Reduction of Energy Consumption for Tire Test Room

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Abstract. This article presents a software-implemented 3-dimensional simulated analysis of a 4-tire test room and the 6-tire test room. The results of the average performance through the simulated analysis of 100 iterations were obtained. The simulation showed the temperature distribution in the test rooms. This objective of this study was to assess the efficiency of the start-up process in each test room and to find the most efficient setup. A promising improvement would be to install the heaters at the bottom of the room under the drums instead of at the ceiling. The results of the simulation will be compared to the data of temperature logging of the tire test rooms once there is availability upon the lifting of the Covid pandemic lockdown restrictions.

1. Introduction

An essential component of any automotive vehicle is the tire. Tires generally comprise mostly of 19% natural rubber and 24% synthetic rubber, and the rest of the tire is made up of metal and other compounds [1][2]. There are multiple types of tires that are manufactured currently, and those include regular passenger tires, motorcycle tires, commercial tires, and specialty tires [3]. Before any of these tires are manufactured on an internationally large scale and sold to the populace, they undergo thorough tests and guidelines to meet certain regulations towards the respective country’s policies for safety justifications.

Although tires may look like simple pieces of rubber that have indentations, they are more intricate than what meets the eye. In general, tire testing is performed in a singular manner, two at the same time, or more with comparable features [4-6]. They are tested simultaneously as to test for different characteristics on the same tire specifications due to test facility constraints. High performance tires will most likely be tested together or a couple of motorcycle tires and passenger tires will be tested together likewise. The tests comprise of endurance, braking and handling at high and low speeds, etc [7-9]. The results from these tests are then compared to the safety regulations.

Tire endurance tests conducted at the Continental Tires comprise of mounting the tire onto a machine that rotates it at a specific speed and loaded pressure against a rotating frictional surface, or rolling drum, that simulates the traits of a road while the temperature of the test room is maintained within a specific range [10-12]. These machines can be customized to meet specific requirements such as endurance, wear, stopping distance, dry traction, and many more [13].

To simulate the characteristics and conditions of a road, specific ranges of temperature are used for specific tire test and are an essential key component to maintain during the tests [14-16]. The knowledge gap at Continental Tyre Technology Centre Malaysia is in how to maintain temperature stability in the tire test rooms and how to quickly reach the appropriate temperature range during test start up. This can be affected by the heat generated by the tires during the endurance test, as large tires and more severe tests would generate more heat. The focus of this paper will be on the latter. This study covers two tire
test rooms used for testing 4 tires and 6 tires simultaneously, as shown in Figure 1, to identify the most efficient measures to reach the required temperature range for testing.

![Test Room Layout](image)

**FIGURE 1. Test Room Layout**

2. **Literature Review**
An analysis of air flow and heat transfer in a room was conducted by Sevilgen and Kilic [17] that can be beneficial towards this study by aiding the process of simulation of heat generated by heaters in the test room as well as the heat removed by the air conditioner and exhaust. As stated by Sevilgen and Kilic, boundary conditions are an essential key component that can affect the results of the simulation. Setting the boundary conditions for the mannequin in their experiment as a constant temperature as to not affect the ambient temperature, for instance. Another key component stated by them would be the humidity of the room to be kept constant as the results would provide a maximum uncertainty of around 2%.

Power consumed and energy generated by the machine can be calculated with the aid of the article by Li et al [18]. The focus of their experiment is to correlate a relationship between the rolling resistance of the tire and the transient temperature. This is simply the energy dissipated per cycle per unit volume, otherwise known as hysteresis energy density [19]. Without disregarding the contact area between the tire and the drum, the articles by the Vehicle Dynamics Institute and Diserens et al can provide beneficial numerical equations and calculation methods towards the energy generated from rolling friction at the contact area [20][21].

In the article by Wang et al [22], the focus of the experiment was to propose a numerical simulation and an optimal design will be proposed for the ginseng drying room. This can prove beneficial towards this study as it provides a structured method in analysing the tire test rooms. The team stated that the location of the heaters in the room are a key component towards the results and that the best location for the heaters is located at the bottom on the floor of the room to provide an equal flow of heat in the room. It was also stated that, if the velocity of air flow by the heaters was not kept constant, the results will fluctuate and cause uncertainties. Lastly, this article provides useful calculations for heat transfer and air flow in the drying room that can be brought over to this study.

3. **Research Methodology**
Following site visits to the Continental Tyre Technology Centre Malaysia test rooms, the first step was to collect the tire testing machine’s data and specifications, as well as the air conditioners and the heaters specifications. The energy generated, heat removed, and heat produced by each machine, air conditioner and heater in the tire test room can be calculated from these data.

