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掺水燃油中水珠粒径对锅炉热效率影响

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摘 要:采用自制的机械微搅拌燃油掺水装置制取不同水珠粒径(9.36,11.27,14.49和20.55 μm)的掺水燃油,再将其应用到某油田热注锅炉进行在线测试。试验结果表明:机械搅拌法制备的掺水燃油比未掺水燃油的锅炉热效率有较大提高,且当掺水燃油中水珠粒径为9.36 μm时,锅炉热效率最高,此时锅炉正平衡效率为89.73%,节油率为4.49%。

关 键 词:机械微搅拌;水珠粒径;掺水燃油;锅炉热效率;节油

中图分类号:TK229.7 **文献标识码**:A

引 言

在石油资源短缺、环境污染严重的局势下,乳化燃油因其在经济与环境领域内具有双重优势成为很有应用前景的节能减排技术之一[1]。在乳化燃油燃烧机理研究过程中,主要为微爆现象的发现。微爆作用理论最早由苏联学者B.H.伊万诺夫提出[2],即水份在液相过热膨胀,使液滴产生"二次雾化"[3]。

邓云丽等在掺水重油分散度研究中认为水在油中分散得越均匀[4],分散的颗粒越微细,其在燃烧过程中的微爆效果越佳,雾化效果越好。肖红飞等研究指出国内工业炉窑燃用掺水乳化重油的效果好坏与其分散相水的微粒大小有很大关系[5]。本实验室通过自制的机械搅拌装置,对掺水燃油中水珠粒径的影响因素做过研究[6]。但是,对分散相水的粒径的研究多是在掺水燃油制备过程中,将其具体应用到燃烧试验中,而研究不同颗粒水珠的掺水燃油对燃烧和节油效果的影响还较少。本研究结合前期研究结果,采用机械微搅拌法,在不添加乳化剂的条件下,制备出不同水珠粒径的掺水燃油,再将其应用于某油田热注锅炉燃烧,探讨掺水燃油中分散相水的粒径大小对锅炉热效率的影响,以期得到具体的科学掺水燃油的数据。

1 实验部分

1.1 微搅拌燃油掺水制备

燃油掺水装置由微搅拌核心单元、水泵、油泵、搅拌电机、水箱、掺水燃油油箱,电气系统等部分组成,机器背面有3个快速接口,分别是掺水燃油出口、燃油入口和纯水入口。微搅拌核心单元采用特制机械搅拌装置,驱动电机依次驱动机械装置的剪切区和对流区。燃油和水从不同角度以一定配比注入剪切区,强大的机械剪切力使油水均匀混合。然后进入对流区,因两个不同方向的流体高速对冲和摩擦,使流体混合均匀,水珠细分成微米量级的微粒均匀分散于燃油中,形成掺水燃油。

采用机械微搅拌法制备掺水燃油[7]。通过电加热和温度变送器(北京昆仑海岸JWB/PT100)控制燃油罐中燃油温度T(℃),利用变频器改变齿轮转速控制搅拌速度ν(r/min),精确控制油流量及水流量以调节掺水燃油中含水量。在掺水量为3.5%的条件下,改变搅拌速度和油温制备出不同水珠粒径的掺水燃油。取样后采用光学显微镜(OLYMPUS BX51)观测掺水燃油中水珠粒径。

1.2 燃油掺水锅炉燃烧试验

本试验在某油田热注锅炉(YZF11-21-P)系统中开展,在原有锅炉基础上加装自制的掺水燃油装置,进行一年的不定期连续试验。该油田注汽锅炉设计特稠油燃油消耗量为0.5 m^3/h,正常运行控制蒸汽干度75%-80%[8]。图1为试验流程示意

