

乳化燃料油在船舶柴油机上的应用研究

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摘 要: 为了实现乳化燃料油在船舶上的应用, 研发了一套重油在线乳化装置, 并在以 G6300ZC18B 型柴油机为动力的宁大 6 号运输船上进行实船试验。试验结果表明: 当掺水率在 16% ~ 24% 时, 乳化质量好, 可作为船舶燃料使用; 乳化燃料油燃烧时, 柴油机爆发压力在 1 ~ 2 MPa 间波动, 排气温度平均下降 12 °C, 冷却水出口温度略有下降, 参数变化都处于正常范围内; 平均节油率为 9.7%, NO_x、CO、碳烟排放平均分别降低 19.6%、20%、35%。

关 键 词: 船舶柴油机; 乳化重油; 掺水率; 燃烧; 减排

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引 言

航运企业对燃油的需求量很大, 因此重油以相对低廉的价格优势成为航运企业主要燃料, 但重油低温下粘度大, 沥青质、胶质含量高, 燃烧时难以充分雾化、不能完全燃烧, 燃油消耗量增加, 污染物排放增加。采用掺水燃烧技术实现节能与减排, 是一种经济、最易实现的方法^[1]。掺水燃烧方面主要技术有使用乳化油、进气道喷水、直接向燃烧室喷水等^[2-3], 其中乳化油技术在节能减排的方面效果比较突出^[4-6]。目前, 关于掺水率的变化对柴油机正常启动、节油方面的影响的研究都是在实验室里进行的。

为了实现乳化燃料油在船舶上的应用, 本课题组研发了一套重油在线乳化装置, 并在以 G6300ZC18B 型柴油机为动力的宁大 6 号运输船上进行实船试验, 研究乳化燃料油对柴油机燃烧排放的影响。

1 重油乳化实船试验

1.1 重油乳化实船测试系统

由于该船未燃用过乳化油, 所以必须对油路进

行改造。根据船舶机舱实际分布状况, 将燃油系统改造为两个并联供油系统: 乳化油供油系统、实际燃油供油系统。智能在线乳化系统安装在柴油机重油日用柜之后, 混油桶之前。如图 1 所示, 两个系统之间由 3 个截止阀进行转换。进水管与水箱连接。进油管与油箱连接, 油箱中装有加热器, 使 120 号重油加热到 85 ~ 100 °C。燃料油与水在乳化装置中乳化。乳化后的燃油经雾化加热器与细滤器到达柴油机中进行燃烧。

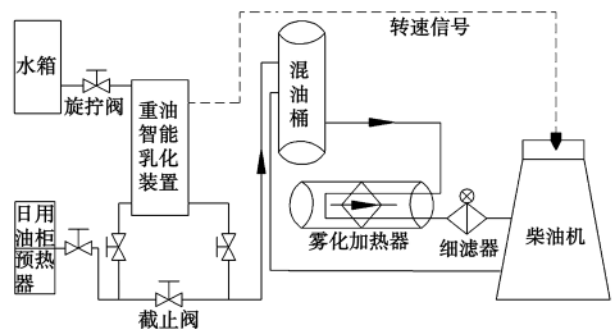


图 1 实船测试示意图

Fig. 1 Schematic diagram of a real ship test

1.2 重油智能在线乳化装置技术原理

宁波大学海运学院自制的重油智能在线乳化技术, 采用 PLC 作为智能控制器, 运用 PID 控制技术, 在未添加乳化剂的情况下, 可以实现油水比例在线混合乳化, 并随柴油机的负荷、转速变化等参数实现油水精确控制, 其工作原理图如图 2 所示。

水流经电磁阀、计量泵、压力缓冲器和单向阀在流量计的后部与重油汇合。重油与水经匀质器混合后进入乳化泵, 经过初次乳化后一小部分乳化油直接流向柴油机, 大部分则沿回流管并经过节流单向阀重新回到乳化泵达到循环乳化效果。这样可将大

