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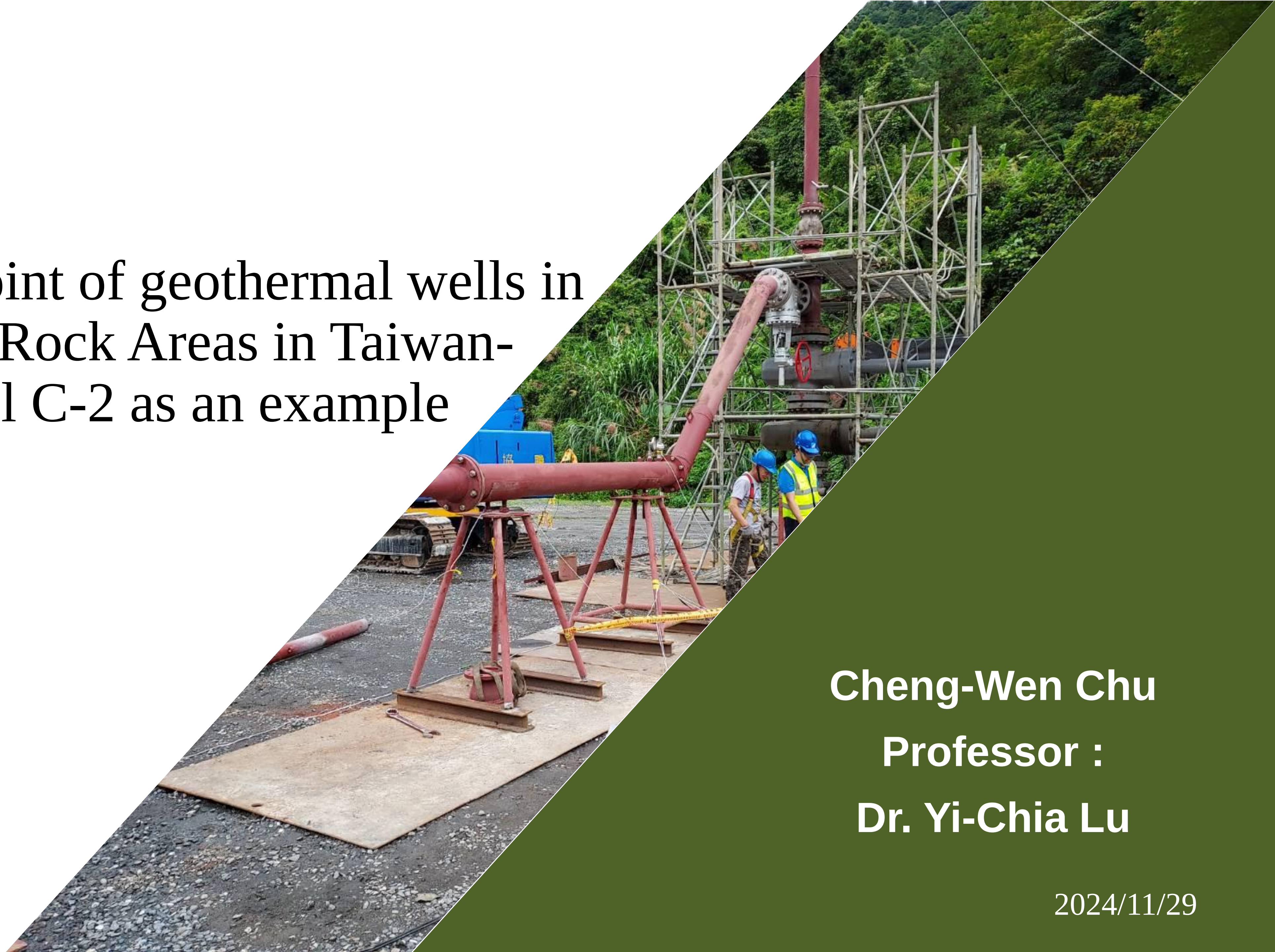
Study on flash point of geothermal wells in Metamorphic Rock Areas in Taiwan-Taking Well C-2 as an example



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Outline

- Introduction
- Methodology
- Results and Discussions
- Conclusions
- Future Work

Location and Formation

Location :

Taiwan , Yilan

Formation :

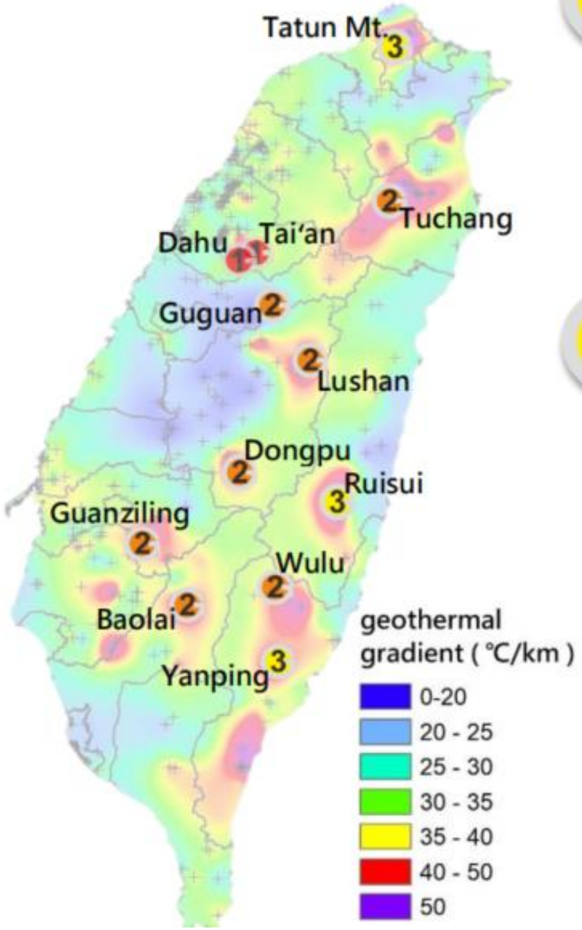
Lushan Formation

Jentse Member

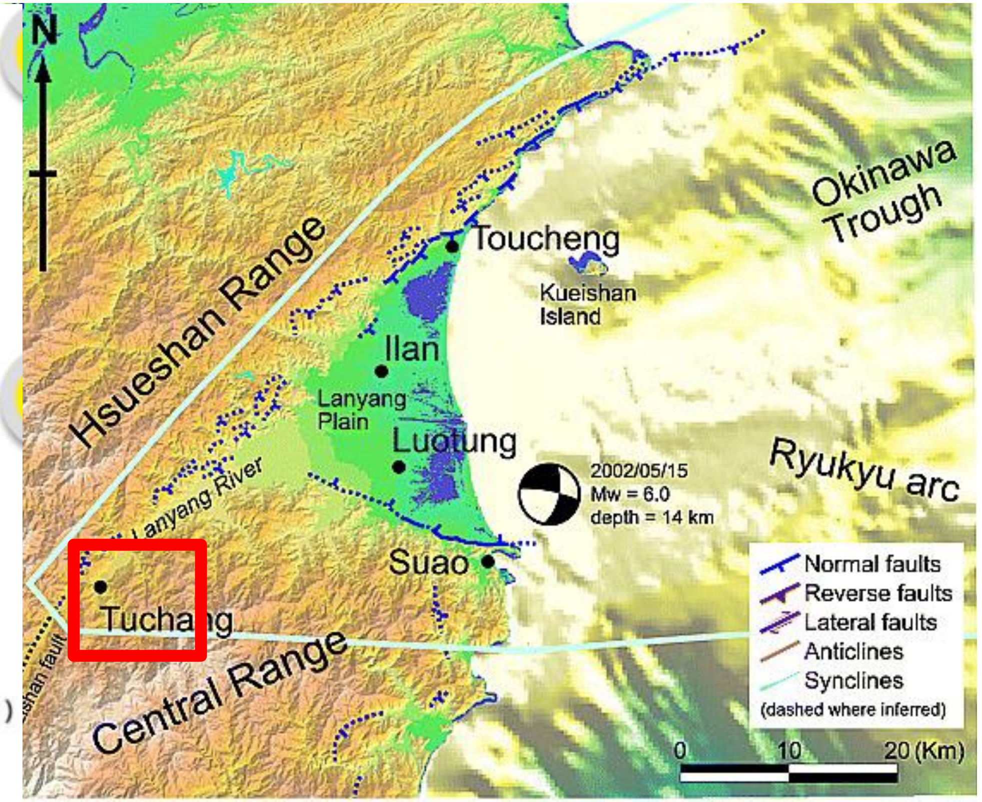
Lithology :

Slate and

Metasandstone



(GMMSA,2024)



(Shyu et al., 2005)

Well C-2 scaling problems

- The geothermal wells in the Lushan Formation exhibit similar water chemistry characteristics and are prone to carbonate scaling, and C-2 is no exception.
- During the discharge test of well C-2, carbonate scaling occurred in the pipe.

