

Figure 1

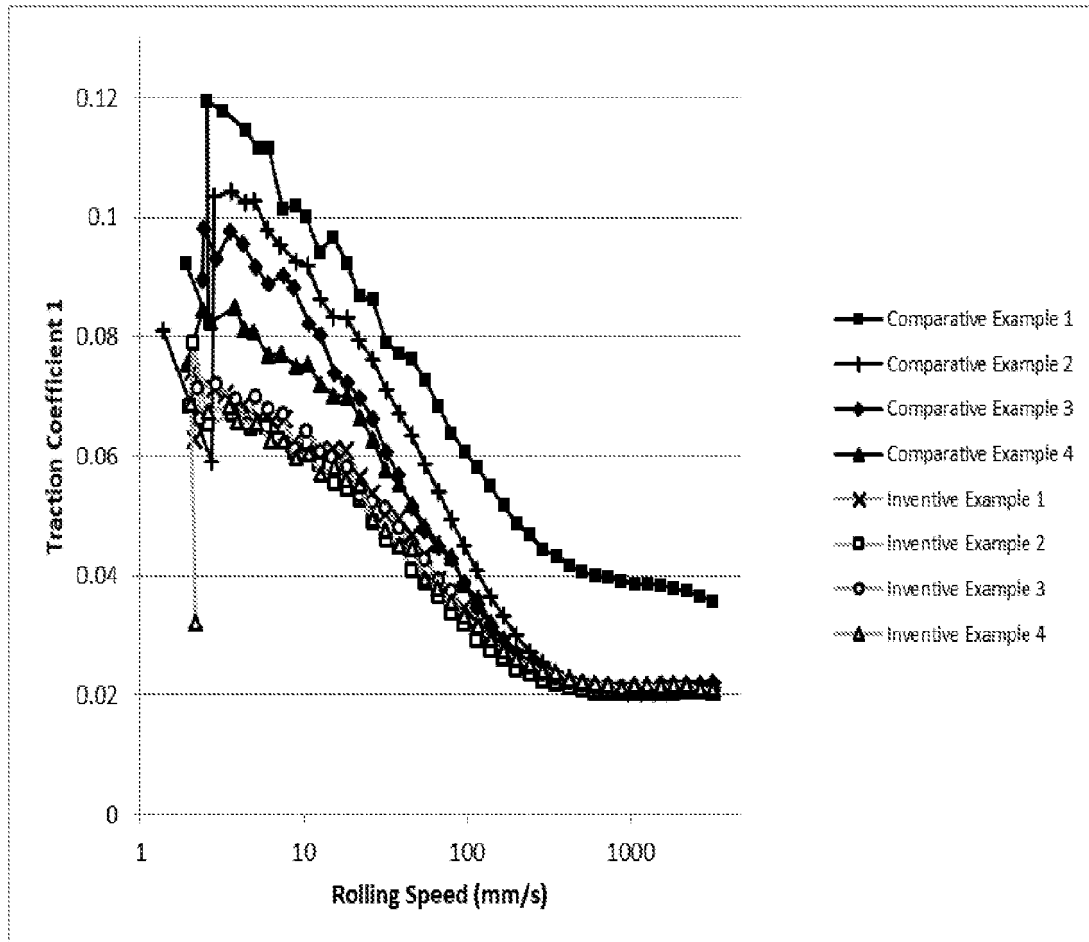


Figure 2

Name	Comparative Example 1	Comparative Example 2	Comparative Example 3	Comparative Example 4	Inventive Example 1	Inventive Example 2	Inventive Example 3	Inventive Example 4
Base Stock - Group 1	79.3							
Base Stock - Group 1	16.3							
Base Stock - Group 3		85.6	85.4	85.6	85.4	86	84.2	82
Base Stock - Group 4		9.9	9.9	9.9	9.9	9.9	10.1	10.1
Molybdenum								
Dithiocarbamate			0.1		0.1	0.1	1	2
Zinc Dithiocarbamate				0.6	0.6	0.1	1	2
Calcium Alkyl Salicylate Detergent								
ZDDP	0.6	0.6	0.6					
Rest of formulation	3.8	3.9	4	3.9	4	3.9	3.7	3.9
Total	100	100	100	100	100	100	100	100
D2896, TBN	8.8	8.8	8.8	9	9	8.8	8.8	8.9
KV100	10.8	10.3	10.3	10.6	10.3	10.6	10.3	10.3
MTM Boundary Traction Coefficient (9 mm/s rolling speed)	0.1018	0.0926	0.0882	0.0749	0.0620	0.0607	0.0611	0.0597
MTM Mixed Traction Coefficient (96 mm/s rolling speed)	0.0608	0.0449	0.0387	0.0384	0.0347	0.0319	0.0335	0.0332
MTM Hydrodynamic Traction Coefficient (880 mm/s rolling speed)	0.0391	0.0208	0.0215	0.0204	0.0207	0.0205	0.0210	0.0213

Figure 3

Name	Comparative Example 5	Inventive Example 5	Inventive Example 6	Inventive Example 7
Base Stock - Group 1	92.5			
Base Stock - Group 1 - KV100 5.2 cSt	3.1			
Base Stock - Group 3- KV100 7.7 cSt		65	75.71	92.3
Base Stock - Group 1 - KV100 31.8 cSt		31.5		
Base Stock - Group 4 - KV100 157.4 cSt			20.9	
Basestock - Group 5 - PMA - KV100 >200 cSt				4.26
Molybdenum Dithiocarbamate		0.1	0.1	0.1
Zinc Dithiocarbamate		0.6	0.6	0.6
Calcium Alkyl Salicylate Detergent		2.32	2.3	2.3
ZDDP	0.6			
Rest of formulation	3.8	0.48	0.39	0.44
Total	100	100	100	100
D2896, TBN	8.7	8.8	8.7	8.7
