CFB combustion and coal slurry gasification

Yue Guangxi
Academician of Chinese Academic Engineering
Professor Tsinghua University

清華大學
Tsinghua University

1 background

2 R&D of circulating fluidized bed combustion (CFB) in Tsinghua

- reconstructing the design theory of CFB combustion
- the scaling of CFB boiler
- update of supercritical CFB
- the optimization of fluidization status in CFB

3 R&D of gasification in Tsinghua

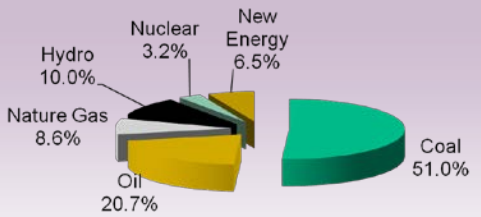
4 remarks

Background

Coal is the major resource of energy in china. Clean coal technology is the most important issue for environment.

Tsinghua is the top engineering school in China. He should be playing as the pioneer on clean coal.

Tsinghua has been cooperating with Chinese energy industry to develop advanced clean coal technology for the past 30 years, especially for circulating fluidized bed (CFB) coal combustion and coal gasification.

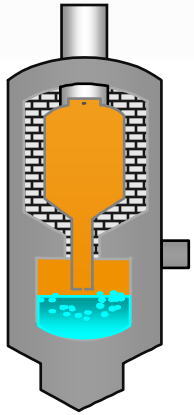


Clean coal is the top issue in China

CFB combustion

Wide fuel flexibility
In furnace de-SOx
Low Nox emission

coal gasification



H2, CO resources for oil refinery and coal chemistry

R&D of CFB in Tsinghua

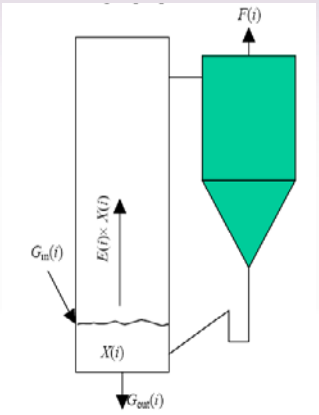
The investigation on the Design theory of CFB combustion

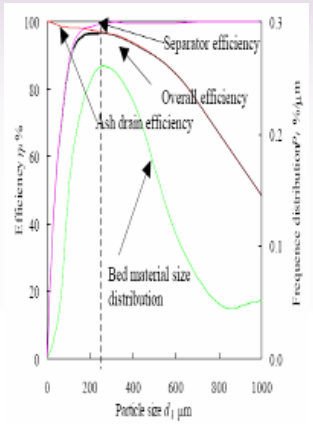
(1) Two phase flow in CFB

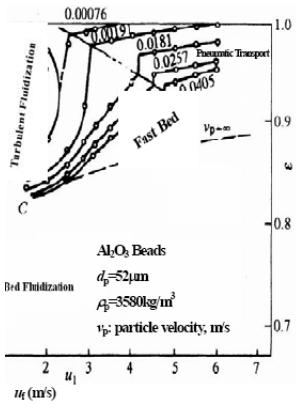
CFB coal combustion process is the multi- size particles open loop system

The fluidization state in CFB furnace is the combination of bubbling bed at bottom, and the fast bed at upper portion.

The fast bed can be multi status depends on the Vg and Gs.







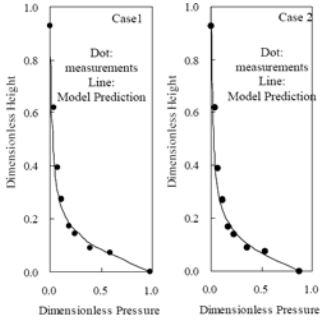


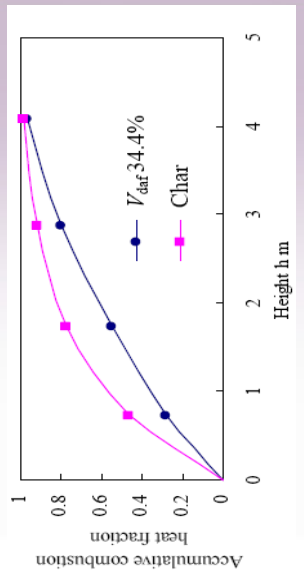
Figure 6 Comparison of model prediction on the pressure drop profiles along the furnace height with the data measured in the field for a 250MWe CFB

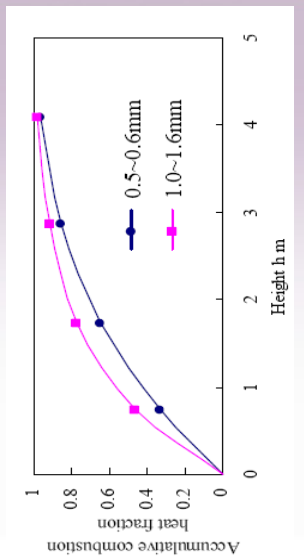
(2) CFB combustion

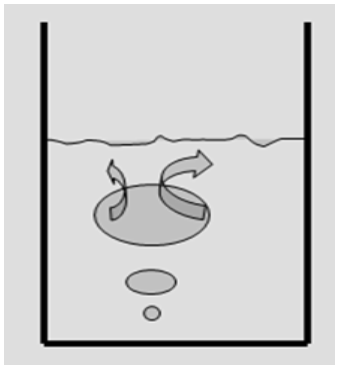
The concept of fractional heat releasing distribution along the furnace height.

