直接空冷系统在中国的发展历程
Development of direct ACC in China

·东北电力设计院有限公司
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1 概述 Summary

电厂空冷技术以其优越的节水性能有效的解决了电力发展与水资源相对匮乏的矛盾，成为富煤缺水地区大容量电站的最佳选择。近十年来，我国先后在北方缺水地区建成了多台300MW，600MW级的空冷机组，并且单机容量越来越大，尤其是1000MW直接空冷机组的投运，成为我国空冷技术发展的里程碑。这些机组相继投运，为我国大型空冷机组的发展积累了大量的宝贵经验。

The ACC technology , which becomes the best option of a large capacity plant in the coal richness and water shortage area, resolves the contradiction effectively between power development and scarce water resources at its superior water saving performance. In the past ten years, our country has built a number of 300MW, 600MW air cooling units in the north of water shortage areas , and the capacity is more and more. Especially the operation of 1000MW direct air cooling unit becomes a landmark in China's air cooling technology development. It has accumulated a lot of valuable experience for the development of large air cooling units in China.

2 我国直接空冷机组的发展及目前的装机规模
Development and capacity of direct ACC units in China

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- 我国的电站直接空冷技术起步于60年代，1966年在哈尔滨工业大学试验电站的50 kW机组上首次进行了直接空冷系统的试验。1967年在山西侯马电厂的1.5 MW机组上又进行了工业性直接空冷系统的试验。真正进入到工业生产领域是在2000年以后，并且迅速展开应用。
  The direct air cooling technology of our country's power plant was started in the 60's,and the test of the direct air cooling system was carried out in the 50 kW unit of Harbin Institute of Technology in 1966. The industrial direct air cooling system was carried out directly in the 1.5 MW unit of Houma Shanxi power plant in 1967. The actual operation in the industrial was in 2000 , and its expansion of the application has been rapid since that time.
- 2001年9月，我国自己设计、制造和安装的国内首台6 MW直接空冷机组，在山西交城义望铁合金厂自备电厂建成投产。
  Our own design, manufacturing and installation of the first 6 MW direct air cooling unit, which was in power plant owned by Shanxi Jiaocheng Yiwang Tiehejin factory ,was built and put into operation in September 2001.

- 2003年，首台200MW直接空冷机组,在山西大唐云冈热电有限责任公司顺利建成投产。The first 200MW direct air cooling unit was successfully put into operation in 2003 in Shanxi, Datang Yungang Thermal Power Co. Ltd.

- 2004年10月，华能榆社投产了2×300MW亚临界直接空冷机组。2 x 300MW sub critical direct air cooling unit of Huaneng Yushe was put into operation in October,2004.

- 2005年4月，山西大同二电厂投产了2×600MW亚临界直接空冷机组。2 * 600MW sub critical direct air cooling unit of Shanxi Datong two power plant was put into operation in April 2005.

- 2008年6月，华能上安电厂投产了2×600MW超临界直接空冷机组。2 x 600MW supercritical direct air cooling unit of Huaneng Power Plant was put into operation in June 2008.

●2008年7月，我国自主设计、制造和安装的国内首台60MW亚临界直接空冷机组，在通辽发电厂建成投产。The first 600MW sub critical direct air cooling unit of China's own design, manufacturing and installation in Tongliao power plant was put into operation in July 2008.

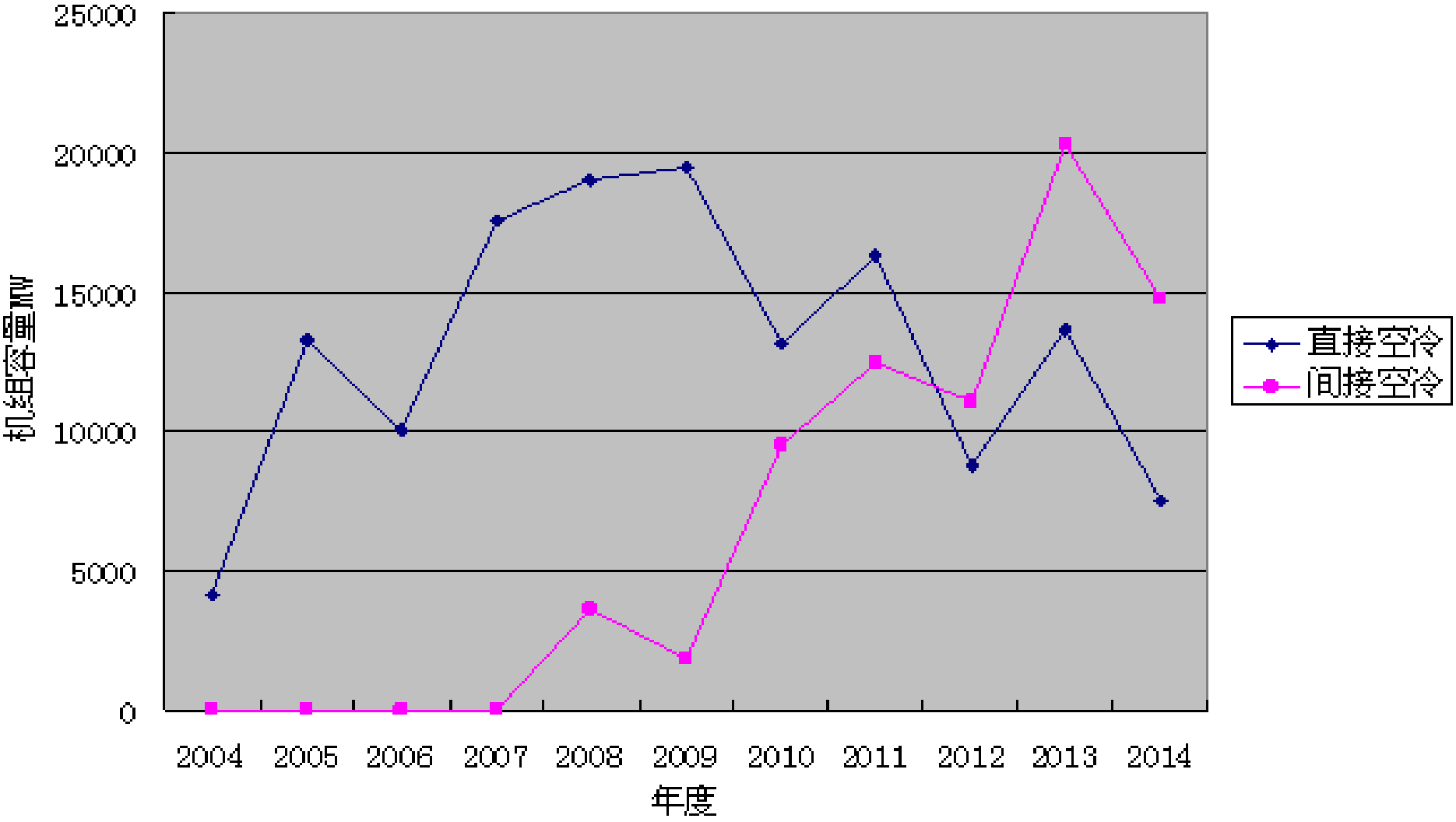
- 2010年12月，华电灵武电厂投产了2×1000MW超超临界直接空冷机组。 2 x 1000MW ultra supercritical direct air cooling unit of Huadian Lingwu power plant was put into operation in December 2010.

