



# Research & Development and Its Application of Circulating Fluidized Bed Boiler Technology in China

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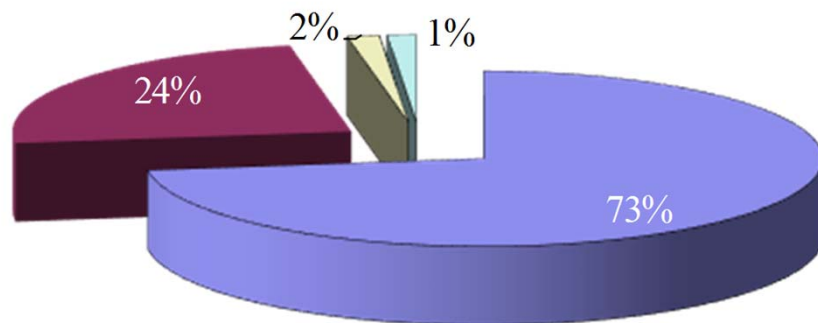
3.2  $\text{NO}_x$  controlled by low  $\text{NO}_x$  combustion

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## 1. Circulating fluidized bed (CFB) for electric power generation in China

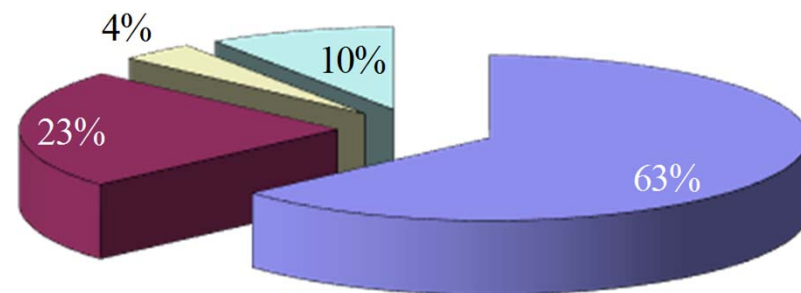
- ❑ Coal is the dominate fuel in China
- ❑ Coal is dirty, its utility produces pollution emission
- ❑ Washing coal is an effective way to control the coal pollution
- ❑ Coal washing by-products a large number of low heating value fuel
- ❑ It should be used cleanly

2004-total capacity 445 GW



■ coal power ■ hydro power ■ nuclear power ■ oil & gas

2020-total capacity 1600 GW



■ coal power ■ hydro power ■ nuclear power ■ oil & gas

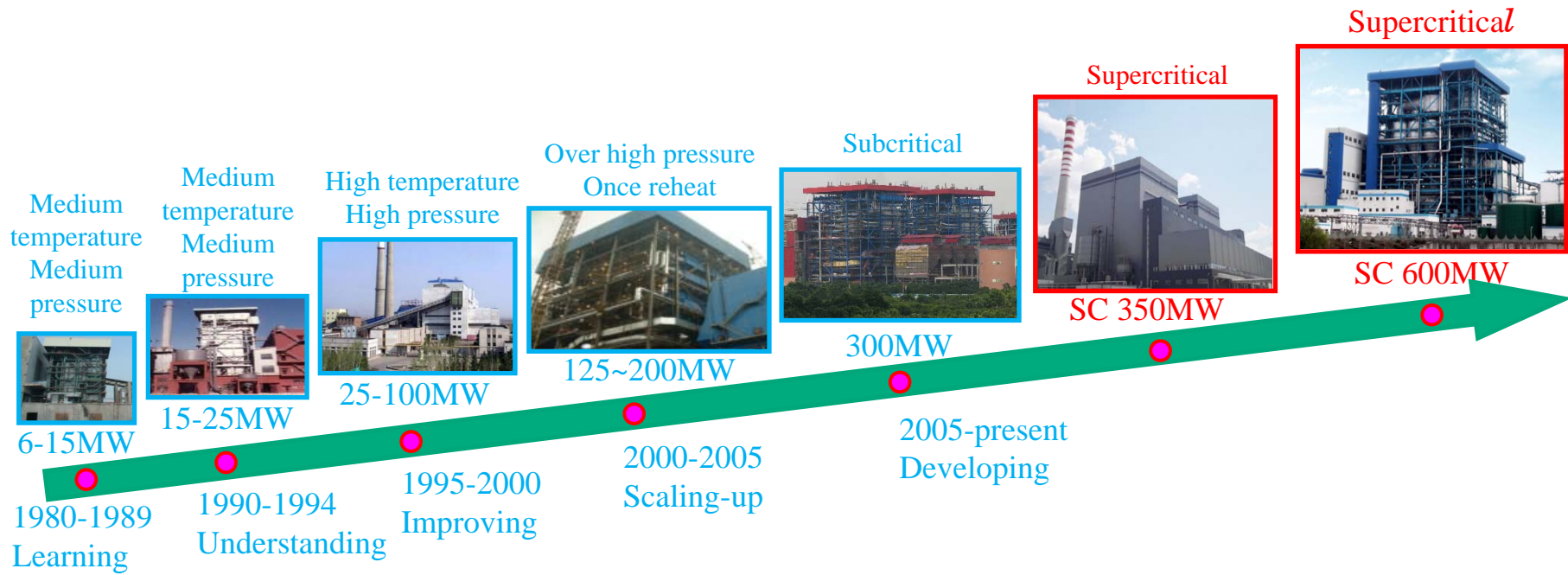
## 1. Circulating fluidized bed (CFB) for electric power generation in China

- ❑ The unique advantages of CFB is high fuel flexibility and low cost emission control.
- ❑ CFB boiler is one of the best way to deal with low grade coal.
- ❑ CFB is very important for the countries in which coal is major energy resource
- ❑ CFB boiler is playing an important role of electric power generation in China.



# 1. Circulating fluidized bed (CFB) for electric power generation in China

including 300MW subcritical CFB boilers, 350MW & 600MW supercritical CFB boilers which dominates Chinese CFB market. Now, the ultra-super critical CFB boiler with capacity of 660MW is being developed.



## 1. Circulating fluidized bed (CFB) for electric power generation in China

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as well as the maximum continuous running time. The CFB boiler plays a essential role in Chinese power generation, the total capacity of CFB unit is more than 100 GW.

And CFB boilers are widely used in China. The CFB boiler number increases every year, by the end of two thousand fifteen, there are about two thousand and eight hundred unit were in commercial operation, and more than three hundreds were under construction. In the same time, the availability of CFB power plant increases also.

## 1. Circulating fluidized bed (CFB) for electric power generation in China

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- ❑ China could supplied varies capacity CFB boiler with varies parameter and varies kinds of fuel: varies kinds of coal, biomass, petroleum coke, and RDF.
- ❑ There are many boiler workers devotes themselves for CFB, such as:
  - Harbin Boiler Workers co., LTD.
  - Dongfang Boiler Group co., LTD.
  - Shanghai boiler Workers co., LTD.
  - Taiyuan Boiler Group co., LTD.
  - Wuxi Huaguang boiler co., LTD.
  - Jinan boiler group co., LTD.
  - ...
- ❑ The CFB boiler performance becomes better and better even better than PC boiler in China. This is due to the technical progress. Here, I would like to take some time to shown two major examples. The first one is:

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## 2. Supercritical CFB boiler design and operation in China

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- ❑ CFB performs very well in fuel flexibility but is not very efficient in power generation
- ❑ Increasing steam parameter to supercritical is the way to improve the power generation efficiency

### Milestone of SU CFB in China

2000—technology feasibility study of SC CFB

2003—the classification of key questions of SC CFB

2006—research program on SC CFB

2007—600MW SC CFB demon. approval

2011—approval of invest.