BEFORE

3.3 inch

AFTER

~3 Weeks

2.7 inch

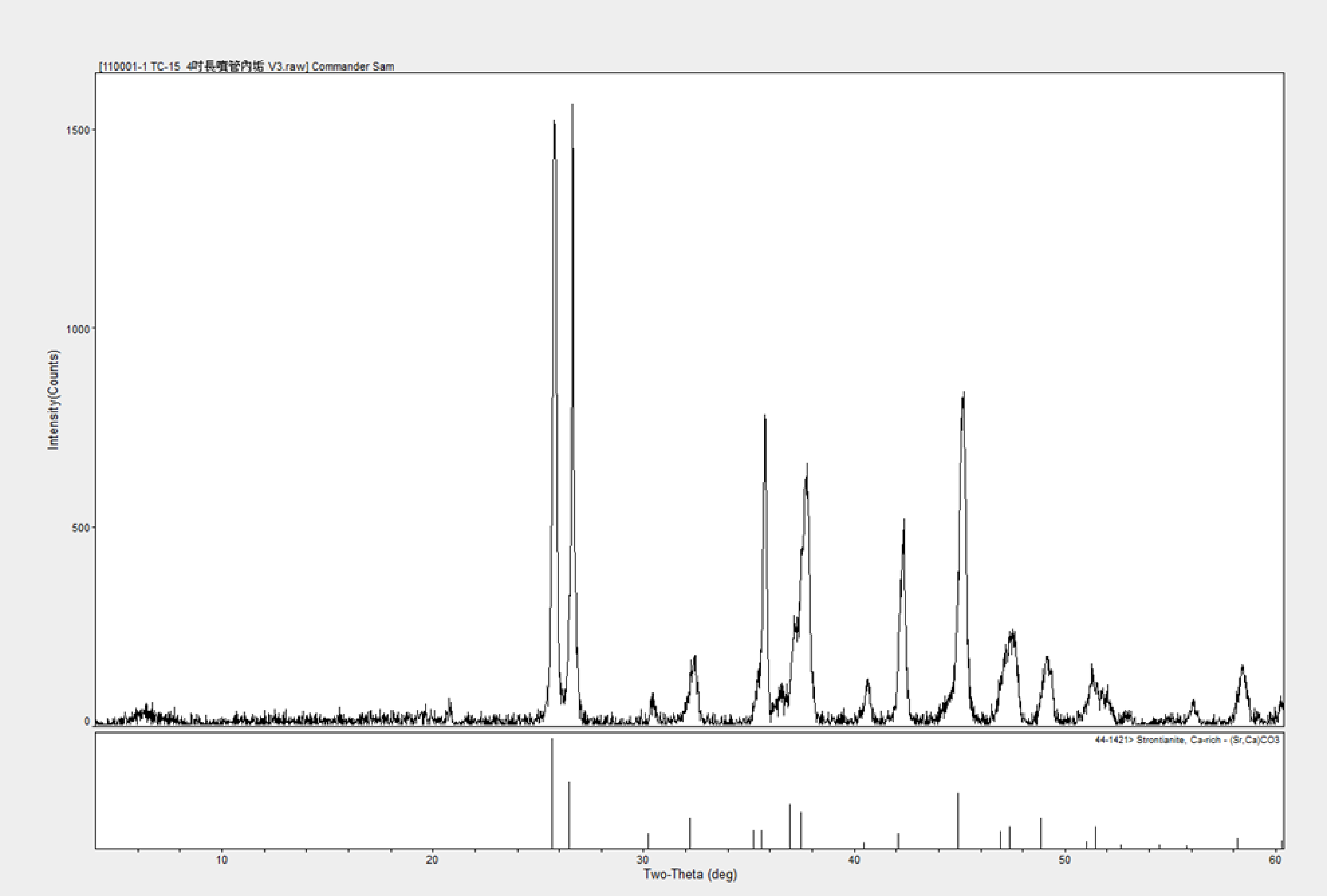
C-2 discharge test

Well C-2 scaling problems

- XRD Analysis

- Carbonate :

Strontianite Ca-rich



Purpose

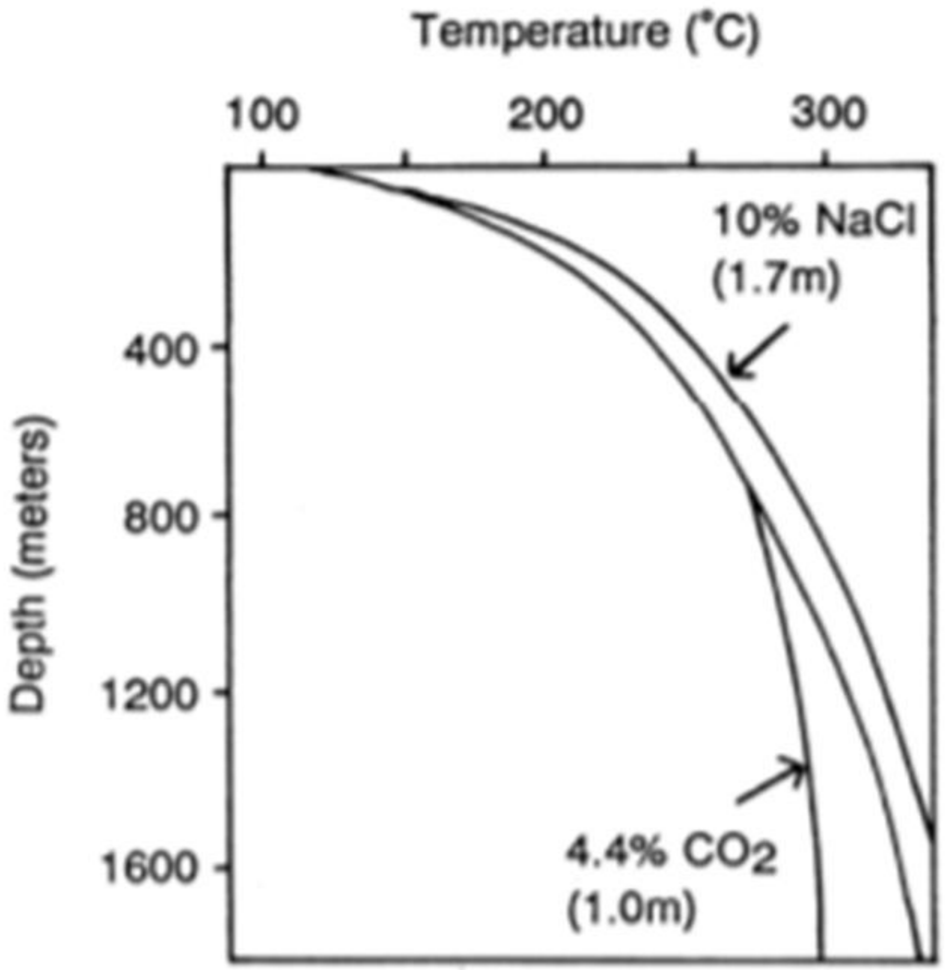
- Understanding the phase changes of CO_2 in carbon dioxide-rich fluids during the discharge period of production wells.
- Clarifying the definition of the flash point and the flash depth.
- Using well C-2 as an example, studying the flash and CO_2 phase change depths during the discharge period, in order to predict the scaling potential.

