The Relationship between $PM_{2.5}$ and Heating in Winter Beijing and Control Measures

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Contents

Many Places in China Encountered Haze Weather in the Winters of 2012-2013

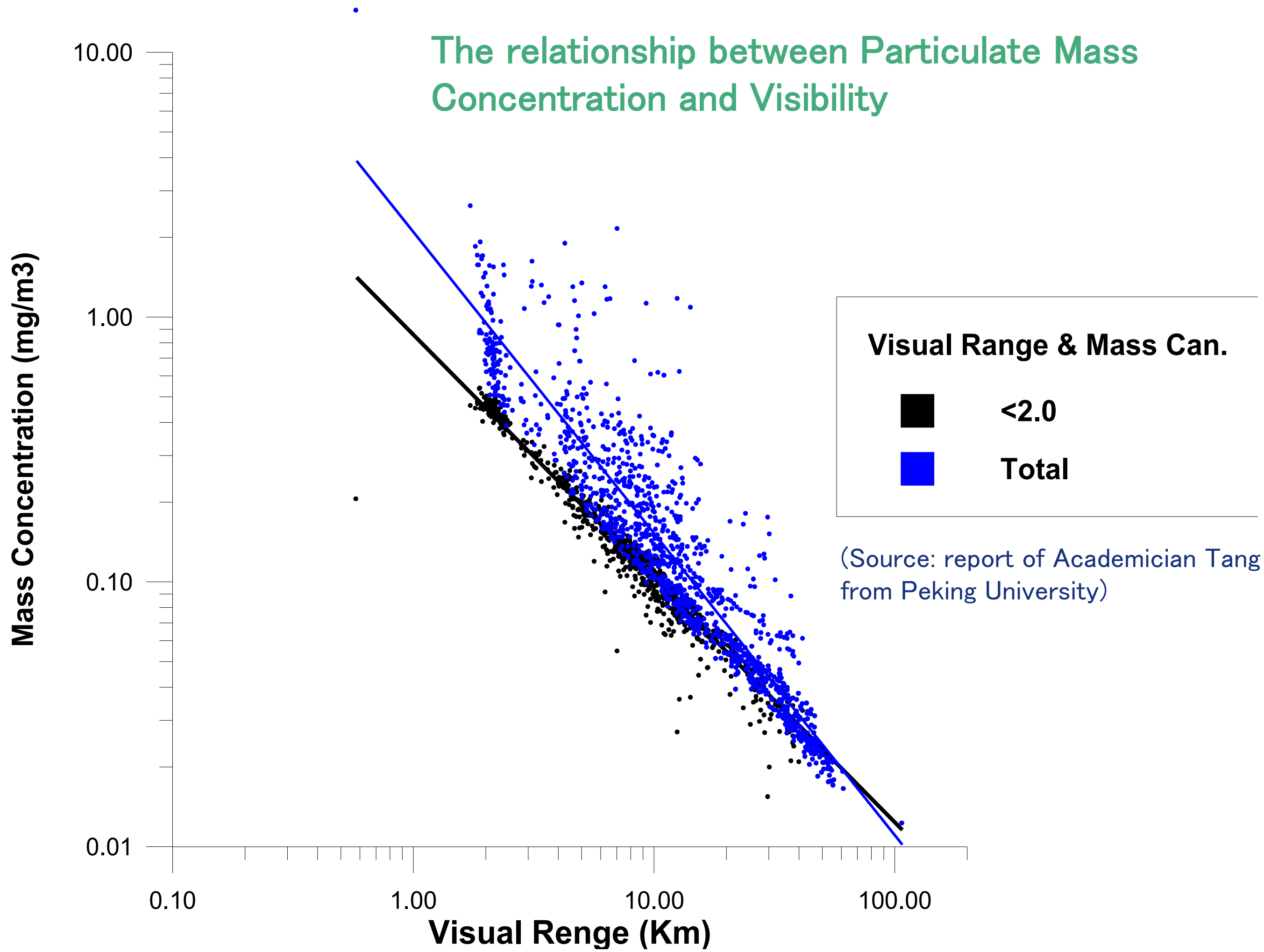
- Many regions in China encountered "severe air pollution", and pollution index of some cities hit upper range limit, particularly in Beijing-Tianjin-Hebei region.
  - On January 12, 2012, air pollution level in Beijing reached Level 6, inhalable particulate concentration ($\mu g/m^3$): 786 in Beijing, 500 in Tianjin and 960 in Shijiazhuang.
  - On October 20, 2013, the first day of the winter heating season in Harbin, air pollution was serious, schools were closed, and PM 2.5 concentration reached 1,000.

- Policies promulgated to tackle air pollution
  - The State Council issued Action Plan for Air Pollution Prevention and Control (Ten Measures to curb air pollution) in September 2013, in which, it stipulates that the overall air quality of China shall be improved within five years, and the number of severely polluted days shall be decreased by a large margin.
  - Beijing Clean Air Action Plan (2013-2017) was also released in September 2013, in which, it stipulates that citywide PM 2.5 concentration shall be lowered by 25% compared to the year of 2012 by 2017. "Conversion from coal to gas" is a priority, with the target of reducing the total coal consumption by 13 million tons compared to 2012 by 2017.

Data source: website of China National Environmental Monitoring Center
Picture source: internet

Main Research Result—Haze is Formed Mainly by $PM_{2.5}$

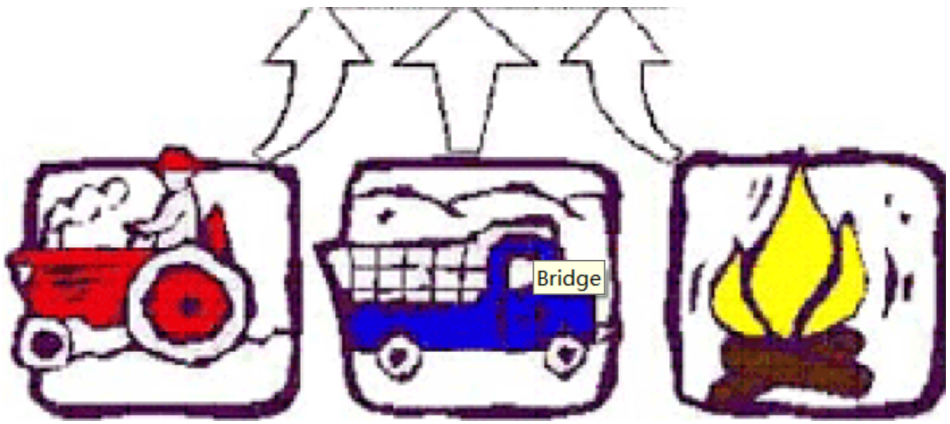
The relationship between Particulate Mass Concentration and Visibility



(Source: report of Academician Tang Xiaoyan from Peking University)

