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循环流化床锅炉燃用准东煤结渣、沾污分析

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摘 要: 在一台因燃用准东煤而严重结渣的循环流化床锅炉内提取结渣灰样, 利用XRF和XRD方法分析了灰样的形态和成份。研究表明: 分离器出口烟道壁面灰渣内层的Na元素以Na_2SO_4形式存在, 同时又有大量$CaSO_4$存在, 形成$Na_2SO_4 - CaSO_4$低熔点复合盐体系。$Na_2SO_4 - CaSO_4$低熔点复合盐被壁面捕捉形成粘性底层, 同时由于Fe、Ca协同作用, 捕捉的灰中矿物质迅速形成低熔点共熔体, 并且固化形成致密的渣层。对于高温再热器管子, 由于Na_2SO_4、$NaK_3(SO_4)_2$或$NaO \cdot Al_2O_3 \cdot 2(SiO_2)$等低熔点化合物以气溶胶形式存在于烟气中, 同时吸附烟气中的飞灰颗粒, 然后沾结在管子表面形成结渣沾污。

关 键 词: 准东煤; 结渣; 沾污; 循环流化床锅炉

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引 言

准东煤田位于准格尔盆地东部, 是煤炭储量为1 640亿t的特大型煤田[1]。勘探资料表明准东煤田各矿区同一煤层煤质比较稳定, 属于特低灰分、特低硫、高热值(高位发热量)、低变质程度的优质天然洁净煤, 准东煤被开采后将大量用于电站锅炉发电。由于对准东煤缺少充分认识, 燃用或掺烧准东煤的锅炉都出现了严重的结渣、沾污现象。由于准东煤是2005年勘探发现的新型煤种, 并且具有高碱金属含量、高水量、低灰分等特点, 国内外针对准东煤燃烧结渣沾污特性的研究还较少。

杨忠灿等人利用西安热工研究院有限公司燃烧试验台, 对准东煤的着火、燃尽、沾污和结渣特性等进行了研究[2], 提出了燃用准东煤锅炉选型的合理建议。部分高校对准东煤的燃烧特性、灰熔融特性及结渣、沾污特性进行了实验研究, 分别对准东煤的结渣机理进行了一定阐述[3-6]。刘静等人对准东煤等新疆煤中的碱金属赋存形态及在高温下的释放迁移规律展开实验和理论研究[7]。李路明介绍了完全燃用准东煤350 MW超临界锅炉的主要汽水、热力参数和布置结构[8]。

由上述可知, 目前对于准东煤结渣沾污特性的研究依然偏少, 其结渣沾污机理尚不明确, 而且现有的研究结论主要是基于试验台研究和工程运行经验提出, 并且分歧较大。本研究对燃用准东煤导致严重结渣沾污的循环流化床锅炉进行取样分析, 研究准东煤的结渣沾污机理, 为解决燃用准东煤锅炉结渣问题提供一些技术参考。

1 取样、制样

1.1 灰样来源及燃煤成分分析

灰样取自新疆米东热电厂一台由东方锅炉厂生产的亚临界、自然循环、一次中间再热、平衡通风和固态排渣循环流化床汽包锅炉, 型号为DG1069/17.4 - Ⅱ1。设计煤种和燃用煤种元素分析、工业分析及灰成分分析如表1、表2所示。该锅炉原燃用设计煤种为准南煤, 由于对准东煤特性认识不足, 该厂在改烧准东煤之前并未对锅炉结构和一、二次风比例做出调整。该锅炉在燃烧准东煤期间, 炉膛温度约为950 ℃。在改烧准东煤3个月后, 主蒸汽温度明显降低, 导致锅炉被迫停炉。检查发现尾部烟道受热面严重堵灰, 炉膛内有很少量焦块, 分离器出口水平烟道受热面表面形成覆盖渣层, 高温过热器上层管子结渣严重。锅炉结构及取样位置如图1所示。