Scaling and flash points

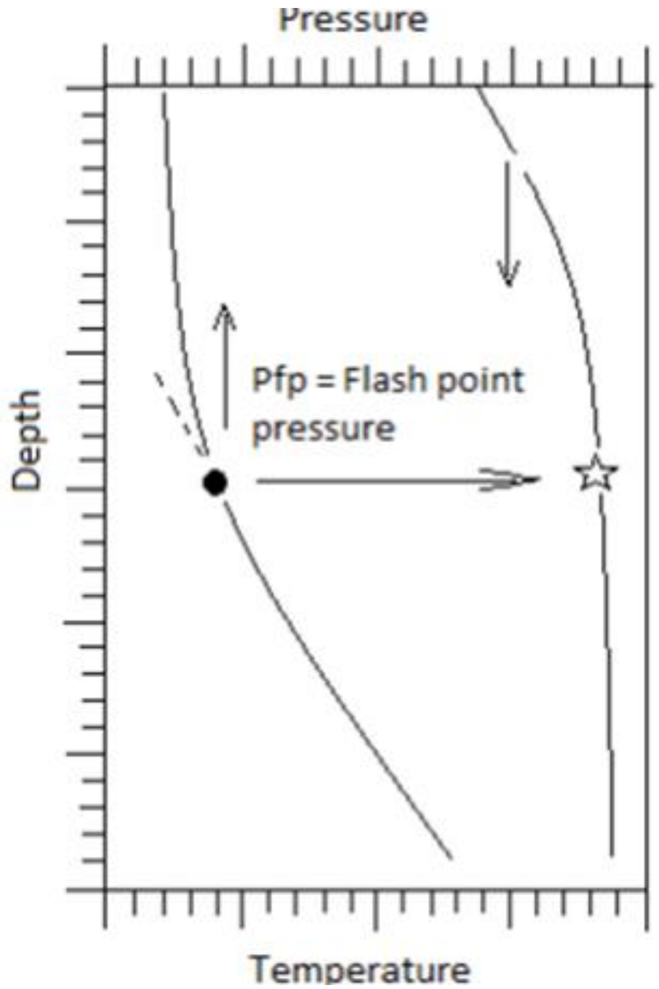
Author	Depiction	Clarify
Stefán Arnórsson, 1978	When water begins to boil under reduced pressure, as the amount of water becomes less, the amount of CO_2 that can be dissolved also becomes less, so CO_2 escapes from the water.	boiling
Niyazi Aksoy et al., 2015	As long as there is gas generation, the change in the slope of the pressure versus depth curve is the flash point.	slope change
Tseng et al.,2015	When the pressure is reduced below the saturation pressure, boiling will occur, and the location where boiling occurs is called the flash point.	boiling
Lee et al.,2012	Since pressure decreases with depth, scaling usually occurs near the flash point during the decompression process.	Beginning to scale
ITRI,2008	After the hydrothermal fluid enters the well pipe, the pressure drops suddenly, causing the geothermal water to boil or the gas to escape. Most of the CO_2 dissolved in the liquid escapes from the hydrothermal fluid when it first reaches the boiling point (flash point)	boiling or Degasing
Huang et al.,2015	Calcium carbonate scaling is mainly caused by the rapid decompression process after drilling, which causes the rapid escape of carbon dioxide in the water, resulting in precipitation in underground reservoirs and hot spring well pipe walls.	Degasing

Scaling and flash points

- Clarify the depth and definition of flash points.



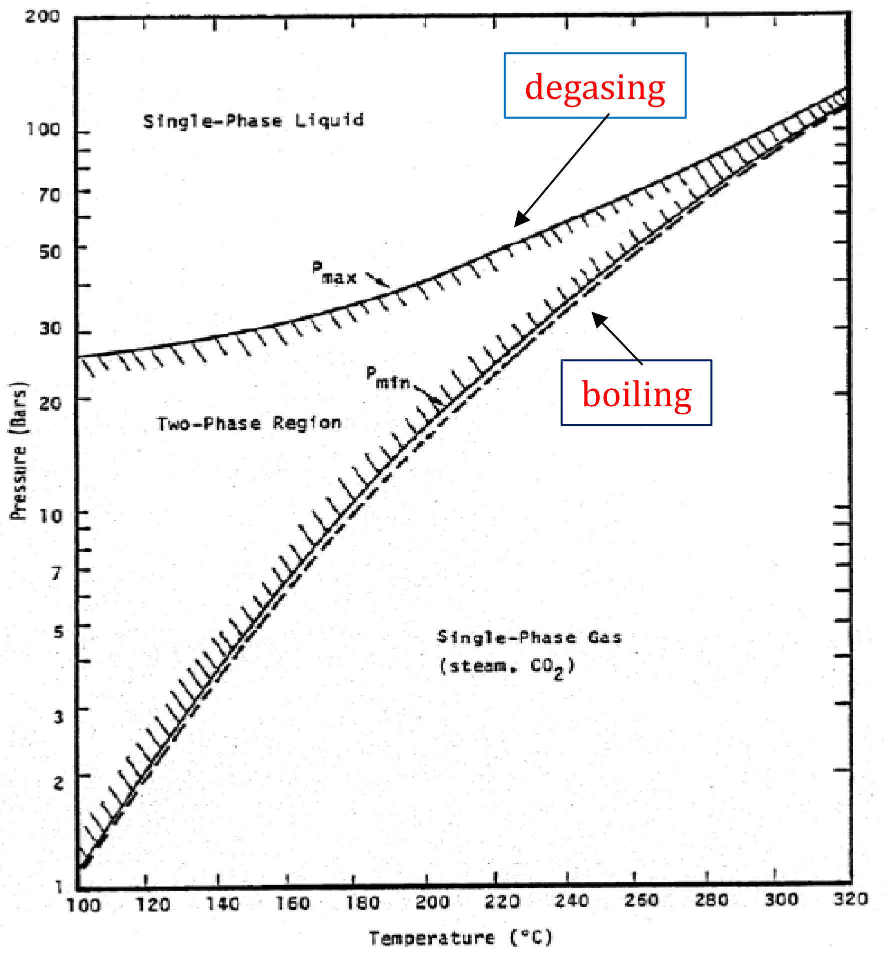
Boiling point to depth
(Nicholson,1993)



Pressure/Temperature vs. Depth Curve
(Niyazi Aksoy et al., 2015)

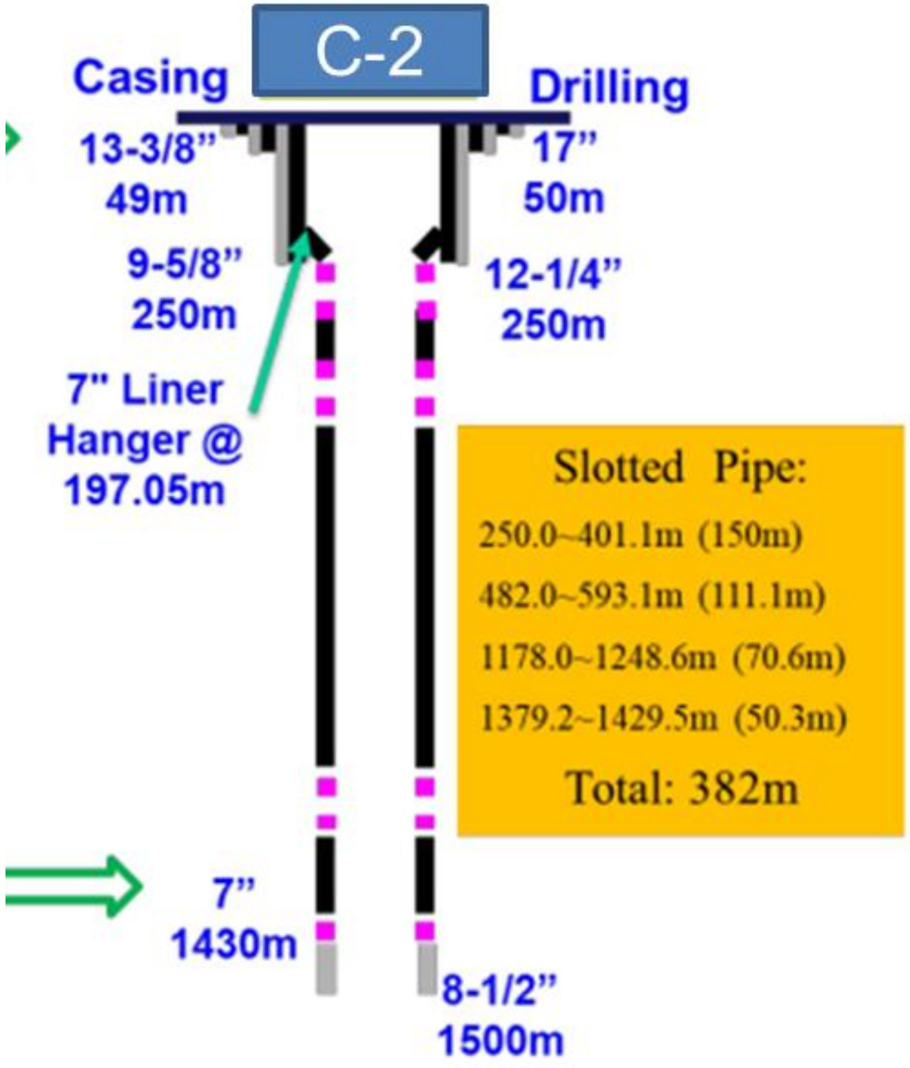
Analysis of flash of carbon dioxide-rich geothermal fluids

- $Ca^{2+} + 2HCO_3^- \leftrightarrow CaCO_3(\downarrow) + H_2O + CO_2(\uparrow)$
  - $HCO_3^- + H^+ \leftrightarrow H_2O + CO_2(\uparrow)$
  - $HCO_3^- \leftrightarrow CO_3^{2-} + H^+$
  - $Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3(\downarrow)$
- If the geothermal fluid rich in non-condensable gas (NCG) rises in the wellbore, it passes through: (1) Deeper carbon dioxide degassing point, (2) The boiling point (saturated vapor pressure) in the shallows, When CO2 is released into the gas phase, the reaction proceeds to the right to produce precipitation.
- If the geothermal fluid does not contain NCG, its flash point will be equal to the boiling point of water, and no carbonate scaling will occur.