KV100	12.2	12.7	13.2	12.7
MTM Boundary Traction Coefficient (9 mm/s rolling speed)	0.0794	0.0479	0.0549	0.0324
MTM Mixed Traction Coefficient (96 mm/s rolling speed)	0.0493	0.0338	0.0322	0.0251
MTM Hydrodynamic Traction Coefficient (880 mm/s rolling speed)	0.04	0.0266	0.0213	0.0209

Figure 4

Name	Comparative Example 6	Inventive Example 8	Inventive Example 9	Inventive Example 10	Inventive Example 11	Comparative Example 7	Inventive Example 12	Inventive Example 13	Inventive Example 14
Base Stock - Group 1 - KV100 12.1 cSt	93.22					45.71			
Base Stock - Group 1 - KV100 5.2 cSt	3.18					49.86			
Base Stock - Group 3 - KV100 7.7 cSt		63.53	89.05	87.67	80.38		94.16	94.46	96.05
Basestock - Group 5 - PMA - KV100 >200 cSt				9.08	16.37				0.7
Base Stock - Group 4 - KV100 157.4 cSt									
Base Stock - Group 1 - KV100 31.8 cSt		33.24					2.57		
Basestock - Group 5 - PIB - KV100 >200cSt			7.71					2.29	
Molybdenum Dithiocarbamate		0.1	0.1	0.1	0.1		0.1	0.1	0.1
Zinc Dithiocarbamate		0.6	0.6	0.6	0.6		0.6	0.5	0.6
Calcium Alkyl Salicylate Detergent		2.26	2.24	2.24	2.26		2.27	2.24	2.24
ZDDP	0.4					0.4			
Rest of formulation	3.2	0.27	0.30	0.31	0.29	4.03	0.30	0.31	0.31
Total	100	100	100	100	100	100	100	100	100
D2896, TBN	8.6	8.6	8.5	8.5	8.5	8.6	8.6	8.5	8.5
KV100, cSt	12.69	12.99	12.88	12.41	13.29	8.52	8.41	9.31	8.37
MTM Boundary Traction Coefficient (9 mm/s rolling speed)	0.0725	0.0558	0.0364	0.0413	0.0184	0.1036	0.0473	0.037	0.0254
MTM Mixed Traction Coefficient (96 mm/s rolling speed)	0.0469	0.0407	0.0286	0.0270	0.0209	0.0612	0.0320	0.0317	0.0260
MTM Hydrodynamic Traction Coefficient (880 mm/s rolling speed)	0.0382	0.0271	0.0231	0.0199	0.0203	0.0377	0.0210	0.0232	0.0211