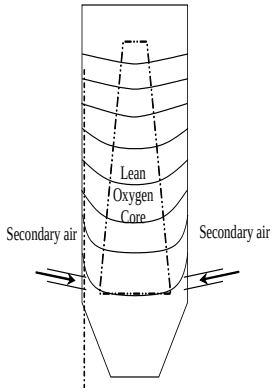
The strong impact of gas diffusion between bubbling phase and emulsion phase on the combustion in dense bed.

The impact of gas mixing on the combustion in furnace.









(3) Heat transfer in CFB furnace

build the correlation of heat transfer coefficient with bulk density in furnace.
Determine the heat flux distribution along the height and width of furnace by field tests

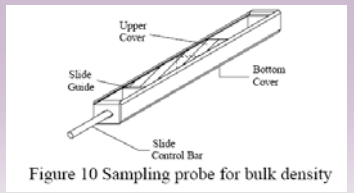
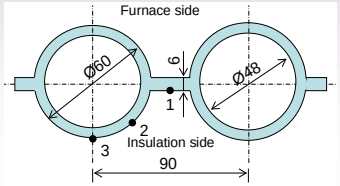
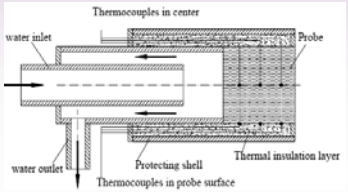
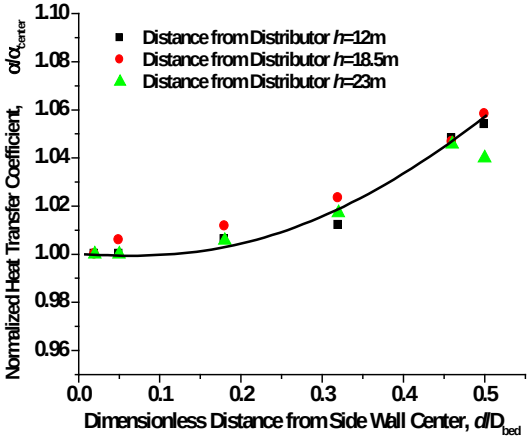
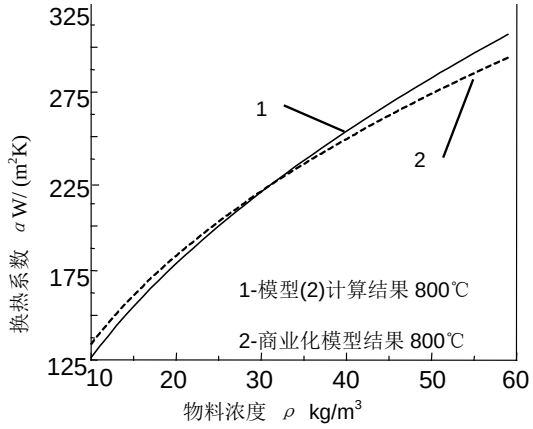


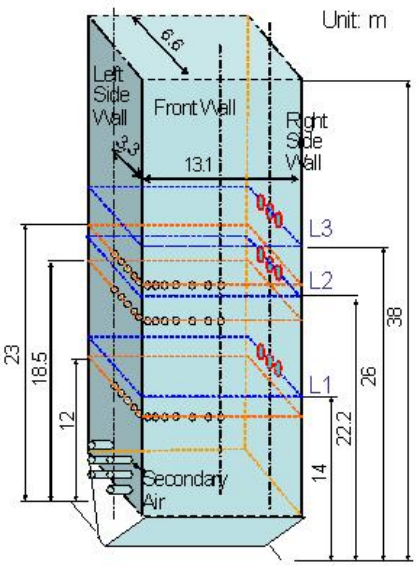
Figure 10 Sampling probe for bulk density







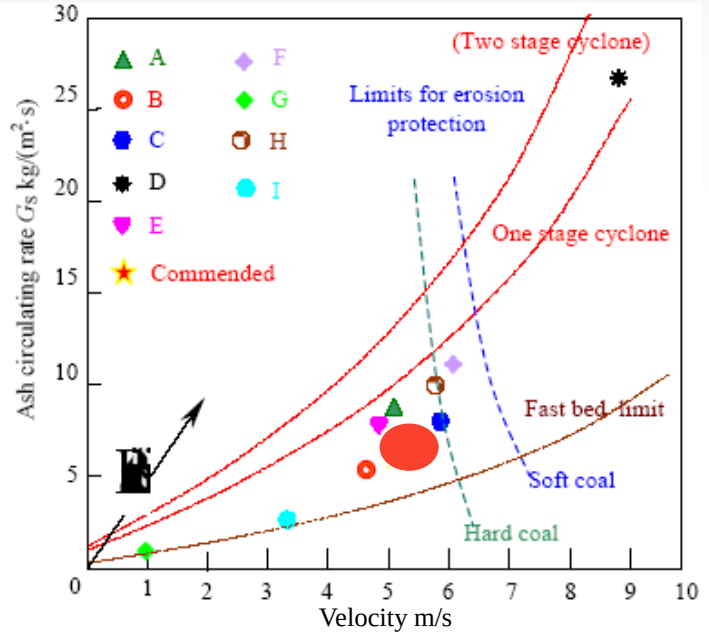




(4) From design theory to design code

Process design guide line in CFB---- CFB fluidization status map (published in 2006)