2012 end—erection

2013.4—commissioning and full load test

2014.7: performance test

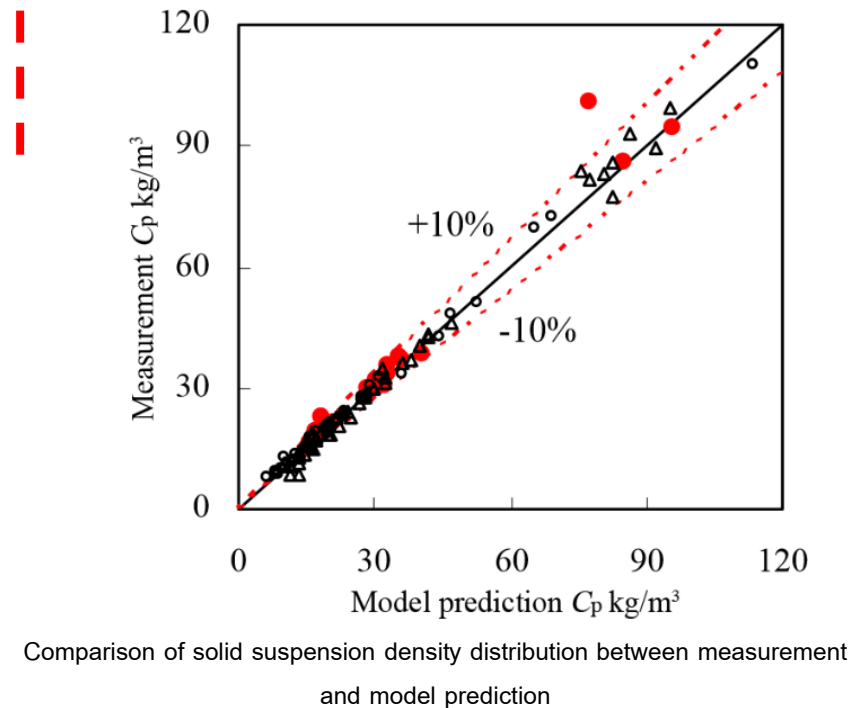
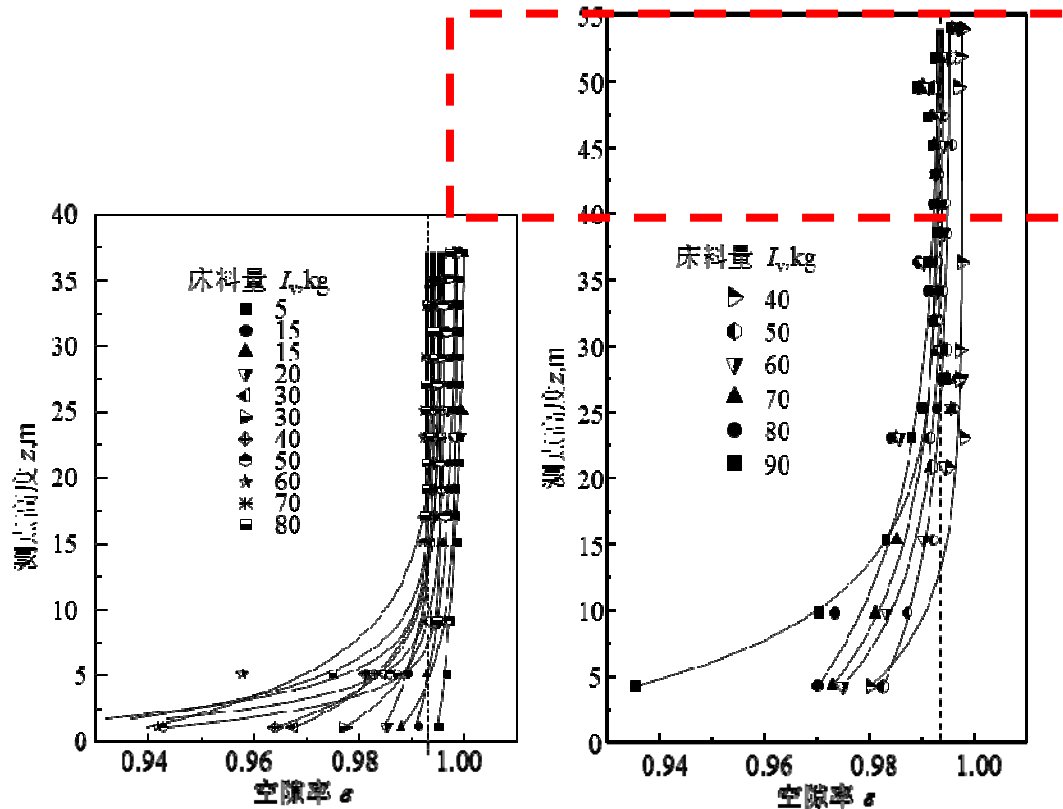
It was realized the CFB future is supercritical

From then a series of investigation on supercritical CFB were conducted including two phase flow, combustion and heat transfer in a larger furnace that never be

## 2. Supercritical CFB boiler design and operation in China

### 2.1 Gas-solid flow of large riser

- The height of a 600MW CFB is 15 m higher than that of a 300MW.
- The gas- solid two-phase flow was studied

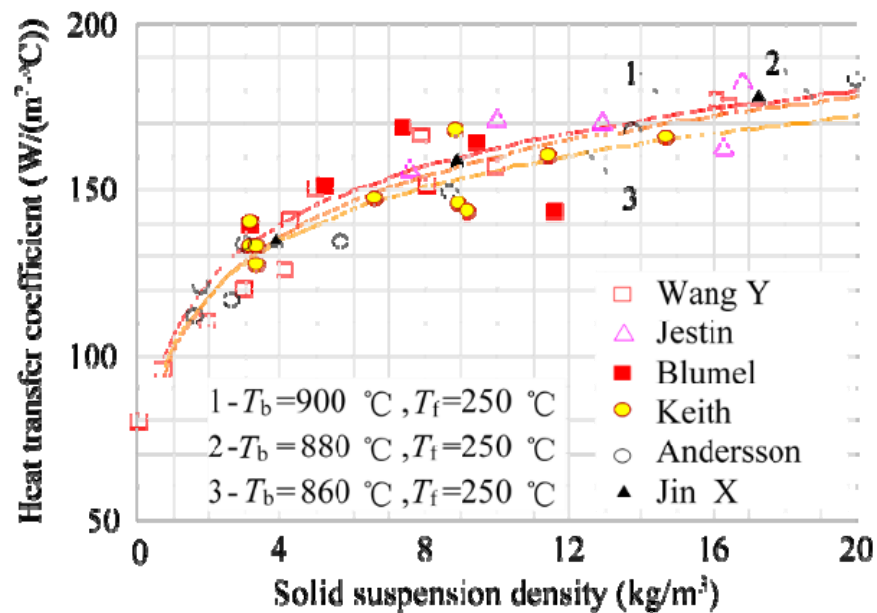


A 55m height CFB test facility was built to investigate the fluidization in such high riser. Based on the systematic measurements in this rig and many other real CFB boilers, a model predicting solid density is suggested. It seems that the model is reasonable by comparison between model and test.