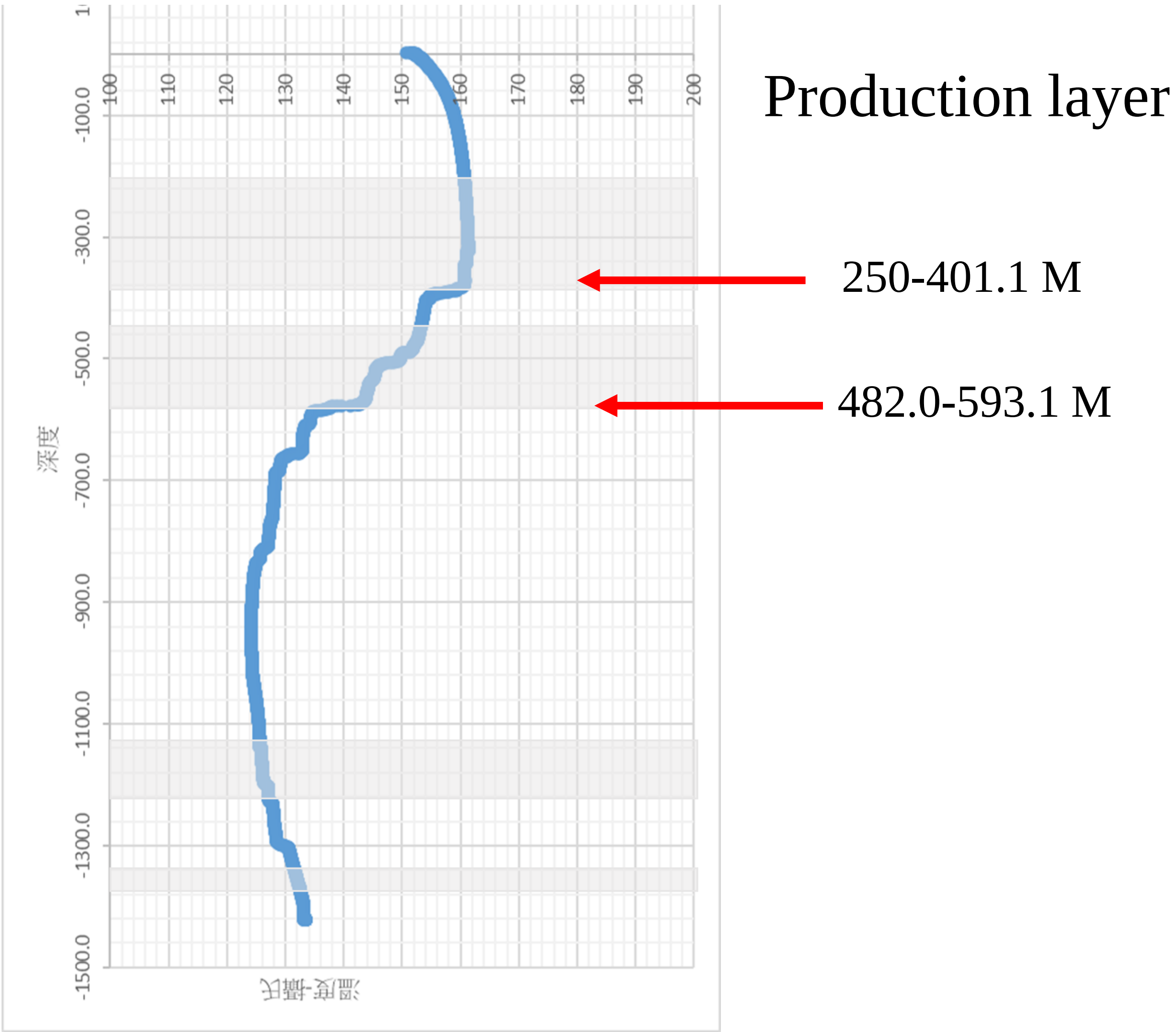


Modified phase diagram of water containing 1%wt CO2
(Pritcharad et al., 1981)

C-2 well design and temperature curve



C-2 well design



C-2 Well Temperature-Depth Curve

PTS Tool

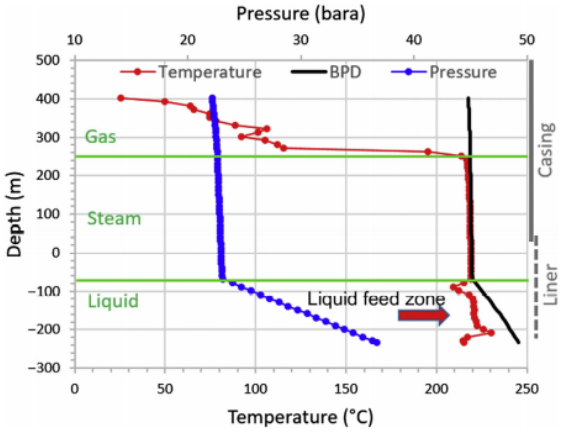
During the discharge test ,different choke sizes (i.e., 4 inches, 3 inches, 2.5 inches, 2 inches) have different flow rates and wellhead pressures.

Set the pressure-temperature-rotor (PTS) tool at the bottom of the well, and pull it up to the surface at a constant speed(1800-3600 ft/hr), recording the pressure-temperature-rotor speed data in the wellbore .

PTS tool
(ITRI,2008)

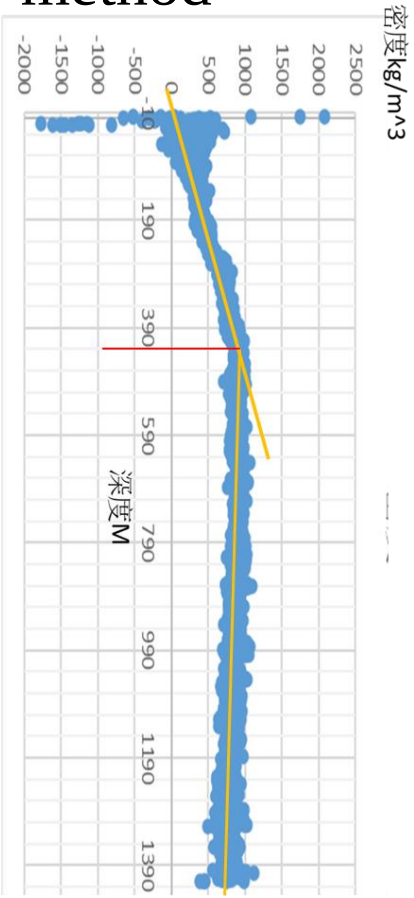
Four ways to interpret flash points Methodology

(1) Pressure-temperature versus depth curve method



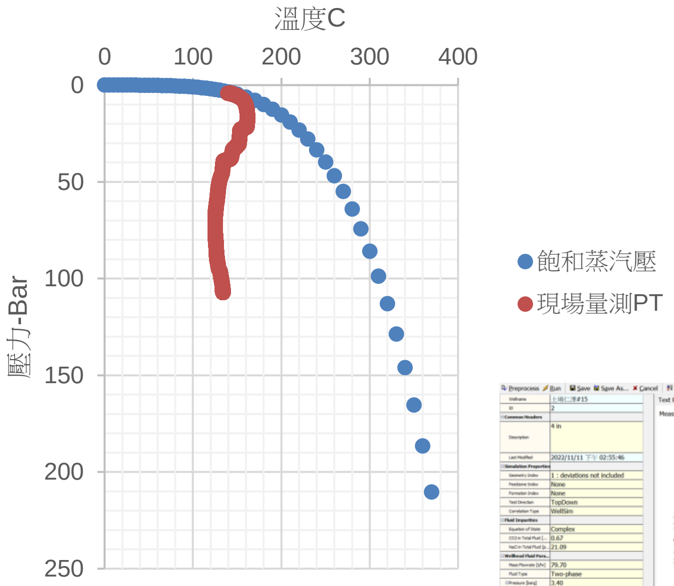
(Sadiq J. Zarrouk et al.,2019)

(2) Pressure gradient curve method

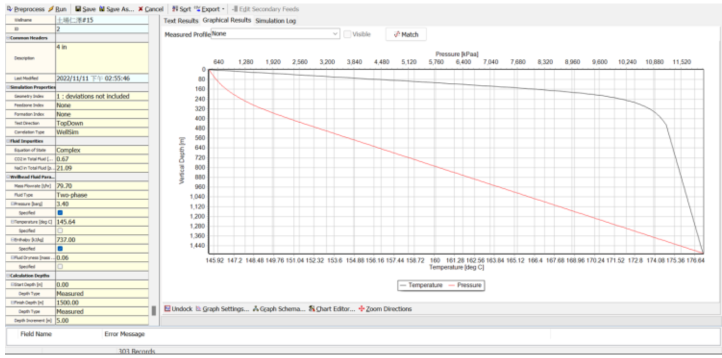


(ITRI,2019)