The fast bed status in CFB is specified by Vg and Gs.
All CFB technologies in the world can be shown in one map.
The status is within a narrow area defined by solids balance line, fast bed conversion line and erosion line.
The map offers the engineer a tool to design the fluidization status of a CFB boiler for specific coal.
Followed by the design guide line of the boiler circulating system according to the "open loop theory"



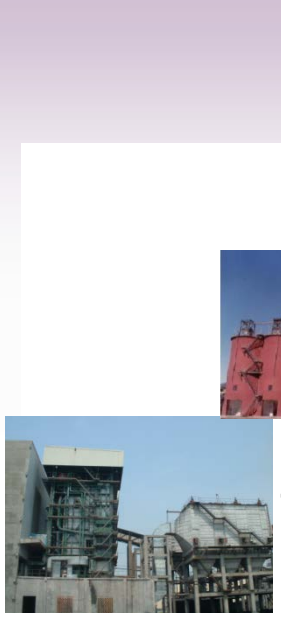
Combustion air system design guide line

- The primary/secondary air ratio– fractional heat releasing in furnace.
- The primary air pressure design --- the material balance theory in CFB
- The second air pressure---- gas maxing in furnace

Heating surface design

both heat releasing in furnace and heat transfer coefficient

Develop CFB boilers based on new design theory



35-75t/h,

75-130t/h

100-300MWe reheat

SC 600MWe

1st 1980-1990, learning

2nd 1990-2000, improvement

3rd, 2000-2005 scaling-up and maturating

4st, 2005-present developing

Technology transfer to Japan

Oji Paper Tomakomai CFB(260t/h)

Tokuyama Reheat CFB(310t/h)

Nippon Paper Ishinomaki CFB(180t/h)

Thai Ajinomoto CFB(75t/h)

State-of-art 600MWe supercritical CFB boiler

Mile stone of SC CFB in China

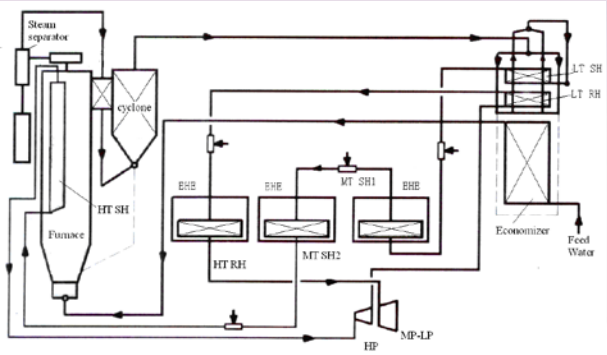
2000: Tsinghua initiated SC CFB feasibility study

2003: Tsinghua finalized the investigation on the key technology issue

2005: started both the design code investigation project and 600MWe
Demonstration project.
2012 : construction
2013.4： 168 hours full load test
2013.5： commercial operation

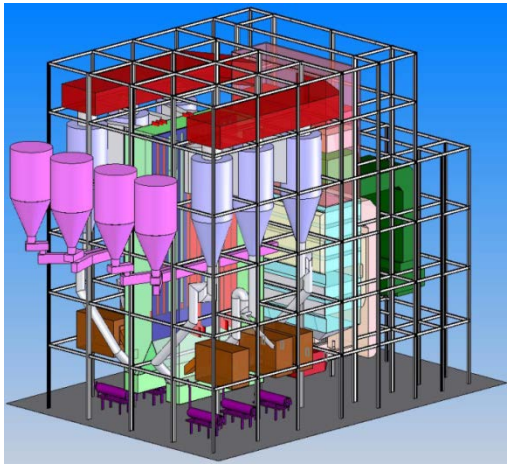
Basic parameter

Steam flow rate: 1900T/h
steam parameter ：
571℃/569℃
25.4MPa
Boiler efficiency ： 92%
SOx: <300mg/Nm3，
NOx: <200mg/Nm3，
generation efficiency : 42%



Design feature

Benson low mass flow
800Kg/m^2 S
Water wall partition furnace
6 cyclone+ 6 EHE
6 rotary water jacket ash cooler



State-of-art 600MWe supercritical CFB boiler

First operating result

	Design	operating
Steam T	571/569	567.5/569.7
Aux. power	8%	6.1%
NOx	＜200mg/Nm3	＜ 160mg/Nm^3
SOx	＜300mg/m3	＜ 200mg/Nm^3
Furnace T	890^{0}C	890^{0}C
Boiler efficiency	91%	92%

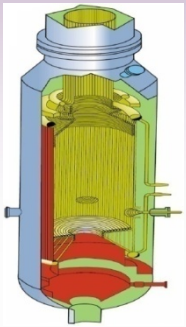
New contract 2X600MW 6X350MW

R&D of gasification in Tsinghua

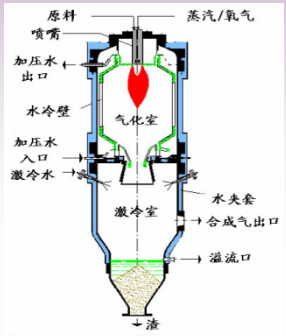
Available technology before Tsinghua:
dry feed+water wall , coal slurry+refractory lining

Why select coal slurry gasification ?
More market because of reliable

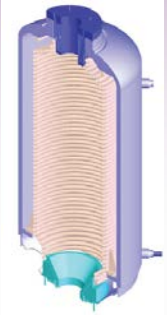
Advantage of Tsinghua
Experienced on coal combustion.
Experienced on engineering.



