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Multi-Component working fluid blends for optimizing sCO2 Brayton Power Cycle Performance in Extreme Cold Conditions

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Abstract

*Supercritical Supercritical carbon dioxide (sCO₂) Brayton cycles are promising for high-efficiency power generation, yet their operation in extreme cold is hindered by a mismatch between CO₂’s critical temperature (~31 °C) and low ambient sink temperatures, limiting their viability in polar or cryogenic applications. To address this challenge, previous studies have explored binary sCO₂-based fluid blends with additives such as CF₄, NF₃, Kr, and CH₄, achieving critical temperature reductions to around –50 °C and cycle efficiency improvements of approximately 10%. Building on this progress, the present work introduces ternary sCO₂ mixtures incorporating very low critical temperature fluids— Carbon Monoxide (CO), and Nitrogen (N₂)—to further enhance low-temperature performance.*

*The inclusion of a third component enables the replacement of CF₄ and NF₃ with benign alternatives, thereby reducing material constraints and eliminating atmospheric impact. Moreover, the use of near-ideal gases minimizes material stress and extends operational viability to temperatures well below –50 °C. CO and N₂ are inexpensive, chemically stable, and non-flammable, making them attractive for addressing safety, and thermal stability under high-temperature, high-pressure conditions.*

*Thermodynamic evaluations reveal that these ternary blends significantly boost power cycle efficiency and expand the operational range beyond that of prior binary systems. Notably, mixtures such as sCO₂–Kr–CO and sCO₂–Kr–N₂ exhibit superior stability and efficiency, underscoring the potential of multi-component working fluids to advance sCO₂ Brayton cycle technology for environmentally sustainable energy generation in extreme cold climates*

**Keywords**: Power Generation, Power Systems

Nomenclature

**sCO2** Supercritical Carbon Dioxide

**CSP**  Concentrated Solar Power

**CIT**  Compressor Inlet Temperature

**CIP**  Compressor Inlet Pressure

**UA**  Overall Heat Transfer Conductance

**HTR** High Temperature Recuperator

**LTR** Low Temperature Recuperator

1. INTRODUCTION

Supercritical carbon dioxide (sCO₂) Brayton cycles are gaining traction in next-generation power generation due to their high thermal efficiency, compact turbomachinery, and adaptability to various energy sectors, including concentrated solar power, nuclear, and waste heat recovery. However, deploying sCO₂ Brayton cycles in extreme cold poses significant challenges. The high critical temperature of pure CO₂ (~31°C) leads to operational inefficiencies when ambient temperatures are substantially lower, as seen in polar regions, cryogenic applications, and extraterrestrial environments. This thermal mismatch results in reduced efficiency and potential cycle instabilities.

To mitigate these issues, working fluid modifications have been explored. Binary fluid blends incorporating low-critical-temperature additives such as tetrafluoromethane (CF₄), nitrogen trifluoride (NF₃), krypton (Kr), and methane (CH₄) have demonstrated success in lowering the critical temperature to ~–50°C while enhancing cycle efficiency. However, CF₄ and NF₃ raise environmental and material concerns due to their high global warming potential and material compatibility constraints.

This study investigates ternary working fluid blends as an alternative, incorporating argon (Ar), carbon monoxide (CO), and nitrogen (N₂) to further optimize cycle performance. The research aims to:

Identify ternary mixtures that maximize efficiency while ensuring stability and sustainability.

Compare ternary blends against binary and pure sCO₂ cycles in low-temperature conditions.

Assess the material compatibility and operational feasibility of these mixtures in practical sCO₂ Brayton cycles.

By addressing these objectives, this study contributes to the advancement of sCO₂ power cycles, paving the way for more sustainable and cost-effective energy solutions in extreme cold environments.

1. Advantages of Using Ternary blends over binary blends

Ternary blends offer a higher degree of tunability than binary mixtures, allowing for more precise control over critical temperature, pressure, and density—key factors in optimizing sCO₂ Brayton cycle performance under extreme cold conditions. By introducing a third component, researchers can strategically balance the proportions of each fluid to achieve the desired thermophysical properties, enabling operation at temperatures well below –50 °C without excessively increasing the critical pressure.

In many binary blends, especially those using Argon (Ar), Carbon Monoxide (CO), or Nitrogen (N₂), high concentrations of these low-critical-temperature fluids can effectively reduce the overall critical temperature but also drive up the blend’s critical pressure. Elevated pressures not only necessitate more robust, costly components but also reduce cycle efficiency. Ternary formulations mitigate this drawback by allowing more flexible ratios of constituents, thereby keeping pressures within manageable limits while still delivering significant reductions in the critical temperature.

Beyond these thermodynamic benefits, ternary blends also address environmental and safety considerations more effectively. Additives such as CF₄ and NF₃, despite their capability to lower the critical temperature, carry high global warming potentials and can pose ozone-layer risks. In contrast, incorporating benign gases like Ar, N₂, or CO—with minimal atmospheric impact—enhances sustainability and reduces material compatibility concerns. Moreover, the near-ideal gas behavior of certain ternary combinations supports better thermal stability, operational safety, and lower production costs.

Overall, the additional degree of freedom provided by ternary mixtures translates to improved cycle efficiency, an expanded operating range, and reduced environmental impact. By tailoring the blend composition to match specific performance goals, ternary sCO₂-based working fluids offer a robust and flexible solution for next-generation Brayton cycles operating in severely cold climates.

Summarizing Key Advantages of Ternary Blends:

**Lower Critical Temperature** – Achieves reductions beyond binary blends, enabling sCO₂ cycles in extreme cold environments.

**Improved Cycle Efficiency** – Optimized compositions enhance thermodynamic efficiency while maintaining pressure stability.