Composition of Aerosol PM 2.5 in Urban Atmosphere

- Primary particulates are discharged by industrial, construction, traffic, electrical, and other production, living activities, and natural sources

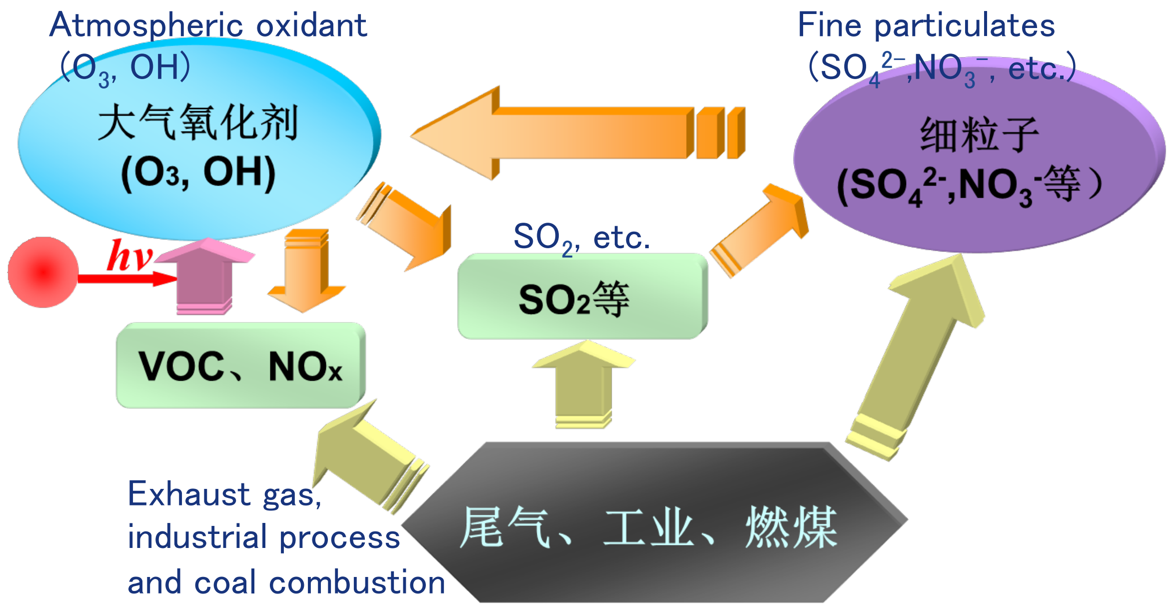


- Various dusts (sand dust, wind dust, dust from building and road)
- All kinds of combustion and industrial processes
  - Metallic elements, carbon black/black carbon/elemental carbon, primary organic matter, etc.

- Secondary particulates are generated as a result of gas-to-particulate conversion
  - VOCs secondary organic particulate
  - SO_2 sulphate particulate
  - NO_x nitrate particulate
  - NH_3 ammonium salt particulate

Chemical Conversion Process in Atmosphere

- **Ozone** can directlyconvert the discharged primary pollutants into aerosol.
- Atmospheric oxidant oxidizes SO2, NOx and VOC into aerosols, like sulfate, ammonium salt, organic particulates, **nitrogen oxides**, etc.
- Due to small particulate size and large superficial area, aerosols provide a large number of **reaction beds** for photochemical reactions, during which the primary pollutants are converted into secondary aerosols.
- **Nitrogen oxides** generated react with VOC to produce more **ozone**.



Source: report made by academician Tang Xiaoyan from Peking University on Mar. 28.

The reaction of converting the primary pollutants into secondary aerosols PM2.5 through photochemical reaction is recycling continuously and non-linearly. Enhanced atmospheric oxidation will lead to generate more secondary aerosols, in which, NO_x is a key factor.

Sources of Aerosol $PM_{2.5}$ in Urban Atmosphere

$PM_{2.5}$ — Mixed:

- **Primary particulates** are discharged by industrial, construction, traffic, electrical, and other production, living activities, and natural sources
- **Secondary particulates** are discharged as a result of gas-to-particulate conversion under photochemical effect

- $PM_{2.5}$ accounts for 50% to 80% of PM_{10}.
- In case of heavy pollution, secondary particulates account for 50% to 80% and the proportion of secondary particulates in $PM_{2.5}$ increases markedly.
- Secondary particulates are formed due to **enhanced atmospheric oxidation. The artificial reason is attributed to the emission of NO_x and VOC.**


Nox and VOC raise the atmospheric oxidability

The original circular reaction

$NO_2 \xrightarrow{hv} NO + O$ (1)

$O + O_2 \rightarrow O_3$ (2)

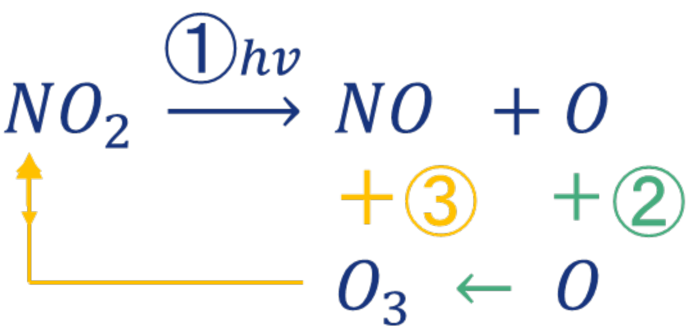
$O_3 + \mathrm{NO} \rightarrow \mathrm{NO_2} + O_2$ (3)

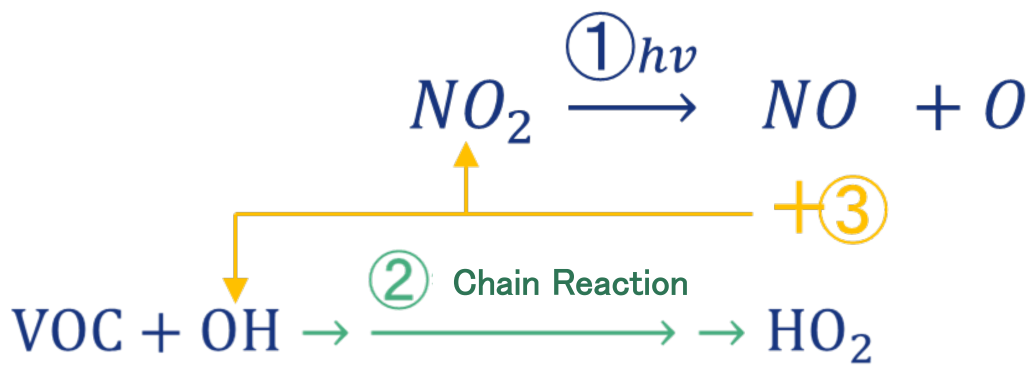
When NOx and VOC exist:

$\mathrm{VOC} + \mathrm{OH} \rightarrow \xrightarrow{\text{Chain Reaction}} \rightarrow \mathrm{HO_2}$ (4)

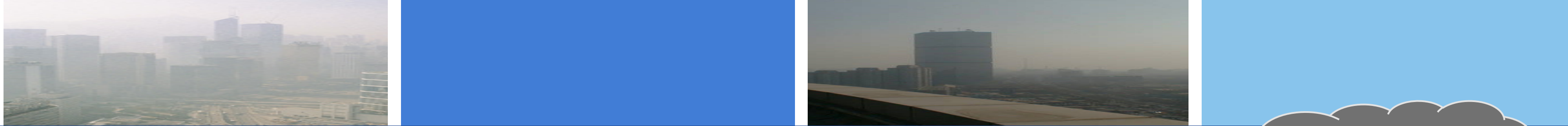
$\mathrm{HO_2} + \mathrm{NO} \rightarrow \mathrm{NO_2} + \mathrm{OH}$ (Quick Reaction) (5)

NO generated from (1) is consumed, so (3) can't continue, O3 is accumulated.

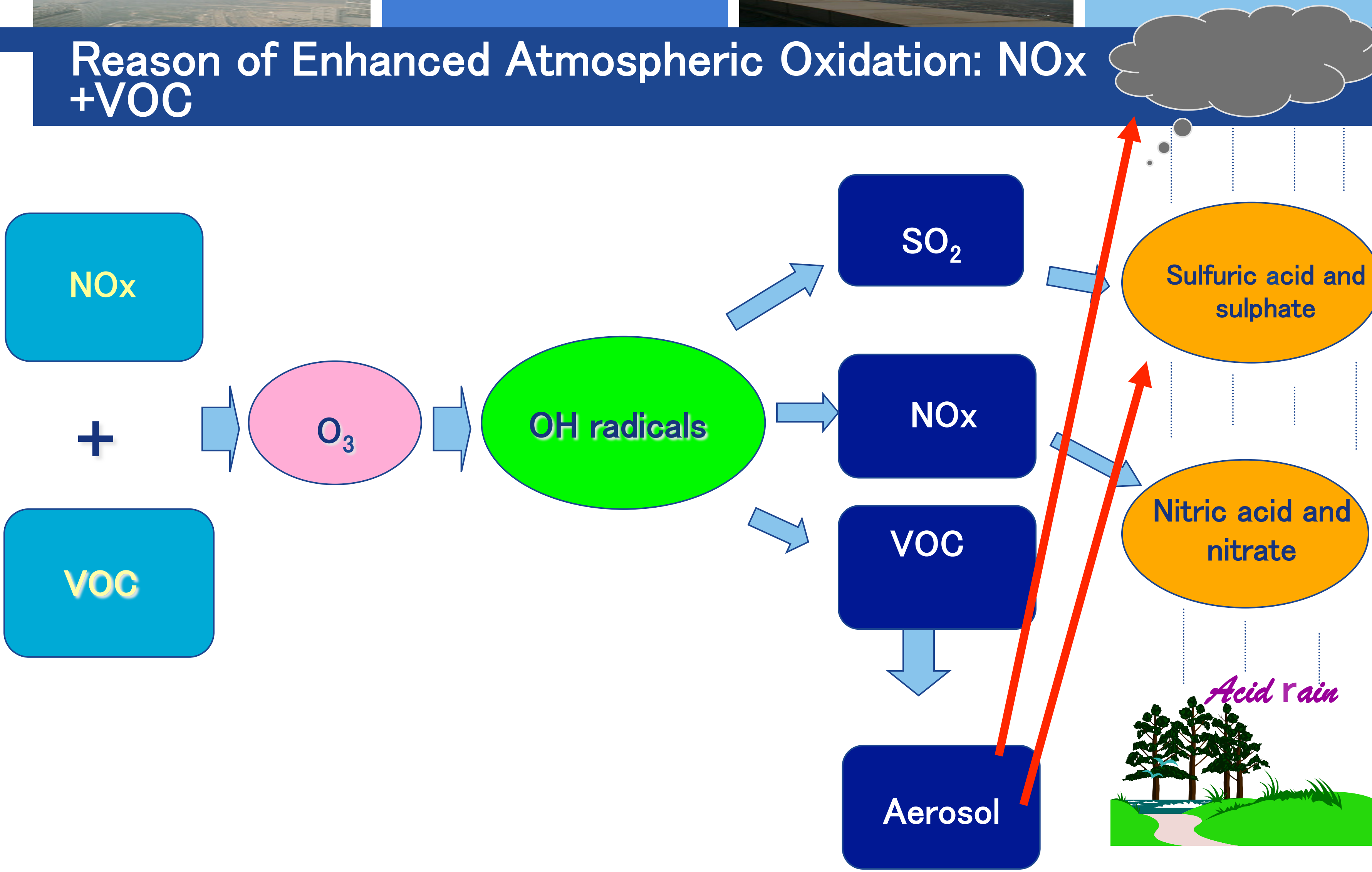




Artificial emission of Nox and VOC raise the atmospheric oxidability.



Reason of Enhanced Atmospheric Oxidation: NOx +VOC



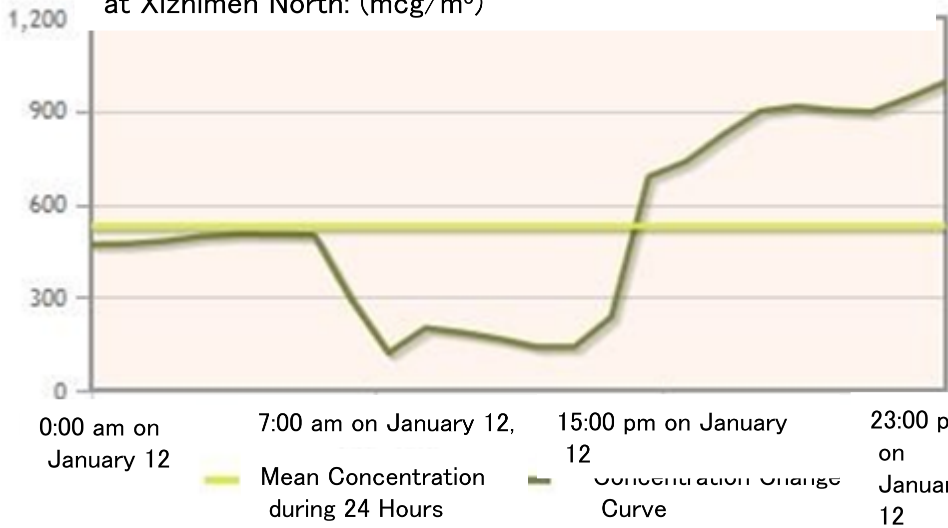
Source: report made by Academician Tang Xiaoyan from Peking University on Mar. 28.

