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Research Article

An Experimental Analysis of Brake Efficiency Using Four Fluids in a Drum Brake System

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Abstract: This paper studies drum brake failure in Mini-buses using an experimental analysis to test the viscosities and the maximum braking force when different fluids such as clean, less dirty, dirty and soapy water solution were used in the braking system. The effects of each of these fluids when successive increments in pedal force were applied at hot and cold conditions for drum brakes were studied. The results of the Thepra Universal Brake Testing Equipment used for the braking efficiency test indicated that a pedal force of 110 kN produce a brake force of 0.61 kN for clean fluid, 0.56 kN for less dirty, 0.51 kN for dirty and 0.92 kN. The value of 0.92 kN which was achieved when the soapy water solution was used indicated a positive braking force and that soap water solution could be used to produce a high pedal force within a very short time (10-30 min) and can therefore be used only in case of emergency. It was observed that the clean brake fluid gave the best braking force followed by the less dirty and finally the dirty brake fluid. In a situation where air has been trapped in the system under hot condition with or without a servo unit, clean brake fluid performed much better at least three times better than the other three fluids. For soap solution, braking was effective only when it was operated at cold condition but less effective when the system was hot. Soap solution is therefore not reliable when used for a very long time but effective only for emergency situations.

Keywords: Brake failure, braking force, drum brake, efficiency, pedal force

INTRODUCTION

According to Hillier (1991), the use of 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. It is therefore very important that the 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.

It is therefore, very important that drum brakes operate with the highest efficiency.

Drum brake assembly: The drum brake is an internally expanding type of brake that uses two shoes attached to a back-plate, which is fixed to a stub axle or axle tube. Each shoe has a 'T' section and a friction lining riveted or bonded to its outer face. At one end of the shoe is fitted a device for expanding the shoe when the brake pedal is depressed. In a simple brake, such as that shown in Fig. 1, a cam is used as a shoe expander, but modern layouts fitted to cars are hydraulically operated pistons for this purpose.

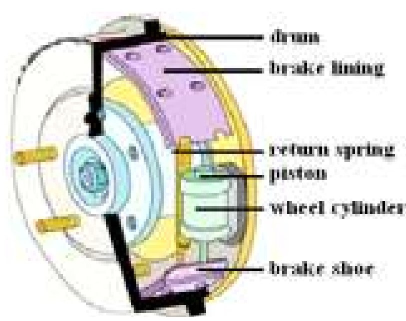

Fig. 1: The drum brake assembly

All shoe-type brakes must have some arrangement to prevent the shoes rotating with the drum. The shoe anchor, which must be rigidly attached to the back-plate, takes the form of a large pin that passes through the shoes, or a housing, against which the shoes butt.

Springs pull the brake shoes on to the back-plate and also return the shoes to the 'off' position after the brake has been applied. In some cases separate springs are used to perform the retention and return functions. The inner cylindrical surface of the cast iron drum is ground to give a smooth surface on to which the brake linings can rub. The drum is generally attached to the

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hub flange by small counter-sunk screws and retained securely by the wheel nuts. If possible, the drums should be exposed so that a good flow of air over the drum is achieved to dissipate the heat and prevent loss of brake efficiency that occurs when the unit gets very hot. Some form of adjuster is provided for each brake to take up excessive clearance due to wear of the friction facing. Since a large leverage is needed between the brake pedal and shoe, a large movement of the shoe would mean that the brake is fully applied. This dangerous condition is avoided by either manually adjusting the brakes periodically, or having an automatic adjuster that continually sets the shoes so that they are always positioned very close to the drum (Heisler, 1989).

The drum brake assembly consists of the following components:

- Wheel cylinder
- Master cylinder
- Back plate
- Brake shoes
- Brake drum
- Springs

The main advantages of the drum brake are:

- The same braking power is available in reverse as well as when moving forward.
- Drum brakes give a greater stopping force for a given size of brake drum.
- Drum brakes have self servo action which gives effective braking.

The main disadvantages of the drum brake are:

- Loss of braking power is more evident during prolong braking which results in overheating of the system.
- The system is more complicated in design.
- Uneven wearing of the braking lining results in vehicle pulling to one side during braking period.
- One problem with drum brakes is fade (this is a condition where the brake performance falls drastically when a brake, especially the friction linings, reaches a given temperature).