Figure 5

Name	Comparative Example 8	Inventive Example 15	Inventive Example 16	Inventive Example 17
Base Stock - Group 1 - KV100 12.1 cSt	76.3			
Base Stock - Group 1 - KV100 5.2 cSt	4.7			
Base Stock - Group 3- KV100 7.7 cSt		35.8	66.9	85.97
Base Stock - Group 1- KV100 31.8 cSt		51.5		
Base Stock - Group 4 - KV100 157.4 cSt			20.5	
Basestock - Group 5 - PMA - KV100 >200 cSt				1.5
Molybdenum Dithiocarbamate		0.1	0.1	0.1
Zinc Dithiocarbamate		0.6	0.6	0.6
Calcium Alkyl Salicylate Detergent		11.50	11.50	11.50
ZDDP	0.45			
Rest of formulation	18.55	0.5	0.5	0.33
Total	100	100	100	100
D2896, TBN	42	41	41	41
KV100	16.9	17.44	18	15.9
MTM Boundary Traction Coefficient (9 mm/s rolling speed)	0.0695	0.0422	0.0348	0.0248
MTM Mixed Traction Coefficient (96 mm/s rolling speed)	0.0455	0.0351	0.0260	0.0276
MTM Hydrodynamic Traction Coefficient (880 mm/s rolling speed)	0.0384	0.0328	0.0217	0.0224

Figure 6

Name	Comparative Example 9	Inventive Example 18	Inventive Example 19	Inventive Example 20
Base Stock - Group 1 - KV100 12.1 cSt	79.6			
Base Stock - Group 3- KV100 7.7 cSt		37.3	58.9	84.6
Base Stock - Group 1- KV100 31.8 cSt		51.56		
Base Stock - Group 4 - KV100 157.4 cSt			29.9	
Basestock - Group 5 - PMA - KV100 >200 cSt				4.3
Molybdenum Dithiocarbamate		0.1	0.1	0.1
Zinc Dithiocarbamate		0.6	0.6	0.6
Calcium Alkyl Salicylate Detergent		10	10	10
ZDDP	0.2			
Rest of formulation	20.2	0.44	0.5	0.4
Total	100	100	100	100
D2896, TBN	35	35	35	35
KV100	20.5	20.5	22.1	19.6
MTM Boundary Traction Coefficient (9 mm/s rolling speed)	0.0639	0.0459	0.0331	0.0247
MTM Mixed Traction Coefficient (96 mm/s rolling speed)	0.0450	0.0375	0.0269	0.0241
MTM Hydrodynamic Traction Coefficient (880 mm/s rolling speed)	0.0419	0.0335	0.0238	0.0207

