Aug. 15th 2024, Qingdao, China

13th CIMAC CASCADES
Qingdao, August 14-15

Nano-additives for Internal Combustion and Micro-Engines: A Boosted Efficiency & Intelligent Emission Control

用于内燃机和微型发动机的纳米添加剂：提高效率和智能排放控制

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[2]Paris-Saclay University, France

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     - Intelligent Emission Control
       智能排放控制 (**中国/法国**行业将采用该模式 2024)
3. **International Collaboration** 国际合作

Academic (学术) :

- Associate Professor : Hangzhou International Innovation Institute, Beihang University, (2024)
  副教授: 杭州市北京航空航天大学国际创新研究院 (2024) / Top #5, China
- Associate Professor : Institute of Engineering Thermophysics, IET-CAS, China (2022-2024)
  副教授: 中国科学院工程热物理研究所 (2022-2024) / Top #8, China
- Associate Professor : Paris Saclay University, France (2016-2022)
  副教授: 法国巴黎萨克雷大学 (2016-2022) / Top #1, Europe

Specializes in : Clean Energy / Low Emissions / Advanced Industrial Processes
专长 : 清洁能源 / 低排放 / 先进的工业流程

Research Interests :
研究方向 :
- Heat & Mass Transfer of Complex Fluids.
- Carbon Neutrality.
- Nanotechnology.
- Energy Control & Optimization.

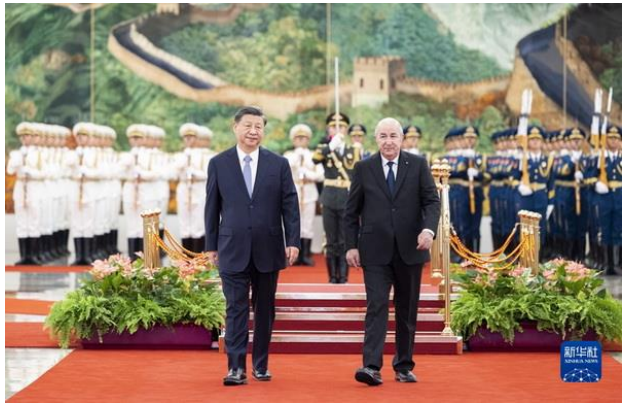
- University Teacher (13 years Experience) :
大学老师 (13年经验) :
- UCAS University, China (invited)
- Paris Saclay University, France.
- Lorraine University, France.
- USTHB University, Algeria.

(i) Deputy Scientific Director of International Research & Cooperation (Europe/Asia) (since 2023)

国际研究与合作部副主任 (欧洲 / 亚洲)

- **President XI JINPING :** represented the strong relationship between Algeria and China in advanced research and clean industrial applications.

我代表了阿尔及利亚和中国在先进研究和清洁工业应用方面的牢固关系.



(July 18-20th, 2023. Beijing, China)

- **Chinese Premier LI QIANG,**
- **Chinese Foreign Minister WANG YI,**
- **French Minister for Europe & Foreign Affairs C. COLONNA :**

represented the strong relations between France and China.

Official launch of France-China Carbon Neutrality Center, Beijing.

中国外交部长王毅，

法国欧洲和外交部长凯瑟琳·科隆纳：

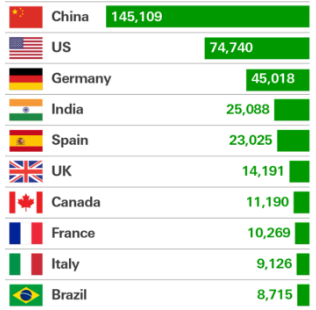
我代表了法国和中国之间的牢固关系。中法碳中和中心在京正式启动.

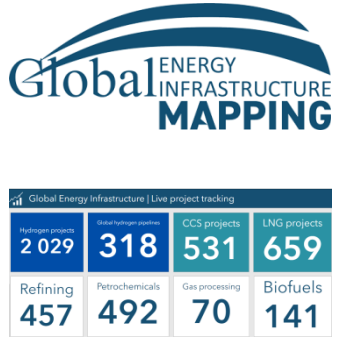
(Nov. 23-24, 2023. Beijing, China)

(ii) Formal Member of International Energy Infrastructure Mapping CCUS (since 2023)

国际能源基础设施测绘CCUS正式成员

- Global project data tools for key decision makers and executives (Europe / Asia)
  为关键决策者和高管提供全球项目数据工具 (欧洲/亚洲)
- High-quality project insights for CCS (**500 projects** / ex-situ oil fields)
  CCS的高质量项目洞察 (超过500个项目/易地油田)





(iii) Formal Member of France CNRS HydroGEMM for H_2 Energy (since 2022)

法国CNRS HydroGEMM H_2的正式成员

- H_2 soil migration and interactions with resident contaminants (**25 projects** / EU-fields)
  H_2土壤迁移及其与常驻污染物的相互作用 (超过25个项目/欧盟领域)
- Microbial H_2 reactivity in underground storage facilities (France / Europe)
  地下储存设施中的微生物H_2反应性 (法国/欧洲)

(国际赞助商)

(iv) Founding Member of 1st Europe Topical School for Training Ph.D.

欧洲博士学院创始成员 (2018 直到今天)

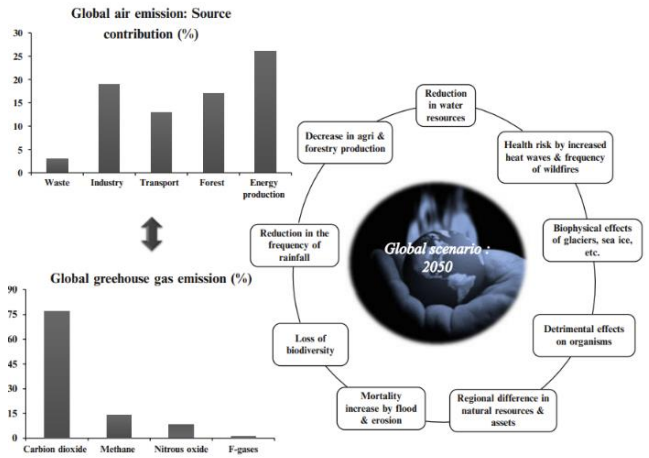
(国际赞助商)

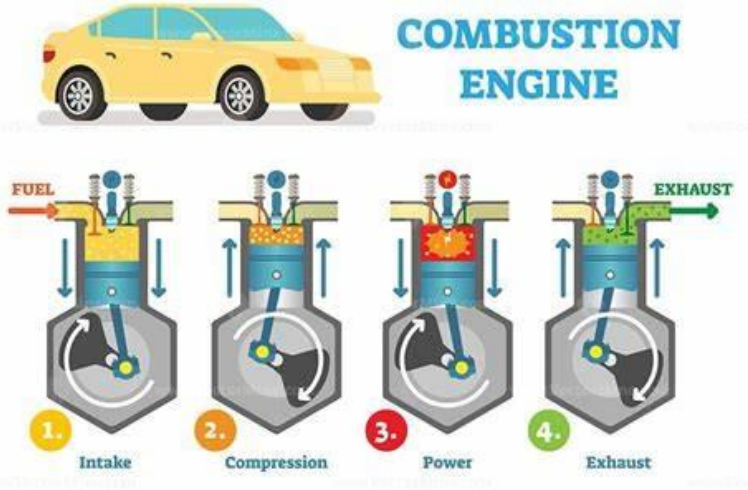
Energy Vs. Green Development

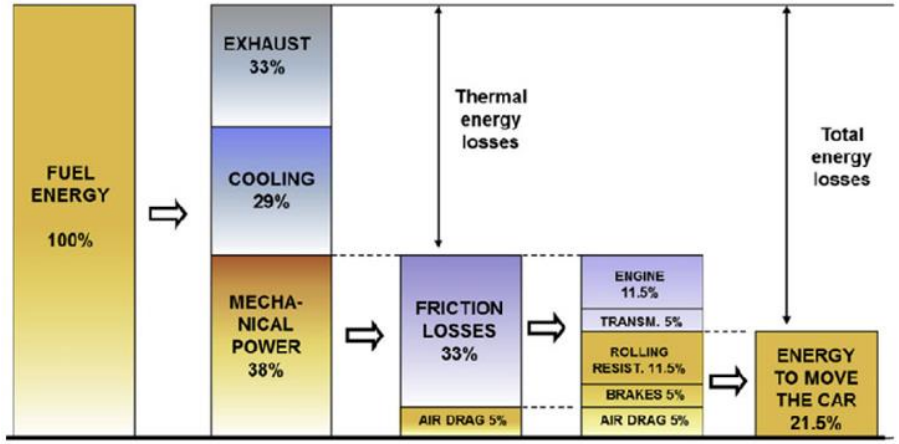
- Balanced Life Based on Energy/Depollution Green Deal
  基于能源/绿色交易的平衡生活

European Green Deal
欧洲绿色协议 (2023-2050)

China/France Green Deal
中国/法国绿色交易 (2023-2050)



