Effective approaches to designing systems fit for CCS in cement industry
适合于水泥行业CCS有效系统设计方法

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CCS introduction
CCS 介绍

The cement industry is one of the world's largest industrial sources of CO_2 emissions, accounting for 1.8 Gt/y in 2005.
水泥工业是世界上排放CO_2量最多的工业之一, 2005年共排放 1.8 Gt/y。

The cement industry represents a good opportunity for CCS, because cement plants are relatively large point sources of CO_2.

水泥厂为 CCS提供了一个很好的机会, 因为水泥厂有大量的CO_2释放出来。

CCS introduction
CCS 介绍

For 5000t/d cement plant, CO_2 emissions is 1.5 M t/y, over 60% of total CO_2 emissions are from mineral decomposition, which means CO_2 emissions is 832kg for 1 ton cement.

对一个**5000t/d**的水泥厂，其**CO_2**绝对排放量为每年**150**万吨，其中煅烧质排放**CO_2**占有**60%**，折合每吨熟料排放**CO_2 832**公斤。

2、*Effective approaches fit for CCS in cement industry*

适合于水泥行业CCS有效系统设计方法

2.1 introduction 介绍

1）This lecture summarises a study which assessed the technologies that could be used for CO_2 capture in cement plants, their costs, and barriers to their use. The work covered new-build cement plants with post-combustion and oxy-combustion CO_2 capture.

这里我们总结了用于水泥厂**CO_2捕集的技术方案评估，成本和可行性**。方案包括**富氧燃烧和燃烧后CO_2捕集。**

2）The basis of the study was a 5-stage preheater with precalciner dry process cement plant with a cement output of 1 Mt/y （2500t/d）.