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图，设计燃油掺水试制装置时将掺水燃油产量定为 0.5 m^3/h。在测试前，关闭燃油掺水装置前的进油阀门，燃油经原锅炉进油阀直接进入锅炉中燃烧，回油直接回到燃油罐中，持续运行至锅炉稳定后进行测试。之后打开燃油掺水装置的进油阀门，控制进口燃油流量，开启搅拌电机，关闭原锅炉进油阀门，调节进水计量泵流量制备掺水燃油，制好的掺水燃油流入掺水燃油罐中，之后经齿轮泵加压进入锅炉中燃烧，回油回到掺水燃油罐中，持续运行至锅炉稳定后进行测试。燃油锅炉本身控制面板显示以下参数：给水温度和压力、蒸汽压力和温度、燃油压力和流量等。使用油田专用湿蒸汽发生器蒸汽干度测定方法测定蒸汽干度（SY 5854－2012 标准）。依据石油产品热值测定法测定燃油热值（GB 384－1981 标准），热电偶温度变送器测量油温和烟温，红外测温仪（美国雷泰 RAYR3IRL3U）测量炉体各点温度。

1.3　分析方法

测试参照 GB/T10180－2003《工业锅炉热工性能试验规程》标准执行。

锅炉热效率计算为：

正平衡效率计算式：

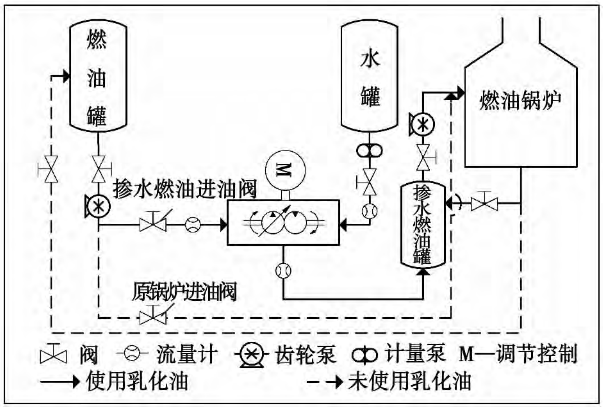

图 1　试验流程图

Fig. 1 Chart showing the flow path of the test

$$\eta_1 = \frac{(D_{sc} + G_q)(h_{gq} - h_{gs}) + D_{zy}\left(h_{zy} - h_{gs} - \frac{\gamma\omega}{100}\right) + G_s(h_{bq} - \gamma - h_{gs})}{BQ_r} \times 100\% \tag{1}$$

式中：η_1—锅炉正平衡效率，%；D_{sc}—输出蒸汽量，kg/h；G_q—蒸汽取样量，kg/h；h_{gq}—过热蒸汽焓，kJ/kg；h_{gs}—给水焓，kJ/kg；D_{zy}—自用蒸汽量，kg/h；h_{zy}—自用蒸汽焓，kJ/kg；h_{bq}—饱和蒸汽焓，kJ/kg；γ—汽化潜热，kJ/kg；ω—蒸汽湿度，%；G_s—锅水取样量（排污量），kg/h；B—燃料消耗量，kg/h；Q_r—输入热量，kJ/kg。

反平衡效率计算式：

$$\eta_2 = 100 - (q_2 + q_3 + q_4 + q_5 + q_6) \tag{2}$$

式中：η_2—锅炉反平衡效率，%；q_2—排烟热损失，%；q_3—气体未完全燃烧热损失，%；q_4—固体未完全燃烧热损失，%；q_5—散热损失，%；q_6—灰渣物理热损失，%。

平均效率：

$$\eta_{avg} = (\eta_1 + \eta_2)/2 \tag{3}$$

式中：η_{avg}—锅炉平均效率，%。

根据锅炉正平衡效率分别计算节油率，节油率计算公式[9]：

$$b = 1 - \eta/\eta' \tag{4}$$

式中：b—节油率，%；η—掺水前锅炉正平衡效率，%；η'—掺水后锅炉正平衡效率，%。

2　实验结果与分析

2.1　不同水珠粒径掺水燃油制备

采用 1.2 节中的方式制备掺水燃油。图 2 为显微镜下不同水珠粒径掺水燃油油样的照片，经测量水珠粒径大小分别为 9.36，11.27，14.49 和 20.55 μm。在显微镜下观测掺水燃油中水珠粒径时，虽然显微镜中可观察掺水燃油的不同层面，但只有最上层面成像最清晰。此层面上的水珠看得最清楚并能反映真实大小，因此统计时不计视野内全部水珠的平均粒径，仅以粒径最大、最清晰的水珠尺寸为准。

