Figure No.	Description	Page No.
1.1	Stribeck curve: Dependence of the friction coefficient on viscosity, speed and load for a lubricated sliding system	5
1.2	Mechanisms of formation of iron sulfide tribofilms from sulfur compounds adsorbed at iron surface	12
1.3	General structure of an ashless dithiophosphate	13
1.4	Molecular structures of N-heterocyclic compounds	15
1.5	Chemical structure of triazine-dialkyldithiocarbamate	15
1.6	Chemical processes leading to $MoS_2$ formation from MoDTC	17
1.7	Chemical structure of dialkyldithiophosphate	20
1.8	Hydrolysis of borate esters	23
1.9	Lamellar structure of boric acid	24
1.10	A schematic representation of the tribochemical reactions between borate esters and stainless steel surfaces	26
2.1	Four ball lubricant tester	36
3.1	Variation of mean wear scar diameter in absence and presence of different concentrations of $\beta$ -lactum additives in paraffin oil at 392N applied load and 60 min. duration	42
3.2	Variation of mean wear scar diameter in paraffin oil with and without different antiwear additives (1% w/v) at 392N applied load for 60 min. test duration	42
3.3	Variation of mean wear scar diameter with time in paraffin oil containing (1% w/v) zinc dibutyldithiophosphate and $\beta$ -lactum additives at 392N applied load	44

3.4	Variation of friction coefficient with time in paraffin oil containing (1% w/v) zinc dibutyldithiophosphate and $\beta$ -lactum additives at 392N applied load	44
3.5	Determination of overall wear rate by varying mean wear volume with time (h) in paraffin oil containing $(1\% \text{ w/v})$ zinc dibutyldithiophosphate and $\beta$ -lactum additives at 392N applied load	47
3.6	Determination of running-in wear rate by varying mean wear volume with time (h) in paraffin oil containing $(1\% \text{ w/v})$ zinc dibutyldithiophosphate and $\beta$ -lactum additives at 392N applied load	49
3.7	Determination of steady-state wear rate by varying mean wear volume with time (h) in paraffin oil containing $(1\% \text{ w/v})$ zinc dibutyldithiophosphate and $\beta$ -lactum additives at 392N applied load	49
3.8	Variation of mean wear scar diameter with applied load in paraffin oil containing (1% w/v) zinc dibutyldithiophosphate and $\beta$ -lactum additives for 30 min. test duration	51
3.9	SEM micrographs at different magnifications of the worn steel surface lubricated with $\beta$ -lactum additives (1% w/v) in paraffin oil for 90 min. test duration at 392 N applied load: (a) Paraffin oil, (b) ZDDP, (c) Cefixime, (d) Cefadroxil and (e) Cephalexin	53
3.10	SEM micrographs of the worn steel surface lubricated with, (a) cefixime and (b) ZDDP ( $1\% \text{ w/v}$ ) in paraffin oil for 30 min test duration at 588 N applied load	54
3.11	3 <i>D</i> -AFM images of the worn steel surface lubricated with $\beta$ -lactum additives (1% w/v) in paraffin oil for 90 min test duration at 392 N applied load: (a) Paraffin oil, (b) Zinc dibutyldithiophosphate, (c) Cefixime, (d) Cefadroxil and (e) Cephalexin	55

3.12	EDX analysis data of the worn steel surface lubricated with paraffin oil in presence and absence of additives $(1\% \text{ w/v})$ for 90 min test duration at 392 N applied load: (a) Paraffin oil, (b) Zinc dibutyldithiophosphate (ZDDP) and (c) Cefixime	56
3.13	EDX analysis data of the worn steel surface lubricated with paraffin oil in presence cefixime additives (1% w/v) for 30 min test duration at 588 N applied load	56
3.14	XPS spectra of tribochemical film formed on worn steel surface lubricated with cefixime additive $(1\% \text{ w/v})$ at 392 N applied load for 90 min. test duration in liquid paraffin. (a). C 1s (b).N 1s (c).S 2p (d). O 1s and (e). Fe 2p	58
3.15	HOMO and LUMO density distributions of $\beta$ -lactum additives respectively for (a,b). Cefixime, (c,d). Cefadroxil and (e,f). Cephalexin	62
4.1	Variation of mean wear scar diameter in absence and presence of different additive concentrations in paraffin oil at 392N applied load and 60 min duration	67
4.2	Comparison of MWD and average COF values of steel balls lubricated with different additives in paraffin oil at 392N; rotating speed: 1200 rpm, temperature: 75°C, test duration: 60 min., concentration: 0.25% w/v of additives	67
4.3	Variation of COF with sliding time in presence and absence of additives in paraffin oil at 392N; rotating speed: 1200 rpm, temperature: 75°C, test duration: 60 min., concentration: 0.25% w/v of additives	68
4.4	Variation of mean wear scar diameter with time in paraffin oil containing fluoroquinolone antibiotics 392N applied load	68
4.5	Variation of mean wear volume with time (h) in paraffin oil containing fluoroquinolone antibiotics 392N applied load	69
4.6	Determination of running-in wear rate by varying mean wear volume with time (h) for paraffin oil containing fluoroquinolone antibiotics at 392N applied load	69