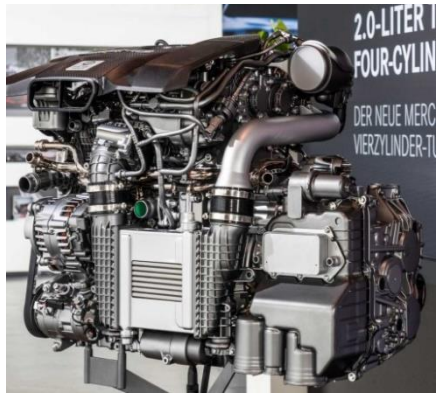




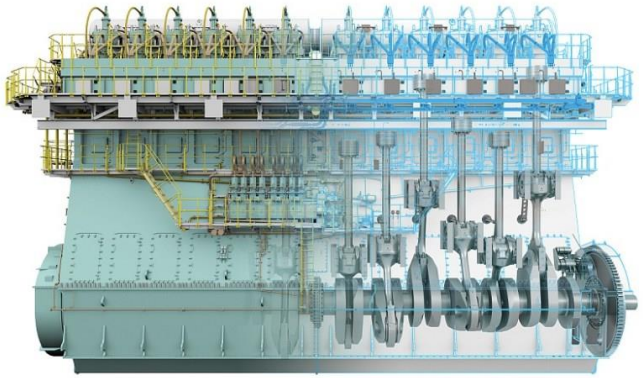
Breakdown of fuel energy consumption and losses in a passenger car engine [1].
乘用车发动机的燃料能耗和损耗细目

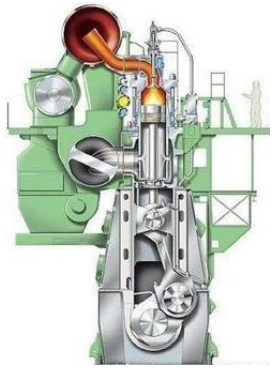
Internal Combustion Engines & Lubricants

- Key Fundamentals



World's Most Powerful 4-Cylinder Engine (2024),
Mercedes-AMG M139 [1]

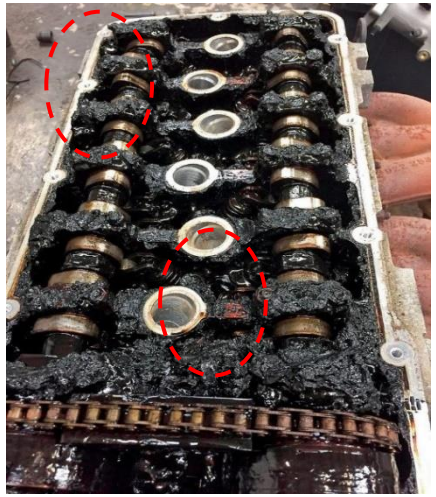




World's Most Powerful 4-Cylinder Marine Engine (2024),
MAN B&W 14K98ME-C7 engine series [3]

Current Issues (当前问题) :

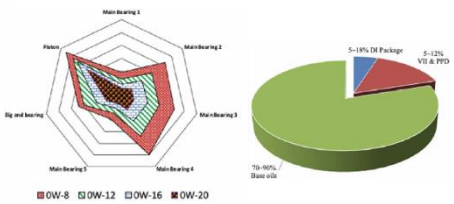
- Short-term engine operation (heating/cooling issue).
  发动机短期运行 (加热-冷却问题)
- Oxidation, low efficiency of detergency additives.
  过度氧化，去污添加剂效率低



Sludge deposition on elements inside the engine [2]

blast-stricken Yang Ming container ship in Ningbo, (2024).
Suffering from cooling issues. [2]

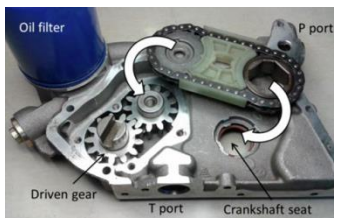
- Key Studies in Past 5 Years (过去 5 年的主要研究)



Lubrication pumps for internal combustion engines: a review.
[M. Rundo et *al.* (2020)]

Exp. + Num.

2020



2021

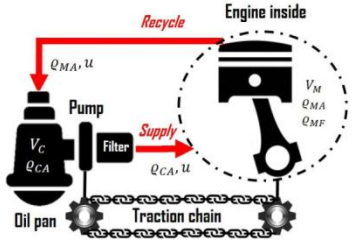
Exp.

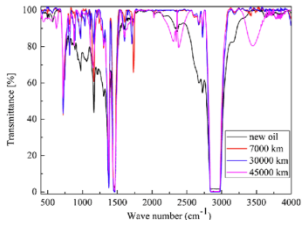
Influence of Lubrication Technology on Internal Combustion Engine Performance: An Overview.
[A. Rahim et *al.* (2021)]

Maximizing Lubricant Life for Internal Combustion Engines.
[S.D. García et al. (2022)]

Exp. & Num.

2022





2023

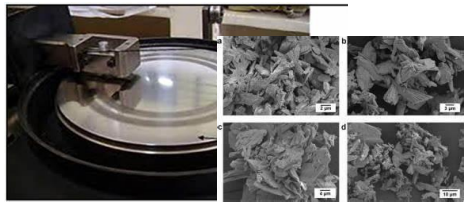
Num.

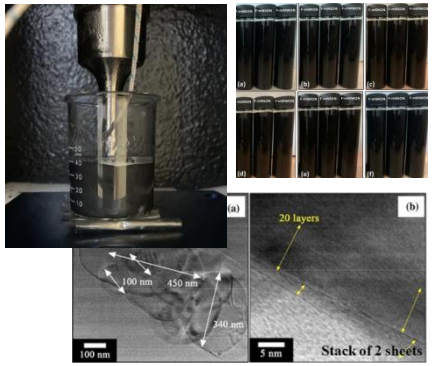
Synthesis of complex polyolester as base stock for high-performance lubricant: Optimization, characterization, and evaluation.
[Z. Liu *al.* (2024)]

Influence of surface activated nanophase Pr6O11 particles on the physio-chemical and tribological characteristics of SAE20W40 automotive lubricant.
[T. Bakaram et *al.* (2024)]

Exp.

2024





2024 **Exp. & Num.**

Characterization and optimization of innovative Nano-lubricants under extreme temperatures and pressures.
[Ragui & Bennacer (2024)]

Our laboratory
Paris-Saclay Univ.
(France)

Key Question (关键问题) :

Lubricant at 100 ^{0}C has a high oxidation capacity and quick decomposition

润滑剂在 100 ^{0}C 时氧化能力强，分解速度快

- Irreversible Oxidation at T ≤ 140 ^{0}C.
  温度等于 140 ^{0}C 时的不可逆氧化作用
- Acidity of oil, and Thermal dissipation
  油的稠度和酸度, 热耗散-失败 (-20%)
- Tar and sludge precipitation
  发动机部件上析出焦油和油泥
- Trace water to worsen the properties (μ)
  润滑油中的微量水会降低其性能

Unbalanced control mechanism of engine-regime and life-performance under conditions of limit lubrication

极限润滑条件下发动机状态和寿命性能的未知控制机制

Work's Targets (目标)

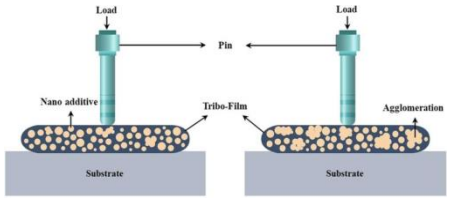
a) Significant reduction in wear and power consumption with nano-lubricants.
使用纳米润滑剂可大幅减少磨损和功耗.

b) Reduce Oxidation by Nano ball-bearing effect, and formation of tribo-film.
通过纳米球轴承效应减少氧化，并形成三重膜

Focus on goals (为什么要关注这些目标)：

If can control oxidation by Nano ball-bearing and tribo-film

通过纳米球轴承效应减少氧化，并形成三重膜



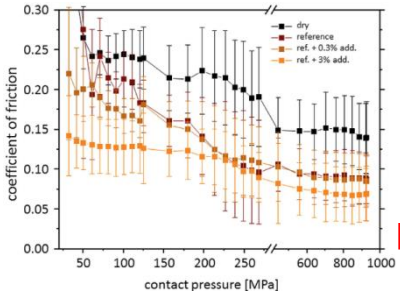
[5]

- Form a life-time protective layer on surfaces.

  在表面形成终生保护层

- High strength lubricating film between pairs.

  接合对之间的高强度润滑膜



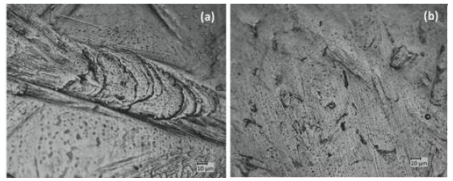
[6]

+35% higher performance under extreme conditions.

在极端条件下性能更高 (+35%)

If can control wear and power consumption with nano-lubricants

使用纳米润滑剂可大幅减少磨损和功耗



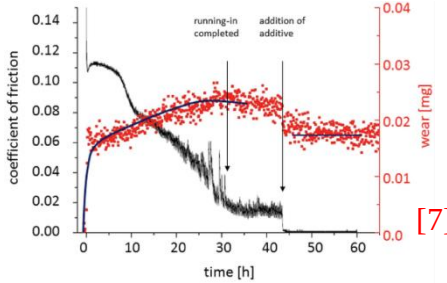
without with nano-add

- Reduce temperature of bearings and gearboxes.

  降低轴承和齿轮箱的温度 (5 - 12 ^{0}C)

- Decrease thermal dissipation and lost power.

