www.dergipark.gov.tr
ISSN:2148-3736
El-Cezerî Fen ve Mühendislik Dergisi
Cilt: 8, No: 1, 2021 (376-388)

El-Cezerî Journal of Science and Engineering
Vol: 8, No: 1, 2021 (376-388)

DOI :10.31202/ecjse.814527

ECJSE

Research Paper / Makale

A GEP-Based Model Approach for Estimating Thermodynamic Properties of R513A Refrigerant

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Received/Geliş: 22.10.2020 **Accepted/Kabul:** 05.12.2020

Abstract: The changes in the politic and environmentally are highly effective in refrigerant choices. Nowadays, it is critical using environmentally friendly and energy-efficient refrigerants for a sustainable future. The R513A refrigerant provides both GWP reduction and increases energy efficiency. Accurate estimates of thermodynamic properties of refrigerant are critical when considering the changing of temperature in a small interval. Many data of thermodynamic properties of refrigerants are hard-to-reach data from literature and tables. In the present study, thermodynamic properties such as entropy, enthalpy and density modelled using gene expression programming (GEP). In this context, for R513A new refrigerant determined mathematical equations through gene expression programming. Developed mathematical models for saturation and superheated R513A refrigerant under different temperature and pressure condition compared experimental data obtained from the literature. The results have shown that the GEP model could be considered as an efficient modelling technique for the estimate data of predicting thermodynamic properties of refrigerants.

Keywords: Gene expression programming, Refrigerant, R513A, Thermodynamic properties

R513A Soğutucu Akışkanın Termodinamik Özelliklerini Tahmin Etmek İçin GEP Tabanlı Model Yaklaşımı

Öz: Soğutucu akışkan seçimlerinde politik ve çevresel faktörler oldukça etkilidir. Günümüzde sürdürülebilir bir gelecek için çevre dostu ve enerji tasarruflu soğutucu akışkanların kullanılması kritik önem taşımaktadır. Soğutma sistemlerinde R513A soğutucu akışkanının kullanımı, hem GWP azaltımı sağlar hem de enerji verimliliğini artırır. Soğutucu akışkanların termodinamik özelliklerinin doğru olarak belirlenmesi oldukça önemlidir. Soğutucu akışkanların termodinamik özelliklerine ilişkin birçok veri, literatür ve tablolardan güçlükle elde edilebilmektedir. Bu çalışmada, entropi, entalpi ve yoğunluk gibi termodinamik özellikler gen ifade programlaması (GEP) kullanılarak modellenmiştir. Bu bağlamda, yeni bir soğutucu akışkan olan R513A için GEP modeli yardımıyla matematiksel denklemler türetilmiştir. R513A soğutucu akışkan için farklı sıcaklık ve basınç şartlarında, literatürden elde edilen deneysel verilerle GEP modelinden elde edilen değerler karşılaştırılmıştır. Elde edilen sonuçlar, GEP modelinin soğutkanların termodinamik özelliklerini tahmin etmede verimli bir modelleme tekniği olarak kullanılabileceğini göstermiştir.

Anahtar Kelimeler: Gen ifade programlama, Soğutucu akışkan, R513A, Termodinamik özellikler

1. Introduction

Refrigeration's history is based on old times. For the first 100 years, the most common refrigerants are the first generation of refrigerants (1830-1930s) that some solvents and other volatile fluids.

How to cite this article
Şencan Şahin, A., Kovacı, T., Dikmen, E., "*A GEP-Based Model Approach for Estimating Thermodynamic Properties of R513A Refrigerant"*, El-Cezerî Journal of Science and Engineering, 2021, 8(1); 376-388.

Bu makaleye atıf yapmak için
Şencan Şahin, A., Kovacı, T., Dikmen, E., "*A GEP-Based Model Approach for Estimating Thermodynamic Properties of R513A Refrigerant"*, El-Cezerî Fen ve Mühendislik Dergisi 2021, 8(1); 376-388.
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Most of them were toxic and flammable, and generally, it caused numerous accident. The second-generation refrigerants realized by shifting to fluorochemicals on the purpose of safety and durability in 1931-1990s. In 2010 and beyond, some restrictions such as global warming, and ozone depletion are forcing shifts to the fourth-generation refrigerants. Then the investigations have focused on the natural refrigerants, mostly water, ammonia, carbon dioxide, hydrocarbons [1, 2]. All hydrochlorofluorocarbons (HCFCs) have required to phase out due to concerns regarding ozone depletion, climate change, and global warming, according to the Kyoto Protocol and Montreal Protocol [3, 4]. This matter could only be achieved with the help of using environment-friendly and with high energy-efficient refrigerants.