不同搅拌速度和油温下，制备出的掺水燃油油样中的水珠粒径不同，具体参数的影响在以前的实验中已研究[6]，搅拌速度及油温对水珠粒径的影响如表 1 所示。由此制备出的不同水珠粒径的掺水燃油为下面的燃烧试验提供燃料。

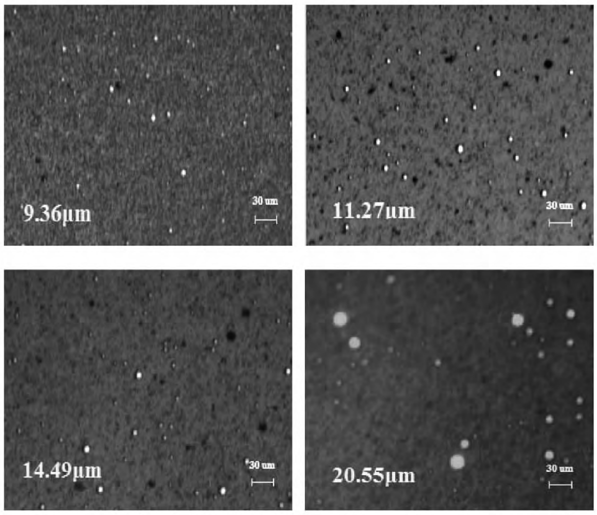

图 2　掺水燃油水珠粒径

Fig. 2 Diameter of the droplets of fuel oil mixed with water

表 1　搅拌速度及油温对水珠粒径的影响

Tab. 1 Effect of the agitation speed and oil temperature on the diameter of the droplets

水珠粒径/μm	搅拌速度/r·min^{-1}	油温/℃
9.36	1 300	83.6
11.27	1 260	79.7
14.49	1 100	82.8
20.55	1 000	77.8

2.2　水珠粒径对锅炉热效率影响

按照 1.2 所述在锅炉上进行燃油掺水燃烧试验，并采用 1.3 节中分析方法分析锅炉热效率。表 2 列出了水珠粒径大小不同时掺水燃油燃烧的锅炉正、反平衡效率及平均效率。当水珠粒径为 9.36 μm 时，掺水燃油的锅炉正平衡效率和平均效率最高，分别为 89.73% 和 89.22%；未掺水燃油的锅炉正平衡效率和平均效率最低，分别为 85.70% 和 86.57%；两结果分别相差 4.03% 和 2.65%。当水珠粒径为 11.27，14.49 和 20.55 μm 时，其锅炉的正平衡效率和平均效率依次降低，但都高于未掺水燃油的锅炉热效率。水珠粒径为 20.55 μm 时，掺水燃油和未掺水燃油的锅炉热效率较为接近，正平衡效率和平均效率分别相差 0.99% 和 0.32%。掺水燃油的锅炉正平衡效率和平均效率如图 3 所示。

表 2　不同水珠粒径的掺水燃油的锅炉热效率

Tab. 2 Thermal efficiency of the boiler burning a mixture of fuel oil and water at various droplet diameters

水珠粒径/μm	正平衡效率/%	反平衡效率/%	平均效率/%
9.36	89.73	88.71	89.22
11.27	88.46	88.66	88.56
14.49	87.54	88.52	88.03
20.55	86.69	87.09	86.89
未掺水	85.70	87.44	86.57