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表 1 煤种的工业分析和元素分析

Tab. 1 Proximate and elementary analysis of the coal rank

煤 种	工业分析/%				元素分析/%					$Q_{net,ar}$
	M_{ad}	A_{ar}	V_{ar}	FC_{ar}	C_{ar}	H_{ar}	O_{ar}	N_{ar}	$S_{t,ar}$	/MJ · kg^{-1}
准南煤(设计煤种)	6.53	47.33	23.31	30.94	34.7	1.95	9.63	0.41	0.91	12.43
准东煤(燃用煤种)	13.97	8.54	23.45	46.62	53.45	2.45	13.03	0.46	0.68	20.05

表 2 煤种的灰组成(%)

Tab. 2 Ash composition of the coal rank

煤种	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
准南煤(设计煤种)	54.39	16.66	1.01	5.20	9.23	6.68	1.55	1.56	1.32
准东煤(燃用煤种)	15.52	5.07	0.18	5.59	30.61	6.72	5.55	0.79	29.05

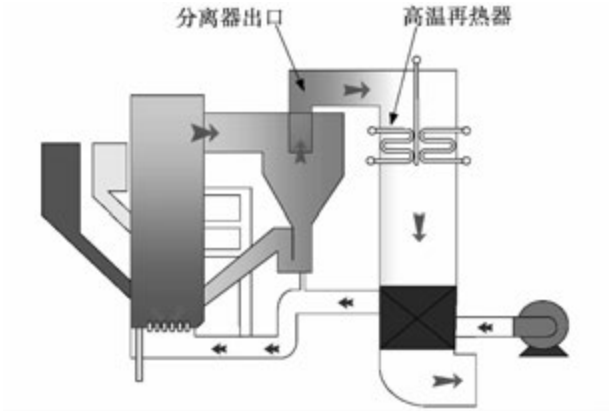

图 1 锅炉结构及取样位置示意图

Fig. 1 Schematic diagram of the structure of the boiler and its sampling locations

1.2 实验内容及分析方法

对该循环流化床锅炉各部位结渣、沾污原料进行详细取样、磨样,然后利用日本理学 D/max2400 型 X 射线衍射仪(XRD)检测每层主要元素的化合物形态,利用德国 Bruker 公司生产的 S4 - Pioneer 型 X 射线荧光光谱仪(XRF)确定每层各主要元素的定量含量,并综合 XRD 分析结果,推断出每层中化合物的大概含量,提出造成该锅炉受热面结渣沾污的有关原因。

1.3 取样及制样

分离器出口壁面上渣样明显分为 2 层:渣体外层为一个深红色致密层;靠近粘结壁面的内层为一个黄褐色致密层。渣体底部深红致密层只占到整个结渣体的 20% -30%。

高温再热器第一排管道迎风面管壁上渣样可以明显的分为 3 层:积灰靠近管道壁面内层为一个淡红色致密层;中间层为深红色致密层;积灰靠近烟气的表面外层是一个黄褐色的疏松层。渣体底部淡红致密层只占到整个积灰的 5% -10% 左右,中间深红色层占整体的 60% 左右。

高温再热器管道转弯弯头的正面管壁上的积灰可以明显的分为 4 层:积灰靠近管道壁面内层为一个淡黄色薄层;中间层为深红色层;次外层是夹杂在灰中间的灰白层;积灰与烟气接触的最外层为是一个淡红色致密层。渣体接触管壁淡黄色薄层只到整个积灰的 10% 左右,外部灰白色层占整体的 40% 左右,中间深红色的灰层约占整体的 25%。

2 灰样成份分析及讨论

2.1 分离器出口壁面上渣样分析

为了确定分离器出口壁面渣体各层中主要元素和化合物形态,对各层渣体进行了 XRF 和 XRD 分析,结果如表 3、图 2 所示。

表 3 分离器出口壁面上渣样各层主要元素分布规律

Tab. 3 Distribution law of element content of the slag on the separator outlet wall