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量的乳化油引回乳化泵的进口实现多次在线乳化，在边乳化、边燃烧的条件下延长乳化油在乳化泵中停留时间，提高乳化质量。单片机通过变频器控制计量泵流量，达到控制掺水量的目的；节流单向阀具有单向节流作用，对经过它的流体进行单方向的节止，通过改变其开度调节乳化泵的出口压力，同时防止水不经过乳化器而直接流入柴油机；压力缓冲器设置在计量泵出口后面，均匀掺水压力，以避免由掺水压力冲击而影响乳化质量；单向阀阻止重油反灌到加水管路。取样阀连接取样支路，用于对乳化装置的乳化性能进行测试。

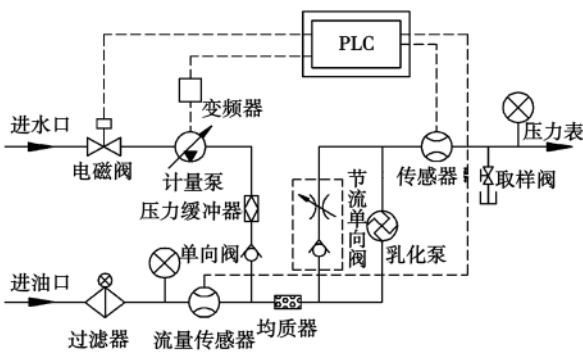


图 2 乳化装置工作原理图

Fig. 2 Schematic diagram of the emulsification device

1.3 船舶原装柴油机

试验用船舶柴油机的型号为 G6300ZC，主要参数如表 1 所示。

表 1 G6300ZC 型柴油机性能参数
Tab. 1 Performance parameters of a diesel

参数	数值
标定功率/kW	1 323
标定转速/r · min ⁻¹	550
冲程数	4
增压	是
缸径/mm	300
行程	380
燃油	120 号重油

1.4 试验仪器及设备

试验过程中，还需用到的测试仪器设备如表 2 所示。

表 2 试验设备
Tab. 2 Test equipment items

仪器设备名称	型号
转速传感器	HE - 01
手提测温器	TC700
最大压力表	DY - 1
排气分析仪	FGA - 4100
烟度分析仪	FBY - 1
电子显微镜	DA1 - 180M
粘度计	NDJ - 1 型

1.5 试验工况

试验在宁波港开往广州航线上进行，考虑海况和实船的动力性因素，选择船舶柴油机在航行中满载时的常用转速进行柴油机燃烧工作参数以及节能减排测试。主机转速为 450 r/min，对应的螺旋桨转速为 180 r/min，查阅柴油机推进特性曲线，柴油机负荷约为 55%。为保证负荷稳定，选择海况良好时进行测试。试验共测试了柴油机转速为 450 r/min 时燃烧掺水率分别为 0%、16%、18%、20%、22% 和 24% 的 6 组数据，在不同掺水率下测试乳化油的乳化质量、柴油机的燃油消耗量、烟气排放量和柴油机的工作参数。

2 试验结果分析

2.1 乳化油质量分析

乳化质量优劣主要通过乳化油掺水率、液珠直径以及粘度进行评价^[8-9]。

不同掺水率下的重油乳化后的颗粒分布情况如图 3 所示。掺水率为 18% 时的乳化效果优于其它，乳化油颗粒分布非常均匀，颗粒直径最小；掺水率为 24% 的乳化油中大分子水含量较多。因此，重油乳化时不要追求过高的掺水率，当掺水过多时，一方面使水汽化的耗热负效应增大，另一方面由于水分子增多所形成的油包水颗粒粒度过大，或者乳化不均匀，甚至形成了水包油，都不利于乳化燃烧。

