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A Mini-Review of Artificial Neural Network and Particle Size Optimization for Optimization of Gas Compressing System

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Abstract
Compressing systems are used to compress gases in the industry. The compressing efficiency is influenced by process variables such as temperature, pressure and flow rate. The optimization and prediction of the optimal conditions for operating of the compressing system is important to minimize energy consumption and improve overall efficiency of the process. In the past decades, several studies have applied artificial neural network (ANN) and the particles swarm optimization (PSO) techniques to optimize and predict the performance of systems. Therefore, this current study reviewed the various studies on optimization and prediction of variables of natural compressing systems using ANN and PSO techniques. The study also compared performance of ANN and PSO with other modelling methods, and reviewed the effectiveness of combining ANN and PSO in optimizing gas compressing systems. From the reviewed studies, this current study concluded that ANN and PSO are effective modelling machine learning algorithms that can be applied to optimize various engineering and scientific systems. Comparison of ANN and PSO with other modelling methods revealed that both model techniques performed better with higher degree of predictions and optimization. Further, the combination of ANN and PSO can improve the prediction and optimization efficiency compared to when individually. Overall, this study highlighted the importance of comprehensive understanding of ANN and PSO as a modelling technique for optimization and prediction of engineering systems such as natural gas compressing system. Therefore, recommended their use for optimization and improvement of natural gas compressing efficiency.

Keywords: *Natural Gas, Compressor, Optimization, ANN, PSO*

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1. Introduction

Natural gas produced from oilfield must be conditioned and compressed before delivery to its final destination. The conditioning and compressing processes are carried out in compressing system such as compressor. The natural gas is dried, sweetened and compressed to specified delivery level (Mokhatab *et al*., 2018). Compressors are useful component of various industrial and commercial equipment used for gas transmission, petrochemical processing, and power generation. The compression system can be designed with single-stage or multistage compressors in parallel trains to share the gas load. Compressors are energy consuming and as such, they can increase the overall cost of compressing system. Hence, it is crucial to operate natural gas compressors at optimal conditions to maximize their performance and efficiency.

One major area of focus for optimization is by reducing energy consumption. However, Engineers and Plant Operators responsible for maintaining the efficiency of gas compressing systems require clear guidelines and templates. These guidelines should provide a quick look into the system performance, help identify potential issues, and outline maintenance strategies. Different options can be used to improve the efficiency of compressor for natural gas compressing systems, such as the application of optimization models. Optimization of process parameters can lead to improvement of the overall performance and reliability of a compressing system. According to Jahangir and Eidgahee (2018), the use of models for analysis of systems can significantly reduce the cost and time of conducting experiments.

This present study reviewed various optimization studies on engineering systems, with emphasis on natural gas compressing systems. Specifically, application of artificial intelligence in modelling of engineering systems was considered in this review study. A clear definition of the implementation strategies of artificial intelligence in modelling of engineering systems can lead to reliable and efficient solution. Some of the artificial intelligence modelling techniques, such the artificial neural networks (ANNs) and particle swarm optimization (PSO) are gaining research attention. These machine-learning algorithms are effective for optimization and prediction of process parameters.

The methodology of ANN was described in details, which can be adopted to study other aspects of engineering problems (Abdulla, 2020; Eidgahee et al., 2020). ANN has also found its application in food processing technology. An earlier study by Hernandez (2009) highlighted the importance of ANN as a modelling tool for solving complex optimization problems in food processing. Researchers in various engineering disciplines, such as structural engineering, have utilized machine-learning algorithms like ANN to predict material strengths and other structural properties (Naderpour et al., 2018; Naderpour et al., 2019). Various studies have provided interesting solutions and effectiveness of ANN and other artificial learning algorithms to mechanical problems (Vilalta et al., 2019; Kozakiewicz et al., 2021). Figure 1 shows the general structuring of ANN algorithm. The program generally involves input and target data, training of the data, creation of hidden layers. There are conditions to verify the accuracy of the optimized parameters. If the accuracy is unsatisfactory, the iteration or the ANN learning process is repeated until optimal value is attained. At the end of the optimization, the training, validation, test and the entire dataset results were obtained and plotted. The mean square error (MSE) and the number of epochs, as well as other useful statistical measures, are also obtained.