The changes in the politic and environmentally are highly significant in future refrigerant choices. The low emissions and high efficiency are fundamental to doing what's right for a sustainable future. HFCs refrigerants such as R404A, R134a and R410A are the most used in different refrigeration and air conditioning applications. R513A and R450A are nowadays very appropriate HFO/HFC mixtures for refrigeration systems. R513A refrigerant at 44/56 mass (percentage) with a GWP100-yr value of 573 is a composition of R134a/R1234yf. This fluid is non-toxic and non-flammable. Some physical properties are given in Table 1. R513A has lower operating compression ratio and higher suction density; therefore, its mass flow rate is higher than R134a. R513A liquid viscosity has lower liquid viscosity in comparison to R134a. The friction of R513A with low GWP is lower than that of R134a [5-12]. The use of R513A provides both GWP reduction and increases energy efficiency.

Table 1. Physical properties of R513A refrigerant [13]

Molecular weight	108.4 g/mole
Composition	R-1234yf/R-134a
Weight %	56.0/44.0
Molecular weight	108.4 g/mol
Boiling point at 1 atmosphere	-29.2 ^{o}C
Critical temperature	96.5 ^{o}C
Critical pressure	3765.7 kPa
Ozone depletion potential (ODP)	0
AR5 Global warming potential	573
ASHRAE safety classification	A1

The conclusion of the experimental comparisons at evaporating temperatures between -15 and 12.5ºC and condensing temperatures between 25 and 35ºC is showed that R513A could substitute R134a achieving better performance and higher cooling capacity [7]. Dey et al. [6] obtained the best performance value at low evaporating and condensing temperatures for R513A. R513A power consumption is determined higher than R134a, and its obtained coefficient of performance is higher, 5% as average. R513A indicated more efficient refrigerant.

Many researchers investigated the comparison of the performance of energy systems using soft computing. Harasami et al. [14] studied the application of neuro-fuzzy models in air conditioning. Kaboli et al. [15] obtained optimized GEP models for long-term electrical energy consumption forecasting by GEP for ASEAN-5 countries. The simulation results confirm the higher accuracy of the proposed optimized GEP models as compared with other artificial intelligence-based models. Sharifi et al. [16] predicted the coefficient of performance (COP) for refrigeration equipment under various R404A refrigerant conditions. Najafi-Marghmaleki et al. [17] Developed a model based on gene expression programming technique for the prediction of experimental density values. The proposed model in the study compared with literature correlations and GEP model is effectively superior to other associations. Dikmen et al. [18] used gene expression programming model to determine the drying behavior of herbal plants. The values obtained from the GEP formulations are determined to be in good agreement with the experimental data. Kaya [19] used an artificial neural network for the performance of parallel-connected vortex tubes.

In recent years, there are extensive researchers in the intelligence and soft computing methods for estimation properties of energy systems. When considered the benefits, further work on this subject is necessary. Many data of thermodynamic properties of refrigerants are hard-to-reach data from literature and tables. This study aims to determine the formulation of realistic mathematical models for R513A refrigerant. The thermodynamic properties data of R513A refrigerant have formulated under different temperature and pressure condition. In this context, GEP (gene expression programming) correlations, which allows evaluation of more complex programs comprised of a few subprograms, were developed for predicting entropy, enthalpy, pressure and density index separately.

2. Modelling

2.1. An Overview of Gene Expression Algorithms

Evolutionary algorithms (EAs) are problem-solving techniques based on the Darwinian evolution theory by natural selection. They include searching within a population of acceptable and possible solutions for the fittest solution. This solution is called an individual, such as a member of the population. Each EAs iteration contains competitive selection solutions through the assessment of a fitness value that shows the quality of the individual solution to the problem [20].

GEP that is the natural development of EAs is highly versatile, and it uses populations of individuals, selects them according to fitness, and takes advantage of the chromosomes and the expression trees specified as ETs [21-23]. The flowchart of a simple GEP algorithm was shown in Fig. 1.

2.2. Data Collection and Variables

Algorithms need data to train. Providing the existence of reliable and accurate data is a crucial step for developing precise and reliable models. In this manner, about 13000 datasets of the thermodynamic properties gathered from the literature [13]. The data bank includes temperature ($^{\circ}$C), pressure (kPa), density (g/m^3), enthalpy (kJ/kg) and entropy (kJ/kg-K) of R513A refrigerant. Saturation and superheated vapor properties of R513A fluid severally determined.

