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Status of Oxygen-Fuel Combustion Technology in China

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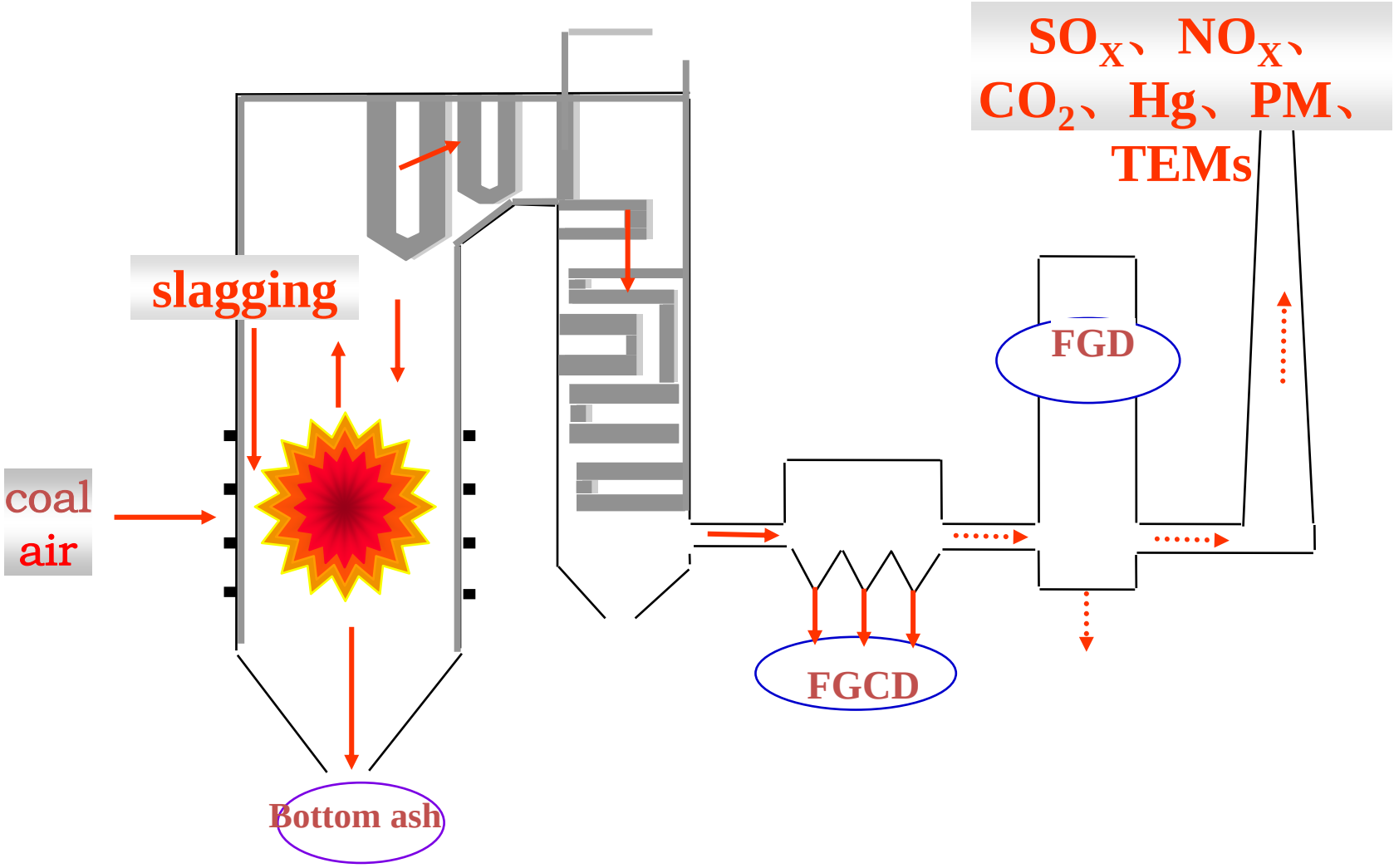
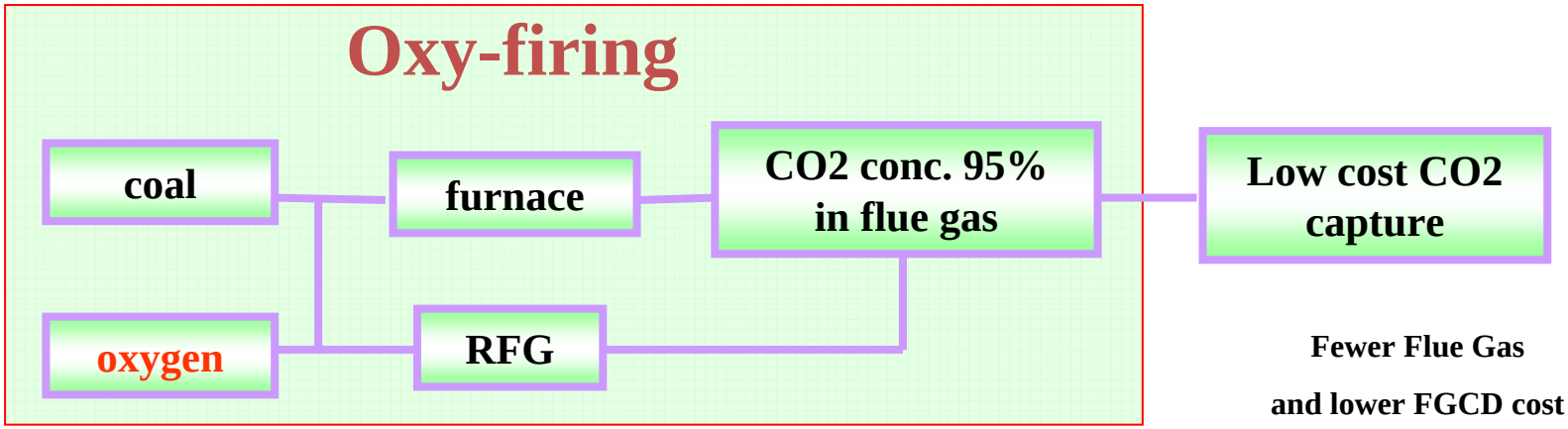
PC power generation technology and its pollutants

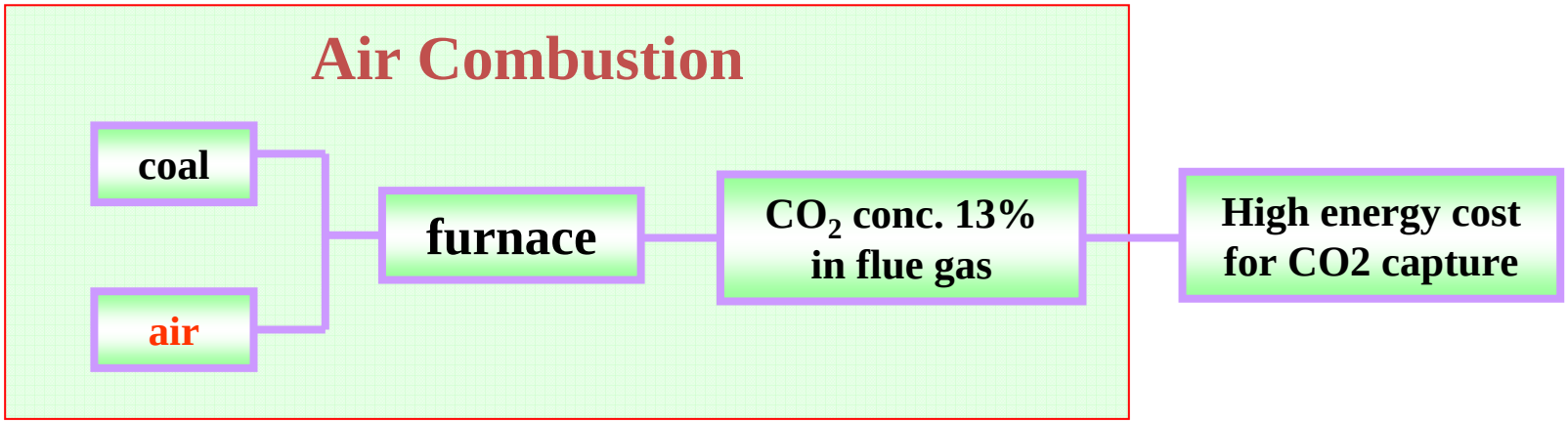


Oxy-firing system with CO_2 capture



Fewer Flue Gas

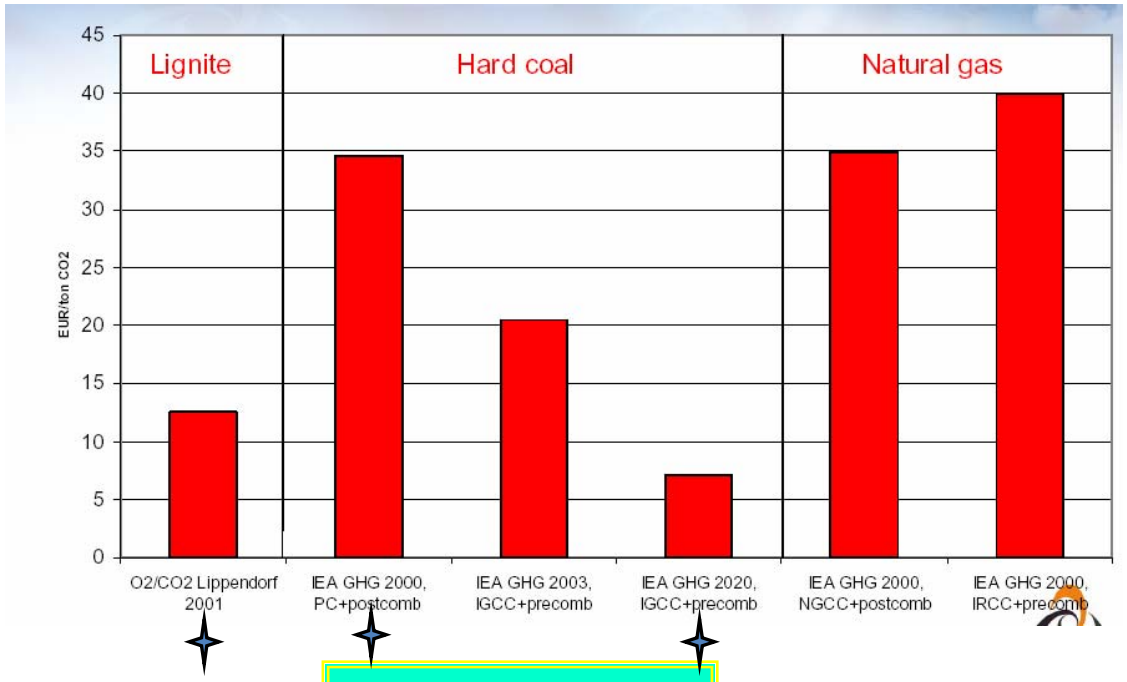
and lower FGCD cost



Since 1991, Argonne

Oxy-firing, O_2/RFG, Oxygen enriched, Oxygen-fuel

Oxy-Fuel Combustion



ASU ~ FGD

CO_2 concentration: 95%

NOx reduction: 30%-70%

SO_2 removal by limestone: 40%-90%

Thermal efficiency increase: 3%

Easy and efficient CO_2 separation, recovery

Merits and demerits of Oxy-firing Technology

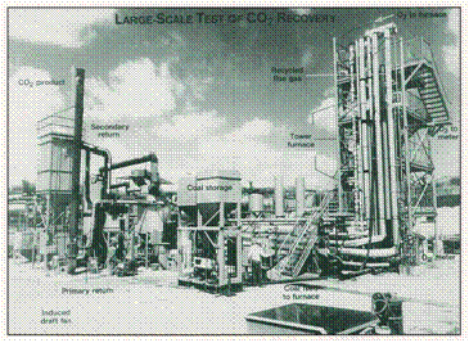
- Merits:
  - Accommodate with current PC technology
  - Enabling technology
  - Multi-pollutants control
  - Reliability, availability, and familiarity

- Demerits:
  - High energy cost for Oxygen production
  - Lower net power output
  - fresh technology and no demonstration experience available

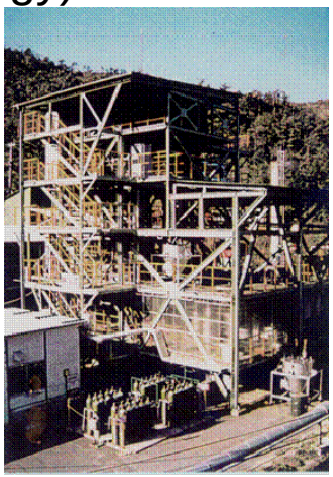
Current Status

- Existing Pilot Scale (<5MWt)
  - EER(CA), 3.2MW; IFRF(Netherland), 2.5MW; IHI(Japan); Air Liquide, B&W(OH), 1.5MW; CANMET(Canada), 0.3MW; Alstom(CT),3.0MW CFB, IVD(Germany) 0.5MW;

- Planned Pilot Demonstration (>20MWt)
  - Vattenfall 30MWt Schwartze Pump Germany, Ground breaking 5/06
  - Japan(IHI)-Austrialia (Queensland) Oxy-fired retrofit with Oxygen plant, PF boiler (Callide A 30MWe Unit owened by CS Energy)
  - Hamilton (OH) B&W 24 MWe retrofit



World's first pilot scale study on Oxy-Coal Combustion with Recycled Flue Gas (Courtesy of Argonne National Laboratory)



1.2 MW Pilot plant for Oxy-Coal Combustion Test Facility (Courtesy of IHI)

WORKSHOP OF THE OXY-FUEL COMBUSTION NETWORK

2005.11 1st 64 participants from 17 countries
2007.1 2nd 85 participants from 16 countries (other 20)

Oxy-firing Studies in China

North China Electric Power University (Beijing)

University only???