2.2 粒径分析

利用 DA1-180M 型显微镜及粒度分析软件对乳化照片进行粒度分析，得到不同掺水率下乳化重油粒径分布如图 4 所示。

在相同的乳化阶段，掺水率为 18% 的乳化油粒径集中在 5 ~ 20 μm 范围内的浓度比其它掺水率大，说明使用宁大智能在线乳化装置乳化重油时，掺

水率为 18% 时乳化效果较好。掺水率在 16% ~ 18% 时, 乳化重油颗粒粒径一般为 5 ~ 20 μm, 90% 以上颗粒直径小于此范围。

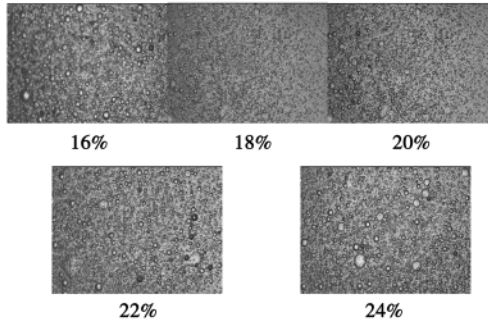


图 3 乳化重油颗粒随掺水率变化的 400 倍显微照片

Fig. 3 400-fold microscopic photo of emulsified heavy oil particles

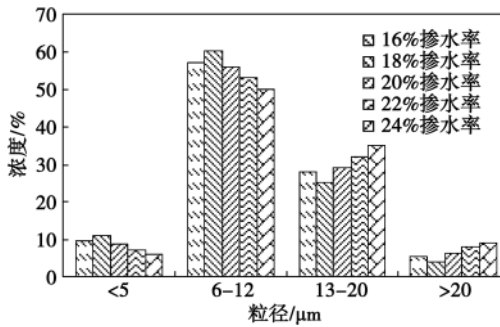


图 4 乳化油粒径随掺水率变化的分布图

Fig. 4 Chart showing the distribution of emulsified oil particles at various water mixing proportions

2.3 粘度分析

一般规定重油进入喷油泵时的粘度值应在 $12 \times 10^{-6} \sim 25 \times 10^{-6} \text{ m}^2/\text{s}$ 范围内。对乳化油粘度与温度关系测试结果如图 5 所示。随温度升高乳化油粘度明显下降, 下降速度逐渐变缓。当乳化油温度达到 85 ~ 100 °C 时, 各掺水率下粘度在 $10 \times 10^{-6} \sim 25 \times 10^{-6} \text{ m}^2/\text{s}$ 范围内。其中温度为 95 °C 时, 粘度为 $15 \times 10^{-6} \text{ m}^2/\text{s}$ 以下, 此时乳化油在管路中流动性能良好, 并且对柴油机燃油系统影响不大。

2.4 工作参数分析

掺水率对柴油机爆发压力的影响如图 6 所示。柴油机燃烧乳化油时, 各缸爆发压力在 1 ~ 2 MPa 范围内上下波动, 当掺水率为 16% 时各缸爆发压力稍

高于未掺水燃烧, 而在其它掺水率下乳化重油燃烧时爆发压力都有降低。从柴油机的手册和维护经验看, 柴油机爆发压力波动处于正常范围, 重油掺水燃烧不对柴油机爆发压力产生不良影响。

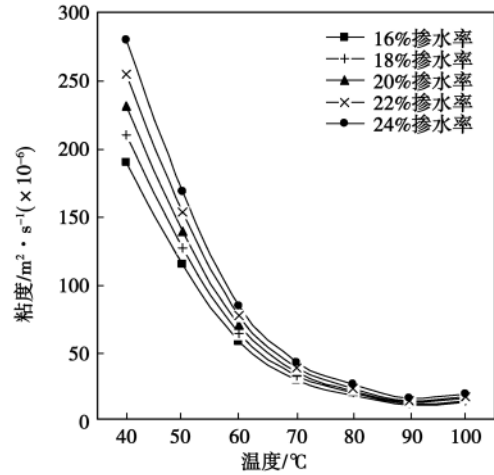


图 5 乳化油粘度随温度的变化曲线图

Fig. 5 Curves showing the change of the viscosity of emulsified oil with its temperature