元素/%	内层	外层
O	45.9	47.2
Ca	13.4	13.7
S	5.55	7.78
Si	9.55	9.83
Al	6.04	5.94
Mg	5.15	4.3
Fe	12.4	7.31
Na	1.04	2.95
Ti	0.477	0.42

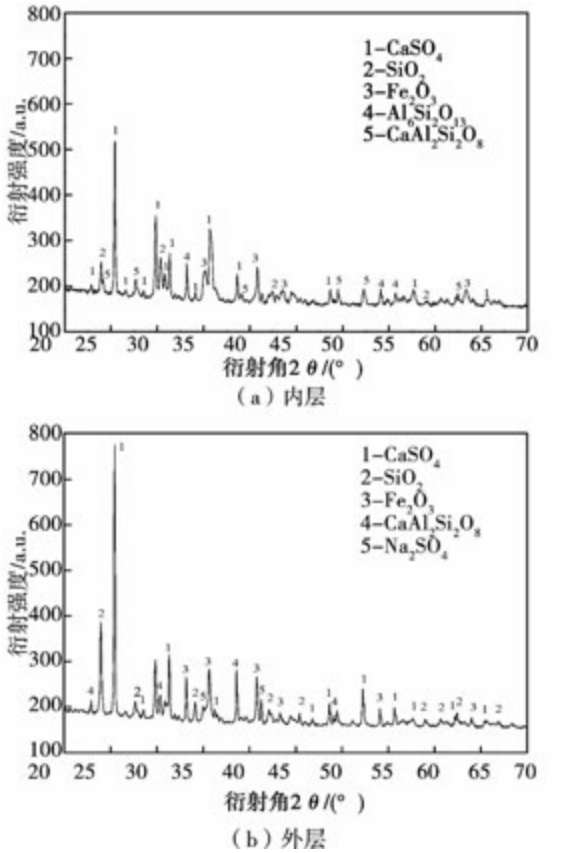

图 2　分离器出口壁面上渣样 XRD 检测图谱

Fig. 2 XRD analyzed results atlas of the slag on the separator outlet wall

可以看出,分离器出口壁面上的渣样主要元素为 O、Ca、Si、Fe 等,以硬石膏($CaSO_4$) 、石英(SiO_2) 、赤铁矿(Fe_2O_3) 、钙长石($CaAl_2Si_2O_8$) 为主要矿物组成。由于灰渣中大量赤铁矿(Fe_2O_3) 存在,所以看起来灰渣呈现红色。

2.2　高温再热器灰样分析

为了确定高温再热器第一排管子迎风面渣体各层中主要元素和化合物形态,对各层渣体进行了 XRF 和 XRD 分析,结果如表 4、图 3 所示。

高温再热器第一排管道迎风面管壁上的灰样主要元素为 Ca、S、Si、Fe、Al 等,以硬石膏($CaSO_4$) 、石英(SiO_2) 、赤铁矿(Fe_2O_3) 、钙长石($CaAl_2Si_2O_8$) 为主要矿物组成。渣样中的 Na 和 Fe 主要集中在灰样的中间层,以 Na_2SO_4和 Fe_2O_3的形式存在。