4.7	Determination of steady-state wear rate by varying mean wear volume with time (h) for paraffin oil containing fluoroquinolone antibiotics at 392N applied load	70
4.8	Variation of mean wear scar diameter with applied load for paraffin oil containing 0.25% w/v of different additives for 30 min test duration	71
4.9	Variation of frictional torque as a function of step loading (with the increment of 98N load at every 10 min of test run) and time for different additives; sliding speed:600 rpm; temperature: 75 °C, additive concentration: 0.25% w/v	72
4.10	SEM micrographs of the worn steel surface lubricated with different additives in paraffin oil for 60 min test duration at 392N applied load: ( <b>a</b> , <b>b</b> ). Paraffin oil, ( <b>c</b> , <b>d</b> ). Ofloxacin ( <b>e</b> , <b>f</b> ). Ciprofloxacin and ( <b>g</b> , <b>h</b> ). Norfloxacin	74
4.11	SEM micrographs of the worn steel surface lubricated with different additives in paraffin oil for 30 min test duration at 686 N applied load: ( <b>a</b> , <b>b</b> ). Ofloxcin, ( <b>c</b> , <b>d</b> ). Ciprofloxacin and ( <b>e</b> , <b>f</b> ). Norfloxacin	75
4.12	2 <i>D</i> and 3 <i>D</i> -AFM images of the worn steel surface lubricated with different additives in paraffin oil for 60 min test duration at 392N applied load: ( <b>a</b> , <b>b</b> ). Paraffin oil, ( <b>c</b> , <b>d</b> ). Of loxacin, ( <b>e</b> , <b>f</b> ). Ciprofloxacin and ( <b>g</b> , <b>h</b> ). Norfloxacin	76
4.13	Surface Roughness parameters obtained from digital processing software of Nanosurf basic Scan 2 for different additives at 392N load for 60 min test duration	76
4.14	2D and 3D-AFM images of the worn steel surface lubricated with different additives in paraffin oil for 30 min test duration at 686N applied load: ( <b>a</b> , <b>b</b> ). Of loxacin, ( <b>c</b> , <b>d</b> ). Ciprofloxacin and ( <b>e</b> , <b>f</b> ). Norfloxacin	77
4.15	Surface Roughness parameters obtained from digital processing software of Nanosurf basic Scan 2 for different additives at 686N load for 30 min test duration	77

4.16	EDX analysis data of the worn steel surface lubricated with (a). Paraffin oil and (b). Ofloxacin for 60 min test duration at 392N applied load	78
4.17	HOMO and LUMO density distributions of fluoroquinolones antibiotics additive	79
5.1	Variation of mean wear scar diameter in absence and presence of different concentrations of additives in paraffin oil at 392N applied load and 60 min duration	88
5.2	Variation of mean wear scar diameter in paraffin oil with and without different antiwear additives $(1\% \text{ w/v})$ at 392N applied load for 60 min test duration	88
5.3	Variation of mean wear scar diameter with time in paraffin oil containing $(1\% \text{ w/v})$ zinc dibutyldithiophosphate (ZDDP) and quinolinium derivatives at 392N applied load	92
5.4	Variation of friction coefficient with time in paraffin oil containing $(1\% w/v)$ zinc dibutyldithiophosphate (ZDDP) and quinolinium derivatives at 392N applied load	92
5.5	Variation of mean wear volume with time (h) in paraffin oil containing $(1\% \text{ w/v})$ zinc dibutyldithiophosphate (ZDDP) and quinolinium derivatives at 392N applied load	93
5.6	Determination of running-in wear rate by varying mean wear volume with time (h) in paraffin oil containing (1% w/v) zinc dibutyldithiophosphate and quinolinium derivatives at 392N applied load	94
5.7	Determination of steady-state wear rate by varying mean wear volume with time (h) in paraffin oil containing $(1\% \text{ w/v})$ with and without additives at 392N applied load	94
5.8	Variation of mean wear scar diameter with applied load in paraffin oil containing $(1\% \text{ w/v})$ zinc dibutyldithiophosphate (ZDDP) and quinolinium derivatives for 30 min test duration	96

