

## An Experimental Analysis of Brake Efficiency Using four Fluids in a Disc Brake System

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**Abstract:** The paper studies disc brake failure in Mini-buses using an experimental analysis to test the maximum braking force when different brake fluids such as clean, less dirty, dirty and soapy water solution were used in the braking system. The experimental results clearly showed that the soap solution appears to be the best fluid as far as low viscosity and stability of viscosity with increase in temperature are concerned. However, the soap solution is not compatible with other fluid which makes it difficult to be substitute as a clean brake fluid. The result of the Thepra Universal Brake Testing Equipment used for the braking efficiency test indicated that a pedal brake of 117 kN produce a brake force of 0.96 kN for clean brake fluid, 0.91 kN for the less dirty, 0.85 kN for dirty and 1.44 kN for soap solution. The value of 1.44 kN which was achieved when the soap solution was used indicated a positive braking force and the indicating that soap solution could be used to produce a high pedal force within a very short time (about 10-30 min) and can therefore be used only in case of emergency. The brake efficiency test indicated that under hot conditions the braking efficiency is reduced and the presence of air in the system renders the braking ineffective because higher pedal force was needed to be able to produce a significant braking force which is noted for causing brake failure.

**Keywords:** Brake fade, brake failure, disc brake, efficiency, pedal force

### INTRODUCTION

When a vehicle is accelerated, energy supplied by the engine causes the vehicle's speed to increase. Part of this energy is instantly used up in overcoming frictional and tractive resistance but a large amount of it remains stored in the vehicle. According to Heinz (1999) this energy of motion is called the kinetic energy and the existence of kinetic energy is observed when a vehicle is moving and neutral gear is selected. The vehicle does not immediately come to rest; instead it travels for a considerable distance before it becomes stationary. In this case the stored energy is used to drive the vehicle against the resistances that oppose the vehicle's motion. Relying on these resistances to slow down a vehicle could cause many problems, so an additional resistance called a brake is needed to convert the kinetic energy to heat energy at a faster rate in order to reduce the speed of the vehicle Mcphee and Johnson (2007). This reduces the speed of the vehicle at a faster rate and brings the vehicle to rest within the shortest possible time when the brakes are applied.

From the point of view of Johnson *et al.* (2003) most automotive systems in use today utilize front disc

brakes, but four-wheel disc systems are also common. In disc brakes, the rotor rotates with the wheel and the pads move out to rub the rotor when the brakes are applied. Most disc brakes use floating calipers. The caliper slides in and out as the brakes are applied and released. The piston moves the inside pad out and pushes the outside pad into the rotor by sliding the caliper back toward the rotor.

The use of disc brakes to reduce speed or bring the vehicle to rest when in motion cannot be over emphasized if the safety of the occupant is to be guaranteed Heinz (1999). To bring a vehicle to a stop, the disc brakes have to absorb all the energy given to the vehicle by the engine and that due to the momentum of the vehicle. This energy must then be dissipated. In most vehicle disc brakes, the energy is absorbed by friction, converted into heat and the heat dissipated to the surrounding air (Thoms, 1988). As the energy is absorbed, the vehicle is slowed down; in other words, its motion is retarded. The brakes must also pull up the vehicle smoothly and in a straight line to bring the vehicle to a stop position.

It is therefore very important that the disc brakes of vehicles operate with the highest efficiency. This could

reduce the rate of accidents due to brake failure so that life and property could be preserved and also to ensure that occupants of these commercial vehicles go about their normal lives without any fear of being involved in an accident. Available crash data in Ghana suggests that about 1,900 persons are killed annually in road traffic crashes (Afukaar *et al.*, 2008) and that more than 40% of the road traffic fatalities are occupants of cars, buses and trucks. Most often than not, some of the road accidents involving commercial vehicles, such as the mini-buses have been attributed to the failure of the disc brakes. The reason for testing the viscosity of these brake fluids, especially that of the soap solution was as a result of the practice of most Ghanaian drivers sometimes using the soapy solution as a substitute to the original brake fluid in the braking system and also using dirty brake fluid which has been used for bleeding purposes. The main objective of this study which is part of a larger work seeks to investigate and establish the reasons for the disc brake failure due to brake fluid also check the efficiency of the four different types of fluids used in the transmission of braking forces. The study looked at the maximum braking force when using clean, less dirty, dirty and soapy water solution in the braking system. It also looked at the braking force when the braking system is with or without servo unit and operating under cold or hot condition with air or without air in the braking system.