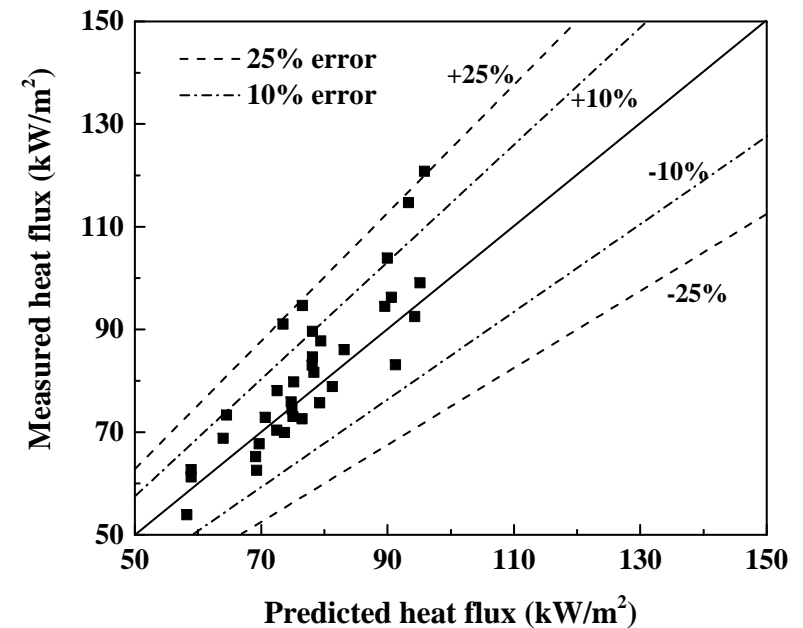
## 2. Supercritical CFB boiler design and operation in China

### 2.2 Heat flux in a CFB boiler

- The safety of the water wall in a SC boiler depends on the heat flux
- Heat flux in a CFB boiler is unknown
- The flux distribution model is suggested



Heat transfer coefficients vs particle density and temperature



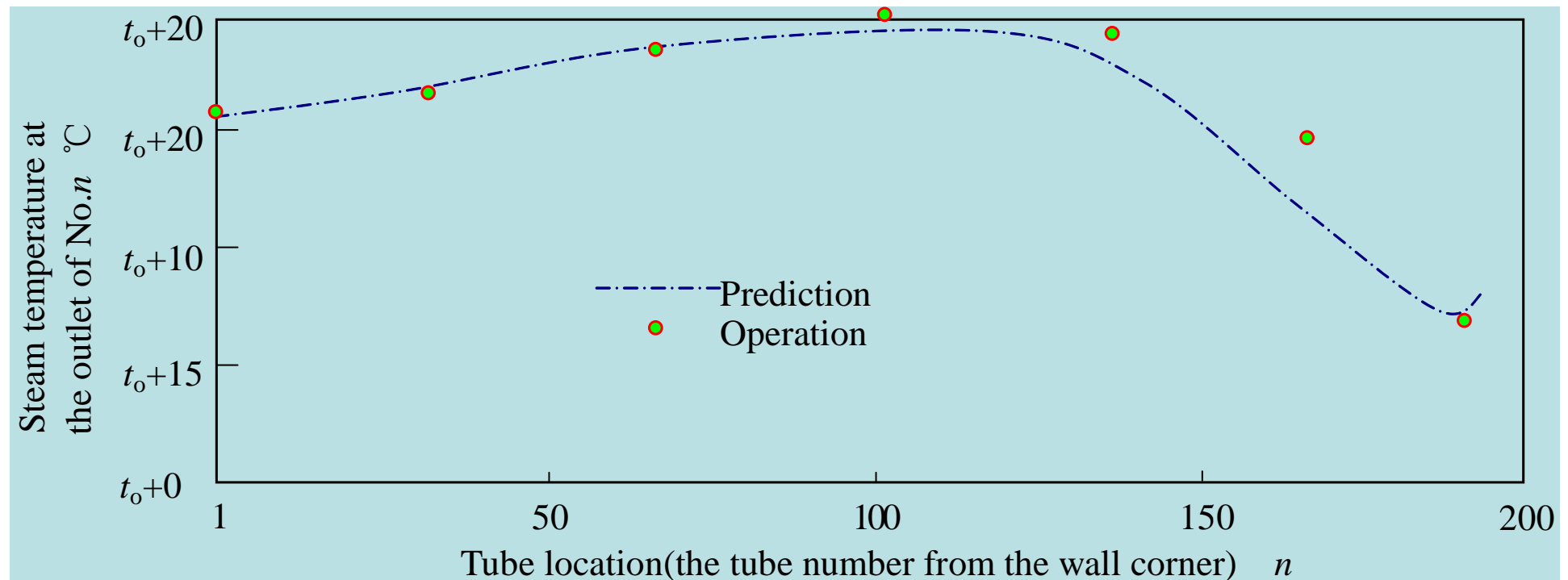
Heat flux model accuracy

**This model is the combination of the local heat transfer model and solid density distribution model. The heat flux distribution model prediction agrees very well with the measurement.**

## 2. Supercritical CFB boiler design and operation in China

### 2.3 Heat transfer of the supercritical water

- With the heat flux model
- The hydrodynamic of the water wall was calculated
- The prediction agrees well with the real boiler operation

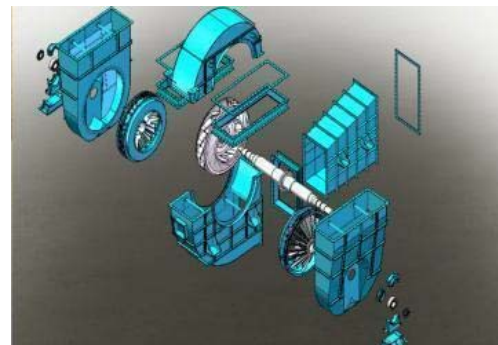
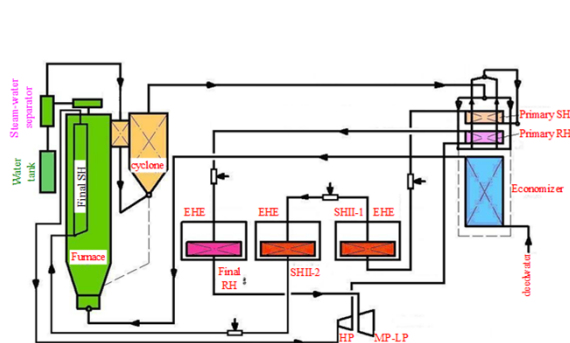
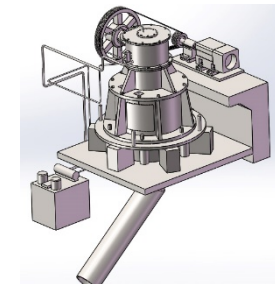
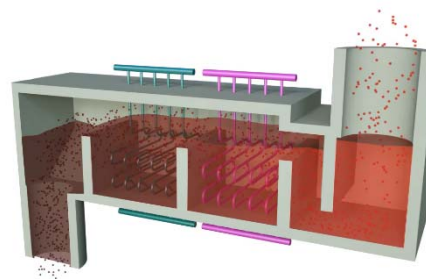
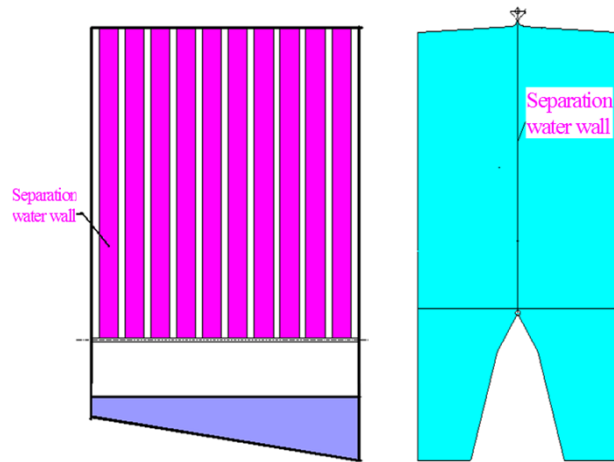


Comparison between model prediction and operation on the water tube outlet temperature

## 2. Supercritical CFB boiler design and operation in China

### 2.4 Practices of SC CFB boiler

- ❑ Based on the clear understanding of supercritical CFB boiler principle
- ❑ A series of patent are invented
- ❑ A new thermal process is created
- ❑ System integration technologies including control are developed
- ❑ The world's first 600MW SC CFB boiler was built in Baima Power Plant



## 2. Supercritical CFB boiler design and operation in China

### 2.4 Practices of SC CFB boiler

Coal in Baima

Item	Unite	Value
Mar	%	7.58
A <sub>ar</sub>	%	43.82
V <sub>daf</sub>	%	14.74
Q <sub>net,ar</sub>	MJ/kg	15.17
S <sub>ar</sub>	%	3.3



- The 600MW SC CFB was successfully demonstrated in Baima Power Plant.
- It was put into commercial operation in April 2014. it runs very well.

