Design and application of a large-scale experimental pipeline for studying the release and dispersion characteristics of CO2 in different phase states

J. Yu, L. Guo, S. Chen, ***X. Yan***[1*], Y. Zhang ***(Dut, China)***

H. Mahgerefteh (*UCL, United Kingdom)*

C. Proust, (*INERIS, France)*

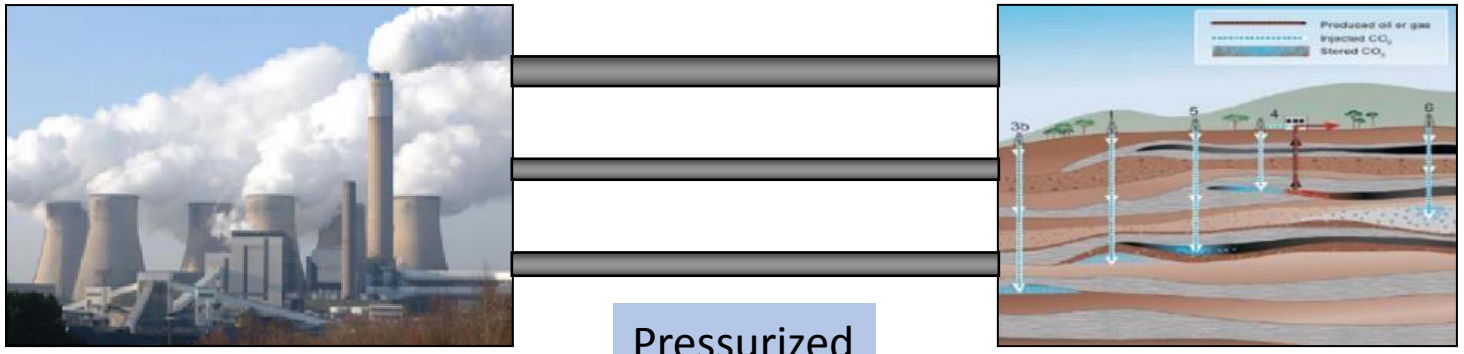
X. Yan: yanxingqing@dlut.edu.cn

Questions:

- What was the problem?
- What have we done?
- How it works out?

What was the problem?

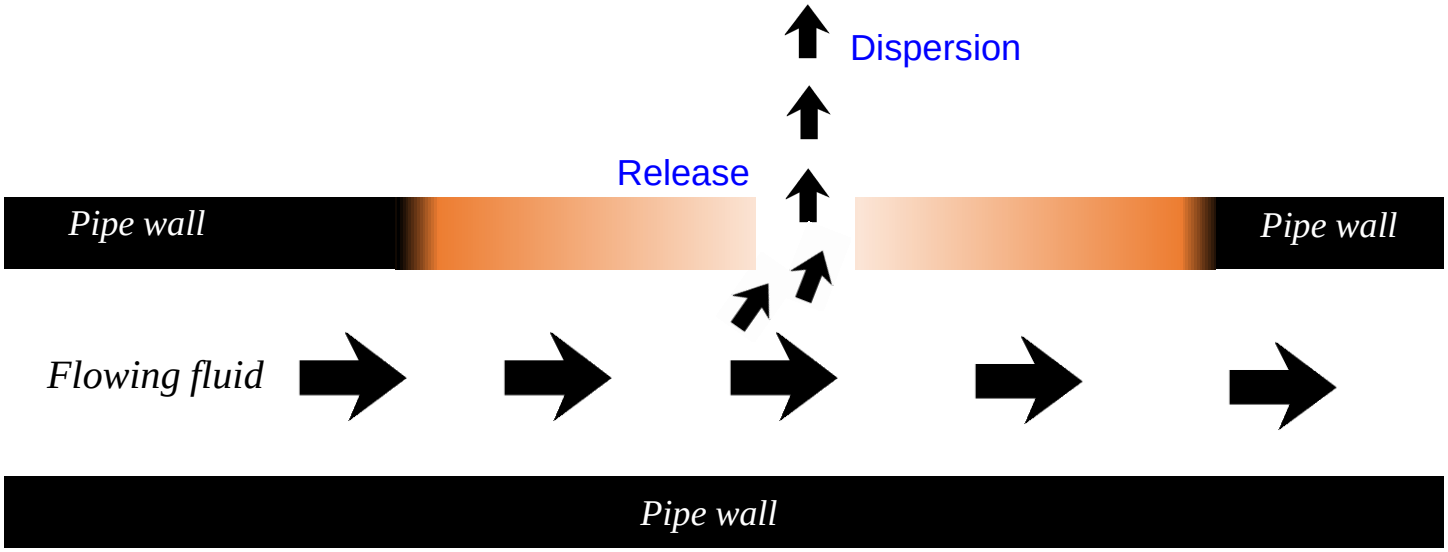
- **Transportation of CO2** from capture source to storage locations is very important in the CCS industrial chain.



