The 11th International Symposium on the Reliability Technology of Internal Combustion Engines

Development of Chinese standard of natural gas engine lubricating oil

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Outline

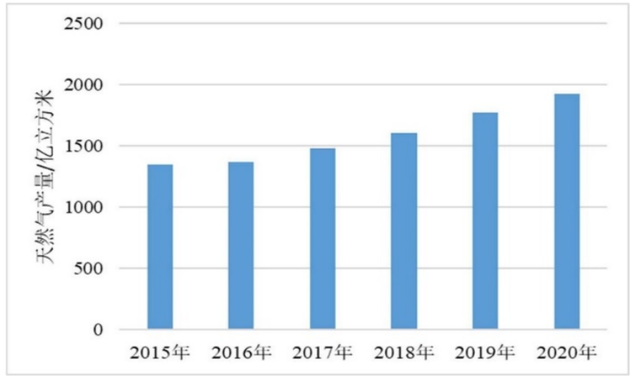
- Background and objectives of natural gas engine lubricating oil development
- Characteristics and lubrication requirements of natural gas engine
- Development of lubricating oil standard for natural gas engine
- Summary and outlook

Background

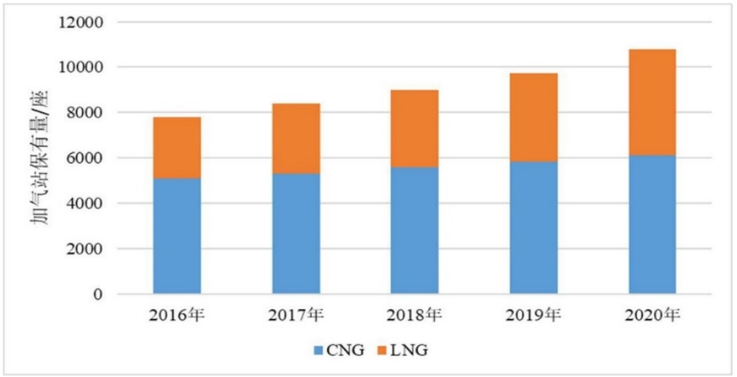
- Industry Demand
- Alliance support
- Alliance’s experience

Industry Demand

- **Opportunities for the development of natural gas engines for heavy trucks**
  - **National dual carbon strategy - natural gas engine opportunities**
    - On October 24, 2021, the State Council issued the "Carbon Peaking Action Plan before 2030": actively expand the application of new and clean energy such as electricity, hydrogen energy, natural gas, and advanced biological liquid fuels in the field of transportation, promote electricity, hydrogen fuel, LNG powered heavy cargo vehicles.
  - **Natural gas carbon reduction potential**
    - Calculated under the condition of equal calorific value, 1kg of LNG (liquefied natural gas) can achieve about 0.28kg of carbon emission reduction.
  - **Mature natural gas supply system**
    - China's natural gas resources have great potential: in 2020, the national natural gas output reached 192.5 billion cubic meters, an increase of 57.9 billion cubic meters, or 43%, over 2015.
    - In 2020, China build more than 4300 supporting CNG / LNG filling stations, and the total number of filling stations reached 10800.



China's natural gas production

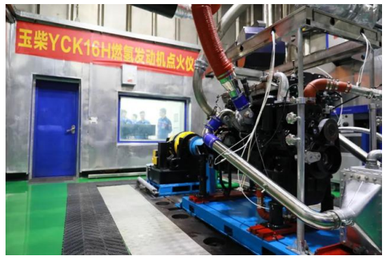


Quantity of natural gas filling stations in China

Industry Demand

- **LNG heavy truck industry is expected to continue to grow**
  - In 2020, the annual sales volume of LNG heavy trucks in China reached 147000, and the number of heavy trucks reached 600000. A number of factors have led to a decline in sales in 2021, with a gradual recovery in 2022.
  - From a long-term perspective, driven by the control of air pollution and the realization of the "double carbon" goal, the number of NG vehicles may reach 1 million to 1.2 million by 2025.

- **Mainstream OEMs begin to deploy H2 internal combustion engines and NH3 internal combustion engines**



Yuchai YCK16H


FAW 13L


Weichai WP13H

Dong Feng & Tsinghua NH3 Engine

Industry Demand - Status Quo of Natural Gas Engines oil specification

- **At present, there is no unified standard and evaluation method for natural gas engine lubricating oil in the world**
  - The industry mainly refers to Cummins CES20092、CES20085、CES20074 specifications
  - Commercial vehicle natural gas engine
    - Enterprises and oil standards refer to Cummins specifications
    - The Oil Drain Intervals of mainstream OEM national VI vehicles is 60000-80000km.
    - Some OEMs put forward the requirement of 100,000 km Oil Drain Intervals , such as FAW, Yuchai, Cummins, Shangchai…
  - Passenger car natural gas engine
    - Generally, there is no special engine oil, gasoline engine oil products are used without any optimization
- **Domestic OEMs put forward the demand for joint development of oil standards and evaluation methods in the industry**

