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Study of Hydrodynamic Retarder & It's Effects on Vehicle Components

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Abstract: As the road conditions are improving over decades, the speed and capacity of CV (commercial vehicles) are also increasing with regularly improving technology. But this also imposes a heavier burden on primary (service) brakes especially in mountain operation. As braking materials not involve comparable to engine and transmission system improvement. Which increase the problem of excessive lining wear and brake fading while decreasing the safety.

Therefore supplementary brake systems like retarders are highly desirable for safe, easy and economical transport. Retarders reduce the wear of primary brakes and increase average speed by dissipating power at relatively low torque over long periods.

There are many views for retarder and lot of questions about "What exactly it is?" In the few pages there is high light on development, working. Retarder effects on different vehicle components, advantages, disadvantages and features are also discussed.

Keywords: hydrodynamic retarder, retarder, automobile, braking.

I. Introduction

The braking of vehicle can consider as "Generation of force at the wheel to oppose the motion of vehicle by dissipating kinetic energy into heat".

Primary (friction) brake can stop the fully loaded vehicle efficiently independent or less dependent of speed. At this time brakes generates high torque and absorbs energy at high rate but for short periods. Then the heat generated is within the dissipation capacity of brake drum and other braking components. But conditions like mountain terrain, brake temperature continuously rise and can achieve equilibrium between heat input and dissipation. Although the linings are developed to work at high temperature, problem of high lining wear and brake fade still exist.

The relation between brake drum temperature and coefficient of friction 'μ' is shown in fig. below.

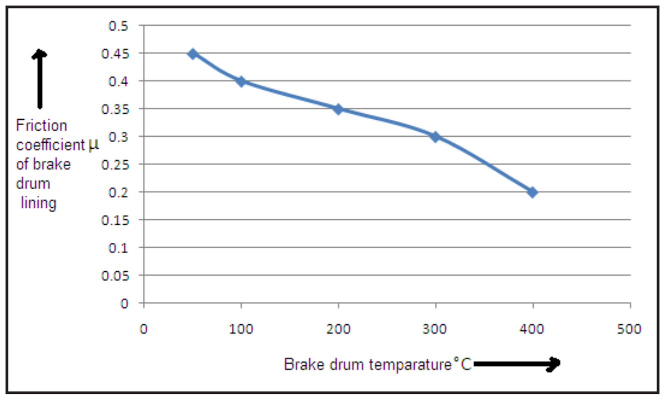

Fig. 1: Brake drum temp V/s μ

Also today the increased output of engine increases the average speed of vehicles (CV) which in terms demand higher brake output. Doubling of speed cause four time conversion of kinetic energy into heat, due to which friction brakes are over strained. The requirement of these cases is brake that absorbs energy (KE) at lower rate over a long period of time, i.e. retarder a device capable of opposing vehicle motion at low level of power dissipation for long period find its application.

There are many types of retarders as

1. Eddy current type
2. Permanent magnetic type
3. Hydrodynamic retarder

Here the consideration is given to only hydrodynamic retarder due to following advantages:

1. High specific performance
2. Wear free running, since power transmitting part are not in contact.

3. Easy heat dissipation, since the heat generated within the oil, can easily transfer.
4. Simple control of braking effect.

II. Development of Hydrodynamic Retarder

The concept hydrodynamic retarder can be traced back in 1877 to W. Froude. He was testing a 2000 HP marine engine on friction brake dynamometer used at that time. This type of dynamometer gives same problem as that of vehicle brake. Froude found the solution on this problem as water brake dynamometer, serve as the basic principle of power absorption for virtually all modern hydrodynamic retarder.

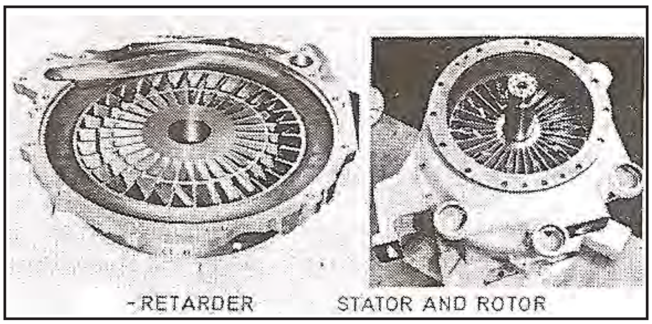

Fig. 2: Stator and rotor

The basic element of original dynamometer, like transmission driven rotor adjacent to a stator mounted on vehicle chassis. A semi toroidal cavity in each side face of rotor coincides with similar cavity in stator, to form two toroidal cavities. Each cavity fitted with the no. of radial vanes inclined at 45^0 to rotor-stator interface.