Figure 7

Name	Comparative Example 10	Inventive Example 21	Inventive Example 22	Inventive Example 23	Inventive Example 24
Base Stock - Group 1 - KV100 12.1 cSt	47.6				
Base Stock - Group 3- KV100 7.7 cSt		25.96	74.1	76.26	58.75
Base Stock - Group 1- KV100 31.8 cSt	41.1	66.1			
Basestock - Group 5 - PMA - KV100 >200 cSt			17.9		
Basestock - Group 5 - PIB - KV100 >200cSt				15.69	
Base Stock - Group 4 - KV100 157.4 cSt					33.28
Molybdenum Dithiocarbamate		0.1	0.1	0.1	0.1
Zinc Dithiocarbamate		0.6	0.6	0.6	0.6
Calcium Alkyl Salicylate Detergent		7	7	7	7
Rest of formulation	11.3	0.24	0.3	0.35	0.27
Total	100	100	100	100	100
D2896, TBN	25	25	25	25	25
KV100, cSt	20.1	19.9	20.1	19.2	20.2
MTM Boundary Traction Coefficient (9 mm/s rolling speed)	0.0624	0.0481	0.0364	0.0237	0.0411
MTM Mixed Traction Coefficient (96 mm/s rolling speed)	0.0465	0.0388	0.0256	0.0252	0.0241
MTM Hydrodynamic Traction Coefficient (880 mm/s rolling speed)	0.0424	0.0371	0.0217	0.0263	0.0220

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Figure 8