### DISC BRAKES

The disc brake consists of an exposed disc which is attached to the hub flange; the two friction pads are pressed on to this disc to give a braking action. Figure 1a, shows the disk brake system of a car and pad that is separated from wheel assembly to better shows the disk

and the pad in sliding contact. As it can be seen, typical disk brake system and caliper assembly of a solid disk brake rotor is completely noticeable. Figure 1b shows schematic form of the disk and the pad in sliding contact assembly. The pads are moved by hydraulic pistons working in cylinders formed in a caliper that is secured to a fixed part of the axle. When the hydraulic pressure is applied to the two cylinders held in the fixed caliper, the pistons move; this action forces the friction pads into contact with the rotating cast iron disc. The sandwiching action of the pads on the disc gives a retarding action and heat generated from the energy of motion is conducted to the disc.

Greater part of the disc is exposed to the air; therefore heat is easily radiated, with the result that the brake can be used continuously for long periods before serious fade occurs. Since the friction pads move at a right angle to the disc, any drop in the friction value does not affect the force applied to the pad. As a result this type of brake is not less sensitive to heat (Mudd, 1972). The disc brake was developed to minimize the fade problems. When fading occurs, the driver has to apply a much larger effort and in extreme cases it becomes impossible to bring the vehicle to rest. No assistance is obtained from the rotating disc to aid the driver in the application of a disc brake to achieve a given retardation. A disc brake requires a greater pedal pressure and to achieve this pressure required the hydraulic braking system using a good quality brake fluid in its operation.

The fluid used in the hydraulic braking systems is a vegetable oil with certain additives. According to Nunney *et al.* (1998) a good brake fluid should have the following requirements, low viscosity, high boiling point, compatibility with rubber components, lubricating properties, resistance to chemical ageing and compatibility with other fluids. However, most

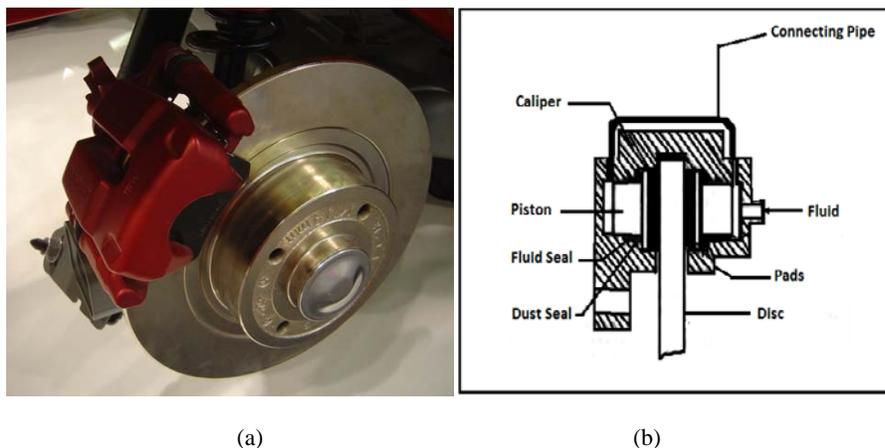


Fig. 1: Disc brake

Ghanaian drivers sometimes used other fluid such as dirty brake fluid, less dirty fluid and even soapy water sometimes as a substituted to the original brake fluid. This study among other things will also investigate which of these brake fluid, clean, dirty, less dirty and soapy water will have the best viscosity, high boiling point and less braking force.

## MATERIALS AND METHODS

The design used for this study was experiment which employed the used of viscometer and Thepra Universal Automotive Brake Testing machine to check the efficiency of the four fluids in the transmission of braking forces.

**Laboratory analysis:** The viscosity tests on the four different liquids were carried out at the Kwame Nkrumah University of Science and Technology (KNUST) Thermodynamics laboratory. The liquids were clean brake fluid, less dirty brake fluid, dirty brake fluid and soap solution. It was necessary to find out how the viscosity of different qualities of brake fluid affected braking efficiency and to find out whether there was any correlation between these and the occurrence of brake failure.