Heavy Pollution Process in Beijing on January 12, 2013

PM 10 Concentration at Xi Zhimen North, 1/12/2013 (traffic pollution monitoring station): (mcg/m3)

Real-time Concentration (mcg/m3)	Mean Concentration during 24 Hours (mcg /m3)	IAQI	Level and Category
993	528	428	Level VI Severe pollution

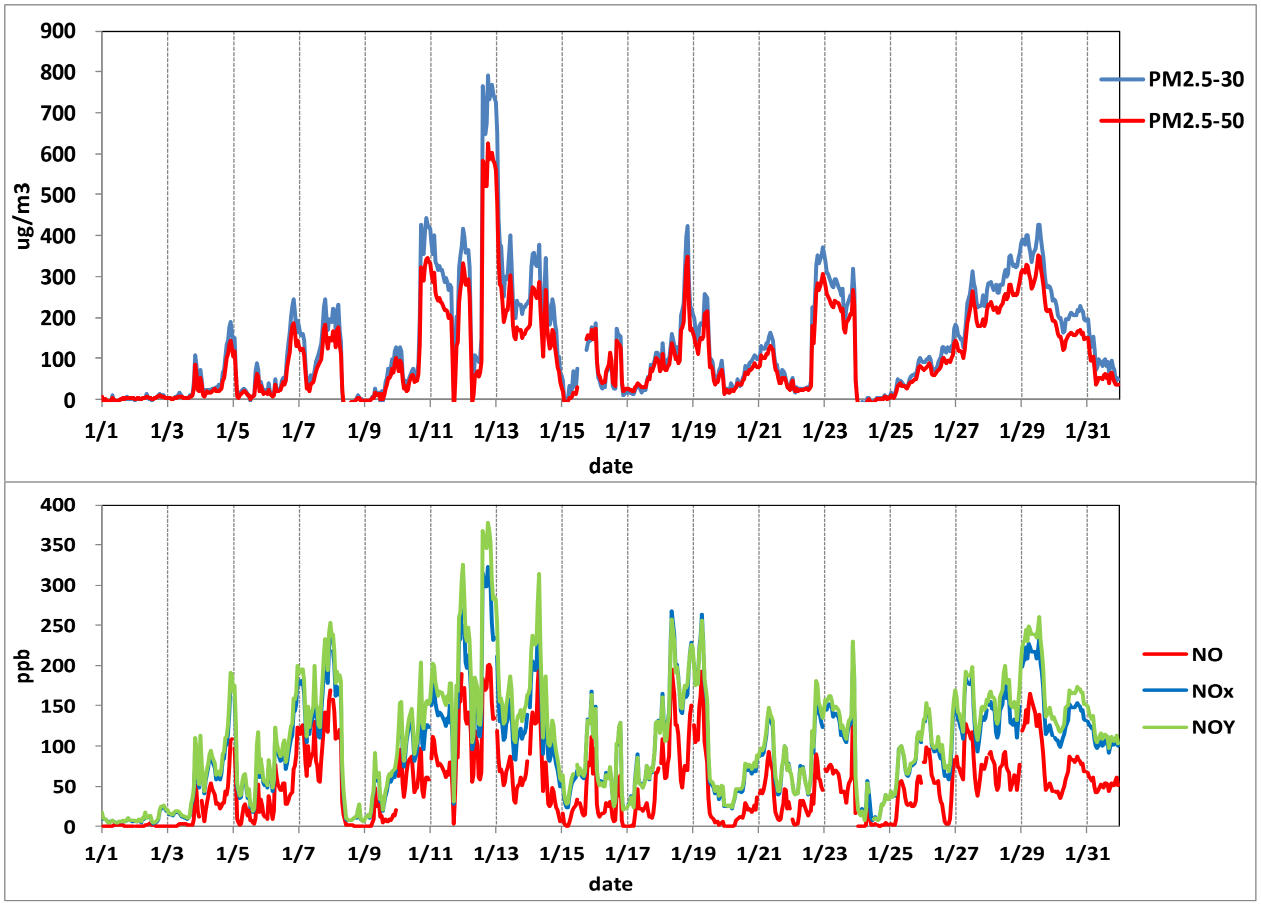
PM 10 Concentration Change Curve over the Past 24 Hours at Xizhimen North: (mcg/m^3)



Source: internet data (north of Xizhimen)
Internet pictures (a residential area in Xicheng District of Beijing,
Picture above: at 8:00 am on January 9, 2013
Picture below: at 8:00 am on January 12, 2013

$PM_{2.5}$ and NO_x Concentration Changing Process at Peking University Monitoring Station in January 2013

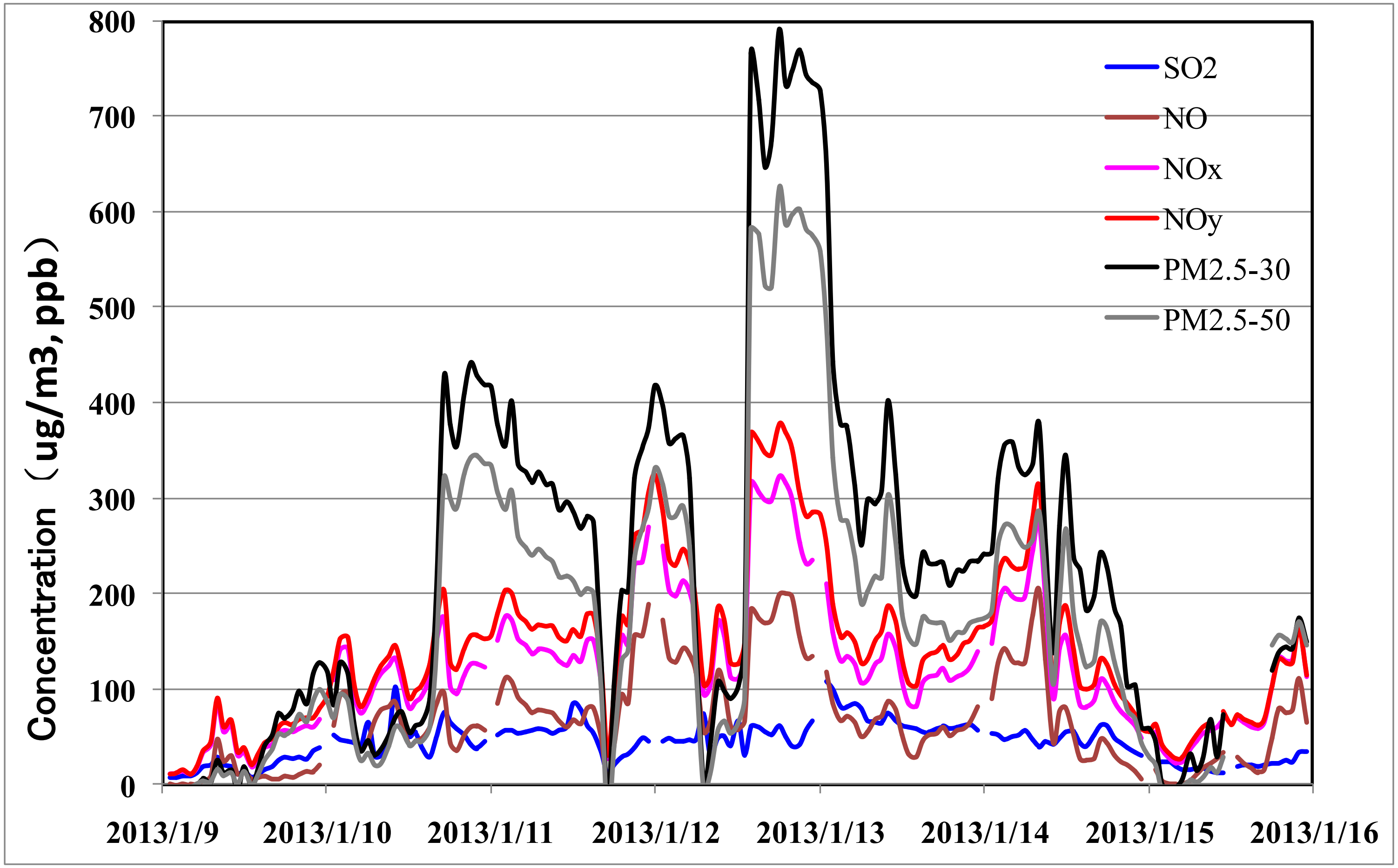
Source: report made by Academician Tang Xiaoyan from Peking University on Mar. 28.