NSFC(1997-) (2001-)(2002-) ; 973 Program(1999-, 2006-); 863 Program(2005-); 985 Program (2005-)

Current Projects

- MOST 国家重大基础研究专项基金(973) “温室气体提高石油采收率的资源化利用及地下埋存”课题 “O2/CO2循环燃烧及污染物的协同脱除” （2006CB705806）2006~2011 500万
- MOST 国家高技术研究发展(863)计划“煤燃烧的CO2减排技术与污染物协同脱除” (2005AA529330) 2005~2007 400万
- NSFC 国家杰出青年基金 “特殊燃烧方式下污染物的协同脱除研究” 邱建荣 2005~2008 100 万
- MOE 985II期 近零排放的煤炭先进发电技术 2005~2007
- MOE 重大项目 “特殊燃烧方式下污染物的协同脱出研究”
- 其他NSFC项目

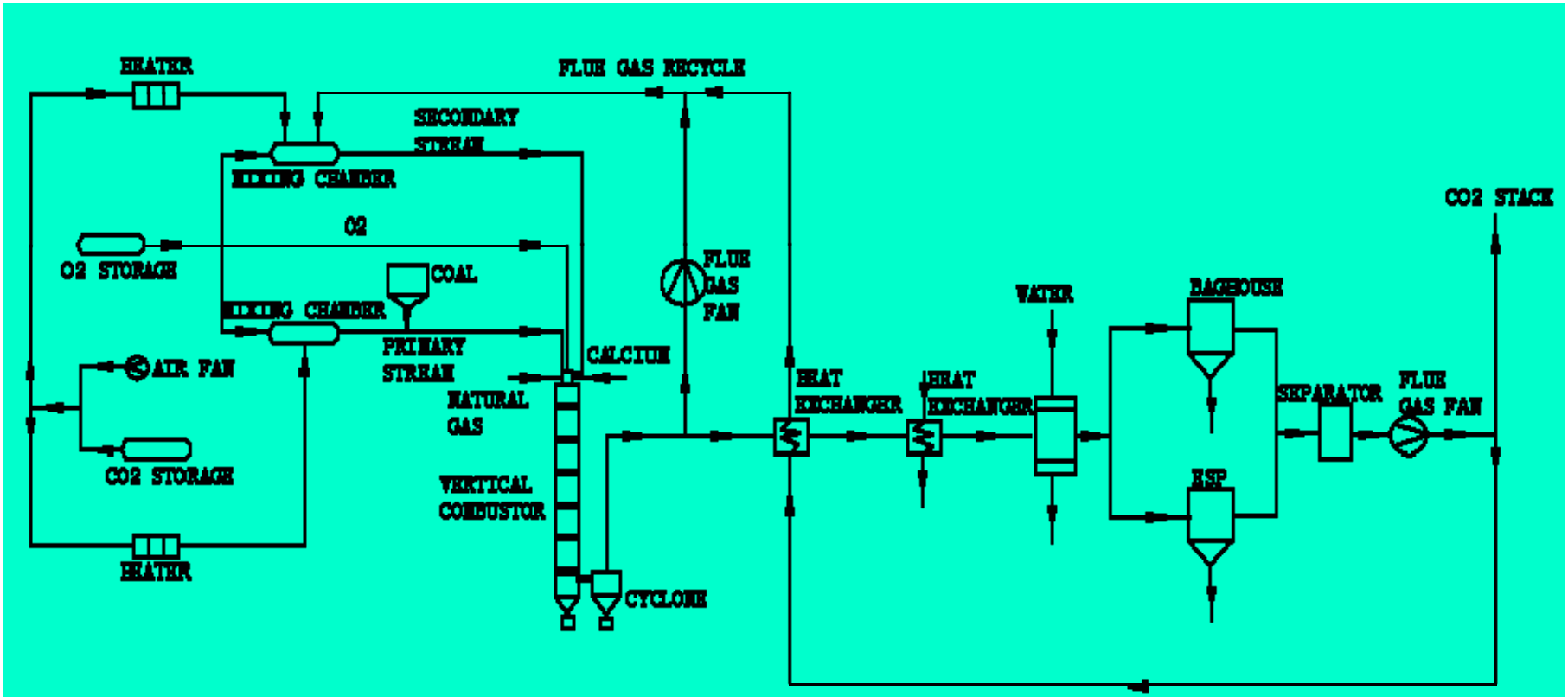
Pilot scale facilities in China

- Oxy-PC
  - 0.3MWe oxy-fuel combustion system with multi-pollutants control, Huazhong Univ. Sci. Tech., Wuhan
  - 10kw entrained flow reactor, Tsnghua Univ., Beijing

- Oxy-CFB
  - Multi-purpose CFB test rig, Zhejiang Univ., hangzhou,
  - 30kw O_2/CO_2 CFB system, Southeast Univ., Nanjing

0.3MWe Oxy-fuel recycle combustion system (HUST)

- **Pilot-Scale**



300KW, inner diameter 600mm， height 8m.

Detect CO2 concentration . (recycle ratio)
Combustion behavior for typical Chinese coals (is feasible for retrofit application?)
SO2/NOx emission and Control, ash deposition

0.3Mw Oxy-firing facility of SKLCC,HUST

项目(单位)		数值
coal（kg/h）		35
Heat capacity（KW）		300
Reactor（mm）	diameter	600
	height	8300
Total air（kg/h）		390
oxygen（kg/h）		89.7
一、二次风比		1：4
炉膛截面风速（m/s，1500℃）		2.07
炉膛截面热负荷（MW/m2）		1.06
炉膛容积热负荷（MW/m3）		0.128

Targets: >95% CO2

~80%De-NOx >90% DeSOx 60~80%DeHg

Progress in construction and operation

2005.10 funded by 863

2006.4 engineering design

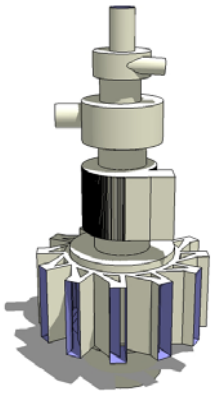
2006.11 construction finish

2006.12 combustion chamber heat up

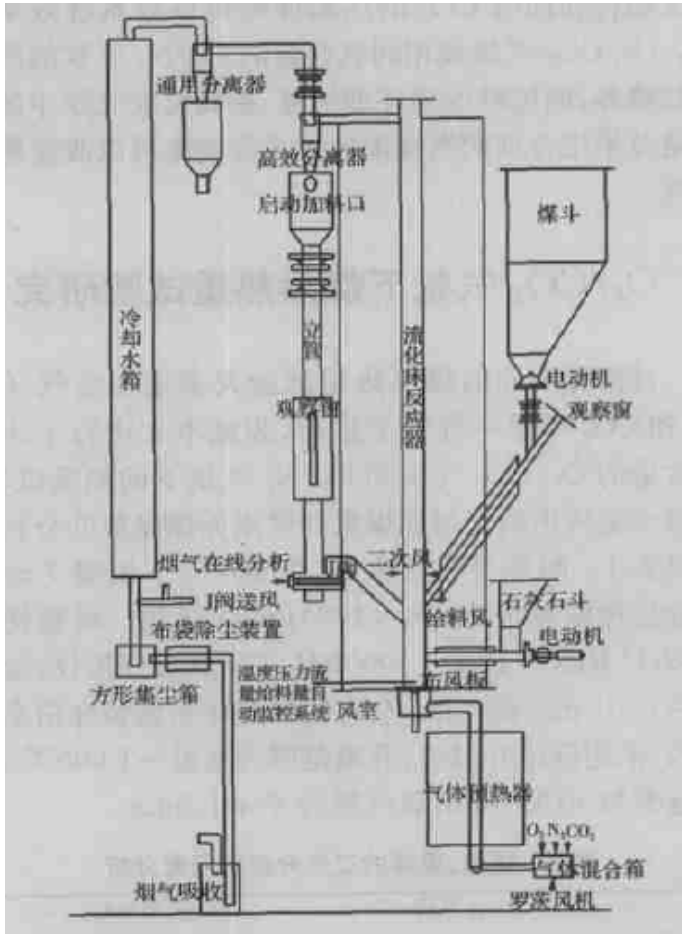
2007.1 first air combustion running

2007.3 flow rate/feed rate calibration

current system retrofit and instruments refine

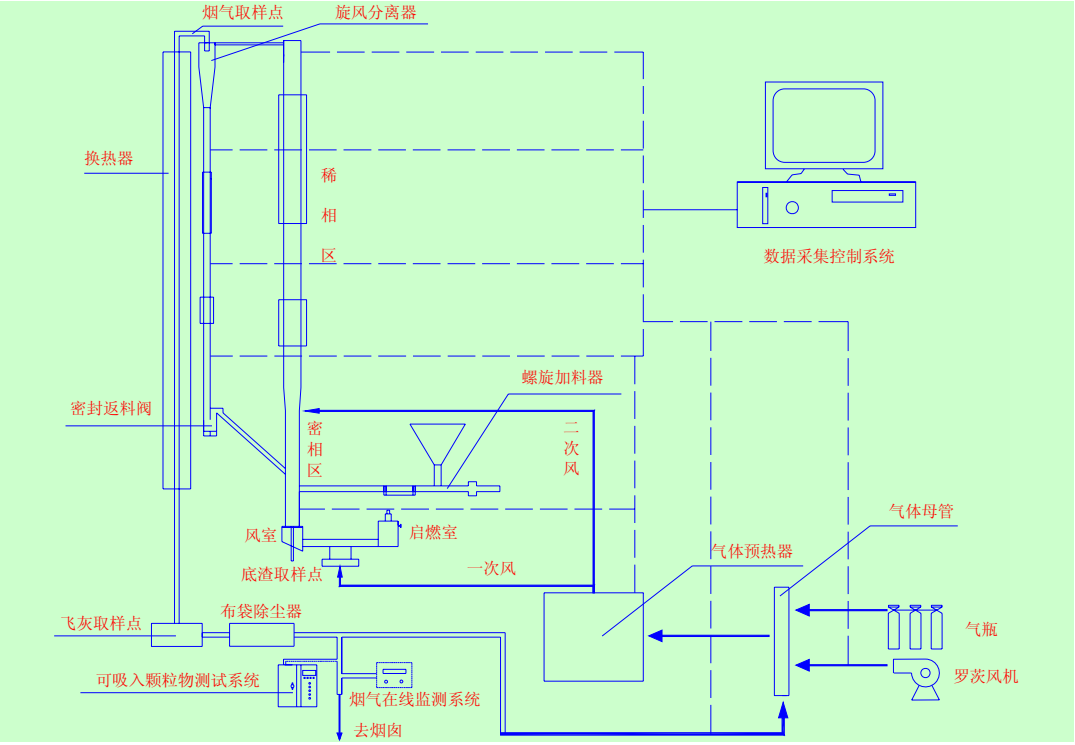


Multi-purpose CFB test rig (Zhejiang Univ.)