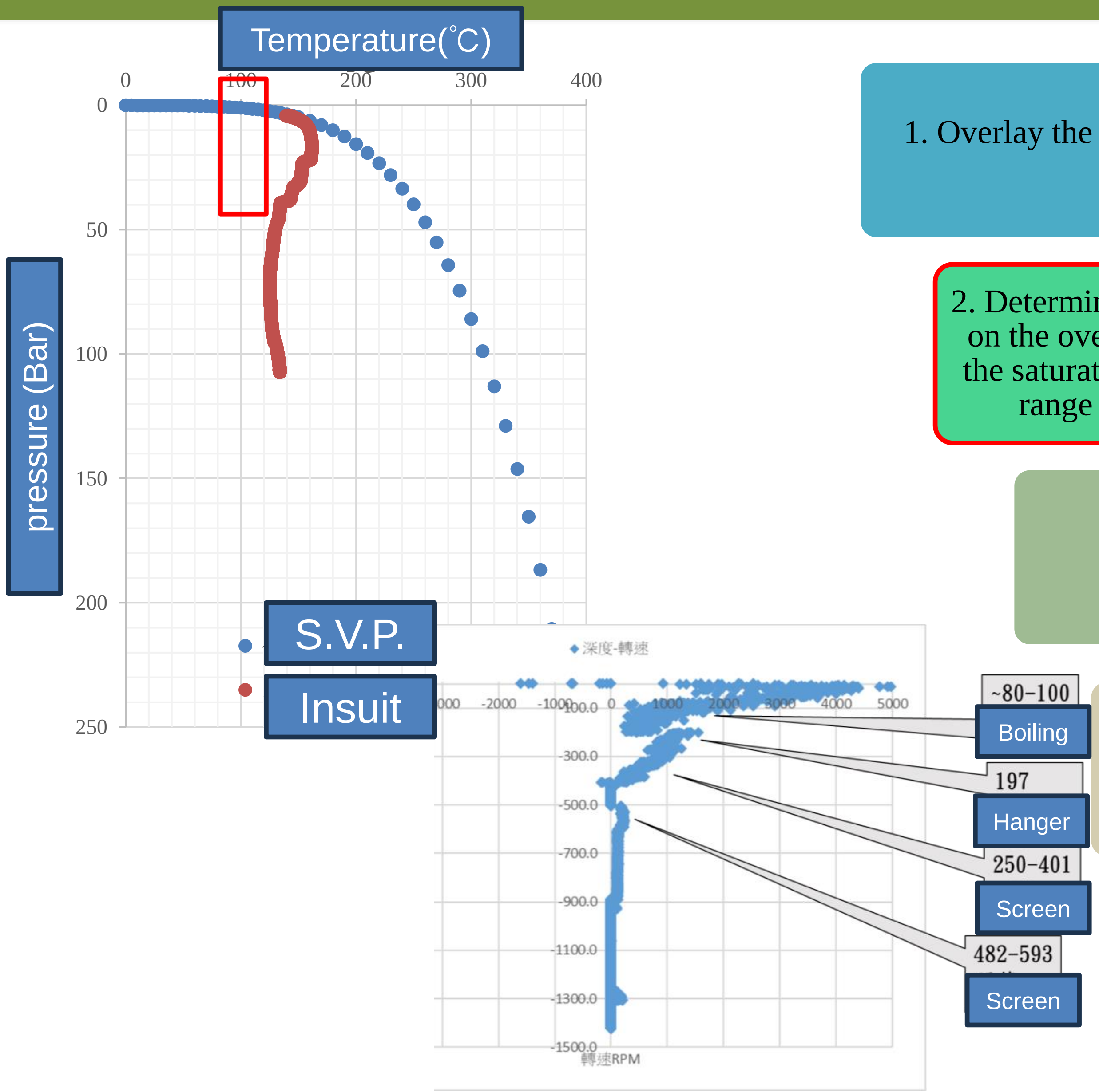
(3) PTS-saturated vapor pressure overlay method



(4) Simulation method



PTS-saturated vapor pressure overlay method



1. Overlay the saturated vapor pressure with the on-site measured PT chart

2. Determine the separation position of the two curves based on the overlay diagram. After careful inspection, calculate the saturated vapor pressure in the appropriate temperature range to calculate its equation. (C-2 is 140-160℃)

3. P=(0.0014*(T^2))-(0.2777*T)+15.964

4. Insert the on-site measurement PT chart into the above equation, and then subtract the on-site measurement value from the value. The point where it turns from positive to negative is the boiling point.