Concentration of NOX and PM2.5 changed relevantly during heavy pollution

Air Quality of Peking University Campus in Mid-January, 2013

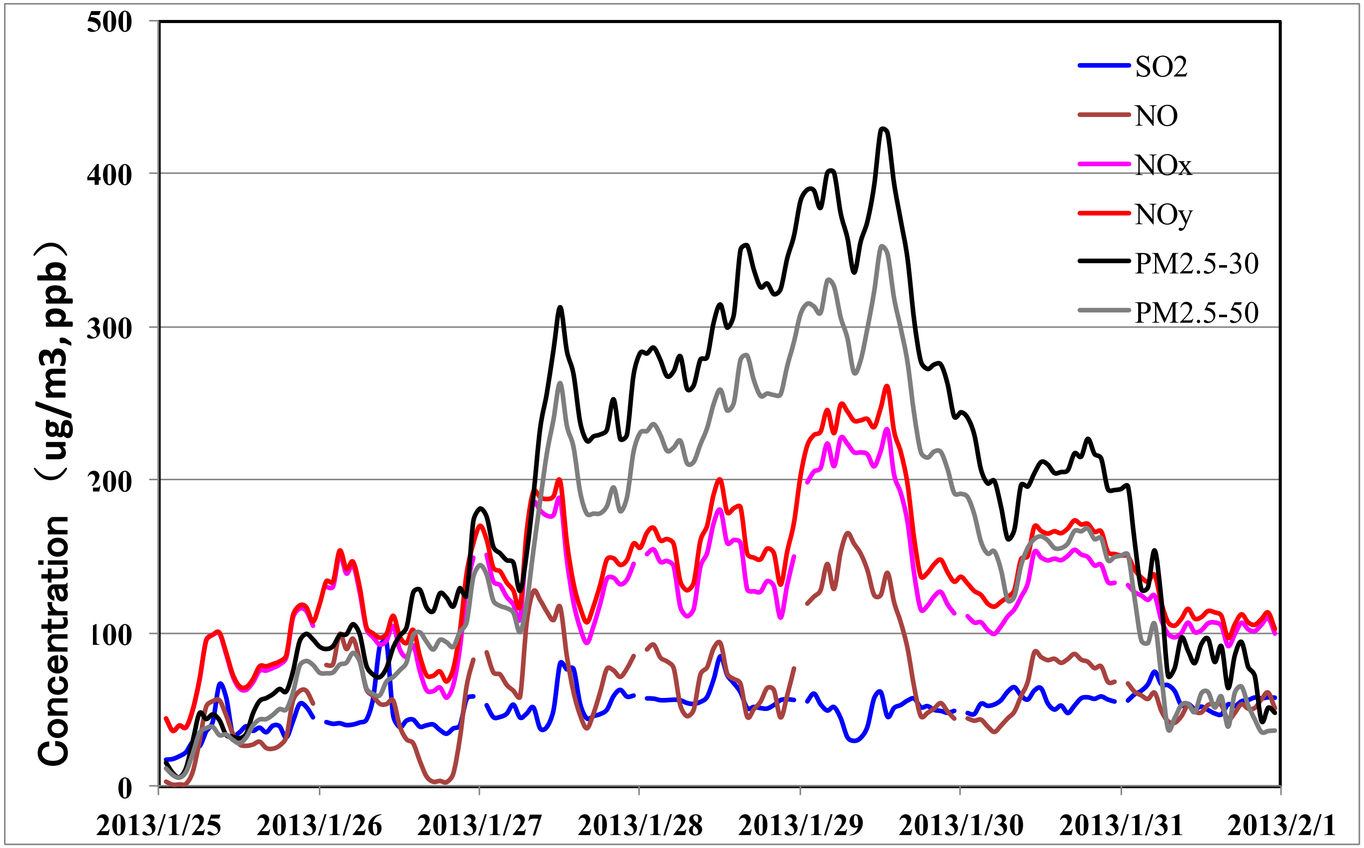
Source: report made by Academician Tang Xiaoyan from Peking University on Mar. 28.



Concentration of NOX and PM2.5 changed relevantly during heavy pollution

Air Quality of Peking University Campus in Late January, 2013

Source: report made by Academician Tang Xiaoyan
from Peking University on Mar. 28.



Concentration of NOX and PM2.5 changed relevantly during heavy pollution

Characters of Heavy Air Pollution

During heavy pollution

- SO_2 concentration remains at a low level, with less changes.

- Concentration changes of NO_X and $PM_{2.5}$ are highly relevant and the changes are simultaneous.

Sources of $PM_{2.5}$ in Urban Area–Summary

- Atmospheric haze is mainly composed of PM2.5, including primary particulates from industrial and other activates and secondary particulates converted from gas

- $PM_{2.5}$ is 50%-80% of PM_{10}. Secondary particulates account for 50%-80% of $PM_{2.5}$. During heavy pollution, percentage of secondary particulates in $PM_{2.5}$ increases significantly.

- Secondary particulates are formed due to increased atmospheric oxidability. The Artificial reason is attributed to emission of NOx and VOC.