为了确定高温再热器第一排管子转弯弯头迎风面渣体各层中主要元素和化合物形态,对各层渣体进行了 XRF 和 XRD 分析,结果如表 5、图 4 所示。

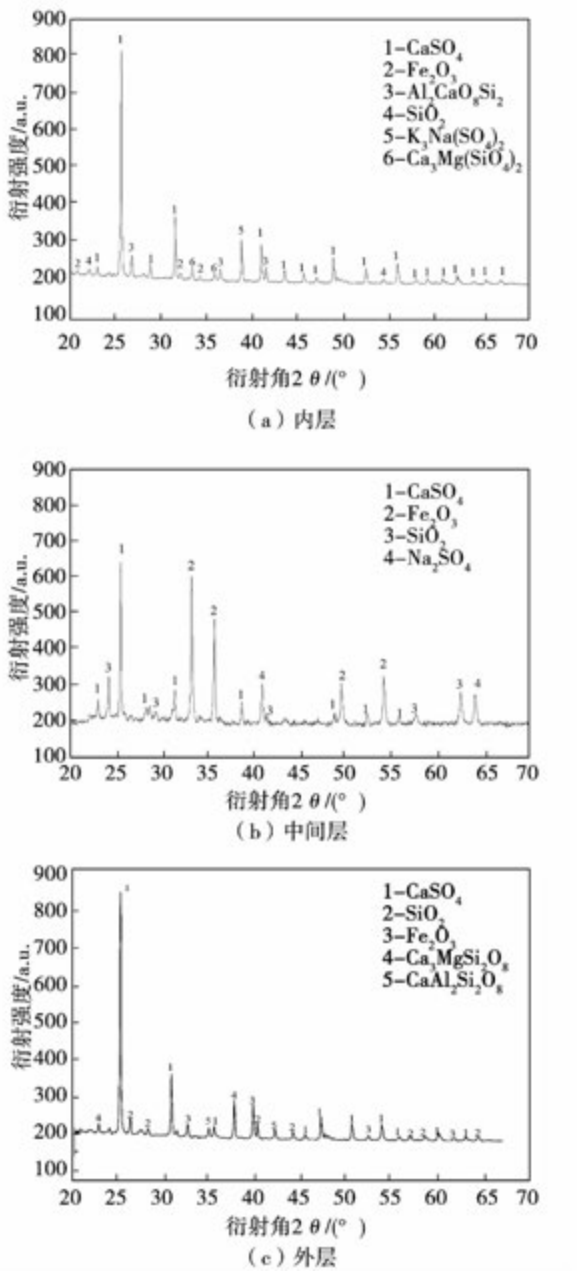

图 3　高温再热器第一排管子迎风面管壁上灰样 XRD 检测图谱

Fig. 3 XRD analyzed results atlas of the slag on the windward side of the high - temperature reheater in the first row tube

高温再热器第一排管子转弯弯头部位灰样主要元素为 Ca、S、Si、Na 等,以硬石膏($CaSO_4$) 、石英(SiO_2) 、赤铁矿(Fe_2O_3) 、铝酸三钙($Al_2Ca_3O_6$) 为主要矿物组成。Na 含量较多,形成化合物复杂,主要以 Na_2SO_4、$NaK_3(SO_4)_2$或 $NaO \cdot Al_2O_3 \cdot 2(SiO_2)$ 形式存在。

表 4 高温再热器第一排管道迎风面管壁上灰样各层主要元素分布规律(%)

Tab. 4 Distribution law of element content of the slag on the windward side of the high-temperature reheater in the first row tube(%)

元素	内层	中间层	外层
O	51.1	38.8	50.8
Ca	14.9	5.27	15.5
S	15.4	11.7	14.6
Si	6.43	1.26	6.49
Al	3.77	0.755	3.79
Mg	1.04	0.903	1.17
Fe	3.35	31	3.77
Na	2.07	8.38	2.24
K	1.33	0.879	0.914

表 5 高温再热器转弯弯头迎风面灰样主要元素分布规律(%)

Tab. 5 Distribution law of element content of the slag on the windward side of the high – temperature reheater in the tube bend elbow(%)

元素	内层	中间层	次外层	外层
O	50.5	48.1	50.3	50.6
Ca	13.7	9.65	15.3	10.9
S	15.4	14.9	17.4	16.6
Si	6.22	4.24	2.01	3.11
Al	3.55	2.67	1.49	2.02
Mg	1.1	1.95	2.07	0.848
Fe	2.59	7.8	1.85	2.89
Na	4.55	8.34	2.24	11.1
K	1.66	1.55	1.04	1.36

