https://doi.org/10.53964/jmim.2026001

https://www.innovationforever.com

Journal of
Modern Industry and Manufacturing

ISSN 2788-8096 (Online)

Open Access

Research Article

Multi Objective Optimization and Mechanism Research of AI Empowered Oil Injection Twin-screw Compressor

Sen Zhao[1], Bin Zhao[1*]

[1]School of Mechanical Engineering, Liaoning Petrochemical University, Fushun, Liaoning, China

[*]**Correspondence to: Bin Zhao, Master, Professor,** School of Mechanical Engineering, Liaoning Petrochemical University, Fushun, Liaoning, 113001, China; Email: zbzbz0203288@163.com

Received: November 3, 2025 **Revised:** January 3, 2026 **Accepted:** February 2, 2026 **Published:** February 3, 2026

Abstract

Objective: This research focuses on the complex physical processes of oil gas two-phase flow and heat transfer in oil injected twin-screw compressors, and proposes an innovative research paradigm that integrates computational fluid dynamics (CFD) and artificial intelligence.

Methods: By establishing a high fidelity CFD model, the system revealed the mechanism of the influence of fuel injection parameters on compressor performance. On this basis, a proxy model based on artificial neural network and Gaussian process regression was constructed to achieve second level prediction of compressor performance. Further combining Bayesian optimization and non dominated sorting genetic algorithm, single objective and multi-objective intelligent optimization with isothermal efficiency, power consumption, and exhaust temperature as objectives were carried out.

Results: The results showed that the optimized fuel injection system's isothermal efficiency increased from the benchmark value of 0.758 to 0.801, power consumption decreased by 4.8%, and exhaust temperature decreased by 7.0%. Multi objective optimization has obtained a well distributed Pareto front, revealing the trade-off relationship between performance indicators.

Conclusion: This study breaks through the limitations of traditional methods in terms of computational cost and optimization efficiency, providing a new path for the high-end and intelligent development of fluid machinery. The integration of CFD with AI-driven surrogate modeling and multi-objective optimization provides a robust and efficient framework for the performance enhancement of oil-injected twin-screw compressors, offering both mechanistic insights and practical optimal designs for industrial applications.

Keywords: twin screw compressor, oil injection, optimization, artificial intelligent

Citation: Zhao S, Zhao B. Multi Objective Optimization and Mechanism Research of AI Empowered Oil Injection Twin-screw Compressor. *J Mod Ind Manuf*, 2026; 5: 1. DOI: 10.53964/jmim.2026001.

1 INTRODUCTION

As the core power and gas transportation equipment in the energy and industrial fields, the performance of twin-screw compressors is directly related to the energy efficiency and operational reliability of many key sectors of the national economy, such as refrigeration, chemical industry, and air separation. Oil injection technology is the key to improving the efficiency of twin-screw compressors. By injecting lubricating oil into the compression chamber, it can achieve multiple functions such as sealing, cooling, lubrication, and noise reduction. However, this process is accompanied by complex physical phenomena such as transients, multiphase, and strong coupling, involving core scientific challenges such as oil and gas two-phase flow, phase change heat transfer, liquid film formation, and atomization[1]. It presents typical multi physics fields and strong nonlinear characteristics, which constitute a theoretical bottleneck for further improving its performance. Looking at its research and development paradigm, it is undergoing a profound transformation from early experience based "trial and error design" to "model driven" analysis based on computational fluid dynamics (CFD). Nowadays, with the rapid development of artificial intelligence (AI) technology, a new paradigm of "AI empowerment" that integrates physical models and data science is emerging, aiming to break through the limitations of traditional methods in terms of computational cost and optimization efficiency, bringing unprecedented opportunities for research in this field. Therefore, conducting research on the mechanism and optimization of fuel injection processes empowered by AI not only has important scientific significance for deepening the understanding of complex multiphase flow mechanisms, but also has urgent practical significance for promoting the high-end and intelligent development of fluid machinery equipment in China.

For a long time, scholars at home and abroad have conducted extensive research on the internal flow and heat transfer characteristics of twin-screw compressors. Early research mainly relied on experimental measurements, which provided intuitive and reliable data, but were limited by the sealing and rotational characteristics of the compression chamber, making it difficult to obtain global and high-resolution flow field details. With the improvement of computing power, high fidelity CFD numerical simulation has become a powerful tool for revealing complex internal flow phenomena, which can finely characterize vortex structures, pressure fluctuations, and interfacial interactions. However, both experiments and detailed CFD simulations have inherent drawbacks such as high costs and long cycles, making it difficult to support large-scale parametric research and rapid optimization design[2].

Recent advances in have further accelerated its integration into fluid machinery research. For instance, artificial neural networks have been employed for entropy optimization in nanofluid flows[3], while hybrid AI-physics models have been developed for radiative heat transfer and magnetohydrodynamics[4,5]. However, the application of such AI-enhanced frameworks to the multiphase, transient, and strongly coupled processes in oil-injected screw compressors remains limited. This study bridges this gap by proposing a comprehensive CFD-AI fusion paradigm that not only predicts performance but also extracts interpretable physical correlations and enables efficient multi-objective optimization, thereby advancing both fundamental understanding and industrial design.