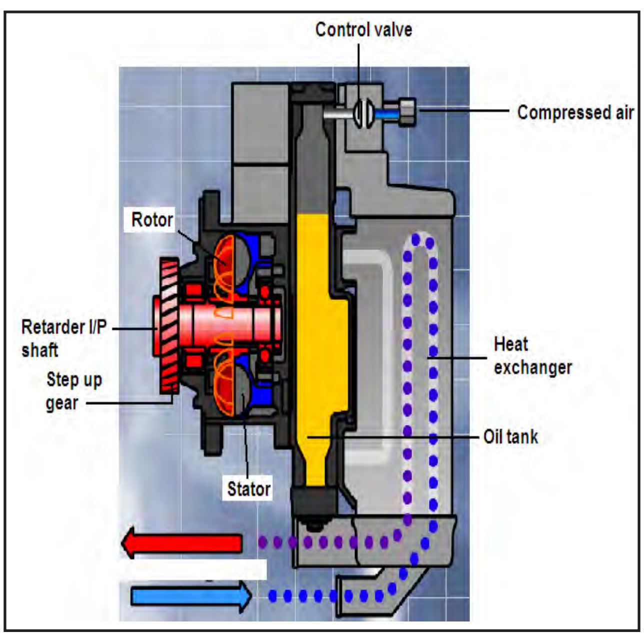

Fig. 3: Working of retarder

When fluid is forced into working chamber between rotor & stator, it is centrifuged onward radially by rotor in to stator cavity, where the fluid is diverted back in to rotor to set up a vortex flow. The velocity imparted in rotor is arrested by vanes in stator & accelerated again as it re entered in the rotor. The energy required to accelerate the liquid in rotor is taken from vehicle KE & converted in to dynamic force that generates torque. Since no work output is there, energy is converted into heat.

Let assume that

D – Rotor diameter

N – Rotor`s speed of rotation

Rotor width increases in proportion to the ‘D’

The force acting on fluid can obtain from centrifugal action of rotor which proportional to rotor diameter ‘D’& square of its speed ‘N’. Also the mass of fluid in vortex flow is proportional to ‘D^3’

Hence the force is proportional to - N^2D^4. Also the retarder torque is proportional to diameter ‘D’.

Therefore torque ‘T’ = KN^2D^5 & power absorbed ‘P’ is given as

$P = KN^3D^5$

Where ‘K’ - retarder constant.

Now the torque is required by a retarder at constant speed on gradient is given by

$$T = \frac{W * R(G - Gr)}{a}$$

Where W – Vehicle weight

R – Wheel radius

G – Percent gradient

Gr – Rolling loss expressed as % gradient

A – Drive ratio between wheel & rotor

& the power dissipated by retarder fluid is given by

$$P = W V (G-Gr)$$

Where v = vehicle speed

It is general practice to use an over-rated retarder to overcome the overheating of fluid due to varying conditions of percentage of gradient (G) & vehicle speed ‘v’.

III. Application to Vehicles

Hydrodynamic retarders can be mounted between transmission & wheel or otherwise on the transmission itself. If retarder is mounted in front of transmission it always rotates in the same direction, irrespective of transmission. Therefore the blade incline to the axis of rotation can be used. The transmission mounted units are common as more stability is achieved.

If retarder is mounted behind the transmission, the direction of rotor changes with driving direction. If retarding is required in both way then straight blades has to use which can affect the retarding capacity.

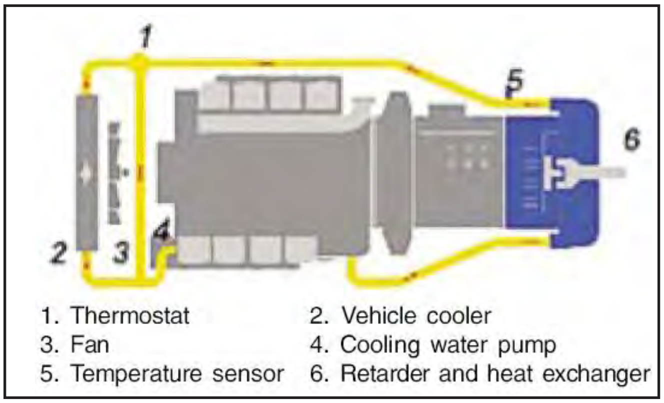

Fig. 4: Components of retarder

The oil used as working fluid have same grade as engine oil. Heat is dissipated to the engine cooling system via an oil to water heat exchanger as shown in fig. as during braking no or very little fuel is injected in combustion chamber, very small amount of heat is generated by engine. So the retarder uses only surplus capacity of engine cooling system. Sensors are permanently measuring the cooling water temperature leaving the retarder.