Cooperation Between the Alliance and Petrochemical Standardization Committee

- **Based on the demand of OEMs, on the 9th Counsil meeting, the Alliance proposed to develop China's independent gas engine oil standard, which was supported by the Petrochemical Standard Commitee.**

发动机润滑油中国标准开发创新联盟
第九次理事会会议纪要

发动机润滑油中国标准开发创新
年 06 月 11 日上午召开第九次理事会
参加会议的有联盟理事长、总顾问、
家和秘书处工作人员，共计 60 人（
联盟理事长、中国内燃机学会理事长
会议听取了关于联盟理事及专家
专项资金使用情况等汇报；审议并通
开发、启动天然气机油规格标准体系
增补十二名专家组成员等事项。
联盟总顾问、石化标委会主任曹
对联盟第一阶段 D1 规格柴油机油标
和肯定，并就下一步做好联盟工作提
规格柴油机油标准已经完成起草和意
批和发布，联盟要根据柴油机的技术
级工作，实现 D1 规格柴油机油标准
越。第二，我国已具备自主开发高水
机必须要有相应的润滑油来配套，联
油机油标准和天然气机油标准的研究
起点、面向未来的要求，落实汽油机
具体工作。经过前期的努力，联盟已
伴，也有能力将 OEM、润滑油及第三方
开展联合创新，又快又好的完成下一
联盟和石化标委会秘书处之间要加强
量完成我国汽油机油和天然气发动机
会议最后，金京寒院士在总结讲
认识开发润滑油自主标准的重要意义
第 1 页 共

油研究所张升副所长。
3. 潍柴动力股份有限公司专家变更为发动机研究院郭灵燕主任工程师。

三、 联盟工作进展

1. 在石化标委会秘书处的积极协调下，国家能源局于 2022 年 5 月 13 日，批准发布了 D1 规格四项台架标准，并于 2022 年 11 月 13 日起正式实施，四项标准的发布，构建了我国柴油机润滑油标准评价体系。

2. 联盟与石化标委会秘书处密切合作，共同完成了 GB 11122/D1 柴油机油标准的征求意见稿和行业意见征求，根据行业普遍支持只增加 D1 规格的反馈意见以及石化标委会和联盟领导的指导，D1 规格产品工作组与石化标委会秘书处国标修订组，共同讨论确定了 GB 11122/D1 柴油机油国家标准修订只增加我国自主开发的 D1 规格送审稿初稿。

3. 会议要求联盟秘书处与石化标委会秘书处密切沟通，尽早确定 GB 11122/D1 标准审查会的时间节点，力争 7 完成标准审查，以满足柴油机 OEM 期盼已久、量身定做的中国柴油机润滑油标准。

四、 关于启动汽油机及天然气发动机油中国标准体系开发事宜

1. 联盟理事一致同意启动汽油机油中国标准体系的自主开发工作。

2. 联盟理事一致同意启动天然气发动机油中国标准体系的自主开发工作。

3. 会议要求联盟秘书处协商石化标委会秘书处共同组建工作组，尽快组织推动落实落细，务必进一步做好 OEM 对润滑需求关注点的深入调研、专家论证，明确重点评价项目和台架试验机型选择等关键工作，力争今年年底完成全部台架的搭建和发动机点火等任务。

五、 关于八家单位申请加入联盟事宜

1. 八家单位参会代表分别介绍了各自单位的基本情况，在履行

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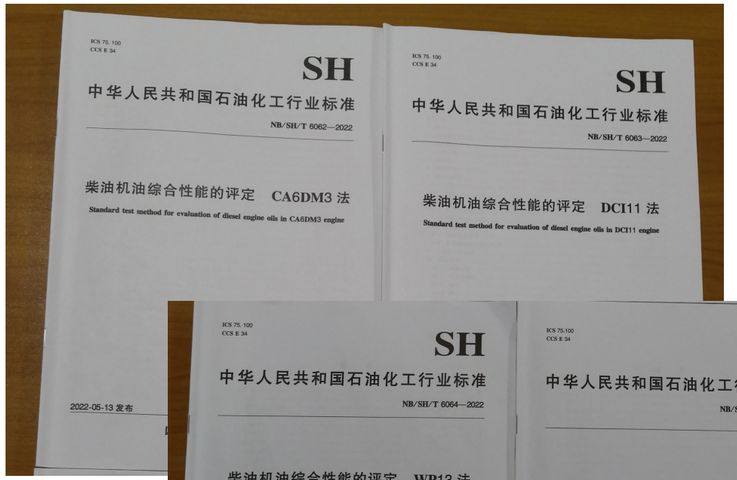
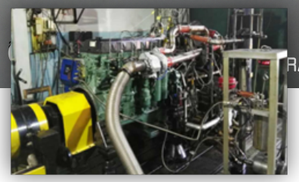
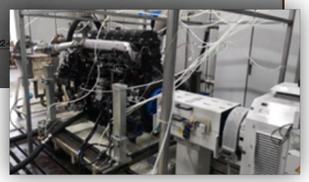
Research Basis- Alliance's experience