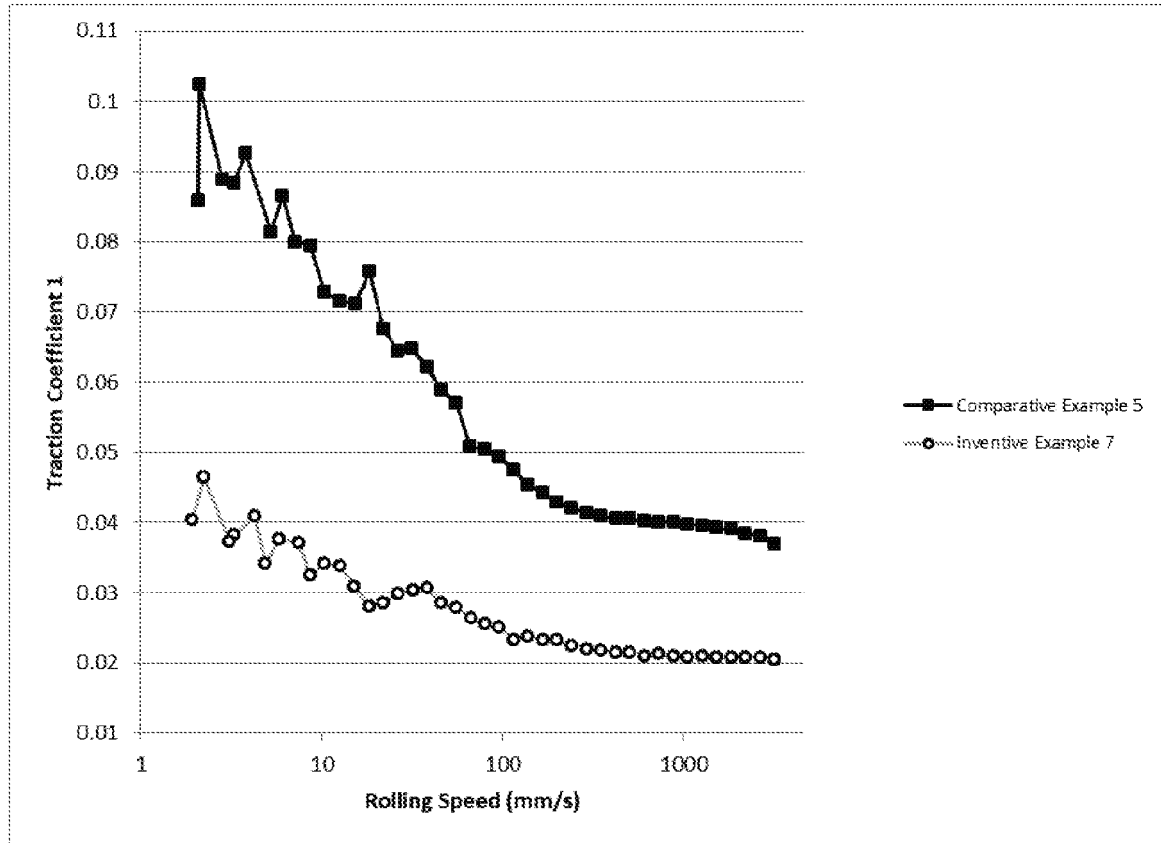
Name	Comparative Example 11	Inventive Example 25	Inventive Example 26	Inventive Example 27	Inventive Example 28	Inventive Example 29
Base Stock - Group 1 - KV100 12.1 cSt	70.1					
Base Stock - Group 3- KV100 7.7 cSt		65.9	67.8	69	65.9	69
Base Stock - Group 1- KV100 31.8 cSt		13				
Base Stock - Group 4 - KV100 157.4 cSt			11	13		
Basestock - Group 5 - PMA - >200 cSt					13.1	13
Molybdenum Dithiocarbamate		0.1	0.1	0.1	0.1	0.1
Zinc Dithiocarbamate		0.6	0.6	0.6	0.6	0.6
Calcium Alkyl Salicylate Detergent		20	20		20	
Rest of formulation	29.9	0.4	0.5	17.3	0.3	17.3
Total	100	100	100	100	100	100
D2896, TBN	70	70	70	70	70	70
Kv100	21	18	16	18	23	22
MTM Boundary Traction Coefficient (9 mm/s rolling speed)	0.0696	0.0501	0.0553	0.0568	0.0309	0.0605
MTM Mixed Traction Coefficient (96 mm/s rolling speed)	0.0507	0.0320	0.0341	0.0434	0.0255	0.0339
MTM Hydrodynamic Traction Coefficient (880 mm/s rolling speed)	0.0478	0.0247	0.0228	0.0246	0.0220	0.0215