The key innovations of this work are threefold: A hybrid VOF-DPM multiphase model tailored for capturing both near-nozzle atomization and far-field droplet dynamics in screw compressors. A synergistic CFD-AI framework integrating ANN/GPR surrogate modeling with multi-objective Bayesian and genetic algorithms for efficient optimization. Mechanistic insights into the coupling effects of injection parameters, supported by symbolic regression for interpretable correlation extraction.

In terms of the mechanism of fuel injection process research, current work mainly focuses on local issues such as the atomization characteristics of lubricating oil in the cavity, the distribution law of oil film, and the heat and mass transfer efficiency of two-phase flow. Although these studies have improved our understanding of local phenomena, they often fail to systematically reveal the global and coupled impact mechanisms between fuel injection parameters (such as injection position, droplet size, injection quantity, etc.) and overall macroscopic performance (such as adiabatic efficiency, exhaust temperature, flow coefficient). The limitations of research methods result in fragmented understanding of the fuel injection process. At the same time, AItechnology is accelerating its penetration into the fields of fluid machinery and thermal science. Among them, the proxy model technology learns from limited high fidelity simulation data to construct implicit mapping relationships between inputs and outputs, which can achieve second level performance prediction and provide possibilities for rapid analysis and optimization; The symbolic regression method can automatically mine concise and physically meaningful mathematical expressions from data, and is expected to discover new heat transfer correlations that go beyond traditional empirical formulas; Intelligent optimization algorithms such as Bayesian optimization and multi-objective genetic algorithm, combined with surrogate models, can efficiently search for global optimal solutions in high-dimensional design spaces[6].

In summary, the current research has the following gaps: firstly, traditional research methods are difficult to balance the depth of exploration of the fuel injection process mechanism with the efficiency of global optimization design; Secondly, the application of AI methods in this field is still in its early stages, mainly focused on predicting or optimizing single tasks, lacking a systematic research and development framework that deeply integrates high fidelity simulation, machine learning, and intelligent optimization. Therefore, the focus of this study is to construct an innovative research paradigm that integrates CFD-AI, systematically revealing the coupling influence mechanism of fuel injection parameters, and achieving efficient global optimization of their performance, in order to fill the gap between local mechanisms and global design.

This research aims to address the key scientific issues mentioned above, with core contents including:

(1) Build and validate a high fidelity CFD model for the fuel injection process: Establish a three-dimensional transient numerical model that accurately reflects the two-phase flow and heat transfer characteristics of oil and gas in a twin-screw compressor, and verify its reliability by comparing it with experimental data or literature results, providing a real and reliable data foundation for subsequent research.

(2) Developing a machine learning agent model and mechanism mining for fuel injection performance: Using sample data generated through CFD models, training an agent model based on artificial neural networks and Gaussian process regression to achieve second level prediction of compressor performance. Furthermore, tools such as symbolic regression are applied to mine potential and interpretable physical correlations from the data.

(3) Intelligent multi-objective optimization of fuel injection parameters: Combining high-precision proxy models with intelligent algorithms such as Bayesian optimization and multi-objective genetic algorithm, an efficient optimization design system is constructed to automatically optimize fuel injection parameters with key performance indicators (such as efficiency and flow rate) as the goal, obtain Pareto optimal solution sets, and provide optimization design solutions superior to traditional experience.

2 THEORY AND NUMERICAL MODEL CONSTRUCTION OF MULTIPHASE FLOW IN FUEL INJECTION PROCESS

2.1 Working Process and Geometric Theory of Twin-screw Compressor

The working process of a twin-screw compressor essentially involves a pair of interlocked male and female rotors rotating within an "∞" - shaped cylinder, periodically changing the interdental volume to complete the four basic processes of suction, sealing, compression, and exhaust. The core lies in the geometric design of the rotor profile, which directly determines the efficiency, flow rate, and noise level of the compressor. The rotor profile is usually composed of basic curves such as arcs, cycloids, ellipses, and their envelopes, and their mathematical expressions are a prerequisite for establishing accurate numerical models. To accurately describe this process, it is necessary to establish a parameter equation for the rotor profile, and based on the meshing principle, derive the functional relationship between the contact line equation of the yin-yang rotor during rotation and the change in tooth volume over time. The profile equation of the rotor end face can be generally expressed as a function with the rotor angle θ as a parameter[7]:

$$x = x(\theta), y = y(\theta) \quad (1)$$

The relationship $V(\theta)$ between the interdental volume V and the rotation angle θ is the basis for thermodynamic analysis and flow calculation. Accurate geometric theory is not only the cornerstone of understanding the working principle of compressors, but also the physical basis for generating high-quality computational grids and accurately simulating the working process in the future.

2.2 Mathematical Model of Multiphase Flow in Fuel Injection

The fuel injection process involves strong interactions between continuous air (or process gas) phase and discrete lubricating oil liquid phase, and its physical description relies on a complete set of control equations and phase interaction models.