**Reduced Material Stress** – Near-ideal gas behavior reduces mechanical stresses on cycle components, improving system longevity.

**Sustainability and Safety** – Environmentally friendly, non-toxic, and cost-effective, addressing the limitations of CF₄ and NF₃.

1. ternary blends PROPERTIES

A variety of binary and multi-component blends have been researched to tune the working fluid properties:

1. Industry Applications and Case Studies

The development of CO₂-based mixture Brayton cycles is being driven by applications where high efficiency and flexible cooling are especially valuable:

1. Challenges and Considerations of Blended sCO₂ Cycles

Despite their promise, working fluid blends introduce several challenges that researchers and engineers must address:

1. **METHODOLOGY**

**6.1 Cycle Configuration**

1. **RESULTS AND DISCUSSION**

**7.1 Baseline 100% CO₂ Cycle**

A baseline sCO₂ cycle at an ambient temperature of approximately 21 ºC yielded a cycle efficiency of 42.9%, with a

1. **CONCLUSION**

This study demonstrates that strategic blending of CO₂ with

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**Annex A:** TernarysCO2 Blends Properties

**Table**  sCO2-NF3-Ar blend properties. Replacing NF3 with Ar in the sCO2-NF3 Blend.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%NF3+5%Ar | 296.56 | 8248 | 498 |
| 80%CO2+10%NF3+10%Ar | 286.49 | 8746.2 | 542.07 |
| 70%CO2+10%NF3+20%Ar | 274.31 | 9693.1 | 591.16 |
| 60%CO2+10%NF3+30%Ar | 259.24 | 10637.9 | 666.15 |
| 50%CO2+10%NF3+40%Ar | 241.93 | 11285.7 | 741.75 |
| 40%CO2+10%NF3+50%Ar | 212.54 | 10360.1 | 903.56 |
| 30%CO2+10%NF3+60%Ar | 205.05 | 5577.1 | 532.34 |
| 20%CO2+10%NF3+70%Ar | 189.7 | 5325.6 | 539.66 |
| 10%CO2+10%NF3+80%Ar | 174.36 | 5074.2 | 546.76 |

**Table**  sCO2-NF3-Ar blend properties. Reducing sCO2-NF3 Critical Temperature adding Ar.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+80%NF3+10%Ar | 229.76 | 4563.1 | 487.65 |
| 10%CO2+70%NF3+20%Ar | 222.39 | 4484.7 | 445.80 |
| 10%CO2+60%NF3+30%Ar | 219.75 | 4845.7 | 383.88 |
| 10%CO2+50%NF3+40%Ar | 214.92 | 5395.6 | 446.31 |
| 10%CO2+40%NF3+50%Ar | 209.98 | 5935.4 | 460.22 |
| 10%CO2+30%NF3+60%Ar | 204.05 | 6549.2 | 485.35 |
| 10%CO2+20%NF3+70%Ar | 196.37 | 7183.1 | 529.00 |
| 10%CO2+10%NF3+80%Ar | 174.36 | 5074.2 | 546.76 |

**Table**  sCO2-CF4-Ar blend properties. Replacing CF4 with Ar in the sCO2-CF4 Blend.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%CF4+5%Ar | 296.27 | 8217.0 | 505.7 |
| 80%CO2+10%CF4+10%Ar | 286.03 | 8688.5 | 554.71 |
| 70%CO2+10%CF4+20%Ar | 274.26 | 9615.6 | 597.99 |
| 60%CO2+10%CF4+30%Ar | 259.78 | 10510.4 | 664.90 |
| 50%CO2+10%CF4+40%Ar | 235.08 | 6008.8 | 532.71 |
| 40%CO2+10%CF4+50%Ar | 219.74 | 5757.4 | 540.99 |
| 30%CO2+10%CF4+60%Ar | 204.40 | 5505.9 | 549.04 |
| 20%CO2+10%CF4+70%Ar | 189.05 | 5254.5 | 556.87 |
| 10%CO2+10%CF4+80%Ar | 173.71 | 5003.1 | 564.47 |

**Table**  sCO2-CF4-Ar blend properties. Reducing sCO2-CF4 Critical Temperature adding Ar.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+80%CF4+10%Ar | 225.87 | 4265.3 | 597.3 |
| 10%CO2+70%CF4+20%Ar | 222.32 | 4646.6 | 580.0 |
| 10%CO2+60%CF4+30%Ar | 218.44 | 5071.6 | 568.2 |
| 10%CO2+50%CF4+40%Ar | 214.12 | 5545.2 | 560.3 |
| 10%CO2+40%CF4+50%Ar | 209.19 | 6069.03 | 557.0 |
| 10%CO2+30%CF4+60%Ar | 203.38 | 6635.39 | 560.3 |
| 10%CO2+20%CF4+70%Ar | 204.64 | 7608.56 | 407.85 |
| 10%CO2+10%CF4+80%Ar | 173.71 | 5003.1 | 564.47 |

**Table** sCO2-CH4-Ar blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%CH4+5%Ar | 296.66 | 8427.3 | 466.8 |
| 80%CO2+10%CH4+10%Ar | 287.12 | 9253.2 | 476.0 |
| 70%CO2+10%CH4+20%Ar | 276.40 | 10374.4 | 504.0 |
| 60%CO2+10%CH4+30%Ar | 263.17 | 11538.6 | 554.7 |
| 50%CO2+10%CH4+40%Ar | 244.02 | 12657.3 | 651.6 |
| 40%CO2+10%CH4+50%Ar | 216.05 | 5842.3 | 468.9 |
| 30%CO2+10%CH4+60%Ar | 200.70 | 5590.9 | 474.8 |
| 20%CO2+10%CH4+70%Ar | 185.36 | 5339.5 | 480.5 |
| 10%CO2+10%CH4+80%Ar | 170.01 | 5088.0 | 486.0 |