Figure 9

Name	Comparative Example 12	Comparative Example 13	Inventive Example 30
Base Stock - Group 1 - KV100 12.1 cSt	65.31	51.71	
Base Stock - Group 1- KV100 31.8 cSt		19	
Base Stock - Group 3- KV100 7.7 cSt			66.9
Basestock - Group 5 - PIB - KV100 >200cSt	2.81		
Basestock - Group 5 - PMA - KV100 >200 cSt			4.09
Molybdenum Dithiocarbamate			0.1
Zinc Dithiocarbamate			0.6
Calcium Alkyl Salicylate Detergent			28
Rest of formulation	31.88	29.29	0.31
Total	100	100	100
D2896, TBN	101	100	103
KV100, cSt	21.74	20.1	22.23
MTM Boundary Traction Coefficient (9 mm/s rolling speed)	0.0742	0.0628	0.0301
MTM Mixed Traction Coefficient (96 mm/s rolling speed)	0.0486	0.0463	0.0294
MTM Hydrodynamic Traction Coefficient (880 mm/s rolling speed)	0.0462	0.0447	0.0228

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Figure 10



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Figure 11

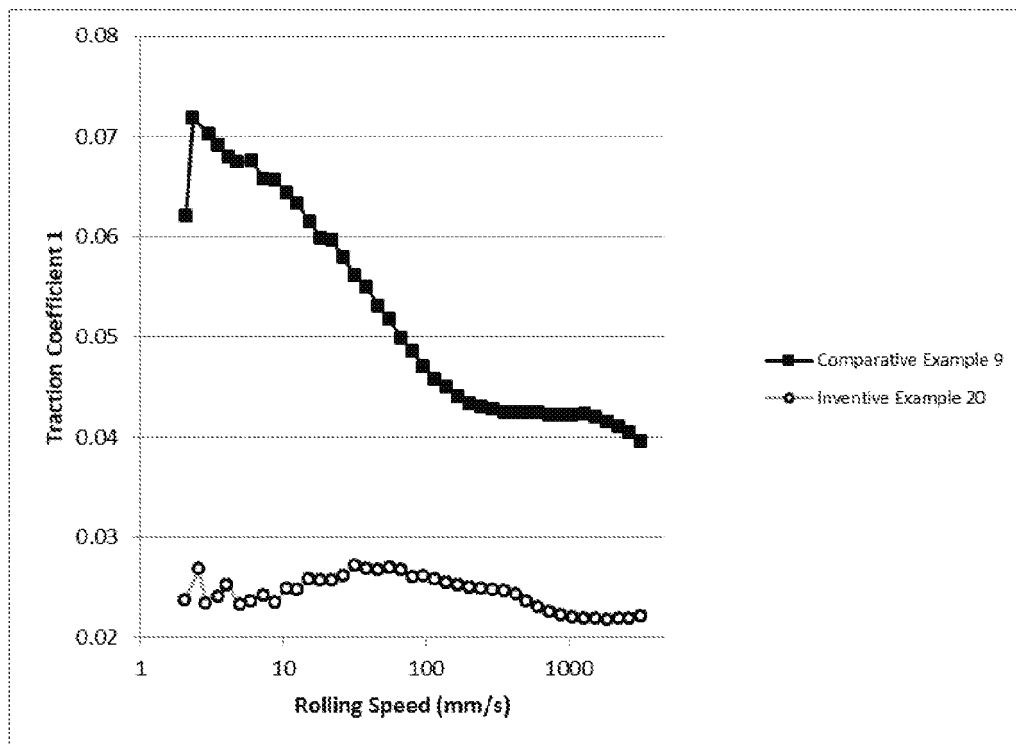


Figure 12

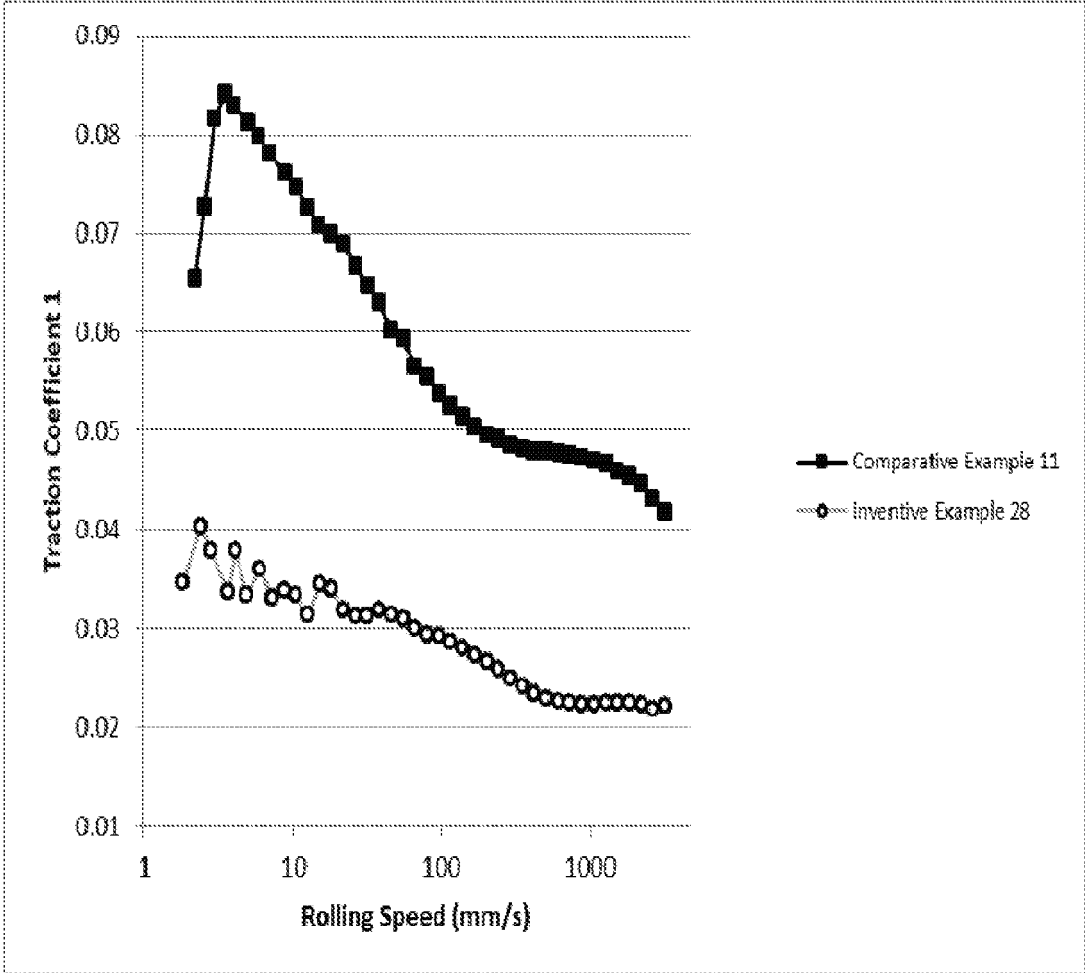


Figure 13

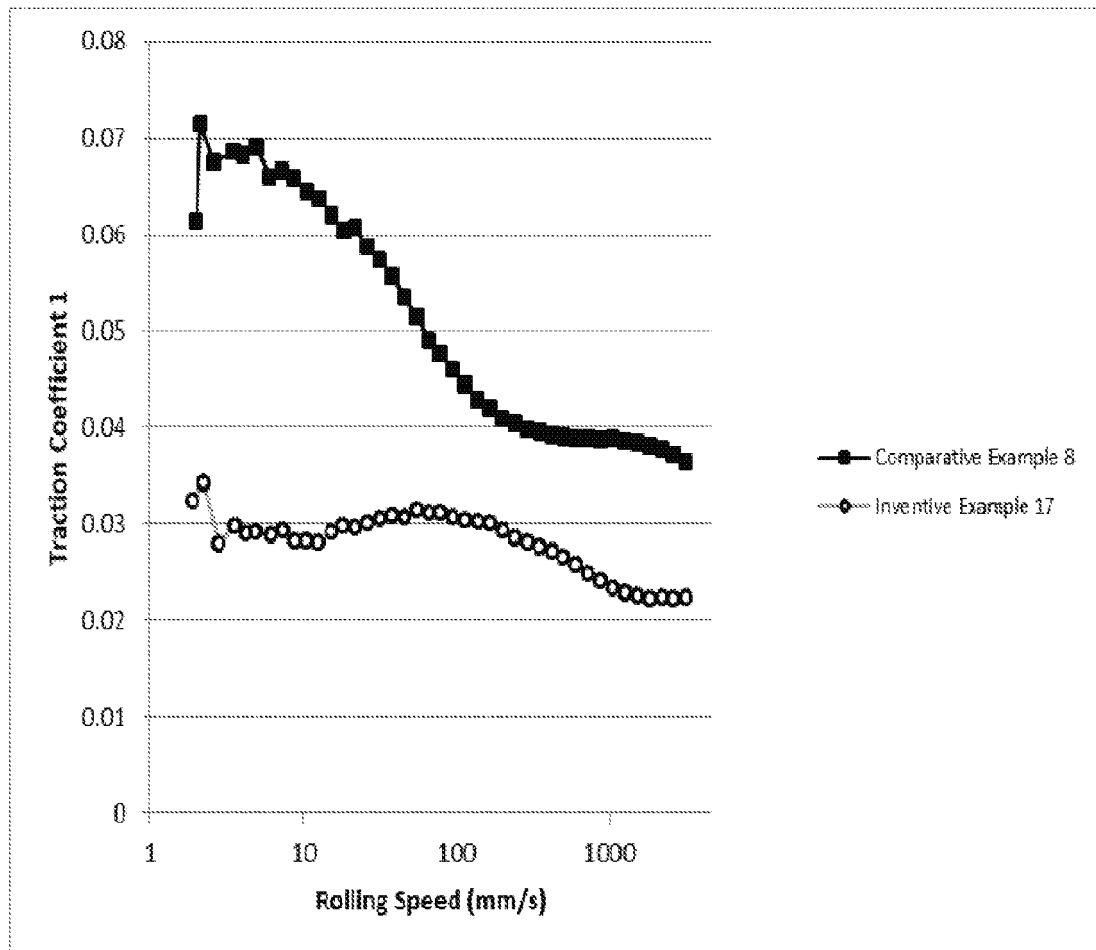


Figure 14

Name	Comparative Example 13	Inventive Example 30
Brake Specific Fuel Consumption [g/kWh]	233.4 ±0.1	232.1±0.3
Percent fuel economy benefit compared to reference	0%	0.5%