试验结果显示，燃油掺水提高了锅炉热效率，且水珠粒径越小其锅炉热效率越高。分析认为主要是由于燃油掺水燃烧会伴随微爆现象的产生，而小粒径水珠的掺水燃油燃烧时可产生更好的微爆效果。掺水燃油燃烧时，经加压通过喷嘴使其雾化燃烧（称为一次雾化），当水达到其过热极限时会膨胀，水蒸气的突然膨胀，使周围的燃油快速的爆炸，形成更细小的油滴，即油滴的微爆现象（称为二次雾化）。爆炸后的油滴与空气接触更充分，燃烧更完全，从而提高锅炉的热效率。另外，由于水的升温、气化吸热，防止了局部高温的形成；而且，含水燃烧能明显减少积炭、结焦和含炭颗粒，有效的消除了燃烧室内的炽热点；燃烧过程产生的 C 粒子还会与水蒸汽发生水煤气反应，水煤气反应过程中会产生 H、O 和 OH 等活性物质，对燃烧反应有促进作用，这些都可能是锅炉热效率提高的原因。

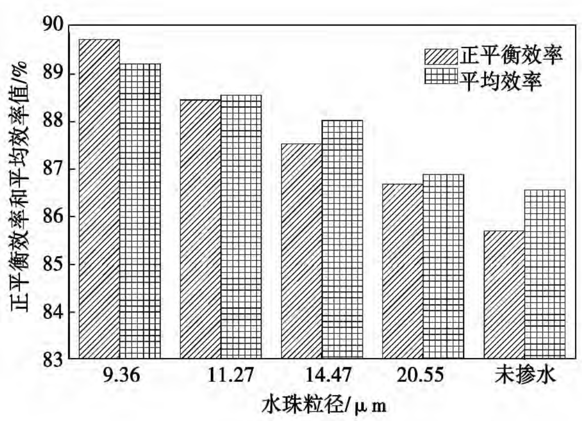

图 3　掺水燃油的锅炉正平衡效率和平均效率

Fig. 3 Direct-method heat balance efficiency and average of the boiler burning a mixture of fuel oil and water

一次雾化雾滴粒径为10－200 μm[10]，二次雾化雾滴粒径可达30－50 μm[11]，为了提高“微爆”强度，水珠粒径必须适当。本试验中燃烧效果最好的是当掺水燃油中水珠粒径为最小的9.36 μm时。原因是粒径越小的水珠，燃油雾化颗粒越细微，与空气接触面积越大，燃烧越充分，锅炉热效率得到更大提高。有研究同样指出，当80%以上的水珠粒径为10 μm左右时，能明显改善燃烧效率[12]。张理齐等使用水珠粒径10 μm以下的乳化油在大型板坯加热炉上燃烧[13]，得到了很好的燃烧效果。但是水珠粒径并不是越小越好，，当水珠粒径过小时，小水珠会先聚集，之后才发生微爆，微爆时间延长，或者还未来得及聚集便已发生膨化，影响微爆发生[14]。由于实验条件所限，未能制备出更小粒径水珠的掺水燃油，其对锅炉热效率的影响在以后研究需进一步验证。

2.3　水珠粒径对节油率影响

采用1.3节中分析方法折算出不同粒径水珠掺水燃油在锅炉燃烧试验中的节油率，如图4所示。随着掺水燃油中水珠粒径的增大，燃油节油率降低。当水珠粒径为9.36 μm时，燃油节油率最高，为4.49 %。当掺水燃油中水珠粒径依次增大到11.27和14.49 μm时，节油率分别降低为3.12 %和2.11 %。当水珠粒径为20.55 μm时，燃油节油率最低，为1.14 %。