**Viscosity test on the various fluids used:** The viscosity test was carried out on a Redwood Viscometer

in Fig. 2 on the four different kinds of fluids to determine their viscosities. The apparatus consists of a vertical cylinder containing the fluid under test which was allowed to flow through a calibrated orifice situated at the centre of the cylinder base. The orifice is closed by a ball valve when it is not being used. The oil cylinder is surrounded by a water jacket which maintains the lubricant under test at a required temperature by means of a Bunsen burner flame applied to the heating tube. The thermometer for the water in the jacket is mounted in a paddle-type stirrer which can be rotated by hand, using the handle (Zammit, 1987).

**Procedure for testing various viscosities of the fluids:** To test the viscosity of a fluid, the water jacket was filled with water with the orifice ball valve in position. Fluid was poured into the cylinder to the level of the pointer. A 50 mL measuring flask was placed centrally under the orifice. The water was stirred gently until the water and fluid thermometers were the same (room temperature, 30°C). The temperature was recorded. The ball valve was then raised and a stopwatch used to record the time (in seconds) for a 50 mL of fluid to flow into the measuring flask. The test was repeated with the fluid temperatures increasing by 10°C each time up to 90°C. All the data for the four different fluids were recorded as shown in Table 1.

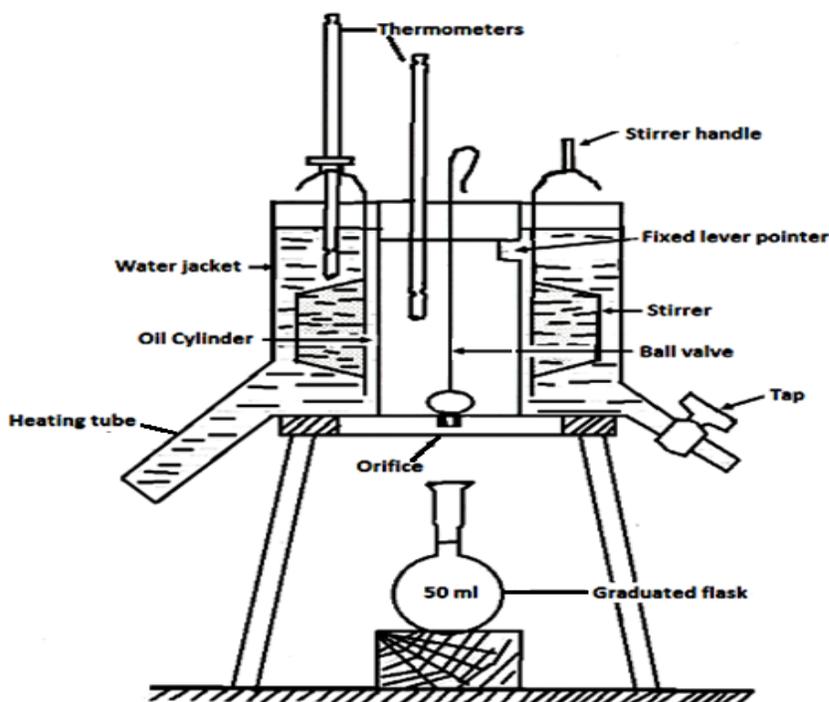


Fig. 2: Redwood viscometer used to determine the viscosity of the fluids

Table 1: Viscosity test

| Temperature<br>°C | Clean fluid |                                    | Less dirty fluid |                                    | Soap solution |                                    | Dirty fluid |                                    |
|-------------------|-------------|------------------------------------|------------------|------------------------------------|---------------|------------------------------------|-------------|------------------------------------|
|                   | Time min    | Viscosity<br>[kgs/m <sup>3</sup> ] | Time min         | Viscosity<br>[kgs/m <sup>3</sup> ] | Time min      | Viscosity<br>[kgs/m <sup>3</sup> ] | Time        | Viscosity<br>[kgs/m <sup>3</sup> ] |
| 30                | 1:22:05     | 82.05                              | 4:54:72          | 230.00                             | 28:00         | 28.94                              | 7:50        | 234.72                             |
| 40                | 1:0:11      | 60.11                              | 2:52:38          | 172.38                             | 25:00         | 25.06                              | 3:18:22     | 198.22                             |
| 50                | 0:50:00     | 50.00                              | 1:46:16          | 106.16                             | 23:00         | 23.30                              | 3:14:02     | 194.02                             |
| 60                | 0:40:47     | 40.47                              | 1:00:47          | 60.470                             | 21:00         | 21.00                              | 3:10:00     | 190.00                             |
| 70                | 0:37:07     | 37.07                              | 0:42:44          | 42.440                             | 20:00         | 20.05                              | 3:07:01     | 187.01                             |