90% confidence intervals (Tukey)

Figure 15

Modes*	Speed (rpm)	% Load
1	900	100
2	900	75
3	900	50
4	900	25

Test Run Order = 4, 3, 2, 1

*Based on Cycle E2 Table 6 of ISO 8178-4:2007

Figure 16

FE Testing Cycle Parameters	Mode 1	Mode 2	Mode 3	Mode 4
Time (min) - 1st set	20	20	20	20
Time (min) - 2nd set	20	20	20	20
Time (min) - 3rd set	20	20	20	20
Time (min) - 4th set	20	20	20	20
Time (min) - 5th set	20	20	20	20
Speed (rpm)	900	900	900	900
Coolant temperature (°C)	kept constant – measured during test			
Fuel temperature (°C)	kept constant – measured during test			
Inlet Air temperature (°C)	kept constant – measured during test			
Oil temperature (°C)	kept constant – measured during test			
Charge air temperature (°C)	kept constant – measured during test			

1. Modes as defined in Figure 15

Figure 17

Engine Parameter	Commercial Engines	Single Cylinder Test Engine
Bore Size (mm)	260-980	108
Stoke/Bore (ratio)	~ 2.5 – 4.4	4.0
RPM	~ 60 – 250	300 – 600
Engine Output (hp/cylinder)	7500 +	100
BMEP (bar)	18 – 21	20
Pressure max (bar)	150 +	150
Load (%)	100 – 15	100 – 25
Marine Cylinder Lubricant Feed Rate (grams/kilowatt hour)	1.4 – 0.6	1.6 – 0.3

Figure 18

Modes	Speed (rpm)	% Load	Power (kw)	BMEP (bar) as Reference