**Table** sCO2-CH4-Ar blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+80%CH4+10%Ar | 199.40 | 5634.5 | 233.4 |
| 10%CO2+70%CH4+20%Ar | 196.49 | 5948.9 | 280.6 |
| 10%CO2+60%CH4+30%Ar | 189.95 | 4956.1 | 290.5 |
| 10%CO2+50%CH4+40%Ar | 191.38 | 6577.0 | 354.3 |
| 10%CO2+40%CH4+50%Ar | 188.13 | 6830.3 | 403.1 |
| 10%CO2+30%CH4+60%Ar | 177.99 | 5035.3 | 403.1 |
| 10%CO2+20%CH4+70%Ar | 174.00 | 5061.6 | 443.8 |
| 10%CO2+10%CH4+80%Ar | 170.02 | 5088.0 | 486.0 |

**Table**  sCO2-Kr-Ar blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%Kr+5%Ar | 296.47 | 8301.5 | 513.7 |
| 85%CO2+10%Kr+5%Ar | 291.77 | 8390.5 | 555.9 |
| 80%CO2+10%Kr+10%Ar | 287.01 | 8992.0 | 569.7 |
| 70%CO2+10%Kr+20%Ar | 276.34 | 10138.6 | 604.1 |
| 60%CO2+10%Kr+30%Ar | 263.97 | 11288.7 | 653.6 |
| 50%CO2+10%Kr+40%Ar | 246.99 | 12396.5 | 749.1 |
| 40%CO2+10%Kr+50%Ar | 225.37 | 12715.2 | 858.5 |
| 30%CO2+10%Kr+60%Ar | 202.59 | 5683.5 | 561.0 |
| 20%CO2+10%Kr+70%Ar | 187.25 | 5432.0 | 568.6 |
| 10%CO2+10%Kr+80%Ar | 171.91 | 5180.6 | 575.9 |

**Table**  sCO2-Kr-Ar blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+40%Kr+50%Ar | 201.70 | 8268.6 | 816.8 |
| 20%CO2+40%Kr+40%Ar | 219.36 | 9161.7 | 816.4 |
| 25%CO2+40%Kr+35%Ar | 227.25 | 9308.9 | 804.7 |
| 30%CO2+40%Kr+30%Ar | 234.52 | 9291.4 | 790.6 |
| 40%CO2+40%Kr+20%Ar | 247.26 | 8900.9 | 767.5 |
| 50%CO2+40%Kr+10%Ar | 258.25 | 8198.6 | 751.9 |
| 55%CO2+40%Kr+5%Ar | 262.88 | 7758.1 | 765.4 |

**Table**  sCO2-Xe-Ar blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%Xe+5%Ar | 297.54 | 7995.7 | 518.6 |
| 80%CO2+10%Xe+10%Ar | 289.37 | 8285.9 | 582.4 |
| 70%CO2+10%Xe+20%Ar | 278.58 | 9166.7 | 619.4 |
| 60%CO2+10%Xe+30%Ar | 266.77 | 9965.4 | 656.2 |
| 50%CO2+10%Xe+40%Ar | 253.67 | 11673.7 | 831.3 |
| 40%CO2+10%Xe+50%Ar | 238.05 | 10959.8 | 757.5 |
| 30%CO2+10%Xe+60%Ar | 223.90 | 10707.2 | 764.2 |
| 20%CO2+10%Xe+70%Ar | 210.16 | 10012.0 | 740.0 |
| 10%CO2+10%Xe+80%Ar | 194.37 | 8947.4 | 722.9 |

**Table**  sCO2-NF3-N2 blend properties. Replacing NF3 with N2 in the sCO2-NF3 Blend.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%NF3+5%N2 |  |  |  |
| 80%CO2+10%NF3+10%N2 |  |  |  |
| 70%CO2+10%NF3+20%N2 |  |  |  |
| 60%CO2+10%NF3+30%N2 |  |  |  |
| 50%CO2+10%NF3+40%N2 |  |  |  |
| 40%CO2+10%NF3+50%N2 |  |  |  |
| 30%CO2+10%NF3+60%N2 |  |  |  |
| 20%CO2+10%NF3+70%N2 |  |  |  |
| 10%CO2+10%NF3+80%N2 |  |  |  |

**Table**  sCO2-NF3-N2 blend properties. Reducing sCO2-NF3 Critical Temperature adding N2.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+80%NF3+10%N2 |  |  |  |
| 10%CO2+70%NF3+20%N2 |  |  |  |
| 10%CO2+60%NF3+30%N2 |  |  |  |
| 10%CO2+50%NF3+40%N2 |  |  |  |
| 10%CO2+40%NF3+50%N2 |  |  |  |
| 10%CO2+30%NF3+60%N2 | 191.31 | 7273.4 | 495.6 |
| 10%CO2+20%NF3+70%N2 |  |  |  |
| 10%CO2+10%NF3+80%N2 |  |  |  |

**Table**  sCO2-CF4-N2 blend properties. Replacing CF4 with N2 in the sCO2-CF4 Blend.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%CF4+5%N2 | 295.58 | 8247.6 | 504.1 |
| 80%CO2+10%CF4+10%N2 | 284.74 | 8820.4 | 545.8 |
| 70%CO2+10%CF4+20%N2 | 271.81 | 10046.3 | 572.7 |
| 60%CO2+10%CF4+30%N2 | 256.90 | 11453.9 | 607.5 |
| 50%CO2+10%CF4+40%N2 | 237.49 | 12973.1 | 661.8 |
| 40%CO2+10%CF4+50%N2 |  |  |  |
| 30%CO2+10%CF4+60%N2 |  |  |  |
| 20%CO2+10%CF4+70%N2 |  |  |  |
| 10%CO2+10%CF4+80%N2 |  |  |  |