5. Use Spinner data to assist in judgment

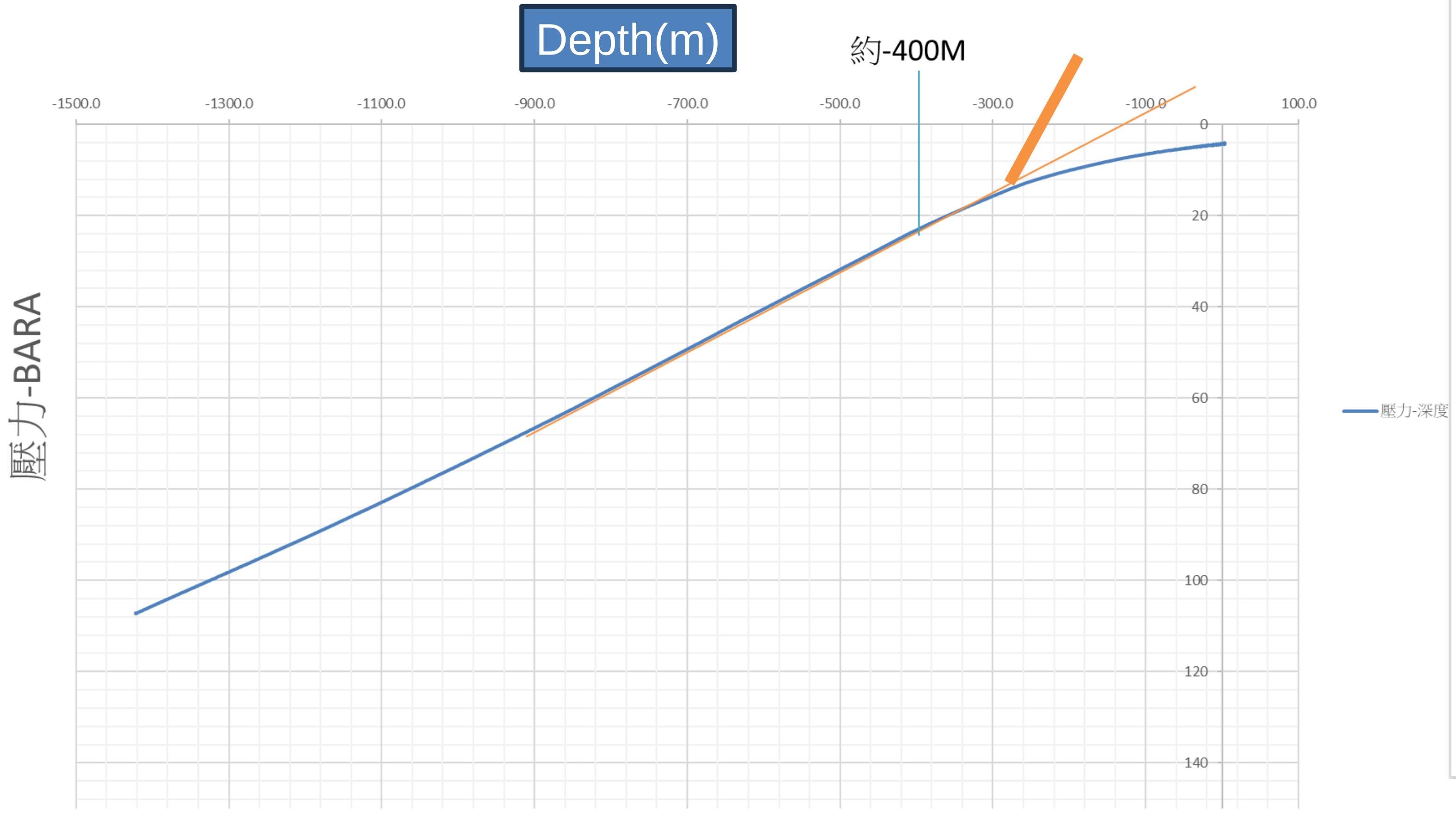
WellSim simulation

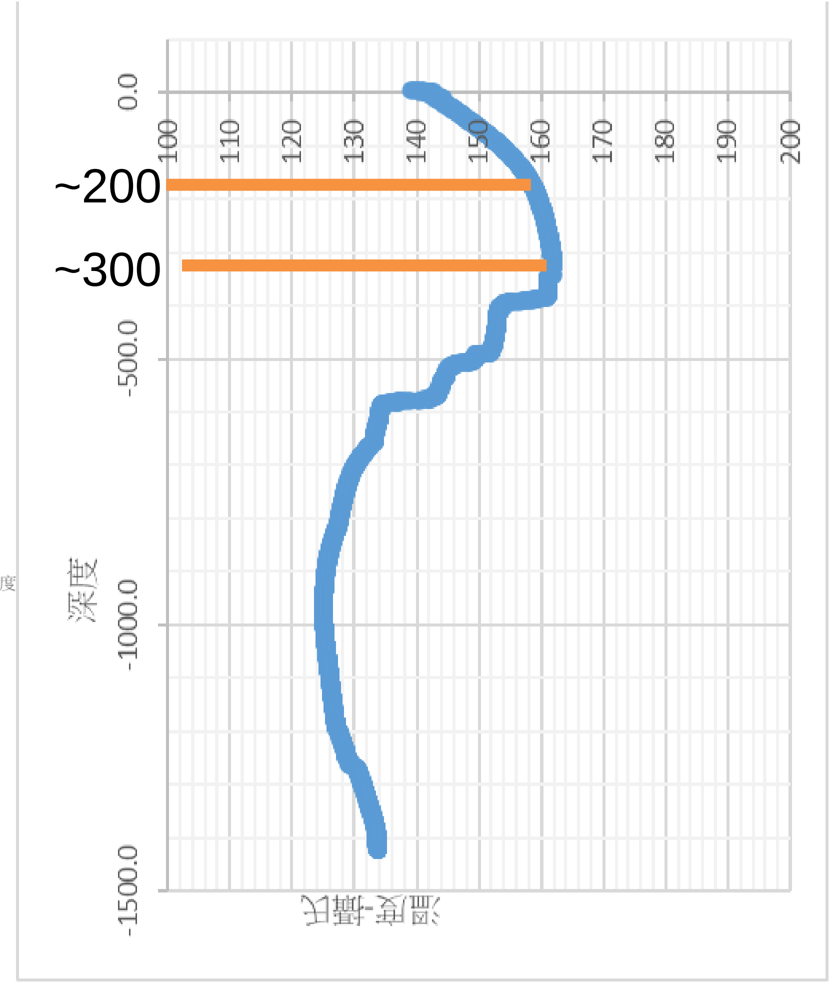
- **The WellSim** was developed for geothermal drilling simulation by GSDS (Geothermal Science and Data Solutions).

- It estimates the stable fluid pattern in geothermal wells using limited input data.
- It uses the TopDown simulation method, which relies on wellhead measurements or estimated data for the simulation.
- The surface parameters for the four choke sizes of Well C-2 include water output, fluid temperature, pressure, dryness, enthalpy (choose any two from the four), CO_2 content, and NaCl content.

Pressure and temperature vs depth curve

(4 inches)

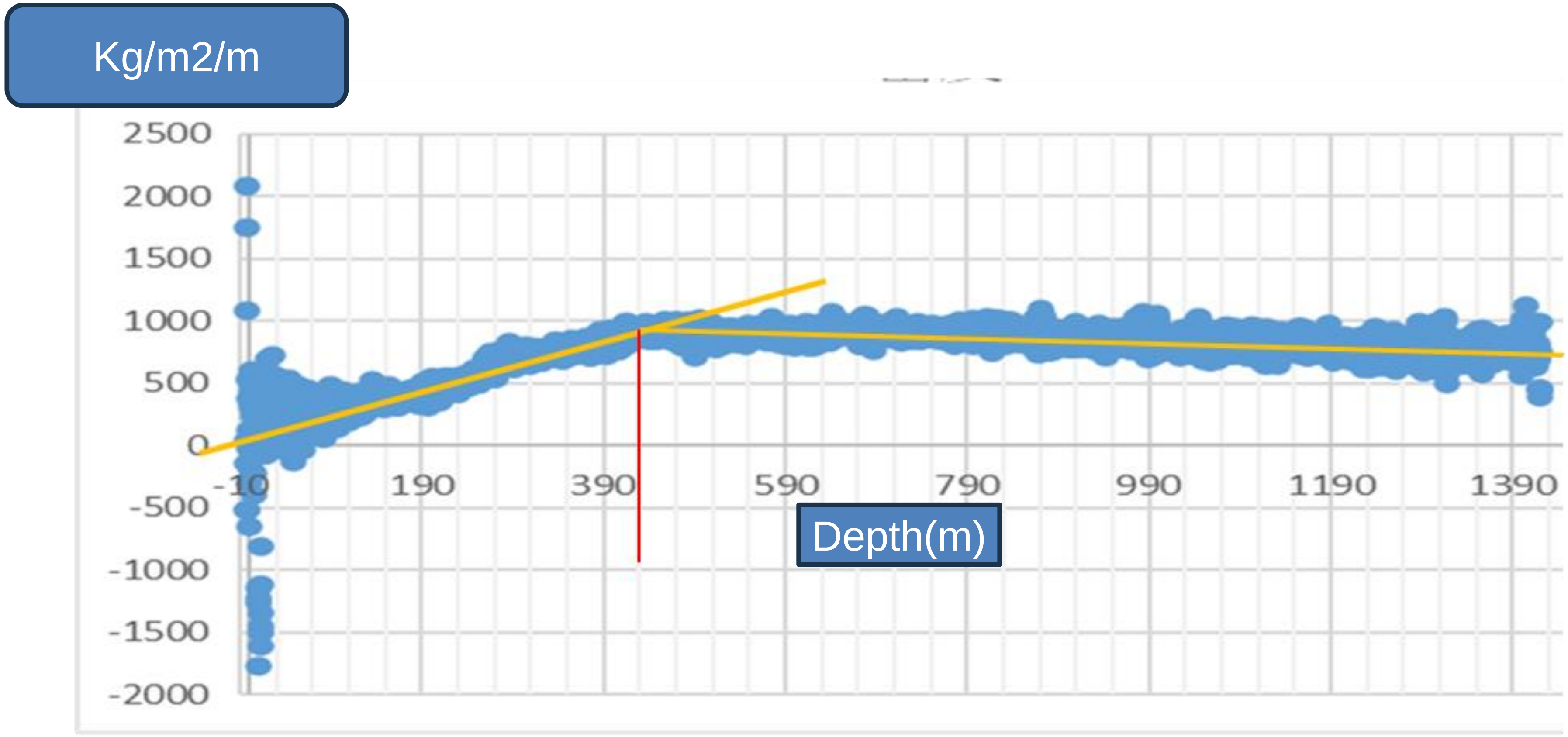




The slope change of the right picture (pressure-depth) is about 400M, and the slope change of the left picture (temperature-depth) is about 200M.