Reactor tube: diameter 89mm*high 2800mm

30kw oxy-CFB facility (Southeast Univ.)



Total heat input: 30kW,

Total coal input: 8Kg/h,

Oxygen: 10Nm^3/h,

fluidization vel.: 4m/s,

dense-phase bed height: 800mm,

diameter: 120mm,

dilute phase bed height: 3000mm,

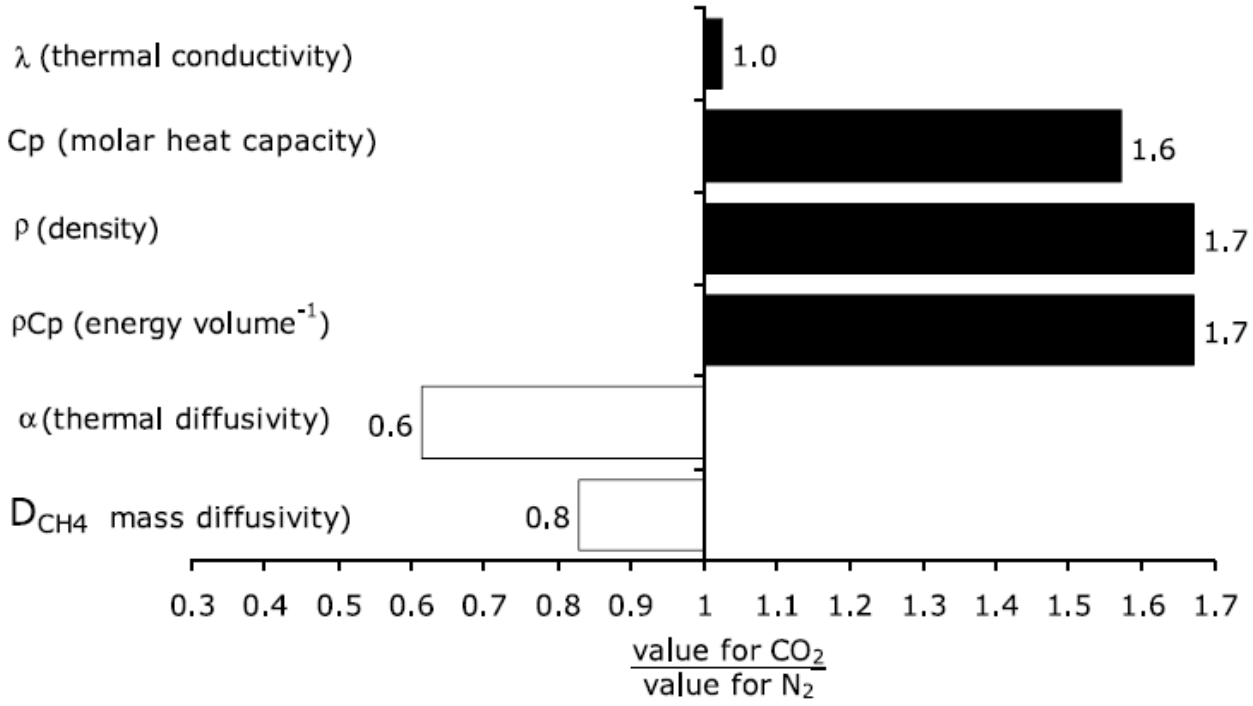
diameter: 150mm。

Targets: >95% CO2

Lab. investigation

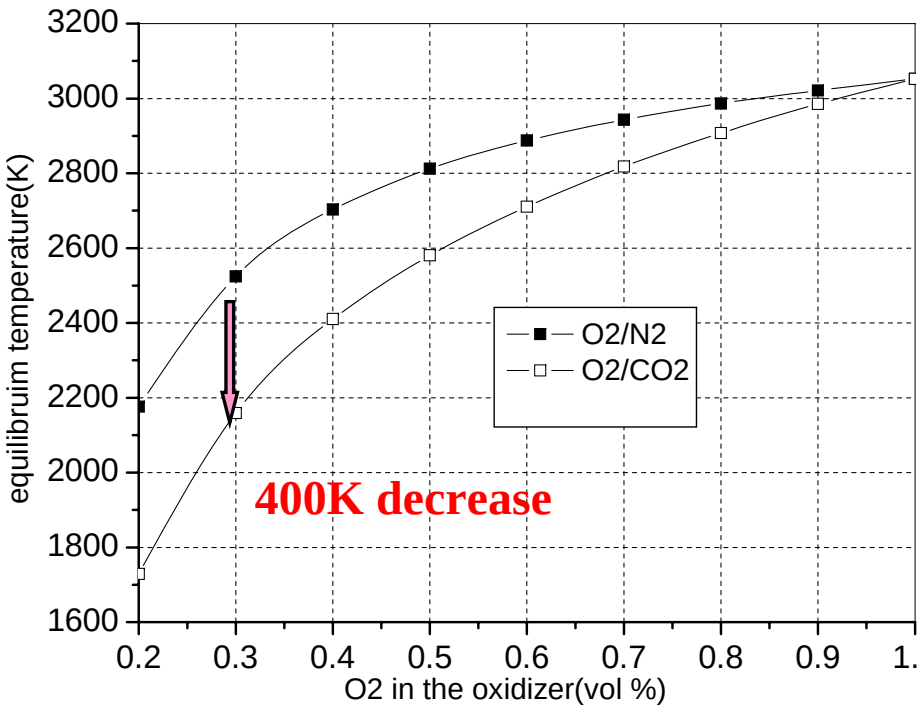
- Flame Characteristics and Combustion behavior
- The mechanism of SO_2 and NOx reduction
- Limestone desulfurization reaction mechanism in O_2/CO_2
- Char Oxidation Mechanism
- Fine Particulate Matter (PM) emission character
- Mercury (Hg) release properties

