Effects of Near-critical Inlet Condition on the Performance of Supercritical CO_2 Compressor

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Introduction

Background:

- The Brayton cycle of supercritical carbon dioxide (sCO_2) is an attractive power generation technology, which offers potential advantage of cycle efficiency. In supercritical state, CO_2 has high specific heat capacity, high density, low viscosity and other qualities. The preceding investigations are concerned with the overall performance of the compressor and do not provide a clear picture of the specific internal-flow characteristic of sCO2 the compressor. Therefore, it is necessary to investigate the quantitative effect of near-critical nonequilibrium phase-change on the performance of sCO_2 centrifugal compressor, so as to improve theoretical guidance for the design and operation strategy of sCO_2 compressor.

Objective:

- A two-stage centrifugal compressor for an 8MWt sCO_2 power cycle test rig .

Centrifugal Compressor

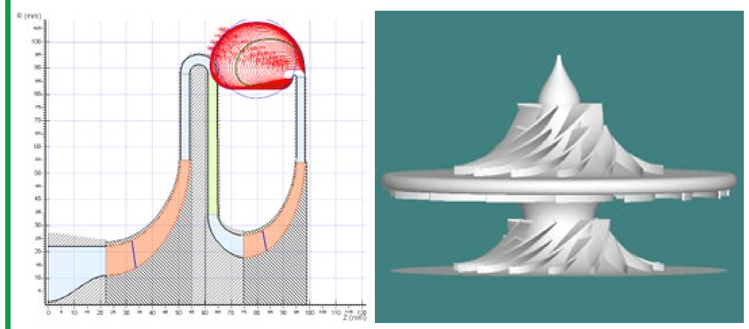

Fig. 1 1D(left) and 3D(right) design diagram of centrifugal impeller

Table. 1 Design parameters of main compressor

Parameters	Unit	Value
Mass flow rate	Kg/s	26.0
Inlet pressure	MPa	8.0
Inlet temperature	K	306.15
Outlet pressure	MPa	24.0
Rotation speed	Rpm	25000
Pressure ratio	-	3.0
Choke mass flow rate at rated rotation speed	Kg/s	30.5
Surge mass flow rate at rated rotation speed	Kg/s	17.5