## 2. Supercritical CFB boiler design and operation in China

### 2.4 Practices of SC CFB boiler

The performance test data are well matching with the design

item	unit	design	test
Power load	MW	600	601
Living Steam pressure	MPa	25.39	24.81
Living Steam temperature	°C	571	569.88
Reheat steam pressure	MPa	4.149	4.04
Reheat steam temperature	°C	569	566.96
Total attemperation flow	t/h	142	109.2
Furnace temperature	°C	890	~890
Boiler efficiency	%	>91.01	91.52
SO <sub>2</sub> emission	mg/m <sup>3</sup>	<380	192.04
Calcium/Sulfur mol. ratio	mol/mol	2.1	2.07
De-SO <sub>2</sub> efficiency	%	96.7	97.12
NO <sub>x</sub> emission	mg/m <sup>3</sup>	<200	111.94
Particulate emission	mg/m <sup>3</sup>	30	9.34

Beside Baima project, there are also other three 600MW SC CFB boiler are ordered.

## 2. Supercritical CFB boiler design and operation in China

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### 2.4 Practices of SC CFB boiler

- With the research and technologies, 350MW are then developed.
- More than 70 are ordered (3 for oversea). 16 boilers are in operation.



350MW SC CFB boilers in Hequ Power Plant



350MW SC CFB boilers in Guojin Power Plant



350MW SC CFB boilers in Datuhe Power Plant



350MW SC CFB boilers for oversea





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3. Ultra-low emission CFB boiler research and application

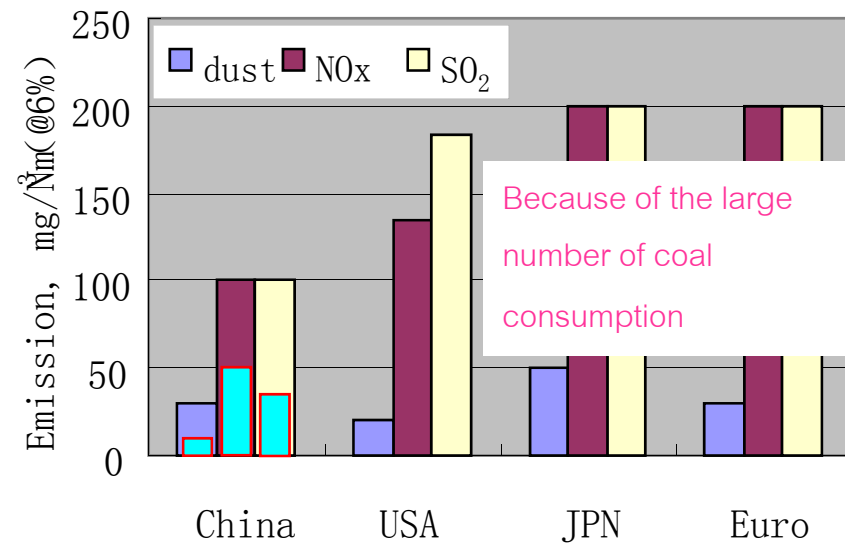
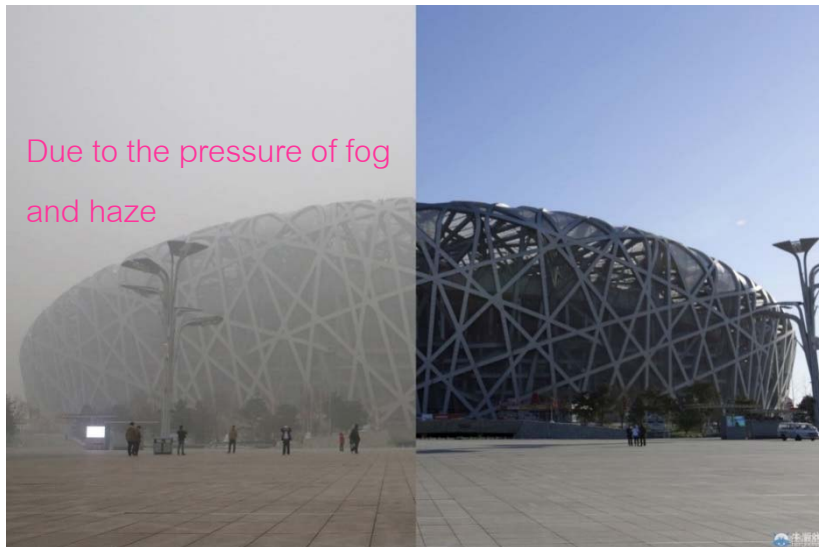
3.1 SO<sub>2</sub> controlled by limestone injection

3.2 NO<sub>x</sub> controlled by low NO<sub>x</sub> combustion

4. Conclusion

### 3. Ultra-low emission of CFB boiler research and application

- One of the CFB boiler advantage is low cost emission control
- CFB matches most regulation by limestone injection and low  $\text{NO}_x$  combustion
- China Emission Limit for Coal-fired Power Plants is most strict  
(GB 13223-2011) :  $\text{NO}_x < 100 \text{ mg/m}^3$ ;  $\text{SO}_2 < 100 \text{ mg/m}^3$   
careful design and operation of a CFB boiler is necessary
- Upgrade action plan requires(2014):  
 $\text{NO}_x < 50 \text{ mg/m}^3$ ;  $\text{SO}_2 < 35 \text{ mg/m}^3$
- CFB is facing great challenge in China



### 3. Ultra-low emission of CFB boiler research and application

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#### 3.1 SO<sub>2</sub> controlled by limestone

#### □ Factors that effect SO<sub>2</sub> emission

the final SO<sub>2</sub> emission concentration  $C$ :

$$C = \frac{1}{A_r k_s \tau \exp\left(-\frac{E}{RT}\right) + \frac{1}{C_o}}$$

What we can do is to increase

$k_s, E$ : reactivity

$A_r$ : surface area

$\tau$ : residence time

$T$ : temperature

$C_o$ : initial SO<sub>2</sub> concentration

Particle size

Cyclone collection efficiency

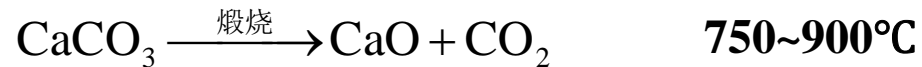
If the cyclone collection efficiency is better, the size of limestone could be finer for the same residence time. If the cyclone collection efficiency is not so good, the limestone has to be coarser.