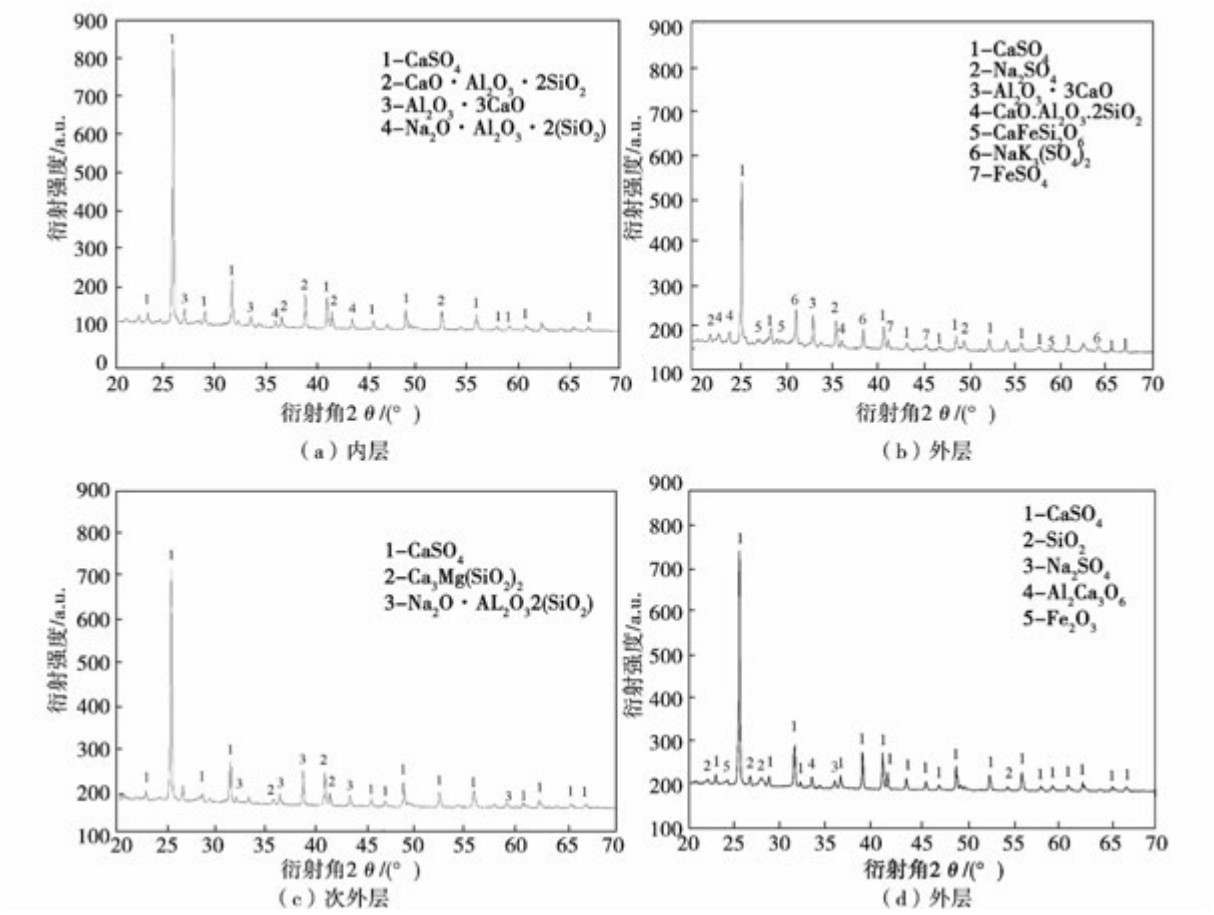

图 4 高温再热器管道转弯弯头的正面管壁上灰样 XRD 分析结果

Fig. 4 The results of XRD analyzed results of the slag on the windward side of the high – temperature reheater in the tube bend elbow