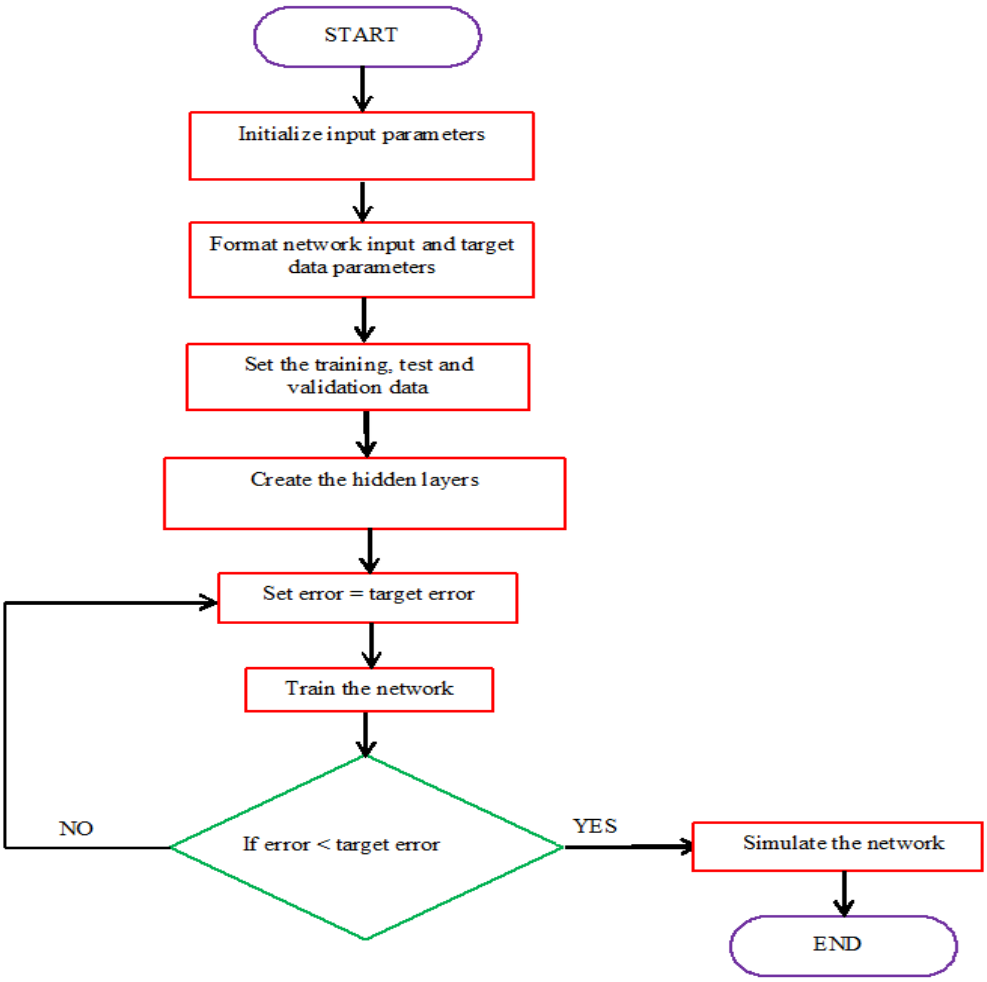

Fig. 1: Flowchart of ANN algorithm for optimization of compressor

Similarly, compressors optimization utilizing PSO has equally shown usefulness in achieving process performance. The particle swarm optimization (PSO) is an emerging technique for optimization of gas compressing systems. The PSO algorithm searches for the optimal compressor configuration based on set of constraint and objective equations (Yang *et al*., 2021). Optimization of engineering systems has been studied using PSO algorithm alone or with a combination of other optimization techniques. Sedki and Ouazar (2012) optimized the minimum cost problem of water distribution networks using optimization algorithm combined with particle swarm optimization (PSO) and evolutional algorithm (EA), while Baek *et al*. (2015) solved the optimization problem of storage tank configuration in a large sewer network using PSO algorithm. Similarly, Arandian and Ardehali (2017) developed an optimization model for solving environmental emission problem of electricity and heating network systems using PSO algorithm.

2. Application of machine learning to natural gas systems

The various studies on application of ANN and PSO algorithm to compressors optimization and predictions are reviewed and summarized in this study.

2.1 Application of ANN for optimization of natural gas systems

Optimization process for compressors with ANN has been described in literature. For instance, Cortés et al. (2009) optimized the operating conditions of compressor performance using the artificial neural network inverse (ANNi). The ANNi is a Nelder–Mead simplex optimization method developed by inverting the neural network to find the optimum parameter value under given conditions. They first developed an artificial neural network (ANN) to predict compressor pressure ratio, isentropic compressor efficiency, corrected speed, and corrected air mass flow rate. Input variables are pressure, temperature, wet bulb and cooler temperatures, filter pressure drop, compressor outlet temperature and pressure, gas turbine net power, exhaust gas temperature, and low mass flow rate. The ANN is a feed forward propagation with one hidden layer, implemented with Levenberg–Marquardt learning algorithm. It is a hyperbolic tangent sigmoid and linear transfer-function. Their optimal performance and best fitting with the training database was obtained at 12 neurons, with good fit ($R^2 > 0.99$) between the simulation and experimental database validation. Therefore, it was recommended that ANN model can be used to predict compressor performance with known input parameters.

Gholamrezaei and Ghorbanian (2010) used the feed forward neural network (FFNN) to reconstruct the performance map of an axial compressor through the utilization of experimental data. The Levenberg–Marquardt algorithm with Bayesian regularization method was used to adjust the weights and biases of the network. The FFNN optimized the mass flow rate, pressure ratio and shaft speed to maximized efficiency. It also predicted the surge line and line of maximum efficiency. The results further indicated that two hidden layers network was sufficient for modelling the complexity of compressor maps, which leaves less space for users to influence the reconstruction compared to some classical approaches where the user is required to examine a number of fitting functions across the experimental data for best fit. Overall, the modelling reduced the cost of compressor performance map.

Abhishek and Goud (2018) presented the process of designing and optimizing axial compressor of a small, transonic jet engine, by utilizing ANN to maximize thrust and minimize unit fuel consumption; and recommended that radial compressor can replace axial compressor to solve the problems associated with thrust and fuel consumption. They highlighted the advantage of radial compressors, which are used mainly for engines with low mass flow ratio. Abhishek and Goud emphasized that the optimization process of axial and radial compressors was similar, but their design differ in some areas. They further showed that the combination of numerical and experimental data revealed that diagonal compressors are more advantageous to use for small engines compared to pure radial compressors. In the study conducted by Schnoes et al. (2018) for optimization of multi-stage axial compressors, different modifications of ANN were used to estimate losses and deviations in blade airfoils, which allowed for designing of new blades with optimized shapes.

Safiyullah *et al*. (2018) developed a diagnostic genetic programming model using machine learning algorithm for determination of gas compressor isentropic head and compared its performance with the specified diagnosis of isentropic head given by the original equipment manufacturer. The maintenance activity of the compressor was predicted via the degradation performance. They developed an empirical equation via the computational codes for the genetic algorithm and then used to predict the optimum time required for routine maintenance of the compressors. They found that with application of the optimization model, the isentropic head was minimized, with improve performance of the compression system. They equally achieved 92% rotational speed between the curves. Overall, they found that the machining learning algorithm can accurately predict the health of compressors, thereby helping in scheduling the time of an equipment maintenance.