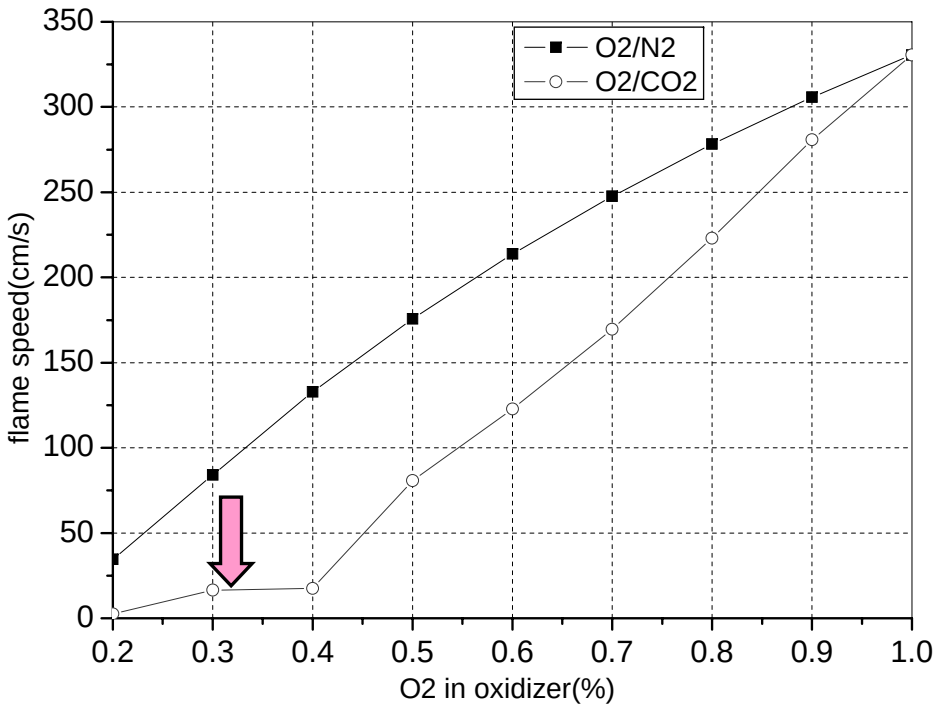
Thermo-physical properties Comparison



1200K

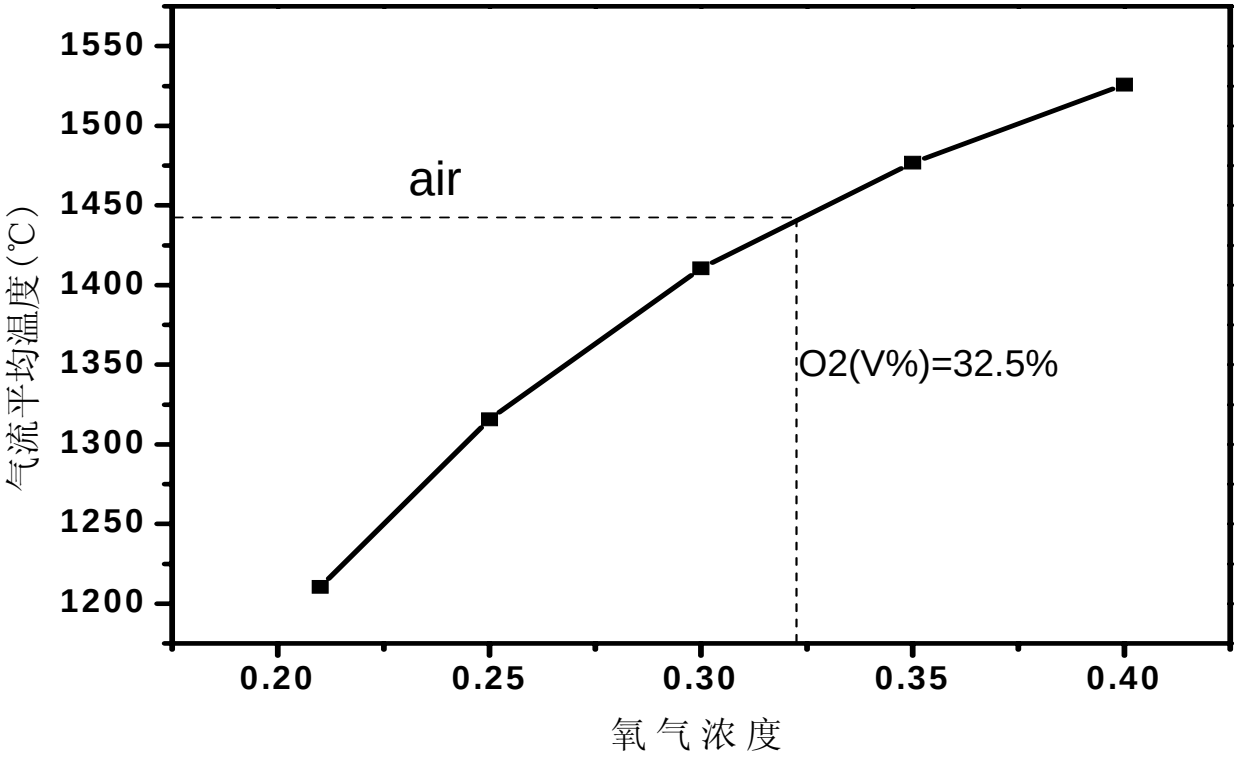
Characteristics of CH4/O2/CO2 flame



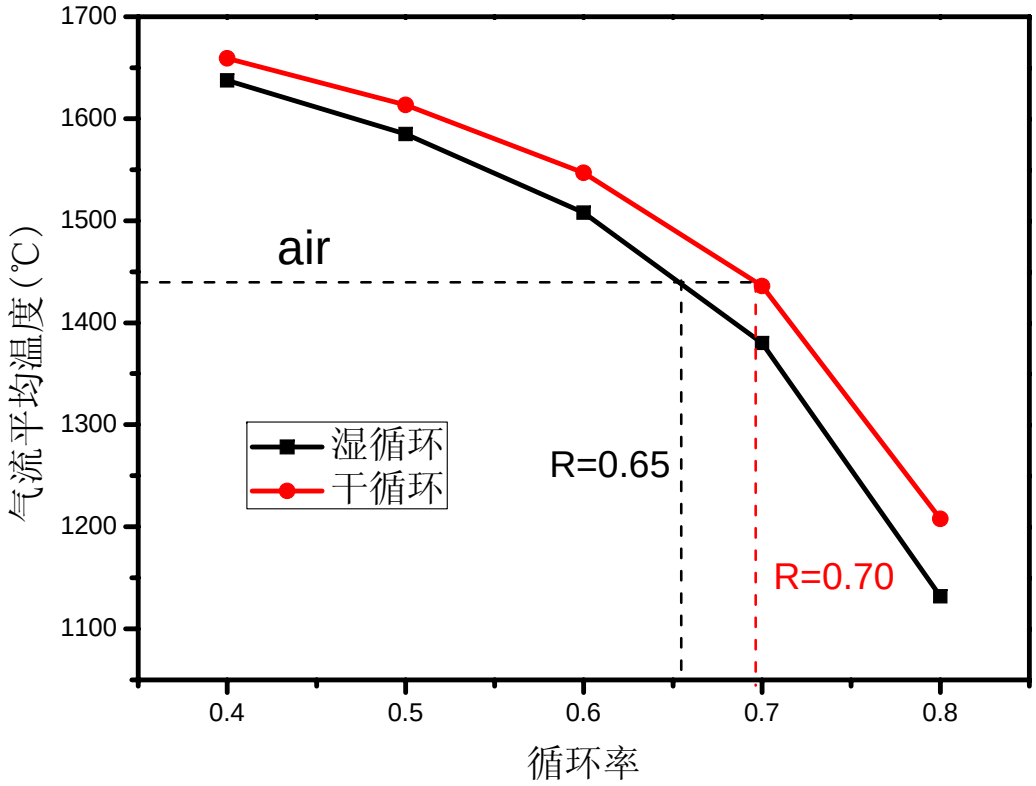


From equilibrium and non-equilibrium calculation of CHEMKIN 4.0+GriMech 3.0

Flame temperature under different Oxygen concentration



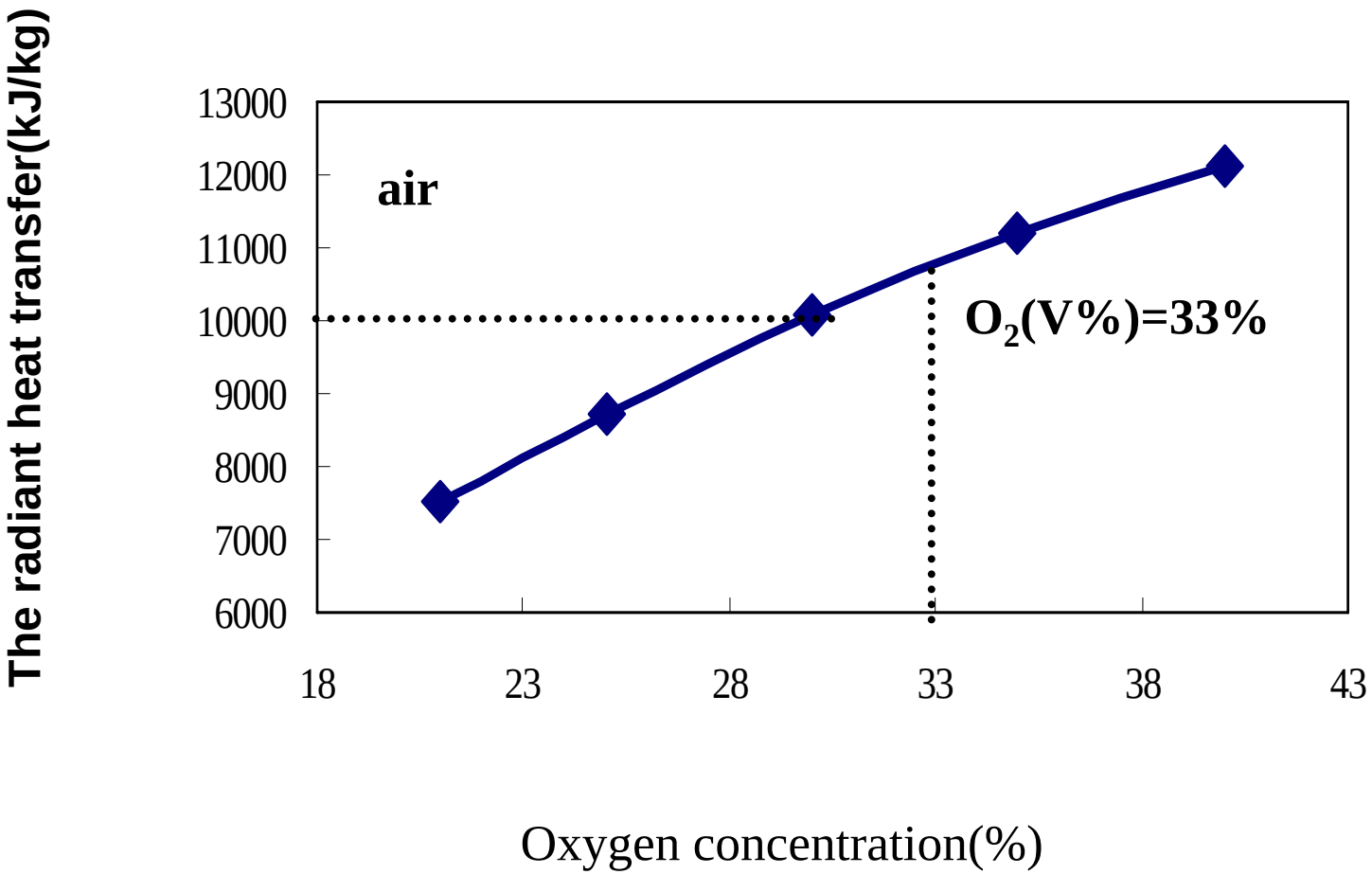
Transition of flame temperature with RFG ratio



$$T_g = 0.925\sqrt{T_{ll}T_l''}$$

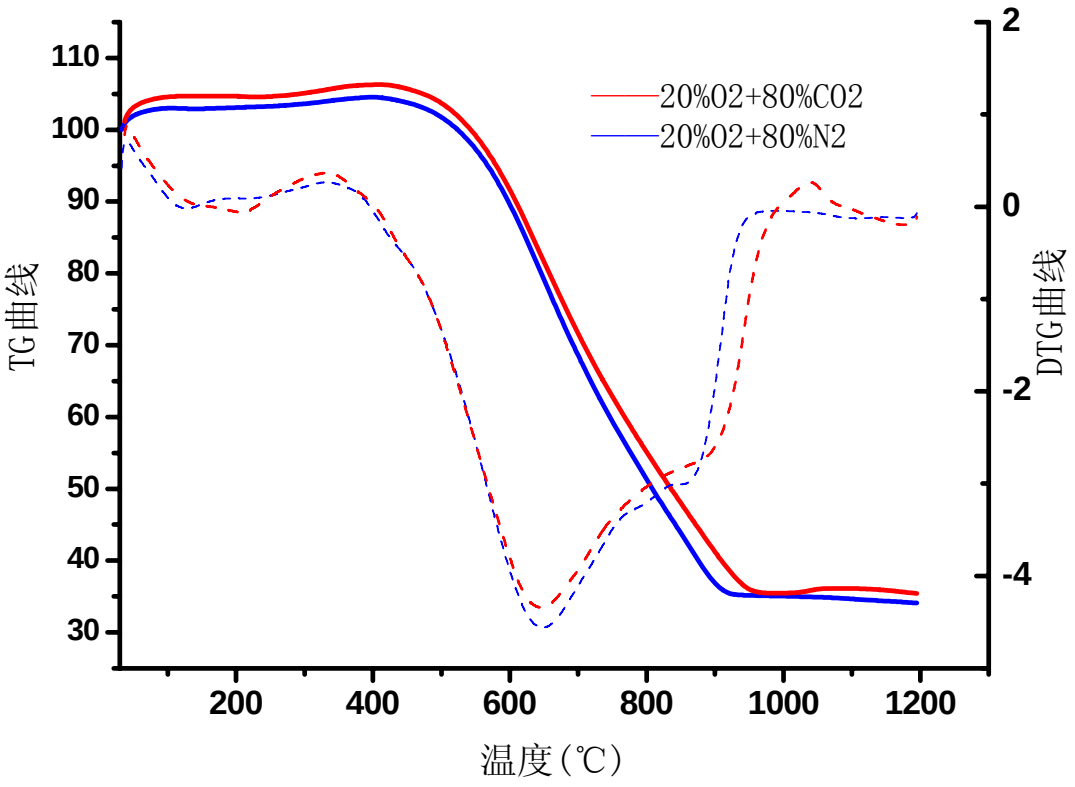
其中T_{ll}为绝热火焰温度(计算至前屏前即折焰角处)，T_l'' 为炉膛出口温度。

Radiant heat transfer



CO2+H2O ~ 95% vs. ~20% for air combustion
Radiant absorption coefficient increased by 30~60%