研究是基于具有五级热器带分解炉的新型干法产量**1 Mt/y(2500t/d)**的生产线。

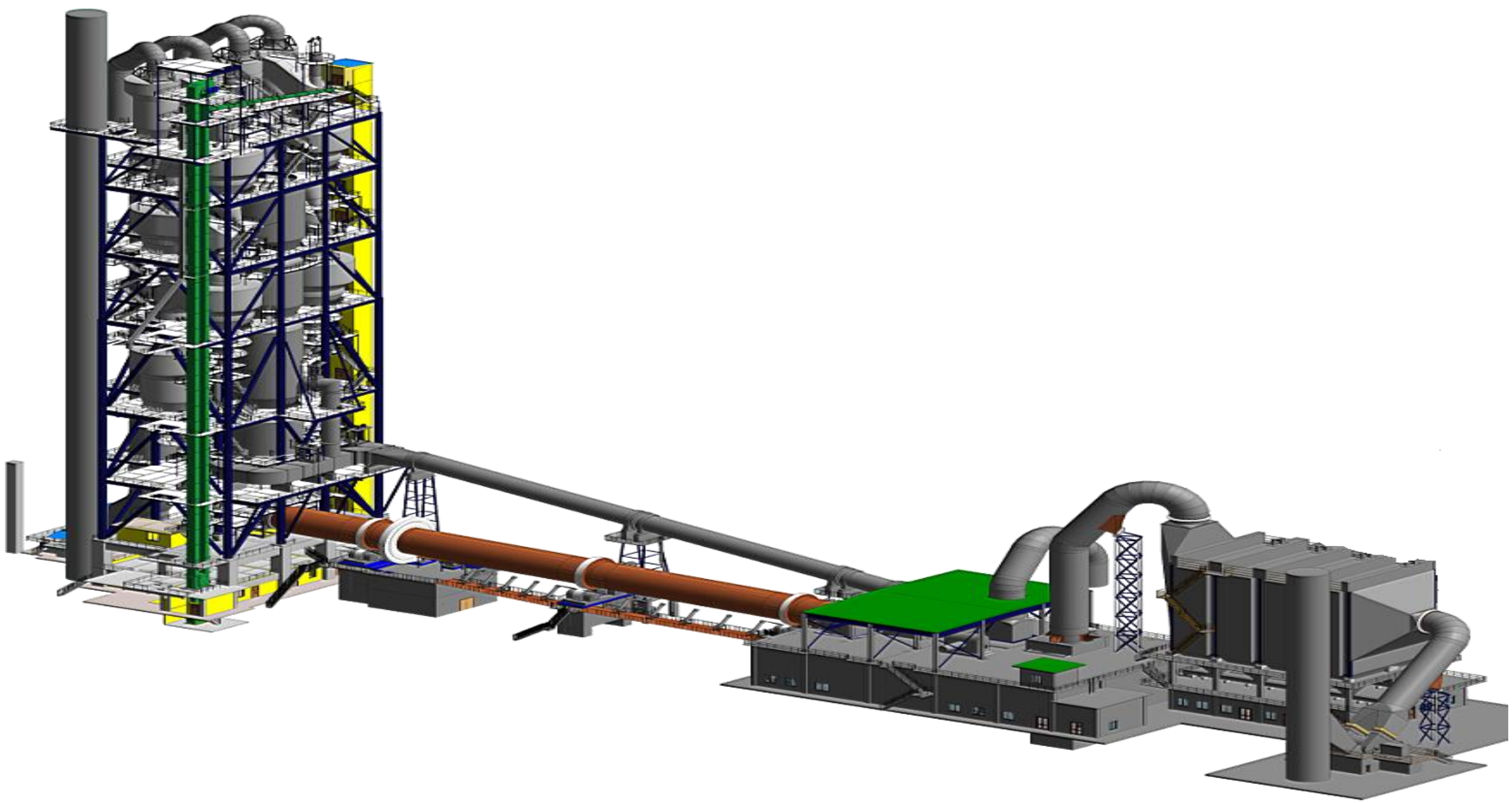


Fig1.Schematic of cement plant
水泥厂工业流程图

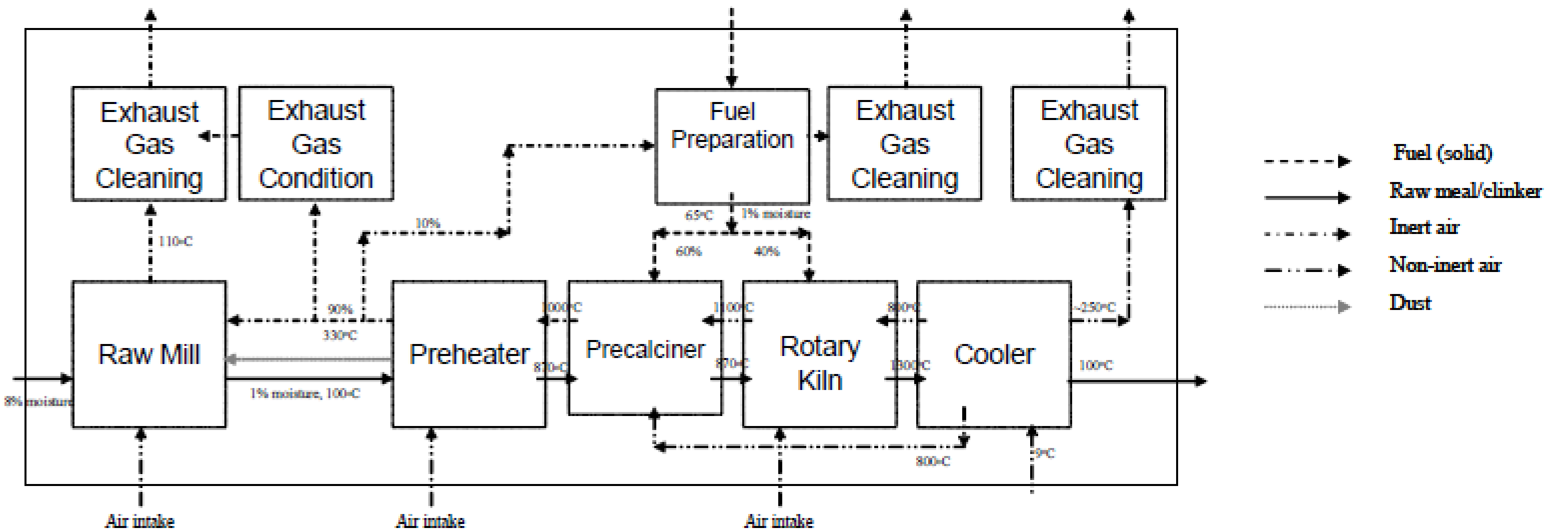


Fig2.Schematic of cement plant without CO2 capture
无 **CO2** 捕集的水泥厂工艺流程图

Additional downstream processes, not shown on Figure 1, include cement milling, packing and loading.
上述图中不包括水泥粉磨，包装和输送