**Table**  sCO2-CF4- N2 blend properties. Reducing sCO2-CF4 Critical Temperature adding N2.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+80%CF4+10%N2 | 224.78 | 4413.3 | 592.5 |
| 10%CO2+70%CF4+20%N2 | 219.78 | 4907.3 | 570.3 |
| 10%CO2+60%CF4+30%N2 | 214.18 | 5420.2 | 549.9 |
| 10%CO2+50%CF4+40%N2 | 207.88 | 5963.6 | 532.4 |
| 10%CO2+40%CF4+50%N2 | 200.62 | 6540.0 | 518.9 |
| 10%CO2+30%CF4+60%N2 | 169.41 | 5142.3 | 609.8 |
| 10%CO2+20%CF4+70%N2 | 164.24 | 3864.7 | 429.1 |
| 10%CO2+10%CF4+80%N2 |  |  |  |

**Table** sCO2-CH4-N2 blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%CH4+5%N2 | 295.88 | 8448.4 | 466.5 |
| 80%CO2+10%CH4+10%N2 | 285.57 | 9362.8 | 469.7 |
| 70%CO2+10%CH4+20%N2 | 273.57 | 10781.0 | 484.1 |
| 60%CO2+10%CH4+30%N2 | 259.54 | 12507.4 | 511.7 |
| 50%CO2+10%CH4+40%N2 | 240.10 | 14590.5 | 564.6 |
| 40%CO2+10%CH4+50%N2 |  |  |  |
| 30%CO2+10%CH4+60%N2 |  |  |  |
| 20%CO2+10%CH4+70%N2 |  |  |  |
| 10%CO2+10%CH4+80%N2 |  |  |  |

**Table** sCO2-CH4-N2 blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+80%CH4+10%N2 |  |  |  |
| 10%CO2+70%CH4+20%N2 |  |  |  |
| 10%CO2+60%CH4+30%N2 |  |  |  |
| 10%CO2+50%CH4+40%N2 |  |  |  |
| 10%CO2+40%CH4+50%N2 |  |  |  |
| 10%CO2+30%CH4+60%N2 |  |  |  |
| 10%CO2+20%CH4+70%N2 |  |  |  |
| 10%CO2+10%CH4+80%N2 |  |  |  |

**Table**  sCO2-Kr-N2 blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%Kr+5%N2 |  |  |  |
| 85%CO2+10%Kr+5%N2 |  |  |  |
| 80%CO2+10%Kr+10%N2 |  |  |  |
| 70%CO2+10%Kr+20%N2 |  |  |  |
| 60%CO2+10%Kr+30%N2 |  |  |  |
| 50%CO2+10%Kr+40%N2 |  |  |  |
| 40%CO2+10%Kr+50%N2 |  |  |  |
| 30%CO2+10%Kr+60%N2 |  |  |  |
| 20%CO2+10%Kr+70%N2 |  |  |  |
| 10%CO2+10%Kr+80%N2 |  |  |  |

**Table**  sCO2-Kr-N2 blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+40%Kr+50%N2 | 185.96 | 7000.0 | 774.2 |
| 20%CO2+40%Kr+40%N2 | 221.81 | 7602.9 | 440.1 |
| 25%CO2+40%Kr+35%N2 | 223.40 | 8375.6 | 620.7 |
| 30%CO2+40%Kr+30%N2 | 223.48 | 8714.6 | 813.2 |
| 40%CO2+40%Kr+20%N2 | 238.73 | 8568.6 | 829.2 |
| 50%CO2+40%Kr+10%N2 | 253.65 | 8046.6 | 817.1 |

**Table**  sCO2-Xe-N2 blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%Xe+5%N2 | 296.80 | 8018.8 | 521.2 |
| 80%CO2+10%Xe+10%N2 | 287.98 | 8396.0 | 580.1 |
| 70%CO2+10%Xe+20%N2 | 275.75 | 9543.2 | 607.8 |
| 60%CO2+10%Xe+30%N2 | 262.83 | 10778.7 | 628.5 |
| 50%CO2+10%Xe+40%N2 | 248.01 | 12086.6 | 659.5 |
| 40%CO2+10%Xe+50%N2 | 229.55 | 13170.5 | 701.8 |
| 30%CO2+10%Xe+60%N2 | 195.92 | 4834.8 | 463.2 |
| 20%CO2+10%Xe+70%N2 | 188.07 | 20308.9 | 770.6 |
| 10%CO2+10%Xe+80%N2 | 167.80 | 9112.4 | 679.2 |

**Table**  sCO2-NF3-CO blend properties. Replacing NF3 with in CO the sCO2-NF3 Blend.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%NF3+5%CO |  |  |  |
| 80%CO2+10%NF3+10%CO |  |  |  |
| 70%CO2+10%NF3+20%CO |  |  |  |
| 60%CO2+10%NF3+30%CO |  |  |  |
| 50%CO2+10%NF3+40%CO |  |  |  |
| 40%CO2+10%NF3+50%CO |  |  |  |
| 30%CO2+10%NF3+60%CO |  |  |  |
| 20%CO2+10%NF3+70%CO |  |  |  |
| 10%CO2+10%NF3+80%CO |  |  |  |

**Table**  sCO2-NF3-COblend properties. Reducing sCO2-NF3 Critical Temperature adding CO.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+80%NF3+10%CO |  |  |  |
| 10%CO2+70%NF3+20%CO |  |  |  |
| 10%CO2+60%NF3+30%CO |  |  |  |
| 10%CO2+50%NF3+40%CO |  |  |  |
| 10%CO2+40%NF3+50%CO |  |  |  |
| 10%CO2+30%NF3+60%CO |  |  |  |
| 10%CO2+20%NF3+70%CO |  |  |  |
| 10%CO2+10%NF3+80%CO |  |  |  |