- Among several types of CO2 transportation, **pressurized pipelines** are regarded as the most efficient and economic means.

What was the problem?

- However, pipelines always suffer from the **risk of failure**. Once failed, CO2 is **released and dispersed**, causing casualties and property losses.
- In this situation, the **safety issues** due to CO2 sudden release from pipelines need to be focused.



What was the problem?

- In particular, the **safety issues** mainly include two aspects:
  - **Release characteristics of fluid** in the pipeline, including pressure, temperature, phase state, decompression wave etc.
    - **May cause long-distance brittle rupture of pipeline!**
  - **Dispersion behavior of CO2** released into atmosphere, including concentration and temperature distributions.

What was the problem?

- Although researchers and several international projects studied these problems, there were **no large-scale experimental pipelines** for studying the **release characteristics** and **dispersion behavior** of CO2, and for providing the validation data for the theoretical and numerical models.

What have we done?

- In the support of the European Union 7th Framework Program (CO2QUEST), we built a large-scale experimental pipeline to perform CO2 release experiments.
- The pipeline was located along a river in a wide field in Anbo town, Dalian city, China.

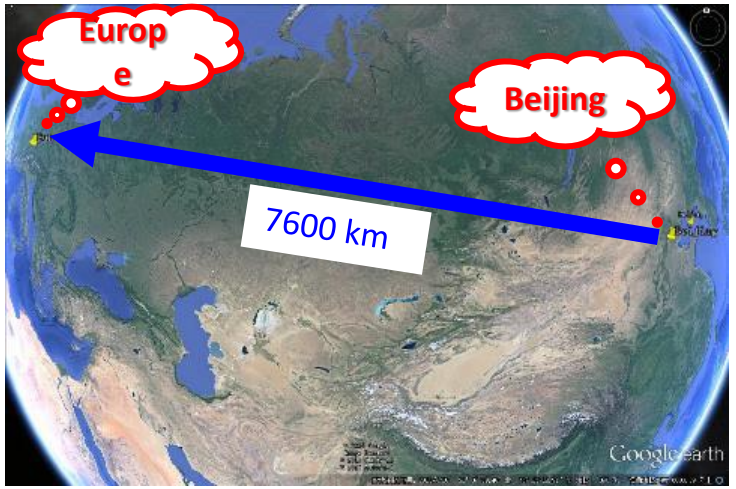
What have we done?

- In the support of the European Union 7th Framework Program (CO2QUEST), we built a large-scale experimental pipeline to perform CO2 release experiments.
- The pipeline was located along a river in a wide field in Anbo town, Dalian city, China.

Where is Anbo town?

What have we done?

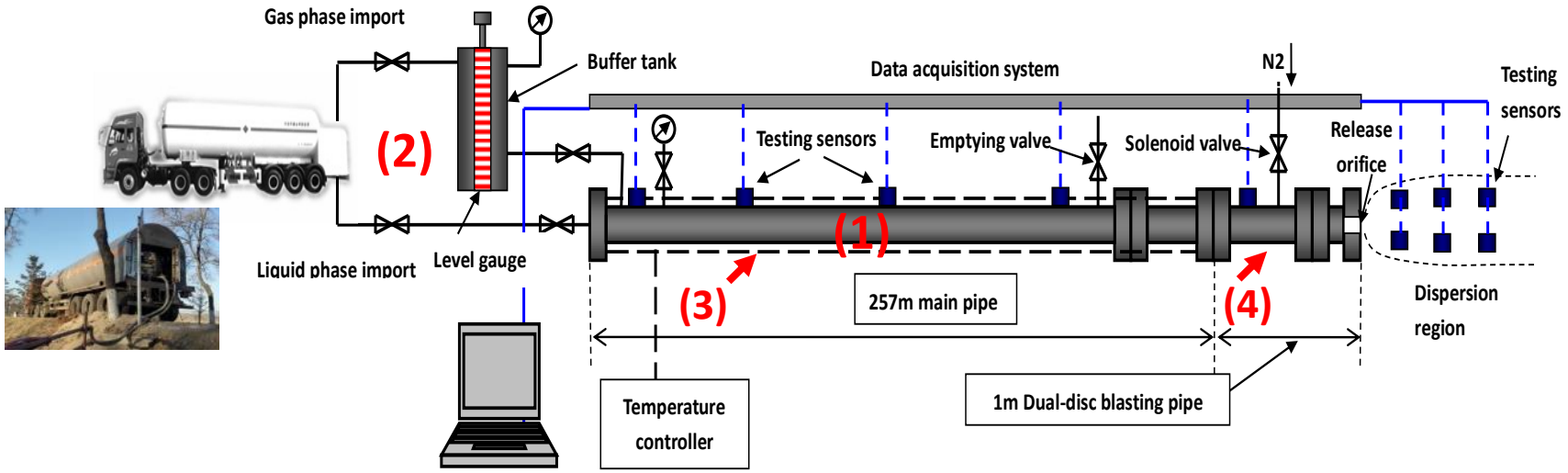
- Where is **Anbo** town?
  - About **120 km** from downtown of Dalian city.
  - Dalian is about **500 km** from Beijing.
  - Beijing is about **7600 km** from Athens.