2.2 Common issues relating to the addition of CO_2 capture to a cement plant 水泥厂涉及到 CO_2 捕集的通常问题

1）Additional Power Requirements：There will be additional power requirements for the operation of the post-combustion capture plant and the CO_2 compression plant.

额外的电力要求：燃烧后捕集和CO_2压缩技术需要额外的电力，用作CO_2压缩之用。

2）**Heat Integration**： Although the cement process has been highly optimised already, both post-combustion and oxy-combustion capture offer potential opportunities to maximise performance through heat recovery from the CO_2 compression system.

热集成：虽然水泥厂过程已经高度优化，但是燃烧后捕集和富氧燃烧仍然存在着很大的机会通过余热回收来最大限度的降低CCS系统能耗。

2.2 Common issues relating to the addition of CO_2 capture to a cement plant
水泥厂涉及到 CO_2 捕集的通常问题

3）Gas pretreatment： The existence of acid gas SO_2、NO_x、HCl in the fuel gas are likely to reduce the absorption efficiency, therefore need a series of pretreatment process(dust removal, desulfurization, denitrification).

烟气预处理：烟气中的**SO_2、NOX、HCl等任何酸性气体的存在都有可能降低吸收的效率**，因此烟气需要经过除尘、脱硫、脱硝等预处理过程。

2.3水泥厂用后燃烧 CO2 捕集的工艺流程图

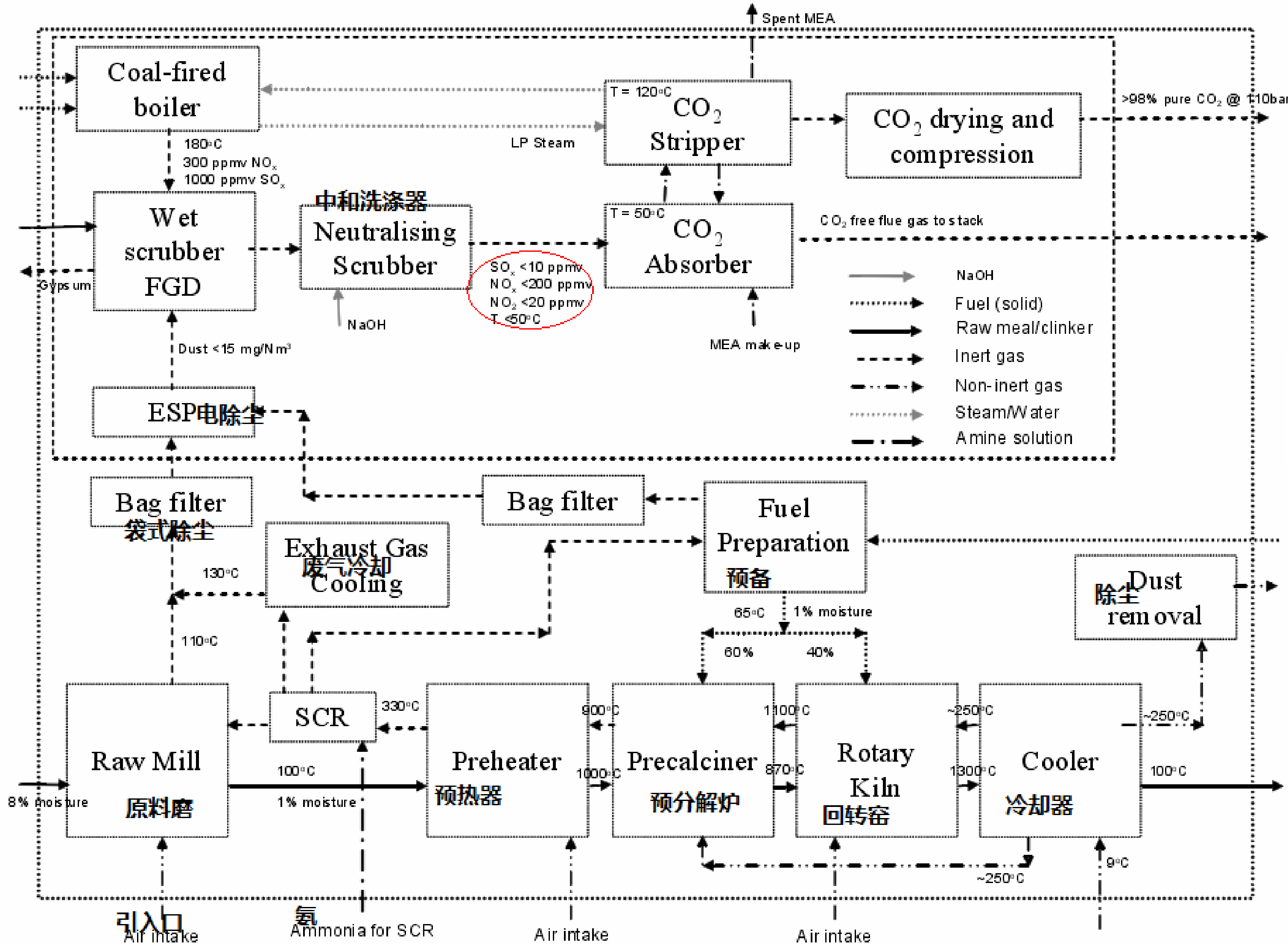


Figure 3 Schematic of cement plant with post-combustion CO2 capture

2.4 key features that distinguish the process from a conventional cement plant.
与传统的水泥厂区分5个关键特征

1）An SCR unit is fitted between the preheater and the raw mill for NOx abatement.
脱硝（**SCR**）单元被设置在预热器和原料磨之间来脱除**NOx**。

2） A wet limestone FGD unit is fitted to remove SOx from the flue gas stream.
湿式石灰石脱硫单元被设置来脱除烟气中的**SOx**。

3） CO2 capture equipment based on MEA amine solvent separation is installed.
CO2捕集系统用MEA溶液吸收系统。

2.4 key features that distinguish the process from a conventional cement plant.
与传统的水泥厂区分5个关键特征

4）A coal-fired CHP plant is installed to generate the low pressure steam for MEA stripping and to provide the additional electrical power for the operation of the amine absorption and the compressor plant.

设置热电联产装置，因为CO_2捕集需要低压蒸汽进行胺类的解析和CO_2压缩之用。

5）The net CO_2 product is compressed, dried and further compressed to pipeline pressures of 110 bara.