| 80                | 0:34:15     | 34.15                              | 0:36:47          | 36.470                             | 20:00         | 20.00                              | 3:02:19     | 182.19                             |
| 90                | 0:30:22     | 30.22                              | 0:34:31          | 34.310                             | 19:00         | 19.50                              | 2:57:59     | 177.59                             |

Values of the various viscosities were calculated using the formula:

$$V = \frac{h_f \rho g D^2}{32 h_f \nu}$$

where,

V : The Viscosity

h<sub>f</sub> : The capillary height

ρ : The density of the fluid

g : Acceleration due to gravity

D : The diameter of the orifice

ν : The velocity (Bird *et al.*, 1960)

### Thepra universal stand automotive brake testing equipment:

The Thepra Universal Stand Automotive brake testing equipment is structured in such a way that the driven part, such as brake disc, was plugged on to the motor shaft. The brake anchor plate and the caliper are fastened to a flange via a linkage of bar which is connected to the flange. The brake force is measured and displayed on a digital indicator. The individual units are plugged into the two span-frames which are fastened to both sides. All the brake components used in the testing equipment are original vehicle components. The pedal force is measured at the actuating linkage of the brake master cylinder and displayed on a digital indicator (Technolab, 2009).

## RESULTS AND DISCUSSION

**Experimental results of viscosity test:** Table 1 present the results of viscosity test in an experiment for the four fluids, using the Redwood Viscometer.

From the test results obtained using Redwood viscometer, Viscosity-Temperature graphs for the fluids were plotted. Figure 3 shows the plot of viscosity against temperature of the four fluids.

From Fig. 3 the dirty fluid has the highest viscosity followed by the less dirty fluid, clean fluid and soap solution in that order. From the results shown in Fig. 2 and the viscosity test shown in Table 1, the soap solution appear to be the best fluid as far as low

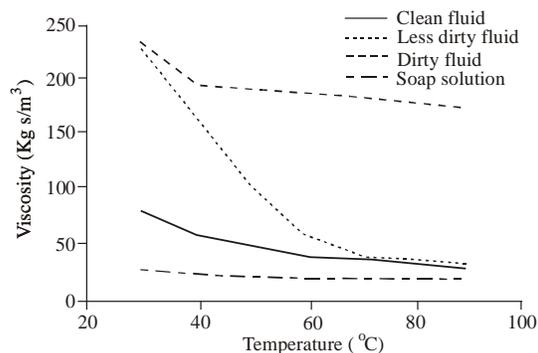


Fig. 3: Viscosity-temperature relationship of the fluids

viscosity and stability of viscosity with increase in temperature are concerned. However, it is less compatible with other fluids, difficult to mix easily with other brake fluids and has a low boiling point which will not make it suitable to be substitute as clean brake fluid (Nunney *et al.*, 1998).

The clean brake fluid is next as far as viscosity and stability of viscosity with increase in temperature are concerned. On the other hand, it satisfies all the other requirements of a good fluid for the braking system given in Table 1. According to Mudd (1972) and Nunney *et al.* (1998), a good brake fluid should have properties such as high boiling point, compatibility with rubber components, good lubrication properties, resistance to chemical ageing (long shelf life) and compatibility with other fluids. The less dirty fluid is very unstable as far as viscosity change with temperature increase is concerned. It is therefore not very reliable in a braking system since its behavior changes as the braking system heats up. The viscosity of the dirty fluid is stable with increase in temperature, however, it is very viscous (235-178 kgs/m<sup>3</sup> in the temperature range 30 to 90°C). It will therefore not be good and effective in brake force transmission. From these results and literature, it is obvious that the clean brake fluid is more suitable for the transmission of braking force as it's possess all the good brake fluid qualities.