It's a little far from here!

What have we done?

- Schematic diagram of the apparatus:



Design tips:

(1) Need a **long pipeline** to work in high pressure, low temperature;

(2) Need a **Cyclic injection system** to fill CO2 from tank car into the pipeline;

(3) Need a **heating system** to increase the initial pressure and temperature;

(4) Need a **control system** to control CO2 sudden release safely;

(5) Need **foundations and reinforcing devices, measurement system, data acquisition system**, and so on.

What have we done?

- Photo of the pipeline:

- Design parameters:

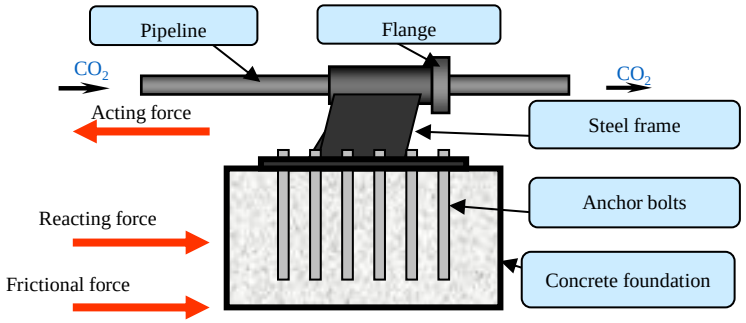
Orientation: nearly East and West direction
Total length: 258 m
External diameter: 273 mm
Thickness: 20 mm
Material: 16Mn
Design pressure: 16 MPa

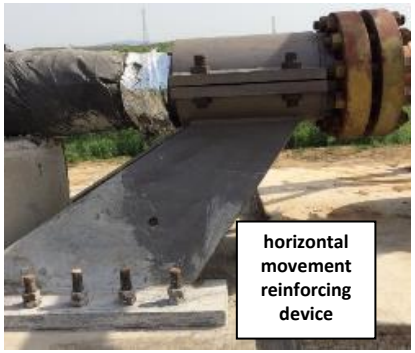
- Process parameters that could be varied:

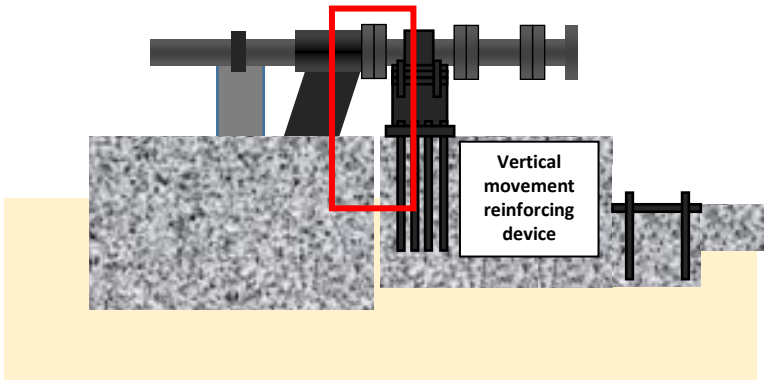
Initial pressure: 0~14MPa;
Initial temperature: 0~40 ° C
Discharge diameter: 0~Full Bore Rupture (243mm)
CO2 purity is changed by adding Inert gas, such as N2 etc.

What have we done?

- Foundations and reinforcing device:
  - More than 20 **concrete foundations** were built to support the pipeline;
  - **Two reinforcing devices** were designed to prevent the **horizontal and vertical movements** respectively during CO2 sudden release.