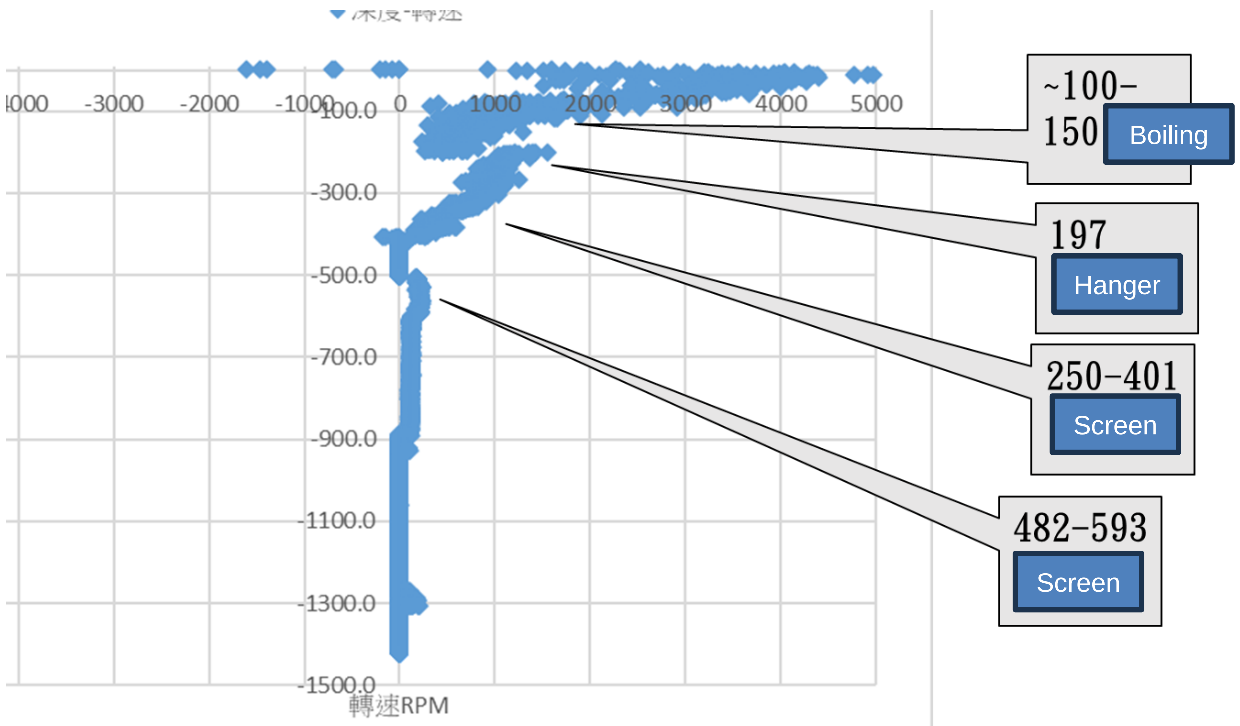
Pressure gradient curve method

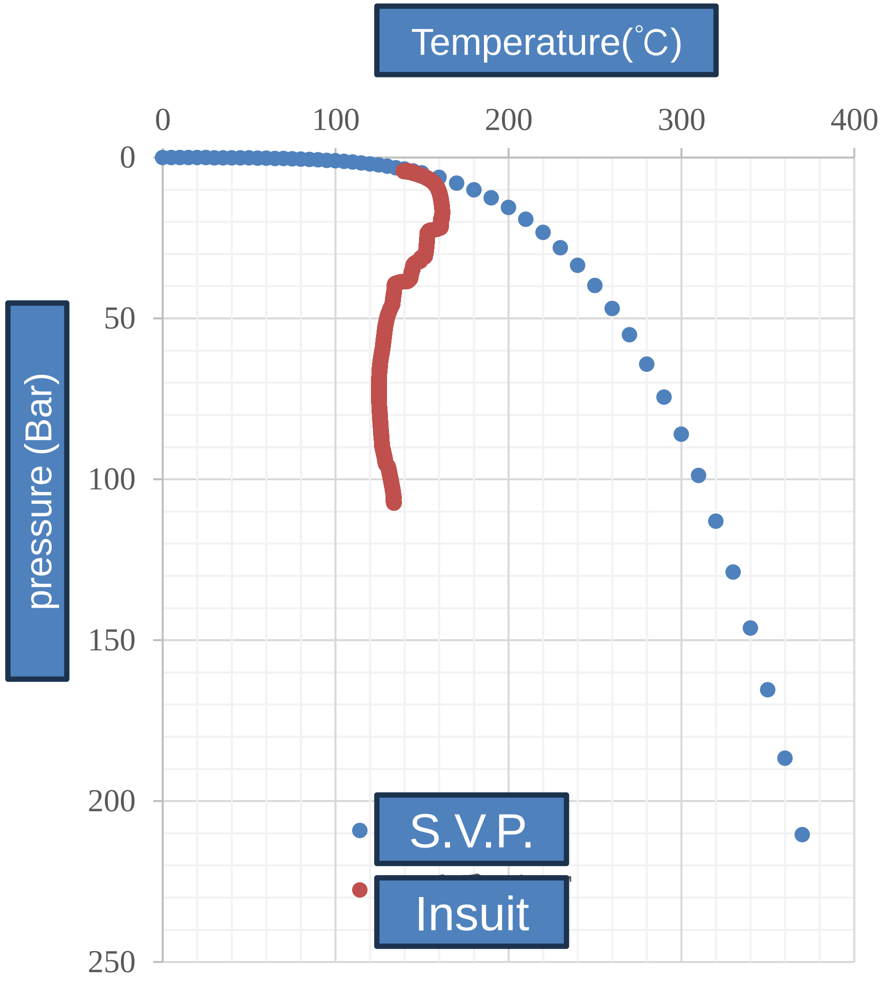
- Pressure gradient curve method 4-inch in Well C-2, the turning point of the curve is about -430M (25.26Bara)。



PTS-saturated vapor pressure overlay method

- The depth where the PT curve separates from the saturated vapor pressure occurs at approximately 80-88M/152°C (6.0-6.2 Bara).
- The boiling point based on the rotor speed, which corresponds to a depth of about 100-150M.





Data input for WellSim

Chock (inch)	CO2(wt%)	NaCl (wt%)	Total Flow rate(TPH)	WHP (BarG)	Enthalpy (kJ/kg)	Gas ratio
4 inches	0.67	0.21	79.7	3.4	737	0.06
3 inches	0.43	0.11	64.1	4.31	685.73	0.03
2.5 inches	0.33	0.09	56.18	4.99	677.83	0.02
2 inches	0.32	0.13	39.72	5.63	661.19	0.01

C-2 Well Fluid Analysis Data

Date	sample	Chock (inch)	pH	Cl^- (ppm)	CO_3^{2-} (ppm)	HCO_3^- (ppm)	Ca2+ (ppm)	Mg++ (ppm)
109/12/04	15-1	2	8.15	7.78	b.d.l	2802	12.3	0.88
109/12/05	15-2	2.5	8.61	5.58	192	2469	11.2	2.6
109/12/06	15-3	3	8.66	6.41	196	2432	6.29	3.74
109/12/07	15-4	4	8.87	9.05	286	2235	9.04	3.5
109/12/24	15-5	4	9.27	12.8	518	1670	3.78	1.57
110/03/17	15-6	4	9.25	12.8	477	1845	b.d.l	b.d.l

Date	sample	Chock (inch)	N_2 (V%)	H_2S (V%)	HCl (V%)	CO_2 (V%)
109/12/04	15-1	2	0.59	0.05	0.01	98.7
109/12/05	15-2	2.5	0.89	0.04	0.01	98.1
109/12/06	15-3	3	0.92	0.06	0.01	98.1
109/12/07	15-4	4	0.99	0.07	0.01	98.0
109/12/24	15-5	4	0.73	0.05	0.01	98.3
110/03/17	15-6	4	3.80	0.05	0.02	95.3

Chock (inch)	CO2(wt%)	NaCl (wt%)	Total Flow rate(TPH)	WHP (BarG)	Enthalpy (kJ/kg)	Gas ratio	NCG/Steam (%)
4 inches	0.67	21.09	79.7	3.4	737	0.067	9.9
3 inches	0.43	10.56	64.1	4.31	685.73	0.030	14.2
2.5 inches	0.33	9.2	56.18	4.99	677.83	0.020	16.4
2 inches	0.32	12.82	39.72	5.63	661.19	0.009	36.7

CO2content : :6.67%×9.9%×98 %=0.67%(wt)

WellSim simulation results (4 inches)

Wellname	ID	Vertical D	Flow Regi
		447.05	Bubble
		452.05	Bubble
		452.496	Flash
		457.496	Liquid

Vertical D	Flow Regi
120	Churn
125	Churn
130	Slug
135	Slug
140	Bubble
142.9773	Flash
147.9773	Liquid

Equation of State	Complex
CO2 in Total Fluid [...	0.67
NaCl in Total Fluid [p...	21.09
Wellhead Fluid Para...	
Mass Flowrate [t/hr]	79.70
Fluid Type	Two-phase
Pressure [barg]	3.40
Specified	☑
Temperature [deg C]	145.64
Specified	☐
Enthalpy [kJ/kg]	737.00
Specified	☑
Fluid Dryness [mass ...	0.06
Specified	☐
Calculation Depths	
Start Depth [m]	0.00
Depth Type	Measured
Finish Depth [m]	1500.00
Depth Type	Measured
Depth Increment [m]	5.00