●截止至2014年末，国内投产的直接、间接空冷机组容量见下表。As of the end of 2014, the capacity of direct and indirect air cooling units in china as follows:

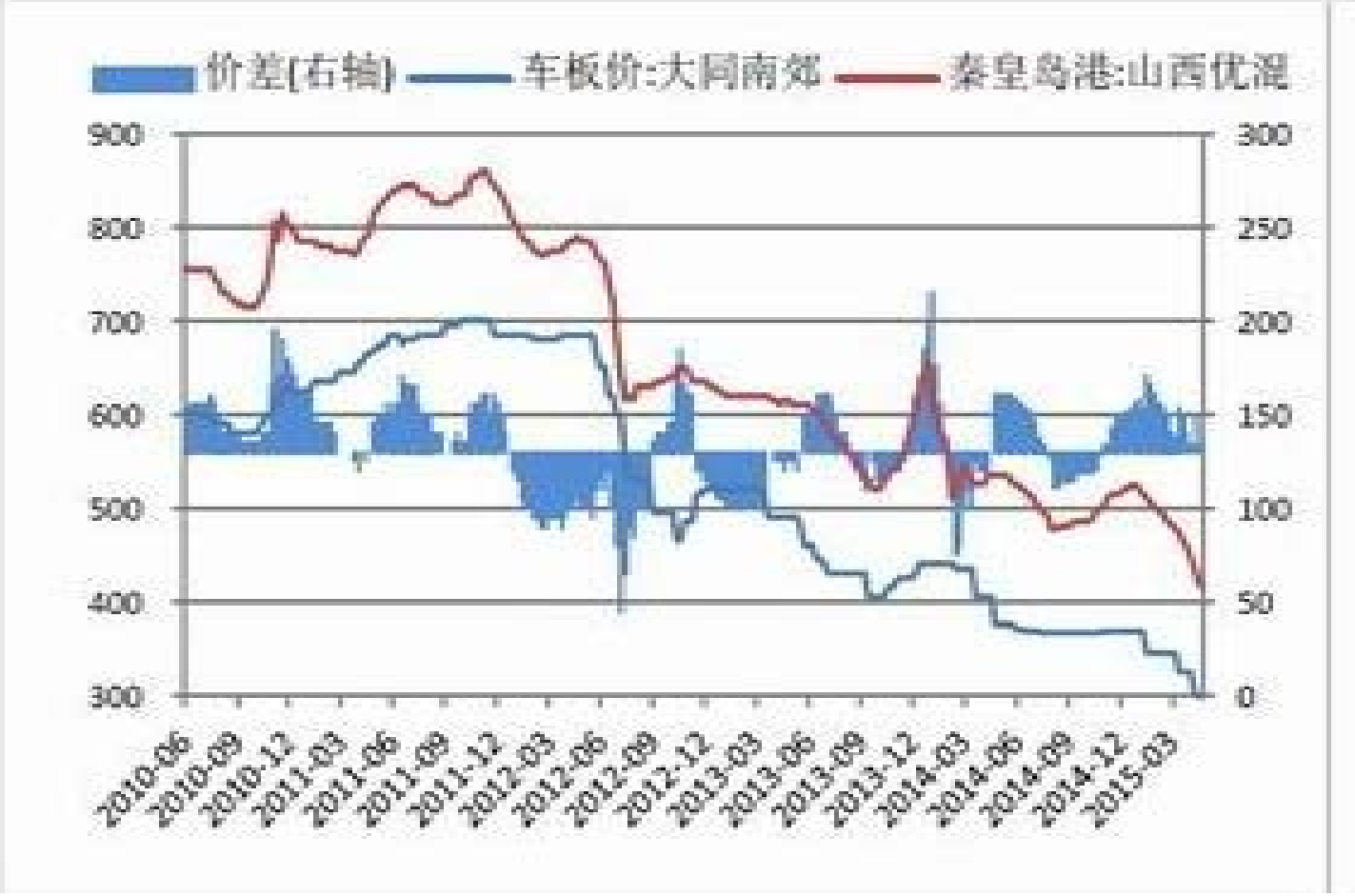
年　份 year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	合 计 Toal
当年建设机组容量 construction units capacity（MW）	4110	13310	10000	17550	22650	22540	22650	28755	19837	33905	22265	200152
直接空冷机组容量（MW） Direct air cooling units capacity (MW)	4110	13310	10000	17550	19050	19480	13125	16270	8750	13630	7520	125375
直接空冷机组比例（%） Proportion of direct air cooling units (%)	100.00	100.00	100.00	100.00	84.11	86.42	57.95	56.58	44.11	40.20	33.77	62.64
间接空冷机组容量（MW） Indirect air cooling units capacity (MW)	0	0	0	0	3600	1860	9525	12485	11087	20275	14745	74777
间接空冷机组比例（%） proportion of indirect air cooling units (%)	0.00	0.00	0.00	0.00	15.89	8.25	42.05	43.42	55.89	59.80	66.23	37.36