The fluid used in the hydraulic brake systems is a vegetable oil with certain additives. The main requirements of a good brake fluid include low viscosity, high boiling point, compatibility with rubber components, lubricating properties, resistance to chemical ageing and compatibility with other fluids according to Nunney *et al*. (1998). However, most Ghanaian drivers use other fluid such as dirty brake fluid, less dirty fluid and even soapy water as substitute to the original brake fluid.

MATERIALS AND METHODS

The design used for this study was experiment which employed the used of viscometer and Thepra Universal Automotive 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. The rational for testing the viscosity of the four fluids, especially that of the soap solution, was as a result of the responses from the questionnaire in the survey. 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 stop-watch 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.

Values of the various viscosities were calculated using the formula:

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

where,
V = The Viscosity
h_f = The capillary height

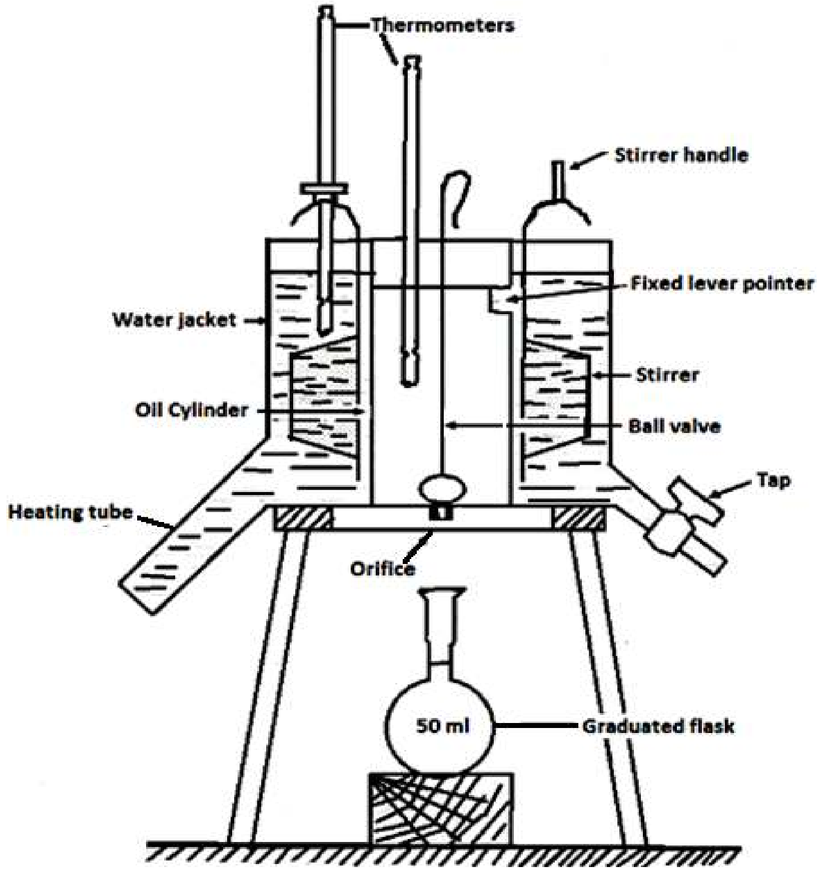

Fig. 2: Redwood viscometer used to determine the viscosity of the fluids

Table 1: Viscosity test

	Clean fluid		Less dirty fluid		Dirty fluid		Soap solution	
Temperature (°C)	Time (min)	Viscosity (kg/m^3)	Time (min)	Viscosity (kg/m^3)	Time (min)	Viscosity (kg/m^3)	Time (min)	Viscosity (kg/m^3)
30	1:22:05	82.05	4:54:72	230.00	7:50	234.72	0.28:00	28.94
40	1:0:11	60.11	2:52:38	172.38	3:18:22	198.22	0.25:00	25.06
50	0:50:00	50.00	1:46:16	106.16	3:14:02	194.02	0.23:00	23.30
60	0:40:47	40.47	1:00:47	60.47	3:10:00	190.00	0.21:00	21.00
70	0:37:07	37.07	0:42:44	42.44	3:07:01	187.01	0.20:00	20.05
80	0:34:15	34.15	0:36:47	36.47	3:02:19	182.19	0.20:00	20.00
90	0:30:22	30.22	0:34:31	34.31	2:57:59	177.59	0.19:00	19.50

Fig. 3: Thepra universal automotive brake testing equipment

ρ = The density of the fluid
g = Acceleration due to gravity
D = The diameter of the orifice
v = 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 parts, such as brake disc or brake drum, are 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) (Fig. 3).