- **Chinese Lubricant Standards Alliance Committee completed the development of four lubricating oil test methods based on CA6DM3, DCi11, WP13, 2.0CTi, etc.**
- **Currently the Alliance possesses the following capabilities:**
  - **Cross industry cooperation mechanism: OEMs feedback lubrication requirements -> the Alliance units cooperate with OEMs in development of corresponding test methods**
  - **Full-process capability of lubricating oil engine bench testing: disassembly, control, physical and chemical analysis, rating, etc.**
  - **Test monitoring system: Reference oil , Engine Test kits, engine bench calibration, etc.**
  - **Lubricating oil registration and certification system**

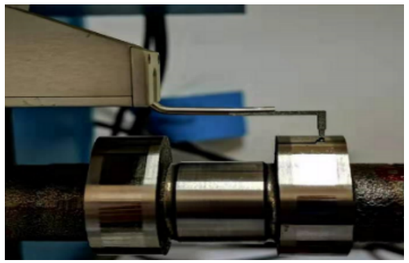


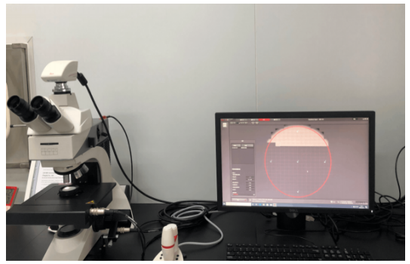


兰州研发CA6DM3 台架



清华苏州汽车研究院 DCI11 台架





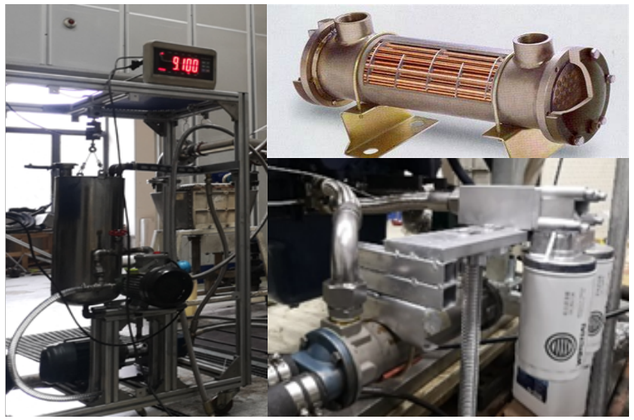
石油化工科学研究院
江淮 2.0CTI 台架

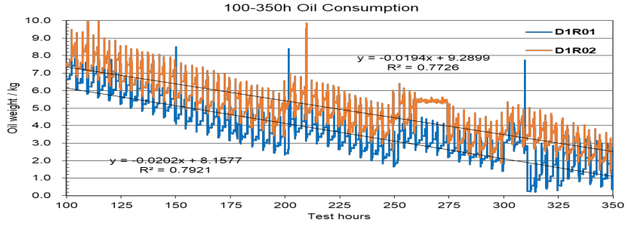
中国汽车技术研究中心 WP13 台架

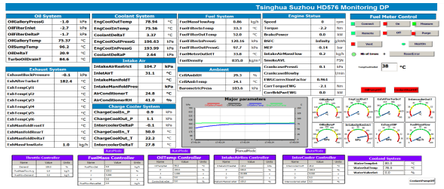
Research Basis - Third-party Labs Cases

Professional lubricating oil bench auxiliary equipment

The real-time oil consumption monitoring system and oil temperature control system are imported from the United States to meet the working conditions and accuracy requirements of lubricating oil testing.





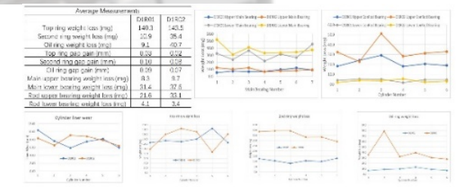


More precise bench control

The boundary condition of the lubricating oil bench test adopts the automatic control mode, and uses the PID dynamic response precise control, its accuracy can reach ±0.5%.

Professional lubricating oil physical and chemical analysis

Cooperates with US Intertek Shanghai Laboratory, and have comprehensive lubricating oil analysis and testing capabilities.