Coal combustion—TG study

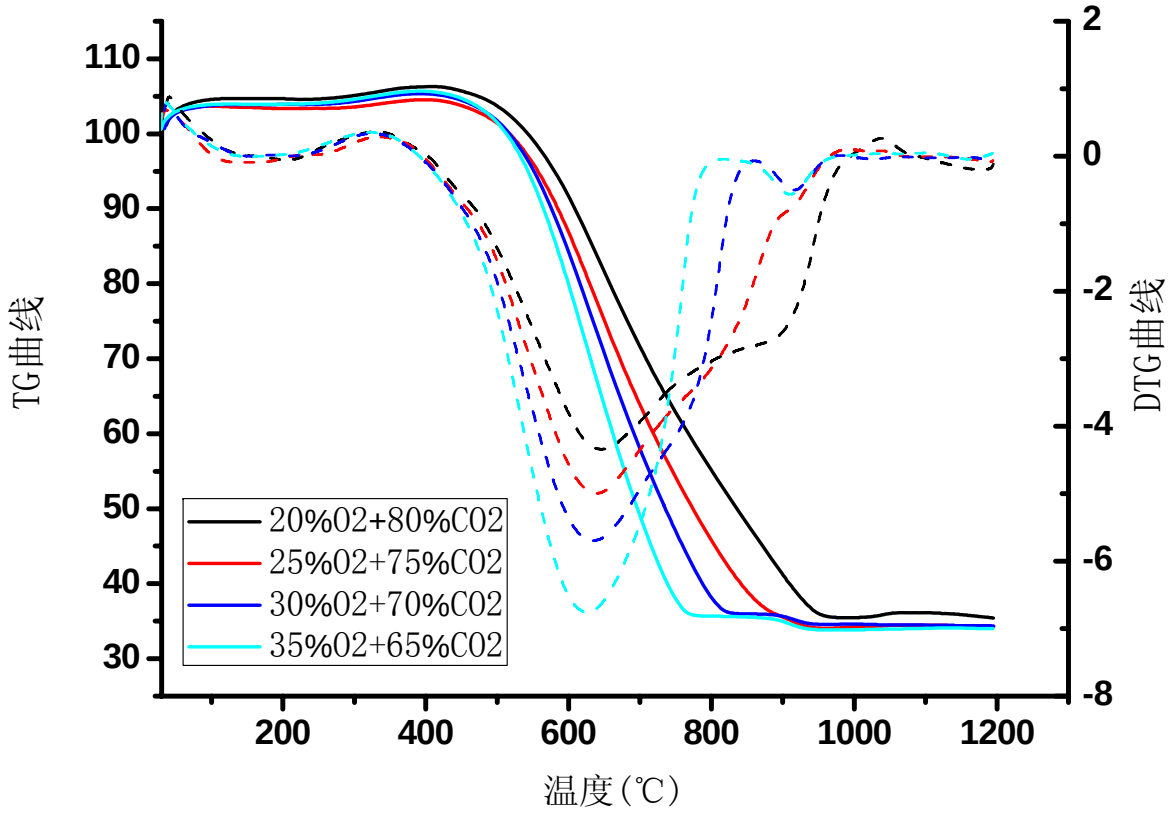


20mg，20℃/min，20-1200 ℃

T_i, T_b slightly increased

Comparison between air and O_2/CO_2 combustion

Coal combustion—TG study

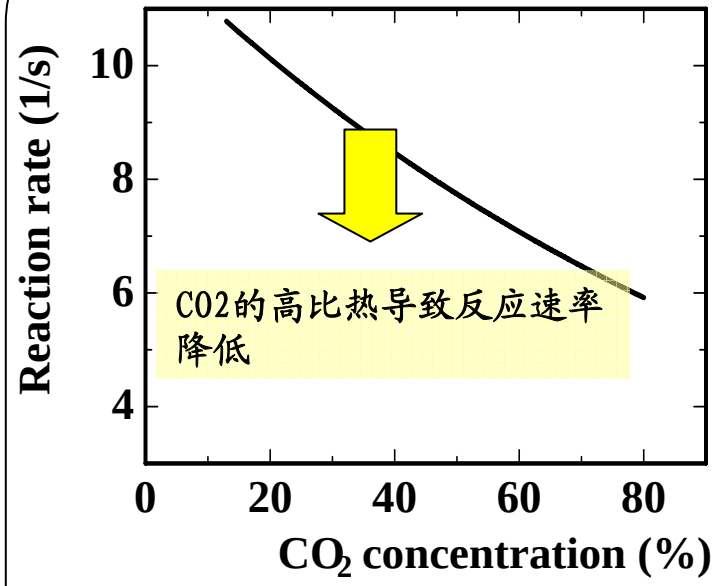


20mg，20℃/min，20-1200 ℃

T_i, T_b decreased with P_{O2} increased

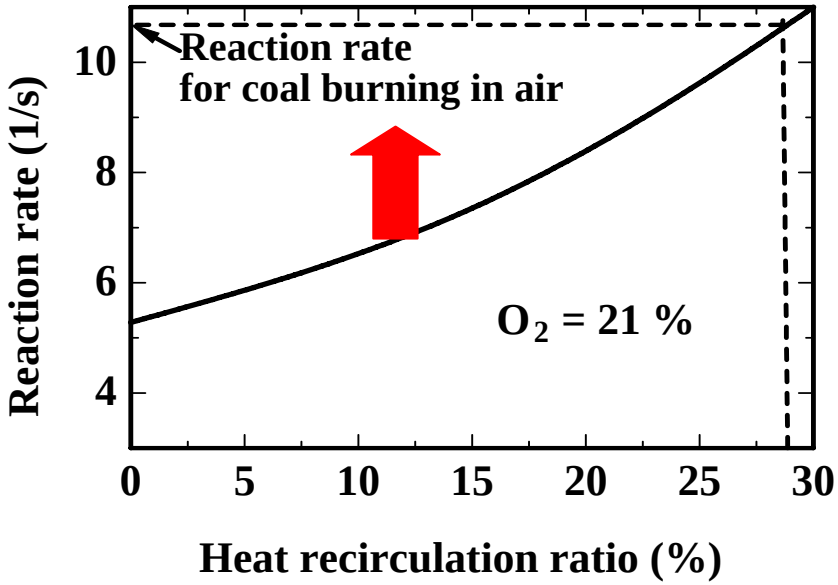
combustion behavior under different O2 conc.

Characteristic of Char oxidation



O_2 = 21 vol. %

反应速率与CO2浓度的关系

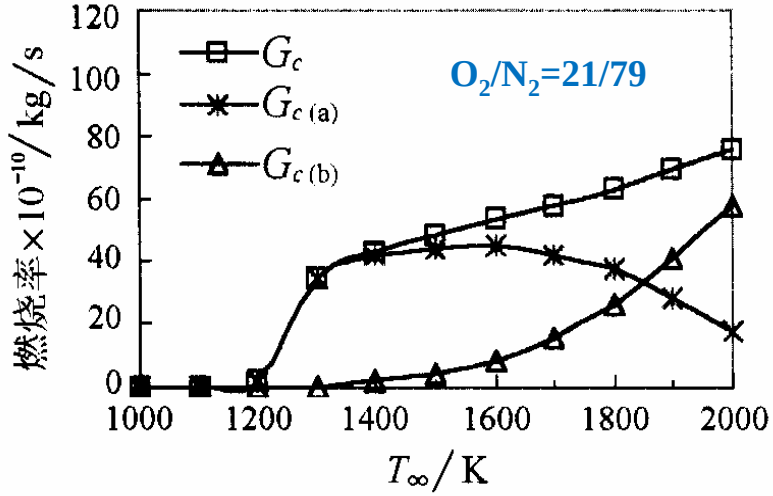


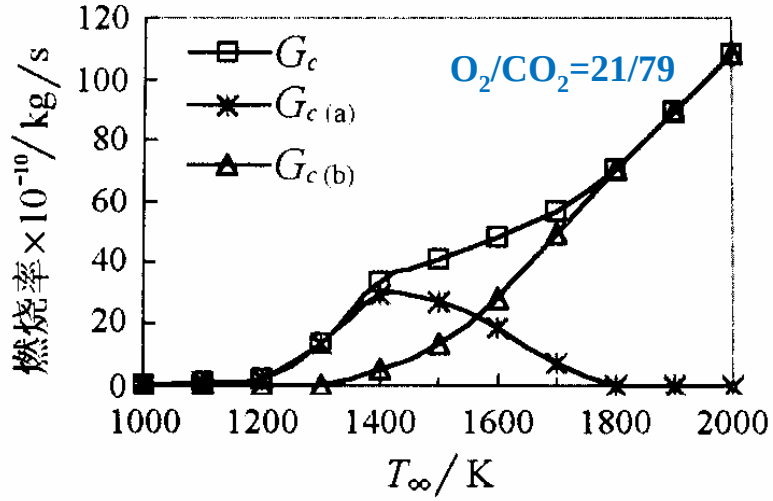
O_2 = 21 vol. %

O_2/CO_2 煤燃烧

热循环对反应速率的影响

Char Oxidation—numerical analysis





(r_s=50um)

Liu Yanfeng et al., J. Eng. Thermo-physics, 1999

Makino et al. 1986

$$L(\overline{Y}_P + \overline{Y}_F) = L(\overline{Y}_P + \overline{Y}_O) = L(\overline{Y}_P - \overline{T}) = L(\overline{Y}_N) = 0$$

a) $C+1/2O_2$ — CO

b) $C+CO_2$ — CO

c) $CO+1/2O_2$ — CO_2

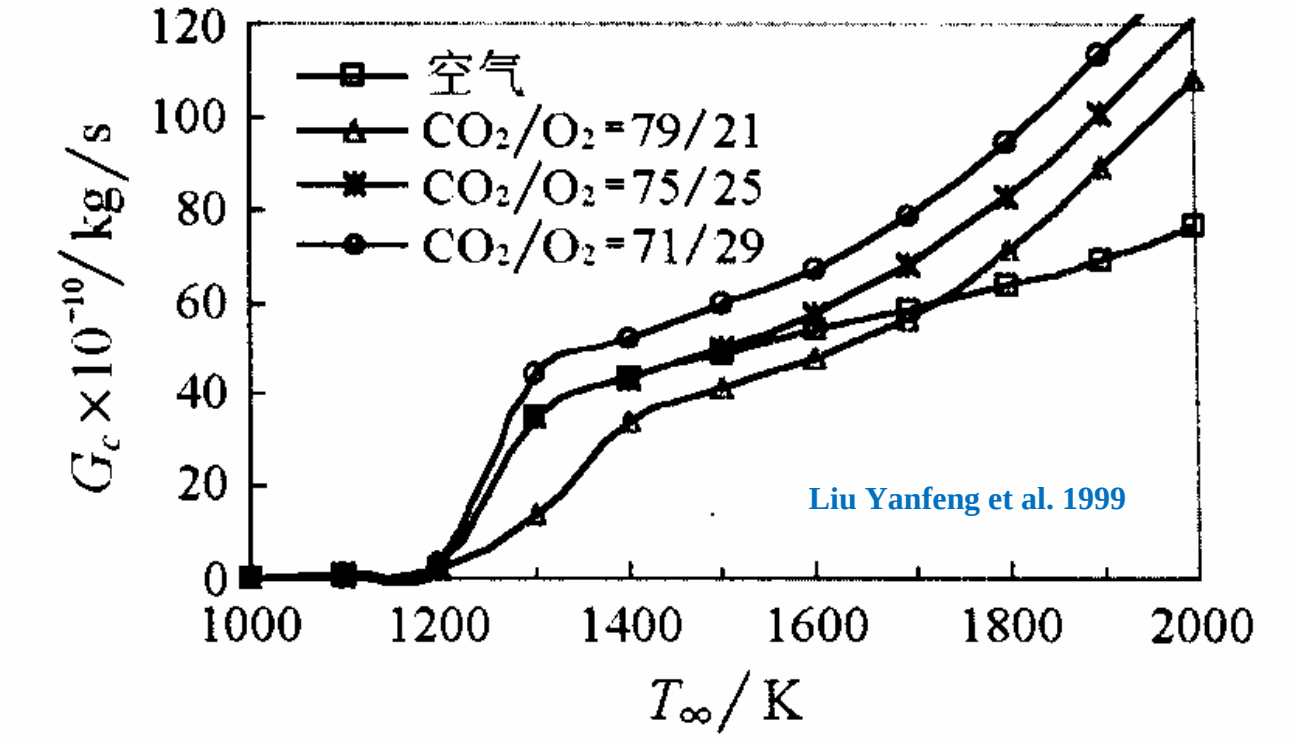
Do_2 ⇓ → G_a ⇓

Yco_2 ⇑ → G_b ⇑

G ⇓⇑

Depends on T_g

Char Oxidation—numerical analysis

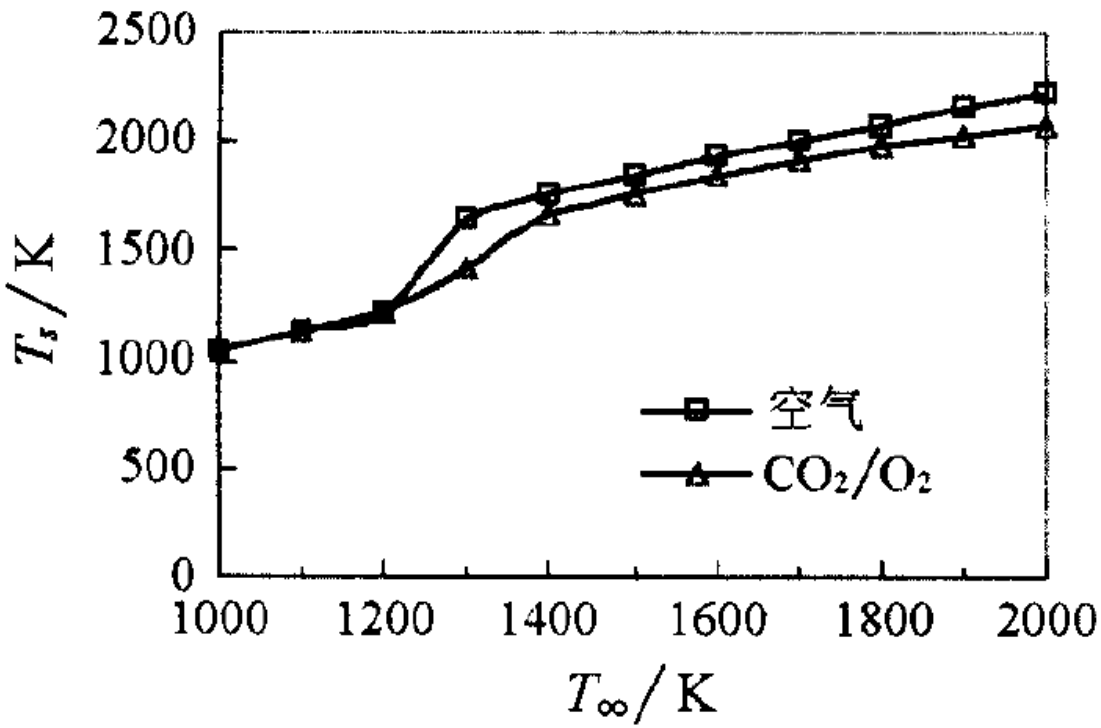


$$G_c = \overline{G}_c \times (4\pi\rho_\infty D_\infty r_s)$$

Increase partial pressure of O2 to >25% to enable a fast char oxidation rate

Density of oxidant exceeds those in air while mass fraction of Oxygen remain less

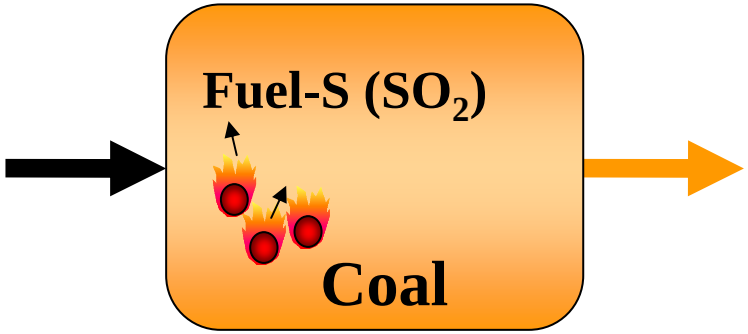
Char Oxidation—numerical analysis



The *particle* temperature can be *200K* lower than those in air at the same Tg

Can have significant influence on mineral/PM behavior

Conventional pulverized coal combustion

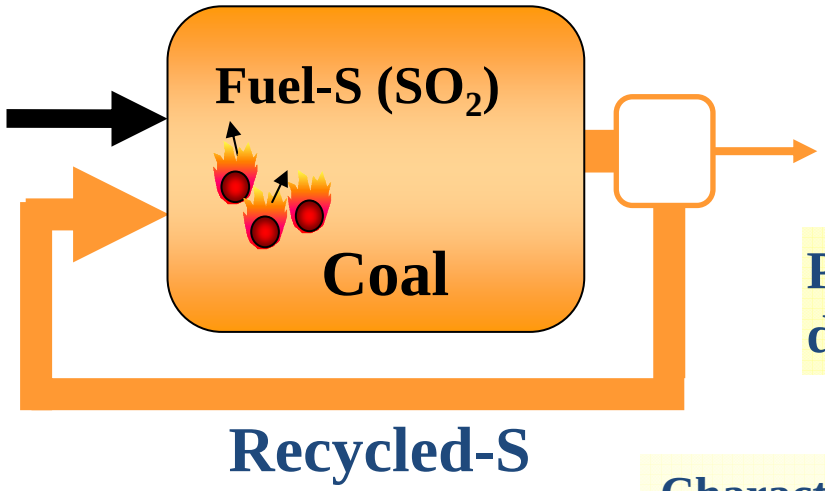


$CaSO_4$ decomposition

↓

Low desulfurization efficiency

O_2/CO_2 pulverized coal combustion



High CO_2 concentration

↓

- Enhance desulfurization reaction?
- Inhibit $CaSO_4$ decomposition?