If the retarder dissipates too much heat to the cooling system, the sensor reduces the retarder output-less heat is dissipated to the cooling system. This mode of operation guarantees that the system won't overheat at any time.

The torque is controlled by injecting fluid from oil tank in to retarder with an air to oil loading tank. Pneumatic pressure on oil is proportional to the electric signal received at control valve. When retarder switched off, the air present in the oil tank escape in to atmosphere as no air pressure on oil tank taking out the oil from rotor.

The retarder is actuated via foot pedal or hand lever through a electronic control unit, which send appropriate signal to the air control valve which is attached with compressed air system of vehicle.

As we know torque is directly proportional to square of rotor speed, so smaller units can give the same retardation torque if speed is increased. So most of retarders use an integral step up gear on rotor shaft

IV. Performance of Different Components

The main function of retarder is to give continuous braking action specially on high downhill travel, so as to prevent primary brakes from high wear & fading by keeping it cool & ready for any emergency use. But it is necessary to check the effect of retarder on other vehicle components.

Effect on Brake Lining

The test was carried out by Voith retarder privet Ltd. USA on the 320 km long route. The difference in altitude was 2,660 m. The gross vehicle weight rating was 17.0 t. It was furnished with a 280 HP engine. The results are converted in to estimates & given as graph below.

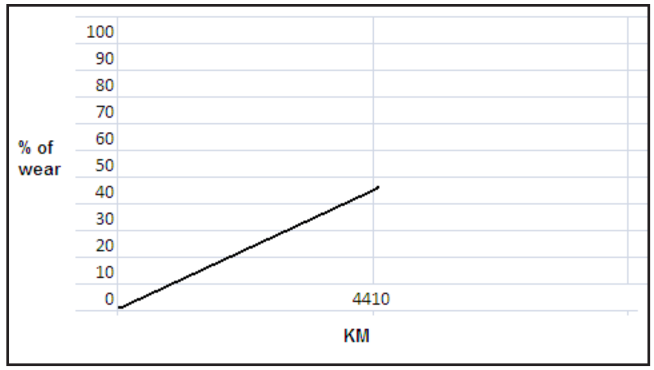

Fig. 5: Tyer wear without retarder

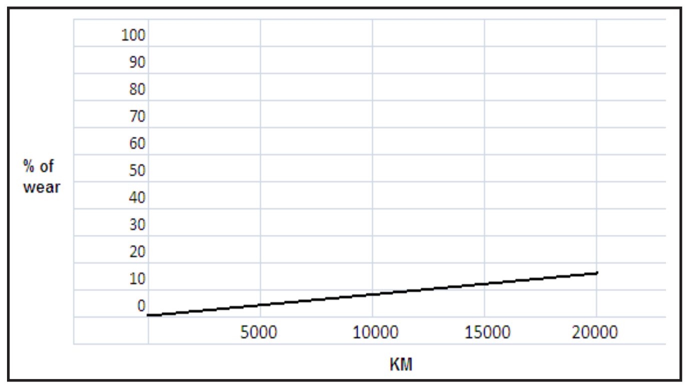

Fig. 6: Tyre wear with retarder

The graph shows clear increase in brake lining life time, as the wear occurred mostly on decline paths where the retarder works most efficiently. Therefore average service life of brake lining increases by nearly ten times with retarder from 4410 Km.

V. Effect on Drive Axels

To check the effect of retarder on drive axels test was conducted by Rockwell Std. Ltd. on a vehicle of frontal area 8.82 m², Gross curb weight of 27216 Kg.