The next step in developing a model is the identification of independent variables as inputs. In this manner, the temperature as an input variable for saturation properties; the temperature and the pressure as an input variable for vapor properties considered. The enthalpy, entropy, density and pressure as an input variable for saturation properties; the enthalpy, entropy and density as an input variable for vapor properties considered as dependent variables. The functionality relation of thermodynamic properties of R513A refrigerant may be considered as follows;

For saturation properties: $\text{Thermodynamic properties } (h, s, \rho, P) = f\,(T_i)$

For superheated vapor properties: $\text{Thermodynamic properties } (h, s, \rho) = f\,(T_i, P_i)$

where h, s, ρ, T and P shows enthalpy, entropy, density, temperature and pressure of R513A refrigerant, respectively.

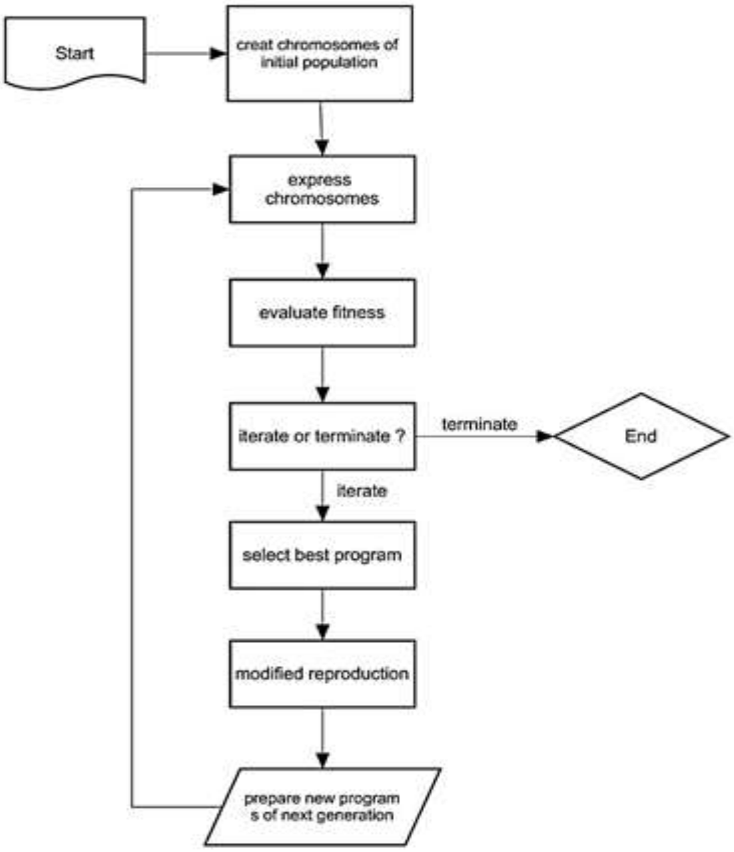

Figure 1. Scheme of GEP algorithm

2.3. Model Development

The derived models presented as non-linear mathematical expressions to predict the thermodynamic properties of R513A refrigerant using the GEP model. The best suitability GEP models chosen based on the simplicity and effectuality of the models. The different GEP model combinations developed according to the trial-and-error approach. The structure and parameter settings in all GEPs are shown in Table 2 and 3. The number of genes and the head size change the features of the chromosomes. As a function set, basic mathematical function employed. The mathematical expressions obtained in the GEP program specified as radians.

The sample number of the GEP algorithm for R513A saturation properties used as 121 for each property. The optimum number of gene for R513A saturation refrigerant determined as three excluding entropy vapor. This number for entropy vapor defined as four.

For the number of training and testing of R513A superheated vapor used 2337 samples for each of enthalpy, entropy and density properties. The optimum number of genes for GEP models of superheated vapor R513A thermodynamic values determined as four for all the situations.