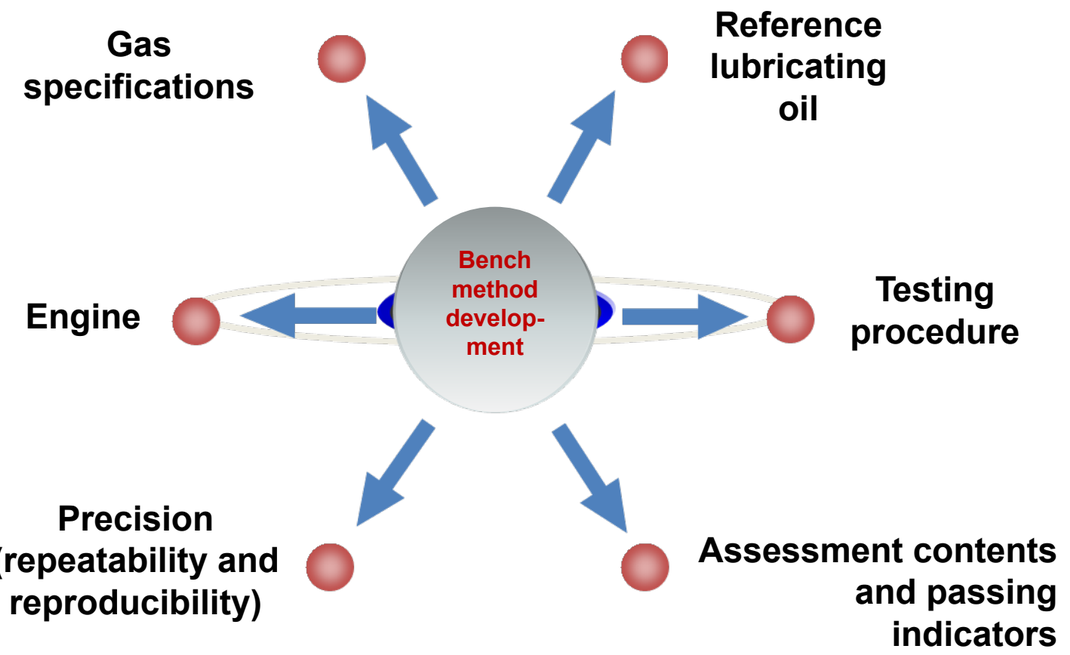


ASTM engine parts rating qualification

Two raters with the American ASTM scoring qualification.

Natural Gas Engine Lubricant Targets

- Develop the lubricating oil bench evaluation method based on the capabilities of the autonomous gas engine according to the China IV emission standard
- Based on the bench evaluation method, Develop Nature gas engine oil specification to meet local OEM's Requirement.
- Prepare for the subsequent development of other types of gas engine lubricating oil specification
  - HCNG engine
  - H2 engine
  - Ammonia internal combustion engine



Outline

- Background and objectives of natural gas engine lubricating oil development
- Characteristics and lubrication requirements of natural gas engine
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Fuel Characteristics

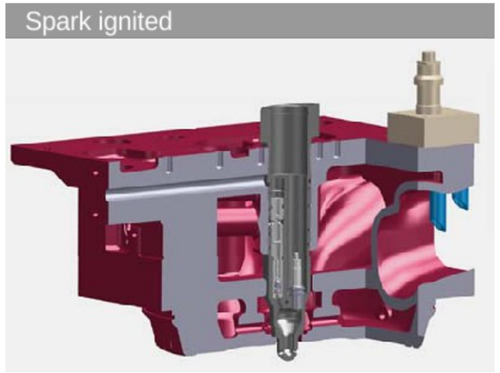
- **Compared with diesel and gasoline, natural gas:**
  - **No heavy components**
  - **high spontaneous ignition point**
  - **high ignition energy requirements**
  - **low laminar flame propagation speed**