CO_2净产品被压缩，干燥并进一步压缩到管道输送压力，也就是110bar。

2.5 Cement Plant With Oxy-combustion CO2 Capture
水泥厂用富氧燃烧 捕集CO2的工艺流程图

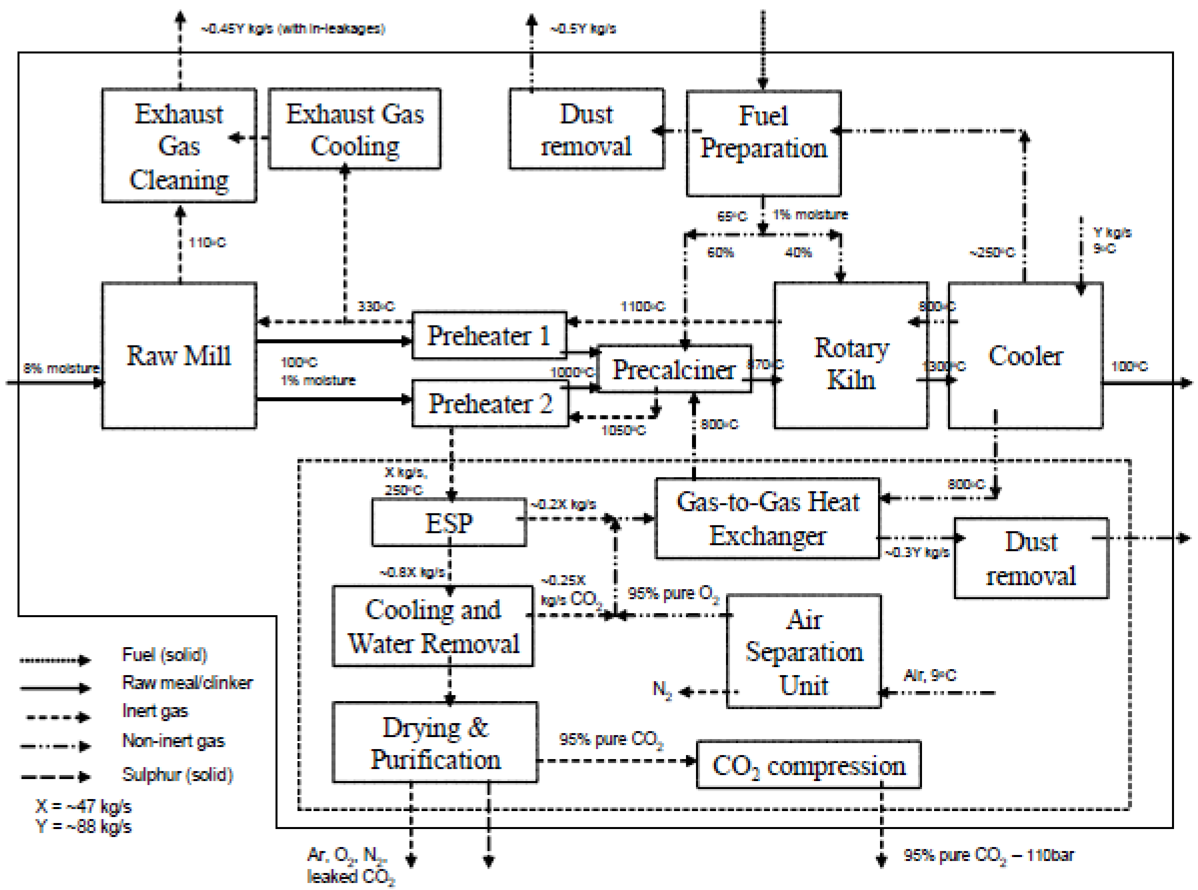


Figure 4 Schematic of cement plant with oxy-combustion CO2 capture

水泥厂用富氧燃烧 捕集CO2的工艺流程图

2.6 Performance With and Without CO2 Capture
水泥厂有无CO2捕集性能分析

Table 1 Summary of Cement Plant Performance With and Without CO_2 Capture

	Unit	Base case (no capture)	Post combustion capture	Oxy-combustion
Fuel and power				
Coal feed 给煤	kt/y	63.3	291.6	72.1
Petroleum coke feed 石油焦炭进料	kt/y	32.9	32.9	27.1
Total fuel consumption (LHV basis) 总油耗	MW	96.8	304.0	97.8
Average power consumption 平均单位电耗	MW	10.2	42.1	22.7
Average on-site power generation 平均发电量	MW	-	45.0	0.7
Average net power consumption 平均净功耗	MW	10.2	-2.9	22.0
CO_2 emitted and captured				
CO_2 captured 捕集量	kt/y	-	1067.7	465.0
CO_2 emitted on-site 现场排放量	kt/y	728.4	188.4	282.9
CO_2 emissions avoided at the cement	kt/y	-	540.0[a]	445.6[a]
Plant 水泥厂减排量	%	-	74	61
CO_2 associated with power import/export CO2净排放量与电力输入/出	kt/y	42.0	-11.8	90.8
Overall net CO_2 emissions	kt/y	770.4	176.6	373.7
CO_2 emissions avoided, including power	kt/y	-	593.8	396.8
import and export CO2减排量，包括电力输入/出	%	-	77	52

[a] The CO_2 emissions avoided are the emissions of the base case plant without capture minus the emissions of the plant with CO_2 capture.