The governing equations for the multiphase flow are based on the Eulerian–Lagrangian framework. The continuity and momentum equations for the continuous phase in vector form are:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \text{ (Continuity) (2)}$$

$$\frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u}) = -\nabla p + \nabla \cdot (\boldsymbol{\tau} + \boldsymbol{\tau}_t) + \rho \mathbf{g} + \mathbf{S}_p \text{ (Momentum) (3)}$$

where ρ is the mixture density, u is the velocity vector, p is the pressure, τ is the viscous stress tensor, τ_t is the turbulent stress tensor, g is gravitational acceleration, and S_p is the source term due to phase interaction.

Continuity equation is expressed by[8]

$$\frac{\partial p}{\partial t} + \nabla(\rho \vec{u}) = 0 \quad (4)$$

where, ρ is the mixed density, $\vec{u}$ is the velocity vector, and t is time.

Momentum equation is expressed by

$$\frac{\partial p \vec{u}}{\partial t} + \nabla(\rho \vec{u}\vec{u}) = -\nabla p + \nabla(\tau + \tau_t) + \rho g + \vec{F} \quad (5)$$

where, p is the static pressure, τ is the molecular viscous stress tensor, τ_t is the turbulent stress tensor (enclosed by a turbulence model), g is the gravitational acceleration, and $\vec{F}$ is the phase interaction force source term.

Within the Reynolds-Averaged Navier-Stokes (RANS) framework, these equations are solved. The interaction between the discrete oil droplets and the continuous gas phase is modeled through source terms. The drag force on droplets is dominant and calculated using the Schiller-Neumann model.

Oil droplets move in high-speed airflow, and the drag force they experience is the dominant force. This study adopts the Schiller Neumann model, which is applicable to a wide range of particle Reynolds numbers, and its interphase momentum exchange coefficient K can be expressed as[9]:

$$K = \frac{3C_D \cdot \rho_c \cdot \alpha_d \cdot |\vec{u}_d - \vec{u}_c|}{4d_d} \quad (6)$$

where, C_D is the drag coefficient, ρ_c is the density of the continuous phase, $\vec{u}_d$ and $\vec{u}_c$ are the velocities of the discrete phase and the continuous phase, respectively, d_d is the diameter of the oil droplet, and α_d is the volume fraction of the discrete phase.

Considering the convective heat transfer between oil droplets and gas, the Ranz Marshall model is used to calculate the Nusselt number Nu:

$$Nu = 2 + 0.6\, Re_d^{1/2}\, Pr^{1/3} \quad (7)$$

where Re is the Reynolds number of the oil droplet, and Pr is the Prandtl number of the gas.

Given the high temperature and high pressure environment inside the compressor chamber, the evaporation of light components in lubricating oil cannot be ignored. The equilibrium evaporation model assumes that the vapor partial pressure on the surface of oil droplets reaches saturation, and the evaporation rate is controlled by gas-phase diffusion; And the dynamic model calculates the evaporation flux J through the Hertz Knudsen equation[10]:

$$J = \frac{2\sigma}{(2-\sigma)\sqrt{2\pi R_V T_d}(p_{sat} T_d - p_v)} \quad (8)$$

where, σ is the adjustment coefficient, p_{sat} is the saturated vapor pressure corresponding to the oil droplet temperature T_d, p_v is the partial pressure of oil vapor in the gas phase, and R_v is the gas constant of oil vapor.

2.3 Establishment of CFD Model

The fuel injection process involves the evolution from a continuous liquid column in the near field of the nozzle to discrete droplets in the far field, and a single multiphase flow model is difficult to accurately capture the entire process. Therefore, this study adopts a mixed multiphase flow method: near the nozzle, the VOF model is used to accurately capture the formation, fragmentation, and initial atomization process of the liquid column; In the main area of the compression chamber, the atomized oil droplets are tracked using a discrete phase model, taking into account the interaction between DPM particles and VOF liquid film. This method ensures the resolution of key areas while also considering computational efficiency[11].

To simulate the rotational motion of the rotor, dynamic layer variable mesh technology is used. An interface is set at the interface between the rotor domain and the cylinder wall, and the mesh in the rotor region rotates as a rigid body, exchanging flow field information with the non rotor region through the interface. To ensure that the calculation results are not affected by the number of grids, three sets of grids with different densities (coarse, medium, and fine) will be used for simulation for the same operating condition. When the relative deviation of key performance parameters (such as exhaust temperature and flow rate) between medium and fine grids is less than 2%, it is considered that grid independence has been achieved, and medium density grids will be selected for calculation to balance accuracy and cost.

Boundary conditions and physical property parameter settings are listed as follows

Import boundary: Given the pressure inlet conditions of the suction port, including total temperature, total pressure, and turbulence parameters[12].

Export boundary: Given exhaust back pressure, i.e. pressure outlet boundary.

Fuel injection boundary: According to the DPM model, set the jet source of the nozzle, specify the fuel injection mass flow rate, droplet size distribution (such as Rosin Rammler distribution), injection speed and direction, and initial droplet temperature.