  减少热耗散和功率损耗 (7% - 28%)

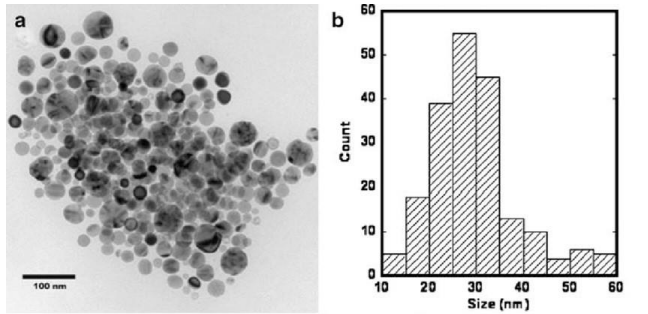


[7]

Better control of engine power up to +28%.

更好地控制发动机功率 (+28%)

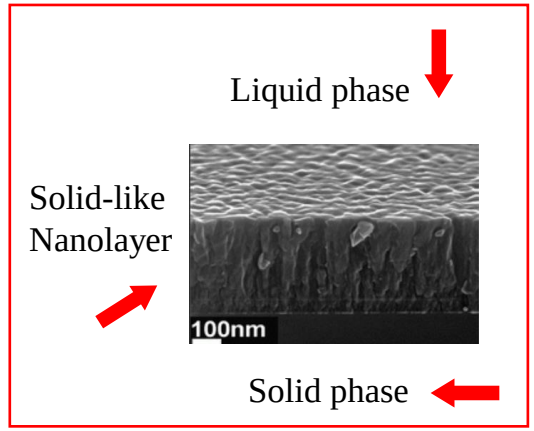
Industrial Nano-additives (工业纳米添加剂) :

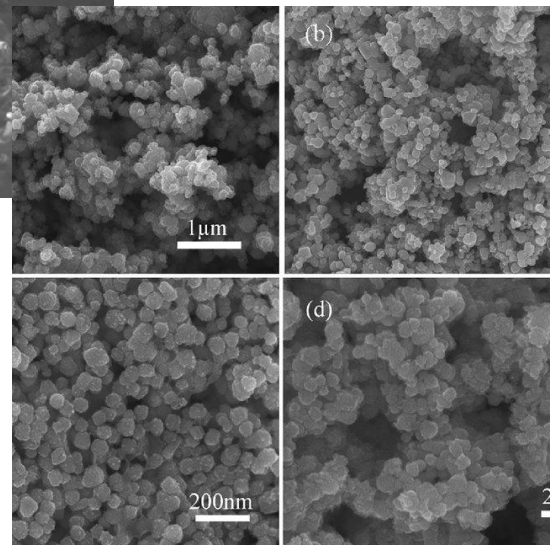


TEM of TiO_2 nanoparticles

Raised from thermally bridging nanolayer idea, a Nanofluid model is based on nanoparticles and a base fluid (1995)

从热桥接纳米层构想中提出 (1995 年)

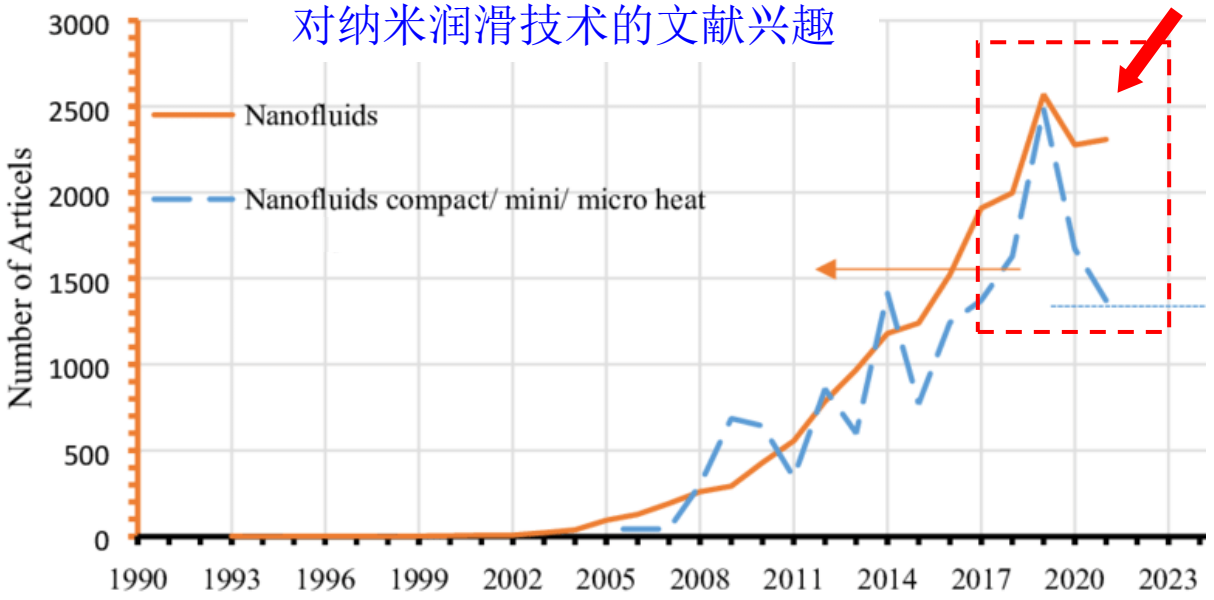




SEM of Cu nanoparticles

Artificial nano-additives admit spherical shapes

人造纳米添加剂可呈球形



Literature interest in Nano-Lubricant technology

Industrial Nano-additives (工业纳米添加剂) :

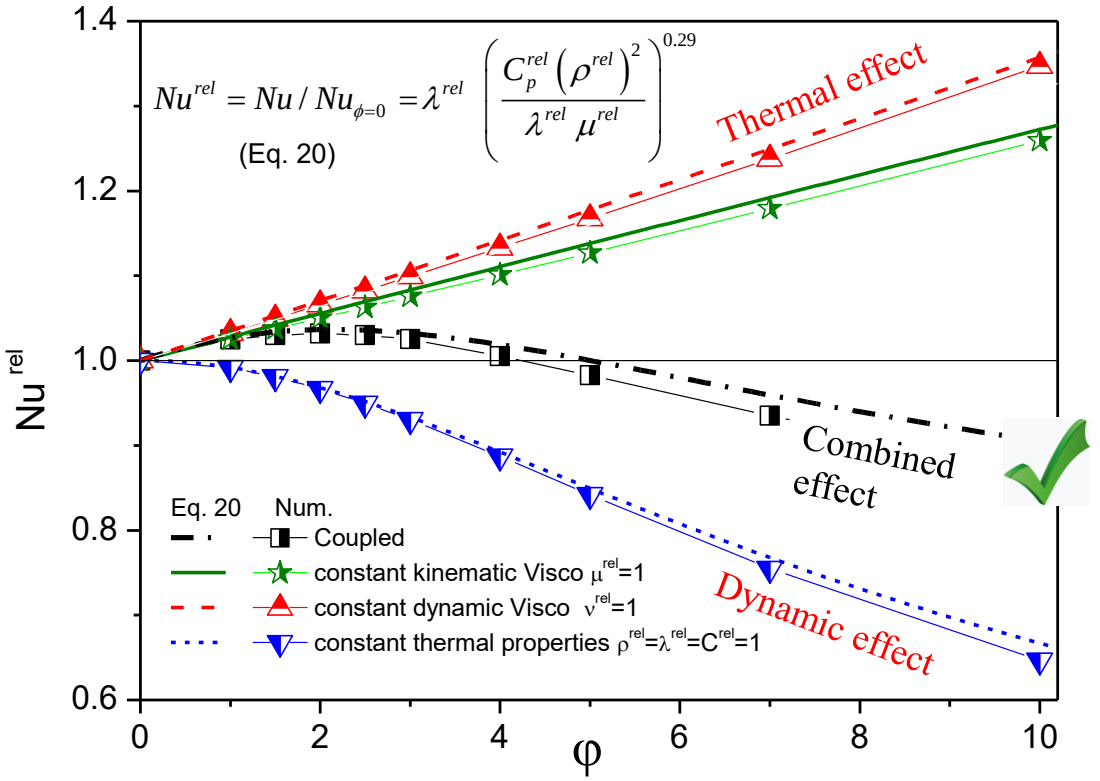
纳米添加特性 (μ, k) 的共同规律

Common laws for nano-additive properties (μ, k)

Model	Property	Formula
Einstein model [100]	Viscosity	$\frac{\mu_{eff}}{\mu_f} = 1 + 2.5\varphi$
Mooney model [102]	Viscosity	$\frac{\mu_{eff}}{\mu_f} = e^{\frac{2.5\varphi}{1-k\varphi}}$
Krieger–Dougherty model [103]	Viscosity	$\frac{\mu_{eff}}{\mu_f} = 1 - \frac{\varphi}{\varphi_m}^{-2.5\varphi_m}$
Nielsen power law model [104]	Viscosity	$\mu_{eff} = \left(e^{\frac{\varphi}{1-\varphi_m}}\right)\mu_f$
Batchelor model [105].	Viscosity	$\mu_{eff} = \left(1 + 2.5\varphi + 6.5\varphi^2\right)\mu_f$
Maxwell model [17]	Thermal conductivity	$\frac{k_{eff}}{k_f} = \frac{k_p+2k_f+2(k_p-k_f)\varphi}{k_p+2k_f-(k_p-k_f)\varphi}$
Bruggeman model [106]	Thermal conductivity	$\varphi\left(\frac{k_p-k_{eff}}{k_p+2k_{eff}}\right) + (1-\varphi)\left(\frac{k_f-k_{eff}}{k_f+2k_{eff}}\right) = 0$
Hamilton–Crosse model [107]	Thermal conductivity	$k_{eff} = \frac{k_p+(n-1)k_f-(n-1)(k_f-k_p)\varphi}{k_p+(n-1)k_f-(k_f-k_p)\varphi}k_f$ where $n = \frac{3}{\psi}$
Wasp model [104]	Thermal conductivity	$\frac{k_{eff}}{k_f} = \frac{k_p+2k_f-2\varphi(k_f-k_p)}{k_p+2k_f-\varphi(k_f-k_p}$