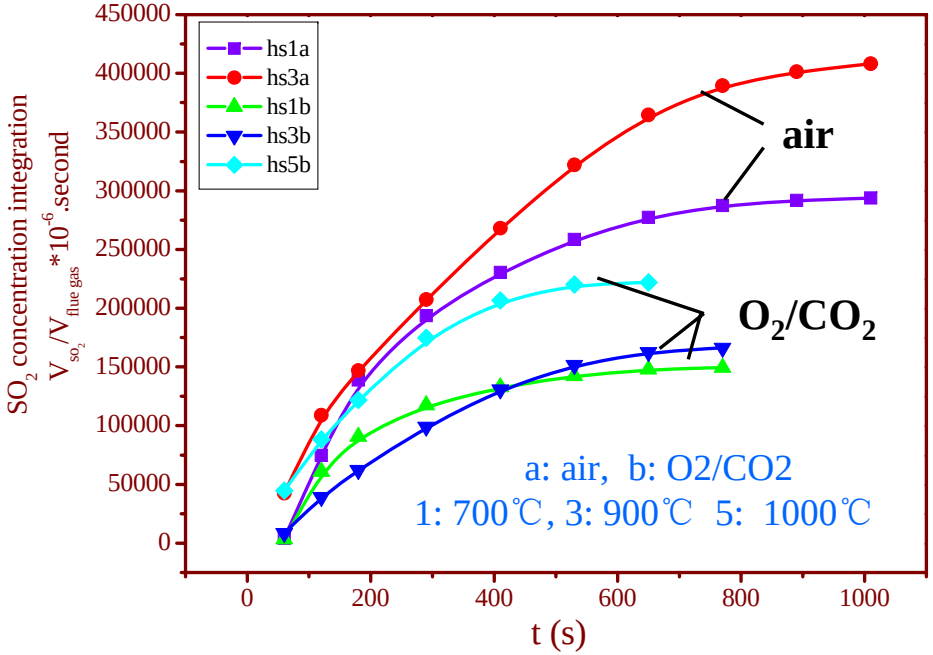
↓

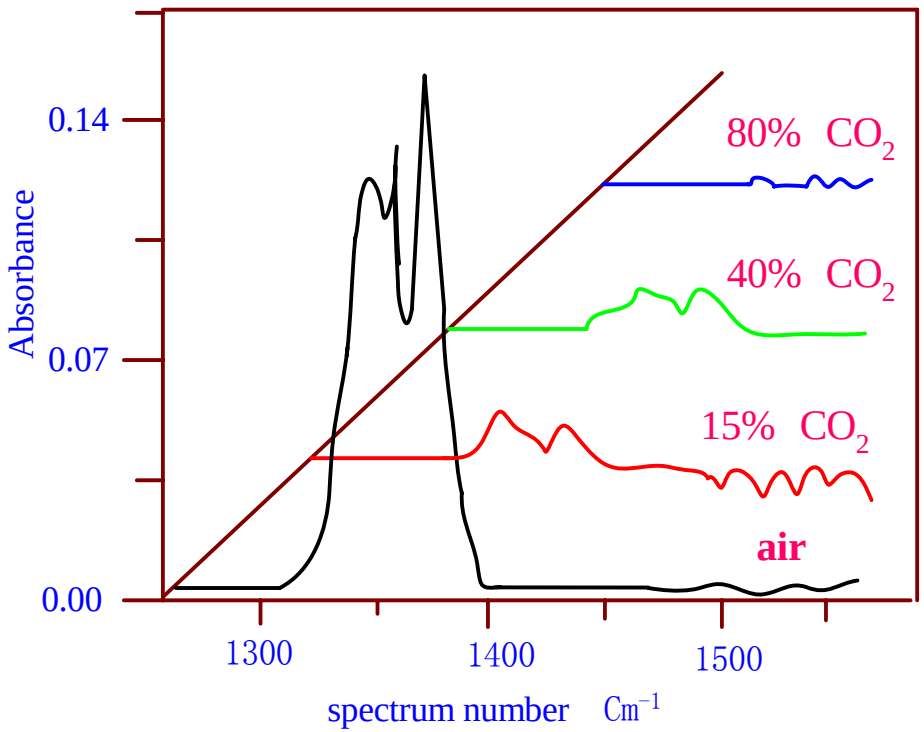
Possibility of high in-furnace desulfurization efficiency

↓

Characteristics and mechanisms: unknown

SO2 Emission





$$C + CO_2 \rightarrow 2CO$$

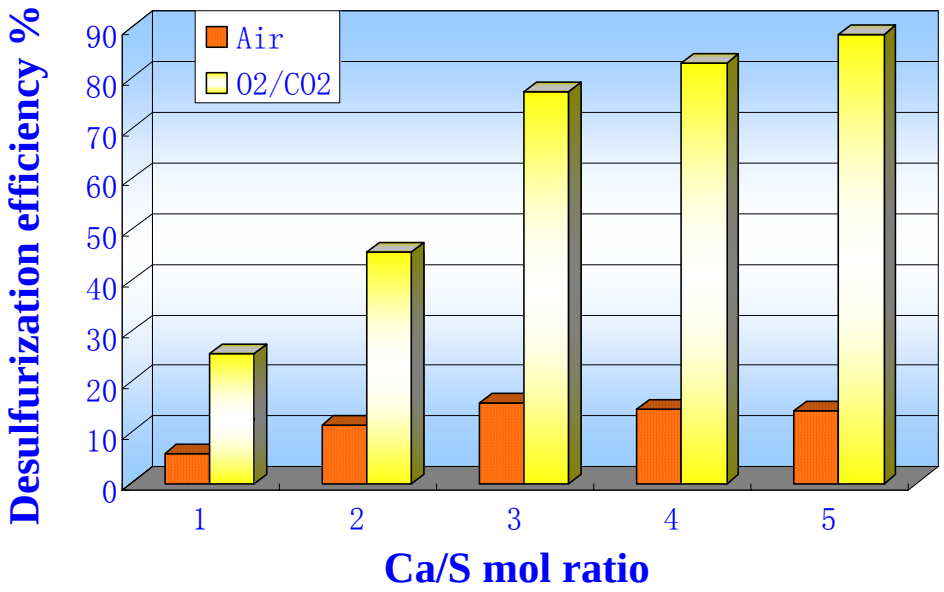
$$2CO + SO_2 \rightarrow CO_2 + S$$

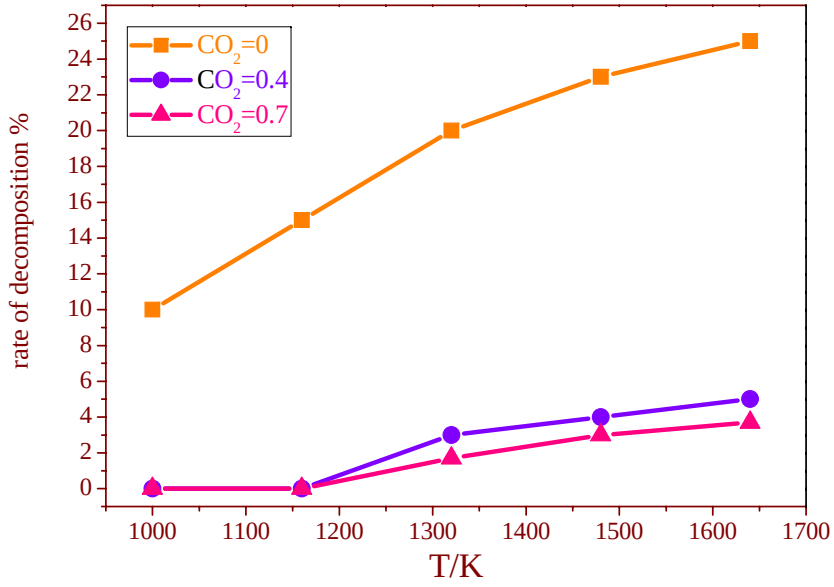
$$CO + S \rightarrow COS$$

$$SO_2 + 2COS \rightarrow 2CO_2 + \frac{3}{2}S_2$$

SO_2 emission decreased about 30-60% for different coals at different temperatures

SO2 Removal by Limestone





CaSO4 decomposition

- The presence of high concentration CO_2 can improve the SO_2 removal efficiency with limestone injection.

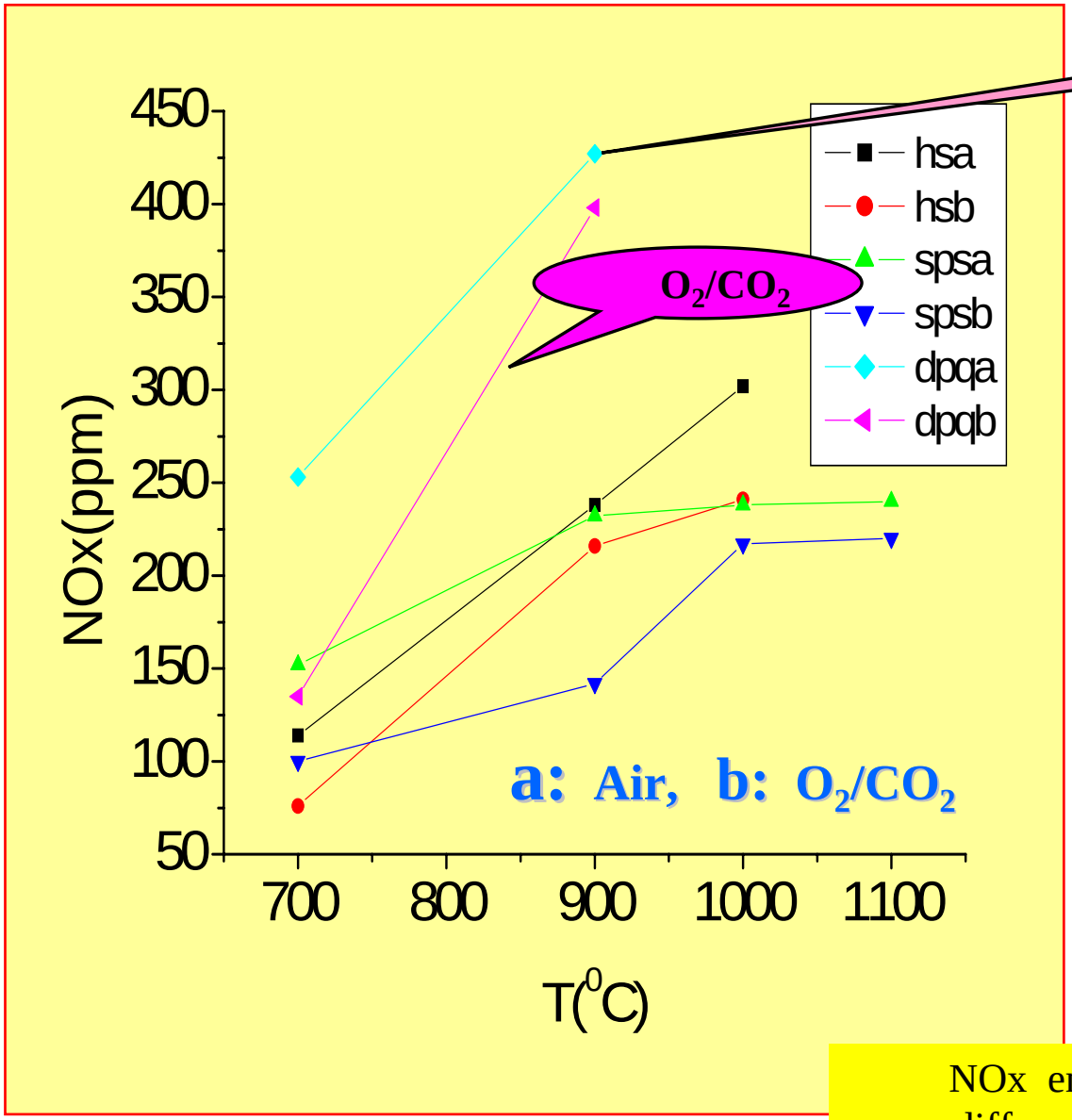
SO2 reduction mechanism in Oxyfuel recycle combustion system