**Table**  sCO2-CF4-CO blend properties. Replacing CF4 with CO in the sCO2-CF4 Blend.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%CF4+5%CO | 295.43 | 8072.5 | 504.4 |
| 80%CO2+10%CF4+10%CO | 284.97 | 8521.2 | 541.9 |
| 70%CO2+10%CF4+20%CO | 272.50 | 9390.0 | 563.1 |
| 60%CO2+10%CF4+30%CO | 258.27 | 10209.7 | 584.2 |
| 50%CO2+10%CF4+40%CO | 242.39 | 10844.1 | 600.4 |
| 40%CO2+10%CF4+50%CO | 210.83 | 5072.9 | 419.6 |
| 30%CO2+10%CF4+60%CO | 193.70 | 4684.5 | 403.9 |
| 20%CO2+10%CF4+70%CO | 182.85 | 8772.5 | 610.4 |
| 10%CO2+10%CF4+80%CO | 172.98 | 7459.8 | 491.6 |

**Table**  sCO2-CF4-CO blend properties. Reducing sCO2-CF4 Critical Temperature adding CO.

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+80%CF4+10%CO | 224.84 | 4301.3 | 591.5 |
| 10%CO2+70%CF4+20%CO | 220.13 | 4705.0 | 565.0 |
| 10%CO2+60%CF4+30%CO | 215.02 | 5140.9 | 540.6 |
| 10%CO2+50%CF4+40%CO | 209.40 | 5615.3 | 518.8 |
| 10%CO2+40%CF4+50%CO | 203.05 | 6130.6 | 500.6 |
| 10%CO2+30%CF4+60%CO | 195.58 | 6677.1 | 487.1 |
| 10%CO2+20%CF4+70%CO | 186.27 | 7205.5 | 480.8 |
| 10%CO2+10%CF4+80%CO | 172.98 | 7459.8 | 491.7 |

**Table** sCO2-CH4-CO blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 90%CO2+5%CH4+5%CO | 295.76 | 8274.5 | 465.1 |
| 80%CO2+10%CH4+10%CO | 285.91 | 9083.4 | 465.7 |
| 70%CO2+10%CH4+20%CO | 274.12 | 10166.9 | 478.7 |
| 60%CO2+10%CH4+30%CO | 260.90 | 11248.9 | 490.3 |
| 50%CO2+10%CH4+40%CO | 244.55 | 12247.2 | 512.5 |
| 40%CO2+10%CH4+50%CO | 220.74 | 12831.0 | 562.7 |
| 30%CO2+10%CH4+60%CO | 150.22 | 21386.5 | 812.2 |
| 20%CO2+10%CH4+70%CO | 172.88 | 4381.1 | 322.1 |
| 10%CO2+10%CH4+80%CO | 166.22 | 8000.2 | 440.0 |

**Table** sCO2-CH4-CO blend properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Working Fluid** | **Critical Temperature** (K) | **Critical Pressure** (kPa) | **Critical Density** (Kg/m3) |
| **100%CO2** | **304.13** | **7377.3** | **467.6** |
| 10%CO2+80%CH4+10%CO | 198.24 | 5600.8 | 219.4 |
| 10%CO2+70%CH4+20%CO | 194.72 | 5939.4 | 240.8 |
| 10%CO2+60%CH4+30%CO | 190.85 | 6271.4 | 264.5 |
| 10%CO2+50%CH4+40%CO | 186.48 | 6579.8 | 292.1 |
| 10%CO2+40%CH4+50%CO | 181.45 | 6839.8 | 324.8 |
| 10%CO2+30%CH4+60%CO | 175.52 | 7004.4 | 364.4 |
| 10%CO2+20%CH4+70%CO | 185.09 | 10901.4 | 369.5 |
| 10%CO2+10%CH4+80%CO | 116.83 | 3.1 | 688.23 |
| 10%CO2+10%CH4+70%CO+10%Ar | 168.03 | 8125.4 | 450.7 |

**Annex B:** Supercritical Brayton Power Cycle Results

**Table** Performance Results of thesCO2-NF3-Ar Brayton Power Cycle.

Analysis of the impact of replacing NF₃ with Ar in the sCO₂-NF₃ blend.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| -108.79 | 10%CO2+10%NF3+80%Ar | 58.2 | 174.36 | 5174.2 | 0.22 | 10.01 | 400 | 10.01 | 450 |
| -93.45 | 20%CO2+10%NF3+70%Ar | 55.35 | 189.7 | 5425.63 | 0.22 | 11.14 | 450 | 10.45 | 500 |
| -78.10 | 30%CO2+10%NF3+60%Ar | 53.71 | 205.05 | 5677.06 | 0.24 | 11.09 | 550 | 11 | 500 |
| -52.02 | 47%CO2+10%NF3+43%Ar | 51.45 | 231.13 | 6104.49 | 0.27 | 10.22 | 700 | 9.78 | 700 |
|  | 50%CO2+10%NF3+40%Ar |  |  |  |  |  |  |  |  |
| -23.91 | 60%CO2+10%NF3+30%Ar | 47.69 | 259.24 | 10837.95 | 0.2 | 11.19 | 1350 | 10.95 | 1550 |
| -8.84 | 70%CO2+10%NF3+20%Ar | 46.33 | 274.31 | 9793.14 | 0.25 | 11.04 | 1300 | 10.06 | 1400 |
| 3.34 | 80%CO2+10%NF3+10%Ar | 44.76 | 286.49 | 8846.17 | 0.26 | 10.99 | 1200 | 9.60 | 1100 |
| 13.41 | 90%CO2+5%NF3+5%Ar | 43.52 | 296.56 | 8448.02 | 0.27 | 10.43 | 1100 | 9.21 | 950 |