Table 2. The parameters of the GEP algorithm R513A saturation properties

Parameters of GEP models	R513A_sat							
	h_f	h_v	s_f	s_v	ρ_f	ρ_v	P_f	P_v
Number of training and testing samples	121	121	121	121	121	121	121	121
Number of generations	1965	4890	2962	37575	4877	12720	14716	40914
Number of chromosomes	30	30	30	30	30	30	30	30
Number of genes	3	3	3	4	3	3	3	3
Head size	7	7	7	7	7	7	7	7
Linking function	Addition	Addition	Addition	Addition	Addition	Addition	Addition	Addition
Mutation	0.00138	0.00138	0.00138	0.00138	0.00138	0.00138	0.00138	0.00138
Inversion	0.00546	0.00546	0.00546	0.00546	0.00546	0.00546	0.00546	0.00546
One-point recombination	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277
Two-point recombination	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277
Gene recombination	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277
Gene transposition	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277	0.00277
Function set	+, –, *, /, exp, 1/x , x^2, x^(1/3), tanh	+, –, *, $10^χ$, √ , log, x^2, x^(1/3), sinh, cosh, tanh	+ , – , * , / , x^y, exp , ln, log, x^2	+ , – , * , / , $10^χ$, exp , ln, -x , x^2 , x^(1/3), tanh,arctan, (1-x)	+, –, *, /, ln, 1/x , x^2, arctan , tanh	+ , – , *, exp, x^2, x^(1/3), (1-x)	+, –, *, -x, (1-x), x^(1/3),	+, –, *, exp, $10^χ$, 1/x , ln, x^(1/3),(1-x)

Table 3. The parameters of the GEP algorithm R513A superheated vapor properties

Parameters of GEP models	R513 superheated vapor		
	h	s	ρ
Number of training and testing samples	2337	2337	2337
Number of generations	14871	6305	3568
Number of chromosomes	30	30	30
Number of genes	4	4	4
Head size	7	7	7
Linking function	Addition	Addition	Addition
Mutation	0.00138	0.00138	0.00138
Inversion	0.00546	0.00546	0.00546
One-point recombination	0.00277	0.00277	0.00277
Two-point recombination	0.00277	0.00277	0.00277
Gene combination	0.00277	0.00277	0.00277
Gene transposition	0.00277	0.00277	0.00277
Function set	+, –, *,√ , 1/x, x^2, x^(1/3), arctan, tanh	–, *, /, x^y, exp, log, 1/x, -x, x^(1/3),(1-x), arctan,	+, –, *, /, $10^χ$, √ , exp, x^y, ln, (1/x), -x, x^2, arctan, tanh

To quantify the prediction performance of the proposed GEP correlations a few evaluation criteria used: the coefficient of determination (R^2), the mean absolute percentage error (MAPE) and the mean square error (MSE) given by:

$$R^2 = \left[\frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2\sum_{i=1}^{n}(y_i-\bar{y})^2}\right]^2 \tag{1}$$

$$MAPE = \left(\sum_{i=1}^{n}\left|\frac{x_i-y_i}{x_i}\right| * 100\right) \Big/ n \tag{2}$$

$$MSE = \sum_{i=1}^{n}\frac{(x_i-y_i)^2}{n} \tag{3}$$

where x_i and y_i show the measured value and predicted one; $\bar{x}$ and $\bar{y}$ indicates mean values at x_i and y_i, respectively. n shows the number of the total number of data.

3. Results and Discussion

One of the essential things in the refrigerant is their changing thermodynamic properties under different temperatures and pressure. In many engineering applications, including the design of a refrigeration system and efficiency calculations, precise knowledge of these properties required. Therefore, it is crucial to develop accurate models for estimation of these properties. This work aims to develop models based on GEP technique for prediction of thermodynamic properties of saturation and superheated vapor of R513A at different temperatures. In the present study, a databank containing about 13000 data points for R513A refrigerant collected from the literature used to develop the models. The eleven GEP correlations developed for predicting entropy, enthalpy, pressure and density, separately. The derived mathematical models were presented as non-linear equations to estimate the thermodynamic properties of R513A refrigerant using the GEP model.

A comprehensive error analysis was applied to the suggested models to guarantee their accuracy the results of all GEP models optimized through statistical measures, including R^2, MSE, and MAPE. The result showed that for thermodynamic properties index, the vast majority of data points was in the applicability domain of the models, and too much outlier didn't detect. As an exception, some deviations observed in the negative and positive end values. Generally, the mean absolute percentage error values of thermodynamic properties were within acceptable limits. The error analysis values and the proposed optimum correlations, which attained by applying the GEP model for estimation are given in Table 4 and 5. The determined GEP models can be used these mathematical expressions in their applications with similar data range.