3　结　论

通过研究燃用准东煤循环流化床锅炉结渣沾污的灰样,分析了灰样的形态和成分,得出以下结论:

对于分离器出口烟道壁面。灰渣内层 Na 元素以 Na_2SO_4形式存在,同时又有大量 $CaSO_4$存在,形成 $Na_2SO_4-CaSO_4$低熔点复合盐体系。分离器出口烟道壁面粗糙,易于捕捉烟气中的灰,$Na_2SO_4-CaSO_4$低熔点复合盐被捕捉形成粘性底层,同时由于 Fe、Ca 协同作用,捕捉的灰中矿物质迅速形成低熔点共熔体,并且固化,形成致密的灰渣。

对于高温再热器管子。由于 Na_2SO_4、$NaK_3(SO_4)_2$或 $NaO\cdot Al_2O_3\cdot 2(SiO_2)$ 等低熔点化合物以气溶胶形式存在于烟气中,同时吸附烟气中的飞灰颗粒,然后沾结在管子表面形成沾污。沾污初期,由于沾污形成的管壁热阻较小,管壁温度主要取决于管内工质参数。此时,管壁温度低于烟气中气溶胶的熔点,因而 Na_2SO_4、$NaK_3(SO_4)_2$或 $NaO\cdot Al_2O_3\cdot 2(SiO_2)$ 等沾结在管壁上,同时发生 $CaSO_4$的低温沉积效应,积灰很快固化,厚度增长。随着沾污积灰厚度增加,污垢热阻远远大于管壁热阻,灰渣的温度趋近于烟气温度,$Na_2SO_4-CaSO_4$等低熔点复合盐不断吸附烟气中飞灰颗粒,形成新渣层。

由于分离器出口烟道壁面温度与烟气温度较为接近,故在此处的渣层主要是烟气中低熔点复合盐被壁面捕捉沉积后吸收灰中矿物质形成的。而高温再热器管子壁面温度与烟气温度相差较大,低熔点化合物在管子壁面上会迅速固化,不断积累导致渣层表面温度升高,直至与烟气温度接近,之后渣层表面的新渣层形成机理与分离器出口烟道壁面的结渣机理基本相似。

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(姜雪梅　编辑)

slag when discharged etc. parameters, the authors studied the influence of the slag removal system on the boiler efficiency and optimized the whole boiler system. It has been found that the critical temperature of the air fed from the bottom of the furnace should be 247.3 ℃. If the temperature of the air is lower than this critical temperature, the boiler efficiency will gradually decline with an increase of the amount of cooling air. After a dry type slag removal system has been adopted for a 600 MW unit, the boiler efficiency will increase by about 0.023%, thus solving the problem that there emerged a high temperature of flue gases in the initial stage of the reconstruction and the steel belt conveyer got stuck. **Key Words**: 600 MW unit, drytype slagremoval, cooling air flow rate, boiler efficiency

低温省煤器对汽轮机组热力经济性影响研究 = **Study of the Influence of a Low Temperature Economizer on the Thermal Cost-effectiveness of a Steam Turbine Unit**[刊,汉]CHENG Dong-tao, MA Ting-shan, CHEN Kai, JU Wen-ping (Xi'an Thermodynamics Academy Co. Ltd., Xi'an, China, Post Code: 710032) //Journal of Engineering for Thermal Energy & Power. -2015, 30(3). -426 -429