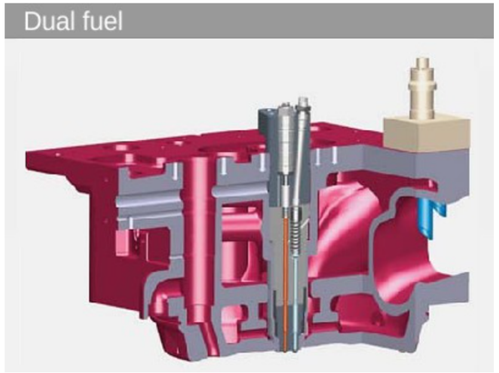
Property	Gasoline	Diesel	Methane	Hydrogen	NH3
Carbon content (mass%)	84	86	75	0	0
Lower (net) heating value (MJ/kg)	43.9	42.5	45.8	119.9	18.748
Density (at 1 bar & 273 K; kg/m^3)	730–780	830	0.72	0.089	638.6
Molecular weight	**~110**	**~170**	**16.043**	2.016	17.031
Boiling point (K)	298–488	453–633	111	20	240
Auto-ignition temperature (K)	**~623**	**~523**	**813**	853	903
Minimum ignition energy in air (at 1 bar & at stoichiometry; mJ)	**0.24**	**0.24**	**0.29**	0.02	8
Stoichiometry air/fuel mass ratio	14.7	14.5	17.2	34.4	6.04
Laminar flame speed in air (at 1 bar & 298 K at stoichiometry; m/s)	**0.37–0.43**	**0.37–0.43**	**0.38**	1.85	0.015
Flammability limits in air (vol%)	1–7.6	0.6–5.5	5.3–15	4–76	15-27
Adiabatic flame temperature (at 1 bar & 298 K at stoichiometry; K)	2580	~2300	2214	2480	2073
Octane number (R+M)/2	86–94	-	120+	130+	110
Cetane number	13–17	40–55	-	-	-

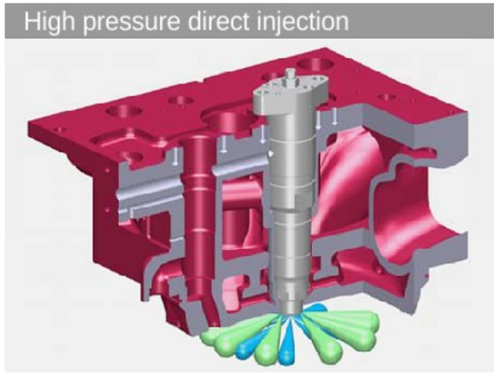
Natural Gas Engine Roadmap

Engine technology routes at different emission stages				
Item	**China IV**	**China V**	**China VI**	**Future direction?**
Fuel supply mode	EPR	CFV single-point / multi-point injection	Electronically controlled single and multi-point injection	Direct injection
Air flow control	Booster intercooler, electronically controlled throttle valve, electronically controlled bleed valve supercharger	Booster intercooler, electronically controlled throttle valve, electronically controlled bleed valve supercharger	Booster intercooler, electronically controlled throttle valve, electronically controlled bleed valve supercharger	Turbocharging intercooling
Ignition method	Independent spark plug ignition	Independent spark plug ignition	Independent spark plug ignition	**Diesel ignition**
Emission control technology	Lean burn+DOC	Lean burn+DOC	Stoichiometric+**EGR+TWC**	DOC+DPF+SCR
λ control		λ closed-loop control, knock sensor detection	λ closed-loop control, knock sensor detection	

- **Main foreign OEMs' technical routes**
  - Fiat: stoichiometric+TWC
  - Cummins: stoichiometric+EGR+TWC
  - Bosch: stoichiometric+EGR+TWC+ASC
  - Woodward: stoichiometric+EGR+TWC+ASC
- **Main domestic OEMs' technical routes**
  - Weichai: stoichiometric+EGR+TWC
  - Yuchai: stoichiometric+EGR+TWC+ASC

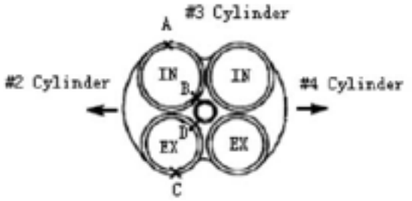






Special Lubrication Requirements for Natural Gas Engines

- **Combustion temperature**
  - Piston cracking, piston crown ablation
  - Exhaust gas temperature is high
  - Lubricant thermal load is high
- **Engine deposit**
  - Knocking, misfire (**laminar flame speed is low and Ignition energy not enough**)
  - Cylinder liner polishing
- **Corrosive wear**
  - Lubricant oxidation
  - Sulfur compounds in natural gas
- **No heavy components**
  - Exhaust valve, valve seat lubricating difficulty
- **Combustion products of high water content**
  - Increased water content in lubricants at low temperatures
- **Exhaust control**
  - Aftertreatment system protection
  - Relationship between PN emission, oil consumption and oil composition
    - oil consumption, evaporation, wear, ash, etc.



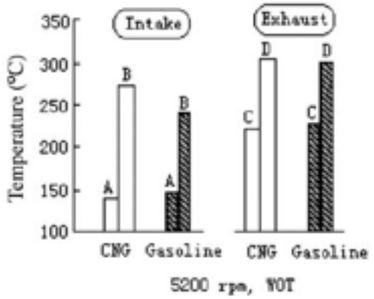


Fig. 15. Valve seat temperature [13].