- **Small amount of SO2 emission**
  - **Small amount of exhausted gas**
  - **COS formation**
  - **SO2 retention by CaO in the coal**

- **Higher Limestone desulfurization efficiency**
  - **Increase of η due to inhibition of CaSO4 decomposition**
  - **Increase of η due to recirculation of flue gas (sorbents)**

About four times longer than in conventional coal combustion owing to gas recirculation

NOx Emission



$C+CO_2 \rightarrow 2CO$

$NO + CO \rightarrow CO_2 + 1/2\ N_2$

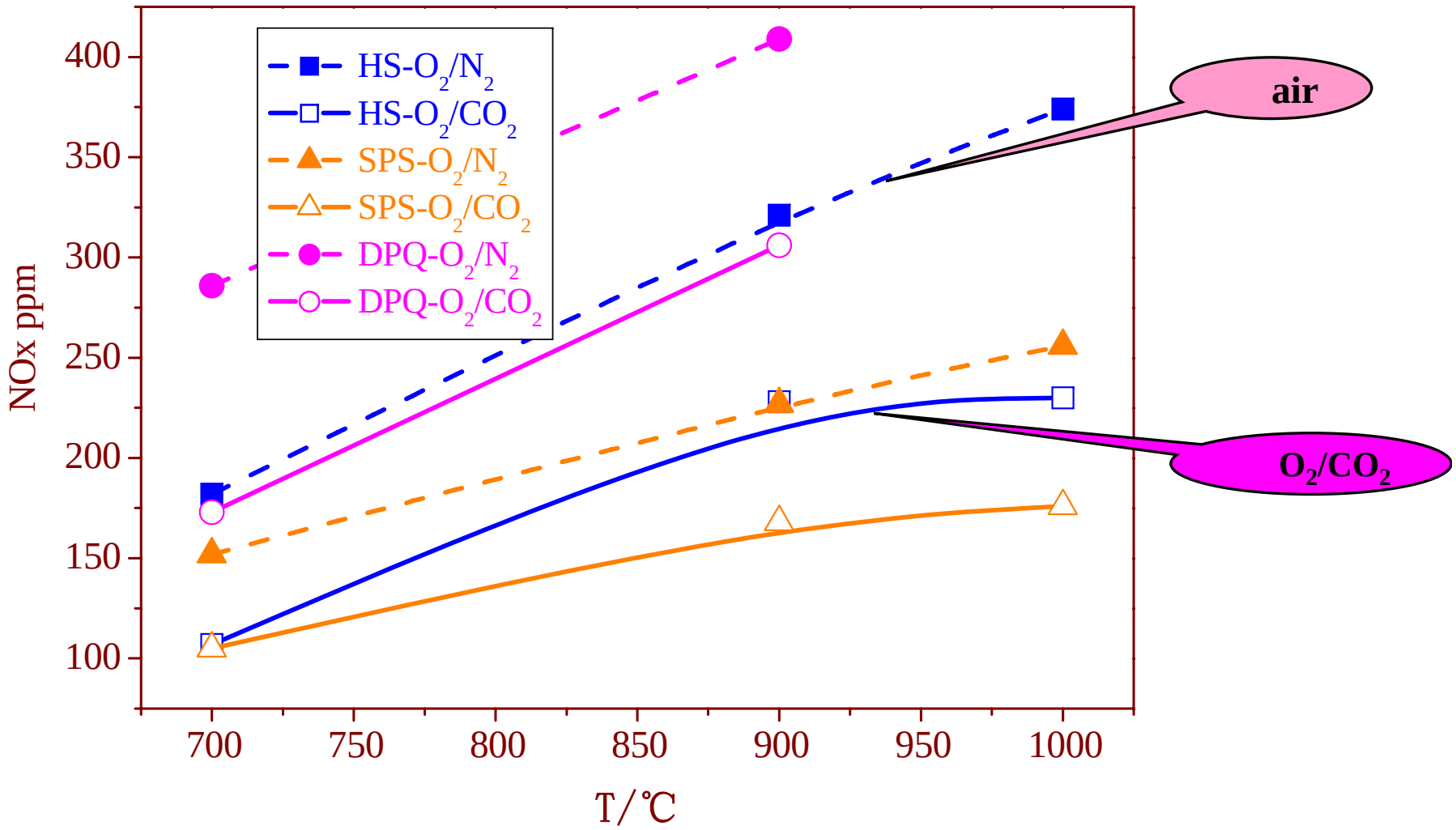
$C+2NO \rightarrow CO_2+N_2$

$2C+2NO \rightarrow 2CO+N_2$

煤中矿物质尤其是Fe和Ca的
存在对半焦与NO的反应有催化作用.

NOx emission decreased about 10-40% for different coals at different temperatures

NOx Emission in Desulfurization

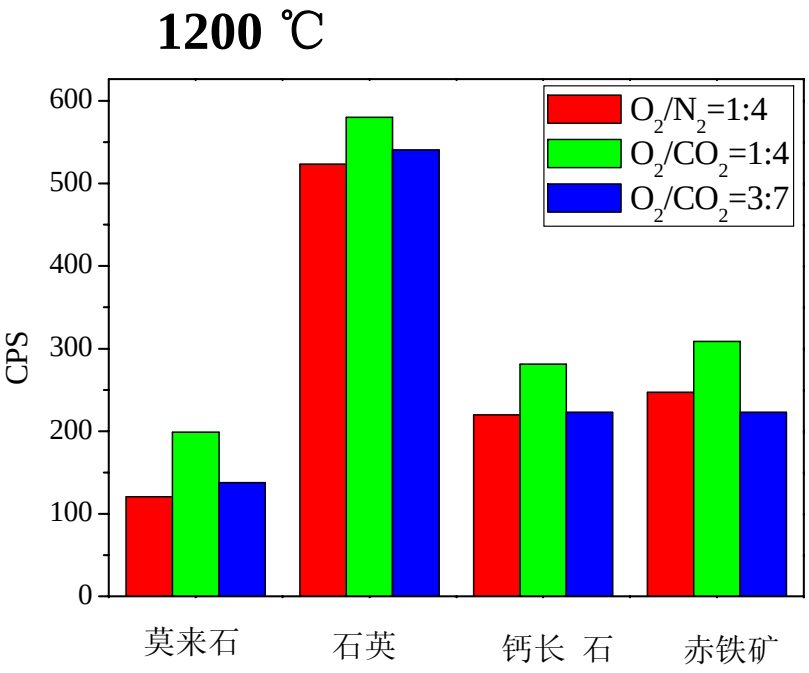


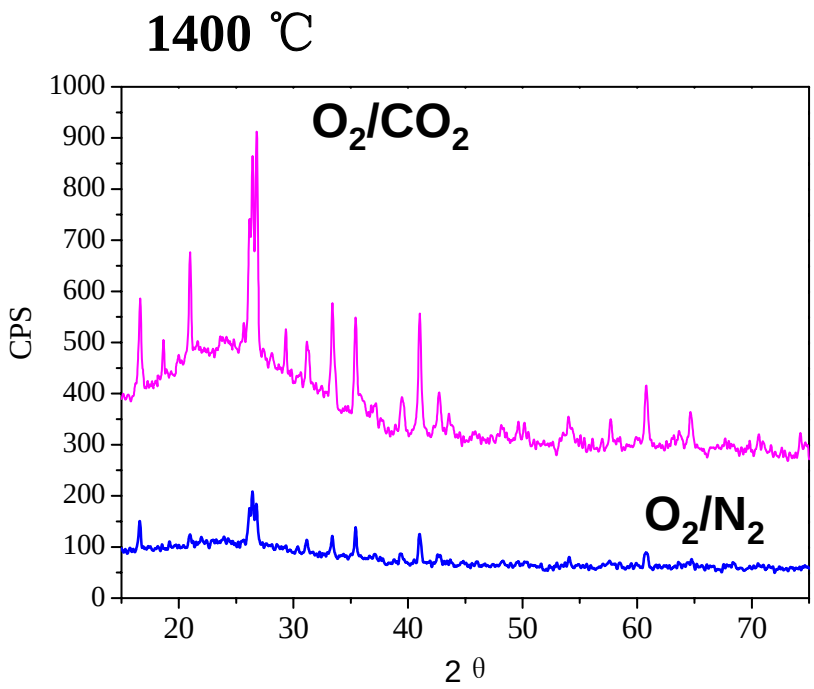
CaCO3的存在对CO与NO的表面反应有催化作用.

NO reduction mechanism in Oxyfuel recycle combustion system

- **Small amount of NO emission**
  - **Small amount of exhausted gas**
  - **No thermal NO**
- **Decrease of N conversion due to increase of CO2 concentration**
- **Reduction of recycled NO in the furnace**
- **Interaction between fuel-N and recycled NO**