The standard equation used is

$$\frac{HP}{TE} = \frac{KPH * 142.62}{33000}$$

Where HP – Horsepower

TE – Tractive effort

KPH – Kilometer per hour

The results of test are tabulated below

TABLE I: Typical performance - Driving

Grade, %	**Level**		**4.5**		**7.5**		**10.5**	
Speed KMph	80.5		29		19.3		14.5	
	TE	HP	TE	HP	TE	HP	TE	HP
Air Resistance	420	56	54	2.6	----	---	----	---
Rolling Resistance ---1.5%	900	120	900	43	900	29	900	22
Grade Resistance	-----	---	2700	130	4500	144	6300	151
Total*	1320	176	3654	175	5400	173	7200	173

TABLE II: Typical performance - Downhill

Grade,%	**4.5**		**7.5**				**10.5**			
Speed, KMPH	**80.5**		**38.6**		**58**		**25.7**		**38.6**	
	TE	HP	TE	HP	TE	HP	TE	HP	TE	HP
Required total	2700	360	4500	288	4500	432	6300	269	6300	404
Air resistance	420	56	97	6.2	219	24	42	108	97	6.2
Rolling resistance	900	120	900	58	900	86	900	38	900	58
Chassis Resistance	457	61	953	61	635	61	1430	61	953	61
Balance	923	123	2550	163	2746	264	3928	168	4350	279

VI. Effect on Wheel Bearing

Using retarder all efforts are taken by drive axel, increasing the load on wheel bearing of drive axel & reducing on other wheel bearings. The results are tabulated with & without retarder.

TABLE III: Wheel Bearing Loading – Downhill TE – Drive Axle

Grade,%	4.5			7.5				10.5			
Speed,Kmph	58		80.5	25.7		38.6	58	16.9		25.7	38.6
Retarder	**No**	**Yes**	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**No**	**Yes**	**Yes**	**Yes**
Rolling Resis.	270	270	270	270	270	270	270	270	270	270	270
Chassis Resis.	635	635	457	1430	1430	953	635	2180	2180	1430	1430
Balance	270	946	923	609	2128	2550	2746	920	3220	3928	4350
Total	1175	1850	1650	2309	3828	3773	3651	3370	5670	5628	5573

From this result it is clear that, the loading of wheel bearing with retarder is marginally higher but reduced with speed. As retarder is used on downhill mostly the total effect on over all bearing life is 0.8 % only.

VII. Effect on Drive unit

The results are tabulated as below

TABLE IV: Bearing life – Rolling Terrain

Assumed			**%Life --Used**				
Kilometer	**Grade, %**	**Speed,Kmph**	**Diff. L.H.**	**Pinion Inner**	**Pinion spigot**	**With retarder**	
						Diff. L.H.	**Spigot**
144840	Level	80.46	5.59	8.28	4.74	5.59	4.74
8046	Up 4.5	28.97	8.51	12.58	7.21	8.51	7.21
8046	Dn. 4.5	57.94	0.10	--------	0.20	2.07	4.26
160934.4	Totals		14.20	20.86	12.15	16.17	16.21
Adjusted miles Average			704,200	479,400	823,000	618,400	616,900

TABLE V: Bearing Life – Hilly Terrain

Assumed			%Life –Used				
Kilometer	**Grade, %**	**Speed,Kmph**	**Diff. L.H.**	**Pinion Inner**	**Pinion spigot**	**With retarder**	
						Diff.L.H.	**Spigot**
130356.9	Level	80.46	5.03	7.45	4.26	5.03	4.26
11265.4	Up 4.5	28.97	11.92	17.64	10.10	11.92	10.10
3281.7	Up. 7.5	19.3	13.56	20.13	11.53	13.56	11.53
804.7	Up 10.5	14.48	8.85	13.13	7.52	8.85	7.52
804.7	Dn. 10.5	16.89	0.61	------	1.24	12.47	25.60
3281.7	Dn. 7.5	25.75	0.59	------	1.22	13.47	25.46
11265.4	Dn. 4.5	57.94	0.14	------	0.29	2.90	5.97
160934.4	Totals		40.70	58.35	36.16	68.20	90.44
Adjusted miles Average			245,700	171,400	276,500	146,600	110,600

From result two things are clear. First is that than plane running, going up & down used bearing life considerably. Secondly use of retarder on downgrade further decrease the bearing life, which can be minimized by descending at higher speed. So overall the use of retarder has negligible effect on wheel bearing life.

Retarder reduce the drive bearing life up to 5% approximately, but not likely to reduce the life of drive unit as a whole.

VIII. Effect on Drive Line, Transmission

The test was conducted by Dana corp. USA. On a path length of 5.152 Km, marked with letters on each 0.322 Km. average grade is 6.5% with steepest at 9.15 %.