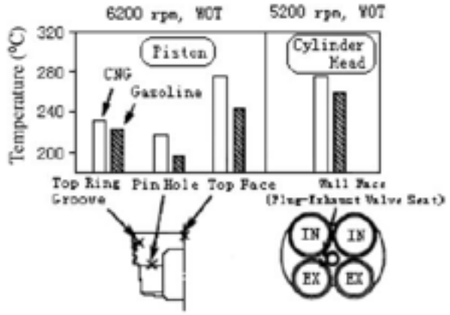
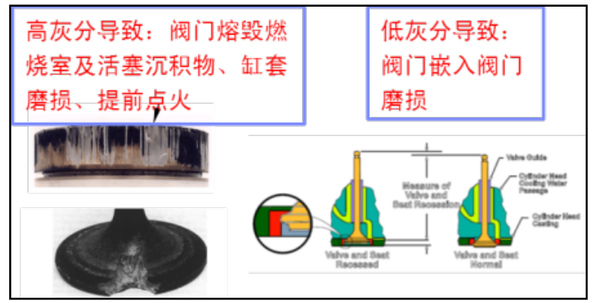
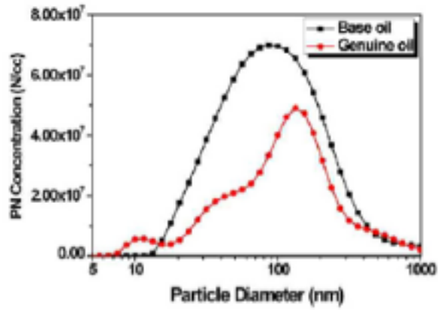


Fig. 14. Temperature of piston and cylinder head [13].

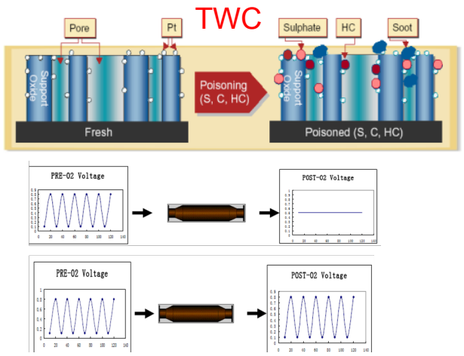
SAE Paper 1999-01-0574





(b) 2000 rpm and 6.0 bar BMEP

Kim, K., Characterization of engine oil additive packages on diesel particulate emissions. Journal of Mechanical Science and Technology 34 (2) (2020)



O2 Sensor

Introduction to Typical Gas Engine Standards

- Physical and chemical control range
- Lubrication problems occurring during evaluation of typical gas engine benches
- Learn from some mature gasoline and diesel oil benches

	CES 20092	CES 20085	CES 20074
Physical and chemical requirements	•Sulfated Ash Level 0.7 - 0.9% •Phosphorous 0.08% of mass maximum •Sulfur shall be 0.40% of mass maximum	• Sulfated Ash Level 0.7 - 0.9% • Calcium 1,800 – 2,300 ppm •Phosphorous 700 – 900 ppm • Zinc 800-1,000 ppm	•Sulfated Ash Level 0.4 - 0.6% •Calcium < 1,200 ppm •Phosphorous 600 – 800 ppm •Zinc 600 - 850 ppm
Engine bench method	COP (gas engine oxidation), LSPI (low speed pre-ignition), COAT (air release)	No	Cummins C8.3 (wear test of gas engine valve system)
Corresponding typical engine	**ISX 12N**	**ISL-G & G NZ**	**8.3L Natural Gas**
Displacement	11.9L	8.9L	8.3L
Air fuel ratio	Stoichiometric	Stoichiometric	Lean Burn
BMEP @ P. Torque		19.15 Bar	13.06 Bar
Aftertreatment	Three-Way Catalyst	Three-Way Catalyst	LEV-na, ULEV-Oxi Cat
EGR?	Yes-Cooled	Yes-Cooled	No
Rocker structure	Roller-follower	Roller-Follower	Tappet
Booster mode	VGT	VGT	Wastegate

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Natural Gas Engine Lubricating Oil Standard Formulation Process