- 按上表绘制曲线图如下：

Draw the chart based on the above form as follows:



●从上图可以看出，2009年我国的直接空冷电站建设达到高峰，此时已经投产的直接空冷机组陆续暴露出一些问题：如夏季运行背压高，抗大风能力较弱等，而此时国内动力煤价格处于高点，见下图：It could be seen from the above chart that China's direct air cooling units of power plant onstruction reached a peak in 2009. The direct air cooling units which had been put into operation gradually exposed some problems at that time: such as high operating pressure in summer, weakness of anti wind capability .But at the same time, the domestic steam coal price was at a high point, see the figures as below:



- 故运行费用相对较低，抗风能力较强的的间接空冷机组在国内逐步发展起来。

  Therefore, the indirect air cooling unit whose operating cost is relatively low, and the units with stronger wind-resistance capability have gradually developed in China.

3 我国直接空冷机组的运行情况

Operating conditions of direct air cooling units in China

- 截止到2014年末，全国投产及在建的300MW级以上的采用直接空冷电厂157座，其中投运的共114座电厂，600MW级以上电厂51座。按照中电联大机组对标报告，参加对标的600MW级以上空冷机组供电煤耗及耗水率平均值如下：

  More than 300 MW of the direct air cooling power plants in production and construction were 157 units until the end of 2014. There were 114 power plants in total which were put into operation, and more than 600 MW were 51 power plants. According to the electrical assembly unit benchmarking report, above 600 MW capacity air cooling units' coal consumption, power supply and water consumption are as follows:

3 我国直接空冷机组的运行情况
Operating conditions of direct air cooling units in China

600MW 级机组运行参数表（2012 年度平均值）

Form of operating parameters of the 600MW unitw (annual average in 2012)

项　　目 Item	统计台数（台） Statistical units (set)	供电煤耗（g/kWh)Coal consumption of power supply	厂用电率（%） Plant power consumption rate	耗水率（kg/kWh） Water consumption rate
超临界空冷机组 Supercritical air cooling unit	23	324.44	6.48	0.31
亚临界空冷机组 Subcritical air cooling unit	42	336.30	7.99	0.31
超临界水冷机组 Supercritical water cooled unit	126	305.27	4.64	1.12
亚临界水冷机组 Subcritical water cooling unit	72	316.29	5.35	1.31

注：其中直接空冷机组 60 台，间接空冷机组 5 台。

Note: The direct air cooling unit are 60 sets,and indirect air cooling unit are 5 sets.

600MW 级湿冷机组平均耗水率表

600MW wet cooling units average water consumption rate

序　号 Order number	分类条件 Classification condition	统计台数（台） Statistical units (set)	耗水率（kg/kWh）Water consumption rate
1	闭式循环 Closed cycle	120	1.96
2	开式循环 Open cycle	115	0.43

■参加对标的300MW级以上空冷机组供电煤耗及耗水率平均值如下：Air cooling units above 300MW electricity consumption and water consumption rate of the average values as follows:

参加对标的 300MW 级以上空冷机组供电煤耗及耗水率平均值如下：
Air cooling units above 300MW electricity consumption and water consumption rate of the average values as follows:

300MW 级机组运行参数表（2011 年度平均值）
Table of operating parameters of the 300MW unit (2011 Annual Average)

项　　目	统计台数（台）Statistical units (set)	供电煤耗（g/kWh）Coal consumption of power supply	厂用电率（%）Plant power consumption rate	耗水率（kg/kWh）Water consumption rate (kg/kWh)
空冷机组 Air cooling unit	27	340.78	7.65	0.35
水冷机组 Water cooling unit	209	331.09	6.00	1.73

300MW 级湿冷机组平均耗水率表 300MW wet cooling units average water consumption rate

序　号	分类条件 Classification condition	统计台数（台）Statistical units (set)	耗水率（kg/kWh）Water consumption rate (kg/kWh)
1	闭式循环 Closed cycle	201	2.14
2	开式循环 Open cycle	142	0.79

■按照上面统计的数据折算，一台600MW机组每年的耗煤量和耗水量如下：

According to the above statistics of data , one 600MW unit are as follows:

600MW 级机组年耗煤量和耗水量（按年利用 4500 小时计算）

600MW unit annual consumption of coal consumption and water consumption(4500 h)

机组型式 Unit type	机组容量（MW）capcity	年发电量（×10⁴kWh）annual power supply	年耗标煤煤量（×10⁴t）coal consumption	年耗水量（×10⁴t）water consumption
超临界空冷 Supercritical air cooling unit	660	297000	90.10	92.07
超临界湿冷 Supercritical water cooling unit	660	297000	86.50	537.57
空冷机组增加值 Increased value of air cooling unit			3.66	-445.50
亚临界空冷 Subcritical air cooling unit	600	270000	83.50	83.70
亚临界湿冷 Subcritical water cooling unit	600	270000	80.80	569.70
空冷机组增加值 Increased value of air cooling unit			2.72	-486.00