Using the 3D modelling software, SolidWorks, models of the tire test rooms were created. Then Computational Fluid Dynamics (CFD) simulation software, ANSYS, was used to provide an initial
simulated analysis to further understand the air flow and heat transfer within the test rooms. To validate the initial simulations, several thermometer probes are needed at specific parts of the test rooms to conduct temperature logging of the ambient temperature to understand the air flow and heat transfer of the room.

However, this can only be conducted with permission from Continental Tyre Technology Centre Malaysia as well as to not hinder their daily operations. In addition, the temperature logging can only be conducted if the current state of the pandemic allows when lockdown restrictions are lifted.

The data provided by Continental Tires are tabulated in Table 1 and 2.

**TABLE 1. Machine Specifications**

| Machine | Type          | Drum Diameter (mm) | Drum Width (mm) | Speed (km/h) |
|---------|---------------|--------------------|-----------------|--------------|
| M6040   | 2 Station (2 units) | 1707               | 500             | 10-250       |
| M6010   | 6 Station     | 1707               | 350             | 20-120       |

**TABLE 2. Air Conditioner and Heater Specifications**

| Items/Machine | M6010 | M6040 |
|---------------|-------|-------|
| Air Conditioner | | |
| Model         | York MYSS100B | Daikin RVN100HMHY1C |
| Quantity      | 2     | 2     |
| Outdoor Power (kW) | 9.20  | 8.65  |
| Heater | | |
| Quantity | 1 | 2 |
| Power Capacity (kW) | 30 | 15 |

The use of Seasonal Energy Efficient Ratio (SEER) Level and the coefficient of performance rating towards cooling can be used to calculate the amount of heat removed. In terms of the contact area, the use of rolling friction and the circumference of the tire can be used to obtain the heat generated from the tire test.

4. **Results and Discussion**

4.1. *Heat Generated by Heater*

The amount of heat generated from one heater is given as 15kW for the 4-station test room and 30 kW for the 6-station test room (Table 2).
4.2. Heat Removed by Air Conditioner in 4-Station Test Room
To calculate the heat removed by the air conditioner, the Coefficient of Performance (COP) rating may be used.

\[ \text{COP}_{\text{cooling}} = \frac{Q}{W} \]  

(1)

Where, Q is the heat removed, and W is the work done by the system. Referring to the information provided by Daikin [23], this specific unit has a SEER Level of 24.5. Assume that when the air conditioner is used during the test, it is functioning at the highest level. In addition, 1 SEER Level is equal to a COP of 0.293 [24]. With this, 24.5 SEER Level is equivalent to a COP of 7.1785. Using Equation (1), the amount of heat removed from the air conditioner is as follows.

\[ \therefore Q = 7.1785 \times 8650W = 62094.03W \]

4.3. Heat Removed by Air Conditioner in 6-Station Test Room
Similar to subsection 4.2, by referring to the information provided by York [25], the specific unit used has a SEER Level of 13. With this information, 13 SEER Level is equivalent to a COP of 3.809. From Equation (1),

\[ \therefore Q = 3.809 \times 9200W = 35042.80W \]

4.4. Heat Generated from Tire Contact Area
The coefficient of rolling friction caused was based on [26]. To create consistency in the results, a specific passenger car tire size of 225/60R16 which suggests that the width of the tire is 225 mm, the aspect ratio of the tire is 60, and the size of the rim is 16 inches. Additionally, the pressure in the tire is kept at 32 psi or 220.632 kPa constantly. Based on this, the length of the tire contact is 141 mm [27]. The loaded pressure provided by Continental Tires is 180 kPa for standard tests.

The equation for rolling friction is shown below in Eq. (2), \( F_r \) is rolling friction, \( \mu_r \) is the coefficient of rolling friction, 0.015 [28], and \( F_N \) is the normal force applied on the tire. To acquire \( F_N \), the formula is as shown below in Eq. (3). Where \( F_N \) is normal force, \( P \) is the loaded pressure applied, and \( A \) is the tire contact area.

\[ F_r = \mu_r \times F_N \]  

(2)

\[ F_N = P \times A \]  

(3)

\[ F_N = 180 \text{ kPa} \times (141 \text{ mm} \times 225 \text{ mm}) = 5.71 \text{ kN} \]

\[ F_r = 0.015 \times 5.71 \text{ kN} = 85.66 \text{ N} \]

The power, or heat generated by the tire can be obtained from the Equation (4).

\[ P = F_r \times v \]  

(4)

The speed of the test provided by Continental is given as 80 km/h [29] for this specific tire size. Converting 80 km/h to m/s and applying Eq. (4),

\[ \therefore P = 85.66 \text{ N} \times 22.22 \frac{\text{m}}{\text{s}} = 1.90 \text{ kW} \]
Assuming that the interaction between the tire and the rolling drum in the 4-Station is similar to the 6-Station, the heat generated by each tire contacting the rolling drum is the same. An assumption was also made that there is no residual heat from the motors in the machine that can cause any significant temperature change. Table 4 shows the total amount of heat generated or removed by the heater, tire contact area or air conditioner, respectively.