Wu et al. (2021) developed a predictive model for forecasting of load in air compressor systems used for generation of electricity in the industry using Artificial Neural Network (ANN). They highlighted that an efficient prediction of electrical load profile of compressed air systems is valuable to industry practitioners and software providers in developing better practice and tools for load management and look-ahead scheduling programs. In their study, two artificial neural networks, which included Two-Layer Feed-Forward Neural Network and Long Short-Term Memory, were used to predict an air compressors electrical load. They evaluated the compressors with three different control mechanisms with a total number of 11,874 observations. They used out-of-sample datasets with 5-fold cross-validation to fit into the models. They obtained a coefficient of determination from 0.24 - 0.94, with root-mean-square errors ranging from 0.05 – 5.83 kW, with the mean absolute scaled errors ranged from 0.20 - 1.33. Their results indicated that both ANN techniques yielded good results for compressors operating at variable speed drive, with average R^2 of 0.8. The results obtained for the long short-term memory model were acceptable for compressors using on/off control, with R^2 of 0.82, while results obtained for air compressors with load/unload type were not satisfactory.

Kozakiewicz et al. (2021) presented the results of a series of numerical research on the possibility of applying Artificial Neural Networks (ANNs) for the ultimate strength calculations of selected parts of rotating machines. The layout and the principle of the algorithm operation were described, beginning from the general assumptions and then moving on to the detailed description of the subsequent modules. The effects of applying the algorithm were presented on the example of the compressor disc analysis. The significant benefits of its application were the reduction of optimization time by about 40% and the disc weight reduction by 0.5 kg, with improved ultimate strength. The accuracy of ANNs was different in each iteration of the presented algorithm. Finally, high accuracy of neural networks was achieved with the following mean values of relevant indices reached in the last iteration: RMSE = 0.5983, MAPA = 0.0733 and R^2 = 0.99895. The further perspectives of the undertaken research were defined at the end. The specific objectives and key findings derived from the various reviews studies on ANN application are summarized in Table 1.

Table 1: Summary of specific objectives and key findings on ANN application

S/N	Author(s)/Year	Specific objectives	Key findings
1	Cortés et al. (2009)	Optimization of compressor operating parameters	Predicted compressor performance with known input parameters
2	Gholamrezaei and Ghorbanian (2010)	Prediction and cost analysis of axial compressor performance map	Predicted surge line. Reduced cost of compressor performance map
3	Abhishek and Goud (2018)	Design and optimization of axial compressor	Minimized fuel consumption
4	Schnoes et al. (2018)	Optimization of multi-stage axial compressors	Estimated losses and deviations in blade airfoils with optimized shapes
5	Safiyullah *et al*. (2018))	Optimization of gas compressor isentropic head	minimized isentropic head with improved compressor performance
6	Wu et al. (2021)	Application of ANN to predict load in air compressor systems	ANN has high degree of load prediction with minimal errors
7	Kozakiewicz et al. (2021)	Application of ANN for compressor disc analysis	Reduction of optimization time and disc weight with improved

	ultimate strength of compressor disc

2.2 Comparison of ANN with other models

Cho et al. (2012) conducted optimization study on centrifugal compressor, with focus on eight influential design variables chosen from the control points. Four design variables were selected to optimize the flow passage between the hub and the shroud, while the other four design variables were used to improve the performance of the impeller blade. The artificial neural network (ANN) optimization algorithm was used. Initially, experimental design was applied to set up the initial data space of the ANN, which was improved during the optimization process using a genetic algorithm. Computational fluid dynamics (CFD) was also used to modify the ANN algorithm and the result compared with the developed ANN. The prediction difference between the ANN and CFD modified ANN was consequently less than 1% after the 6th generation. Using this optimization technique, the computational time for the optimization was greatly reduced and the accuracy of the optimization algorithm was increased. The efficiency was improved by 1.4% without losing the pressure ratio, and Pareto-optimal solutions of the efficiency versus the pressure ratio were obtained through the 21st generation.

Fei et al. (2016) developed an artificial neural network that integrated feed-forward back-propagation neural network with Gaussian kernel function to predict compressor performance map. To demonstrate the potential capability of the proposed ANN approach for typical interpolated and extrapolated predictions, the performance of the novel ANN approach was compared with two other ANN modelling methods: feed-forward back-propagation neural network (FFBPNN) and support vector machine (SVM). A sensitivity assessment of the different models was also performed on 48, 32 and 18 number of training samples. Their results indicated that the proposed novel ANN has superior prediction performance to the existing FFBPNN and SVM, especially for extrapolation with small samples. They recommended the modified ANN for optimization of compressor performance and improvement of modelling, simulation analysis, condition monitoring, and fault diagnosis of gas turbine compressor.

Vilalta et al. (2019) used various regression models and Artificial Neural Network (ANN) to predict the performance of centrifugal compressor map. The compared the accuracy and efficiency of Gaussian Process Regression (GPR) and ANN in modelling the pressure ratio, given the mass flow rate and rotational speed of a centrifugal compressor. Preliminary results showed that both GPR and ANN predicted the compressor performance map well for both interpolation and extrapolation. However, GPR showed better prediction than ANN when the rotational speed was below 60,000 rpm, while ANN performed better when rotational speed was above 60,000 rpm. Figure 2 shows the prediction accuracy of GPR and ANN against speed, which is indicated by the magnitude of MSE. The data augmentation and minimization effects were also evaluated, and was observed that data augmentation of the rotational speed was more effective and improved the ANN performance than the mass flow rate data augmentation due to the inherent pressure ratio data distribution in mass-flow-rate and rotational-speed space.

Kozakiewicz and Kieszek (2022) presented a process of selecting and optimising ANN to predict the stress distribution in disc-drum structure of compressor stage in an aircraft turbine engine due to reduce time of analysis. The proposed algorithm determined the von Mises stress and optimized the structure. This study described a parametric model for compressor stage aimed at reducing stress distribution for training artificial neural networks. A comparative analysis of three selected neural network training algorithms (GDM, SCG, and RPROP), combined with the optimisation of their structure, were presented. The results showed that the algorithm with the momentum method (GDM) had the worst match to the training and test data, while the conjugate gradient (SCG) algorithm and the resilient back propagation (RPROP) algorithm have good and comparable accuracy of compressor unit predictions. The specific objectives and key findings derived from the various reviews' studies on the comparison of ANN modelling with other models are summarized in Table 2.