4 我国直接空冷技术的发展成果

The development of direct air cooling technology in China

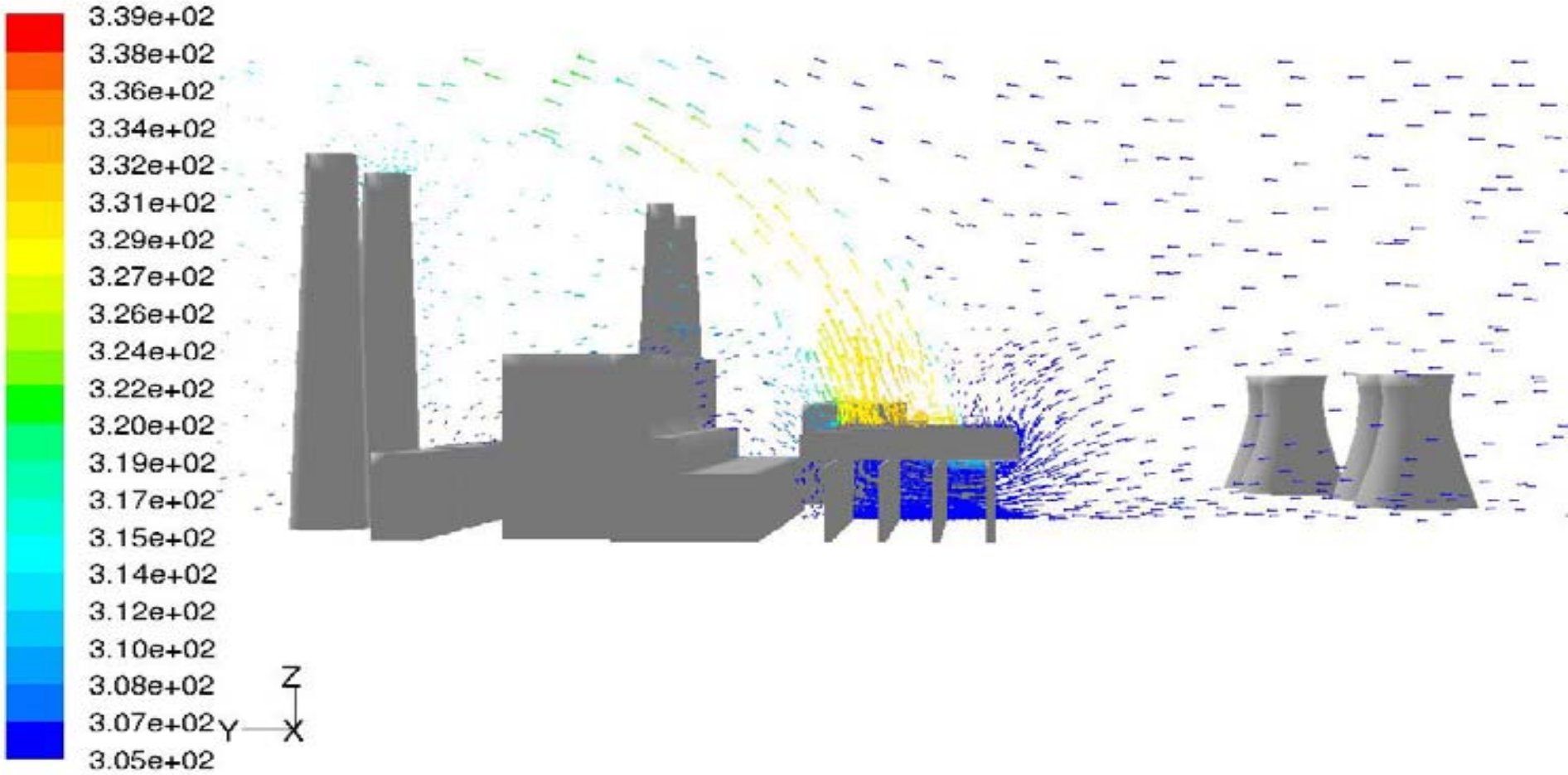
4 我国直接空冷技术的发展成果

The development of direct air cooling technology in China

- 2004年开始，依托于通辽发电厂600MW亚临界直接空冷机组项目，我国开始了直接空冷系统的自主设计。主要进行了以下研究项目：Relying on the 600MW sub critical direct air cooling unit in Tongliao power plant , China began to design the direct air cooling system. It mainly carried out the following research projects:

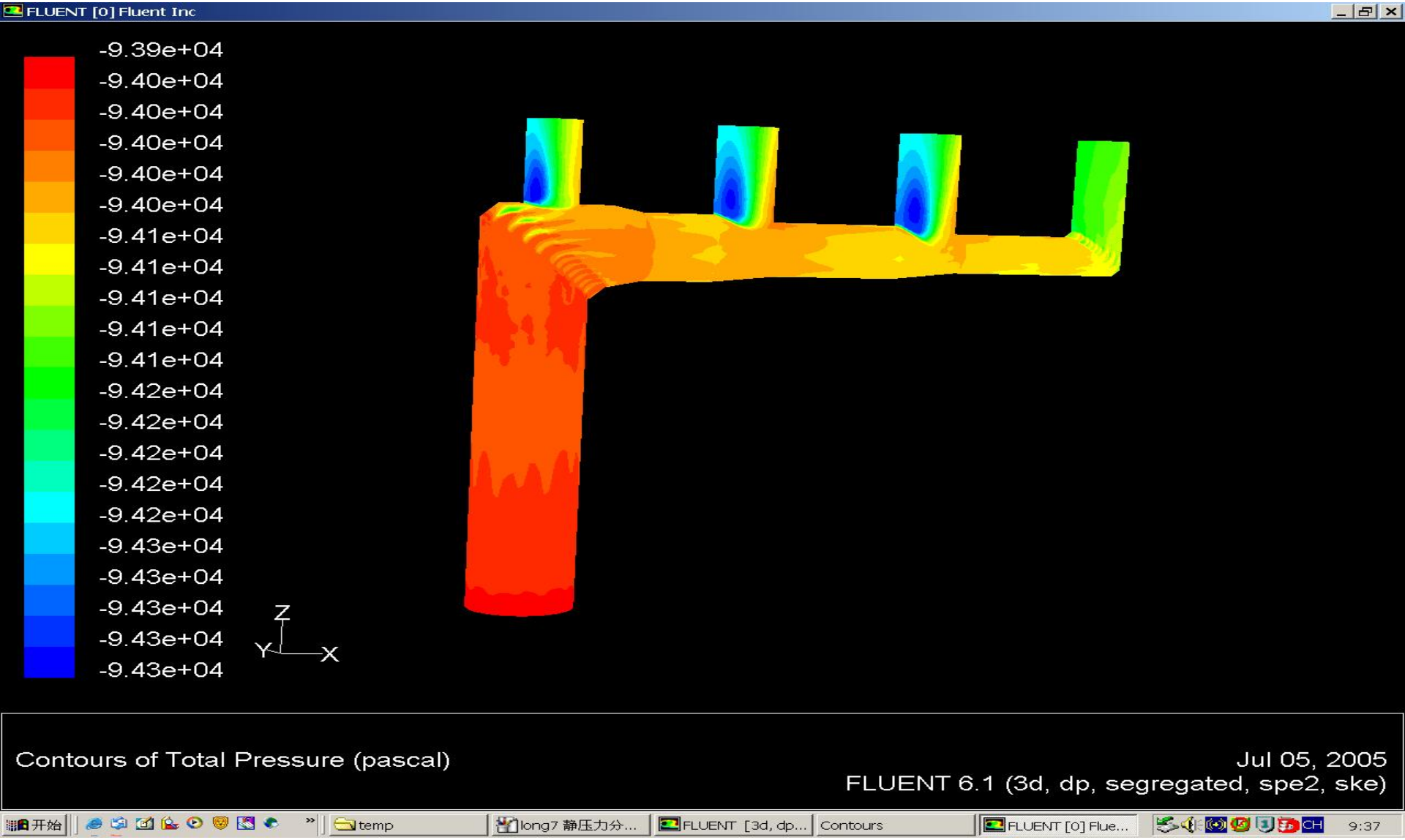
1. 《直接空冷系统优化设计技术研究》《direct air cooling system optimization design and technology research》包括：空冷系统设计气温的确定；直接空冷系统热力计算、空气阻力的计算和优化计算方法的确定；环境风对空冷凝汽器系统性能的影响。Including: Determination of air cooling system design temperature;Determination of thermodynamic calculation of direct air cooling system, air resistance calculation and optimization calculation method; environmental wind effects on the cooling condenser system performance.
2. 《直接空冷排汽管道设计技术研究》《Research on design and technology of direct air cooling exhausted steam pipe》主要是大直径薄壁负压排汽管道的设计。Design of large diameter and thin wall negative pressure exhausted steam pipe.
3. 《空冷凝汽器支撑结构设计技术研究》《Research on design and technology of supporting structure for air cooling condenser》包括：钢筋混凝土环形柱的斜截面抗剪；风机扰力对平台结构的振动影响；平台结构的整体抗震性能问题；桁架节点的受力性能问题。Including: the diagonal section of reinforced concrete circular column, the influence of the wind disturbance force on the vibration of the platform structure, the overall seismic performance of the platform structure, the mechanical performance of the truss joints.
4. 《超临界空冷机组凝结水系统设计研究》《Design of condensate system for super critical air cooling unit》主要是凝结水精处理用离子交换树脂的选型。Selection of ion exchange resin for the treatment of condensate water.

1.环境风对直接空冷系统影响和空冷凝汽器布置的数模试验 Simulator test regarding the effect of ambient air on the direct air cooling system and the layout of air cooling condenser.