Mineral tranformation





1200 ℃时不同气氛下主量矿物相无明显变化

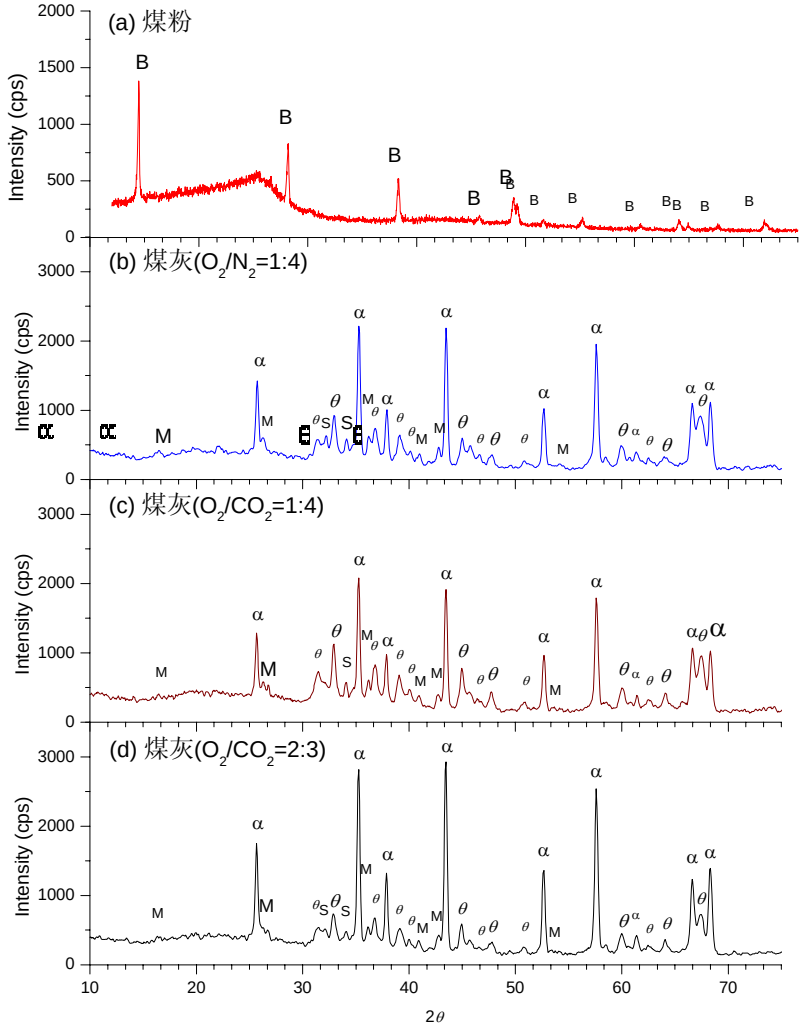
高浓度CO_2下晶相矿物含量较高

高浓度CO_2气氛使得燃烧时煤颗粒温度降低，熔融程度降低

Mineral transformation

high-aluminum coal
DTF results

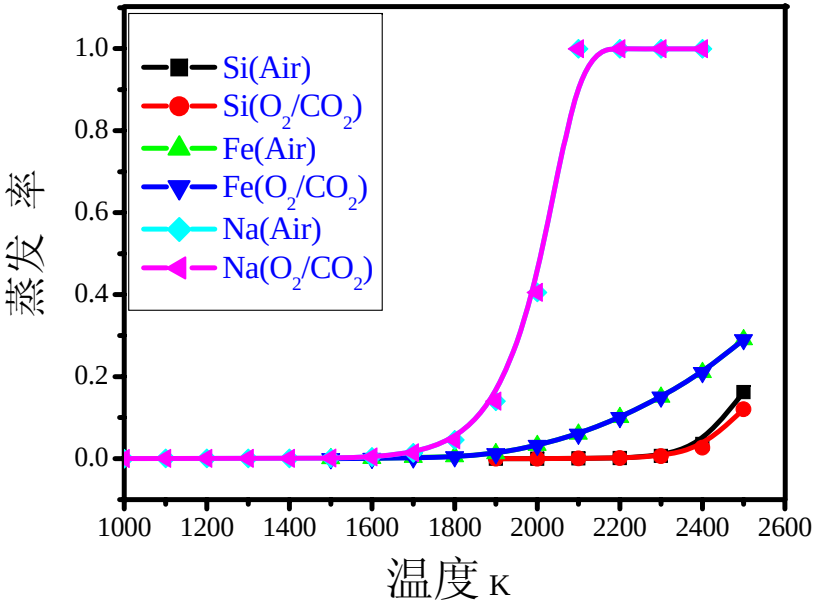
- No new mineral phase was identified for O2/CO2 case, but did affect the relative amounts of phases in ashes
- α-Al_2O_3 /θ-Al_2O_3 increases with increasing O2:CO2



XRD spectra of the pulverized coal and its DTF ashes
(B, boehmite; , -Al_2O_3; , -Al_2O_3; M, mullite; S, Ca/Al-containing silicates).

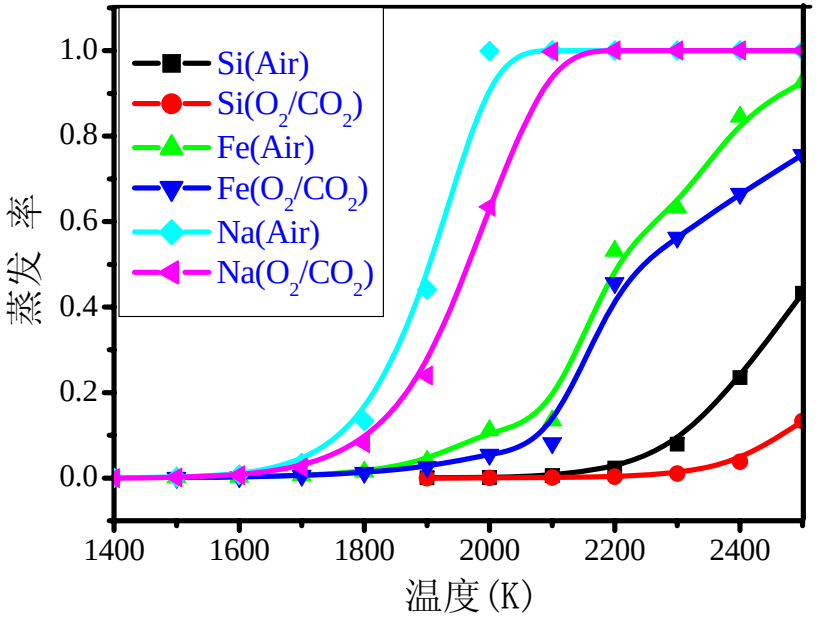
Comparison of Mineral evaporation

氧化性条件



No significant influence under oxygen rich condition

还原性条件



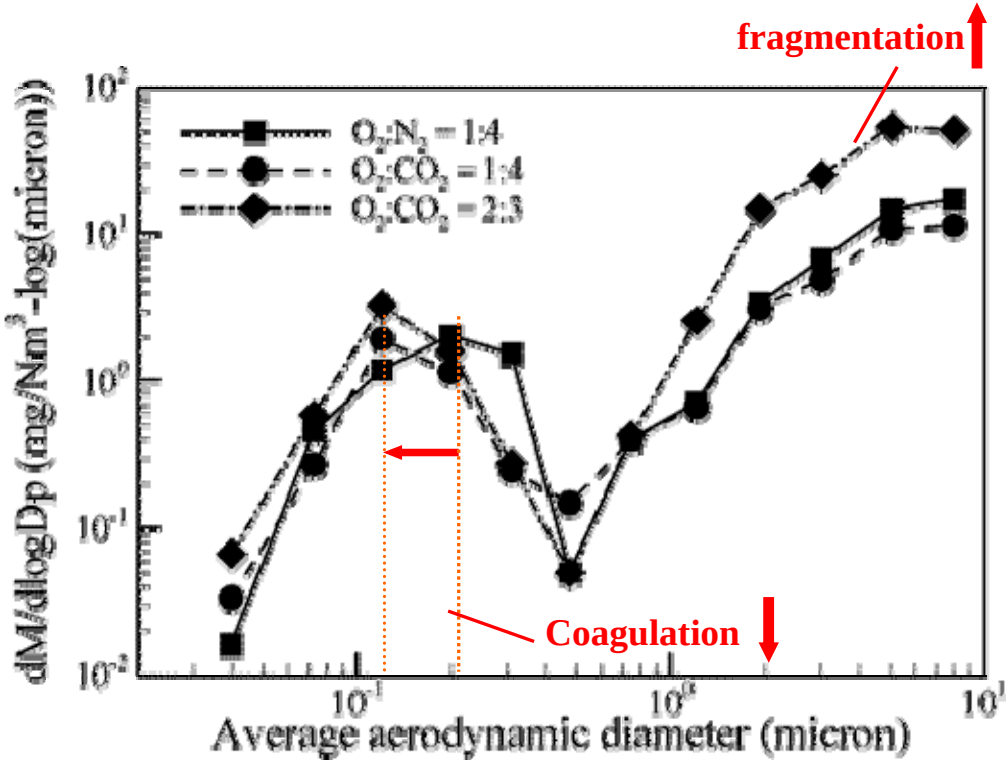
Retention under oxygen lean condition

高浓度CO_2气氛使得还原性条件下CO/CO_2值降低，抑止矿物的蒸发：

$$MO(s)+CO(g)=CO_2(g)+M(g)$$

particulate matter (PM) emission

- Bi-modal distribution
- O_2:CO_2=1:4
  Tp ⇓ , $PM_{0.1}$ PM_{10}⇓ 30%
- O_2:CO_2=2:3
  Tp ⇑ , $PM_{0.1}$ PM_{10}⇑ 2~4

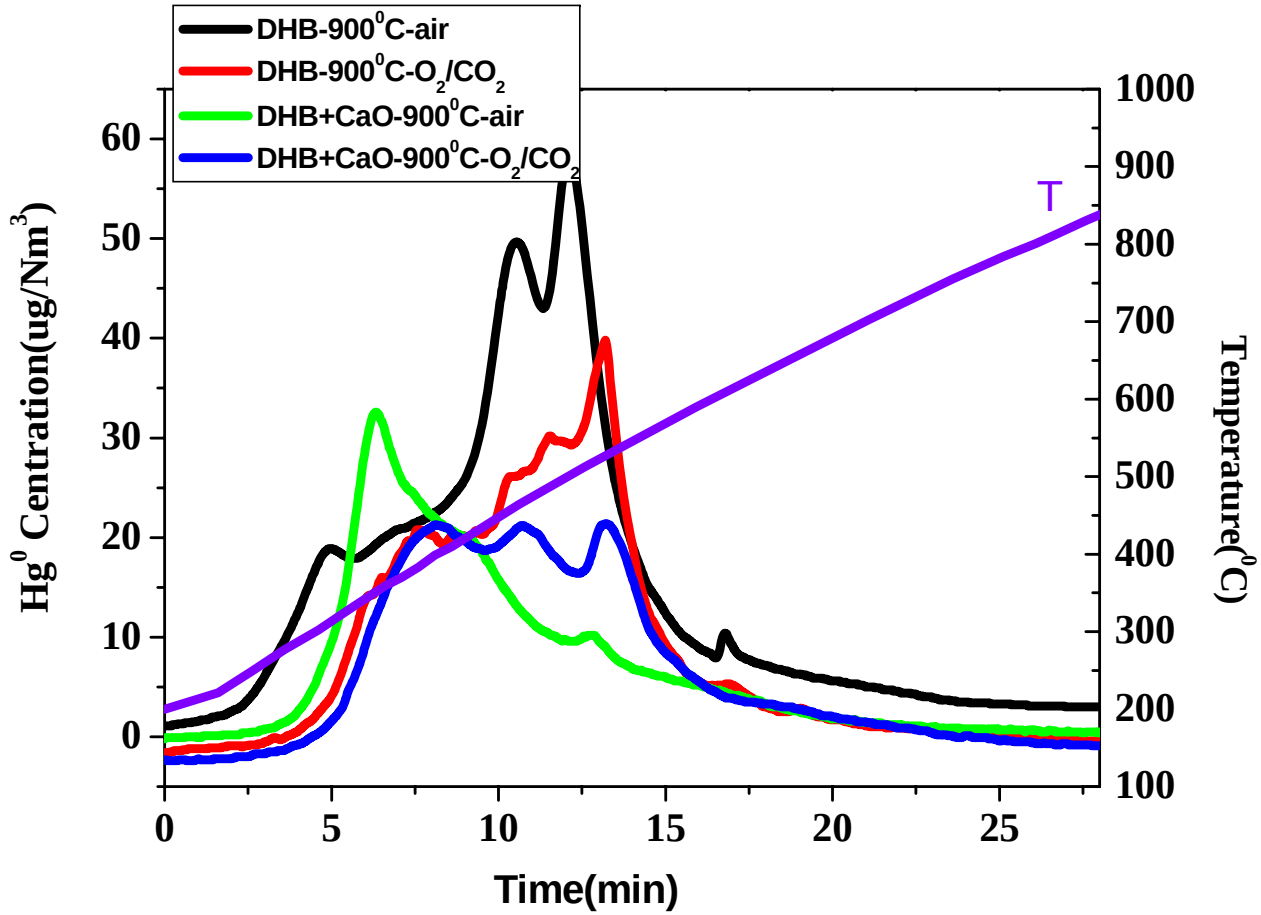


T_{gas} = 1673K

Size distribution of the ash particles collected in the DLPI

Shen et al., Energy Fuel, 2007, 21(2):435

Hg release and capture by CaO



新型燃烧方式下Hg的释放减少； CaO加入后两种气氛下Hg的析出峰明显降低；CaO可捕获烟气中部分气相Hg2+(g)；

What's already approved (summary)

- **No practical/technology barrier to implement Oxy-firing**
- **NOx/SOx emission can be controlled by low cost and simple approach**
- **Improved mineral/PM/Hg behavior in comparison of air combustion**
- **Weakness of coal ignition、char oxidation and burn-out can be avoid by increase partial pressure of oxygen from 21% to 29%**
- **A compact combustion chamber and smaller FGCD can be used to decrease the investment**

Ongoing and future work

- Technology-economics evaluation
- Char oxidation
- Flame stability and radiation
- Mineral/PM/Hg behavior
- More data sets from pilot facility
- CFD sub-models develop and validation

Difficulty or barrier

- Policy drive
- Government support
- Industry participant
- Cost reduct methods (CLC, OTM)
- ‘Clean coal’ image or roadmap
- ….

Thank You!