Table 4. Mathematical expression and performance of GEP models for R513A

No	The mathematical expression of the model	R^2	MSE	MAPE
1	$\rho_f = [(-3{,}54 * 10^{-3}) * T] - 6{,}53 - tanh\left(tanh(-3{,}7 - arctan(T))\right) + 7{,}021$	0.996742472	9.93343E-05	0.667820
2	$\rho_v = exp\sqrt[3]{exp\sqrt[3]{(T-1{,}12) - \sqrt[3]{T}}} + 1 - \sqrt[3]{38{,}92 + T} + exp\sqrt[3]{exp\sqrt[3]{(T + 11{,}43) - \sqrt[3]{T}}}$	0.99955057	0.768329622	0.745921
3	$h_f = 198{,}71 + \sqrt[3]{(-0{,}11 - T^2) * (1{,}96 - 2T)} + exp\left(exp\left(\frac{\sqrt[3]{T}}{2{,}026} - 0{,}99\right)\right)$	0.999917994	0.706204802	0.314494
4	$h_v = 10^{tanh\sqrt[3]{\sqrt[3]{sinh(82{,}19-T)-3{,}17}}} + 10^{log(316{,}227+\sqrt[3]{5{,}63T})} + 54{,}43 - sinh\sqrt[3]{25{,}98 - T}$	0.998062751	2.015663042	0.269539
5	$P_f = \sqrt[3]{(1-T) + 12{,}01} + 271{,}607 + \left(\sqrt[3]{T} * (T - 17{,}06) + \sqrt[3]{T} * 1{,}34\right) + 14{,}62T$	0.999566299	187.0868948	1.856229
6	$P_v = 6{,}34T + 0{,}157T^2 + ln\left(10^{(0{,}286*exp(6{,}2)-9{,}55)}\right) + ln\left(10^{\left(3{,}24\left(T-\sqrt[3]{T}\right)\right)}\right)$	0.999189425	374.7810991	2.888494
7	$s_f = 0{,}0048(0{,}56 + T) + 0{,}979 + ln(0{,}99)$	0.999794907	1.1822E-05	0.312192
8	$s_v = arctan\left(ln\left(10^{2{,}29} + \frac{T}{5{,}11} - \sqrt[3]{T}\right)\right) + 10^{10^{-2{,}7-exp(T/15{,}748)}} + tanh\left(-exp(-2{,}98) + tanh(arctan(-6{,}35))\right) + \left(\left(1 - arctan(\sqrt[3]{T})\right) T^2 10^{-5{,}3}\right)$	0.998649257	4.44022E-07	0.031181

The proposed GEP models demonstrate satisfactory performance in estimating the enthalpy and entropy values of fluid and vapor R513A with very good mean absolute percentage error. Average of R^2 values determined as 0.99. These models proposed could be estimated and generalized in consequence of low and similar MAPE and MSE values.

The proposed GEP models demonstrated satisfactory performance in estimating the superheated vapor values of R513A with a good MAPE. The formulated in this study identified non-linear expressions get easy to determine thermodynamic properties without the need for the complex formulas and hard-to-reach data.

Table 6-9 referred some examples values of actual, GEP model, error and percentage difference for each of entropy, enthalpy, density and pressure values of saturation R513A refrigerant. As seen in the tables, the present prediction performances are close to the ideal fit of the proposed models.

Table 5. Mathematical expression and performance of GEP models for R513A superheated vapor

No	The mathematical expression of the model	R^2	MSE	MAPE
1	$\rho = \frac{1}{18{,}78 * tanh(1/P)} - 2{,}22 + arctan(\frac{265{,}364}{P-9{,}98})^{265{,}364} - \left[\left((10{,}83 * P) - (T * P)\right) * (-1{,}12 * 10^{-4})\right]$	0.98474407	64.67070923	1.712480
2	$h = arctan((T+P)^2)\, 8{,}46^2 \sqrt{8{,}46} + \left(2{,}063 + \sqrt[3]{P}\right) * arctan(-0{,}22T) + \sqrt[3]{T} + T - 1{,}17 - \frac{43{,}98}{tanh(-9{,}206P)}$	0.984716037	95.8270278	0.932260
3	$s = log\left(arctan\left(\sqrt[3]{\frac{\sqrt[3]{1{,}07^T}}{41{,}57}}\right)\right) + \sqrt[3]{exp\left(-\sqrt[3]{10{,}19 + 0{,}18P}\right)} + 1 - \frac{1}{1{,}64 + \frac{3{,}66}{P}} - \sqrt[3]{-2{,}4\sqrt[3]{\sqrt[3]{\sqrt[3]{P}}}}$	0.989533132	0.000318704	0.610156

Table 6. Some examples actual, GEP model, error and percentage difference enthalpy values for R513A saturation