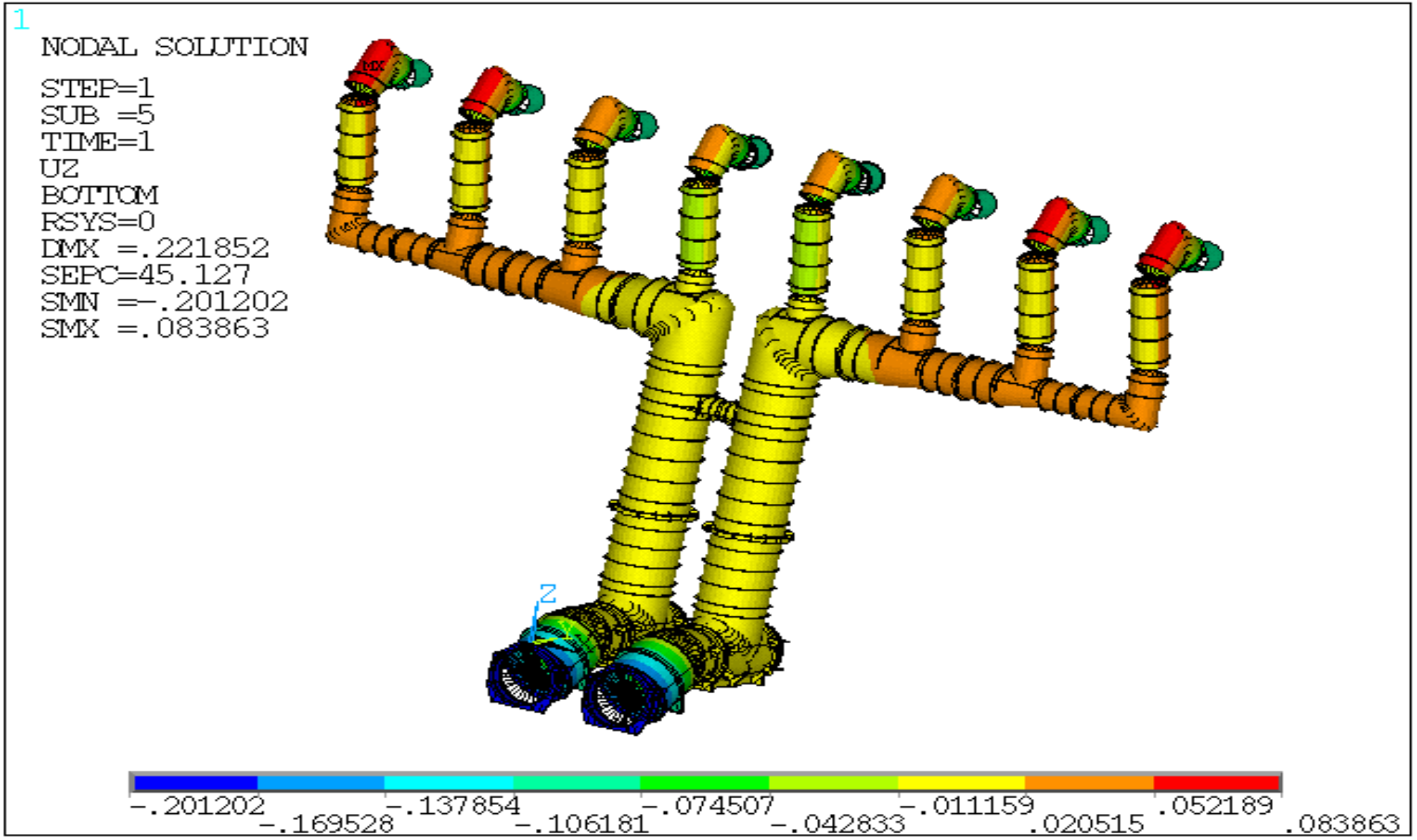


2. 空冷系统风洞模拟实验 Wind tunnel simulation experiment of air cooling system .

3. 排汽管道内的流体特性进行数学和物理模型试验 Mathematical and physical model tests of the characteristics of the fluid in steam exhausted pipes .

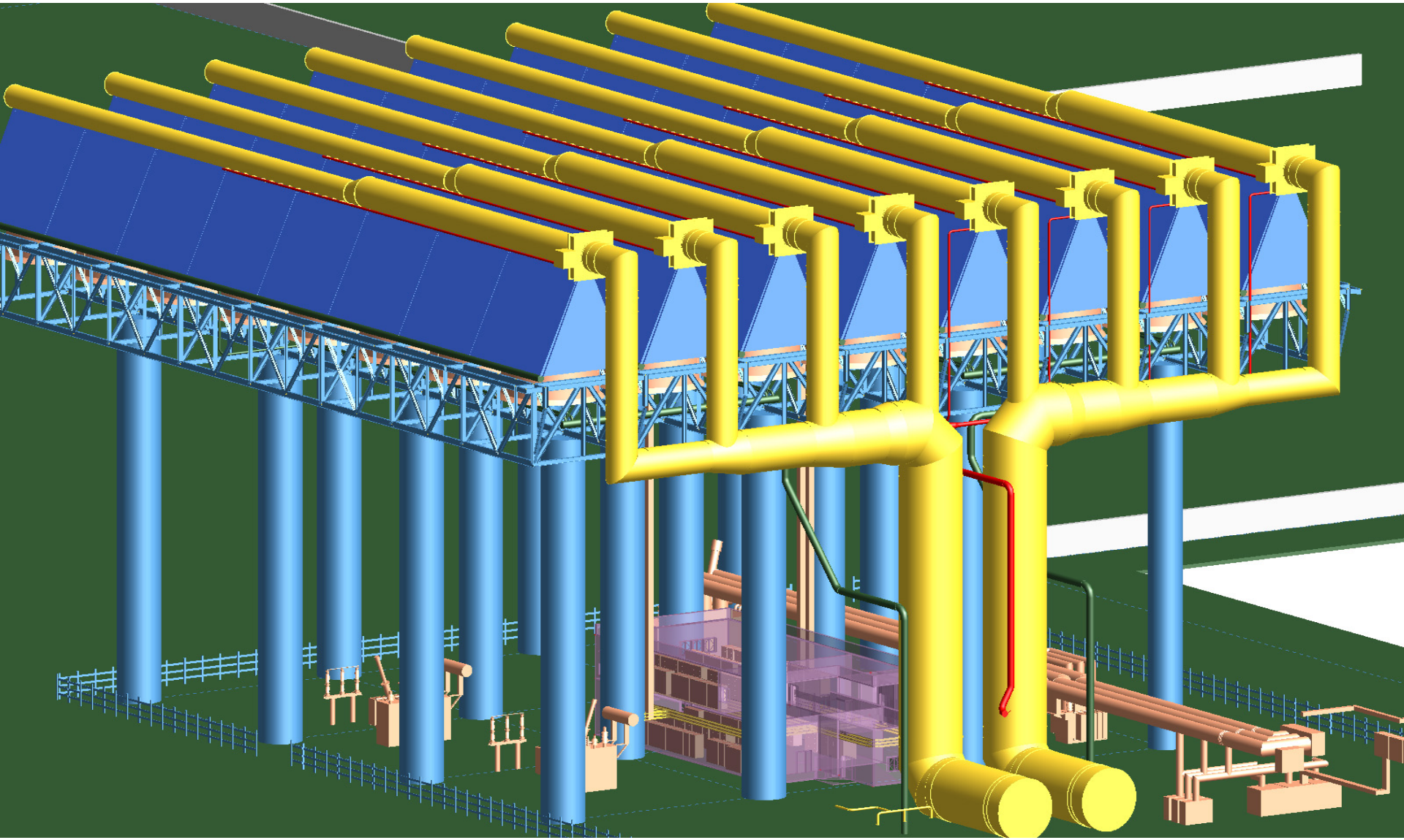


4. 空冷岛管件系统结构强度的有限元分析 Finite element analysis of structural strength of air cooling unit’s pipe system .



5. 空气冷凝器支架结构大模型试验 Large model test of air condenser bracket structure.

- 形成了具有自主知识产权的直接空冷系统设计 Design of direct air cooling system with independent intellectual property rights.