2.7 Costs With and Without CO2 Capture
水泥厂有无CO2捕集成本分析

Table 2 Summary of Cement Plant Costs With and Without CO_2 Capture

	Unit	Base case (no capture)	Post combustion capture	Oxy-combustion
Capital cost[a] 资本成本	€M	263	558	327
Operating costs 经营成本				
Fuel 燃料	€M/y	6.7	21.5	6.9
Power 电力	€M/y	4.0	-1.1	8.7
Other variable operating costs 其他变动经营成本	€M/y	6.1	10.6	6.4
Fixed operating costs 固定经营成本	€M/y	19.1	35.3	22.8
Capital charges 资本支出	€M/y	29.7	63.1	36.9
Total costs 总成本	€M/y	65.6	129.4	81.6
Cement production cost 水泥生产成本	€/t	65.6	129.4	81.6
CO_2 abatement costs CO2吸收成本				
Cost per tonne of cement product 每吨水泥产品的成本	€/t	-	63.8	16.0
Cost per tonne of CO_2 captured 捕获每吨CO2的成本	€/t	-	59.6	34.3
Cost per tonne of CO_2 emissions avoided 每吨CO2减排成本	€/t	-	107.4	40.2

[a] Note that the capital costs include miscellaneous owners' costs but exclude interest during construction, although this is taken into account in the calculation of overall production costs.

需要注意的是，资本成本包括各样业主的成本，但不包括建设期利息，虽然这是考虑到在整体生产成本的计算

2.8 conclusions 结论

1) Oxy-combustion offers the lowest cost solution for CO2 capture at new-build cement plants but research and development is needed to address a number of technical issues to enable this technique to be deployed.
在新建的水泥厂中富氧燃烧是二氧化碳捕集成本最低的解决方案，但研究和开发需要解决一系列的技术问题，使得这项技术难以推行。

2) Costs are estimated to be €40/tonne of CO2 avoided for a 1Mt/y(2500t/d) cement plant with oxy-combustion， while €107/t with post combustion.
对**2500t/d**水泥厂，富氧燃烧**CO2**的捕集成本是**40€/t**，而后燃烧成本将增加，是**€107/t** 。

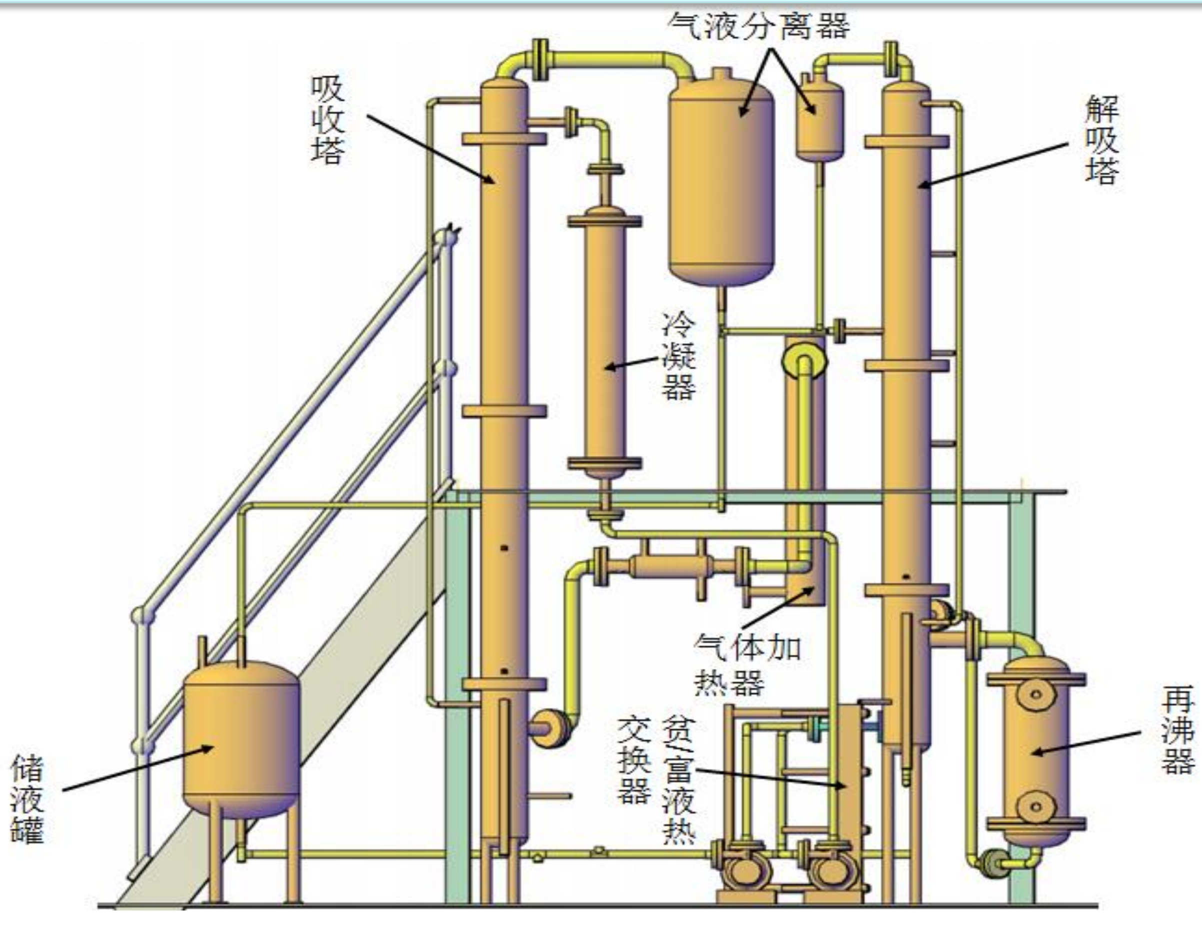
3) The cost of CO2 capture at a cement plant using oxy-combustion is expected to be similar to the cost at a typical coal-fired power plant. The quantity of oxygen required per tonne of CO2 captured is about three times lower at a cement plant but the economies of scale are less favourable.
水泥厂使用富氧燃烧二氧化碳捕集的成本预计将类似于一个典型的燃煤电厂的**CO2**捕集成本。在水泥厂，捕捉每吨**CO2**所需的氧气量大约低**3**倍，但是对规模经济是不太有利的。