Field Name	Error Message

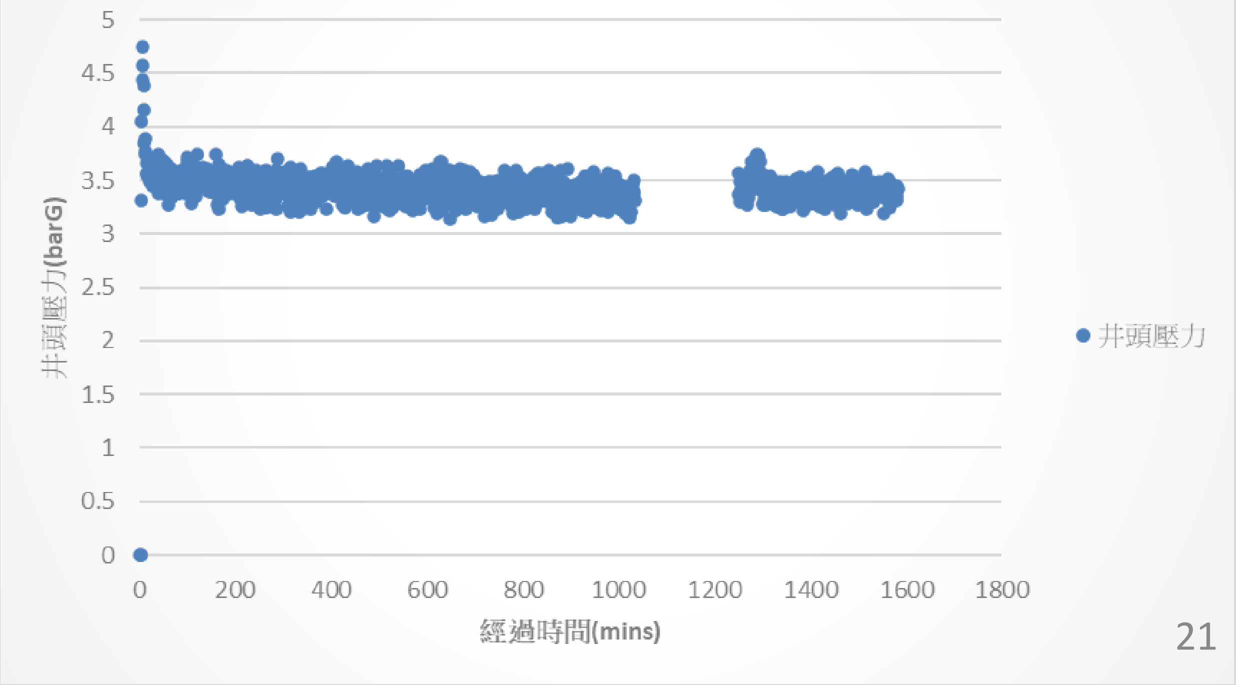
303 Records

- CO_2 0.67 wt%
  Flash point : 452.496M
- CO_2 0 wt%
  Flash point : 142.977M

- The flash point corresponds to the boiling point if there is no influence from CO2.
- Based on the WellSim simulation results, the flash point is the carbon dioxide vaporization point.

The possible reason for misjudging the flash point depth

- The fluctuation range of the wellhead pressure measurement value during 4-inch discharge flow is approximately 1 Bar.
- It is speculated that poor fluid flow stability inside the well may lead to pressure instability, which could cause changes in the flash point depth.



Comparison table of four methods

Determine depth	Pressure-temperature vs depth curve method-Degassing	Pressure gradient curve method-Degassing		PTS-saturated vapor pressure overlay method-Boiling		Spinner fast rising position-Boiling	WellSim simulates flash point	WellSim simulates the flash point without CO2
4 inches	~400 m	430 m	(25.26Bara) 152.9℃	80-88m	(6.00-6.20Bara) 152℃	100-150 m	452.496m	142.977m
3 inches	~320 m	350 m	(25.46Bara)	30-40 m	(6.01-6.19Bara) 152℃	50-80 m	209.248m	26.209m
2.5 inches	~270 m	300 m	(25.83Bara)	not obvious	(5.98-6.14Bara) 151℃	0-30 m	136.512m	3.178m
2 inches	~170 m	250 m	(24.72Bara)	not obvious	(6.47-6.61Bara) 152℃	not obvious	102.745m	--

- Pressure-temperature vs depth curve method and Pressure gradient curve method-Degassing
- PTS-saturated vapor pressure overlay method and Spinner fast rising position-Boiling
- Simulation method -Degassing. Without CO2-Boiling.

Conclusions

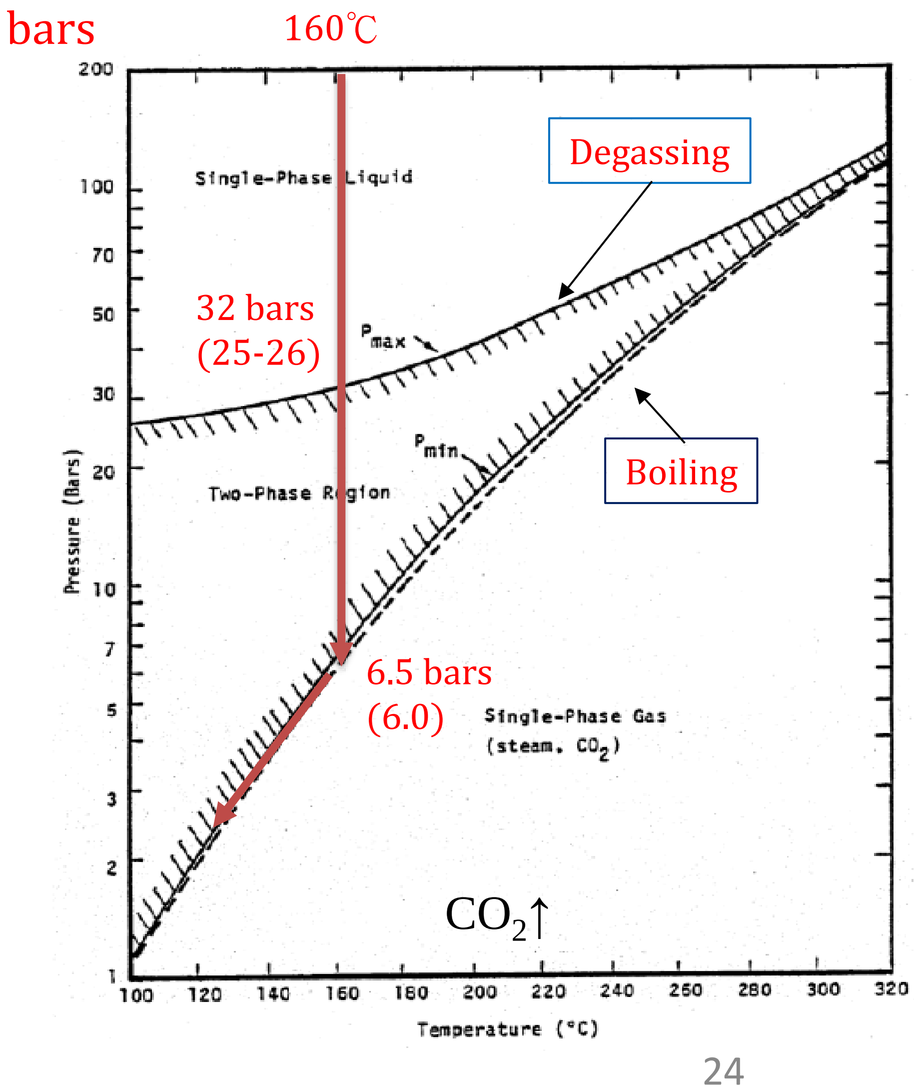
- There are currently many definitions of flash point. Because geothermal fluid rich in CO2 rises due to rapid decompression, CO2 degassing occurs in deep, and geothermal fluid boils in shallow, both of which produce carbonate scaling. This study recommends using WellSim's definition to define the flash point by using the pressure-depth slope turning point, that is, the degassing point.

- Pressure-temperature vs depth curve method and Pressure gradient curve method-Degassing
- PTS-saturated vapor pressure overlay method and Spinner fast rising position-Boiling
- Simulation method -Degassing. Without CO2-Boiling.

Conclusions

- Combining the phase diagram of the geothermal fluid from Well C-2 with the geothermal fluid containing 1wt% CO2, the phase changes during the rise and decompression of the geothermal fluid can be roughly obtained. The words pressure and temperature in the figure are the base map data, and the actual measurement data of the C-2 well are in brackets.

- According to the measured data from well C-2, the degassing point of CO_2 will be encountered during the rise and depressurization process at a pressure of 25-26 bar, and the boiling point will be reached at a pressure of approximately 6.0 bar and a temperature of around 152°C. If the geothermal fluid contains 1 wt% CO_2, it will reach the CO2 degassing point at a pressure of 32 bar and the boiling point of the geothermal fluid at a pressure of 6.5 bar.



Conclusions

Workflow

1. PTS
2. Chemical analysis, calculation of CO_2 content
3. Pressure-temperature vs depth curve method and Pressure gradient curve method-Degassing
4. PTS-saturated vapor pressure overlay method and Spinner fast rising position-Boiling
5. WellSim simulation

Future Work

- More Well Analysis.
- Investigate suitable scale-inhibition system design or pressure-control design to make power plant stable.
- Data analysis of temperature, pressure, flow rate and other data of geothermal well heads and key components of power plants.
- Surface pipe flow analysis and scaling depth prediction.

Thanks for your attention