To put a low temperature economizer into operation will directly affect the operation state of its boiler and steam turbine. The heat rate reduction method for steam turbines is regarded as an effective and practical method for analyzing and evaluating the influence of a low temperature economizer on the thermal cost-effectiveness of the whole unit. With a 1 000 MW unit serving as an example, the influence of the putting-into-operation of its low temperature economizer on the thermal cost-effectiveness of the steam turbine unit was calculated through conducting a heat rate test and by using the equivalent enthalpy drop calculation method respectively. The results calculated by using both methods are in good agreement. Under the condition of the steam turbine unit operating at a test load of 1 000 MW, 900 MW, 800 MW, 700 MW, 600 MW and 500 MW, the heat rate of the steam turbine decreased by 45.1, 46.5, 55.6, 43.9, 45.3 and 41.1 kJ/kW · h respectively after the low temperature economizer had been put into operation, thus leading to a notably high thermal cost-effectiveness of the steam turbine unit and achieving a conspicuous energy-saving result. **Key Words**: low temperature economizer, steam turbine, heat rate, equivalent enthalpy drop

燃用准东煤循环流化床锅炉结渣沾污分析研究 = **Analysis and Study of the Slagging and Contamination of a CFB Boiler Burning Zhundong-originated Coal**[刊,汉]CHEN Heng, WANG Yun-gang, MA Hai-dong, ZHAO Qin-xin (Education Ministry Key Laboratory on Thermo-fluids Science and Engineering, Xi'an Jiaotong University, Xi'an, China, Post Code: 710049) //Journal of Engineering for Thermal Energy & Power. -2015, 30(3). -430 -434

Ash samples were taken from the slagging and contamination locations in a circulating fluidized bed seriously slagged by burning Zhundong-originated coal and the morphology and composition of the ash samples were analyzed by using the XRF and XRD method. It has been found that the Na element in the inner layer of the ash and slag on the wall surface of flue gas ducts at the outlet of the separator exists in the form of Na_2SO_4 and in the meantime, a great deal of $CaSO_4$ is present, forming a Na_2SO_4-$CaSO_4$ low melting point compound salt system. The low melting point compound salts are captured by wall surfaces to form a viscous base course and at the same time, under a synergistic action of Fe and Ca, the mineral substances captured from ash rapidly turn to be a low melting point eutectoid and are solidified to form a compact slag layer. For tubes in the high temperature reheater, the low melting point compounds such as Na_2SO_4, $NaK_3(SO_4)_2$ or $NaO.Al_2O_3.2(SiO_2)$ exist in the form of aerosol in the flue gases and in the meantime, adsorb particles in the flying ash and then, adhere to tube surfaces to form slags and contaminants.

Key Words: Zhundong-originated coal, slagging, contamination, CFB (circulating fluidized bed) boiler

离心泵闭式叶轮反求技术研究 = **Study of the Reverse-solution-seeking Technology for Closed Impellers in Centrifugal Pumps**[刊,汉]TANG Jian, LAI Xi-de, SONG Wei, ZHANG Wei (College of Energy Source and Environment, West China University, Chengdu, China, Post Code: 610039) //Journal of Engineering for Thermal Energy & Power. -2015, 30(3). -435-440

To quickly assimilate and absorb advanced technologies relating to some blades of centrifugal pumps both in domestic and abroad excellent in performance and conduct a retrofit design, a three-dimensional laser scanner was used to acquire the data of models and in combination with the quick curved surface restructuring method for impellers, the laser triangle method was employed to develop a set of reverse solution seeking methods for closed impellers of centrifugal pumps. With the help of the wax-molding shape-taking technology, the flow passages inside the impeller were measured, solving the problem that the data of a closed passage cannot be acquired by using the laser scanning method. A precision positioning of a flow passage and its cover plates was conducted based on iterative closest point (ICP) data alignment theory and a curved surface restructuring strategy based on the "point-triangle grid-curved surface patch-curved surface" in combination with "point-line-surface" was proposed, thus enhancing the modeling precision and efficiency. With a closed impeller in a centrifugal pump serving as an example, the feasibility of the method in question was verified by utilizing the hydraulic performance simulation. **Key Words**: centrifugal pump, closed impeller, reverse solution seeking, curved surface restructuring, hydraulic performance simulation