Enthalpy for R513A sat								
T	**h_f**				**h_v**			
(°C)	Actual (kJ/kg)	GEP Model (kJ/kg)	Error	Percentage difference (%)	Actual (kJ/kg)	GEP Model (kJ/kg)	Error	Percentage difference (%)
-20	174.3	174.2759	0.02408	0.01382	364.9	364.1779	0.72214	0.19790
-10	187.0	186.9132	0.08679	0.04641	371.2	369.5872	1.61282	0.43449
0	200.0	199.6226	0.37739	0.18870	377.5	377.3371	0.16294	0.04316
10	213.3	213.8612	0.56120	0.26310	383.6	384.6444	1.04442	0.27227
20	227.0	227.6376	0.63762	0.28089	389.4	388.8180	0.58197	0.14945
30	241.1	241.6668	0.56678	0.23508	394.8	394.8564	0.05636	0.01428
40	255.6	256.0782	0.47822	0.18710	399.8	398.5922	1.20778	0.30210

Table 7. Some examples actual, GEP model, error and percentage difference entropy values for R513A saturation

Entropy for R513A sat								
T	s_f				s_v			
(°C)	Actual (kJ/kgK)	GEP Model (kJ/kgK)	Error	Percentage difference (%)	Actual (kJ/kgK)	GEP Model (kJ/kgK)	Error	Percentage difference (%)
-20	0.903	0.89966	0.00334	0.36988	1.656	1.655573	0.00043	0.02579
-10	0.952	0.948059	0.00394	0.41400	1.652	1.651528	0.00047	0.02860
0	1.000	0.996457	0.00354	0.35425	1.65	1.649574	0.00043	0.02582
10	1.047	1.044856	0.00214	0.20476	1.649	1.649077	0.00008	0.00468
20	1.094	1.093255	0.00075	0.06811	1.648	1.648907	0.00091	0.05504
30	1.141	1.141654	0.00065	0.05729	1.648	1.648468	0.00047	0.02843
40	1.188	1.190052	0.00205	0.17276	1.648	1.647665	0.00034	0.02034

Table 8. Some examples actual, GEP model, error and percentage difference density values for R513A saturation

Density for R513A sat								
T	ρ_f				ρ_v			
(°C)	Actual (g/m^3)	GEP Model (g/m^3)	Error	Percentage difference (%)	Actual (g/m^3)	GEP Model (g/m^3)	Error	Percentage difference (%)
-20	1.324	1.315154	0.00845	0.63812	8.220	6.90021	1.31979	16.05585
-10	1.293	1.280791	0.01171	0.90594	11.990	11.0078	0.98220	8.19183
0	1.260	1.254599	0.00540	0.42868	17.011	15.43043	1.58057	9.29144
10	1.226	1.219697	0.00620	0.50597	23.586	23.59071	0.00471	0.01997
20	1.190	1.184316	0.00558	0.46924	32.095	32.63713	0.54213	1.68915
30	1.151	1.148934	0.00237	0.20551	43.038	43.78488	0.74688	1.73540
40	1.110	1.113551	0.00385	0.34703	57.095	57.7863	0.69130	1.21080

Table 9. Some examples actual, GEP model, error and percentage difference pressure values for R513A saturation

Pressure for R513A sat								
T	P_f				P_g			
(°C)	Actual (MPa)	GEP Model (MPa)	Error	Percentage difference (%)	Actual (MPa)	GEP Model (MPa)	Error	Percentage difference (%)
-20	150.808	145.2394	5.56863	3.69253	150.337	126.0848	24.25222	16.13190
-10	223.954	216.0749	7.87906	3.51816	223.582	212.7657	10.81631	4.83774
0	321.926	274.6612	47.26477	14.68188	321.68	319.0502	2.62978	0.81752
10	449.774	433.7282	16.04582	3.56753	449.655	456.8372	7.18219	1.59727
20	612.915	582.0502	30.86476	5.03573	612.889	638.0254	25.13644	4.10130
30	817.135	760.407	56.72804	6.94231	817.132	851.9636	34.83164	4.26267
40	1068.622	1020.807	47.81534	4.47449	1068.536	1098.002	29.46601	2.75761

When the tables examined, it has seen the mean absolute percentage error values of enthalpy and entropy were gave much better results to values of density and pressure. In general, the mean absolute percentage error values of all of the thermodynamic properties gave good results. On this basis, the GEP models might be applied to formulate hard-to-reach data in thermodynamic properties of the refrigerant.