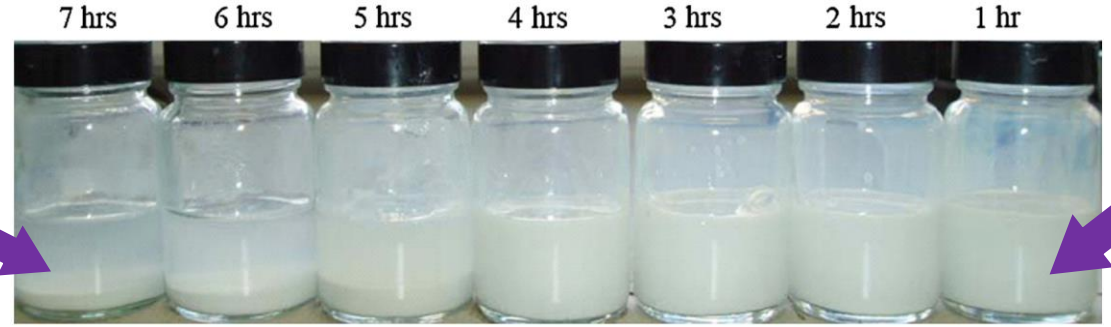
Conjugate effect:

Thermal (k) ✗ Dynamic (μ) ✓



Bennacer et *al.* IJHMT (2014)

Industrial Nano-additives (工业纳米添加剂) :



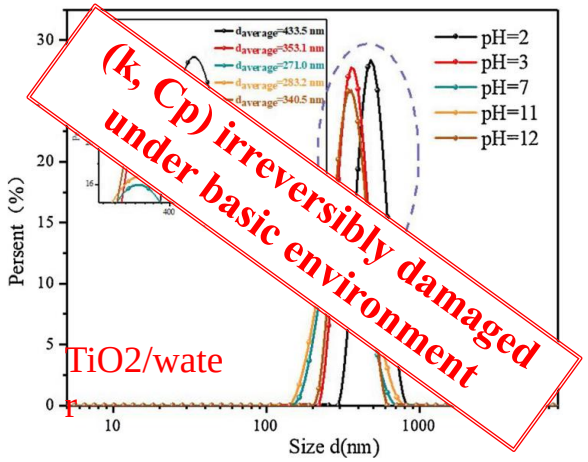
Issue: Nanoparticles sedimentation during synthesis

问题： 合成过程中的纳米颗粒沉积

Bennacer & Ragui, Fr-Lab

Solutions !! (暂定解决方案)

k/Cp 在基本环境下受到不可逆转的破坏



(k, Cp) irreversibly damaged under basic environment

PH control

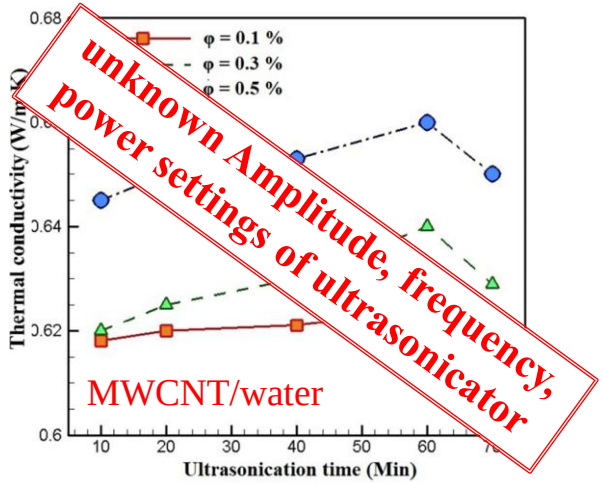
不可逆的固-固碰撞

surfactants degrade > 60 °C, irreversible solid–solid collision

Surfactant + Mg(OH)2/DIW ays)

Surfactants

超声波发生器的未知功率设置



unknown Amplitude, frequency, power settings of ultrasonicator

Ultrasonic Agitation

不可逆转地破坏流变特性

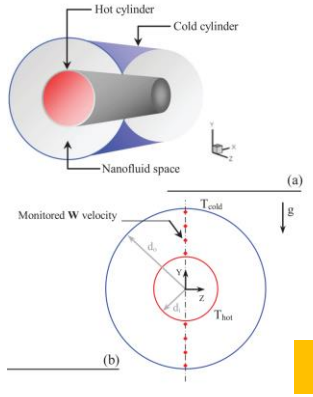
Irreversibly damaged rheological properties

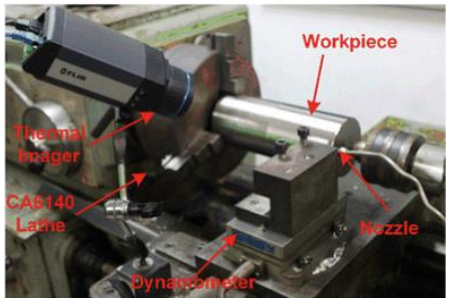
High pressure homogenization

所有实验方案均告失败 ！

Achievement #1: New non-settling mechanism of aggregate Nano-Additives with self-thermal agitation (model adopted in **French/UK industry 2021**)

利用自热搅拌实现骨料纳米添加剂不沉降的新机制 (2021 **法国/英国**工业采用的模式)





Exp. Equipment 使用的实验设备

16 nanofluids 使用了 16 种纳米流体

Key finding:

- 1st record of intermittent 3D spiral & 2D multicellular flow patterns for nanofluids.

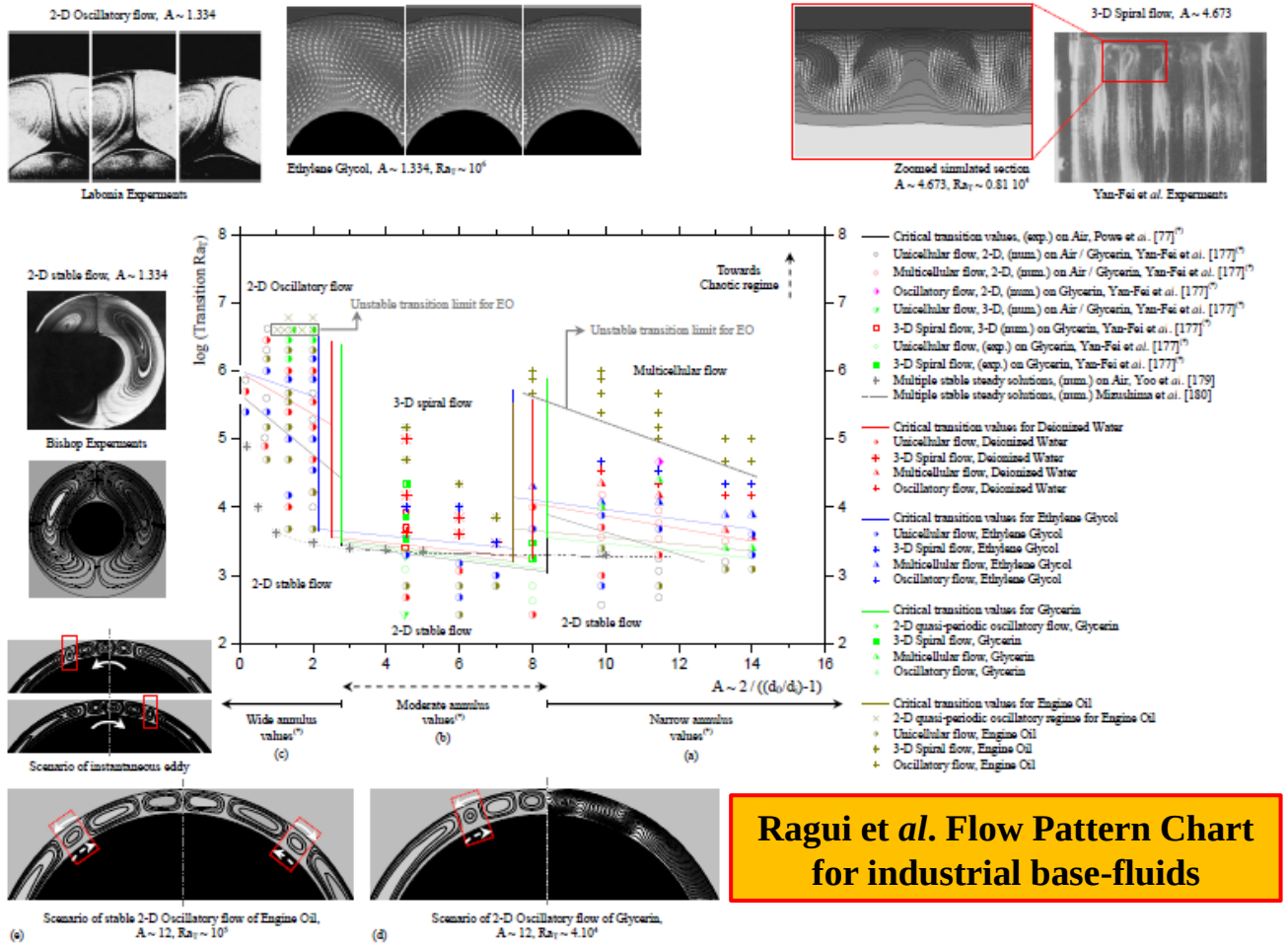
  首次记录间歇性三维螺旋和二维多细胞流动模式.