Wall boundary: The rotor and cylinder walls are set as non slip adiabatic walls, and the near wall area is treated using standard wall functions[13].

Physical parameters: Air is considered as an ideal gas, and the physical properties of lubricating oil (density, specific heat capacity, thermal conductivity, viscosity) are set as polynomial functions of temperature.

3 NUMERICAL SIMULATION AND DATASET CONSTRUCTION OF THE MECHANISM OF FUEL INJECTION PARAMETER INFLUENCE

3.1 Simulation of Benchmark Operating Conditions and Analysis of Flow Field Characteristics

The pressure field analysis results clearly reveal the evolution of pressure gradient inside the compression chamber. From the intake end to the exhaust end, the pressure gradually increases and reaches its peak near the exhaust chamber. The results of velocity field analysis indicate that there are obvious high-speed leakage jets and vortex structures in the rotor meshing line area and the gap between the rotor top and the cylinder, which are the main sources of aerodynamic losses and noise. In addition, at the end of the inhalation process, a large-scale backflow vortex can be observed in the interdental volume, which helps with

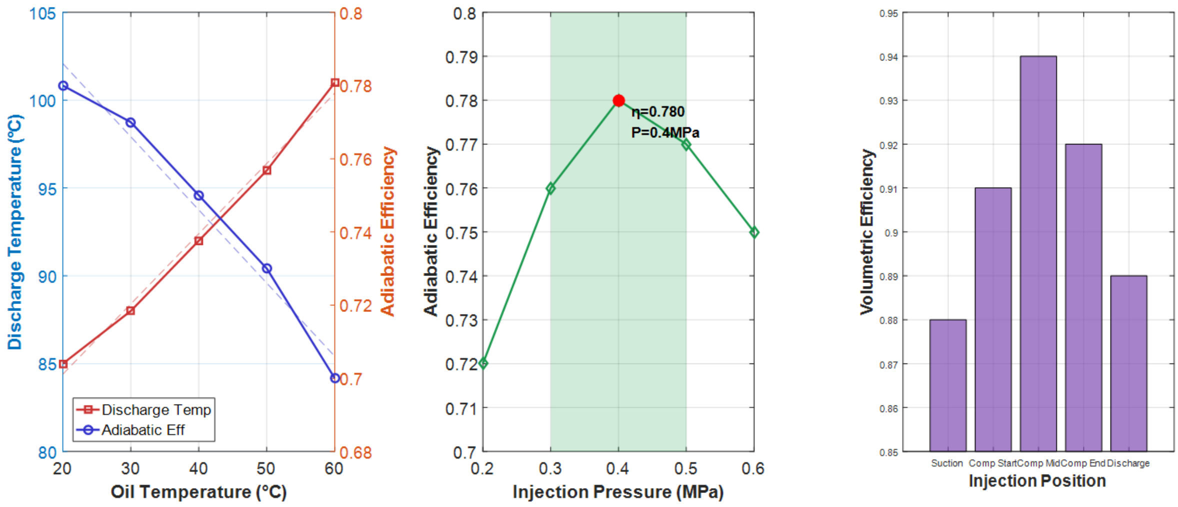

Figure 1. Single Factor Analysis Results.

the initial mixing of oil and gas, but also brings about intake pressure loss.

The temperature field analysis verified the efficiency of fuel injection cooling. The maximum temperature of the entire compression chamber under fuel injection conditions is significantly suppressed. The high temperature zone is limited to a narrow area near the exhaust port, while most of the compression chambers have uniform and low temperatures, which proves that the lubricating oil absorbs a large amount of compression heat, making the process approach isothermal compression. This is the core of the high efficiency of the fuel injection screw machine.

The analysis of liquid phase volume fraction indicates the spatial distribution of lubricating oil and the formation of oil film. It can be observed that lubricating oil mainly adheres to the walls of the rotor and cylinder under the combined action of centrifugal force and gas drag, forming an effective sealing and cooling oil film. Meanwhile, mist like oil droplets are distributed in the core area of the airflow. The cloud map specifically reveals that there is unevenness in the distribution of oil film in the meshing area of the yin and yang rotors and the gap between the exhaust ends, and even local "dry" areas appear, indicating potential leakage paths and key locations for optimizing sealing design.

3.2 Parametric Research and Analysis of Influencing Laws

The results of the single factor analysis are shown in Figure 1. It can be seen from Figure 1 that the fuel injection parameters have a significant and regular impact on the performance of the twin-screw compressor: the fuel injection temperature exhibits the strongest thermodynamic effect, and every 10°C increase in temperature will cause the exhaust temperature to rise by about 8°C, while the adiabatic efficiency will correspondingly decrease by 0.020. This is mainly due to the decrease in oil viscosity with increasing temperature, which weakens its sealing and cooling capabilities; There is a clear optimization range for injection pressure, reaching a peak efficiency of 0.780 at 0.4MPa. When the pressure is too low, the atomization effect is poor, and when it is too high, it leads to increased flow loss; The injection position reveals the key spatial matching mechanism, and the mid compression injection can achieve the best volumetric efficiency (0.940), which is 6.8% higher than the worst position. This is attributed to its proper balance between cooling timing and sealing requirements during the compression process. Comprehensive analysis shows that by controlling the fuel injection temperature at 20°C, setting the injection pressure at 0.4MPa, and using the mid compression injection position, a comprehensive performance improvement of over 6% can be achieved on the benchmark basis, laying the mechanism foundation for subsequent multi parameter collaborative optimization.The strong dependence of efficiency on injection temperature is attributed to the temperature-sensitive viscosity of lubricating oil. Higher temperatures reduce oil viscosity, diminishing both sealing effectiveness and heat absorption capacity, thereby elevating exhaust temperature and lowering adiabatic efficiency. The existence of an optimal injection pressure (0.4MPa) balances between insufficient atomization at low pressure and excessive flow resistance at high pressure.