空冷岛三维视图1 Air cooling island in 3D views 1

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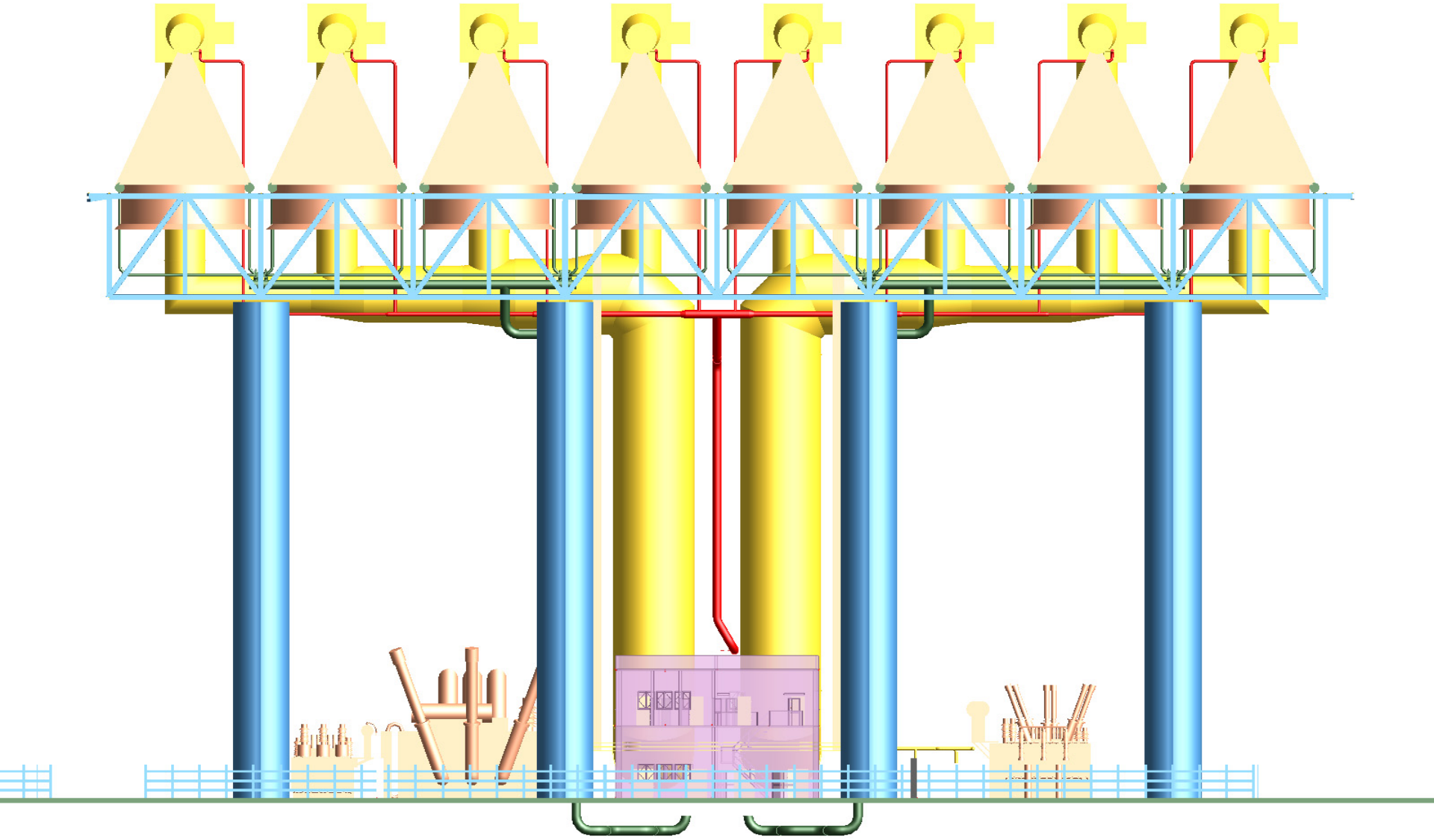

空冷岛三维视图2 Air cooling island in 3D views 2

- 并在总结各方面经验教训的同时，形成了一系列的标准和规范： Formulate a series of standards and codes by summing up the experience and lessons in all aspects:

1. 《火力发电厂直接空冷系统设计技术规程》《Technical specification for design of direct air cooling system of thermal power plant》
2. 《直接空冷系统性能试验规程》（DL/T 244-2012）《Direct air cooling system performance test code》(244-2012 DL/T)
3. 《直接空冷系统验收导则》电力行业标准《Direct air cooling system acceptance guide》electric power industry standard
4. 《直接空冷机组真空严密性试验方法》(DL/T 1290-2013)《Direct air cooling unit vacuum tightness test method》(DL/T 1290-2013)
5. 《火力发电厂直接空冷系统运行导则》《Guide for operation of direct air cooling system of thermal power plant》
6. 《发电厂直接空冷凝汽器单排管管束》《Single row tube bundle of power plant direct air cooled condenser》
7. 《火力发电厂空冷岛排汽管道施工及验收标准》《Standard for construction and acceptance of exhausted steam pipe for power plant air cooling island 》
8. 《火力发电厂空冷岛钢结构施工及验收标准》《Standard for construction and acceptance of steel structure for power plant air cooling island》
9. 《电站空冷风机》《Power station air cooling fan》

- 对直接空冷系统的各个方面进行规范。Specification for all aspects of the direct air cooling system.

5 直接空冷主要设备情况
Main Equipments of ACC

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Main Equipments of ACC

- **直接空冷汽轮机Direct air cooling steam turbine**

  我国的直接空冷汽轮机是在湿冷汽轮机的基础上发展起来的，空冷汽轮机的问题焦点在于低背压（高负荷能力）下经济性与高背压极小容积流量下的安全可靠性问题，前者允许但不经济；后者不允许出现。主要体现在：The direct air cooling steam turbine is developed on the basis of wet steam turbine.Air cooling steam turbine focus economy under the low pressure (high load capacity) and safety and reliability under high pressure and minimum volume flow rate. The former allows but not economic; the latter is not allowed to appear. Main reasons as follows:

1. **运行工况随环境气温变化较频繁 The operating conditions changes frequently with the ambient air temperature.**
2. **实际运行中容易在不同负荷下出现高背压 The high pressure can easily happen under different loads in the actual operation .**
3. **异常情况如夏季最高温度时如甩负荷、而部分空冷风机损坏，此时最高气温再加上100%甩负荷旁路、风机损坏等条件下确定的最高背压，可达75kPa-85kPa，必然进入鼓风发热工况而引起机组跳闸。Abnormal situation such as load shedding under the highest summer temperature, and some damaged air cooling fans. At this time,,maximum pressure can reach up to 75kPa-85kPa under the condition of the highest temperature plus 100% shedding load bypass and damaged fans. The breakers will definitely stop because of blower overheat.**

- 国内主要汽轮机厂家有针对性的，分别开发出有各自特点的空冷汽轮机：

The domestic main steam turbine manufacturers have specialized in developing the respective characteristics of the air cooling steam turbines:

哈汽	末级叶片长度（mm）terminal blade length	450	600	620	680	940	1100
	环形面积（m^2）circular area			4.52		8.33	
	适用机型（MW）application models	150MW等级 class	200MW等级 class	300~600MW等级 class	600MW	600~1000MW	1000MW
上汽	末级叶片长度（mm）terminal blade length	435	540	665	720	910	1050
	环形面积（m^2）circular area	2.42		4.43	6.0	7.60	9.2
	适用机型（MW）application models	135MW等级 class		300~600MW等级 class	600MW	600~1000MW	1000MW
东汽	末级叶片长度（mm）terminal blade length	410	658	661	770	863	1030
	环形面积（m^2）circular area	2.25	4.17	4.85	6.47	7.5	9.5
	适用机型（MW）application models	135MW等级 class	200MW等级 class	300~600MW等级 class	600MW	600~1000MW	1000MW

5 直接空冷主要设备情况
Main Equipments of ACC

- 直接空冷散热器 Direct air cooling condenser

空冷散热器是空冷电厂的关键设备之一，单排管散热器在国内直接空冷机组中应用最为广泛，国内制造厂均已研制成功，并有大量的供货业绩。Air cooling condenser is one of key equipments in power,single row tube condenseris most widely used in the direct air cooling unit. It has been researched and developed successfully and supplied a lot by domestic manufactures.

单排管钎焊设备 Single row brazed welding pipe device

管束自动焊接 Automatic welding tube

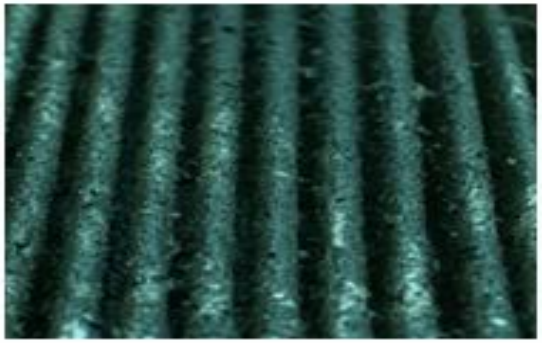
5 直接空冷主要设备情况
Main Equipments of ACC

- **大气沉积污垢对空冷设备传热影响试验Deposited fouling from air infulence on air cooling equipment heat transfering test**

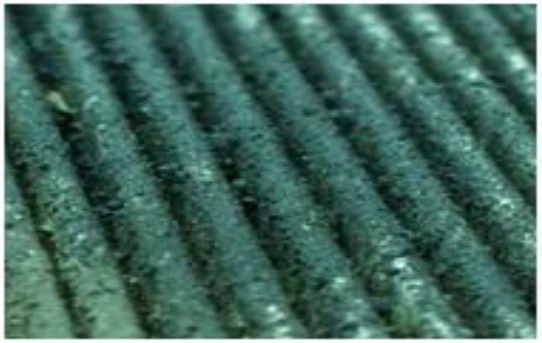
污垢厚度0.32～0.35mm

污垢厚度0.65～0.68mm

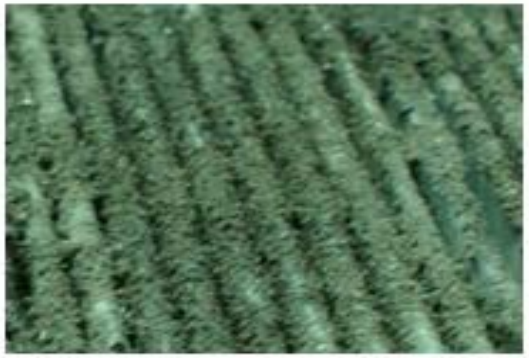
污垢厚度0.89～0.93mm



污垢厚度1.36～1.40mm



污垢厚度1.79～1.83mm



污垢厚度2.18～2.22mm

实验不同污垢厚度试验件

6 直接空冷系统发展趋势
Development tendency of direct air cooling system

6 直接空冷系统发展趋势
Development tendency of direct air cooling system

- 经过近十多年的摸索和总结，大家对直接空冷和间接空冷有了方方面面的认识，在今后的电站建设上，对冷却系统的采用上会更加理性；We know the direct air cooling and indirect air cooling with all aspects after nearly10 years of exploration and summary. We will be more rational on construction of power plants;
- 空冷系统节水性虽好，但煤耗较高，空冷汽轮机的各项参数将会进一步提高，供电煤耗进一步降低；Air cooling system is good at water saving, but it causes high coal consumption. Air cooling steam turbine parameters will be further improved, so the coal consumption is further reduced;
- 直接空冷散热器散热效率向更高的方向发展；Direct air cooling condenser cooling efficiency is developed towards a higher direction;
- 具有防大风能力的直接空冷系统更具有竞争能力；The direct air cooling system with the ability of anti wind is more competitive;
- 给水泵汽轮机与主机同轴驱动技术和汽动给水泵排汽直接进入主机空冷系统技术得到一定程度的应用； It has been applied at some points that water supply pump turbine, the main engine isometric drive technology, and the exhausted steam of water supply pump goes into the host air cooling system directly;
- 自然通风的直接空冷系统得到小规模应用。Direct air cooling system with natural ventilation is applied with small scale.

·谢谢各位领导和专家！

·THANK!

·不足之处请多提宝贵意见！