- 1st record of self-thermal agitation during flow dynamics.

  首次记录工业纳米流体中的自搅拌现象.

- Model extrapolated to nano-lubricant for engines.

  推断用于发动机的纳米润滑剂模型.

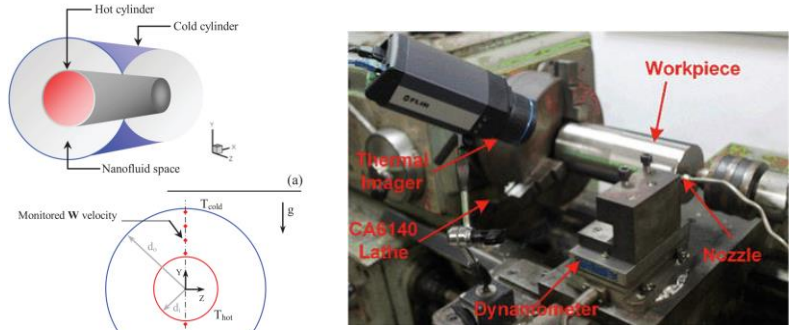


Ragui et *al.* Flow Pattern Chart for industrial base-fluids

Ragui et *al.* POF, (2021)

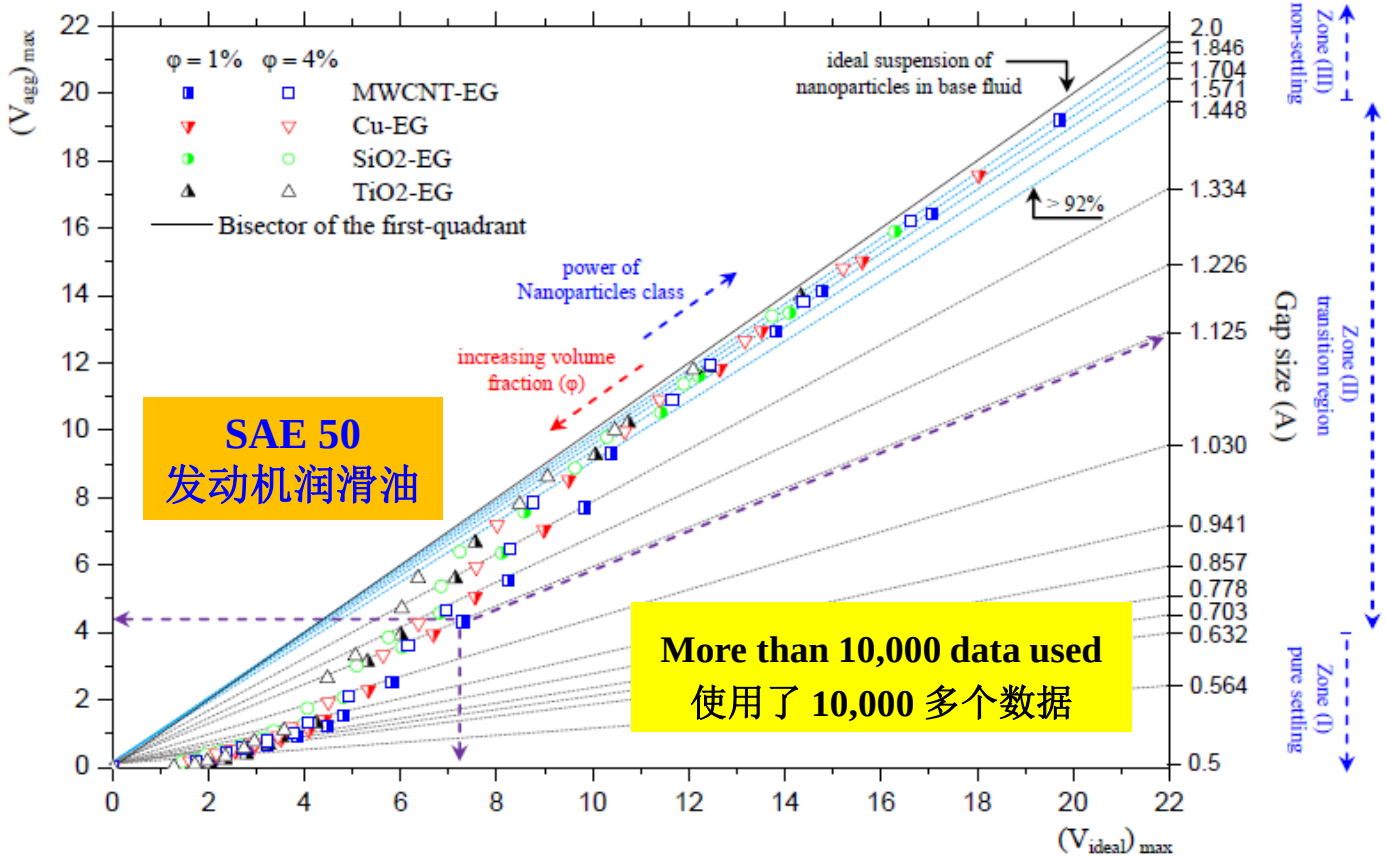
Achievement #1: New non-settling mechanism of aggregate Nano-Additives with self-thermal agitation (model adopted in **French/UK industry 2021**)

利用自热搅拌实现骨料纳米添加剂不沉降的新机制 (2021 **法国/英国**工业采用的模式)



Exp. Equipment 使用的实验设备

16 nanofluids 使用了 16 种纳米流体



Ragui et *al*. Non-settling Chart for Industrial Nano-additives (key model in literature)

Ragui et *al*. POF, (2021)

Key finding:

- 1st record of intermittent 3D spiral & 2D multicellular flow patterns for nanofluids.

  首次记录间歇性三维螺旋和二维多细胞流动模式.

- 1st record of self-thermal agitation during flow dynamics.

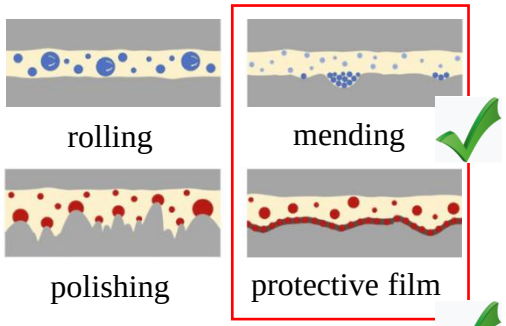
  首次记录工业纳米流体中的自搅拌现象.

- Model extrapolated to nano-lubricant for engines.

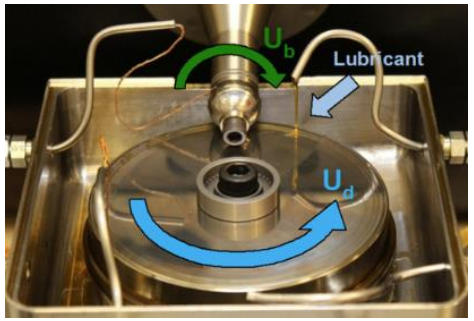
  推断用于发动机的纳米润滑剂模型.

Achievement #2: Reduce wear by formation of tribo-film, and Nano ball-bearing effects (model adopted in **French industry 2023**)

通过纳米滚珠轴承效应和三重膜的形成减少磨损 (2023 法国工业采用的模式)