Physical and chemical limit require-ments

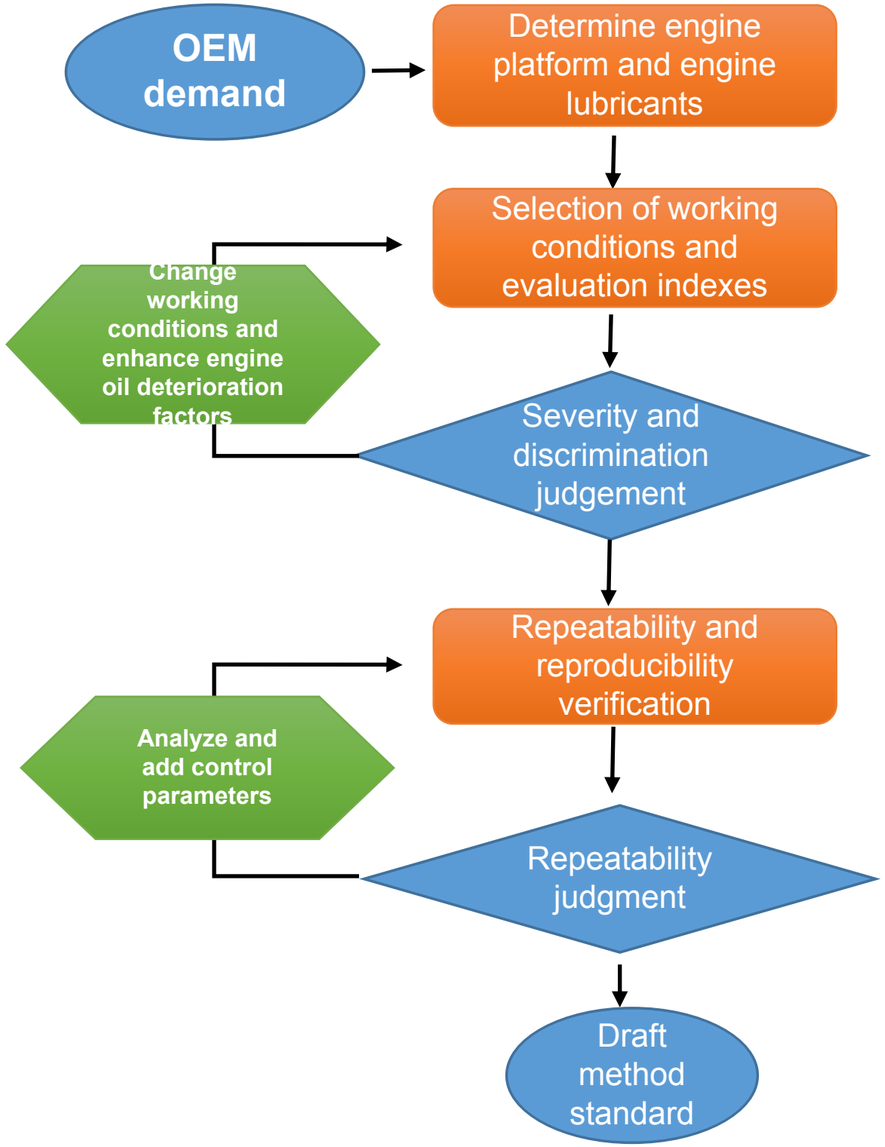
- SAE J300 viscosity classification is adopted. Physical and chemical and simulation test items refer to API standards.
- SAPS limit requrements
- Elements content limit requirements?

Develop-ment of bench test method

- Using China VI gas engine as a platform to evaluate high-temperature detergency, anti-oxidation and nitrification, anti-wear, and knock suppression

Research project

- Relationship between PN emission and engine oil consumption
- Prospective study on lubrication performance requirements of H2/NH3 internal combustion engines



The Demand for Oil Performance of China VI Engines Has Increased

Oil-related reliability risks of heavy-duty natural gas engines in China

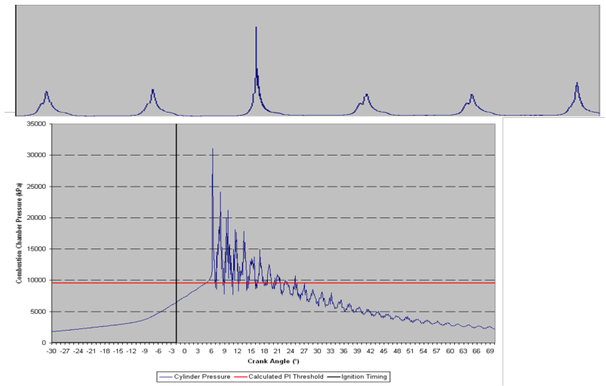
Spare parts	Changes compared to China V natural gas engine	Reliability risks
Cylinder head	High combustion temperature, Higher thermal load	Cylinder head cracks, high oil temperature and high temperature aging
Piston	In-cylinder combustion temperature is high, thermal load increases, piston temperature rises	Piston cracking, melting top, engine oil gumming and coking
Cylinder bore, piston ring, valve and seat ring	High combustion temperature, high exhaust gas temperature, increased thermal load	Wear, strain, seal damage, engine oil gumming and coking
Booster	High exhaust temperature, high vortex and seal and bearing temperatures	Poor lubrication and cooling, oil coking, wear, and shaft breakage
Lubrication system	The heat dissipation of the whole machine increases, and the oil temperature rises	Oil temperature is high, oil life is affected
Aftertreatment	TWC replaces DOC in the catalyst, and the catalyst inlet temperature is high	The aging of the catalytic converter is aggravated, and the original PN is greatly affected by the oil