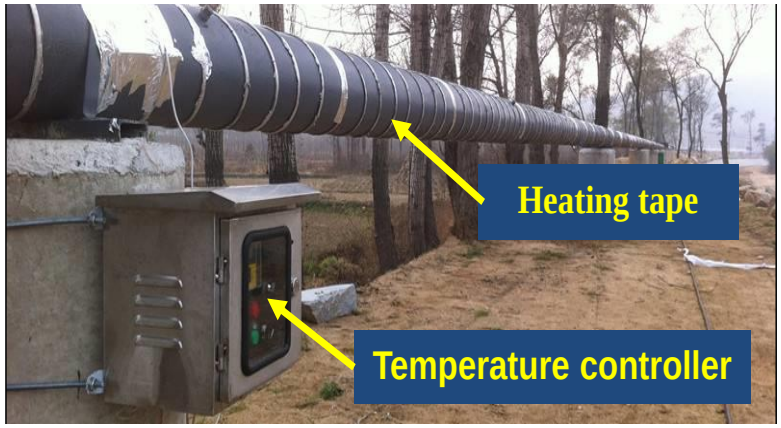






What have we done?

- Heating system:
  - In order to increase the initial temperature and pressure, a **heating system** was designed, including heating tape, temperature controller, and the insulation layer .



What have we done?

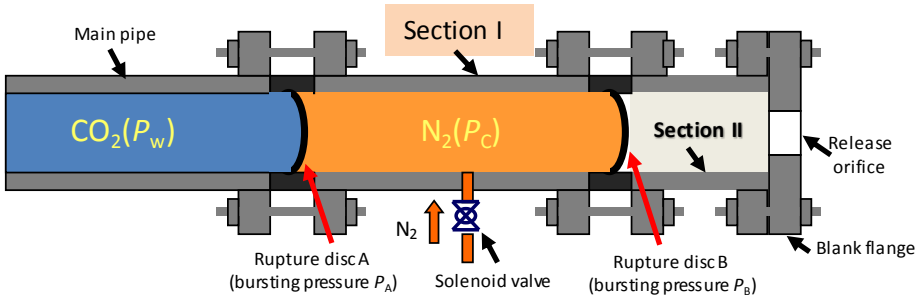
- Control of CO2 sudden release

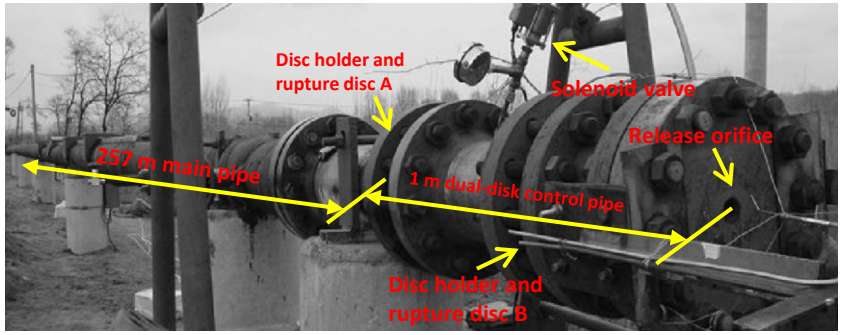
  - **Safe and precise control** of CO_2 sudden release was the basic function of this apparatus. In order to accomplish this function, a **dual-disk control pipe** was designed at the end of the pipeline.

What have we done?

- Control of CO2 sudden release

Schematic diagram and the photo:

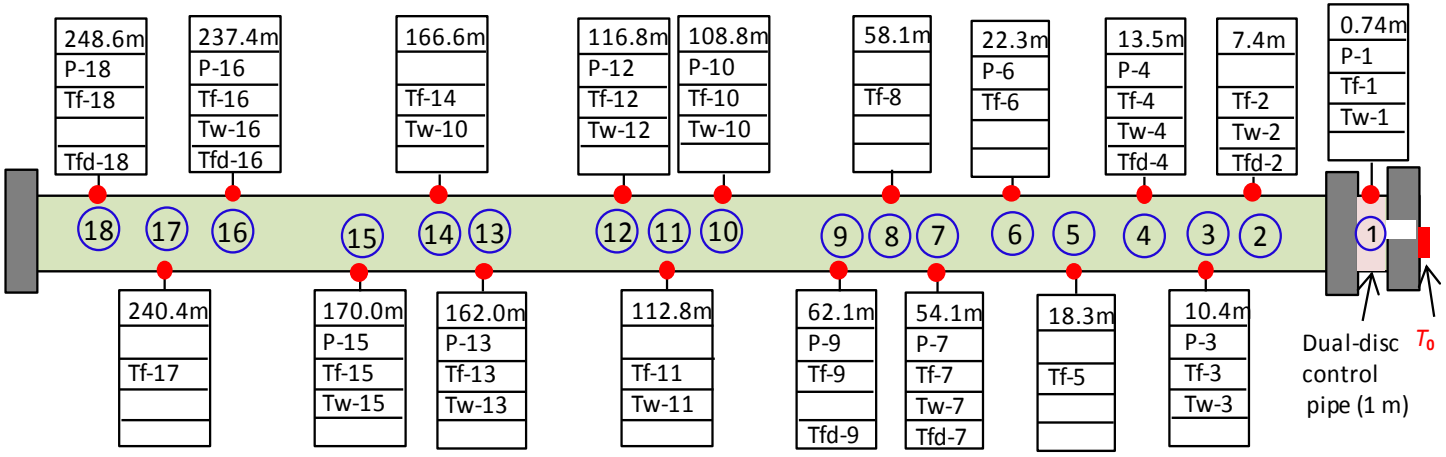




- It consists of two **pipe sections** (section I and section II), and **two bursting discs**.
- During the filling process to the pipe, **N_2 was filled into Section I**. By adjusting the pressure of N2, two rupture discs do not rupture(*Pc>Pw-PA*; $P_c < P_B$).
- When doing experiments, **extra N_2 was filled into Section I** to make rupture disc B rupture. Shortly, rupture disc A ruptured. CO_2 is released through orifice.

What have we done?

- Measurement scheme of the pipeline

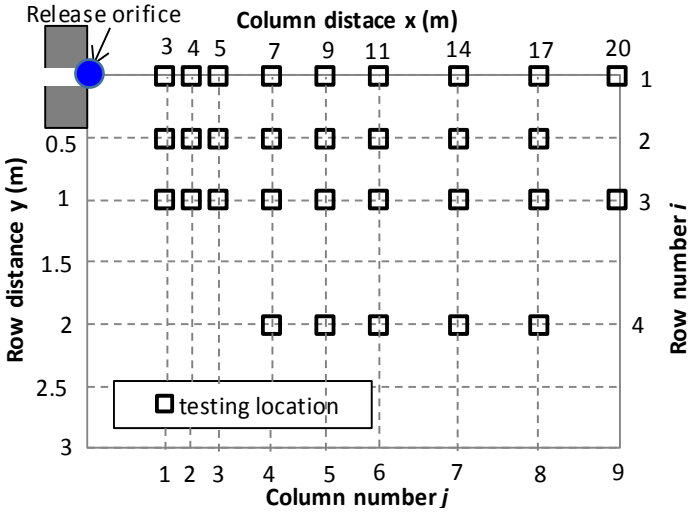


✓ **18 locations** were selected to install sensors:

- 12 pressure transducers test **fluid pressures** in the pipelines (***P-i***).
- 18 thermocouples test **upper fluid temperatures** (***Tf-i***).
- 6 thermocouples test the **bottom fluid temperatures** (***Tfd-i***).
- 12 thermocouples test the **pipe wall temperatures** (***Tw-i***).
- An extra thermocouple test the **centre temperature of the release orifice** (***T0***).

What have we done?

- Measurement scheme in dispersion area



✓ **Thermocouples and CO2 concentration sensors** were both arranged on vertical masts at different distances. All sensors were located at the same horizontal plane with release orifice.

✓ **A coordinated system** was defined to describe the testing points, taking the release orifice as the origin. The distances for each row and column were labelled on the x-axis and y-axis. Row number i and column number j were used to represent the testing points.

What have we done?