RESULTS AND DISCUSSION

Experimental results of viscosity test: This section gives the results and discussion of the experiment on the four fluids, tested using the Redwood Viscometer. From the test results in Table 1, Viscosity-Temperature graphs for the fluids were plotted. Figure 4 shows the plot of viscosity against temperature of the four fluids.

From Fig. 4 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. 4 and the requirements of brake fluid given at the introduction according to Nunney *et al*. (1998), the soap solution appear to be the best fluid as far as low viscosity and stability of viscosity with increase in temperature are concerned. However, it is less compatible with other fluids and may not mix easily with other brake fluids. One other disadvantage of the soap solution is its low boiling point.

It is therefore not a good fluid for a brake system. 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 the introduction according to Nunney *et al*. (1998); namely 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 may change 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^3 in the temperature range 30 to 90°C). It will therefore not be good and effective in brake force transmission. From these results, it is obvious that the clean brake fluid is more suitable for the transmission of braking force.

Experimental results of the drum brake system: This section gives the results and discussion of experiments conducted with a drum brake system using the four fluids in a disc brake system under different conditions.

Drum brake in cold condition with and without servo: When a pedal force of 110 kN was applied, a brake force of 0.61 kN was obtained for clean fluid, 0.56 kN for less dirty and 0.51 kN for dirty. By comparing these results with the respective braking forces for disc brake in cold condition, the brake force is lower here, implying that disc brakes in cold condition are more preferable to drum brakes in cold condition.

The trend follows in the soap solution which gives a brake force of 0.92 kN which is lower than that of the disc brake.

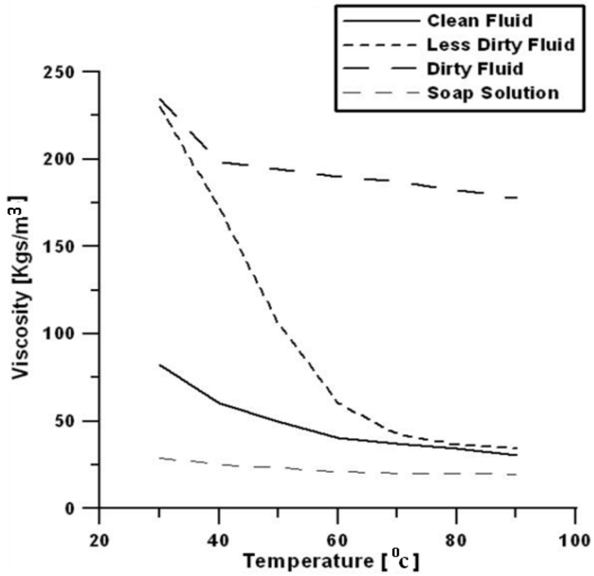

Fig. 4: Viscosity-temperature relationship of the fluids

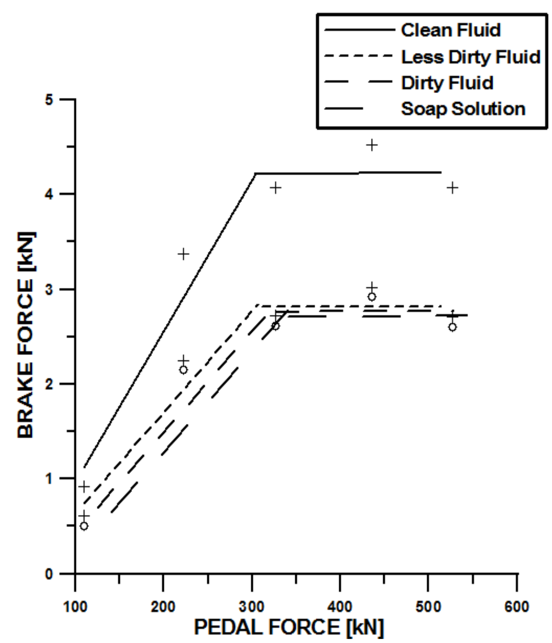

Fig. 5: Results of drum brake in cold condition with servo

Table 2 gives the results of the experiment of a drum brake system in cold condition with servo using the Thepra universal automotive brake testing equipment. Figure 5 shows the plot of the brake force against the pedal force using the test results in Table 2.