2.8 conclusions 结论

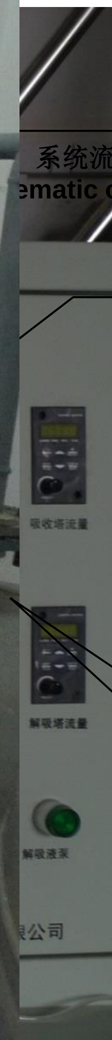
4) The cost of postcombustion capture at a cement plant is expected to be substantially higher than at a power plant, mainly because of lower economies of scale and the need to install FGD, NOx reduction and steam generating plant.

水泥厂燃烧后捕获的成本预计将高于电厂，这主要是因为较低的规模经济和需要安装烟气脱硫装置，减少氮氧化物和蒸汽发生装置。

3、*Cooperation with Tianjin University*
与天津大学合作



Schematic of CO2 capture in Tianjin University's lab
CO2分离提纯实验室装置系统图



系统流程图
ematic of process

数据采集控制系统
Data collection system

导热油加热系统
Heat conduction oil system

4、*Next step*
下一步计划

1.Improve the existing chemical absorption CO_2 capture system to establish the experimental device that suit to our requirement.

对现有化学吸收法捕集CO2的实验系统进行改造，建立适合我们课题要求的实验装置。

2.Study the influence of the solvent component (MEA, DEA, MDEA and their mixtures) on the CO_2 absorption for cement kiln gas, to choose the optimal solvent.

研究吸收剂的成分（**MEA、DEA、MDEA及其混合液**）对水泥窑混合气体中**CO2**吸收效果的影响，进而确定最佳的吸收剂。

4、*Next step*
下一步计划

3. Investigate the dynamic performance of the assisted heat source (including solar energy and industrial waste heat), the impact of the variation of the assisted heat source on the absorption and desorption efficiency, therefore to determine the optimal coupling mode.

研究辅助热源的动态响应特性（包括太阳能和工厂余热），研究辅助热源的变化对吸收与解吸效率的影响，进而确定最佳的辅助热源的耦合方式。

Thank you!