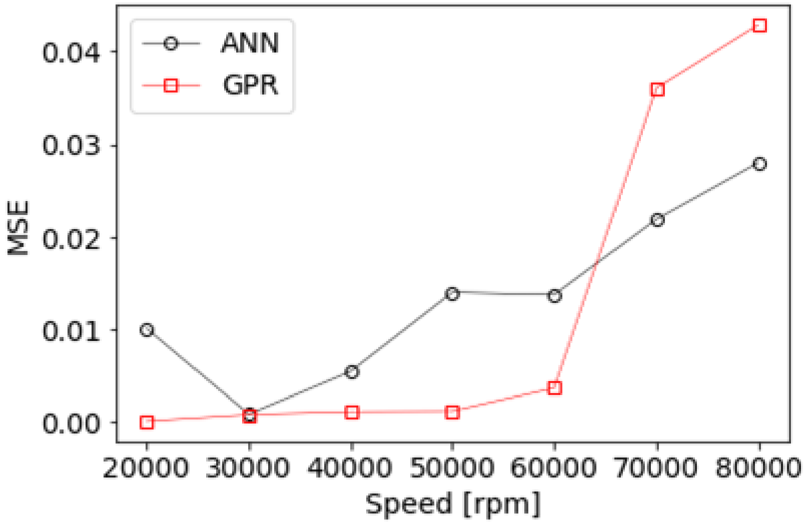

Fig. 2: Comparison extrapolation GPR and ANN (Vilalta et al., 2019)

Table 2: Summary of specific objectives and key findings on comparison of ANN with other models

S/N	Author(s)/Year	Specific Objectives	Key findings
1	Cho et al. (2012)	Compared the optimization of centrifugal compressor using ANN and CFD model	The CFD modified ANN performed better than ANN alone, with increase in optimization accuracy and compressor efficiency.
2	Fei *et al*. (2016)	Developed a novel FFANN model to predict compressor performance map and compared with feed-forward back-propagation neural network (FFBPNN) and support vector machine (SVM)	The novel ANN model has better prediction of compressor performance than FFBPNN and SVM
3	Vilalta et al. (2019)	Compared the prediction of centrifugal compressor map the performance with ANN and Gaussian process regression (GPR)	Both model techniques have good prediction accuracy and efficiency. GPR showed better prediction than ANN when speed was below 60,000 rpm, while ANN performed better when rotational speed was above 60,000 rpm.
4	Kozakiewicz and Kieszek (2022)	Compared the performance of three neural network algorithms (GDM, SCG, and RPROP) optimizing stress distribution in disc-drum of compressor	GDM performed poorly compared to SCG and RPROP algorithms, with good and comparable predictions

2.3 Application of PSO for optimization of natural gas systems

Another optimization model that has been used to optimize gas compression system is the particle swarm optimization (PSO). The PSO concept searches for the best position of variables that optimizes the overall performance of the system based on set of constraint and objective equations. Hence, gas compressors have been optimized using the PSO algorithm.

Madoliat *et al*. (2017) simulated and optimized a natural gas transmission network control system using the particle swarm optimization (PSO) to simplify the complexity of solving transient nonlinear PDE flow equations with known inlet and outlet pressures. According to the authors, the PSO estimated different values for the network inlet flow rates, and with the estimated values, boundary conditions were known at the network inlets and discretized flow equations were linearized. These linear flow equations were solved for the network inlet nodes. This procedure was continued for the next nodes until it reached the network outlets. After the simulation, the differences between the calculated and actual network outlet pressures were defined as a cost function or error. Eventually, these algorithms yielded the optimum inlet flow rates which minimized the cost function. Thus, the calculated pressures and flow rates at different gas network nodes, which were obtained using the optimum inlet flow rates were used as the true values. The results of the proposed modelling approach reduced the complexity of solving network transient flow equations with the defined boundary conditions, while the simulation results confirmed the accuracy and efficiency of PSO in optimization of natural gas transmission network control system.

Yousif *et al*. (2018) used the particle swarm optimization (PSO) technique to study the minimization of operational cost at optimal power dispatch associated with microgrids coupled with natural gas network system. The microgrid was powered by natural gas turbine, which resulted to increase in load and congestion in the gas network. However, congestion concerns and load balance were eliminated through proper coordination of the electric grid and optimal dispatch of interactive networks. By the application of PSO, the coupled network problem was solved. Thus, 7-node natural gas system coupled with the IEEE bus 33 test system was used, and the proposed technique provided an optimal power dispatch scheme, which reduced the operational cost by 0.6710 million RMB (Chinese currency) per day. Moreover, it was indicated that power sharing between the main grid and microgrid reduced in such a way to help the main grid to shave the load curve peaks.

Debbah and Kherfane (2018) developed a genetic algorithm and particle swarm optimization (GA/PSO) of robust sliding mode controller in order to study the characteristics, uncertainties and bifurcation behaviour axial compressor of gas turbine. Firstly, robust theory based on equivalent sliding mode control was developed via linear matrix inequality approach to achieve a robust sliding surface, and then introduced the GA/PSO optimization to find the optimal switching controller parameters with the aim of driving the variable speed axial compressor to the optimal operating point with minimum control effort. Since it is difficult to find the model uncertainties and system characteristics, the adaptive design is considered one of the most used strategies to deal with these problems. Simulation tests were conducted to confirm the effectiveness of the proposed controllers. This proposed approach has significant impact on the stability of the compression system as it reduced instabilities, surge and rotating stall in the compressor system while increasing the performances. The study also observed that the proposed controllers do not require precise knowledge of the compressor map, or the upper bound of the uncertainties and perturbations. It does not also use a full-state feedback.