From Fig. 5 it can be observed that for the same pedal force the clean fluid transmitted the highest amount of brake force followed by the less dirty, soap solution and dirty fluid in that order. This implies that in cold condition with a servo, the clean fluid performs best followed by the less dirt, soap solution and dirty fluid respectively.

Table 2: Drum brake in cold condition with servo

Clean		Less dirty		Dirty		Soap solution	
Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)
125	0.56	110	0.61	140	0.51	110	0.92
237	2.20	222	2.25	252	2.15	222	3.38
326	2.67	311	2.72	341	2.62	311	4.08
435	2.97	420	3.02	450	2.92	420	4.53
527	2.66	512	2.71	542	2.61	512	4.07

Table 3: Results of drum brake in cold condition without servo

Clean		Less dirty		Dirty		Soap solution	
Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)
131	0.08	131	0.03	131	0.02	131	0.12
249	0.14	249	0.05	249	0.04	249	0.21
331	0.35	331	0.12	331	0.09	331	0.53
420	0.58	420	0.19	420	0.15	420	0.87
534	0.94	534	0.31	534	0.24	534	1.41

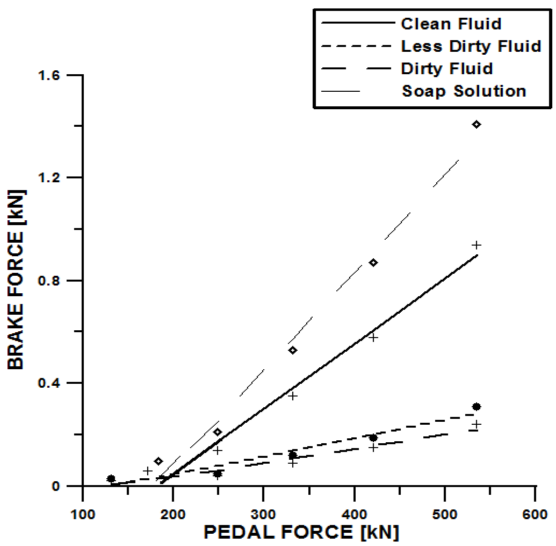

Fig. 6: Results of drum brake in cold condition without servo

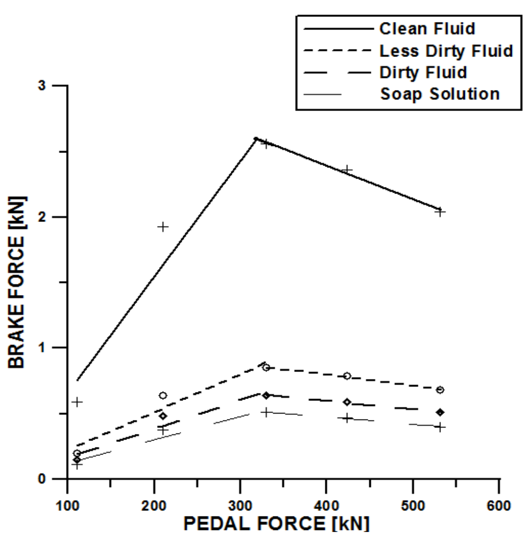

Fig. 7: Results of drum brake in hot condition with servo

Table 3 gives the results of the experiment of a drum brake system in cold condition without servo using the Thepra universal automotive brake testing equipment. Figure 6 shows the plot of the brake force against the pedal force using the test results in Table 3.

From Fig. 6 it can be observed that in the experiment with a servo, under cold condition in a drum brake, the soap solution is the best in the transmission of brake force followed by the clean fluid, less dirty fluid and dirty fluid in that order. Under this condition, the soap solution perform best among all the four fluids followed by clean, less dirty and dirty fluids in that order.