Table 2: Results of disc brake in cold condition with servo

| Pedal force (KN) | Brake force (KN)  |                        |                   |               |
|------------------|-------------------|------------------------|-------------------|---------------|
|                  | Clean brake fluid | Less dirty brake fluid | Dirty brake fluid | Soap solution |
| 117              | 0.96              | 0.91                   | 0.85              | 1.44          |
| 210              | 1.42              | 1.47                   | 1.63              | 1.13          |
| 321              | 1.88              | 1.83                   | 1.85              | 1.22          |
| 422              | 2.12              | 2.07                   | 2.14              | 0.91          |
| 506              | 2.25              | 2.20                   | 2.21              | 0.82          |

Table 3: Results of disc brake in hot condition with servo

| Pedal force (KN) | Brake force (KN)  |                        |                   |               |
|------------------|-------------------|------------------------|-------------------|---------------|
|                  | Clean brake fluid | Less dirty brake fluid | Dirty brake fluid | Soap solution |
| 120              | 0.95              | 0.90                   | 0.85              | 0.19          |
| 236              | 1.73              | 1.68                   | 1.63              | 0.34          |
| 312              | 1.95              | 1.90                   | 1.85              | 0.39          |
| 447              | 2.24              | 2.19                   | 2.14              | 0.44          |
| 502              | 2.31              | 2.26                   | 2.21              | 0.46          |

**Experimental results of the disc brake system:**

These sections present the results and discussion of the experiments using the four fluids in a Disc brake system under different conditions. Test results for hot and cold conditions of the Disc brake system using a servo system and without using a servo system were considered.

**Disc brake in cold condition with and without servo unit:**

The result in Table 2 clearly shows the pedal force and the brake force for clean, less dirty, dirty and soap solution when using disc brake in cold condition with servo unit with the Thepra Universal Brake Testing Equipment. A pedal brake of 117 kN produce a brake force of 0.96 kN for a clean brake fluid, 0.91 kN for the less dirty, 0.85 kN for dirty and 1.44 kN for soap solution. Comparatively, a maximum brake force is achieved when the fluid is clean. When there is the presence of dirt, the brake force decreases and therefore more pedal force is needed to take up the loss created by the dirt. Hence the greater the dirt, the greater the pedal force required.

The value of 1.44kN which was achieved when the soap solution was used indicated a positive braking force compared with all the three fluids at the same pedal force. Subsequent pedal forces applied as shown in Table 2 gave a reduction in the brake force when soap solution was used. The implication was that soap solution could be used to produce a high pedal force within a very short time (about 10-30 min) and can therefore be used in case of emergency.

From Table 2, it can be observed that for the same pedal force of 117 KN the soap solution transmitted the highest amount of brake force followed by the clean fluid, less dirty fluid and dirty fluid in that order. This implies that in cold condition using servo, the soap solution performs best followed by the clean, less dirty and dirty respectively.

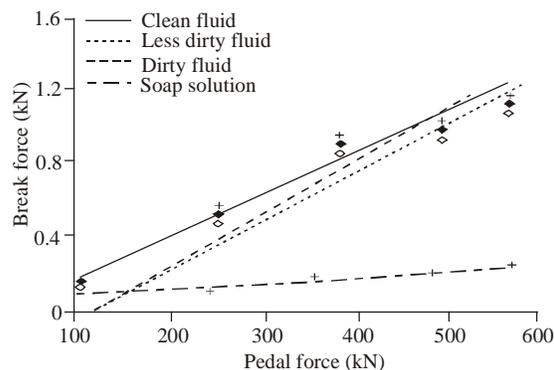


Fig. 4: Results of disc brake in hot condition without servo

**Disc brake in hot condition with servo unit:** When the experiment was carried out using a disc brake under the hot conditions with the introduction of a servo, a pedal force of 120 kN gave a brake force of 0.95 kN for clean fluid, 0.90 kN for less dirty, 0.85 kN for a dirty fluid and 0.19 KN for soap solution. The result could be explain that, the clean brake fluid gave the highest brake force follow by less dirty, dirty and soap solution. It was observed that the soap solution perform poorly at this time recording a brake force of 0.19 KN as shown in Table 3.