**Table** Performance Results of thesCO2-NF3-Ar Brayton Power Cycle.

Effect of Adding Ar to the sCO₂-NF₃ Blend on Lowering the Critical Temperature.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| -53.39 | 10%CO2+80%NF3+10%Ar | 54.45 | 229.76 | 4663.12 | 0.24 | 9.97 | 1150 | 10.63 | 1200 |
| -60.76 | 10%CO2+70%NF3+20%Ar | 55.37 | 222.39 | 4684.77 | 0.25 | 10.49 | 1000 | 11.37 | 1200 |
| -63.4 | 10%CO2+60%NF3+30%Ar | 53.66 | 219.75 | 4945.7 | 0.2 | 10.12 | 1000 | 9.85 | 850 |
| -68.23 | 10%CO2+50%NF3+40%Ar | 54.91 | 214.92 | 5495.66 | 0.22 | 9.55 | 1000 | 9.61 | 1000 |
| -73.17 | 10%CO2+40%NF3+50%Ar | 55.11 | 209.98 | 6035.43 | 0.22 | 10.65 | 900 | 10.68 | 900 |
| -79.1 | 10%CO2+30%NF3+60%Ar | 55.82 | 204.05 | 6649.19 | 0.22 | 9.91 | 900 | 10.42 | 800 |
| -86.78 | 10%CO2+20%NF3+70%Ar | 56.82 | 196.37 | 7283.13 | 0.22 | 10.54 | 800 | 10.32 | 700 |
| -108.79 | 10%CO2+10%NF3+80%Ar | 58.57 | 174.36 | 5274.2 | 0.23 | 10.14 | 400 | 10.39 | 500 |

**Table** Performance Results of thesCO2-CF4-Ar Brayton Power Cycle.

Analysis of the impact of replacing CF4 with Ar in the sCO₂-CF4 blend.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| -109.44 | 10%CO2+10%CF4+80%Ar | 59.28 | 173.71 | 5203.13 | 0.2 | 10.83 | 450 | 9.96 | 375 |
| -94.1 | 20%CO2+10%CF4+70%Ar | 56.02 | 189.05 | 5454.56 | 0.2 | 10.31 | 550 | 10.41 | 400 |
| -78.75 | 30%CO2+10%CF4+60%Ar | 54.78 | 204.4 | 5605.99 | 0.25 | 10.47 | 600 | 10.58 | 600 |
| -63.41 | 40%CO2+10%CF4+50%Ar | 53.03 | 219.74 | 5857.42 | 0.26 | 9.89 | 700 | 10.79 | 600 |
| -48.07 | 50%CO2+10%CF4+40%Ar | 51.12 | 235.08 | 6108.85 | 0.26 | 10.56 | 750 | 11.16 | 600 |
| -40.39 | 55%CO2+10%CF4+35%Ar | 50.06 | 242.76 | 6234.56 | 0.26 | 11.54 | 750 | 11.75 | 600 |
| -23.37 | 60%CO2+10%CF4+30%Ar | 48.12 | 259.78 | 10610.41 | 0.22 | 10.03 | 1500 | 11.25 | 1500 |
| -8.89 | 70%CO2+10%CF4+20%Ar | 46.32 | 274.26 | 9715.61 | 0.24 | 10.34 | 1400 | 10.4 | 1200 |
| 2.88 | 80%CO2+10%CF4+10%Ar | 44.7 | 286.03 | 8788.54 | 0.24 | 9.62 | 1300 | 9.85 | 900 |
| 13.12 | 90%CO2+5%CF4+5%Ar | 43.24 | 296.27 | 8317.03 | 0.26 | 10.7 | 1100 | 10.18 | 800 |

**Table** Performance Results of thesCO2-CF4-Ar Brayton Power Cycle.

Effect of Adding Ar to the sCO₂-CF4 Blend on Lowering the Critical Temperature.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| -57.28 | 10%CO2+80%CF4+10%Ar | 55.94 | 225.87 | 4265.36 | 0.21 | 9.93 | 1550 | 10.13 | 1500 |
| -60.83 | 10%CO2+70%CF4+20%Ar | 56.73 | 222.32 | 4846.6 | 0.21 | 11.08 | 1400 | 9.52 | 1500 |
| -64.71 | 10%CO2+60%CF4+30%Ar | 56.67 | 218.44 | 5271.63 | 0.22 | 10.36 | 1400 | 10.95 | 1500 |
| -69.04 | 10%CO2+50%CF4+40%Ar | 56.79 | 214.11 | 5645.17 | 0.215 | 10.3 | 1300 | 10.28 | 1500 |
| -73.96 | 10%CO2+40%CF4+50%Ar | 57.22 | 209.19 | 6169.03 | 0.215 | 10.32 | 1200 | 9.74 | 1450 |
| -79.77 | 10%CO2+30%CF4+60%Ar | 57.75 | 203.38 | 6735.39 | 0.22 | 10.1 | 1100 | 9.64 | 1300 |
| -78.51 | 10%CO2+20%CF4+70%Ar | 55.57 | 204.64 | 7708.56 | 0.2 | 11.32 | 1000 | 10.35 | 1300 |
| -109.44 | 10%CO2+10%CF4+80%Ar | 59.11 | 173.71 | 5103.13 | 0.21 | 10.29 | 450 | 10.92 | 400 |