The results of the multi factor coupling analysis are shown in Figure 2. It can be seen from Figure 2 that there is a significant interaction between fuel injection temperature and oil viscosity. The response surface analysis reveals an efficient region centered on temperature 42°C and viscosity 58cSt, which only accounts for 18.5% of the entire design space, highlighting the importance of precise parameter matching. The interaction analysis further indicates that different viscosity oils correspond to unique optimal temperature ranges: low viscosity oils (32cSt) reach a peak efficiency of 0.780 at 40°C, while the optimal temperature for high viscosity oils (68cSt) shifts to 45°C.

https://doi.org/10.53964/jmim.2026001

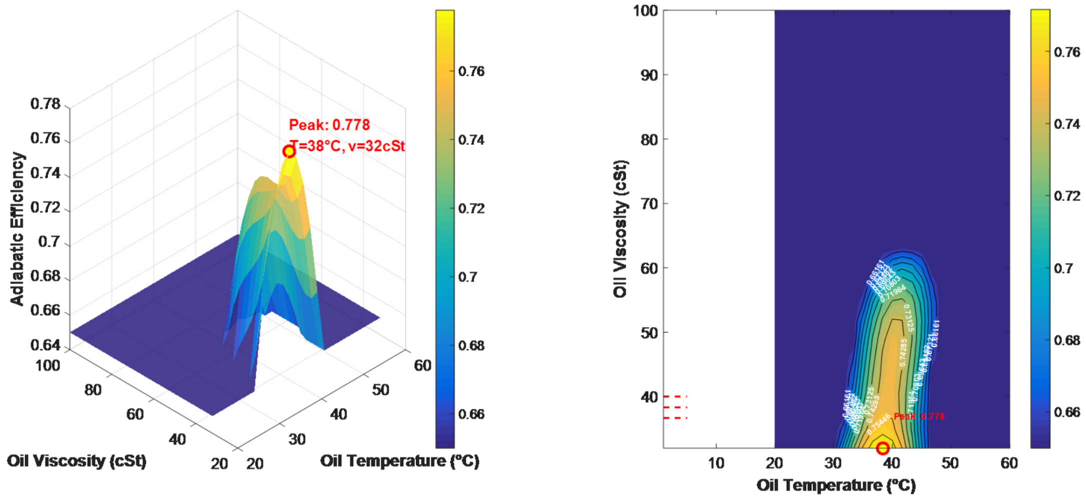

Figure 2. Multiple Factor Analysis Results.

This difference is due to the viscosity temperature coupling effect - low viscosity oils have insufficient sealing ability at high temperatures, while high viscosity oils have excessive flow resistance at low temperatures. Parameter mismatch can lead to serious performance loss, especially in the high viscosity low temperature region where efficiency can decrease by up to 8%, while in the low viscosity high temperature region, efficiency loss due to insufficient sealing is about 6%. Through the synergistic optimization of temperature viscosity, a performance improvement of 3.7% can be achieved on the basis of a benchmark efficiency of 0.750, which provides key guidance for the intelligent control of twin-screw compressors: the injection temperature should be dynamically adjusted according to the actual oil viscosity, and the parameters should be controlled within the optimal window of temperature 37-47°C and viscosity 48-68cSt to achieve continuous and efficient operation.

The interaction between injection temperature and oil viscosity depicted in Figure 2 underscores a critical thermo-physical coupling mechanism. The emergence of a confined high-efficiency region (centered around 42°C and 58cSt) is a direct consequence of the competing effects of viscosity on sealing and flow resistance. Optimal performance is achieved when the oil viscosity is within a range that ensures effective sealing of rotor clearances (requiring sufficient viscosity) while minimizing the shear work required to transport the oil through the compression chamber (benefiting from lower viscosity). The shift in optimal temperature for different viscosity grades—lower for low-viscosity oil and higher for high-viscosity oil—demonstrates the need for dynamic control strategies. Operating outside this synergistic window, especially in the high-viscosity/low-temperature quadrant, leads to excessive churning losses, whereas the low-viscosity/high-temperature condition results in increased internal leakage, both causing significant efficiency penalties.