### 3. Ultra-low emission of CFB boiler research and application

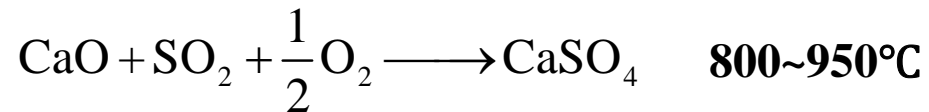
#### 3.1 SO<sub>2</sub> controlled by limestone

##### □ the effect of temperature

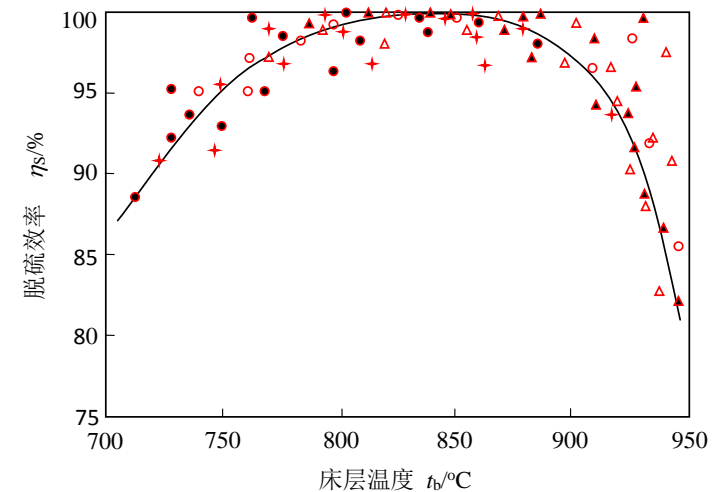
- **Calcination reaction:**



- **Desulphurization reaction:**



- **Decomposition of desulfurization products:**



The effect of temperature on desulphurization efficiency

The temperature should be balanced because the higher temperature causes higher SO<sub>2</sub> capture reaction speed, however, the decomposition speed of desulfurization products is also increases. The temperature is optimized to around 850C.

### 3. Ultra-low emission of CFB boiler research and application

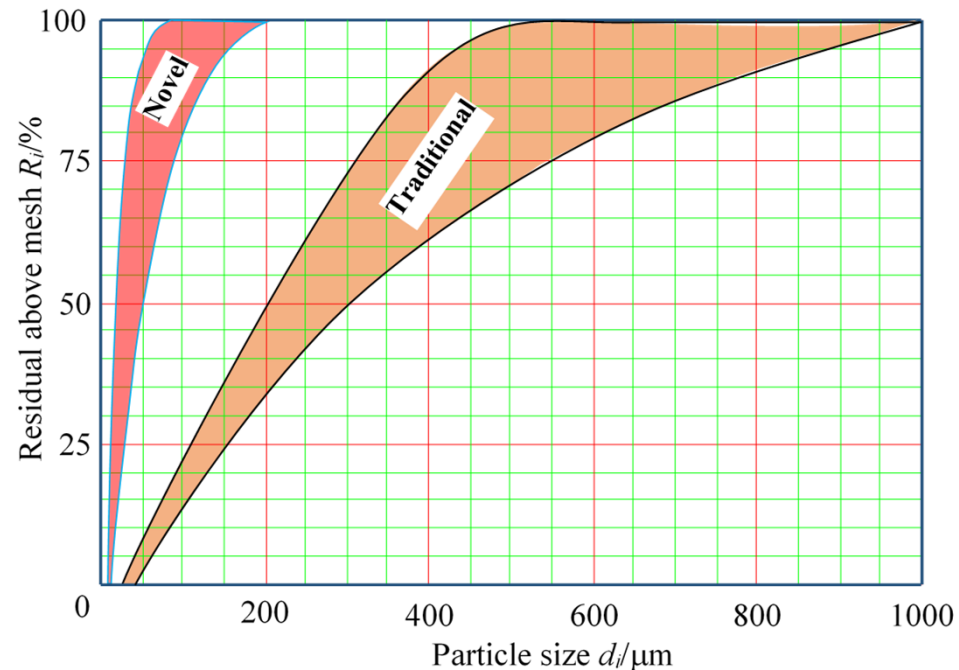
#### 3.1 SO<sub>2</sub> controlled by limestone

- The cyclone collection efficiency should be improved:

fly ash  $d < 50 \mu\text{m}$ , bottom ash  $\bar{d} < 200 \mu\text{m}$

In the optimized temperature,

- A new limestone size distribution : limestone particle size could be smaller



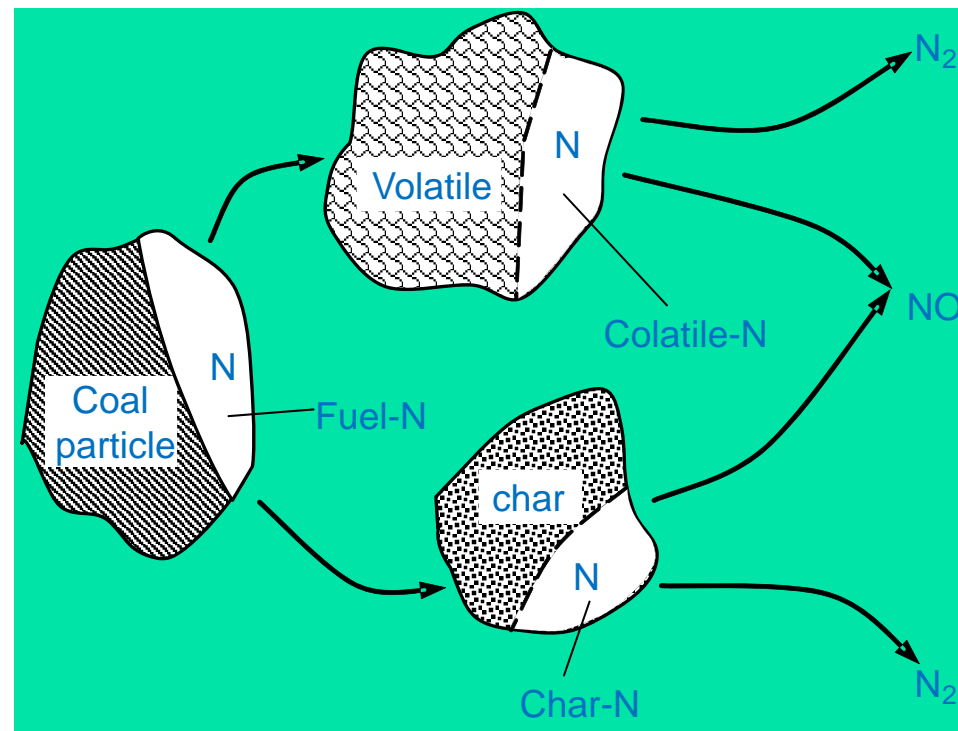
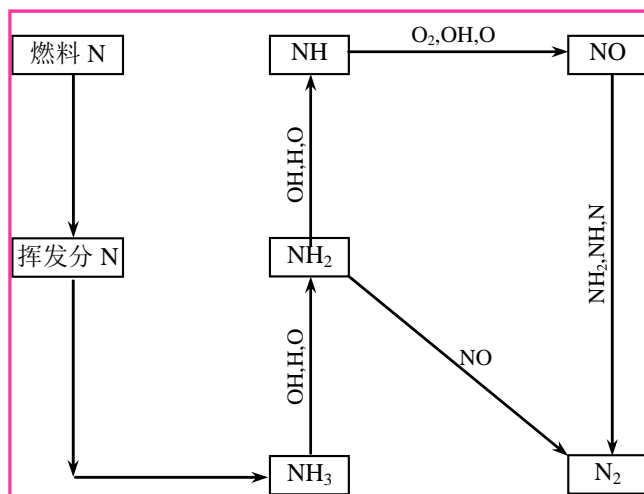
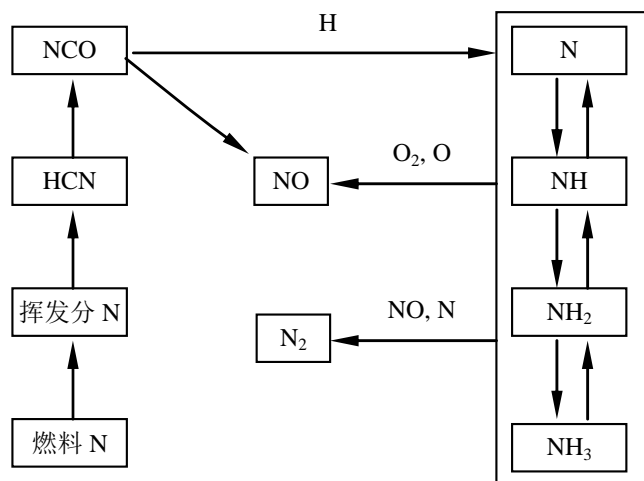
**Recommended particle size distribution of limestone for higher efficiency SO<sub>2</sub> capture**