Shell

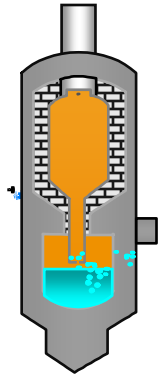


GSP



HT-L

two stage



Texaco

four nozzle

清華大學
Tsinghua University

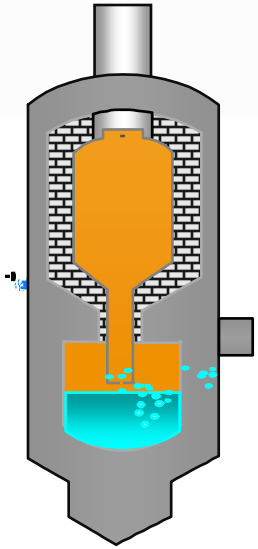
Fundamental research of gasification in Tsinghua

Set up full sets of coal gasification test facility including: cold model, TGA, PTGA, PLMF, start burner, pneumatic transport, hot gasifier facility

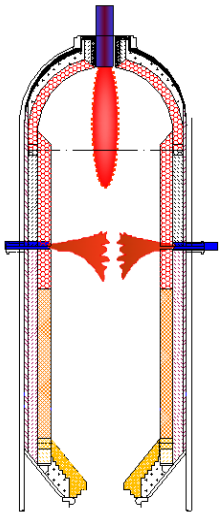
First approach of Tsinghua gasification technology –oxygen staging gasification

Target: improve the mixing of coal slurry droplets; decreasing the temperature of burner; even the temperature in gasifier.

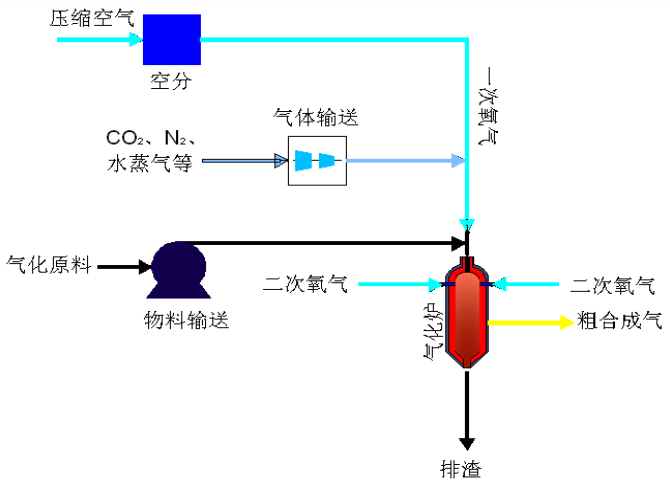
Approach: introducing the concept of staged air in combustion to coal slurry gasification.



texaco



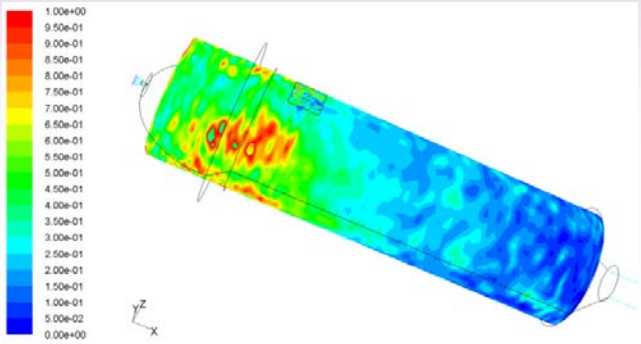
Staged oxygen

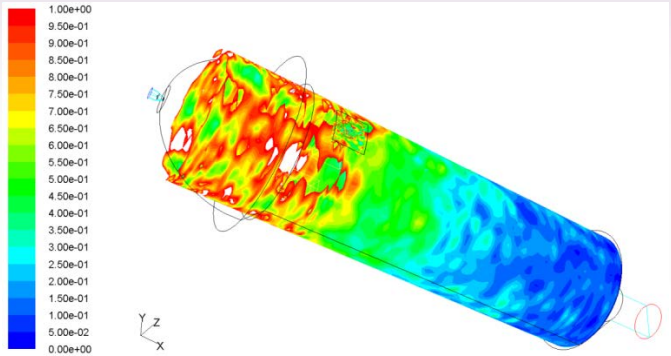


Process of staged oxygen

清華大學
Tsinghua University

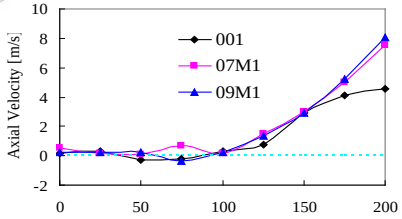
Cold test and modeling proved staged oxygen can improve the mixing