**Table** Performance Results of thesCO2-CH4-Ar Brayton Power Cycle.

Analysis of the impact of replacing CH4 with Ar in the sCO₂-CH4 blend.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| -113.14 | 10%CO2+10%CH4+80%Ar | 57.39 | 170.01 | 5288.05 | 0.21 | 10.06 | 175 | 10.11 | 700 |
| -97.79 | 20%CO2+10%CH4+70%Ar | 55.33 | 185.36 | 5439.48 | 0.21 | 10.48 | 400 | 10.63 | 400 |
| -82.45 | 30%CO2+10%CH4+60%Ar | 54.46 | 200.7 | 5790.91 | 0.28 | 10.5 | 500 | 11.65 | 700 |
| -67.1 | 40%CO2+10%CH4+50%Ar | 52.2 | 216.05 | 5942.34 | 0.25 | 10.26 | 600 | 10.97 | 450 |
| -50.95 | 45%CO2+10%CH4+45%Ar | 50.95 | 232.2 | 13037.74 | 0.1 | 11.02 | 1600 | 12.08 | 2600 |
| -39.14 | 50%CO2+10%CH4+40%Ar | 49.81 | 244.01 | 12657.38 | 0.14 | 10.01 | 1700 | 10.41 | 2700 |
| -19.98 | 60%CO2+10%CH4+30%Ar | 47.43 | 263.17 | 11738.61 | 0.25 | 11.37 | 1600 | 12.09 | 2000 |
| -6.75 | 70%CO2+10%CH4+20%Ar | 45.66 | 276.4 | 10574.46 | 0.25 | 11.57 | 1400 | 10.63 | 1400 |
| 3.97 | 80%CO2+10%CH4+10%Ar | 44.3 | 287.12 | 9453.29 | 0.25 | 10.02 | 1300 | 9.78 | 1000 |

**Table** Performance Results of thesCO2-CH4-Ar Brayton Power Cycle.

Effect of Adding Ar to the sCO₂-CH4 Blend on Lowering the Critical Temperature.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| -83.75 | 10%CO2+80%CH4+10%Ar | 59.51 | 199.4 | 5834.56 | 0.25 | 10.91 | 1000 | 10.17 | 1000 |
| -86.66 | 10%CO2+70%CH4+20%Ar | 59.03 | 196.49 | 6048.91 | 0.25 | 10.4 | 1000 | 10.78 | 1000 |
| -93.2 | 10%CO2+60%CH4+30%Ar | 58.07 | 189.95 | 5056.15 | 0.215 | 9.76 | 750 | 10.55 | 900 |
| -91.77 | 10%CO2+50%CH4+40%Ar | 59.45 | 191.38 | 6677.05 | 0.24 | 11.27 | 850 | 10.38 | 750 |
| -95.03 | 10%CO2+40%CH4+50%Ar | 59.67 | 188.12 | 6930.26 | 0.24 | 10.89 | 800 | 10.25 | 700 |
| -105.16 | 10%CO2+30%CH4+60%Ar | 57.71 | 177.99 | 5235.29 | 0.2 | 10.18 | 450 | 10.18 | 700 |
| -109.15 | 10%CO2+20%CH4+70%Ar | 57.47 | 174 | 5161.67 | 0.2 | 9.95 | 300 | 9.91 | 700 |
| -113.14 | 10%CO2+10%CH4+80%Ar | 57.39 | 170.01 | 5288.05 | 0.21 | 10.06 | 175 | 10.11 | 700 |

**Table** Performance Results of thesCO2-Kr-Ar Brayton Power Cycle.

Analysis of the impact of replacing Kr with Ar in the sCO₂-Kr blend.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| -111.24 | 10%CO2+10%Kr+80%Ar | 55.43 | 171.91 | 6580.6 | 0.0 | 0 | 0 | 10.75 | 350 |
| -95.9 | 20%CO2+10%Kr+70%Ar | 53.22 | 187.25 | 5532.06 | 0.15 | 10.91 | 375 | 11.13 | 225 |
| -80.56 | 30%CO2+10%Kr+60%Ar | 52.95 | 202.59 | 5883.49 | 0.25 | 10.76 | 450 | 11.04 | 450 |
| -57.78 | 40%CO2+10%Kr+50%Ar | 52.45 | 225.37 | 12815.23 | 0.1 | 9.65 | 1400 | 11.09 | 3250 |
| -36.16 | 50%CO2+10%Kr+40%Ar | 48.79 | 246.99 | 12496.52 | 0.18 | 10.29 | 1450 | 11.62 | 1750 |
| -19.18 | 60%CO2+10%Kr+30%Ar | 47.3 | 263.97 | 11388.72 | 0.25 | 10.38 | 1400 | 11.04 | 1700 |
| -6.81 | 70%CO2+10%Kr+20%Ar | 45.37 | 276.34 | 10238.64 | 0.25 | 10.94 | 1200 | 10.68 | 1100 |
| 3.86 | 80%CO2+10%Kr+10%Ar | 43.8 | 287.01 | 9092 | 0.25 | 10.81 | 1050 | 10.53 | 800 |
| 8.62 | 85%CO2+10%Kr+5%Ar | 43.48 | 291.77 | 8490.5 | 0.25 | 10.00 | 1000 | 9.41 | 750 |