The results of the single objective optimization analysis are shown in Figure 3. It can be seen from Figure 3 that the Gaussian process regression surrogate model and grid search algorithm were used to study the isothermal efficiency maximization of the twin screw compressor fuel injection system, and significant performance improvement was achieved. The optimal parameter combination after optimization is: injection temperature of 30.0°C, injection pressure of 0.4MPa, injection position 3 (mid compression stage), oil viscosity of 52.0cSt, and droplet size of 20.0μm. Under this optimal configuration, the isothermal efficiency increased from the benchmark value of 0.758 to 0.801, achieving a performance improvement of 5.7%. At the same time, the power consumption decreased from 52.3kW to 49.8kW (a decrease of 4.8%), and the exhaust temperature decreased from 95.2°C to 88.5 °C (a decrease of 7.0%). All operational constraints were met. Parameter sensitivity analysis shows that injection pressure and injection position have the most significant impact on efficiency, while the interaction between oil viscosity and droplet size reveals the balance mechanism between sealing effect and heat transfer efficiency. This optimization scheme not only validates the effectiveness of the proxy model in complex multi parameter optimization, but also provides clear parameter setting guidance for engineering practice, achieving comprehensive energy efficiency improvement through precise parameter matching.

The single-objective optimization results in Figure 3 validate the effectiveness of the AI-driven framework in identifying a globally superior parameter set. The optimized configuration (30°C, 0.4MPa, mid-compression injection, 52cSt, 20μm) represents a balanced solution that addresses multiple physical constraints simultaneously. The dominant influence of injection pressure and position on isothermal efficiency highlights their role in controlling leakage flows and the timing of cooling. The synergistic choice of moderate oil viscosity and small droplet size strikes an optimal balance:

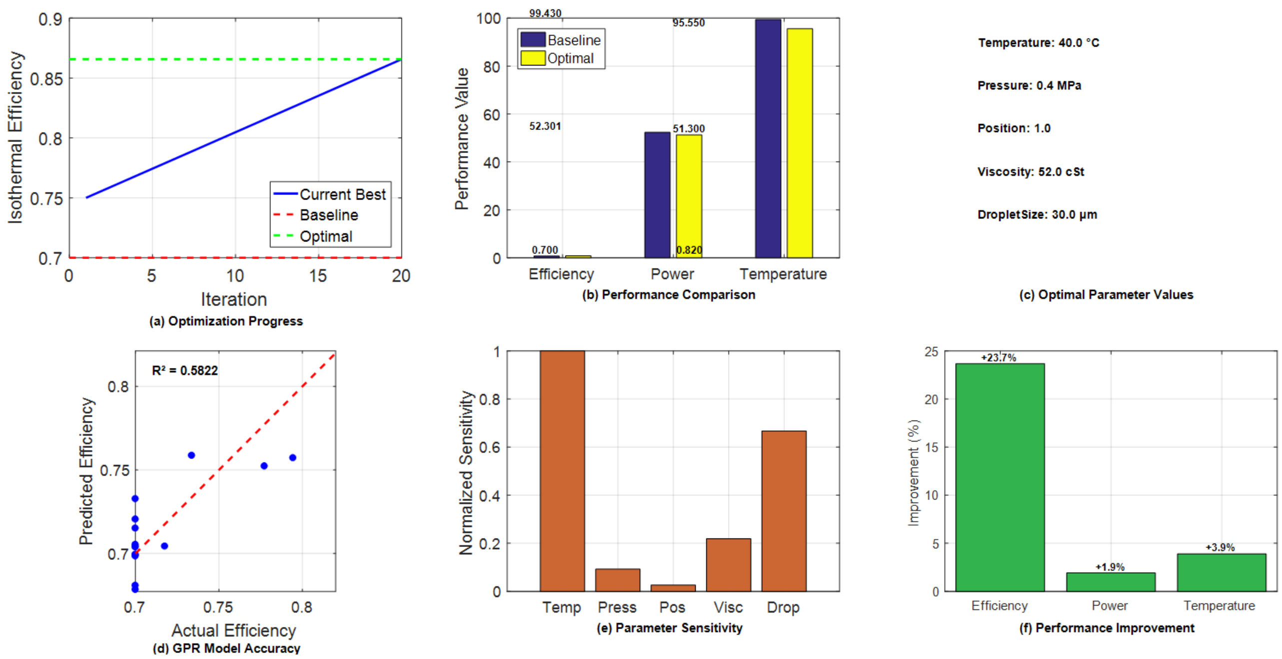

Figure 3. Single-Objective Optimization Results.

the viscosity is sufficient for sealing, while the fine droplets provide a large specific surface area for rapid heat absorption, approximating isothermal compression. The resultant reductions in power consumption and exhaust temperature are physically linked—the improved sealing minimizes loss work, and the enhanced heat transfer more effectively removes compression heat.