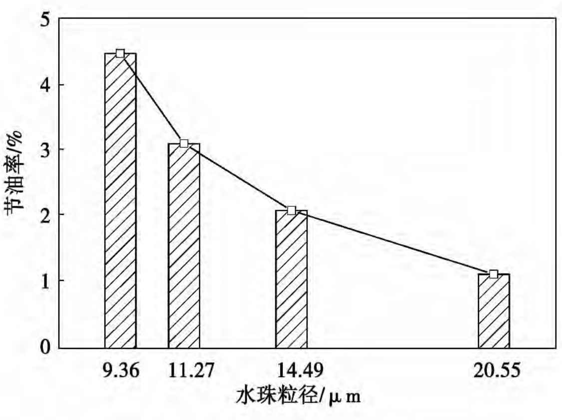

图4　水珠粒径对节油率的影响

Fig.4 Effect of the droplet diameter on the fuel oil saving rate

试验结果显示，掺水燃油中水珠粒径影响节油效果，水珠粒径越小节油效果越好，水珠粒径太大时节油效果不明显。分析认为主要是粒径较小的水珠微爆效果佳，燃烧更加充分，提高了锅炉热效率，降低了燃料消耗。许多掺水燃油工业性应用试验的结果与本研究所得结果相似。张理齐等在热轧厂大型板坯加热炉燃用水珠粒径10 μm以下的乳化油试验中[13]，得到了3.84 %的节油率。唐文武将乳化重油应用到轧钢加热炉[15]，加热炉综合热效率提高约2.5%，节油率达6.73%。徐业鹏等使用工业炉燃用乳化油[16]，节油约3.4%－10 %。关于燃用掺水燃油的节油效果，从节油3%－5%甚至到更高均有报导[16]。这种差异可能因为掺水燃油的制备及应用的具体情况不同，如制备工艺、燃烧设备、燃油类型和燃烧工况等。

3　结　论

（1）机械微搅拌法制备的掺水燃油燃烧时对锅炉热效率有较大提高。相比未掺水燃油，掺水燃油锅炉正平衡效率最多可由85.70%提高到89.73%；

（2）水珠粒径对掺水燃油锅炉热效率、燃油节油率的影响显著。水珠粒径越小，掺水燃油的锅炉热效率和节油率越高，燃烧效果越好，燃油消耗越低；

（3）机械搅拌法制备的掺水燃油中水珠粒径为9.36 μm时，其锅炉热效率最高达89.73%，节油率最高达4.49%。

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(陈 滨 编辑)

With CO_2 serving as the refrigeration agent, experimentally studied were the boiling heat exchange characteristics of a low temperature fluid inside a micro-channel having an inner diameter of 0.6 mm and 1.5 mm respectively and quantitatively analyzed was the influence of various parameters under various operating conditions on the heat exchange coefficient when the low temperature fluid flows through the pipeline under the test condition. The research results show that the model proposed in the literature [7] has a relatively high prediction precision. When the error was controlled in a range of 30%, the theoretical prediction precision ratio (ratio of the test data and those obtained from the model) of the heat exchange coefficient before the dry-out takes place can be up to 79.8% and the average deviation can be up to 21.8% while after the dry-out has taken place, the theoretical prediction precision ratio of the heat exchange coefficient can be up to 18.4% and the average deviation can be up to 59.9%. **Key words:** carbon dioxide, heat exchange coefficient, dry-out, boiling heat exchange of a flow

600 MW **低质量流速垂直管圈超临界煤粉锅炉设计开发 = Development of the Design of a** 600 **MW Low Mass Flow Speed Supercritical Pulverized Coal-fired Boiler With a Vertical Tube Coil [刊,汉]** ZHANG Man, ZHANG Hai, LU Jun-fu, WU Yu-xin, ZHANG Da-long (Education Ministry Key Laboratory on Thermal Science and Power Engineering, Department of Thermal Energy Engineering, Tsinghua University, Beijing, China, Post Code: 100084) //Journal of Engineering for Thermal Energy & Power. – 2014, 29(3). –267 –273