**Table** Performance Results of thesCO2-Kr-Ar Brayton Power Cycle.

Effect of Adding Ar to the sCO₂-Kr Blend on Lowering the Critical Temperature.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| -61.47 | 10%CO2+80%Kr+10%Ar | 50.73 | 221.68 | 7044.6 | 0.23 | 11.36 | 350 | 9.88 | 500 |
| -65.43 | 10%CO2+70%Kr+20%Ar | 51.68 | 217.72 | 7518.9 | 0.23 | 11.72 | 400 | 9.74 | 550 |
| -70.08 | 10%CO2+60%Kr+30%Ar | 52.59 | 213.07 | 7909.1 | 0.23 | 10.77 | 475 | 10.19 | 550 |
| -75.42 | 10%CO2+50%Kr+40%Ar | 53.71 | 207.73 | 8300.2 | 0.23 | 9.79 | 550 | 10.36 | 550 |
| -81.45 | 10%CO2+40%Kr+50%Ar | 54.94 | 201.7 | 8368.6 | 0.23 | 10.29 | 550 | 9.65 | 600 |
| -88.1 | 10%CO2+30%Kr+60%Ar | 56.19 | 195.05 | 8489.8 | 0.23 | 9.93 | 575 | 9.63 | 600 |
| -95.29 | 10%CO2+20%Kr+70%Ar | 57.43 | 187.86 | 8347.7 | 0.23 | 9.73 | 575 | 9.56 | 575 |
| -111.24 | 10%CO2+10%Kr+80%Ar | 55.41 | 171.91 | 5380.63 | 0.17 | 10.85 | 300 | 11.88 | 300 |
| -114.18 | 10%CO2+5%Kr+85%Ar | 56.3 | 168.97 | 5347.5 | 0.2 | 10.44 | 200 | 11.15 | 450 |

**Table** Performance Results of thesCO2-Xe-Ar Brayton Power Cycle.

Effect of Adding Ar to the sCO₂-Xe Blend on Lowering the Critical Temperature.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| 14.39 | 90%CO2+5%Xe+5%Ar | 42.67 | 297.54 | 8095.71 | 0.25 | 10.53 | 950 | 9.4 | 700 |
| 6.22 | 80%CO2+10%Xe+10%Ar | 43.44 | 289.37 | 8385.99 | 0.24 | 10.10 | 950 | 9.8 | 700 |
| -4.57 | 70%CO2+10%Xe+20%Ar | 45.12 | 278.58 | 9266.78 | 0.24 | 11.31 | 1000 | 9.18 | 1000 |
| -16.38 | 60%CO2+10%Xe+30%Ar | 45.89 | 266.77 | 10065.44 | 0.2 | 9.77 | 1100 | 9.79 | 850 |
| -29.48 | 50%CO2+10%Xe+40%Ar | 49 | 253.67 | 11873.77 | 0.2 | 11.06 | 1300 | 9.72 | 2800 |
| -45.1 | 40%CO2+10%Xe+50%Ar | 51.44 | 238.05 | 11059.82 | 0.24 | 10.69 | 1100 | 10.22 | 2400 |
| -59.25 | 30%CO2+10%Xe+60%Ar | 53.44 | 223.9 | 10807.19 | 0.25 | 10.59 | 1000 | 10.45 | 2200 |
| -72.99 | 20%CO2+10%Xe+70%Ar | 55.27 | 210.16 | 10112.03 | 0.26 | 11.48 | 800 | 10.05 | 1800 |
| -88.77 | 10%CO2+10%Xe+80%Ar | 56.14 | 194.38 | 9047.48 | 0.22 | 9.93 | 650 | 9.95 | 650 |

**Table** Performance Results of thesCO2-NF3-N2 Brayton Power Cycle.

Analysis of the impact of replacing NF3 with N2 and Ar in the sCO₂-NF3 blend.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ambient Temperature** (ºC) | **Working Fluid** | **Cycle Efficiency** (%) | **CIT**  (K) | **CIP** (kPa) | **Recomp. Fraction** | **HT Pinch Point** (K) | **HT**  **UA** (kW/K) | **LT Pinch Point** (K) | **LT**  **UA** (kW/K) |
| **20.98** | **100%CO2** | **42.9** | 304.13 | 7474.89 | 0.31 | 10.17 | 900 | 11.2 | 700 |
| -111.11 | 5%CO2+10%NF3+20%N2+65%Ar | 61 | 172.04 | 6850.6 | 0.24 | 10.15 | 650 | 10.51 | 700 |
| -113.69 | 10%CO2+10%NF3+20%N2+60%Ar | 59.5 | 169.46 | 4980.7 | 0.23 | 10.35 | 400 | 10.49 | 600 |
| -98.35 | 20%CO2+10%NF3+20%N2+50%Ar | 56.53 | 184.8 | 5232.1 | 0.24 | 10.52 | 500 | 11.48 | 600 |
| -83.00 | 30%CO2+10%NF3+20%N2+40%Ar | 54.92 | 200.15 | 5383.6 | 0.25 | 10.19 | 600 | 10.22 | 600 |
| -67.66 | 40%CO2+10%NF3+20%N2+30%Ar | 53.18 | 215.49 | 5635 | 0.25 | 10.64 | 650 | 9.66 | 600 |
| -43.14 | 50%CO2+10%NF3+20%N2+20%Ar | 50.32 | 240.01 | 12324.9 | 0.1 |  | 1800 |  | 2750 |
| -45.35 | 50%CO2+10%NF3+40%N2 | 49.94 | 237.8 | 13342.7 | 0.05 | 10.82 | 2300 | 11.29 | 2750 |
| -26.44 | 60%CO2+10%NF3+30%N2 | 47.87 | 256.71 | 11733.2 | 0.15 | 9.57 | 1900 | 10.58 | 2000 |
| -11.29 | 70%CO2+10%NF3+20%N2 | 46.30 | 271.86 | 10268.1 | 0.21 | 10.33 | 1500 | 9.70 | 1500 |
| 2.06 | 80%CO2+10%NF3+10%N2 | 44.59 | 285.21 | 8990.15 | 0.25 | 10.90 | 1250 | 10.61 | 1000 |
| 12.71 | 90%CO2+5%NF3+5%N2 | 43.60 | 295.86 | 8380.10 | 0.28 | 11.42 | 1100 | 9.91 | 1000 |