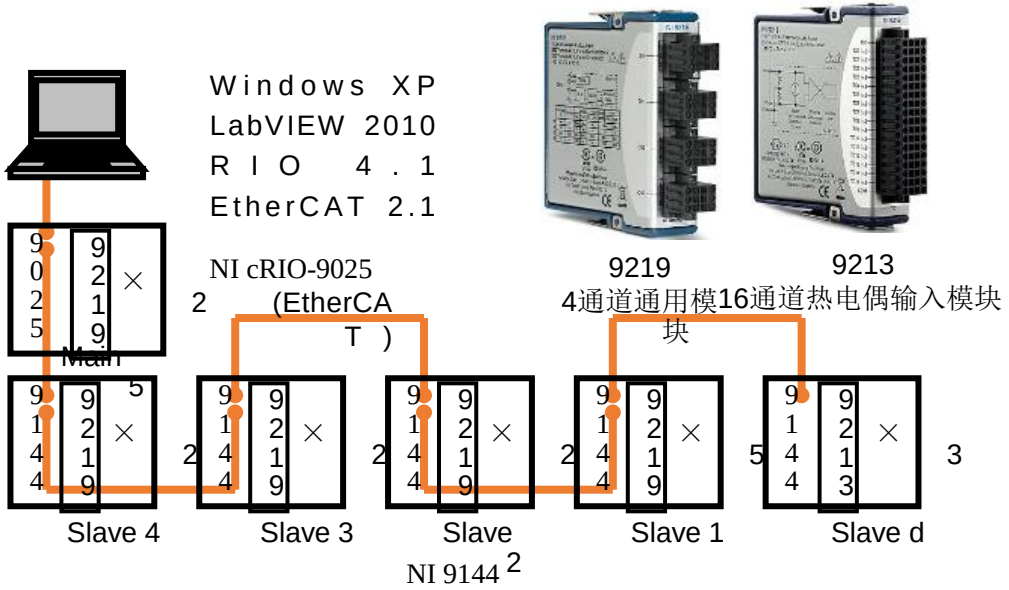
- Other measurement

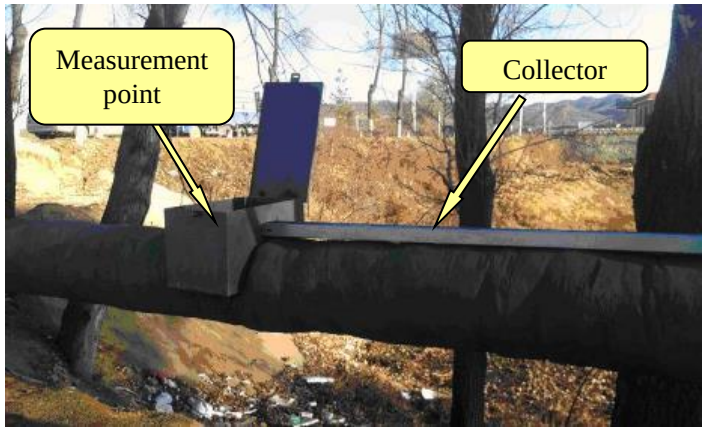
✓ A small **weather station** was built to measure the ambient temperature, pressure, humidity, and wind speed and direction.

✓ Several video cameras were placed to record the release appearance from upper, lower and side directions. **A drone** was used to record the appearance from the air.

What have we done?

- Data acquisition system

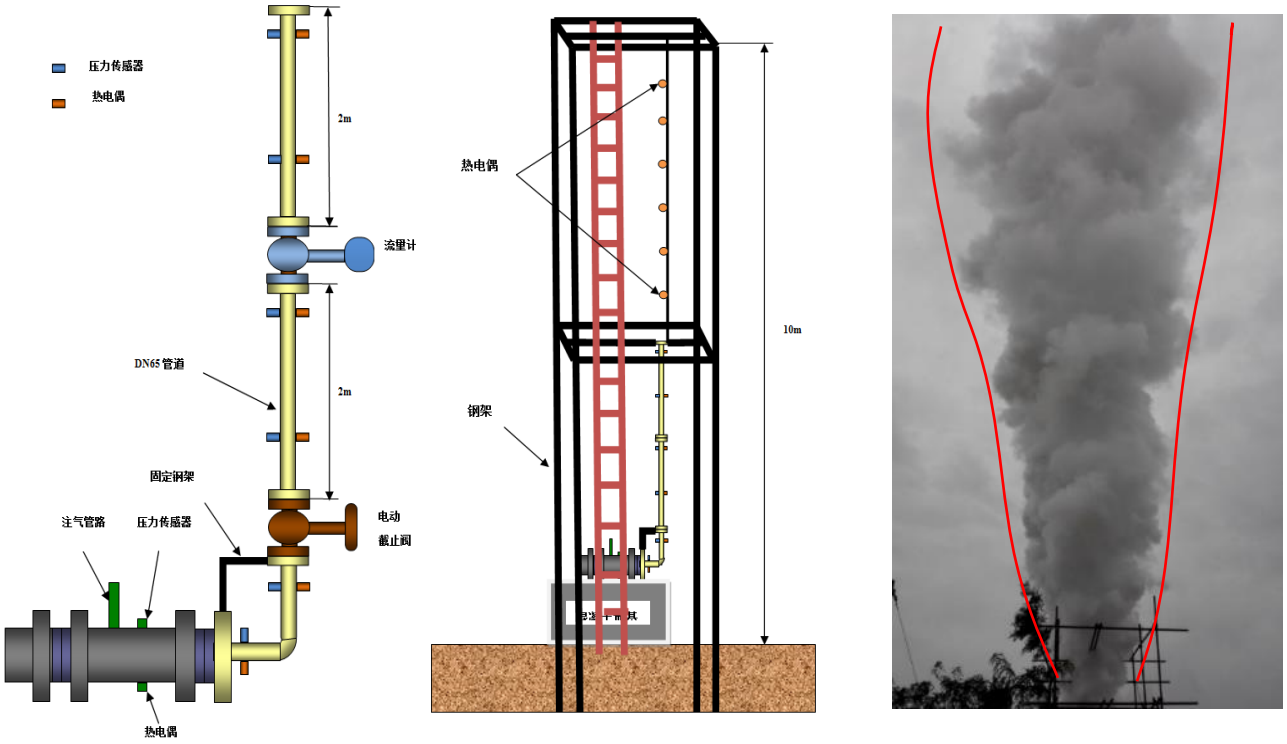




✓ A data acquisition system was built. The acquisition code was programmed by LabView software from the NI company.