Drum brake under hot condition with and without servo: Drum brakes generally are not good heat dissipaters and this reduces the friction between the rubbing surfaces hence the braking force decreases. A pedal force of 110 kN gave a brake force of 0.59 kN for clean, 0.20 kN for less dirty and 0.15 kN for dirty which are lower compared to the disc brake in hot condition implying that drum brakes are not reliable when in hot condition. The soap solution gave the least brake force because of the evaporation of the solution into gas, therefore instead of transmitting power, the pedal force was used to compress air.

Table 4 gives the results of the experiment of a drum brake in hot condition with a servo and Table 5 gives results of the same conditions without a servo. Figure 7 shows the plot of the brake force against the peal force using Table 4 and Fig. 8 shows a similar plot using Table 5.

From Fig. 7 and 8 it can be observed that under hot conditions for the drum brake with and without servo, the trend is generally the same. The soap solution performed very badly compare with the other fluids, unlike its performance under cold condition. Generally, the clean fluid performed best in terms of transmission of brake force followed by the less dirty, dirty and soap

Table 4: Results of drum brake in hot condition with servo

Clean		Less dirty		Dirty		Soap solution	
Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)
110	0.59	110	0.20	110	0.15	110	0.11
210	1.93	210	0.64	210	0.48	210	0.38
330	2.56	330	0.85	330	0.64	330	0.51
423	2.36	423	0.79	423	0.59	423	0.47
531	2.04	531	0.68	531	0.51	531	0.40

Table 5: Results of drum brake in hot condition without servo

Clean		Less dirty		Dirty		Soap solution	
Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)
112	0.09	112	0.02	112	0.02	112	0.01
217	0.13	217	0.04	217	0.03	217	0.04
335	0.53	335	0.18	335	0.13	335	0.10
413	0.61	413	0.20	413	0.15	413	0.12
505	0.84	505	0.28	505	0.21	505	0.16

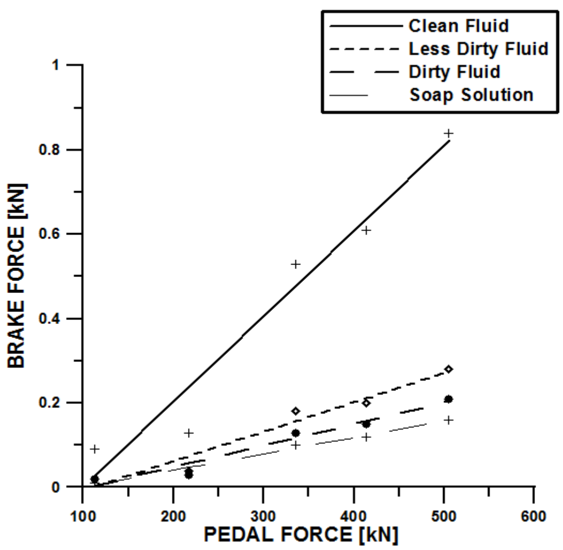

Fig. 8: Results of drum brake in hot condition without servo

solution respectively for the case where a servo was used. Without a servo, the best was clean fluid followed by the dirty, less dirty and soap solution in that order.

Drum brake with air in system under cold condition with and without servo: At a constant pedal force of 131 kN, a braking force of 0.71 kN was obtained in the clean fluid, 0.27 kN for less dirty, 0.18 kN for dirty and 0.12 kN for soap solution. For the soap solution, soap has the tendency to form ladder easily especially in the presence of air. This increases the air in the system resulting in lower braking force.

Table 6 gives the results of the experiment of a drum brake with air in the brake system under cold condition with servo and Table 7 gives the results of the experiment under the same condition but without the use of a servo. Figure 9 shows the plot of the data in Table 6 and Fig. 10 shows the plot of the results in Table 7.

From Figure 9 and 10 it can be observed that when air is trapped in the system, for a drum brake, the trend of the performance of the fluids in transmitting brake force is similar in both of the cases when a servo is used and when no servo is used. The clean fluid performed best followed by the less dirty, dirty and soap solution in that order.