China VI heavy-duty natural gas engine oil performance requirements

Oil performance	Problem solving
Oxidation resistance	Meet the use demand of the engine under high temperature conditions and increased heat load, and inhibit the increase of acidic substances and viscosity caused by excessive oxidation of the lubricating oil
High temperature detergency	Effectively inhibits the formation of piston ring sticking, piston deposits and carbon deposits
Wear resistance	Prevents engine valve system, cylinder liner, piston ring and other components from wearing, improves engine reliability
Early ignition resistance	Avoids engine damage caused by low-speed early ignition caused by deposits
Emission friendly	Due to the increase of exhaust temperature, the aging of the catalyst is aggravated. The original PN is greatly affected by the engine oil, and there are certain requirements for the ash content of the engine oil
Low friction	The adoption of EGR + TWC is the result of comprehensive consideration of various factors. At present, the market has high requirements for gas consumption, and engine oil is required to have low friction and high reliability properties
Demulsibility	Resists high moisture content in combustion products
Nitrification resistance	Avoid the influence of engine oil with NOX generated by high-temperature combustion

Suggestions on Bench Method Development

- **Oil properties to be evaluated**
  - Oxidation resistance
  - Anti-nitrification
  - High temperature detergency
  - Wear resistance
  - Early ignition resistance
  - Demulsibility
  - Others
- **Suggested main evaluation items**
  - Oil viscosity increase
  - Oxidation , nitration
  - Piston deposits
  - Oil consumption
  - Spark plug deposits
  - Valve seat wear



The performance difference between natural gas engine oil and diesel oil

Performance	Diesel oil standards	Independent natural gas engine oil standard	CES 20092
Dispersion	XXX		
Abrasion resistance	XXX	XX	
Acid neutralization	XXX	X	X
Anti-nitrification	X	XXX	XXX
Oxidation control	XXX	XXX	XXX
Spark plug deposit control		XXX	XXX
Avoid seat retraction/ablation		XX	
Demulsibility		X	
Combustion chamber deposit control		XX	XX
Three-way catalytic converter compatibility		XXX	XXX
DPF compatibility	X		
LSPI		XX	XX

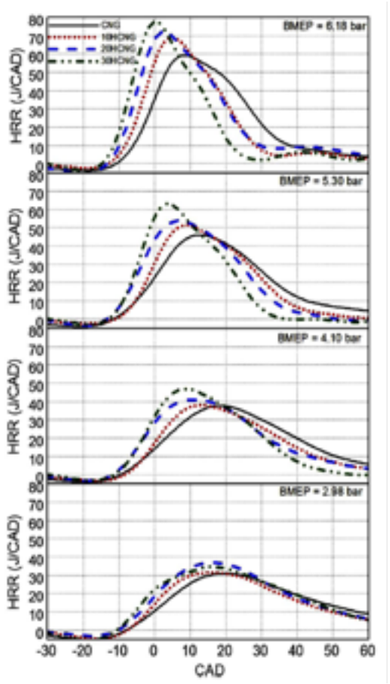
Bench Method Development Recommendations

Number of bench methods to be developed

- 2-3 benches
- Adopt domestic mainstream OEM representative engine
- High temperature performance evaluation bench
  - High temperature and high load conditions
  - 300-400h
  - Evaluation of engine oil viscosity growth, oxidation value, nitrification value, piston deposit, engine oil consumption, spark plug deposit
- Wear of valve system
  - Taking into account low temperature high water content and high temperature wear conditions
  - Typical valve system wear (rocker arm, swing arm)
  - Valve seat and pipe wear
- Pre-ignition knock：
  - Based on diesel engine development V.S. using gasoline engine

Research projects

- Relationship between PN emission and oil consumption and oil composition
- Prospective study on lubrication performance requirements of H2/NH3 internal combustion engines



H2 engine:

- Faster heat release rate
- More prone to pre-ignition, knocking
- More H_20

Speech Outline

- Background and objectives of natural gas engine lubricating oil development
- Characteristics and lubrication requirements of natural gas engine
- Formulation of lubricating oil standard for natural gas engine
- Summary and outlook

Summary and Outlook

- Under the low carbon strategy, the booming gas engine industry puts forward special lubrication requirements
- Perfect system and rich experience: with the completion of the development of the independent D1 oil standard, the Chinese Lubricant Standards Alliance Committee has also established a sound standard development and maintenance system.
- Developing this generation while researching on the the next one： prepare for the development and use of newer gas-fueled engines.

Never forget why you started, and your mission will be accomplished!

Thank you! Looking forward to your feedback!