Controlling NO_x and VOC is the key to address $PM_{2.5}$ pollution

- NO_x and VOC are culprits accounting for heavy $PM_{2.5}$ pollution:
  - **Increased atmospheric oxidation, leading to oxidization of various gases into particulate matters**
  - Harmful to human body; NO_x is oxidized in the atmosphere and form H_2NO_3 after absorbing water. With extinction effect, H_2NO_3 and organic matters generate organic nitric matter.
- Controlling NOx and VOC is the key to address PM 2.5 pollution。
  - NO_x emission sources: mainly from fossil fuel combustion, which is easy to be centrally controlled
  - VOC emission sources: chemical industry, automobile exhaust, laundry, cooking, straw combustion, etc.

NO_x Emission Intensity by Unit Fuel

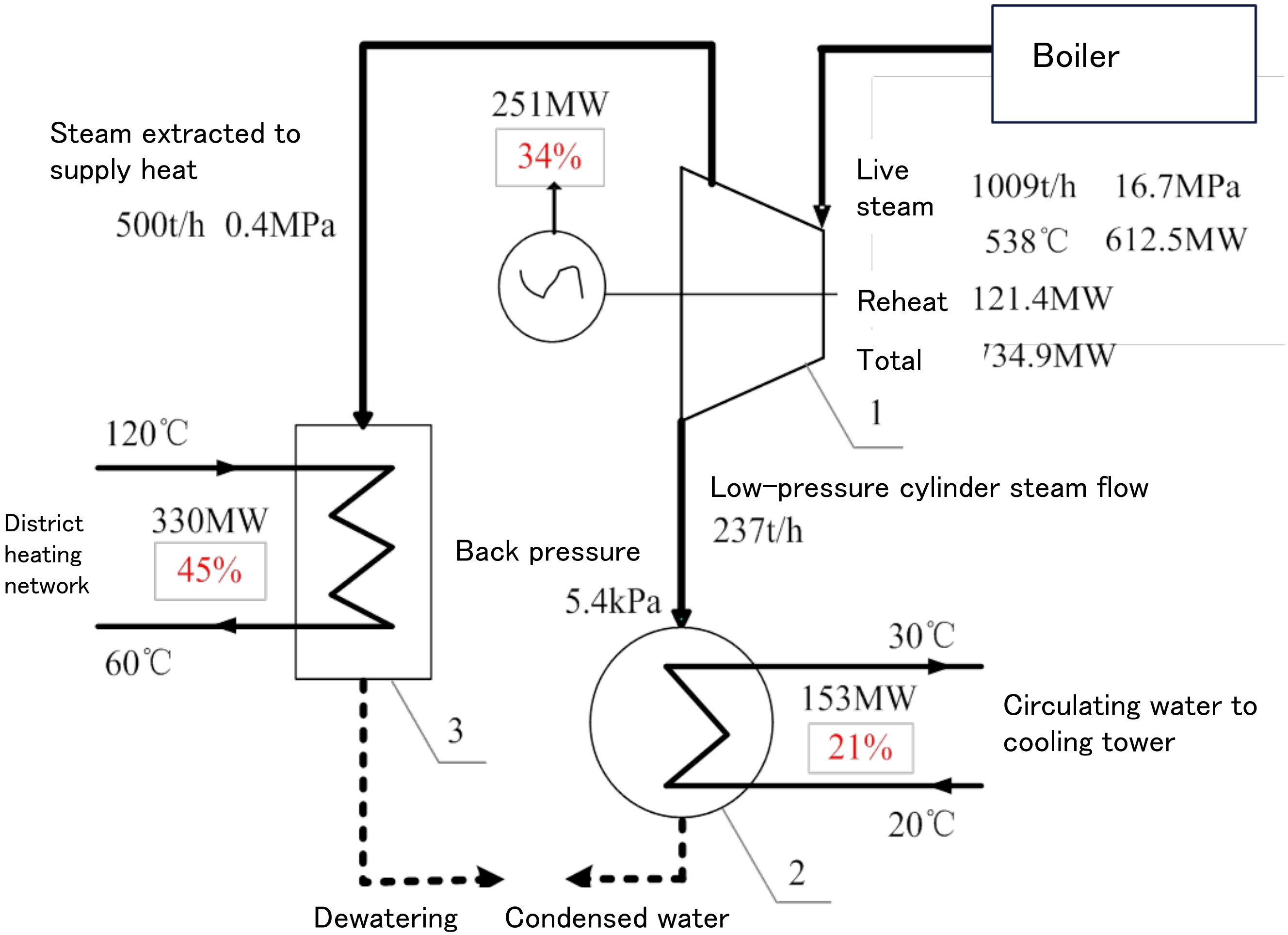
Combustion Equipment	Emission Intensity kg/tce	mg/m^3 slu gas	Notes
Large coal-fired combined heat and power system (CHP)	2	200	After denitration
Coal-fired circulating fluidized bed	<0.5	<50	Adding SNCR in recent years
Large gas-fired boiler	0.8	100	After denitration, national standard, equaling to 1.1g/m3 natural gas
Gas-steam combined cycle CHP	1.2	52	After denitration, national standard, equaling to 1.5g/m3 natural gas
	0.7	30	After denitration, Beijing standard, equaling to 0.9g/m3 natural gas

NO_x emitted from gas-fired CHP is 60% of that from conventional large coal-fired CHP (adding fuel with the same heat amount)

Characteristics of Gas-fired CHP

- To achieve high power generation efficiency, high combustion temperature is required, thereby emitting a large amount of NOx.
- Heat-to-electricity rate of gas-fired CHP is smaller than that of coal-fired CHP.
  - In terms of combined heat and power generation, gas-fired CHP has smaller heat-to-electricity rate, or larger electricity generation, so more fuel is combusted in gas-fired CHP in order to get the same amount of heat. **NOx emission from gas-fired CHP is larger than that from coal-fire CHP.**

Coal-fired Central Heating System

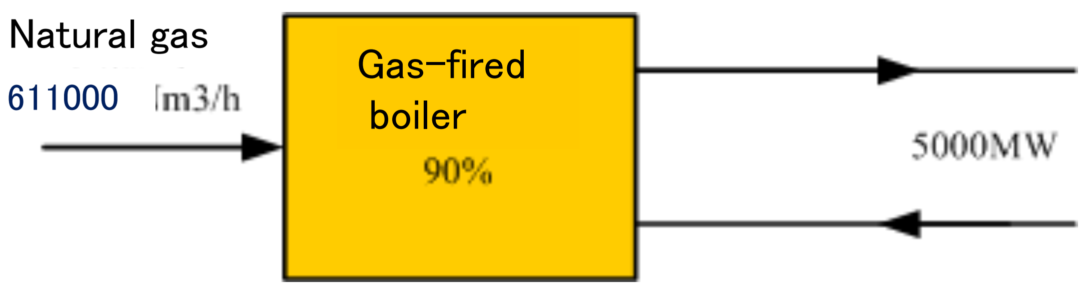


Subcritical 300 MW Heat Supply Unit--Combined Heat and Power Generation Heat Supply System Diagram

Heating area is 100 million m².