Warchol *et al*. (2018) presented a computational method for achieving an optimal operation of compressor units used in industrial gas storage systems. The proposed method was capable of operating with a mix of compressor types with different operational parameters, different power drives, and different types of construction, such as the reciprocal and turbo compressors. The goal of the optimisation was to find an optimal compressors configuration and distribution of the compressor loads for each instance of time. The proposed method was based on conversion of a multidimensional discrete-continuous optimisation problem into a set of independent combinatorial and nonlinear optimisation problems. The derived mathematical algorithms take advantages of PSO methods and dynamic programming applied to the nonlinear optimisation problem. The application of the optimisation algorithm reduces the energy consumption of the compressors and the operational costs.

Yazdani and Mousavi (2018) modelled the optimal performance of compressed natural gas station using the particle swarm optimization (PSO) algorithm which was simulated in FORTRAN programming software. The natural gas was considered as a real gas and was modelled using AGA-8 equation of state developed for computing of compressibility factor and other thermodynamic properties. This study focused on the computation of compressor work, which was described as a polytropic compression process of a real gas in a three-stage compressor. Also, the fast-filling process of the compressor was modelled based on mass conservation and thermodynamics first law in a non-adiabatic cylinder. From the model, the compressor work, lost heat in the coolers, final temperature and accumulated mass of the gas, fill ratio and refuelling process time were computed for different pressure arrangement of the storage tanks at five ambient temperatures. The optimal operational conditions of the compressor as obtained from the particle swarm optimization model algorithm were recorded at pressure arrangement of 4, 8.1, 16 and 20.5 MPa for the station tanks at ambient temperature 273.15 K.

Ren (2019) developed an optimization algorithm for effective power generation and scheduling based on the basic principle of PSO. The study was motivated by the increasing demand for electricity caused by rapid economy development. The influence of parameter selection on the efficiency of the optimization in consideration to compression factor was evaluated. The simulation results show that parameter selection influenced the efficacy of particle swarm optimization method for effective power generation and scheduling process.

Shi et al. (2019) also employed PSO algorithm for black powder (BP) source identification within gas pipelines network. The model was based on one-dimensional model which described the transport and deposition of BP. The development of the model resulted due to a worldwide concern on the challenges black powder posed to the natural gas industry from the producing wells to the consuming points. According to the authors, BP can endanger pipeline operations, damage to instruments and contamination of final products supplied to customers. Black power formation inside natural gas pipeline mainly occurred due to corrosion of internal walls of pipeline arising from a complex chemical reaction. However, the optimization algorithm was used to solve constrained optimization problems. The study concluded that the application of the optimization algorithm on the gas transmission pipeline network proved effective for identification and quantification of BP source at different junctions simultaneously.

Zheng *et al*. (2019) developed an optimization model using PSO approach for enhancing a steady production of coal bed methane (CBM) in the field through information and data from compressors in a natural gathering network in China. According to the authors, natural gas is importance to Chinese government as a clean energy source and it is an odourless and smokeless combustion process, which has made its usage, particularly the CBM, increased to 3.4% of China's total natural gas production in 2017, and a further increase to 9.2% in the subsequent year. However, due to the complexity of CBM gathering networks, the pressurization scheme lacks guidance in practice and is mainly decided by experience to guide the practical production process, but the application of mixed-integer nonlinear programming (MINLP) model to optimize the pressurization scheme using PSO reduced the challenges of proper guidelines of the production process. A two-stage improved genetic algorithm that utilized PSO algorithm was used in developing the model. 132 production wells, 10 manifolds and 1 central processing facility of a real CBM field in China were used to validate the model. The PSO-optimized MINLP model considered the cost of facilities and electricity, which maximizes the daily net profit of CBM field companies. The results showed that at optimal condition, the total production increased from $3.39\times10^5 m^3/d$ to $3.73\times10^5 m^3/d$ with a growth rate of 10.0%, while the daily net profit increased from 3.70×10^3USD/day.

Jia *et al*. (2021) combined multi-objective evolutionary algorithm with PSO to optimize the performance and efficiency of a gas compressor used in natural gas transporting system. The authors demonstrated that hybrid models can effectively optimize the trade-off between energy consumption and compression ratio while satisfying various constraints such as pipeline pressure and flow rate. The specific objectives and key findings derived from the various review's studies on the application of PSO algorithm are summarized in Table 3.

Table 3: Summary of specific objectives and key findings on PSO application

S/N	Author(s)/Year	Specific Objectives	Key findings
1	Madoliat *et al*. (2017)	Applied PSO algorithms for transient analysis of natural gas pipeline	Simulated and optimized a natural gas transmission network control system using PSO to simplify the complexity of solving transient nonlinear flow equations.
2	Yousif *et al*. (2018)	Minimization of operational cost at optimal power dispatch in natural	PSO optimized power dispatch, and reduced operational cost by 0.6710

		gas network system using PSO	million RMB per day.
3	Debbah and Kherfane (2018)	Optimization of compressor control parameters using PSO algorithm	The model approach reduced instabilities, surge and rotating stall in the compressor system while increasing the performances.
4	Warchol *et al*. (2018)	Optimisation of compressor load distribution using PSO	The optimisation algorithm reduced energy consumption and operational cost of compressors
5	Yazdani and Mousavi (2018)	Optimization of compressed natural gas performance using PSO algorithm	PSO algorithm optimized the input parameters for optimal performance of compressed natural gas station
6			
7	Ren (2019)	optimization of power generation and scheduling based on PSO algorithm	Parameter selection influenced the efficacy of PSO method for effective power generation and scheduling process
8	Shi *et al*. (2019)	To identify black powder (BP) source within gas pipelines network using PSO algorithm	Model effectively identified and quantified BP source at different junctions simultaneously
9	Zeng *et al*. (2019)	To optimize compressor performance using PSO to enhance steady production of coal bed methane	At optimal operating condition, the total production and daily net profit increased
10	Jia *et al*. (2021)	To optimize the performance and efficiency of a gas compressor in natural gas transporting system using combined multi-objective evolutionary algorithm with PSO	The hybrid models effectively optimized the trade-off between energy consumption and compression ratio