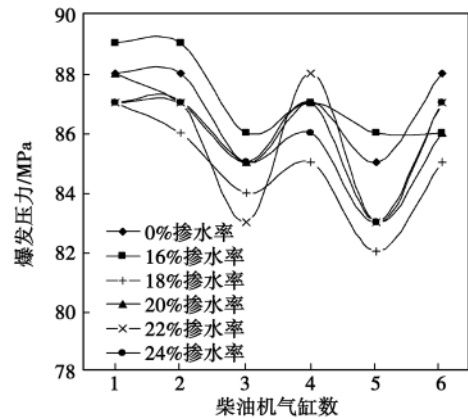


图 6 爆发压力随掺水率的变化

Fig. 6 Explosion pressure vs. water mixing proportion

掺水率对排气温度的影响如图 7 所示。燃烧乳化重油时, 排气温度均降低, 且排气温度降低平均值随掺水率增大而增大。柴油机排气温度平均下降 12 °C, 原因是水蒸发吸收气化潜热降低气缸内温度。

掺水率对冷却水出口温度的影响如图 8 所示。柴油机掺水燃烧时各缸的冷却淡水排出温度均稍有降低, 原因是柴油机的淡水冷却系统控制着冷却水进口温度, 使进口淡水温度保持恒定。

2.5 节能及烟气排放分析

掺水率对烟气排放及节油率的影响如图 9 所

示在燃烧掺水比为 16% ~ 24% 的乳化油时,耗油量明显降低。掺水率为 20% 时最大节油率为 12% ,掺水率为 24% 时最小节油率为 7.3% ,平均节油率为 9.7% 。

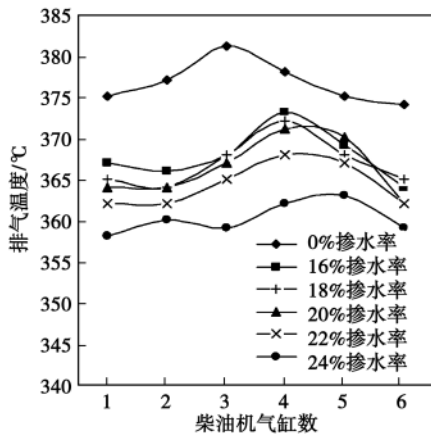


图7 排气温度随掺水率的变化

Fig. 7 Outlet cooling water temperature vs. exhaust gas temperature

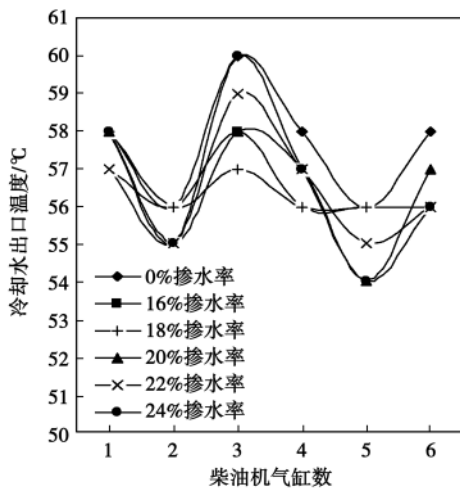


图8 冷却水温度随掺水率的变化

Fig. 8 Cooling water temperature vs. water mixing proportion

柴油机燃烧乳化重油能明显减少 NO_x 的排放, NO_x 排放降低率最大达到 25% ,最小为 16.3% ,平均降低幅度达到 19.6% 。乳化重油雾化燃烧时,由于水的汽化作用推迟燃油和空气的混合;乳化重油雾化燃烧过剩空气系数下降,乳化重油中的水在燃烧室内汽化要吸收热量,加上水对油粒的溶解作用使油汽和空气混合均匀,燃烧室温度降低且燃烧趋于均匀,降低 NO_x 的生成量。

CO 的排放量在各掺水率下均有降低,在掺水率为 20% 时,CO 排放降低最大,达到 27.4% ,平均降低率为 20% 。原因是柴油机燃烧乳化重油时,由于水煤气反应,一部分 CO 与氧气进一步反应生成了 CO₂ 气体,减少了 CO 气体的生成。