What have we done?

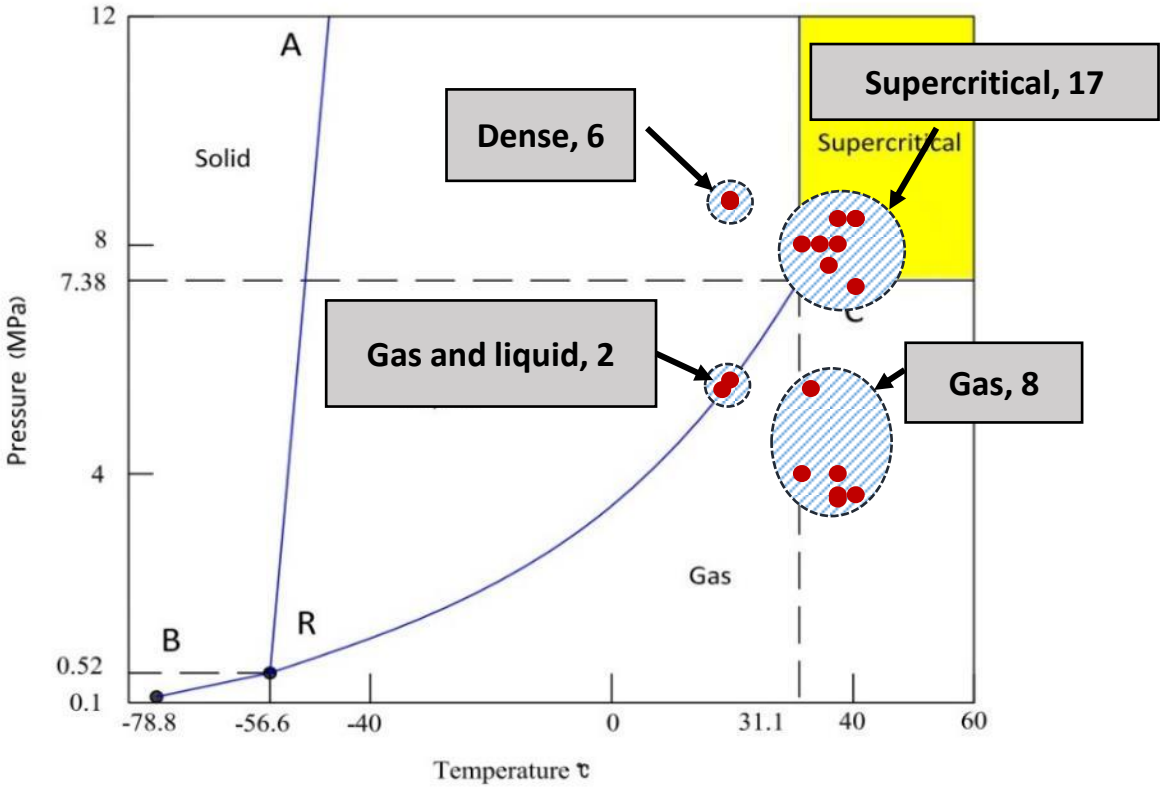
- Vertical release experiments



✓ We also designed the vertical release experimental system, which consists of electrically operated valve, flowmeter and the steel frame.

How it works out?

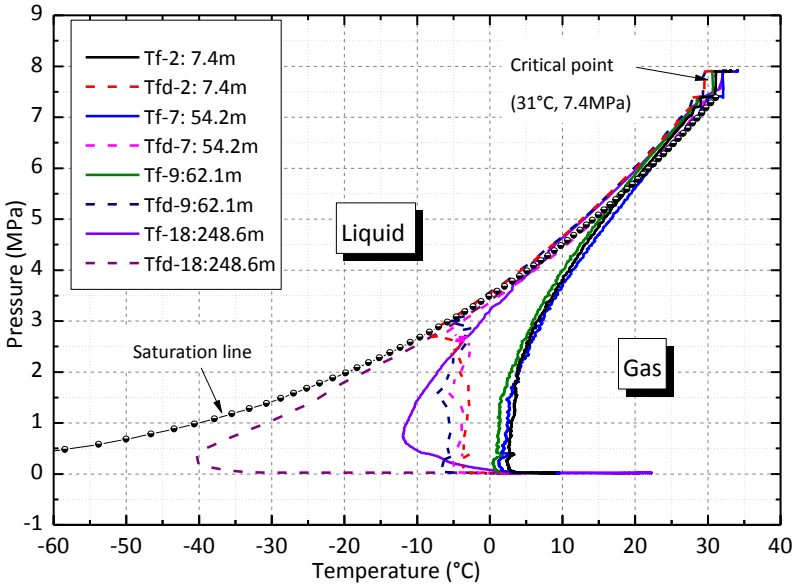
- Besides CO2QUEST, the pipeline has been used in the research project of Sinopec Petroleum Engineering Corporation.
- Till now, more than 30 times release experiments were performed.
- The experimental medium covered the **gas phase CO2, dense phase CO2, supercritical phase CO2, and CO2 with impurities**.