5.9	SEM micrographs at different magnifications of the worn steel	97
	surface lubricated with different additives (1% w/v) in paraffin oil for 90 min test duration at 392N applied load: (a) Paraffin oil, (b) ZDDP, (c) $[DIP-Q]^+Br^-$ and (d) $[P-Q]^+I^-$	
5.10	SEM micrographs of the worn steel surface lubricated with (a) $[DIP-Q]^{+}Br^{-}(b) [P-Q]^{+}I$ and (c) ZDDP (1% w/v) in paraffin oil for 30 min test duration at 588N applied load	98
5.11	3 <i>D</i> -AFM images of the worn steel surface lubricated with different additives $(1\% \text{ w/v})$ in paraffin oil for 90 min test duration at 392N applied load: (a) Paraffin oil (b) ZDDP (c) [DIP-Q] <sup>+</sup> Br <sup>-</sup> and (d) [P-Q] <sup>+</sup> I <sup>-</sup>	99
5.12	Surface Roughness parameters obtained from digital processing software of Nanosurf-basic Scan 2 for different additives at 392N load for 90 min test duration	100
5.13	3 <i>D</i> -AFM images of the worn steel surface lubricated with different additives (1% w/v) in paraffin oil for 30 min test duration at 588N applied load: (a) ZDDP (b) $[DIP-Q]^+Br^-$ and (c) $[P-Q]^+\Gamma$	101
5.14	EDX analysis data of the worn steel surface lubricated with paraffin oil in presence and absence of different additives (1% w/v) for 90 min test duration at 392N applied load: (a) Paraffin oil, (b) ZDDP, (c) $[DIP-Q]^+Br^-$ and (d) $[P-Q]^+\Gamma$	102
5.15	XPS spectra of tribochemical film formed on worn steel surface lubricated with the $[DIP-Q]^+Br^-$ additive $(1\% w/v)$ at 392N applied load for 90 min test duration in liquid paraffin. (a) C1s (b) N1s (c) Br3d <sub>3/2</sub> (d) Fe2p and (e) O1s	104
5.16	Frontiers molecular orbital images (HOMO and LUMO) of different quinolinium derivatives	106
6.1	<sup>1</sup> H NMR spectra of the synthesized Schiff base additive	110
6.2	Variation of mean wear scar diameter for paraffin oil as a function	112
Kalyani	Indian Institute of Technology (Banaras Hindu University) Varanasi	viii

of increasing different additive concentrations at 392 N applied load for 60 min test duration

- 6.3 Effect of change in concentration of different additive 112 formulations on mean wear scar diameter in paraffin oil at 392N applied load for 60 min duration
- 6.4 Variation of mean wear scar diameter and average coefficient of 113 friction values in absence and presence of different additives concentrations with borate ester in paraffin oil at 392N applied load and 60 min duration
- 6.5 Variation of mean wear scar diameter with time in paraffin oil
  114 containing of 1% w/v of Schiff base, borate ester and synergistic formulation at 392N applied load
- 6.6 Variation of mean wear volume with time in paraffin oil 114 containing 1% w/v of Schiff base, borate ester and synergistic formulation at 392N applied load
- 6.7 Determination of running-in wear-rate for paraffin oil in the 115 presence and absence of Schiff base, borate ester and synergistic formulation (1% w/v) at 392 N applied load
- **6.8** Determination of steady-state wear-rate for paraffin oil in the **115** presence and absence of Schiff base, borate ester and synergistic formulation (1% w/v) at 392 N applied load
- 6.9 Variation of mean wear scar diameter with applied load in paraffin 117 oil containing 1% w/v of Schiff bases, borate ester and synergistic formulation for 30 min test duration
- 6.10 SEM micrographs of the worn steel surface lubricated with paraffin oil in presence and absence of different additives (1% w/v) for 60 min test duration at 392N applied load: (a) Paraffin oil, (b) SB and (c) SB+BE
- 6.11 *3D*-AFM images of the worn steel surface lubricated with paraffin **118**