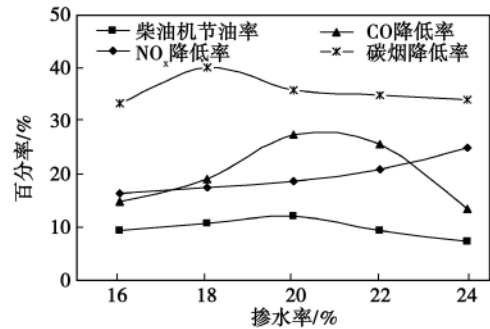


图9 节油与排放随掺水率的变化

Fig. 9 Change of the energy-saving and emission-reduction with the water mixing ratio

碳烟下降明显,碳烟排放最大降低幅度为 40% ,平均降低幅度为 35% 。原因:乳化重油雾化燃烧时水蒸气溶解作用,使因少量高温热裂解产生的浮状碳粒子与水蒸汽发生水煤气反应,生成可燃气体 CO 和 H₂ ,这些产物在高温下与空气接触后发生剧烈的链式反应,减少烟气中碳烟含量。

3 结论

(1) 经宁波大学自行研制的智能在线乳化装置乳化的 120 号重油可作为船舶燃料使用。

(2) 以 G6300ZC 柴油机为主机的船舶以满载正常航行时即 55% 负荷情况下,燃烧掺水率在 16% ~ 24% 乳化重油时能够可靠、稳定运行。

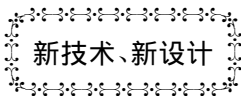
(3) 宁大六号柴油机在燃烧乳化油时,平均节油率为 9.7% ,NO_x 排放平均降低 19.6% ,CO 平均降低 20% ,碳烟排放平均降低达 35% 以上,船舶柴油机燃烧乳化重油具有可观的经济效益和环境效益。

参考文献:

[1] 孙培岩,李剑钊,唐运榜,等.基于 AVR 单片机的柴油机油-水在线乳化自控系统[J].测试技术学报,2005,19(2):141-145.
SUN Pei-yan, LI Jian-zhao, TANG Yun-bang, et al. AVR single-chip-based oil-water on-line emulsification control system for diesels[J]. Journal of testing technology 2005, 19(2): 141-145.

- [2] Lif A ,Holmberg K. Water-in-diesel emulsions and related systems [J]. Advances in Colloid and Interface Science ,2006 ,123: 231 - 239.
- [3] Tauzia X ,Maiboom A ,Shah S. Experimental study of inlet manifold water injection on combustion and emissions of an automotive direct injection Diesel engine [J]. Energy 2010 ,35(9) : 3628 - 3639.
- [4] Farfaletti A ,Astorga C ,Martini G et al. Effect of water/fuel emulsions and a cerium-based combustion improver additive on HD and LD diesel exhaust emissions [J]. Environmental Science and Technology 2005 ,39(17) : 6792 - 6799.
- [5] 史德胜 ,许 锋 ,隆武强. 可控掺水燃烧降低柴油机排放的燃烧分析 [J]. 内燃机工程 2006 ,27(1) : 18 - 22.
SHI De-sheng ,XU Feng ,LONG Wu-qiang. Analysis of the controllable water-blended combustion to reduce the emissions of a diesel [J]. Internal Combustion Engine Engineering ,2006 ,27(1) : 18 - 22.
- [6] 楼狄明 ,边 威 ,谭丕强. 共轨柴油机燃用乳化柴油试验研究 [J]. 车用发动机 2010(3) : 74 - 78.
LOU Di-ming ,BIAN Wei ,TAN Pi-qiang. Experimental study of a common-rail diesel burning emulsified diesel oil [J]. Automobile Engine 2010(3) : 74 - 78.
- [7] 牟永福. 柴油掺水乳化的试验研究 [J]. 农业机械学报 ,1995 ,26(3) : 128 - 130.
MU Yong-fu. Experimental study of diesel oil emulsification blended with water [J]. Journal of Agricultural Machinery ,1995 ,26(3) : 128 - 130.
- [8] 吴江霞 ,孙 平 ,蔡亿昔. 乳化燃油的特性及其在内燃机中的应用研究 [J]. 江苏大学学报(自然科版) ,2002 ,23(5) : 69 - 73.
WU Jiang-xia ,SUN Ping ,CAI Yi-xi. Characteristics of emulsified fuel oil and its applications in internal combustion engines [J]. Journal of Jiangsu University (Natural science edition) ,2002 ,23(5) : 69 - 73.
- [9] 齐 柳 ,穆文俊 ,赵德智 等. 乳化油的开发与应用 [J]. 抚顺石油学院学报 ,1999 ,19(3) : 14 - 18.
QI Liu ,MU Wen-jun ,ZHAO De-zhi et al. Development and application of emulsified oil [J]. Journal of Fushun Petroleum College ,1999 ,19(3) : 14 - 18.