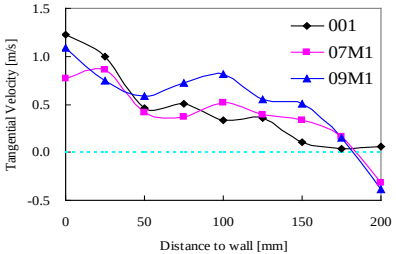




Without secondary oxygen

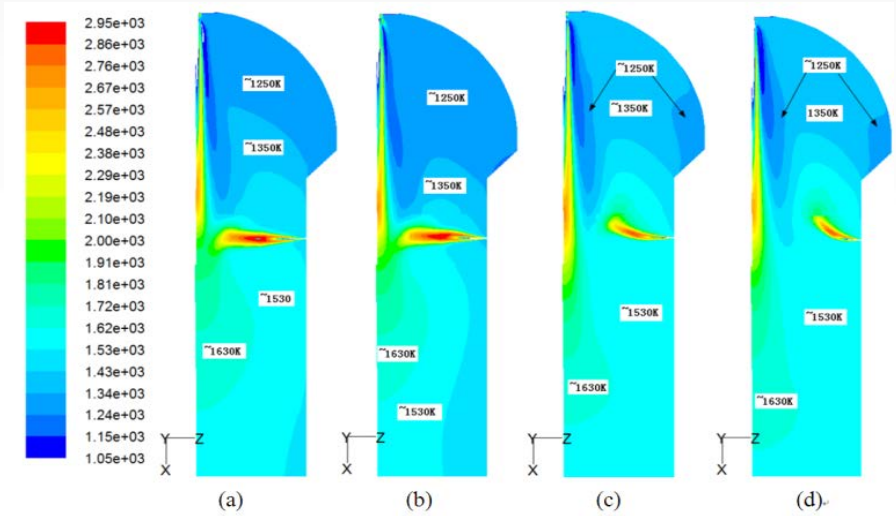
With secondary oxygen

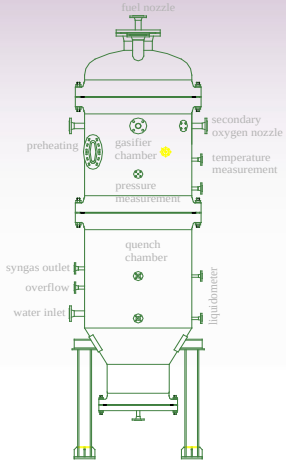


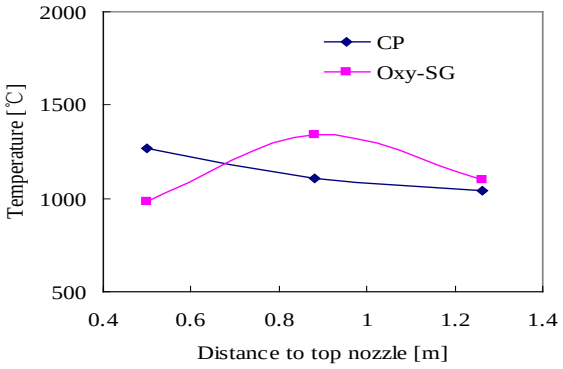


Comparison of the solid concentration near the wall

Modeling and hot test proved the staged oxygen can even the temperature distribution







Performance of 500T/d staged oxygen coal slurry gasifier



Capacity: 500 tons/d
Startup: Jan.23, 2006
$CO+H_2$>83%
Heating value of the syngas: 9～10MJ/Nm^3
O_2 consumption: 367.6Nm^3/1000Nm^3($CO+H_2$)
Coal consumption: 553.5kg/1000Nm^3($CO+H_2$)

Comparison of Texaco and staged oxygen coal slurry gasification

表 7 不同气化装置运行指标比较

气化装置		装置能力 吨煤/(台·日)	有效气成分 $(CO+H_2)$ %	比氧耗 Nm^3O^2 /$kNm^3(CO+H_2)$	比煤耗 kg 煤 /$kNm^3(CO+H_2)$	碳转化率 %	备注
引进水煤浆气化炉	上海焦化有限公司[1]	500	80.7	412	638	95.3	神府煤，煤浆浓度 62.5%
非熔渣－熔渣分级气化炉	第一阶段氧气不分级的典型运行数据	500	81.2	390.5	570.7	96.8	神木煤，煤浆浓度 60.5%
	氧气分级，主喷嘴中心不加 CO_2	500	82.87	370.4	555.9	97.91	煤质分析见表 2，煤浆平均浓度 60.16%
	氧气分级，主喷嘴中心加入 CO_2	500	83.51	361.0	548.0	99.06	煤质分析见表 2，煤浆平均浓度 59.74%

Advantage of staged oxygen technology

1.Efficiency improved

2.Working life of slurry nozzle is double.

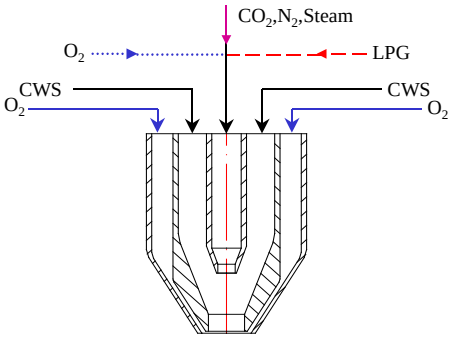
3.Staged oxygen nozzle is simple and with unlimited life.

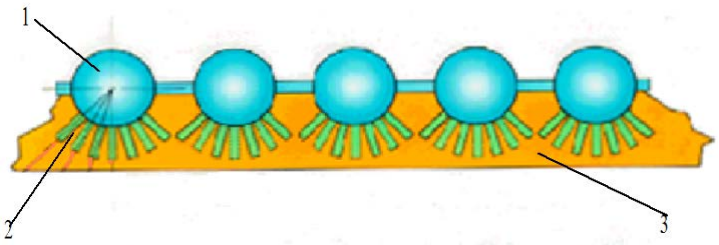
Second approach of Tsinghua gasification technology- coal slurry water membrane wall gasifier

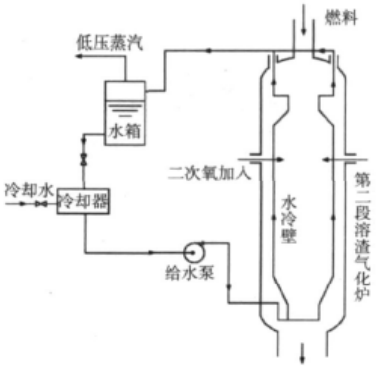
Target: high ash melting T coal gasification; avoid refractory consumption, shorten ignition time.

