analysis by considering test tyres, normal load and inflation pressure as independent variable; whereas the deflection and contact