Result & Discussion

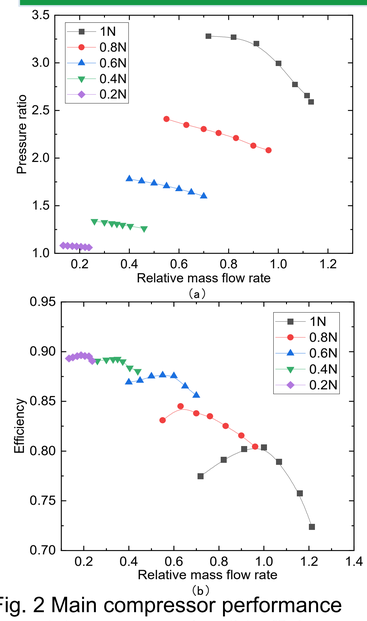

Fig. 2 Main compressor performance curve:(a) pressure ration;(b) efficiency

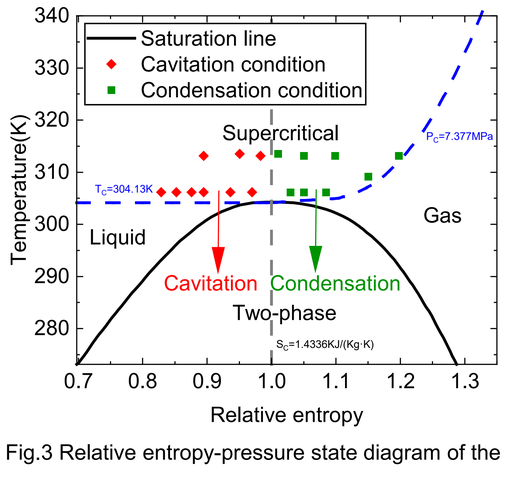

Fig.3 Relative entropy-pressure state diagram of the CO_2

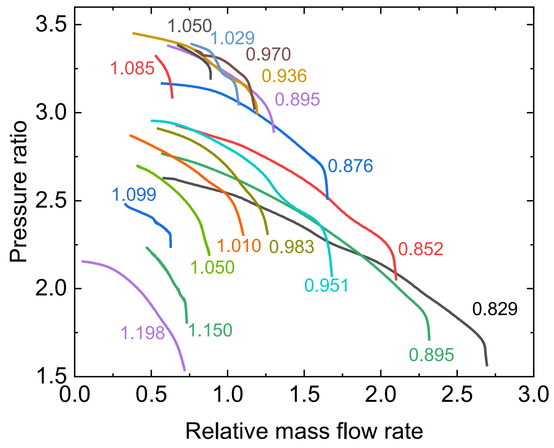

Fig.4 Performance curve at various relative entropy

- If the relative entropy is smaller than one, the sCO_2 fluid behaves like liquid. The phase-change occurs as cavitation. The compressor has a large pressure ratio and small temperature rise, reflecting the characteristics of pump. The small temperature rise is consistent with the fact that compressibility in liquid states is low. If the inlet relative entropy is greater than one, the sCO_2 behaves like gas. The phase-change occurs as condensation. The stable operation range will move to the small mass flow as whole, since the small density. It is easier to condense comparing to cavitation for the same entropy level. The pressure ratio increase with the increase of relative entropy in general. The surge mass flow rate is nearly the same but the choking-limit mass flow rate decreases with the increase of the relative entropy, since the drop in the speed of sound.

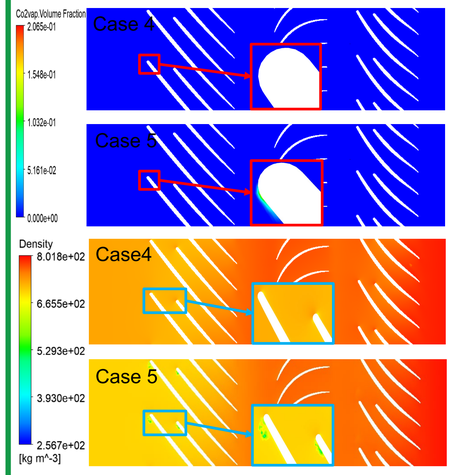

Fig.5 Contour of compressor at 90% span for case4 and 5

- Two realistic thermodynamic states are now simulated, with the same relative entropy. These two conditions are representative of high (case 4) and low (case 5) temperature.
- On the whole, the temperature and pressure rise along the flow passage. However, there will be a local region of low temperature and pressure in the leading edge of the blade.
- Due to the nonequilibrium phase change effect, cavitation does not occur in the leading edge of the blade, even if the local low temperature and pressure region at case 4 is below the critical point. A well-defined region of low density is observed at the leading edge and the trailing edge of the blade at case 5, which can indicate the occurs of cavitation. The cavitation occurs on the suction side and the suction occurs on the upstream which result from the choke. What is more, the front loading may trigger the cavitation. In return, a sudden drop of pressure takes place which prompts a sharp decline in the speed of sound. And then the relative Mach number is suddenly rising, which turns to cause the blockage.

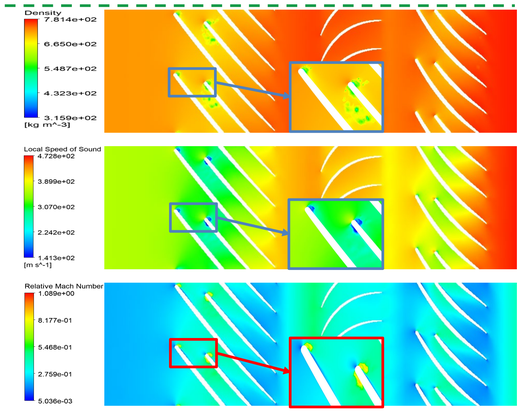

Fig.6 Contour of compressor at 90% span for large mass flow rate

Main Conclusions

1)The supercritical and subcritical thermophysical properties of CO_2 are included in the real gas property table, the properties of the two-phase region are well considered. The metastable properties are calculated by the inverse interpolation.

2)If the inlet relative entropy is smaller than one, the sCO_2 behaves like liquid. The phase-change occurs as cavitation on the leading edge of the blade. Pressure ration increase with the increase of relative entropy. But the choking-limit mass flow rate decrease, since the drop in the speed of sound. As the relative entropy increase, the cavitation becomes severer, which resulting in wide range of two-phase region. When this two-phase region grows wider enough to cover the channel, the choke will soon happen. If the inlet relative entropy is greater than one, the sCO_2 behaves like gas. The phase-change occurs as condensation. The stable operation range will move to the small mass flow, since the small density. It is easier to condense comparing to cavitation for the same entropy level.