Approach: introducing natural circulating water wall membrane of boiler to gasifier instead of expensive refractory bricks.

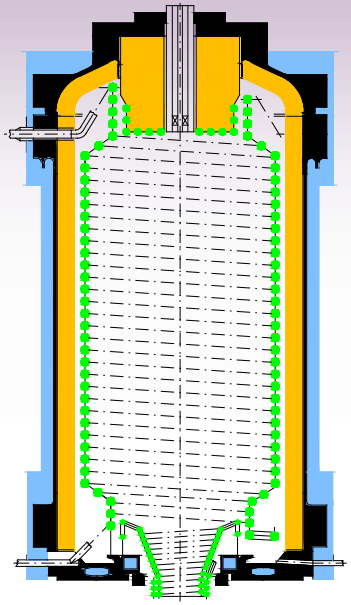
Introducing the concept of “flame igniting flame” in coal combustion to gasifier instead of “hot brick ignite coal flame”





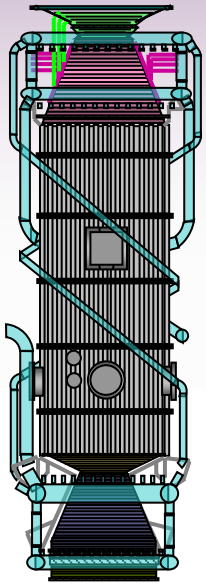


Comparison of different water wall design



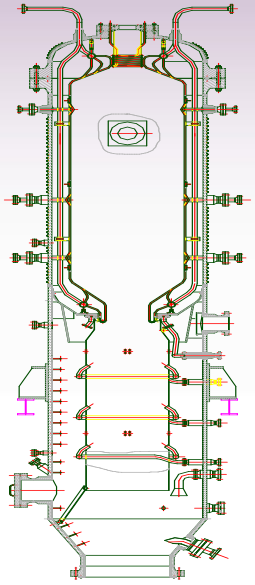
GSP gasifier

Coil tube
Bottom support
Forced circulating



Shell gasifier

Combined coil tube and vertical tube
Forced circulating
Bottom support

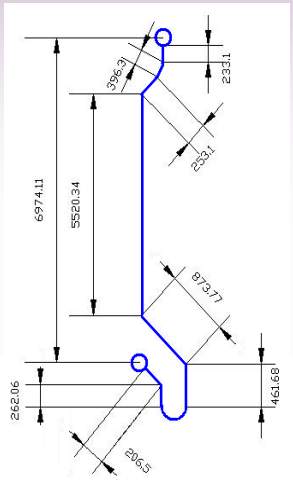


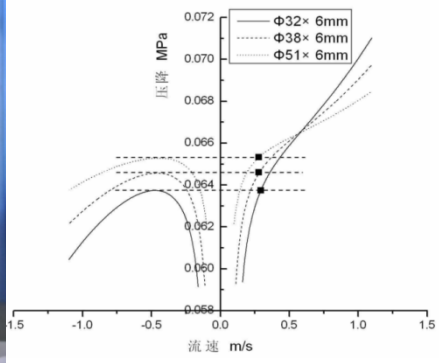
Tsinghua gasifier

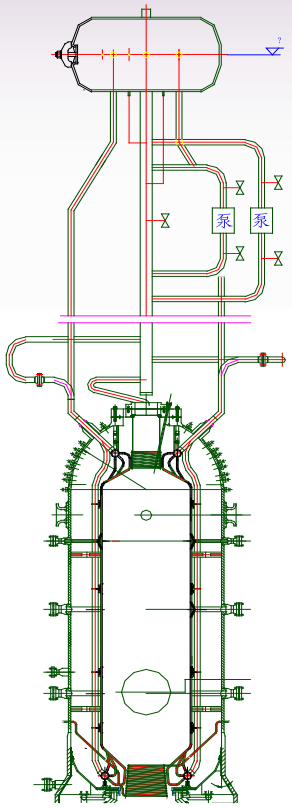
Full vertical tube membrane
Natural circulating design
Hanging support

Modeling and operating proved safe hydrodynamics in natural

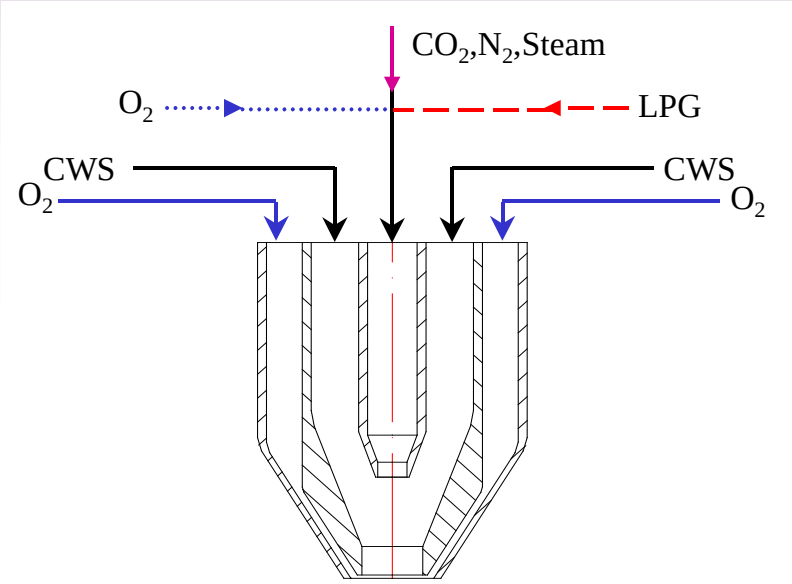
The water membrane is designed as safe natural circulation. The water system was forced circulating operating with pump.
In case, the black out, the system automatically switched to natural circulation mode to keep from tube overheat.