Analyzed were commonly seen specific features of several water wall arrangement modes of supercritical pulverized coal-fired boilers, tangentially and wall opposed combustion modes and principles for choosing the key parameters of a vertical tube coil water wall and designed and developed was a low mass flow speed vertical tube coil 600 MW supercritical pulverized coal-fired boiler. Under the full load operating condition, the design mass flow speed of the water wall was 940 kg/m^2s. The version under discussion adopted the low mass flow speed vertical tube technology developed by the Siemens Company. In combination with such merits as simple in the structure of vertical water walls and the self-compensated characteristics of the working medium at a low mass flow speed, the throttle orifice was removed, thus avoiding the complex structure of both water walls and lower headers, and at the same time, eliminating the safety hazard as the tube walls have exceeded the allowable temperature, created by any clogging in the structure of the throttle orifice during operation. An intermediate mixing header was provided between the upper and lower water wall in the furnace to mix with the working medium coming from the lower part of the furnace and minimizing the temperature deviation at the working medium side caused by non-uniform heat absorption and difference in the structure of the furnace. Finally, the authors described the structure of the boiler under discussion and predicted its performance. **Key words:** 600 MW, supercritical, low mass flow speed, vertical tube coil, design

掺水燃油中水珠粒径对锅炉热效率影响 = Influence of the Water Drop Particle Diameter in Fuel Oil Dilu-

ted and Mixed with Water on the Thermal Efficiency of a Boiler [刊,汉] ZHANG Lu,ZHU Yi-min,LI Tie, TANG Xiao-jia,ZHANG Hong-peng (Environmental Pollution Treatment Research Institute,Dalian Maritime University,Dalian,China,Post Code: 116026) //Journal of Engineering for Thermal Energy & Power. - 2014,29(3). -274-278

A self-made mechanical micro agitation fuel oil water-dilution-mixing device was adopted to prepare fuel oil mixed with water in various water drop particle diameters (9.36 μm,11.27 μm,14.49 μm and 20.55 μm) and such fuel oil was applied in a thermally-injected boiler in an oil field for an on-line test. The test results show that the thermal efficiency of the boiler burning the fuel oil diluted and mixed with water prepared by using the mechanical agitation method can be improved remarkably when compared with that burning the fuel oil not diluted and mixed with water and when the water drop particle diameter of the fuel oil mixed with water is 9.36 μm,the thermal efficiency of the boiler will be highest. In such a case,the direct balance efficiency of the boiler will be 89.73% and the oil saving rate will be 4.49%. **Key words:** mechanical micro agitation,water drop particle diameter,fuel oil diluted and mixed with water,thermal efficiency of a boiler,oil saving

燃煤锅炉NO_x排放浓度的智能预报 = Intelligent Prediction of the NO*x* Emissions Concentration of a Coal-fired Boiler [刊,汉] YIN Ling-xiao,WANG Ming-chun,SHANG Qiang (College of Energy Source and Environment,Nanjing,China,Post Code: 210096) //Journal of Engineering for Thermal Energy & Power. - 2014,29(3). -279-283

On the basis of the hot state test data,the BP neural network and supporting vector machine regression algorithms were used respectively to establish models controlling the NO_x emissions characteristics of a coal-fired boiler and verify the accuracy of the models. The research results show that the maximum prediction error,minimum prediction error and mean variance of the specimen by using the BP network model are 4.263%,0.556% and 2.2133% respectively and those by using the supporting vector machine model are 2.121%,0.091% and 0.4549% respectively. Both intelligent technologies can make a relatively accurate prediction of NO_x emissions under various operating conditions of the boiler,however,the supporting vector machine model is obviously superior to the neural network model in terms of general-purpose capability,converging speed and optimization etc. **Key words:** NO_x,boiler,neural network,supporting vector machine

磁场强度对层流预混火焰燃烧过程中NO_x生成特性的影响 = Influence of the Intensity of a Magnetic Field on the NO_x Production Characteristics During the Laminar Flow Premixed Flame Combustion [刊,汉] CHEN Wei-peng,ZHU Bing-sen,LI Bao-wei,WU Wen-fei (Inner Mongolia University of Science and Technology,