Drum brake with air in system under hot condition with and without servo: Braking force obtained for the four fluids in Table 1 indicated that the clean fluid had the highest braking force, followed by the less dirty and then the dirty. The least braking force was recorded when soap solution was used to conduct the experiment. This can be seen when the pedal force was 224 kN. Braking forces of 2.04, 0.68, 0.51 and 0.44 kN were obtained for clean, less dirty, dirty and soap solution respectively. The soap solution had the least brake force because when the solution became hot, it evaporated the more resulting in making the fluid less dense. Again, the soap solution will ladder easily to increase the amount of air in the system. The pedal force will then compress air instead of transmitting fluid. Hence the braking efficiency was reduced.

Table 8 gives the result of a drum brake in hot condition with air trapped in the system with servo using the Thepra universal automotive brake testing equipment and Table 9 gives the results of a drum brake in hot condition with air trapped in the system without a servo using the Thepra universal automotive brake testing equipment. Figure 11 shows a plot of the brake force against the pedal force using the test results in Table 8 while Fig. 12 shows a plot using the test results in Table 9.

It can be observed from Fig. 11 and 12 that for a drum brake with air in system under hot condition the

Table 6: Results of drum brake with air in system under cold condition with servo

Clean		Less dirty		Dirty		Soap solution	
Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)
131	0.71	131	0.27	131	0.18	131	0.12
224	2.16	224	0.72	224	0.54	224	0.32
311	2.74	311	0.91	311	0.69	311	0.64
411	3.05	411	1.02	411	0.76	411	0.72
542	2.89	542	0.96	542	0.79	542	0.77

Table 7: Results of drum brake with air in system under cold condition without servo

Clean		Less dirty		Dirty		Soap solution	
Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)
154	0.08	154	0.03	154	0.02	154	0.01
262	0.24	262	0.08	262	0.06	262	0.04
362	0.56	362	0.17	362	0.14	362	0.12
454	1.00	454	0.33	454	0.25	454	0.16
568	1.38	568	0.46	568	0.35	568	0.28

Table 8: Results of drum brake with air in system under hot condition with servo

Clean		Less dirty		Dirty		Soap solution	
Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)
126	0.86	126	0.28	126	0.22	126	0.16
224	2.04	224	0.68	224	0.51	224	0.44
306	2.33	306	0.77	306	0.58	306	0.54
424	2.46	424	0.82	424	0.62	424	0.59
575	2.12	575	0.71	575	0.64	575	0.62

Table 9: Results of drum brake with air in system under hot condition without servo

Clean		Less dirty		Dirty		Soap solution	
Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)	Pedal force (kN)	Brake force (kN)
171	0.03	171	0.02	171	0.01	171	0.01
276	0.23	276	0.08	276	0.06	276	0.04
380	0.49	380	0.16	380	0.12	380	0.08
464	0.73	464	0.24	464	0.18	464	0.14
564	1.02	564	0.39	564	0.26	564	0.21