- The original SO<sub>2</sub> emission could be less than 35 mg/m<sup>3</sup>

### 3. Ultra-low emission of CFB boiler research and application

#### 3.2 NO<sub>x</sub> controlled by low NO<sub>x</sub> combustion

□ In CFB combustion, most NO<sub>x</sub> is fuel NO<sub>x</sub>

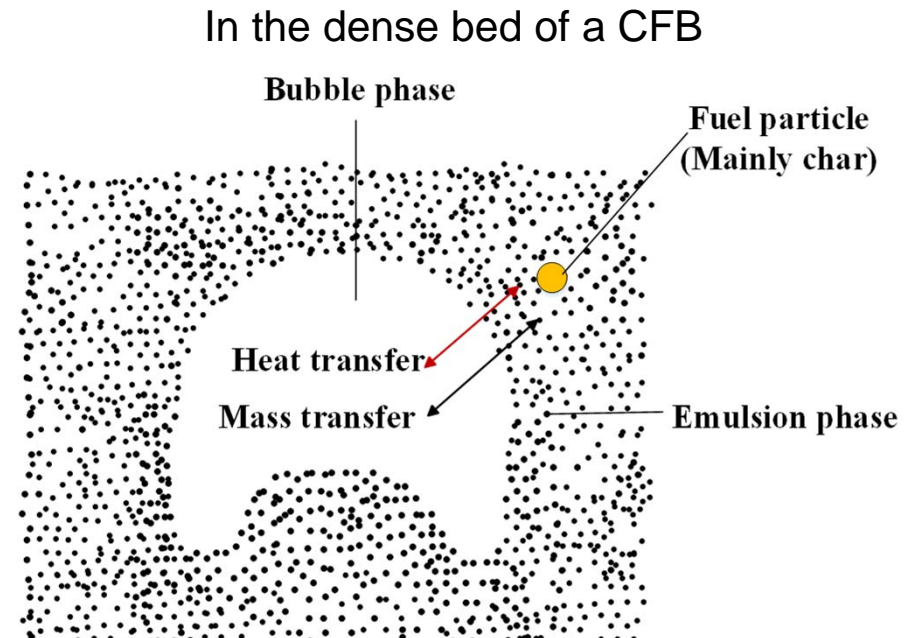
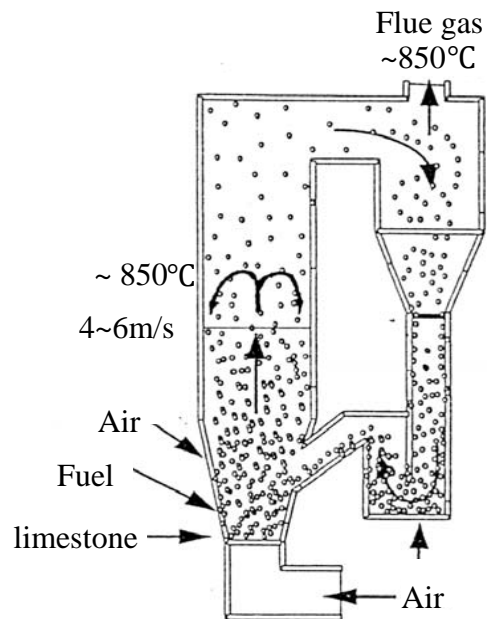


So the combustion atmosphere should be controlled carefully to reduce the formation of NO<sub>x</sub> from fuel Nitrogen.

### 3. Ultra-low emission of CFB boiler research and application

#### 3.2 NO<sub>x</sub> controlled by low NO<sub>x</sub> combustion

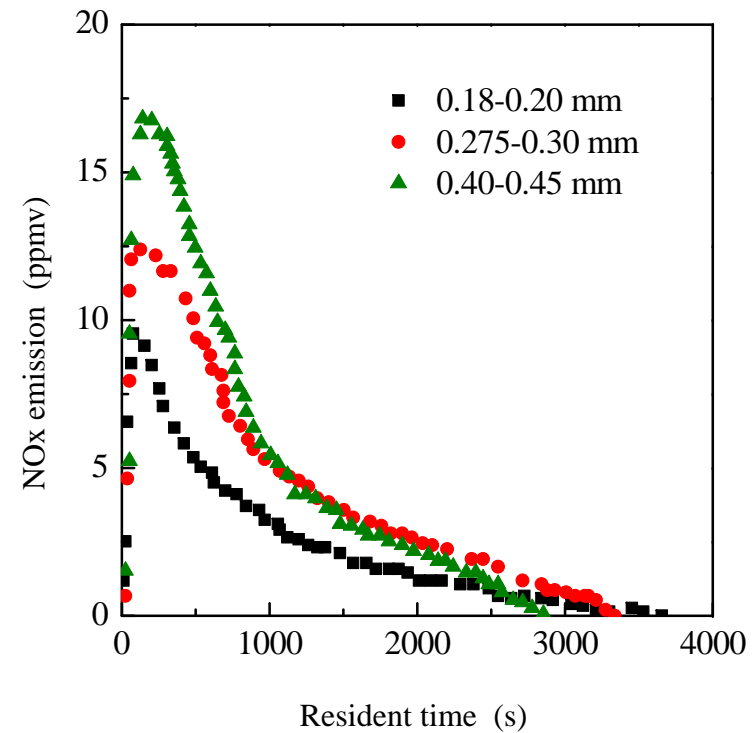
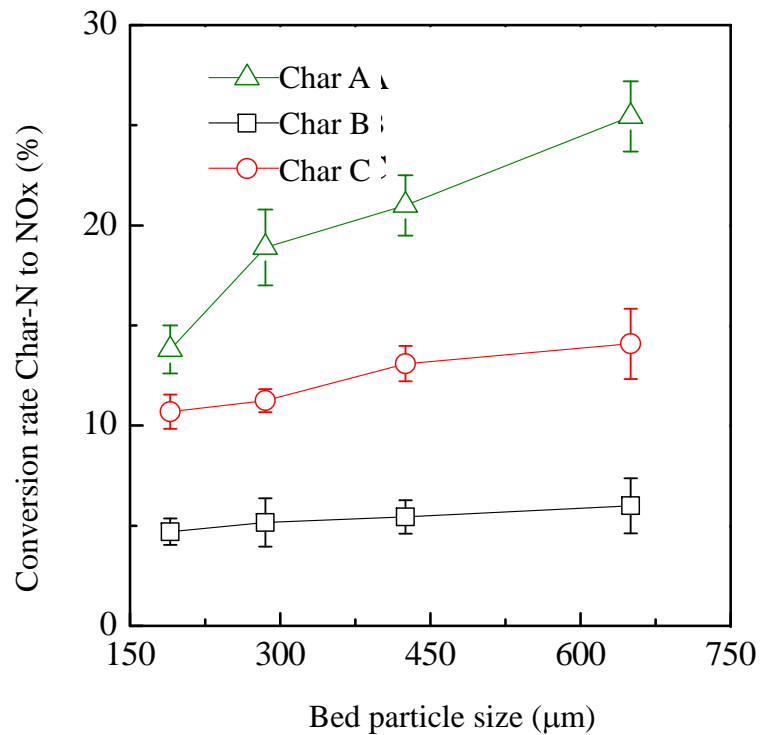
- ❑ The fuel particles are in emulsion phase. The gas pass through it at minimum velocity. This velocity depends on particle size.
- ❑ The mass transfer in the emulsion phase is also depends on the particle size. The trend is same
- ❑ The finer the particle, the less the gas velocity, the less the Oxygen, the more reduced the atmosphere.