**TABLE 3. Heat Generated and Removed by the Heaters, Air Conditioners and Tire Contact Area**

| Station | Total Heat Generated by Heater (kW) | Total Heat Removed by Air Conditioner (kW) | Total Heat Generated by Tire Contact Area (kW) |
|---------|------------------------------------|--------------------------------------------|-----------------------------------------------|
| 4 Station | 15                                 | 62.09                                      | 7.61                                          |
| 6 Station | 30                                 | 35.04                                      | 11.42                                         |

Data from Table 4 is then used for the CFD simulation. The initial 3D models were created as shown in Figure 2 and 3. In Figure 2, the locations of the heater and air conditioner are as specified by the current conditions at Continental. The heater and air conditioner in the initial 4-Station room are placed directly opposite each other on the walls perpendicular to the separation. Whereas for the initial 6-Station room, referring to Figure 3, this figure represents a slice of the room to have a better understanding and view of the room model. The location of the air conditioners is placed opposite each other as well as the location of the heaters. These locations are as specified by the current situation at Continental.

**FIGURE 2.** Initial 4-Station 3D Model

**FIGURE 3.** Initial 6-Station 3D Model

Next, the 3D models run through the ANSYS software where a mesh for both models are created to influence the accuracy of the results as shown in Figure 4 and 5 below. These mesh elements allow for governing equations to be solved on predictably shaped and mathematically defined volumes through the software [30].
Then, the air flow and temperature distribution of air is analysed and recorded. The air flow is represented by Figure 6 and 7. From both these figures it is shown that there is a lot of collision occurring which can lead to inefficient airflow throughout the rooms. In Figure 6, it is shown that there are portions of the room that the air does not cover. Similarly, in Figure 7, due to the collision between the air conditioners and heaters the air is centralised towards the top middle portion of the room not allowing for even air flow and heat transfer.

The temperature distribution of the initial 4-Station room is represented by Figures 8 to 12. The temperature distribution is tabulated in increments of 5 degrees Celsius starting from 17°C to 37°C as to have a better understanding of how the temperature is distributed at different stages. The reason behind these temperatures is due to the maximum performance of both air conditioner and heater, respectively. At 27°C is when the required temperature range is reached for this specific tire size. When referring to Figure 8, the coldest air distributed throughout the room is located right at the air conditioner outlet.
FIGURE 8. Temperature distribution of the Initial 4-Station model at 17°C

Figure 9, at 22°C, shows how the temperature is distributed and focused on the rolling drums and does not have and even airflow throughout the room.

Figure 10, at 27°C, shows how the temperature is distributed throughout the entire room. Due to the airflow of the room and the collisions as well, the temperature is distributed similarly to the airflow in Figure 6.

In Figure 11, the temperature distribution at 32°C shows the temperature distributed mostly at the heater location with a slight trail on one of the rolling drums.

Similarly, in Figure 12, the temperature at 37°C is distributed and localised solely on the exit of the heaters only.
The temperature distribution of the initial 6-Station room is represented by Figures 13 to 17. Similar to the simulation conducted on the initial 4-Station room, the data is tabulated in increments of 5 degrees Celsius starting from 17°C to 37°C. Since the tire size is kept constant, the required temperature range is reached at 27°C. In Figure 13, the temperature distributed at 17°C. It is shown that the temperature at this stage is localised at the exit of the air conditioner only similarly in Figure 8.

In Figure 14, it is shown how the temperature is distributed at the 22°C stage. Most of the temperature is distributed in the corners of the room rather than evenly throughout the room.

In Figure 15, the temperature distributed at the 27°C stage is shown to be colliding with each air conditioner and heater output and is also centralised at the top of the room rather than evenly throughout the room.
FIGURE 15. Temperature distribution stages of the Initial 4-Station model at 27°C

In Figure 16, shows how the temperature distribution at 32°C is localised and focused on the exit of the heater.

FIGURE 16. Temperature distribution stages of the Initial 4-Station model at 32°C

Similar to Figure 16, in Figure 17, it shows how the temperature distribution at 37°C is localised and focused on the exit of the heater.

FIGURE 17. Temperature distribution stages of the Initial 4-Station model at 37°C

The time taken for the initial models to reach the required temperature are 5-6 minutes and 6-7 minutes for the 4-Station room and 6-Station room respectively. From here, new locations for the air conditioners and heaters will be created in new models to run through the same simulation as the initial models. This new location is selected as the optimal location as hot air rises and cold air sinks. By allowing the heater to be placed below the rolling drums, this would allow for the hot air to flow evenly throughout the room as compared to the initial design where the air flow was concentrated above the rolling drum, collisions between the systems and was not evenly spread throughout the room. The new
mesh of each room was also created and is simulated through the software with similar parameters as the initial simulations. Figures 18 and 19 are the results of the new model designs of each test room.