1	280	30	7.2	3.9
2	280	70	16.8	9.1
3	410	30	14.9	5.5
4	410	70	34.7	12.8
5	545	30	21.8	6
6	545	70	50.8	14.1

Figure 19

FE Testing Cycle Parameters	Mode 1	Mode 3	Mode 2	Mode 5	Mode 4	Mode 6
Time (min) - 1st set	50	50	50	50	50	50
Time (min) - 2nd set	50	50	50	50	50	50
Time (min) - 3rd set	50	50	50	50	50	50
Time (min) - 4th set	50	50	50	50	50	50
Time (min) - 5th set	50	50	50	50	50	50
Power (kW)	7.2	14.9	16.8	21.8	34.7	50.8
Speed (rpm)	280	410	280	545	410	545
Torque (Nm)	245.3	346.3	572.4	381.4	808	890
BMEP (bar) - as reference	3.9	5.5	9.1	6	12.8	14.1
Lube Feed Rate, g/kWh	kept constant during the test					
Coolant temperature (°C)	kept constant – measured during test					
Fuel temperature (°C)	kept constant – measured during test					
Inlet Air temperature (°C)	kept constant – measured during test					
Oil temperature (°C)	kept constant – measured during test					
Charge air temperature (°C)	kept constant – measured during test					

1. After a 30 minute warm up each oil is run for 5 loops. The first loop data is excluded from data analysis and the last sixty seconds of each mode of the remaining four loops is recorded for data analysis.
2. Modes as defined in figure 18