2.5 Comparison of PSO algorithm with other optimization models

The performance of PSO in optimizing the operating variables or process performance has been compared with other optimization models. PSO algorithm can also be modified to improve its performance. For instance, to improve the flow performance of tandem cascades on and off design incidence angle and to increase the stable operation range of compressors, Song and Liu (2018) developed an optimization system for tandem cascades based on an adaptive particle swarm optimization cum population diversity control (APSO-PDC). First, the APSO-PDC was proposed based on adaptive selection of particle roles and population diversity control. The adaptive selection of particle roles, which combined the evolutionary state and dynamic particle state estimation method, sorted the particles into three roles to help different particles execute different search tasks during the optimization process. The population diversity control, on the other hand, combined comprehensive learning strategy of the particle swarm optimizer with evolutionary state to strengthen the exploration ability and avoiding falling into the local optima. The performance of the APSO-PDC technique was evaluated using 11 unimodal and multimodal functions. Comparison of the APSO-PDC technique with six previously developed PSO modelling techniques showed that the APSO-PDC has better performance in terms of algorithm accuracy and reliability. In addition, APSO-PDC was validated by optimizing two large-turning tandem cascades, including low-dimension (5 optimization variables) and high-dimension problems (34 optimization variables), and comparison of the optimization results with the other six PSOs demonstrated that the APSO-PDC has the fastest convergence speed and also simultaneously controlled the population diversity better.

Sharma and Baloni (2020) applied PSO to optimize an S-shaped compressor transition duct due to pressure loss coefficient and non-uniformity of flow along the length of the S-shaped transition duct. According to the authors, a high-bypass turbofan engine normally transfers air from low to high-pressure compressor through the S-shaped transition duct. Further, the conventional design approach is time-consuming and does not guarantee an optimal solution for these problems. Therefore, to ensuring the maximum performance of the S-shaped transition duct, it is required that the total pressure loss is minimized while maximizing the uniform flow of a compressor. However, the optimization was achieved using the 2-dimensional axisymmetric approach for computational fluid dynamics as a design tool for performance evaluation with optimization techniques. The simulation model was validated with available experimental results. The correlation between the dependent and independent variables was established using the second-order polynomial response surface methodology. In addition, individual optimization was carried out using PSO and gray wolf optimization algorithms. The performance comparison of the optimization methods showed that the best solution was obtained with the PSO optimization algorithm. The PSO optimized duct reduced the pressure loss coefficient by 28.14%, while the non-uniformity index reduced by 43.33% with 6.37% reduction in length compared to the baseline S-shaped duct. Table 4 summarized the specific objectives and key findings derived from the various reviews studies on the comparison of PSO algorithm with other models.

Table 4: Summary of specific objectives and key findings on comparison of PSO with other models

S/N	Author(s)/ Year	Specific objectives	Key findings
1	Song and Liu (2018)	Comparison of developed adaptive particle swarm optimization cum population diversity control (APSO-PDC) with six modified PSO algorithms for optimization of tandem cascades in compressor system	The proposed APSO-PDC model has better performance in terms of algorithm accuracy and reliability. The APSO-PDC has the fastest convergence speed, and it simultaneously controlled the population diversity better
2	Sharma and Baloni (2020)	To compare the performance of PSO with gray wolf optimization algorithm in minimization of loss in pressure coefficient and reduction in non-uniformity of S-shaped transition duct length.	The PSO algorithm outperformed the gray wolf optimization algorithm in optimizing the S-shaped compressor transition duct. The PSO algorithm reduced the pressure loss coefficient by 28.14%, non-uniformity index by 43.33%, and the S-shape transmission duct length by 6.37% compared to the baseline S-shaped

2.6 Combined optimization with ANN and PSO

While the ANN and PSO algorithms have shown to be effective in optimization and prediction of engineering systems, the performance of both algorithms have been compared by various researchers. However, the PSO can be combined with any of the optimization model to improve better performance of gas compressors. Though, the applicability and effectiveness of such combination will depend on the specific goal and constraints of the compressor system.

Bashiri et al. (2019) optimized the shape of impeller of centrifugal pump to reduce energy consumption and improve the efficiency and head. They used evolutionary algorithm by combining artificial neural network (ANN) and particle swarm optimization (PSO) algorithms. This modified model was validated using computational fluids dynamic (CFD) data. The pump experimentally investigated in test rig and measured data were used to verify the numerical results. The optimized results were verified by comparing with the characteristic curves of the initial pump results. The optimized results showed that the pump efficiency improved by 3.2%, while the head increased by 5.52m. In addition, the authors concluded that the combination of the different optimization modelling techniques improved the energy efficiency and performance of the centrifugal pump impeller compared to ANN or PSO alone.

Zhang *et al*. (2021a) performed optimization analysis on fault diagnosis of compressor system using principal components analysis (PCA) based on artificial neural network (ANN) algorithm, particle swarm optimization (PSO) algorithm and least squares support vector machine (LSSVM) algorithm. The relationship between the working principle of the compressor system, the fault phenomenon, and the root cause was analyzed. Recorded fault data obtained through the fault signal for various fault occurrence states on the compressor was used as input variables for the models. The results showed that the PSO, LSSVM and ANN were effective in fault diagnosis with a maximum fault recognition efficiency of 10.4% higher than other compared models. The test sample classification time was reduced by 0.025 seconds, but the PSO and the LSSVM fault diagnosis models have more efficient fault recognition rate and accuracy. Therefore, the proposed models for fault diagnosis system can effectively be used to identify compressor fault and improve its efficiency.