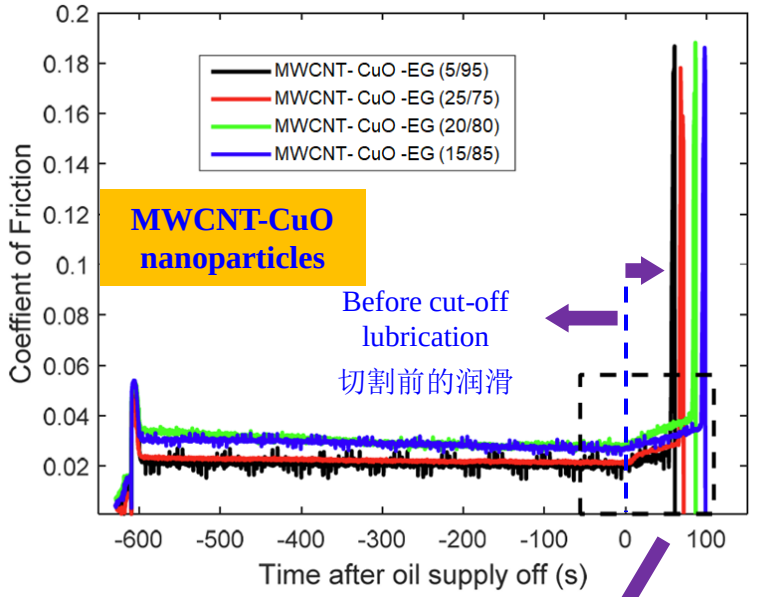


Different mechanisms for tribological properties
摩擦学特性的不同机理



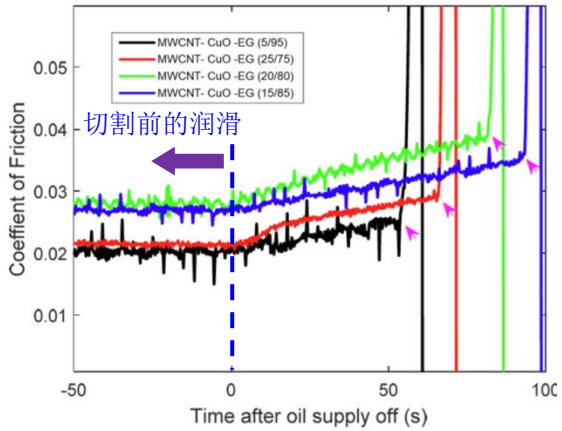
Exp. Equipment 使用的实验设备

SAE nanofluids 使用了 16 种纳米流体



MWCNT-CuO nanoparticles

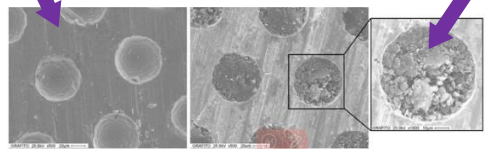
Before cut-off lubrication
切割前的润滑



Zoomed area
放大区域

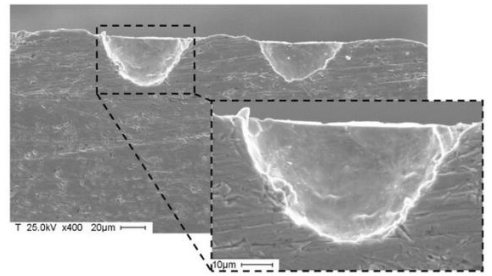
Textured surface
纹理表面

Nano-additives
纳米添加剂

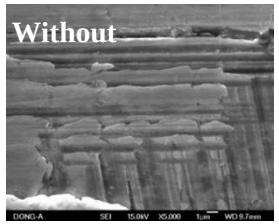


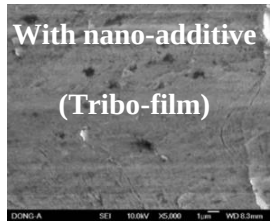
Without

With nano-additives



Mending mechanism 修补机制
based **MWCNT-CuO-EG (15/85)**





surfaces of disc specimens frictional tested

Ragui et *al*. CNRS-France, (2022)

Key finding:

- 1st record of irreversible mending based on added nano-additives.
  首次记录基于纳米添加剂的不可逆修补机制.
- Improved loss-of-lubrication performance.
  提高失润滑性能.

SAE 50
发动机润滑油

- Model extrapolated to nano-lubricant for engines.
  推断用于发动机的纳米润滑剂模型.

Achievement #2: Reduce wear by formation of tribo-film, and Nano ball-bearing effects (model adopted in **French industry 2023**)

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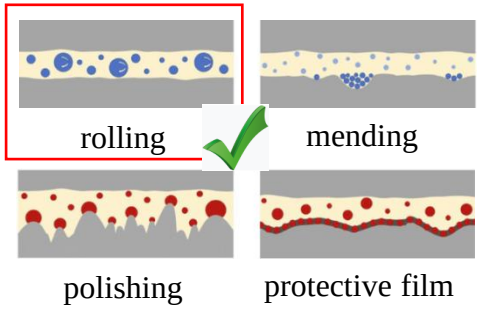
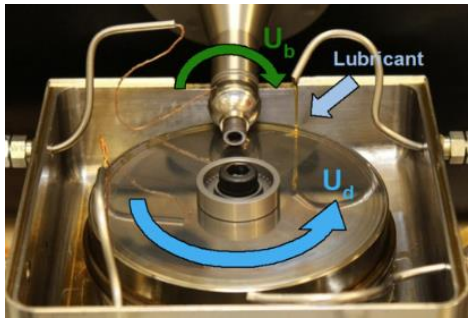
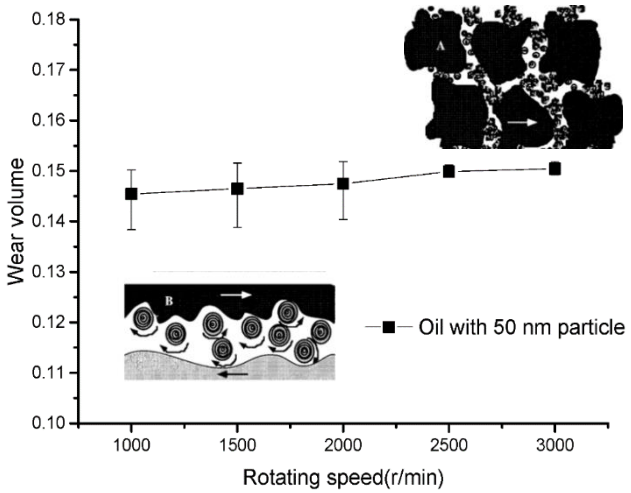


Different mechanisms for tribological properties
摩擦学特性的不同机理

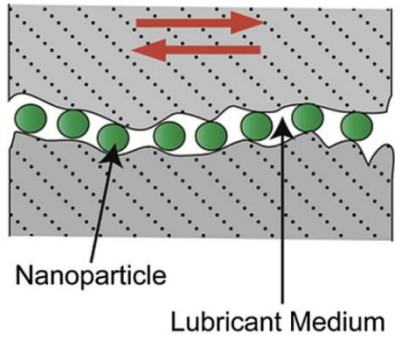


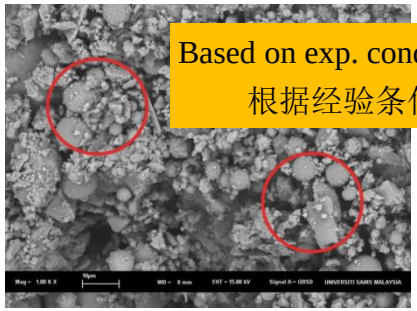
Exp. Equipment 使用的实验设备

SAE nanofluids 使用了 16 种纳米流体



Nano ball-bearing effect
纳米滚珠轴承效应

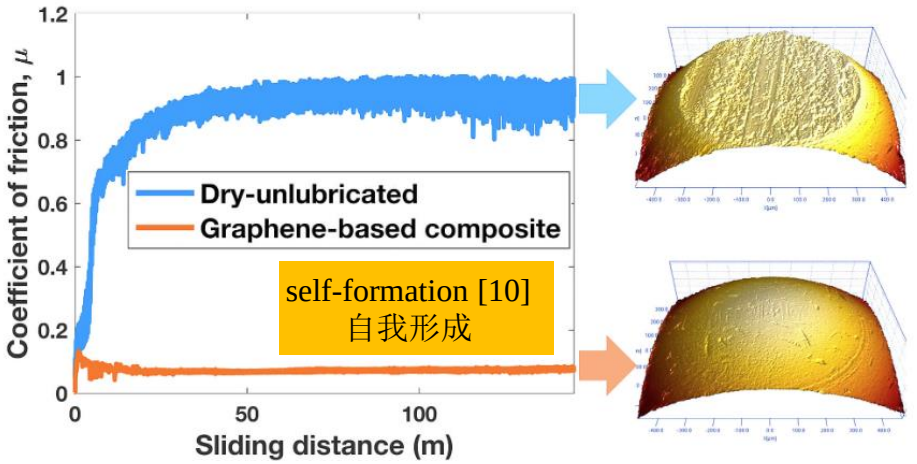


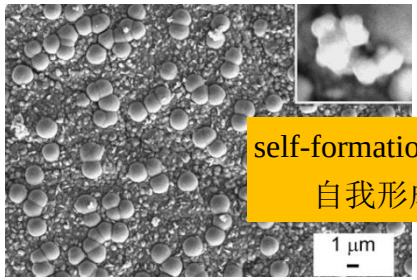


Based on exp. conditions
根据经验条件

Key finding:

- Recording nano ball-bearing effect with carbon nano-additives.
  用碳纳米添加剂记录纳米球轴承效应.
- Improved loss-of-lubrication performance.
  提高失润滑性能 (18 %).
- Model extrapolated to nano-lubricant for engines.
  推断用于发动机的纳米润滑剂模型.