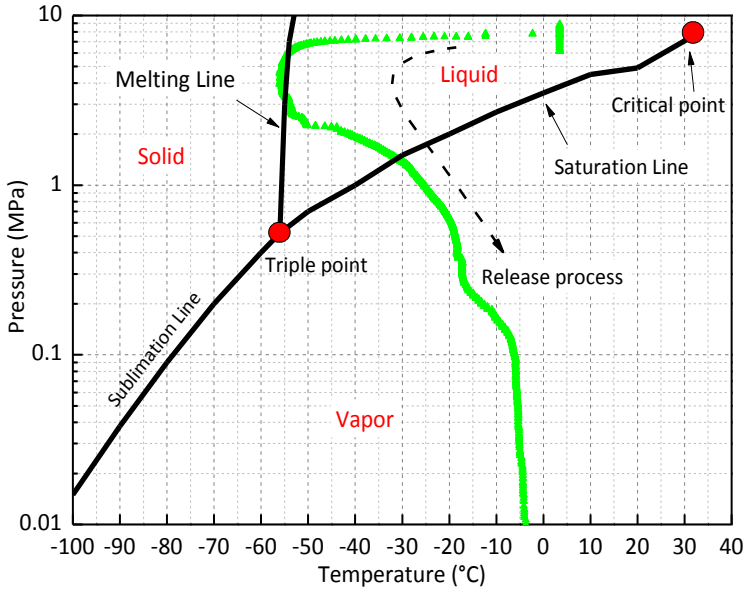


How it works out?

- What did we get?

➢ By analyzing the pressure and temperature data, **phase state changes** of CO2 in pipeline and through release orifice were obtained.



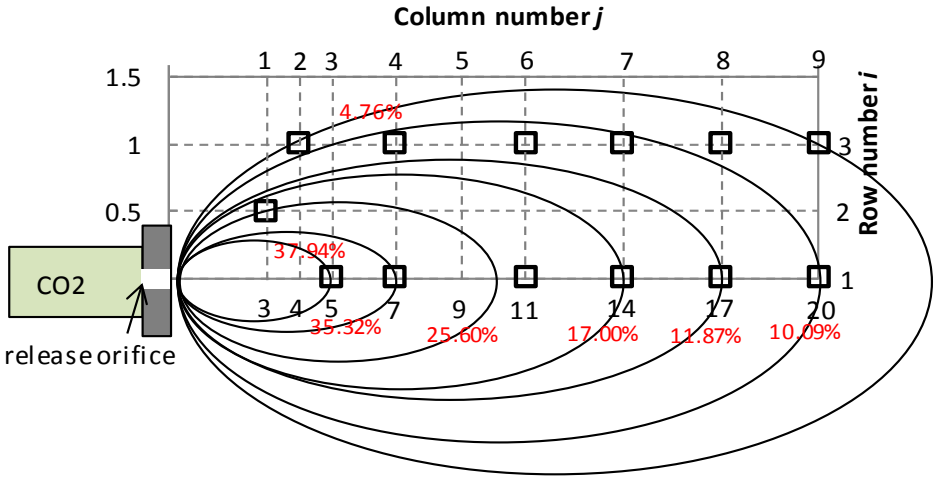


How it works out?

- What did we get?

➢By analyzing the pressure change with time at different locations, the **decompression wave behavior** was obtained.

➢By analyzing the concentration data with time at different locations, the **concentration distributions** at dispersion region were obtained.



How it works out?

- What did we get?
  - **Release CO2 plumes** were recorded by video camera.

How it works out?

- What did we get?
  - Release appearance recorded by the drone in a full bore rupture test.

Conclusions:

- **An industrial pipeline has been built for studying CO2 release and dispersion behavior, and for providing information for the design and application of CO2 transportation pipeline.**

- **This pipeline has bee used in several projects. Practical results are being analysed and produced.**

Prospects:

- **Everybody is welcomed to visit our university and this apparatus.**

- **Looking for more cooperation on safety issues of CO2 transportation.**

Acknowledgement:

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Thanks for your attention!