The liquefaction of natural gas is imperative before it can be transported, which is designed to be carried out under fixed conditions. The gas liquefaction process can be feasible under variable conditions through process optimization. Ahmad *et al*. (2022) proposed an optimization model, developed by combining the artificial neural network (ANN) with the particle swarm optimization (PSO). The developed PSO-ANN model was used to predict the decision variables of a single mixed refrigerant (SMR) liquefied natural gas (LNG) process for its feasible design under varying conditions. The accuracy of the predicted set of decision variables was verified by inputting them into Aspen HYSYS. The output of the SMR-LNG process was the overall power at a constrained minimum internal temperature approach (MITA) value ($1.0 \leq \text{MITA} \leq 3.0$). The predicted results of the PSO-ANN model were compared with those of the classical ANN back propagation learning method and the prediction accuracy of the proposed PSO-ANN model was more effective than the classical ANN back propagation method with up to 80% prediction accuracy. In addition, the proposed model can predict diverse range of temperatures and pressures that make the LNG process feasible under variable conditions with better MITA value. Table 5 summarized the specific objectives and key findings derived from the various reviewed studies on the combination of ANN and PSO techniques.

Table 5: Summary specific objectives and key findings on combination of ANN and PSO algorithms

S/N	Author(s)/Year	Specific objectives	Key findings
1	Bashiri *et al*. (2019)	To optimize the shape of impeller of centrifugal pump and reduce energy consumption in order to improve the efficiency by combining ANN optimization with PSO algorithm	The combined approach optimized improved the pump efficiency by 3.2%, while the head increased by 5.52m. The ANN-PSO combined optimization technique improved the energy efficiency and performance of the centrifugal pump impeller better compared to ANN or PSO alone. at increasing the energy efficiency and head.
2	Zang *et al*. (2021a)	performed optimization analysis on fault diagnosis of compressor system using principal components analysis (PCA) based on artificial neural network (ANN) algorithm, particle swarm optimization (PSO) algorithm and least squares support vector machine (LSSVM) algorithm.	The results showed that the PSO, LSSVM and ANN were effective in fault diagnosis with a maximum fault recognition efficiency of 10.4% higher than other compared models. The test sample classification time was reduced by 0.025 seconds, but the PSO and the LSSVM fault diagnosis models have more efficient fault recognition rate and accuracy. Therefore, the proposed models for fault diagnosis system can effectively be used to identify compressor fault and improve its efficiency.
3	Ahmad *et al*.	To investigate the	The predicted compressor variables by

(2022)	performance of combined ANN-PSO algorithm in predicting the variables of single mixed refrigerant of liquefied natural gas process	PSO-ANN model were more accurate than the classical ANN back propagation method with up to 80% prediction accuracy. The proposed model can predict diverse range of temperatures and pressures under variable conditions with better MITA value

3. Conclusion

This review study summarized the various works conducted on the optimization and prediction of variables of natural compressing systems using artificial neural network (ANN) and the particles swarm optimization (PSO) leaching techniques. The study assessed the performance of ANN and PSO in analysing and optimizing compressing systems as reported by the various studies. It also explored their performances in comparison to other modelling methods, and reviewed the effectiveness of combining ANN and PSO in optimizing gas processing or compressing systems. From the reviewed studies, it can be concluded that ANN and PSO are effective modelling machine learning algorithms that can be applied to various engineering and scientific systems with high implementation speed. Comparison of ANN and PSO with other modelling methods revealed that ANN and PSO performed better with higher degree of predictions and optimization of process variables for optimal performance of the overall systems. The reviewed studies also showed that ANN and PSO can be combined to further improve their performance efficiency in predicting and optimizing the compressing systems. Overall, this study highlighted the importance of comprehensive understanding of the application of ANN and PSO in modelling of engineering system such as natural gas compressing system. Therefore, recommended the use of ANN and PSO in optimization of compressors to improve the compression of efficiency of natural gas in compression stations and other applications.

References

Abdulla, N.A. (2020) Using the artificial neural network to predict the axial strength and strain of concrete-filled plastic tube. Journal of Soft Computing in Civil Engineering, 4(2): 63–86.

Abhishek, S. and Goud, B.N. (2018) Compressor design optimization for a high speed jet engine. IOP Conference Series: Materials Science and Engineering, 455, 012036.

Ahmad, A., Qadeer, K., Naquash, A., Riaz, F., Hasan, M., Qyyum, M.A. and Lee, M. (2022) Particle swarm-assisted artificial neural networks for making liquefied natural gas processes feasible under varying feed conditions. Frontiers in Energy Research, 10, 917656.

Arandian, B. and Ardehali, M.M. (2017) Effects of environmental emissions on optimal combination and allocation of renewable and non-renewable CHP technologies in heat and electricity distribution networks based on improved particle swarm optimization algorithm. Energy, 140: 466-480.

Baek, H., Ryu, J., Oh, J. and Kim, T.-H. (2015) Optimal design of multi-storage network for combined sewer overflow management using a diversity-guided, cyclic-networking particle swarm optimizer – A case study in the Gunja subcatchment area, Korea. Expert Systems with Applications, 42(20): 6966-6975.

Bashiri, M., Derakhshan, S. and Shahrabi, J. (2019) Design optimization of a centrifugal pump using particle swarm optimization algorithm. International Journal of Fluid Machinery and Systems, 12(4): 322-331.

Cho, S-Y., Ahn, K-Y., Lee, Y-D. and Kim, Y-C. (2012) Optimal design of a centrifugal compressor impeller using evolutionary algorithms. Mathematical Problems in Engineering, Volume 2012, 752931.

Cortés, O., Urquiza, G. and Hernández, J.A. (2009) Optimization of operating conditions for compressor performance by means of neural network inverse. Applied Energy, 86: 2487–2493

Debbah, A. and Kherfane, H. (2018) GA/PSO robust sliding mode control of aerodynamics in gas turbine. Acta Universitatis Sapientiae Electrical and Mechanical Engineering, 10: 42-66.