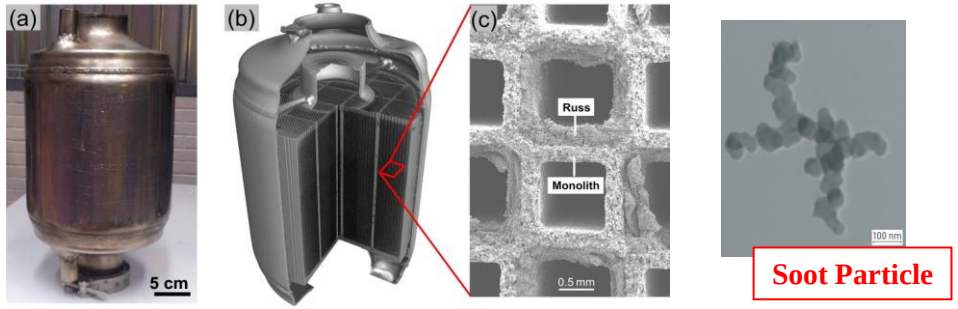




self-formation [10]
自我形成

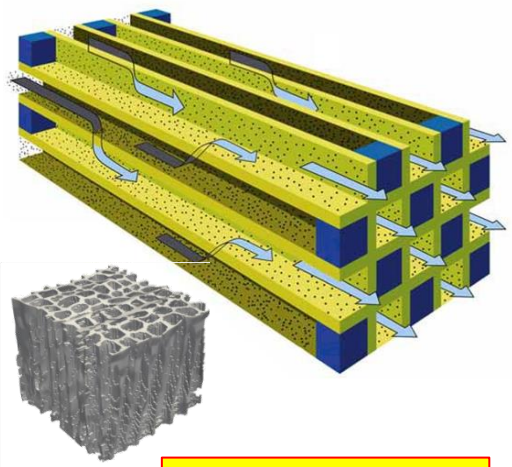
Intelligent Emission Control : 智能排放控制 (中国/法国行业将采用该模式 2025/2026)

Exp. Equipment 使用的实验设备

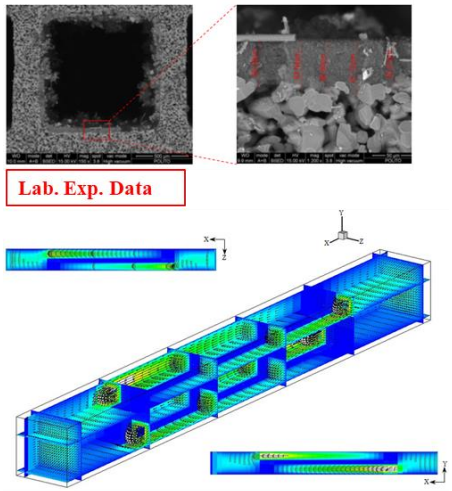


Soot Particle

Eliminating Soot particles in Multi-scale FAP Filter

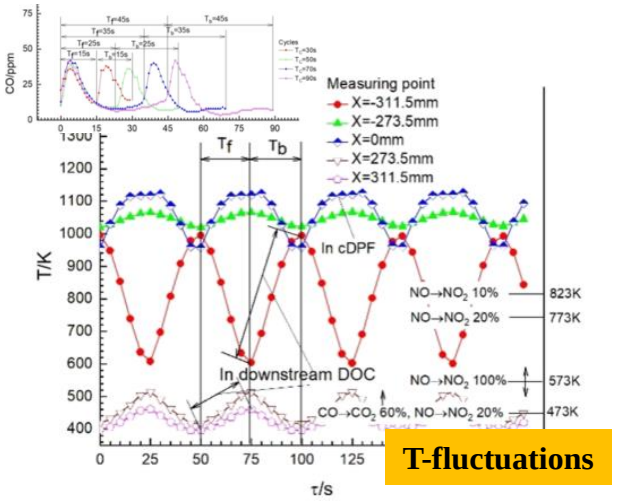


FMG-FAS Full Multigrid method

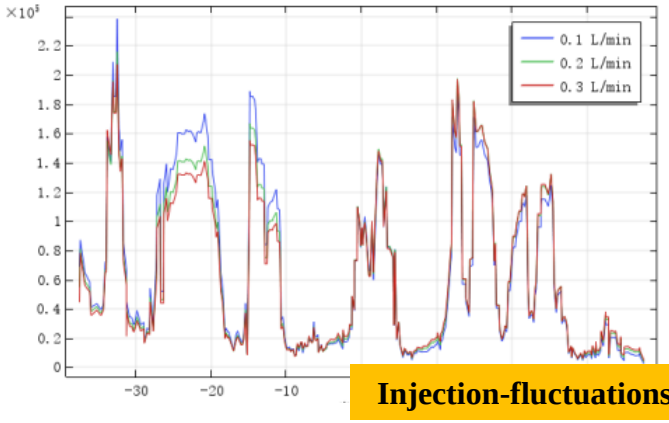


Lab. Exp. Data

Ragui et *al.* JHMT, (2018-2022)



T-fluctuations



Injection-fluctuations

CNRS grant project No: 2019/33/B/STF4/01427

		0,144 (m)
		11 10^{-6} (m)
		0,254 (m)
		4 10^{-3} (m)
		0,34 (m)
		1,51 10^{-3}(m)
L_s	Epaisseur des parois	380 10^{-6} (m)
N_c	Nombre de canaux	Env. 4200
Q_v	Débit volumique	0,014-0,166 (m^3/s)
V_f	Volume total	0,00414 (m^3)
V_{stock}	Volume de stockage des cendres	0,00132 (m^2)
S_f	Surface de filtration	3,5 (m^2)
ρ_{SiC}	Masse volumique du carbure de silicium	1800 (kg/m^3)
ε	Porosité total des parois	0,41

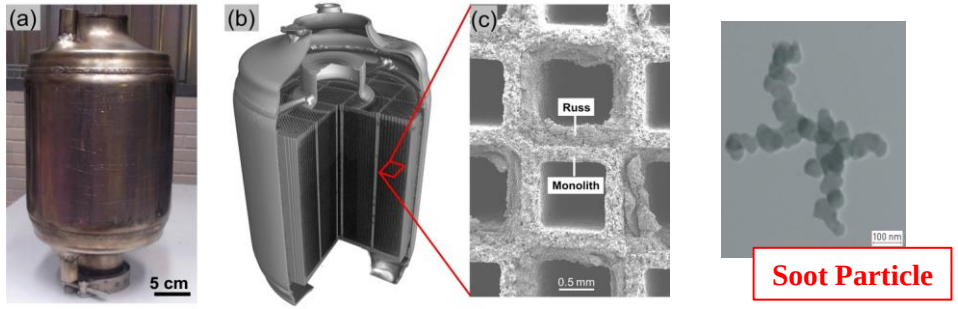
FAP dimension for experiments (Paris-Saclay University)

Key finding:

- Pore-scale deposition Scenario of Soot nanoparticles.
  烟尘纳米颗粒在孔隙尺度沉积的瞬态情景.
- Full control of ($\Delta p/\dot{m}$) under surface concentration.
  完全控制表面过滤下的压降.
- Design of ultrafine particle filtration mechanism.
  设计超细颗粒过滤机理.

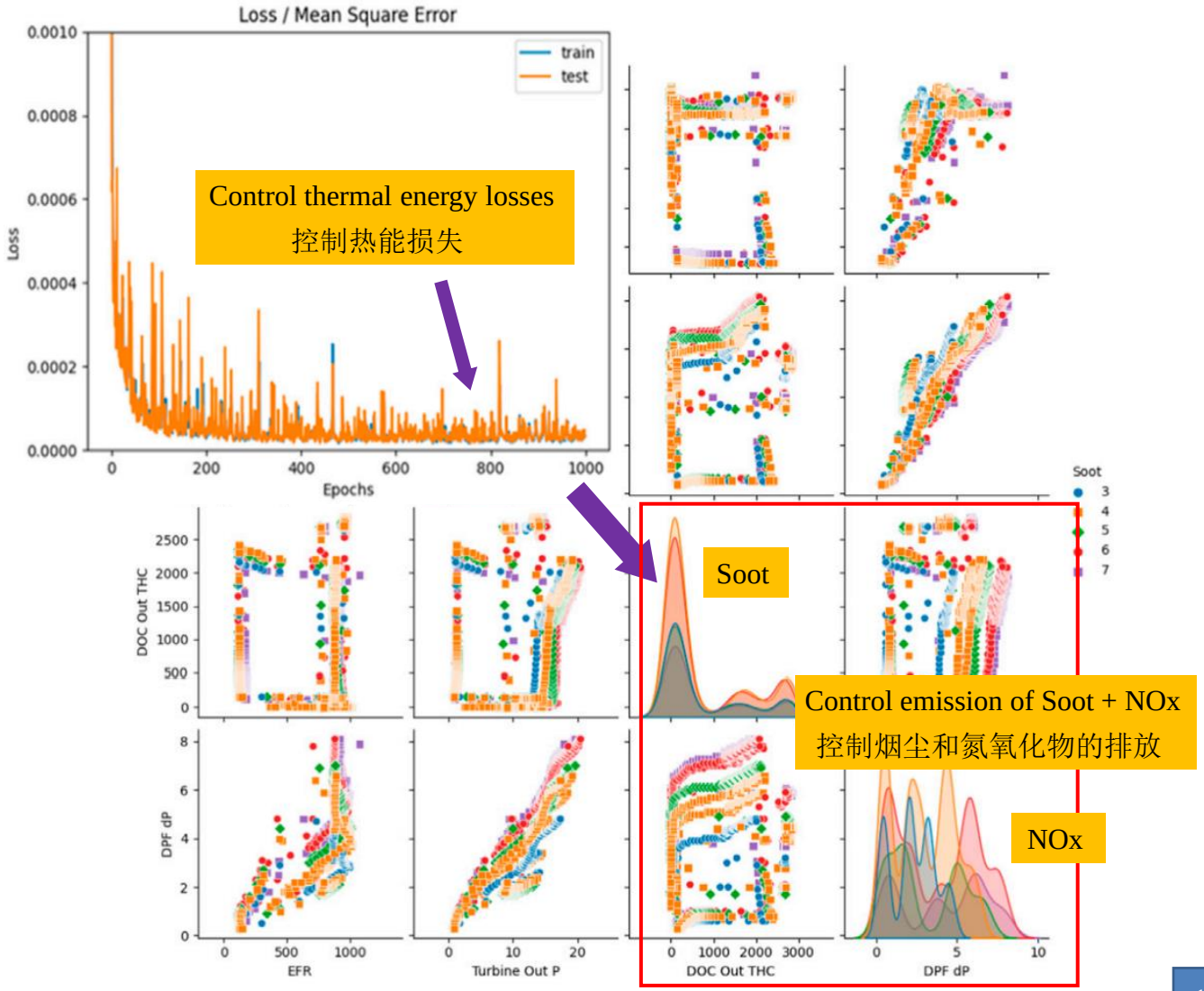
Intelligent Emission Control : 智能排放控制 (中国/法国行业将采用该模式 2024)