### 3. Ultra-low emission of CFB boiler research and application

#### 3.2 NO<sub>x</sub> controlled by low NO<sub>x</sub> combustion

□ The effect of particle size on NO<sub>x</sub> emission in dense bed is confirmed by experimental.



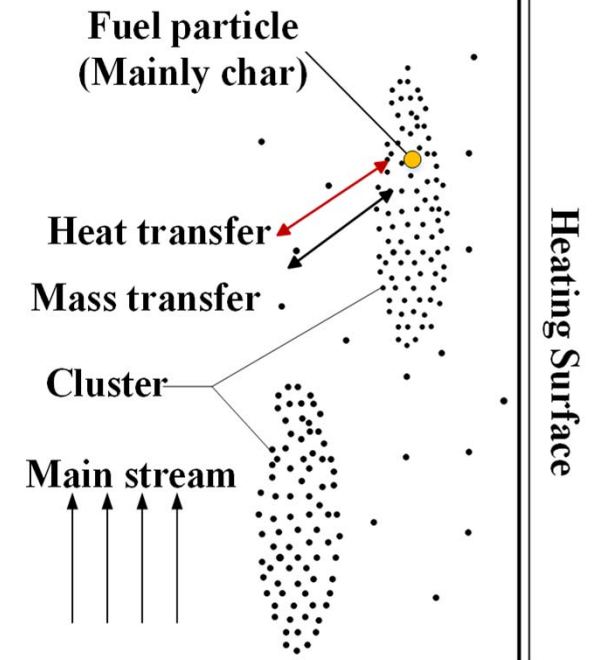
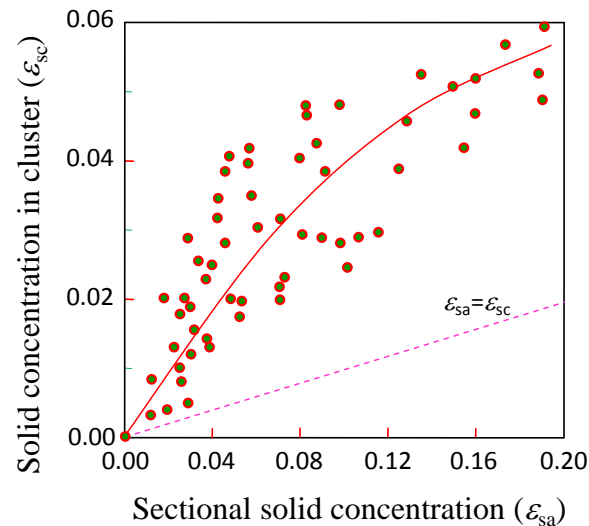
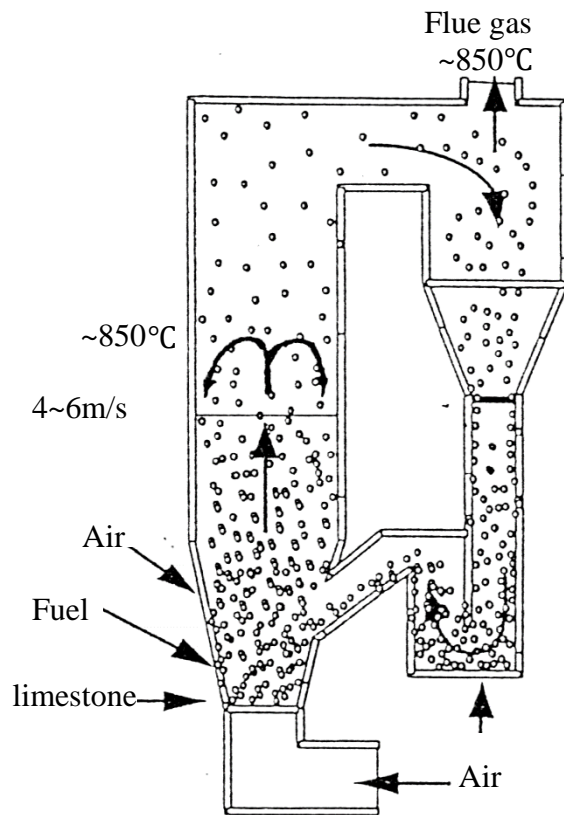
With the bed particle size decreasing, the NO<sub>x</sub> emission decreases.



### 3. Ultra-low emission of CFB boiler research and application

#### 3.2 NO<sub>x</sub> controlled by low NO<sub>x</sub> combustion

- ▣ The combustion behavior in free board is similar as that in dense bed. The cluster is enhanced and its density is higher by smaller particle size or higher circulating flow rate. The finer the particle and the bigger the circulating flow rate, the more reduced the atmosphere.