Drive shaft torque is measured by a strain gauge bridge mounted on output shaft of retarder (at sensitivity axis at 45 to longitudinal axis of the shaft.) calibrated at 6775 N-m capacity torsion testing machine. Readings are obtained by oscillograph.

Gross vehicle weight = 27851Kg, Tire static radius= 513.1 mm, Tire revolution per Km= 790

The results tabulated as below

TABLE VI: Torques present on driveline (descent) withought retarder

Letters	Torque, n-m	Vehicle speed, kmph
A	-534.3	30.5
B	-801.4	30.5
C	-534.3	25.74
D	-400.734	32.18
E	-534.3	28.97
F	-534.4	24.14
G	-400.7	32.2
H	-267.2	33.79
J	-534.3	32.2
K	-667.9	28.96
L	-400.7	32.2
M	-801.4	33.79
N	-267.2	30.5
O	-667.9	28.968
P	-801.4	32.2
Finish	-801.4	27.36

TABLE VII: Torques present- Vehicle Making Descent with Hydraulic retarder

Letters	Torque, n-m	Vehicle Speed, kmph
A	-935.1	32.2
B	-2404.5	32.2
C	-3072.36	33.79
D	-2270.1	35.40
E	-3072.4	35.40
F	-3072.4	35.40
G	-2671.6	32.2
H	-2938.78	35.4
J	-3072.4	35.4
K	-2404.5	35.4
L	-1335.8	35.4
M	-2137.3	35.4
N	-2938.8	35.4
O	-1335.8	35.4
P	-2671.6	38.62
Finish	-3072.4	38.62

Table VI & VII gives torque for test with & without retarder on descent path.

The average time for descent with brake only was 10 min. 7 sec. For 5.152 Km with speed 30 Kmph. & the average time for descent with retarder was 9 min. 13 sec. with speed 34

Kmph .54 sec. Faster than the time taken by brakes only. The following graphs show the readings of oscillograph.

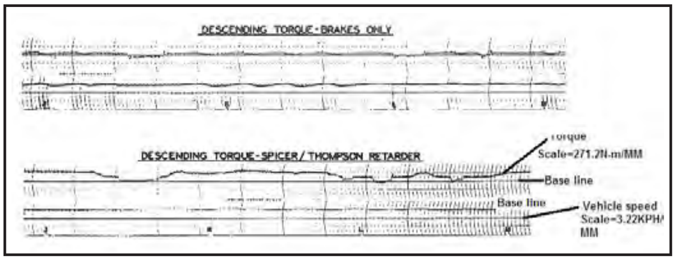

Fig. 7: Graph readings

The results obtained from comparison test shows that increase in torque on driveline & transmission with retarder. These values provide basic guideline to design components of driveline & transmission with retarder.

Retarder's Effect on Engine

It is most advantageous. Retarder system dissipates absorbed heat in cooling system of vehicle; maintain constant operating temperature of engine. This keeps valve & piston hot with stabilized sizes ready for full power application. Downhill travel of four minutes will drop engine temperature to drop 82 to 52 °C. On larger descends the serious temperature drop may cause expensive failure of piston & rings.

IX. Effect on Tyres

This Test was conducted by The Firestone tire & rubber Co. USA.

Gross vehicle weight= 27851 Kg

Weight on front axle= 10415 Kg, remaining weight is beard by driving axel.

Tyres – 11.00 -20 12 ply Firestone nylon with 75 psi cold pressure. Tyre (on driving axel) is fitted with revolution counter & 2 thermocouples.

Dynamic slip is the amount of slippage between the tire & the road which takes place on a rolling tire. It is directly proportional to tire wear this phenomenon is shown in fig below.

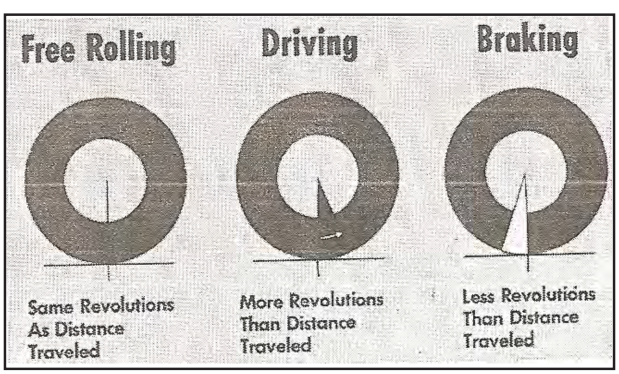

Fig. 8: Slip effect

The free rolling gives zero slip and normal driving gives positive slip while braking gives negative slip.