- The maximum fuel consumption: 1,367 t/h coal equivalent
- Total fuel consumption during heating season: 3.94 million tons of coal equivalent
- Instant NOx emission: 2.7t/h
- Total NOx emission: 8,000 tons

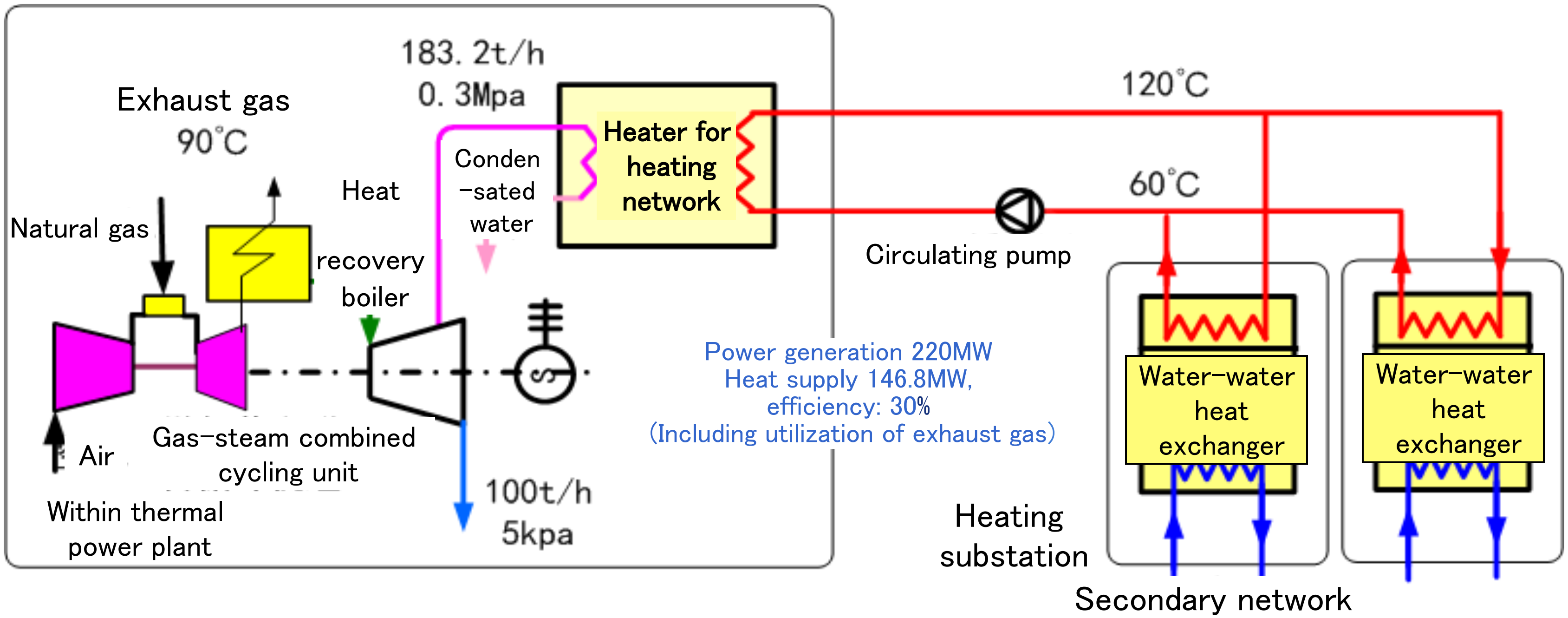
Gas–fired Boiler Heating



Heating area is 100 million m^2.

- The maximun fuel consumption: 514,000 m^3/h
- Total fuel consumption during heating season: 1.48 billion m^3
- Instant NOx emission: 0.6 t/h
- Total NOx emission: 2,000 tons