Similar to Figures 4 and 5, the meshes of the new model designs were created as represented in Figures 20 and 21 below.

Then, the new meshes are placed into the simulations with the same parameters as the initial simulations. Figures 22 and 23 show the results of air flow of the new models. As shown in Figures 22 and 23, the air flow of both rooms significantly covers more volume of the room and there are also less collisions between the air flow of the air conditioners and heaters.

Figure 24 shows how the temperature distribution at 17°C is concentrated at the exit of the air conditioner only, similar to Figures 8 and 13.

![New 4-Station 3D Model](image1)

**FIGURE 18.** New 4-Station 3D Model

![New 6-Station 3D Model](image2)

**FIGURE 19.** New 6-Station 3D Model

![Mesh of New 4-Station 3D Model](image3)

**FIGURE 20.** Mesh of New 4-Station 3D Model

![Mesh of New 6-Station 3D Model](image4)

**FIGURE 21.** Mesh of New 6-Station 3D Model
FIGURE 22. Air flow of the New 4-Station Model  

FIGURE 23. Air flow of the New 6-Station Model

FIGURE 24. Temperature distribution stages of the New 4-Station model at 17°C

Figure 25 shows how the temperature distribution at 22°C flows over the drum as well as the tires.

FIGURE 25. Temperature distribution stages of the New 4-Station model at 22°C

Figure 26 shows how the temperature distribution at 27°C flows evenly throughout the new 4-Station room and covering more volume of the room when compared to the initial model at the same stage in Figure 10.
FIGURE 26. Temperature distribution stages of the New 4-Station model at 27°C

Figure 27 shows how the temperature distribution at 32°C is spread evenly under the rolling drum and rises alongside.

FIGURE 27. Temperature distribution stages of the New 4-Station model at 32°C

Similar to Figure 27, Figure 28 shows how the temperature distribution at 37°C is centralised towards the exit of the heater at this stage.

FIGURE 28. Temperature distribution stages of the New 4-Station model at 37°C

Moving on to the New 6-Station Model, Figure 29 shows how the temperature distribution is localised at the air conditioner exit only.
FIGURE 29. Temperature distribution stages of the New 6-Station model at 17°C

Figure 30 shows how the temperature distribution at 22°C is colliding at the rolling drum instead of colliding and spreading to the corners when compared to Figure 14.

FIGURE 30. Temperature distribution stages of the New 6-Station model at 22°C

Figure 3 shows how the temperature is distributed at 27°C and how the temperature is rising evenly throughout the room as compared to Figure 15 where it was centralised above the rolling drum.

FIGURE 31. Temperature distribution stages of the New 6-Station model at 27°C

Figure 32 shows how the temperature distribution at 32°C is localised and focused on the exit of the heater only.
FIGURE 32. Temperature distribution stages of the New 6-Station model at 32°C

Similar to Figure 32, Figure 33 shows how the temperature distribution at 37°C is centralised on the exit of the heater only.

FIGURE 33. Temperature distribution stages of the New 6-Station model at 37°C

The time taken for the new models designs to reach the required temperature range for this specific tire size is around 4-5 minutes and 5-6 minutes for the new 4-Station room and new 6-Station room, respectively. Table 4 summarizes the time taken for each model to reach the required temperature range.

| Station       | Time Taken to reach required temperature range (min) |
|---------------|-----------------------------------------------------|
| Initial 4 Station | 4.5-5.5                                              |
| Initial 6 Station | 5.5-6.5                                              |
| New 4 Station  | 3.5-4                                                |
| New 6 Station  | 4.5-5                                                |

When comparing Figures 6, 7, 22 & 23, it is shown that the new setup provides better air flow throughout the test rooms. This would also suggest better heat transfer as the air flow covers more volume throughout the rooms. When comparing the figures of the temperature distribution of the initial and new model rooms, it is shown that the new models have better temperature distribution throughout each test room at each stage. This is due to the better air flow in each room. From Table 4, the model of
the new setups also reached the required temperature range in a shorter amount of time. This would be due to the better airflow and temperature distribution.

5. Conclusion
In conclusion, two tire test rooms were modelled and simulated. However, the thermometer probes for temperature logging were not set up due to the current lockdown situation caused by the Covid pandemic. As a proposed improvement, the recommended location for the heaters in both rooms should be below the rolling drums of the test machine so as to allow for better heat flow throughout the test rooms and this could be observed by comparing the air streamline movements of the simulated models of the initial and new setups. The simulation showed shorter time taken to reach the required test temperature range.

Future work would continue into investigating measures for maintaining temperature stability in the two tire test rooms while the tests are ongoing. This would require an understanding of the room designs and the factors that affect the cooling load of the rooms [31][32].

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