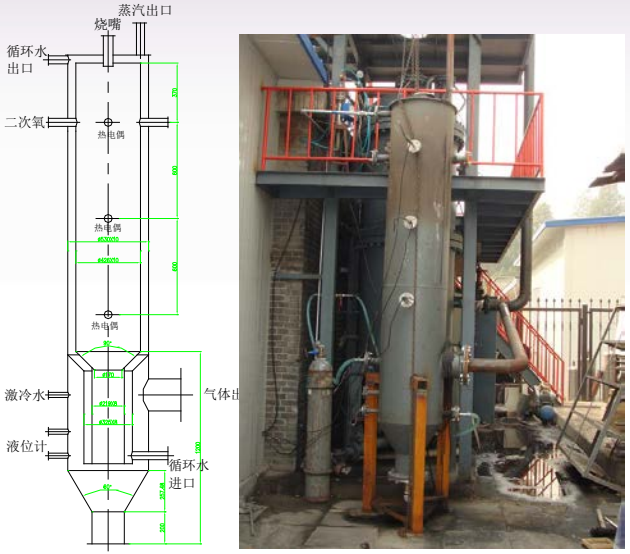




Experiments proved the reliability of “flame ignite flame”



Dual function nozzle



Flame igniting flame test facility

清華大學
Tsinghua University

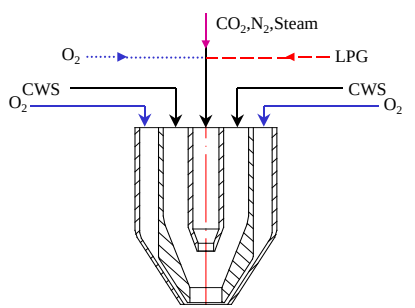
Operating experience for the first demonstration of water wall slurry feed gasifier

- The first demonstration with capacity of 600T/d was ignited in 2011/8/22 and continually operating for 140 days (world record).
- The coal ash melting T is 1520^0C, that is far higher than Texaco limitation.

Unique feature of Tsinghua coal slurry feed water wall gasifier

Feature 1: fast start up (3 hours from cold start to full load)

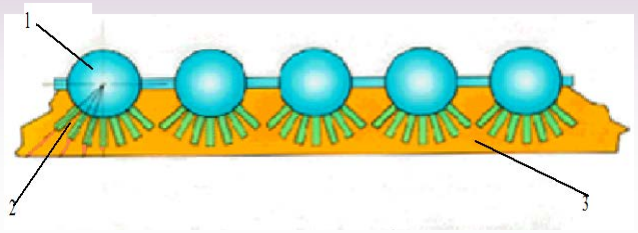
For Texaco tech. A start nozzle should be used to heat up the refractory until furnace T reach over 1000^0C. Then pull out start nozzle and insert working slurry nozzle. The slurry is ignited by hot refractory. This process needs three day and the exchange of nozzles is unsafe.

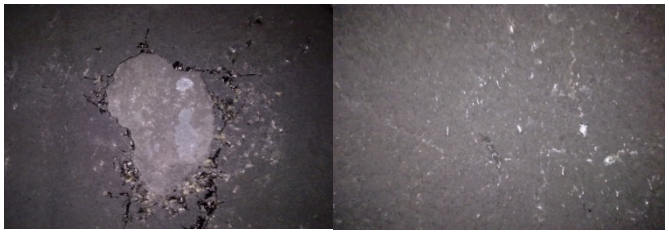


Dual function nozzle start with fuel gas, then ignites the slurry, until coal slurry flame stabilized. Then switch off the fuel gas and switch on central oxygen. Total start to full load time is 3 hours. The operation is by switching the valves.

Feature 2: life time guarantee for water wall membrane and its SiC refractory layer

Because of perfect design of water membrane and high heat conductivity of SiC refractory layer , the liquid slagging forms a stable layer to protect the refractory and membrane. After 2 years operating, the SiC layer is still like new. No need for maintenance . For Texaco gasifier, the working life of expensive refractory bricks is less than 2 years.





Feature 3: the surface T of pressure vessel is much lower than Texaco

For water membrane gasifier :

- surface T of pressure vessel 104^0C,
- lower radiative heat loss,
- cheaper material 14Cr1MoR

For brick refractory gasifier:

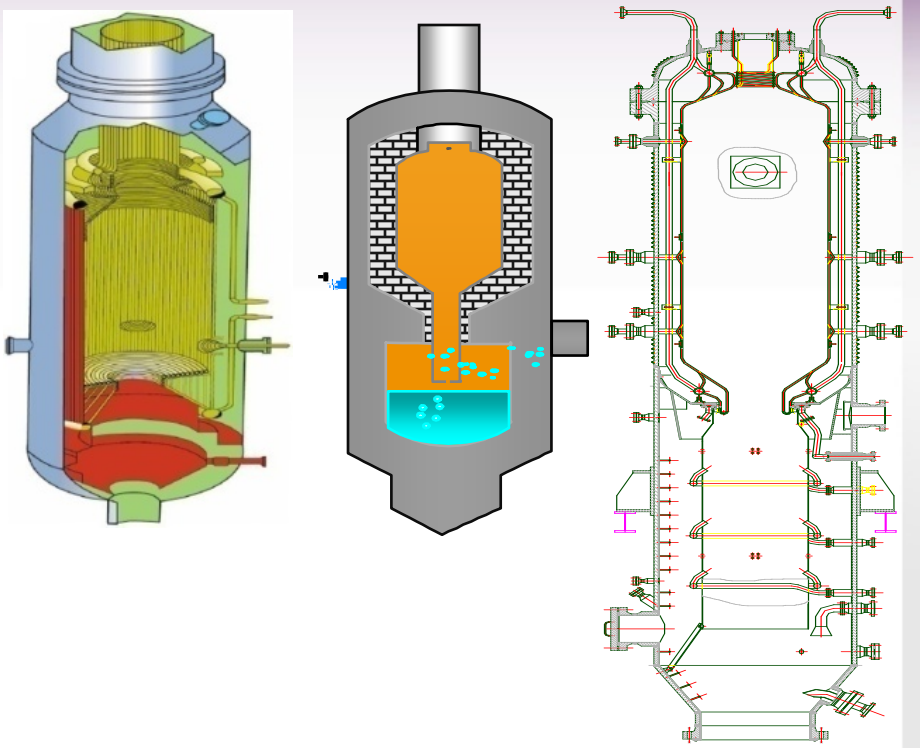
- Surface T of pressure vessel is 225^0C
- higher radiative heat loss
- expensive material SA387

Feature 4: water natural circulation protection for membrane as circulating pump lose power

DCS screen indicated as pump shot down, the natural circulating rate in water membrane was still keeping at proper amount to cool down the tube.

Feature 5 more capacity for same diameter pressure vessel

Compare with Texaco, water membrane save space of thick refractory bricks.
Compare with Shell, new water membrane don't need the space between water membrane and pressure vessel for maintenance access.
For same diameter pressure vessel can get more room for gasification reaction- means more capacity .
For example:
110000NM3/day capacity
diameter of gasifier
Texaco 3.2m
Tsinghua 2.8m



清華大學 Tsinghua University

Feature 6 water membrane slurry gasifier can almost accept any melting T coal

Item	Unit	Bituminous	10% anthracite	20% anthracite	30% anthracite
Slurry rate	m^3/h (t/d)	27.39(500)	27.39(500)	27.39(500)	28.16
coal content in Slurry	%	58.01	59.9	61.5	59.55
Oxygen rate	Nm3/h	12881	13211	14203	14565
O2/coal	—	470	493.2	500.4	516.8
Syn. Gas rate	Nm3/h	85976	84611	84000	99206
T of syn.gas	℃	210.2	207.9	212	213.8
Surface T of vassal	℃	140.7	105	105	96.7
Cooling water T	℃	227	192.1	198	201.5
Steam rate	t/h	1.370	4.134	4.391	3.9
CO	%	40.4	43.56	43.87	42.83
CO2	%	22	21.9	23	24.4
H2	%	37.71	36.3	34.05	32.97

Field test was successfully done for coal mixture with an anthracite (melt T over 1500^0C)

清華大學 Tsinghua University

Marketing of water membrane coal slurry gasification technology

New projects of

No.	Customer	Parameters of gasifier	Coal type	CO+H2 rate	Final product
1	China Offshore Oil Tianye Chemical Co., Ltd	ϕ2800mm/6.5MPa	Bituminous	159000	Ammonia, Methanol
2	Hebei Yangmei Zhengyuan Chemical Co. Ltd (Pingshan)	ϕ2800mm/3.5MPa	Bituminous, Anthracite	90000	Ammonia
3	Xinjiang Tianzhi Chenye Chemical Co. Ltd.	ϕ2800mm/6.5MPa	Bituminous, Anthracite	120000	ethylene glycol, Mechanol
4	Xinganmeng Wulan Taian Energy Chemical Co. Ltd.	ϕ3200mm/6.5MPa	Lignite	193900	Ammonia
5	Yangquan Coal Industry (Group) Co. Ltd. (Pingding)	ϕ2800mm/4.5MPa	Bituminous	69000	ethylene glycol
6	Xinjiang Guotai Xinhua Mining Co. Ltd.	ϕ2800mm/4.0MPa	Bituminous	85000	Methanol
7	Jinmen oil refining plant	ϕ2800mm/6.5MPa	Bituminous	200000	H2
8	Jishan sub-company of Shanxi Yangmei Fengxi Fertilizer Industry (Group) Co., Ltd	ϕ2800mm/4.0MPa	Bituminous	50000	Ammonia
9	Hebei Qian'an Fertilizer Co., Ltd.	ϕ2800mm/6.5MPa	bituminous	110000	Ammonia

From Sep. 2012 to now, total licensing project is 16, that is more than the summation of all other technology providers

Retrofitting projects

1. Guizhou Xincheng Coal chemistry Co. (NWRICI technology)
2. Hilongjiang Beidahuang AgricultureCo. (GE technology)

Remarks

- R&D of CFB combustion and coal gasification are very active in China because of market driven.
- It looks like original CFB and gasification technologies invented by advanced country still have space to improve.
- The contribution of Tsinghua on CFB and gasification is somehow engineering innovation but not science revolution. While such innovation is more welcomed by Chinese industry.