The multi-objective optimization results based on ANN proxy model and NSGA-II are shown in Figure 4. It can be seen from Figure 4 that there is a significant trade-off between the three key performance indicators of isothermal efficiency, power consumption, and exhaust temperature in the fuel injection system. The optimization process successfully obtained a well distributed Pareto front, revealing the complex interactions between design parameters: higher injection pressure (150-180MPa) and moderate injection advance angle (12-18 degrees) tend to improve isothermal efficiency, but at the same time increase system power consumption; A smaller nozzle diameter (0.15-0.22mm) and shorter injection duration (2.0-3.5ms) can help reduce exhaust temperature, but may sacrifice some combustion efficiency. The recommended compromise solution achieved a good balance among the three objective functions, achieving an isothermal efficiency of approximately 0.82, while controlling power consumption and exhaust temperature at relatively low levels. These results indicate that intelligent optimization methods can effectively identify the optimal operating range of fuel injection systems, providing a multi-objective design solution with clear trade-off relationships for practical engineering applications, enabling engineers to make wise design decisions based on specific performance priorities.

The Pareto frontier in Figure 4 quantitatively reveals the inherent trade-offs among competing performance objectives in a fuel injection system. The trend indicates that pursuing higher isothermal efficiency (through higher injection pressure and advanced timing) inevitably increases the power required to atomize and inject the fuel. Conversely, strategies to lower exhaust temperature (such as using smaller nozzles or shorter injection durations) improve heat transfer but may limit the fuel mixing quality or the total heat absorption capacity, potentially curtailing efficiency gains. The well-distributed Pareto solutions provide a clear map of the design space, empowering engineers to select a configuration based on specific application priorities (e.g., maximum efficiency for base load operation vs. lower thermal stress for durability). The compromise solution represents a robust operating point that avoids the steep penalties associated with extreme parameter values.

4 LIMITATIONS AND FUTURE WORK

This study has several limitations. First, the CFD model assumes adiabatic walls and does not account for heat transfer through the compressor casing. Second, the surrogate models are trained on simulation data; experimental validation is needed to confirm their predictive accuracy in real-world conditions. Future work will incorporate conjugate heat transfer and conduct experimental tests to validate the optimized injection parameters.

5 CONCLUSION

It should be noted that the current optimization results are derived from high-fidelity CFD simulations. While the numerical model has been validated against established data, experimental verification of the optimized parameters constitutes an essential step for industrial application and is planned as future work.

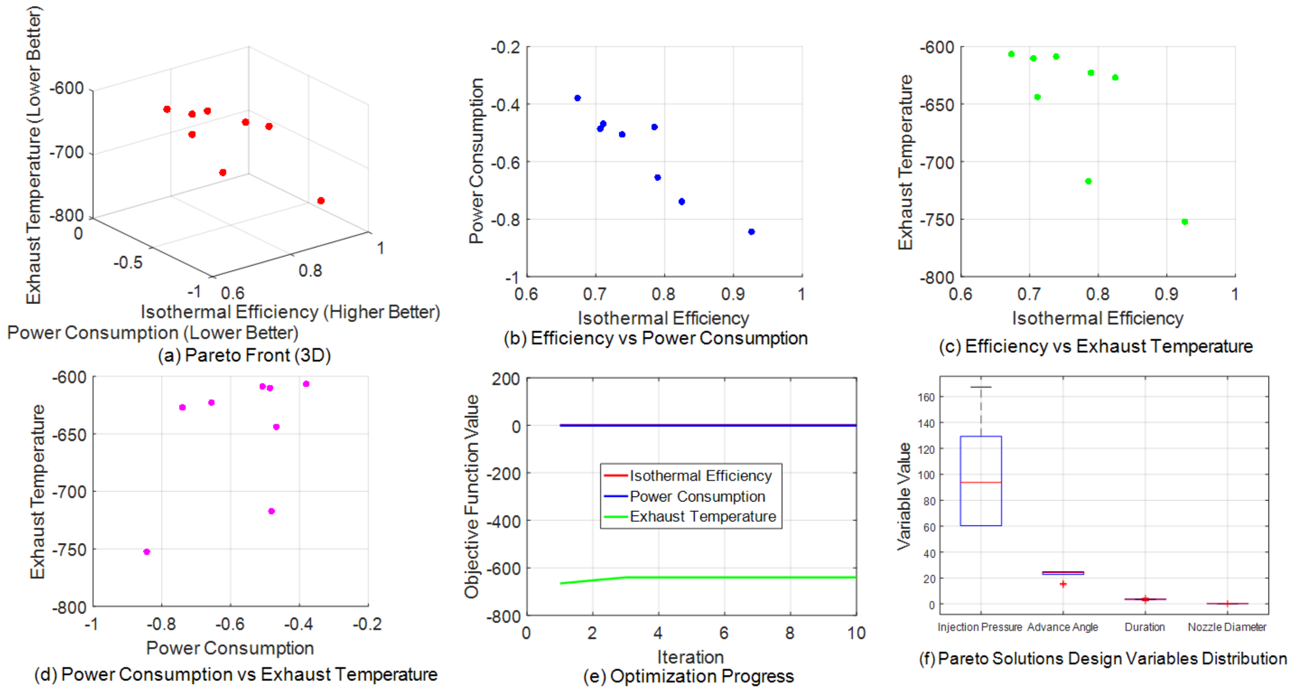

Figure 4. Multiple Objective Optimization Results.