Eidgahee, D.R., Rafiean, A.H. and Haddad, A. (2020) A novel formulation for the compressive strength of IBP-based geopolymer stabilized clayey soils using ANN and GMDH-NN approaches. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 44: 219–229.

Fei, J., Zhao, N., Shi, Y., Feng, Y. and Wang, Z. (2016) Compressor performance prediction using a novel feed-forward neural network based on Gaussian kernel function, Advances in Mechanical Engineering, 8(1): 1–14.

Gholamrezaei, M. and Ghorbanian, K. (2010) Compressor map generation using a feedforward neural network and rig data, Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 224(1): 97–108.

Hernandez, J.A. (2009) Use of neural networks and neural network inverse in optimizing food processes. Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 4 (061): 1-11.

Jahangir, H. and Eidgahee, A. (2018). New and robust hybrid artificial bee colony algorithm – ANN model for FRP-concrete bond strength evaluation. Composite Structures, 2021, 257.

Jia, Y., Zhu,Y. and Liu, L. (2021) Optimization of natural gas compressor station operation using a hybrid multi-objective evolutionary algorithm. Journal of Natural Gas Science and Engineering, 102, 103915.

Kozakiewicz, A. and Kieszek, R. (2022) Artificial neural network structure optimisation in the pareto approach on the example of stress prediction in the disk-drum structure of an axial compressor. Materials, 15, 4451.

Kozakiewicz, A., Kieszek, R. and Rogólski, R. (2021) Optimization of a jet engine compressor disc with application of artificial neural networks for calculations related to time and mass criteria. Advances in Science and Technology Research Journal, 15(2): 208–218.

Madoliat, R., Khanmirza, E. and Pourfard, A. (2017) Application of PSO and cultural algorithms for transient analysis of natural gas pipeline. Journal of Petroleum Science and Engineering, 149: 504–514

Mokhatab, S., Poe, W.A. and Mak, J.Y. (2018) Handbook of Natural Gas Transmission and Processing: Principles and Practices. Gulf professional publishing. https://doi.org/https:// doi.org/ 10.1016/C2017-0-03889-2.

Naderpour, H., Nagai, K., Fakharian, P. and Haji, M. (2019) Innovative models for prediction of compressive strength of FRP-confined circular reinforced concrete columns using soft computing methods. Composite Structures, 215: 69–84.

Naderpour, H., Rafiean, A.H. and Fakharian, P., (2018) Compressive strength prediction of environmentally friendly concrete using artificial neural networks. Journal of Building Engineering, 16: 213–219.

Ren, Y. (2019) Particle swarm optimization with compression factor for solving the power systems economic dispatch problem. Journal of Physics: IOP Conference Series, 1302, 022091.

Safiyullah, F., Sulaiman, S.A., Naz, M.Y., Jasmani, M.S. and Ghazali, S.M.A. (2018). Prediction on performance degradation and maintenance of centrifugal gas compressors using genetic programming, Energy, 158: 485–494.

Schnoes, M., Voß Ch. and Nicke, E. (2018) Design optimization of a multi-stage axial compressor using through flow and a database of optimal airfoils. Journal of the Global Power and Propulsion Society, 2: 516-528.

Sedki, A. and Ouazar, D. (2012) Hybrid particle swarm optimization and differential evolution for optimal design of water distribution systems. Advanced Engineering Informatics, 26(3): 582-591.

Sharma, M. and Baloni, B.D. (2020) Design optimization of S-shaped compressor transition duct using particle swarm optimization algorithm. Springer Nature Applied Sciences, 2(2): 1972-1988.

Shi, J., Al-Durra, A., Matraji, I., Al-Wahedi, K. and Abou-Khousa, M. (2019) Application of particle swarm optimization (PSO) algorithm for black powder (BP) source identification in gas pipeline network based on 1-D model. Oil & Gas Science and Technology - Review. IFP Energies Nouvelles, 74: 47 – 62.

Song, Z. and Liu, B. (2018) Optimization design for tandem cascades of compressors based on adaptive particle swarm optimization. Engineering Applications of Computational Fluid Mechanics, 12(1): 535-552.

Vilalta, P.C., Wan, H. and Patnaik, S.S. (2019) Centrifugal compressor performance prediction using Gaussian process regression and artificial neural networks. Proceedings of the ASME 2019 International Mechanical Engineering Congress

& Exposition, 11-14th November, 2019, Salt Lake City, UT, USA.

Warchol, M., Swirski, K., Ruszczycki, B. and Wojdan, K. (2018) The method for optimisation of gas compressors performance in gas storage systems, International Journal of Oil, Gas and Coal Technology, 17(1): 12-33.

Wu, D-C., Asl, B.B., Razban, A. and Chen, J. (2021) Air compressor load forecasting using artificial neural network. Expert Systems with Applications, 168, 114209.

Yang, J.H., Kim, D.H. and Lee. X.J. (2021) Particle swarm optimization for compressor performance optimization. Journal of Natural Gas Science and Engineering, 69: 23-38.

Yazdani, H. and Mousavi, S.R. (2018) Determining the optimal performance of compressed natural gas (CNG) station based on PSO algorithm. Journal of Energy Management and Technology, 2(3): 39-44.

Yousif, M., Ai, Q., Gao, Y., Wattoo, W.A., Jiang, Z. and Hao, R. (2018) Application of particle swarm optimization to a scheduling strategy for microgrids coupled with natural gas networks. Energies, 11(12): 3499 – 3514.

Zhang, K., Su, J., Sun, S., Liu, Z., Wang, J., Du, M., Liu, Z., & Zhang, Q. (2021) Compressor fault diagnosis system based on PCA-PSO-LSSVM algorithm. Science Progress, 104(3): 1–16.

Zheng, T., Liang, Y., Wang, B., Sun, H., Zheng, J., Li, D., Chen, Y., Shao, L. and Zhang, H. (2019) A two-stage improved genetic algorithm-particle swarm optimization algorithm for optimizing the pressurization scheme of coal bed methane gathering networks, Journal of Cleaner Production, 229: 941-955.