Gas–fired CHP Central Heating System

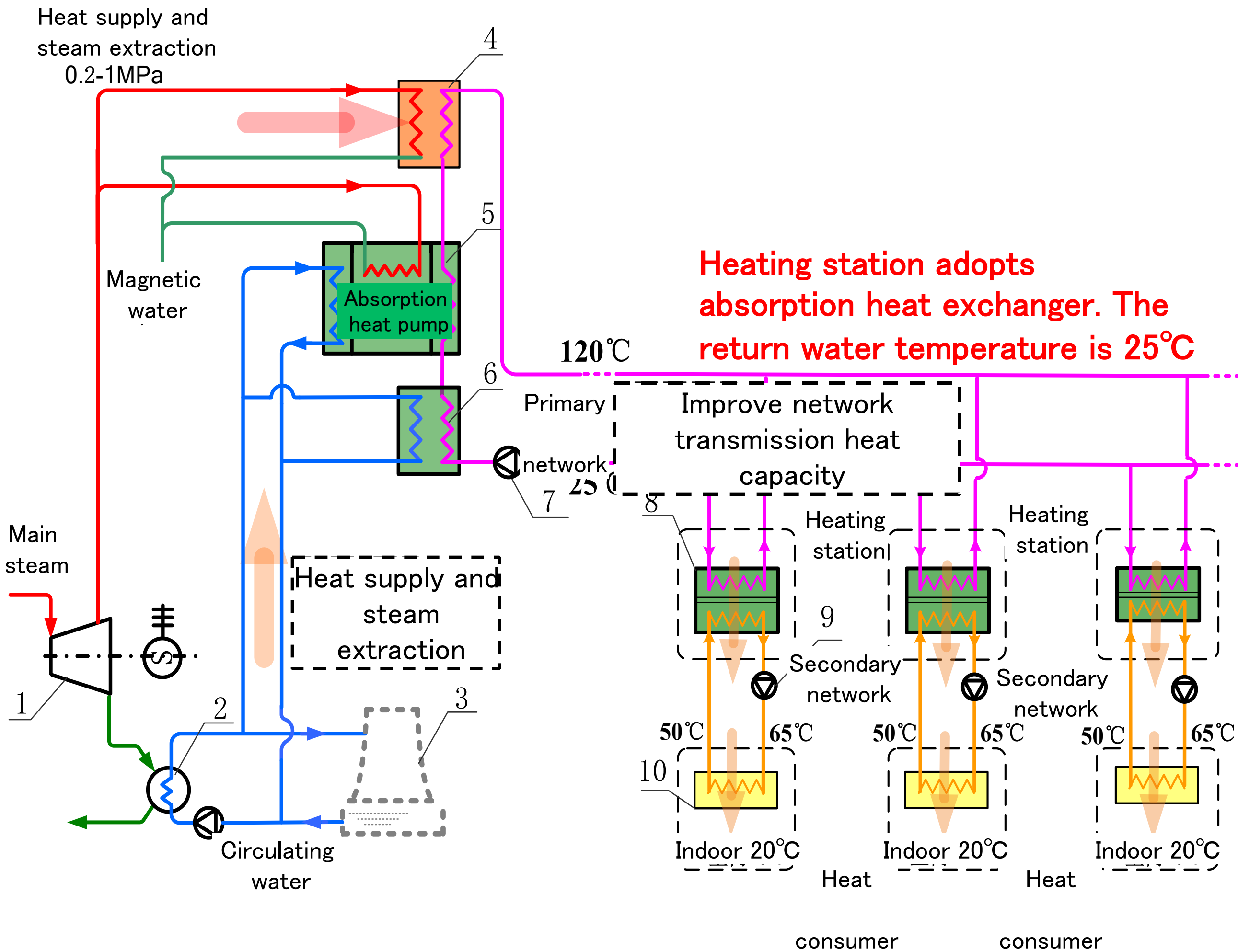


9E––220MW Unit––Combined Heat and Power Generation Heat Supply System Diagram

Heating area is 100 million m^2.

- The maximum fuel consumption: 1.54 million m^3/h
- Total fuel consumption during heating season: 4.44 billion m^3
- Instant NO_x emission : 2.3 t/h
- Total NO_x emission: 7,000 tons (National Standard)

Coal-fired CHP Central Heating System Based on Absorption Heat Exchanger



Heating area is 100 million m².

- The maximum fuel consumption: 904 t/h coal equivalent
- Total fuel consumption during heating season: 2.6 million tons of coal equivalent
- The largest NOx emission : 1.8 t/h
- Total emission NOx: 5,000 tons

Subcritical--300MW Heat Supply Unit--Combined Heat and Power Generation Heat Supply System Diagram

Comprehensive Comparison

(Heating area is 100 million m^2.)

Heating Mode	Instant Fuel Consumption		Total Emission during Heating Period		Generated Power	Generating Capacity	Instant No_x Emission during Heating Season	Total No_x Emission during Heating Season
	Tons of Coal Equivalent/h	Ten Thousand m3/h	Ten Thousand Tons of Coal Equivalent	100 Million m3	Ten Thousand MW	100 Million Kilowatt Hours	Ton/h	Ten Thousand Tons
Coal-fired CHP	1367	–	394	–	0.38	108.8	2.7	0.8
Gas-fired Boiler	–	51	–	14.8	–	–	0.6	0.2
Gas-fired CHP	–	154	–	44.4	0.70	201.6	2.3 (National) 1.4(Beijing)	0.7(National) 0.4(Beijing)
Coal-fired CHP Based on Absorption Heat Exchanger	904	–	260	–	0.24	67.8	1.8	0.5

Summary: four coal power plants in downtown Beijing (Huadian, Guohua, Shijingshan and Gaojing) have been converted into gas-fired CHP. If they contribute the same amount of heat to Beijing, total NOx emission by gas-fired CHP will not decrease. Coal combustion can perform better.


Coal Combustion Can Perform Better

Source: Report of Shanghai Waigaoqiao No. 3 Power Plant from January to June 2013

Actual Measurement Results

Parameter	Unit	Quantity	Note
Generating capacity	100 million kilowatt-hour/half a year	57.28	Two units: #7 and #8
Coal consumption	g/kilowatt-hour	274.65	
SO2	kg/tce	0.47	China national environmental protection standard: 2kg/tce; #7 unit after overhaul inspection: 0.17kg/tce
NOx	kg/tce	0.37	China national environmental protection standard: 4.5kg/tce; #8 unit emission with SCR; emission from gas-fired CHP: 1.2kg/tce
Dust	kg/tce	0.12	China national environmental protection standard: 0.5kg/tce;

The Chinese independent and advanced clean coal technology is featured by very small pollutant emission, and during power generation NO_x emission from coal combustion is lower than that from gas combustion.

If Applying Technologies of Shanghai Waigaoqiao Coal Power Plant to Combined Heat and Power Generation

The technology adopted in Shanghai Waigaoqiao Coal Power Plant is independent and advanced. If it is applied to combined heat and power generation, NO_x emission will be lowered sharply.

(Heating area is 100 million m^2.)

Heating Mode	Instant Fuel Consumption		Total Emission during Heating Period		Generated Power	Generating Capacity	Instant Nox Emission during Heating Season	Total Nox Emission during Heating Season
	Tons of Coal Equivalent/h	Ten Thousand m3/h	Ten Thousand Tons of Coal Equivalent	100 Million m3	Ten Thousand MW	100 Million Kilowatt Hours	Ton/h	Ten Thousand Tons
Coal-fired CHP	1367	–	394	–	0.38	108.8	2.7	0.8
Coal-fired CHP based on absorption heat exchanger technology	904	–	260	–	0.24	67.8	1.8	0.5
Coal-fired CHP based on Shanghai Waigaoqiao technology	1922	–	553	–	0.34	99.0	0.71	0.2
Coal-fired CHP based on Shanghai Waigaoqiao technology and absorption heat exchanger technology	878	–	253	–	0.16	45.3	0.33	0.09
Gas-fired boiler	–	51	–	14.8	–	–	0.6	0.2
Gas-fired CHP	–	154	–	44.4	0.70	201.6	2.3(National) 1.4(Beijing)	0.7(National) 0.4(Beijing)

By adopting the independent clean coal combustion technology of China, while the same heat quantity is generated, NO_x emitted from coal-fired CHP is only 13% of that from gas-steam combined cycle, and even lower than gas-fired boiler!

China is lack of natural gas resources

- Natural gas accounts for over 30% of the total energy in developed countries. Currently, natural gas accounts for no less than 5% of the total energy in China, and it will not exceed 8% by considering deep development and import in the future unless shale gas is successfully exploited in an all-round way.

- At present, many north cities in China carried on "coal to gas conversion", causing serious short supply of natural gas[1].
  - NDRC pointed that the gas supply gas might be 22 billion m^3 and sent out 2 pre-warnings that gas shortage might occur this winter [2].
  - Personnel from China National Petroleum Corporation: in this winter and spring next year the imbalance between supply and demand of natural gas will be most serious over past years.

1) http://business.sohu.com/20131031/n389292005.shtml
2) http://finance.sina.com.cn/money/future/futuresnyzx/20131111/085717282334.shtml

Important Conclusions

- The main cause of heavy haze is $PM_{2.5}$, 50%–80% of which are secondary particulates. Control measures for secondary particulates are key to decrease $PM_{2.5}$ and tackle heavy haze.

- NO_x raises the atmospheric oxidability, leading to generate large amounts of secondary particulates. NO_x is the main culprit of heavy haze in Beijing.

- It should be cautious to replace coal-fired CHP with gas-fired CHP, since gas-fired CHP will not mitigate air pollution.

Thank you!
(Open for Questions)

Research Participants

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