(丛 敏 编辑)



生态能源燃料装置

在燃烧理论发展的基础上建立起来的新方法 ,以此在超绝热状态下气化并通过气态产物的充分燃烧来获得燃料和电能 ,已制造出具有原创性的工业化装置。

可用生物燃料、高灰份碳、油页岩、泥渣、泥炭、石油和化学工业的废弃物、固体生活垃圾等作为再生燃料来代替天然气和发热量低(1 ~ 30 MW) 的重油。

装置的特色:

- 同时解决生态和能源问题;
- 有效系数达 95% ;
- 降低有害产物的生成(有害产物的含量为同类产品的 1/10 ~ 1/100) ;
- 可利用高灰份(90%) 和高湿度(60%) 的燃料;
- 各操作单元的模型化有助于实现各种不同的工艺流程;
- 低成本 ,成套设备的成本为同类产品的 1/2 ~ 1/3;
- 消除工业废料场和日常生活垃圾场。

(有意了解该技术可与编辑部联系)

On a fixed bed reactor, the reduction effectiveness of NO-coal coke at a high temperature in different atmospheres at various oxygen concentrations was investigated and XPS (X-ray photoelectron spectroscopy) was used to analyze the oxygen-contained functional groups on the surface of coal coke after pre-treatment at various oxygen concentrations. The research results show that at a high temperature, oxygen still plays its remarkable role in promoting the NO-coal coke reduction reaction and there exists also a critical oxygen concentration (0.25%) phenomenon, which is somehow less than that (1%) at a low temperature. It can be found from the XPS analytic results that the effect of oxygen on the surface of coal coke is to produce surface oxygen-contained functional groups (C(O)) to promote the NO reduction. A proper oxygen concentration can help form saturated C(O) active sites, making the reduction effectiveness attain its optimum. With a rise in temperature, the total quantity of C(O) will decrease slightly, the possible cause of which is that an excessively high temperature makes the C(O) on the surface of coal coke very easy to attain its saturation and the redundant oxygen will be discharged in the form of O. **Key words:** surface functional group, XPS (X-ray photoelectron spectroscopy), coal coke, oxygen

基于改进型 GA 优化 FNNC 的 SG 水位控制系统仿真研究 = **Simulation Study of a Steam Generator (SG) Water Level Control System Based on Improved Genetic Algorithm and Optimized Fuzzy Neural Network Control** [刊, 汉] CHENG Qi-ming, HU Xiao-qing, WANG Ying-fei, XUE Yang (College of Electric Power and Automation Engineering, Shanghai College of Electric Power, Shanghai, China, Post Code: 200090) // Journal of Engineering for Thermal Energy & Power. - 2012, 27(2). - 232 ~ 236