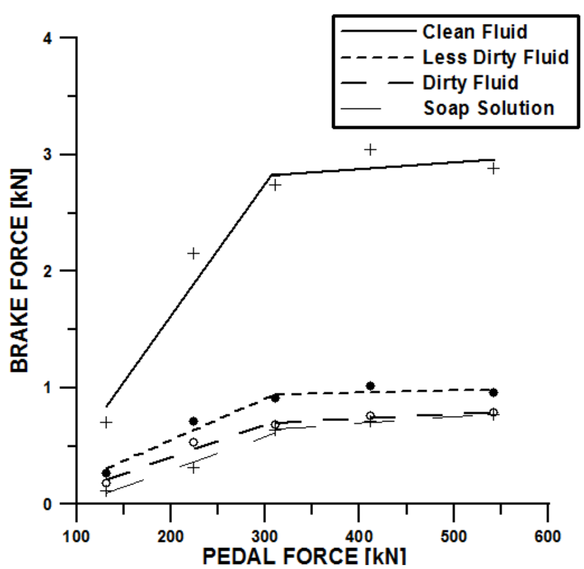

Fig. 9: Results of drum brake with air in system under cold condition with servo

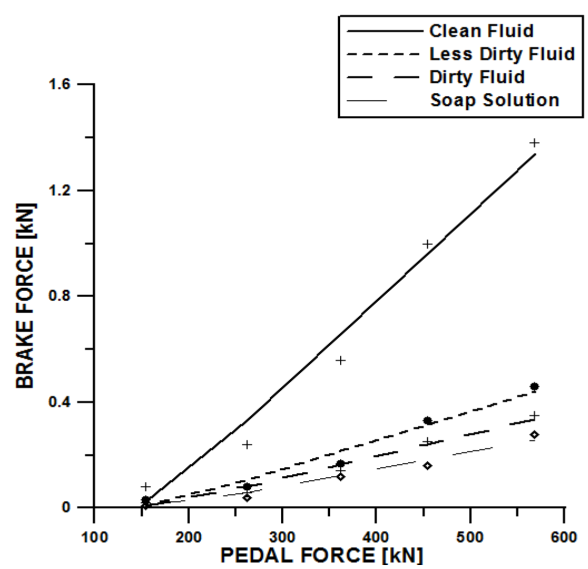

Fig. 10: Results of drum brake with air in system under cold condition without servo

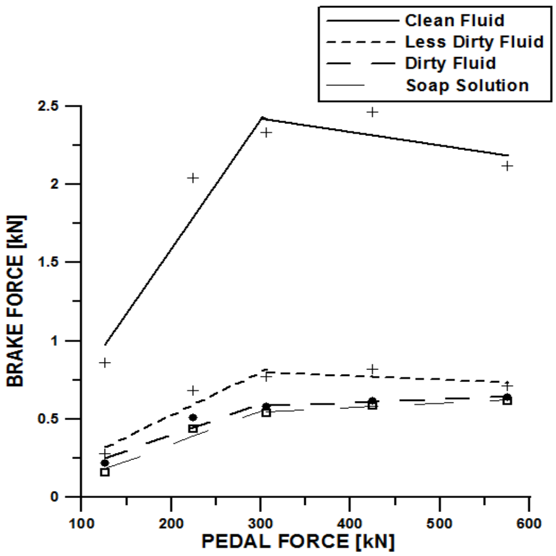

Fig. 11: Results of drum brake with air in system under hot condition with servo

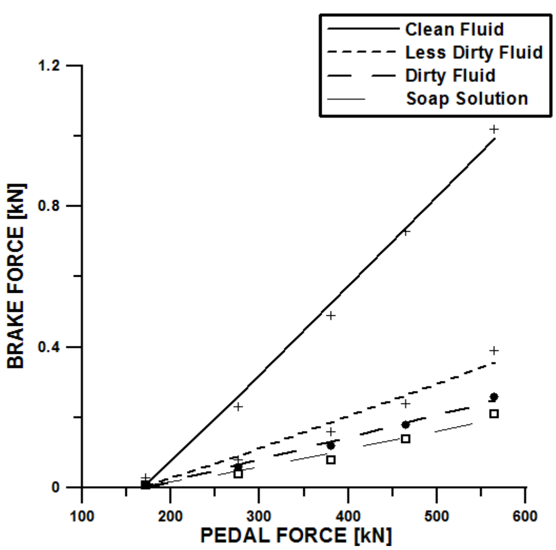

Fig. 12: Results of drum brake with air in system under hot condition without servo

trend of the performance of the four fluids is similar for both of the cases when a servo was used and when no servo was used. The clean fluid performed much better (at least three times better) than the other three fluids. The next is the less dirty fluid, followed by the dirty fluid and the soap solution in that order. It is very clear that the effect of dirty contamination of fluid in a drum brake under hot condition is a very drastic reduction in the brake force.

CONCLUSION

Drum brakes have self-servo action, so less pedal operating force are required to produce higher stopping power. Under cold condition i a drum brake, soap solution is the best fluid material of the transmission of brake force, followed by clean fluid, less dirty and dirty fluid. Under hot conditions for drum brakes with and without the use of servo, clean brake fluid transmits higher braking force compared to soap solution. When drum brakes are operated under cold condition with a servo unit, because of the large contact area of the brake shoe with the drum a greater braking force is achieved. In a situation where air has been trapped in the system under hot condition with or without a servo unit, clean brake fluid performed much better at least three times better than the other three fluids. Brake linings used in drum brakes have a large contact surface area with the drum, for this reason the use of hand brake mechanism is very effective.

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