The test consists of two run each with brakes only & with retarder assistance. This result as tabulated below.

Table VIII: Dynamic Slip Testing

	Tire Revolutions	Revolution Dynamic Slip	Ft Dynamic Slip	% Dynamic Slip
1418 free revolution -15,380 ft course- 7%Average Grade – 32.2Kmph				
DESCENDING				
Tractor and trailer brakes	1393.5	22.5	244	1.6
Hydraulic retarder	1385.5	32.5	352	2.3
CLIMBING HILL				
Drive tires	1438	20	217	1.4
82 free revolution -9557 ft course- 7.6%Average Grade – 56.3Kmph				
DESCENDING				
Tractor and trailer brakes	864	18	195	2.0
Hydraulic retarder	856	26	282	2.9
CLIMBING HILL				
Drive tires	887	5	54	0.6

DESCENDING				
Tractor and trailer brakes	864	18	195	2.0
Hydraulic retarder	856	26	282	2.9
CLIMBING HILL				
Drive tires	887	5	54	0.6

For brakes only the slip is 74.37m or 1.6% while with retarder the slip is 107.29m or 2.3% while normal driving.

While descending the hill with grade of 7.6% at 56.3 kmph brake gives 59.4m or 2% of slip & retarder gives 85.95 m or 2.9% of slip i.e. with retarder there is negligible more wear of driving tires.

X. Effect on Tyre Temperature

Test data at 64.4kmph on 20 min. at descent the table is shown below.

64.4Kmph Descent – Repeated 20-minute Cycle Reading at Bottom of Hill

TABLE IX: Effect of Temperature

	Bead Temperature, C	**Drum Temperature C**
DRUM BRAKES		
Cycle1	55.55	160
Cycle2	75	226.66
Cycle3	119.44	260
HYDRAULIC RETARDER		
Cycle4	108.88	140.55
Cycle5	87.77	118.33
Cycle6	74.44	93.33

In only three cycle with drum brake only temperature of hot drum reaches at 260°C producing smoke from brake lining and bed temperature reaches 199°C. Reversion of rubber begins 121-132°C.

The next three runs made with hydraulic retarder. After 6th cycle the drum temperature is dropped to 93°C from 141°C and bed temperature drop to 74°C from 108°C. Shoulder temperature does not show any significant temperature change.

The use of retarder eliminates tire bed problem due to overheating. This test results are shown in graph on next page.

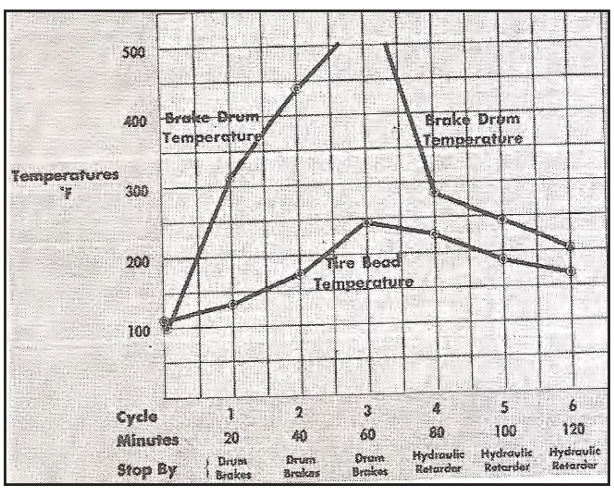

Fig. 9: Tyre temperature graph

XI. CONCLUSION

The concept of hydrodynamic retarder & it`s application to heavy commercial & commercial vehicles are discussed in this paper. Hydrodynamic retarder brakes are extremely suitable for driving at higher speed on downhill gradients, it is very efficient mechanism with high power to weight ratio.

The effect of retarder on drive axel, drive line, transmission & engine, tyre are checked with various tests & from data & results it can be concluded that there is some extra wear on drive axel & drive line bearings but can be make up with the advantages in term of engine efficiency, tyre & brake lining life improvement.

The use of retarder for vehicle downhill control is very easy & the components of present drive-train & capacity required no significant design change.

Reducing the weight of mechanism using small size rotor & use of light alloy in overall construction economically must be considered as a future scope. So as to reduce the overall inertia of system.

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