The water level in a steam generator will directly influence the safe and stable operation of a whole nuclear power plant. However, the highly complexity, nonlinearity and time variation etc. characteristics of the steam generator itself cause the traditional cascade PID (proportional, integral and differential) control and other methods difficult to achieve a good control effectiveness. On the basis of the cascade control, the authors adopted the fuzzy neural network to control the water level of a steam generator. Such a control algorithm can give full play of the merits of the fuzzy control and neural network. In addition, to diminish the influence of the controller performance on the initial value selection of the fuzzy neural network, an improved genetic algorithm was used for parameter optimization of the fuzzy neural network controller. The simulation results show that both interference-resistant capacity and robustness of the control method thus designed are improved greatly when compared with those of the traditional cascade PID control and conventional fuzzy neural network control. **Key words:** steam generator, water level control, fuzzy neural network, improved genetic algorithm, cascade PID control

乳化燃料油在船舶柴油机上的应用研究 = **Study of the Applications of Emulsified Fuel Oil in Marine Diesels** [刊, 汉] PANG Hong-lei, ZHENG Dao-cang, WU Guang-bin (Ningbo University, Ningbo, China, Post Code:

315211) ,FU Lei (Qingdao Maritime Bureau ,Qingdao ,China ,Post Code: 266011) //Journal of Engineering for Thermal Energy & Power. - 2012 27(2) . - 237 ~ 241

To realize applications of emulsified fuel oil on ships ,a set of heavy oil on-line emulsification device was developed and a real-ship test was performed on Ningda No. 6 transportation vessel powered by a Model G6300ZC18B diesel engine. The test results show that when the water dilution ratio ranges from 16% to 24% ,the fuel oil can attain a good emulsification quality and serve as a kind of fuel oil on ships. When burning the emulsified fuel oil ,the diesel engine will have an explosive pressure fluctuating within a range from 1 to 2 MPa ,the exhaust gas temperature will drop averagely by 12 °C and the cooling water outlet temperature will decline slightly. The above-mentioned parameters are changed in their normal variation range. Moreover ,the average oil saving rate reaches 9.7% and NO_x ,CO and carbon-flue-gas emissions decrease by 19.6% ,20% and 35% respectively. **Key words:** marine diesel ,emulsified heavy oil ,water dilution ratio ,combustion ,emissions reduction

乙醇掺混燃烧对柴油机油耗影响的实验研究 = **Experimental Study of the Influence of Ethanol Mixed and Diluted Combustion on the Oil Consumption of a Diesel** [刊 ,汉]DANG Shuai ,ZHONG Bei-jing ,GONG Jing-song ,YUAN Zhen (College of Aeronautics and Astronautics ,Tsinghua University ,Beijing ,China ,Post Code: 100084) // Journal of Engineering for Thermal Energy & Power. - 2012 27(2) . - 242 ~ 245

After a heat absorption ,ethanol can be pyrolyzed partially and produce a mixture of several gases. To study the oil saving effectiveness of gas mixing and dilution combustion in a diesel engine ,the diesel system was modified: let ethanol to absorb the waste heat of the exhaust gas by passing through a miniature and efficient heat exchanger mounted on the exhaust gas pipe of the diesel engine and after a pyrolysis in a part ,the gas mixture thus produced is fed into the combustor of the diesel engine via an inlet pipe to improve the combustion. On the system under discussion ,an oil-saving experimental study was conducted at constant power-various rotating speeds and rated speed-various powers. The research results show that the system in question can have a relatively good oil-saving and energy-saving effectiveness at both high and low powers. When operating at 1500 r/min. the diesel engine can achieve a possible highest oil-saving rate and energy-saving rate of 40% and 13.5% respectively. When operating at 2000 r/min ,the diesel can attain a possible highest oil-saving rate and energy-saving rate of 24% and 5.7% respectively. The measurement data of the gas mixture pyrolyzed from ethanol induce one to conclude that the oil-saving principle of the system mainly depends on ethanol steam at a low power while mainly on gases with small molecules at a high power. **Key words:** internal combustion engine ,ethanol ,pyrolysis ,oil saving

高负荷氦气压气机平面叶栅数值试验及叶型优化 = **Numerical Experiment and Blade Profile Optimization**