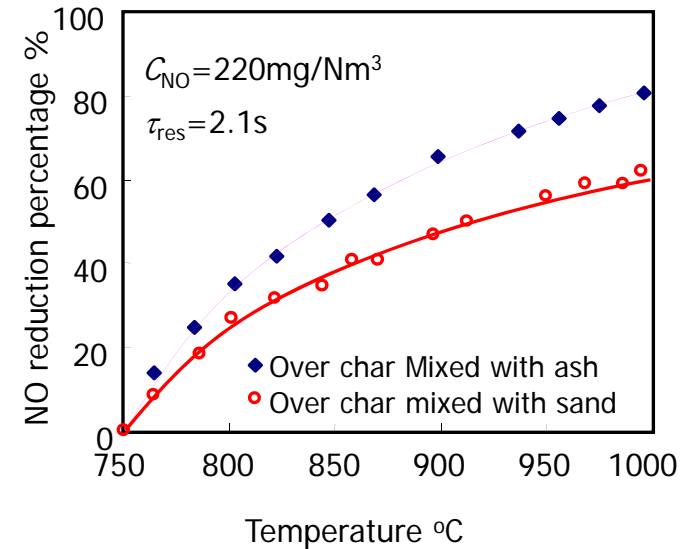
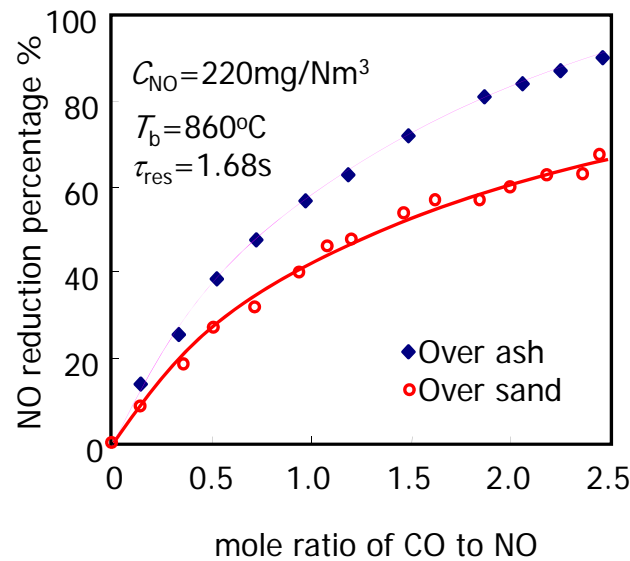
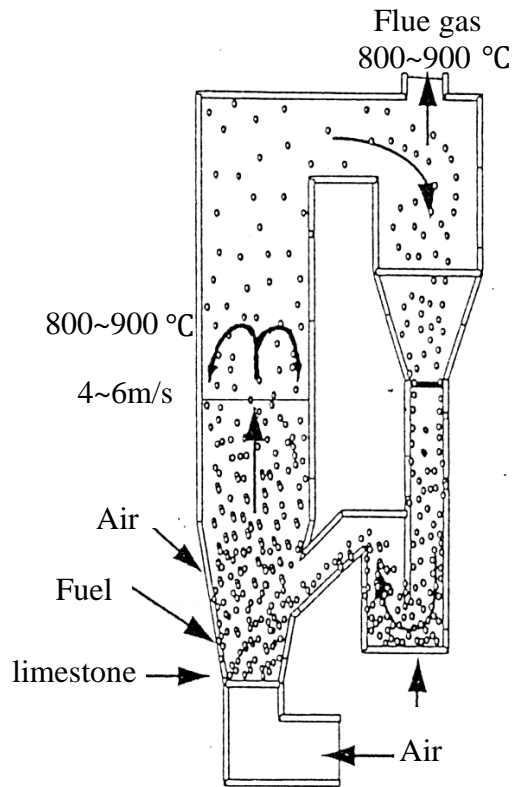


### 3. Ultra-low emission of CFB boiler research and application

#### 3.2 NO<sub>x</sub> controlled by low NO<sub>x</sub> combustion

□ The reduction of NO<sub>x</sub> by CO and Char decreases NO<sub>x</sub> emission.

The concentration of carbon monoxide in CFB is pretty high



$$k_{\text{NO-CO}} = 4.43 \times 10^{10} \exp\left(-\frac{9.561 \times 10^7}{RT}\right) \gamma_{\text{ash}}$$

$$k_{\text{NO-char}} = 4.41 \times 10^{12} \exp\left(-\frac{2.063 \times 10^5}{RT}\right) \gamma_{\text{ash}}^{2.92}$$

$$\gamma_{\text{ash}} = X_{\text{SiO}_2} + 1.18X_{\text{Al}_2\text{O}_3} + 4.74X_{\text{CaO/MgO}} + 110.23X_{\text{Fe}_2\text{O}_3}$$

There is a large number of char in bed material.

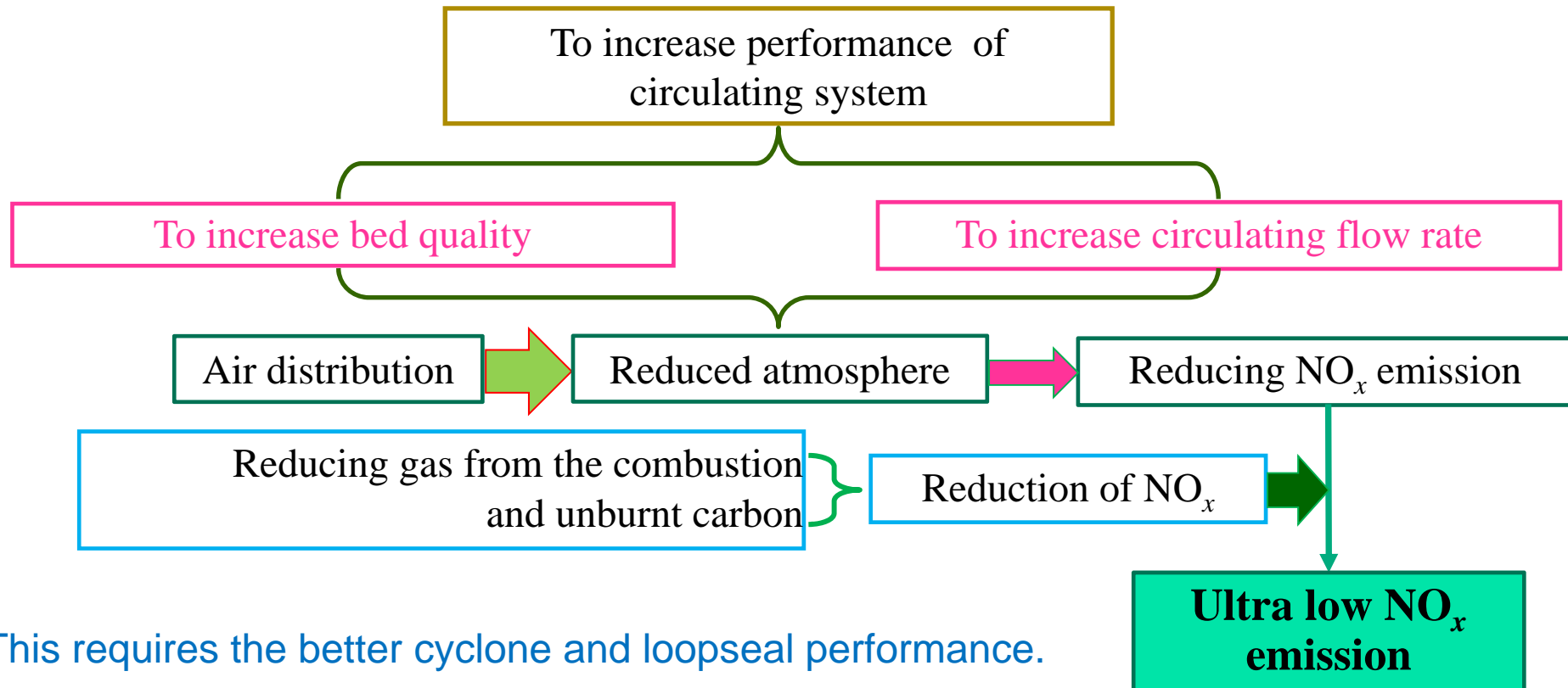
The ash from fuel combustion promotes the reduction reaction as a catalyst.

### 3. Ultra-low emission of CFB boiler research and application

#### 3.2 NO<sub>x</sub> controlled by low NO<sub>x</sub> combustion

- Technical routing of low NO<sub>x</sub> combustion
- fly ash  $d < 50 \mu\text{m}$ , bottom ash  $\bar{d} < 200 \mu\text{m}$

Thus the key of Low-nitrogen combustion of CFB boiler is



This requires the better cyclone and loopseal performance. This is confirmed by real boilers. Practices shown that the better bed quality is necessary for low NO<sub>x</sub> emission .



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4. Conclusion

## 4. Conclusion

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- CFB is the best choice for low grade coal utilization for the countries where coal is major energy source.
- Chinese spend several decades to study CFB boiler. Now there are several boiler workers in China could supply CFB boilers.
- By the end of 2015, there are more than 2800 CFB boilers with total capacity of more than 100GW were in commercial operation in China.
- The achievements of supercritical CFB and ultra-low emission CFB are successful, and this encourages the CFB boiler future in China.



**Thank you for your attention!**