**Disc brake in hot condition without servo:** Figure 4 shows a plot of disc brake in hot condition without servo unit. It can be observed that, under hot conditions for the disc brake without servo, the trend is generally the same. The soap solution performed very badly compare with the other fluids, unlike its performance under cold conditions. This may be due to evaporation of the fluid making the fluid compressible; as if air was in the braking system. Generally, the clean fluid performed best in terms of transmission of brake force followed by the less dirty, dirty and soap solution in that order.

Table 4: Results of disc brake with air in system under cold condition with servo

| Pedal force (KN) | Brake force (KN)  |                        |                   |               |
|------------------|-------------------|------------------------|-------------------|---------------|
|                  | Clean brake fluid | Less dirty brake fluid | Dirty brake fluid | Soap solution |
| 165              | 0.30              | 0.28                   | 0.37              | 0.32          |
| 265              | 0.44              | 0.49                   | 0.65              | 0.43          |
| 378              | 0.53              | 0.54                   | 0.74              | 0.52          |
| 456              | 0.61              | 0.57                   | 0.76              | 0.56          |
| 567              | 0.74              | 0.60                   | 0.79              | 0.62          |

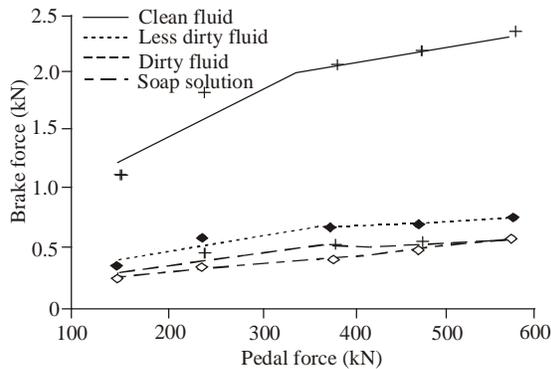


Fig. 5: Results of disc brake with air in system under hot condition with servo

**Disc brake with air in system under cold condition:**

Braking force for this experiment was generally low as compared with the case when air was not trapped in the system as shown in Table 4. When the experiment was conducted with a pedal force of 165 kN, braking force of 0.32 kN soap solution was obtained, for 0.37 KN for dirty, 0.28 KN for less dirty and 0.30 kN for clean fluid. This is in line with literature because according to Mudd (1972) the presence of air in the braking system makes the system ineffective since much of the drivers effort will be used to compress the air leaving very little for the brake application. Again, the soap solution did not give the least braking force because when the system is cold, soap solution is effective and its density is higher since there is no occurrence of evaporation of the solution.

**Disc brake with air in system under hot condition:**

The Fig. 5 shows the plot of a graph indicating disc brake with air in the system under hot condition clearly shows that, when a pedal force of 152 kN was applied, a brake force of 1.11 kN was obtained for clean, 0.37 kN for less dirty, 0.28 kN for dirty and 0.26 kN for soap solution. It was observed that the maximum brake force was attained when the fluid was clean and on the introduction of dirty fluid, the brake force reduced drastically, though the pedal force was very high at 152 kN in the hot condition.

Soap solution provides the least brake force because the air content in the system increases due to

evaporation and hence the pedal force compresses air rather than transmitting power. As the system heats up, the air in the system expands thereby reducing the braking efficiency which results in brake failure.

**CONCLUSION**

The study was conducted using an experiment performed on a Thepra Brake Testing Equipment to check the efficiency of the four fluids in the transmission of braking forces. According to the viscometer test shown that the soap solution appears to be the best fluid as far as low viscosity and stability of viscosity with increase in temperature is concerned. However, it is less compatible with other fluids, difficult to mix easily with other brake fluids and has a low boiling point which will not make it suitable to be substituted as a clean brake fluid.

Again, when air is trapped in the braking system, which results in the brake fluid being compressible, higher pedal force was needed to be able to produce a significant braking force.

Also, when brakes are operated under hot conditions its efficiency is reduced, a fault known as brake fade occurs as a result of the heating up of the brakes which creates less frictional resistance between rotating disc and the frictional pads.

Finally, Soap solution when used at cold condition produces high braking force but becomes less effective after prolong use due to the presence of heat which evaporates the soap solution.

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