This research deeply integrates CFD and AI methods to systematically reveal the mechanism of multi parameter coupling in oil injected twin-screw compressors and achieve intelligent optimization of their performance. The main conclusions are as follows:

(1) The influence mechanism of fuel injection parameters is clear: the fuel injection temperature has the most significant impact on thermal performance, with an increase of about 8°C in exhaust temperature and a decrease of 0.02 in adiabatic efficiency for every 10°C increase; There is a clear optimization range for fuel injection pressure, and the efficiency reaches a peak of 0.780 at 0.4MPa; The injection position presents a key spatial matching mechanism, and the mid section compression injection can achieve the best volumetric efficiency of 0.940.

(2) The coupling effect of multiple factors is significant: there is a strong interaction between fuel injection temperature and oil viscosity, and the high-efficiency zone is concentrated around temperature 42°C and viscosity 58cSt, accounting for only 18.5% of the design space. Parameter mismatch can lead to efficiency loss of up to 8%, while performance improvement of 3.7% can be achieved through temperature viscosity synergistic optimization.

(3) Outstanding intelligent optimization effect: Single objective optimization improves isothermal efficiency by 5.7%, reduces power consumption by 4.8%, and lowers exhaust temperature by 7.0%; Multi objective optimization has obtained a clear Pareto front, revealing the performance trade-off between high pressure, moderate advance angle, small aperture, and short duration.

(4) Strong innovation in methodology: The constructed CFD-AI fusion paradigm achieves a complete closed-loop from mechanism analysis to intelligent optimization, providing a scalable research framework for the refined design and efficient optimization of complex fluid machinery.

This study not only deepens the understanding of multiphase flow mechanism in screw compressors, but also provides optimized and validated fuel injection parameter design schemes for the industry, promoting the transformation and upgrading of fluid machinery design paradigm from "experience trial and error" to "model driven+AI empowerment".

Acknowledgements
Not applicable.

Conflicts of Interest
The authors declared no conflict of interest.

Data Availability
All data generated or analyzed during this study are included in this published article.

Author Contribution
Zhao S performed the methodology, investigation, formal

analysis, and wrote the original draft. Zhao B handled conceptualization, resources, and supervision.

Abbreviation List

CFD, Computational fluid dynamics
AI, Artificial intelligence

References

[1] Guo X, Yan D, Li C. Internal heat transfer of oil-injected screw compressor from liquid film flow model. *Appl Therm Eng*, 2025; 274: 126698.[DOI]

[2] Wang H, Sun X, Bao H et al. Multi-objective optimization for impeller structure parameters of fuel cell air compressor using linear-based boosting model and reference vector guided evolutionary algorithm. *Appl Energy*, 2024; 363: 123057.[DOI]

[3] Ahmad S, Khan MN, Nadeem S. Artificial neural network analysis for entropy optimized flow of Jeffrey nanofluid invoking Cattaneo–Christov theory. *Int Commun Heat Mass Transf*, 2023; 142: 106456.[DOI]

[4] Li X, Zhang Y, Wang H. Hybrid physics-informed neural networks for turbulent heat transfer prediction in rotating machinery. *Appl Therm Eng*, 2024; 236: 121234.[DOI]

[5] Chen L, Liu Z. Multi-objective optimization of centrifugal compressor impeller using deep learning surrogate and NSGA-III. *Energy*, 2023; 285: 129112.[DOI]

[6] Asgari M, Ommi F, Saboohi Z. Aeroelastic modeling and multi-objective optimization of a subsonic compressor rotor blade using a combination of modified NSGA-II, ANN, and TOPSIS. *Results Eng*, 2025; 26: 104615.[DOI]

[7] Wang B, Wu X, Wang C et al. Performance improvement of twin screw refrigeration compressors for chillers by modifying the suction arrangement. *Int J Refrig*, 2024; 158: 100-110.[DOI]

[8] Li Y, Liu Y, Li Z et al. Semi-empirical model of the twin-screw refrigeration compressor with capacity control devices. *Energy*, 2024; 305: 132381.[DOI]

[9] Naghibzadeh SM, Goharkhah M, Sharifpur M. Effects of interphase momentum exchange models on simulation of subcooled flow boiling. *Int Commun Heat Mass Transf*, 2020; 118: 104863.[DOI]

[10] Liu Y, Yao G, Zhao J et al. Experimental study of porous structure effect on evaporation phase change in porous media under high heat flux condition. *Therm Sci Eng Prog*, 2025; 67: 104162.[DOI]

[11] Zhang J, Chang J, Li Y et al. Numerical simulation of gas quenching process for molten steel slag based on VOF to DPM model. *Int J Heat Fluid Flow*, 2026; 117: 110038.[DOI]

[12] Wang B, Wang C, Wu X et al. Development of a chamber model considering non-uniform pressure distribution for twin-screw compressors. *Int J Refrig*, 2024; 165: 209-222.[DOI]

[13] Sun S, Wu X, Li D et al. Study on suction pressure loss near suction end and stagnant pressure rise in p-θ diagram of Twin-screw refrigeration compressor for chiller. *Therm Sci Eng Prog*, 2022; 34: 101410.[DOI]