	oil in presence and absence of different additives (1% w/v) for 60 min test duration at 392N applied load: (a) Paraffin oil, (b) SB, (c) BE and(d) SB+BE	
6.12	EDX-spectra of the worn steel surface lubricated with synergistic mixture (SB+BE) for 60 min test duration at 392N applied load	119
6.13	Graphical representation of energy gaps (Hartree) between HOMO and LUMO density distributions for the studied additives	120
7.1	Powder X-ray Diffraction pattern of pure ZnO and Mg-doped-ZnO nanoparticles having different particle size	126
7.2	TEM-image of ZMO nanoparticles along with selected area electron diffraction (SAED) pattern	126
7.3	Energy dispersive X-ray spectrum showing constituents and chemical composition of ZMO nanoparticles	127
7.4	(a). Relative absorbance of SZMO and SZMO-2 nanoparticles at different time intervals and the UV-Visible spectra of SZMO nanoparticles at different settling times (in inset) and (b). Optical photographs of the different SZMOs NPs suspended in pure paraffin oil at different settling times	128
7.5	Variation of mean wear scar diameter in absence and presence of different additive concentrations in paraffin oil at 392N applied load and 60 min duration	131
7.6	Comparison of MWD and COF of steel balls lubricated with different nanoparticles in paraffin oil at 392 N; rotating speed: 1200 rpm, temperature: 75 °C, test duration: 60 min., concentration: 0.25% w/v of nanoparticles	131
7.7	Variation of COF with sliding time in presence and absence of different nanoparticles in paraffin oil at 392N; rotating speed: 1200 rpm, temperature: 75 °C, test duration: 60 min., concentration: 0.25% w/v of nanoparticles	132

Kalyani	Indian Institute of Technology (Banaras Hindu University) Varanasi	xi
7.17	2D and 3D-AFM images of the worn steel surface lubricated with	142
7.16	2 <i>D</i> and 3 <i>D</i> -AFM images of the worn steel surface lubricated with different additives in paraffin oil for 60 min test duration at 392N applied load: ( <b>a</b> , <b>b</b> ). Paraffin oil, ( <b>c</b> , <b>d</b> ). SZMO, ( <b>e</b> , <b>f</b> ). SZMO-1 and ( <b>g</b> , <b>h</b> ). SZMO-2 nanoparticles	142
7.15	SEM micrographs of the worn steel surface lubricated with different nanoparticles in paraffin oil for 30 min test duration at 490 N applied load: ( <b>a,b</b> ). Paraffin oil, ( <b>c,d</b> ).SZMO and ( <b>e,f</b> ).SZMO-2 nanoparticles	141
7.14	SEM micrographs of the worn steel surface lubricated with different nanoparticles in paraffin oil for 60 min test duration at 392N applied load: ( <b>a</b> , <b>b</b> ). Paraffin oil, ( <b>c</b> , <b>d</b> ). SZMO and ( <b>e</b> , <b>f</b> ). SZMO-2 nanoparticles	140
7.13	Variation of frictional torque as a function of step loading (with the increment of 98N load at every 10 min of test run) and time for different SZMOs nanoparticles; sliding speed:600 rpm; temperature: 75 °C, additive concentration: 0.25% w/v	136
7.12	Variation of mean wear scar diameter with applied load for paraffin oil containing 0.25% w/v of SZMOs nanoparticles for 30 min test duration	135
7.11	Determination of steady-state wear rate by varying mean wear volume with time (h) for paraffin oil containing SZMOs nanoparticles at 392N applied load	134
7.10	Determination of running-in wear rate by varying mean wear volume with time (h) for paraffin oil containing SZMOs nanoparticles at 392N applied load	133
7.9	Variation of mean wear volume with time (h) in paraffin oil containing SZMOs nanoparticles at 392N applied load	133
7.8	Variation of mean wear scar diameter with time in paraffin oil containing SZMOs nanoparticles at 392N applied load	132

different additives in paraffin oil for 30 min test duration at 490N applied load: (**a,b**). Paraffin oil, (**c,d**). SZMO and (**e,f**). SZMO-2 nanoparticles

- 7.18 EDX analysis data of the worn steel surface lubricated with paraffin oil in presence and absence of different additives for 60 min test duration at 392N applied load: (a).SZMO nanoparticles and (b). Paraffin oil
- 7.19 Elemental mapping of the various elements on worn steel surface 144 lubricated with SZMO nanoparticles for 60 min test duration at 392N applied load; (a). C, (b). O, (c). Mg, (d).Zn and (e). Fe
- 7.20 EDX analysis data of the worn steel surface lubricated with paraffin oil in presence of different nanoparticles for 30 min test duration at 490N applied load: (a). SZMO and (b). SZMO-2