Some examples values of actual, GEP model, error and percentage difference for entropy, enthalpy, density and pressure values for superheated vapor R513A refrigerant are presented in Table 10.

Generally, the mean absolute percentage error values of thermodynamic properties have given good results. Especially, saturation values of fluids have given slightly better results by comparison with superheated vapor values.

The outcomes of this study point out that the developed models are estimating target data with acceptable accuracy—the accuracy of the models guaranteed by used different statistical techniques. Corresponding expression tree of each gene for derived GEP models are shown in Fig. 2-12.

Table 10. Some examples actual, GEP model, error and percentage difference values for R513A superheated vapor

		Enthalpy for R513A				**Entropy for R513A**				**Density for R513A**			
T (°C)	P (kPa)	Actual (kJ/kg)	GEP Model (kJ/kg)	Error	Percentage difference (%)	Actual (kJ/kgK)	GEP Model (kJ/kgK)	Error	Percentage difference (%)	Actual (kg/m^3)	GEP Model (kg/m^3)	Error	Percentage difference (%)
50	180	425.8	423.637	2.1623	0.50783	1.854	1.85693	0.00293	0.15819	7.46826	7.46723	0.0010	0.01377
50	220	425.3	423.059	2.2404	0.52680	1.838	1.83802	0.00003	0.00154	9.191176	9.20262	0.0114	0.12452
50	230	425.1	422.926	2.1738	0.51138	1.834	1.83379	0.00021	0.01120	9.624639	9.62088	0.0037	0.03906
50	240	425	422.796	2.2035	0.51848	1.831	1.82972	0.00127	0.06944	10.06036	10.03428	0.0260	0.25926
100	425	471.9	471.401	0.4983	0.10560	1.923	1.92406	0.00106	0.05536	15.45595	15.76159	0.3056	1.97751
150	2400	509.5	512.885	3.3850	0.66439	1.896	1.91093	0.01493	0.78758	86.95652	87.44684	0.4903	0.56387
150	2600	507.7	512.327	4.6270	0.91137	1.887	1.90632	0.01933	1.02435	95.2381	94.96692	0.2711	0.28474