Exp. Equipment 使用的实验设备



Soot Particle

Eliminating Soot particles in Multi-scale FAP Filter



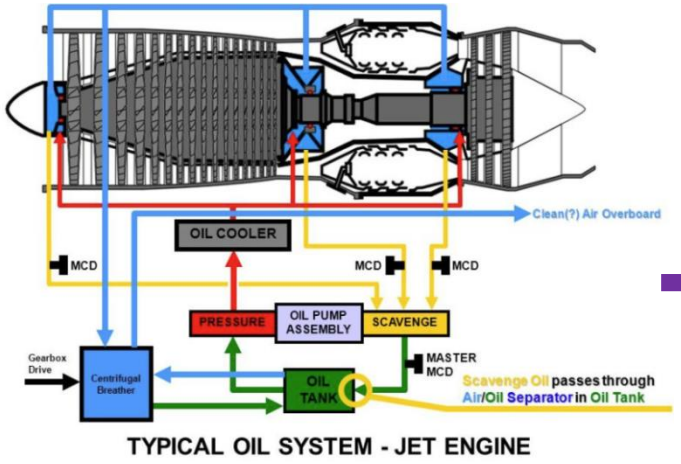
Key finding:

- Nano-lubricants decreases thermal dissipation (engine losses).
  纳米润滑剂可降低热耗散 (发动机损耗).
- Full control of emitted ($\dot{m}_{soot/NOx}$) for clean environment.
  全面控制排放物 ($\dot{m}$烟尘/氮氧化物)，实现清洁环境.
- Intelligent emission control mechanism for field application.
  现场应用的智能排放控制机制.

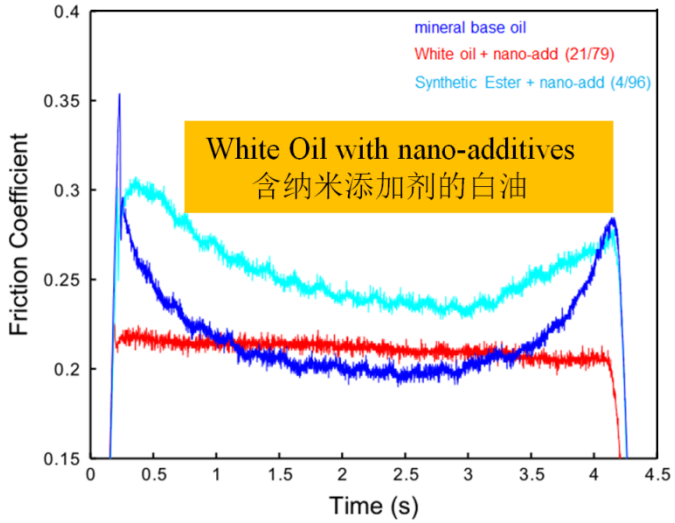
Innovative Team Work : Super Lubricant based a mixture of (CO_2/nano-additives) for new generation of turbines **(China/France Project, 2023-2026)**

用于新一代涡轮机的基于（二氧化碳/纳米添加剂）混合物的超级润滑剂

Joint International CNRS-NSFC Project (2022-2024)

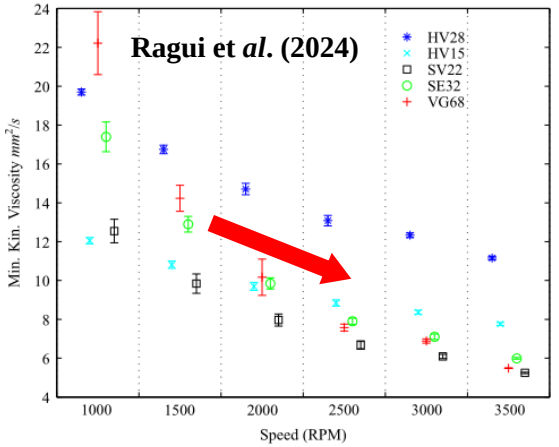


TYPICAL OIL SYSTEM - JET ENGINE

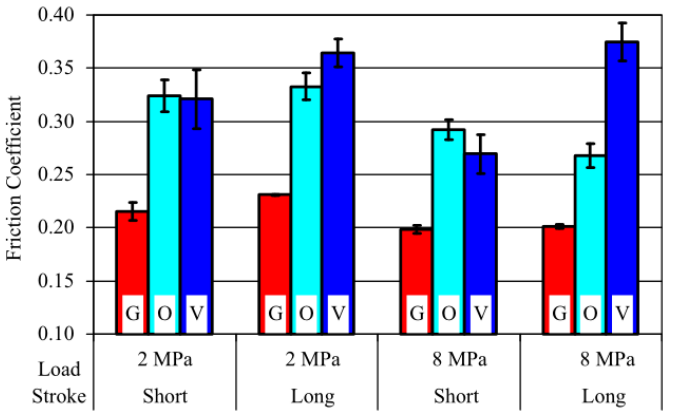


Key finding:

- New super-lubricant reduce friction at break-away.
  新型超级润滑剂可减少断裂时的摩擦力.
- Benefit of reduced power loss.
  减少功率损耗的好处.
- Less harmful to natural environment.
  对自然环境的危害较小.



Minimum viscosity in bearing at 2 MPa.
轴承中的最小粘度，2 MPa.



Contact pressure of 2-8 MPa

(i) Research Advantages (研究优势)

- Provide a life-time protective layer on surfaces by using innovative self agitated nano-lubricants.
  使用创新的自搅拌纳米润滑剂，为表面提供终生保护层.
- Improved loss-of-lubrication performance. Decrease thermal energy losses.
  提高润滑损耗性能。减少热能损失.
- Better control of emitted soot and SOx/NOx clean environment, due to a better internal combustion mechanism.
  由于采用了更好的内部燃烧机制，因此能更好地控制烟尘和 SOx/NOx 的排放，从而实现清洁环境。.

(ii) Future Strategy (未来战略)

- Combine China lubrication technology with that France/UK, with interest to Carbon Neutrality Market.
  将中国的润滑技术与法国/英国的润滑技术相结合，关注碳中和市场.
- Launch cooperation with Qingdao Petrochemical industry to develop new lubricant products.
  与青岛石化合作开发新型润滑油产品.

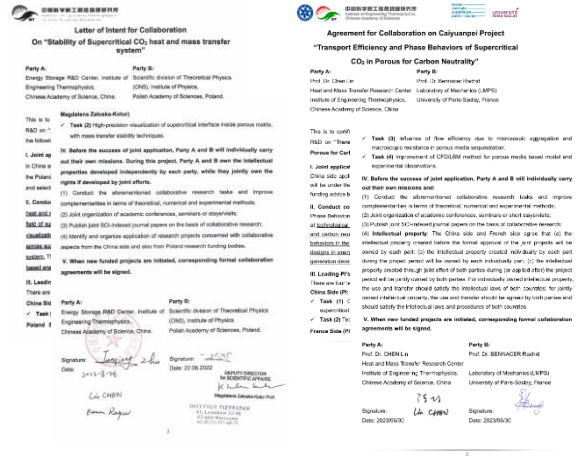
Current Collaboration with “Aeronautic Hangzhou Base”

目前与 "航空杭州基地 "的合作

合作协议 (合作协议 法国, 波兰, 日本..)

Academic Partners 学术/研究伙伴

- UCAS University, China. 中国科学院大学, 中国 (#5 Best Global Univ.)
- Tohoku University, Japan. 日本东北大学 (#3 Best Global Univ.)
- Paris-Saclay University, France. 法国巴黎萨克雷大学 (#1 Best Global Univ.)
- Lorraine University, France. 法国洛林大学 (#15 Best Global Univ.)
- Cracow University of Technology, Poland. 克拉科夫理工大学，波兰 (#32 Best Global Univ.)
- Campania “L. Vanvitelli” University, Italy. 意大利坎帕尼亚大学 (#30 Best Global Univ.)
- Queen’s University, Canada. 加拿大皇后大学 (#15 Best Global Univ.)
- University of Nevada, USA. 美国内华达大学 (#100 Best Global Univ.)
- University of Manchester, United Kingdom. 英国曼彻斯特大学 (#5 Best Global Univ.)
- Imperial College London, United Kingdom. 英国伦敦帝国理工学院 (#7 Best Global Univ.)



Collaboration Agreements (with Univ. from France / Poland / Japan …)

Collaboration with French/UK lubricant companies 与法国和英国润滑油公司合作

Aug. 15th 2024, Qingdao, China

13th CIMAC CASCADES
Qingdao, August 14-15

Nano-additives for Internal Combustion and Micro-Engines: A Boosted Efficiency & Intelligent Emission Control

用于内燃机和微型发动机的纳米添加剂：提高效率和智能排放控制

[1, 2]Karim RAGUI

[1]Hangzhou International Innovation Institute, Beihang University, China

[2]Paris-Saclay University, France

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