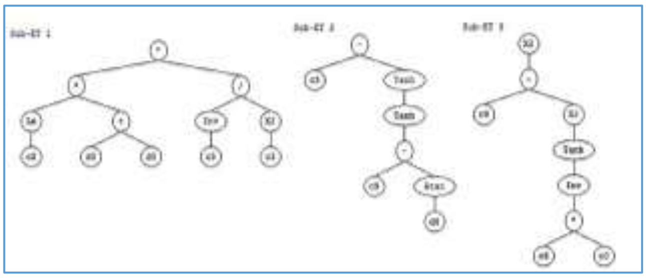

Figure 2. Expression tree of saturation R513A density fluid

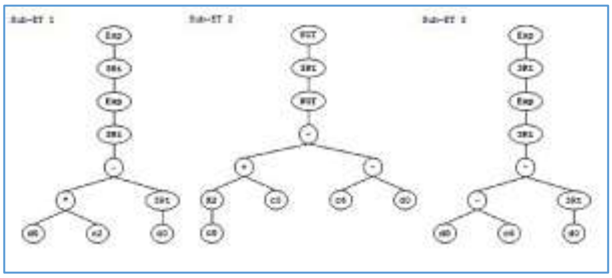

Figure 3. Expression tree of saturation R513A density vapor

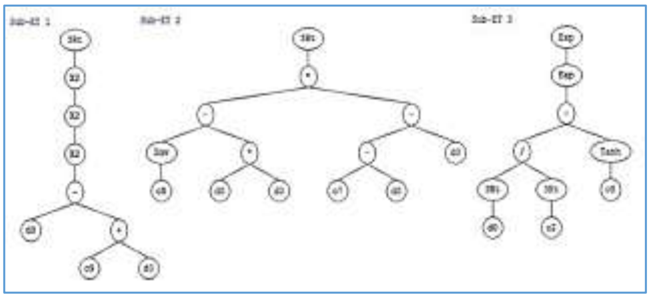

Figure 4. Expression tree of saturation R513A enthalpy fluid

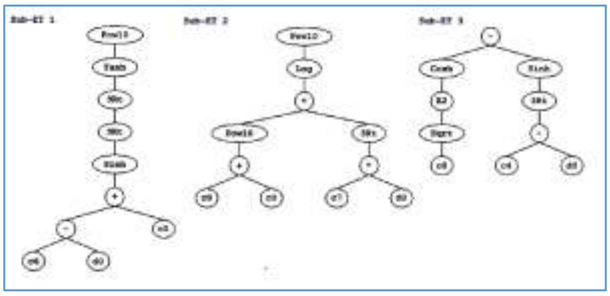

Figure 5. Expression tree of saturation R513A enthalpy vapor

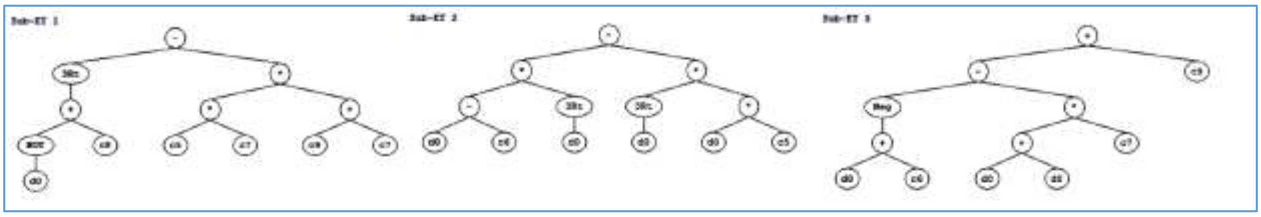

Figure 6. Expression tree of saturation R513A pressure fluid

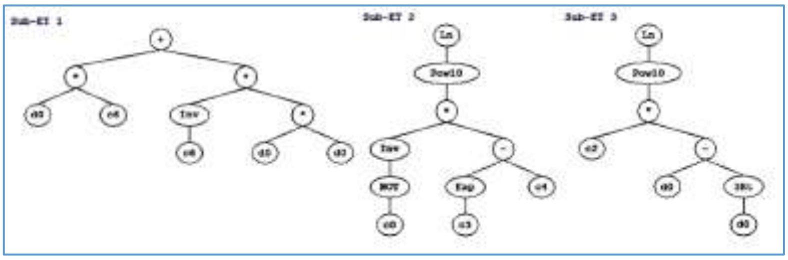

Figure 7. Expression tree of saturation R513A pressure vapor

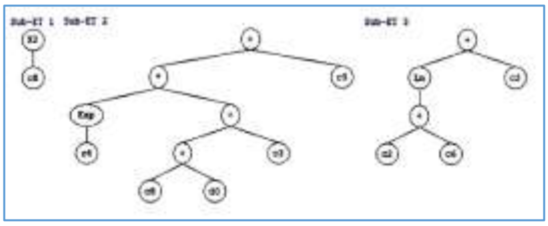

Figure 8. Expression tree of saturation R513A entropy fluid

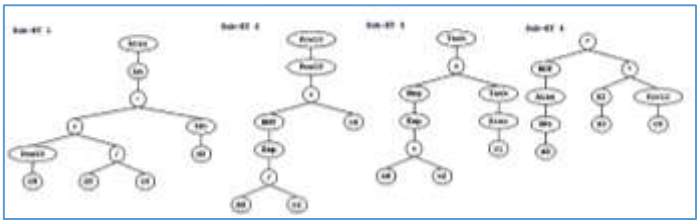

Figure 9. Expression tree of saturation R513A entropy vapor

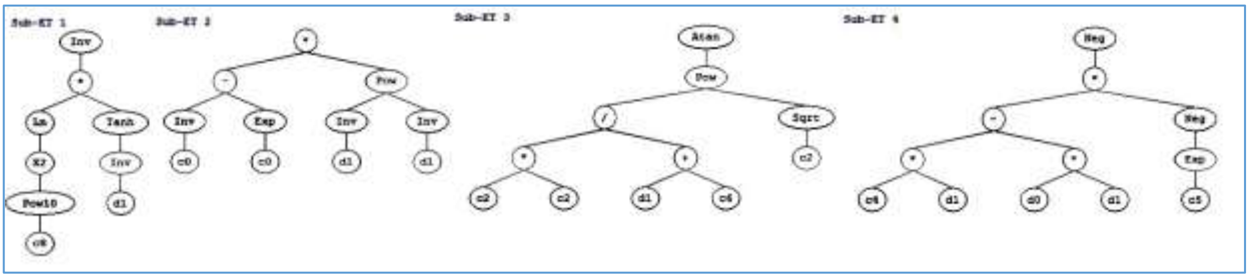

Figure 10. Expression tree of superheated vapor R513A density

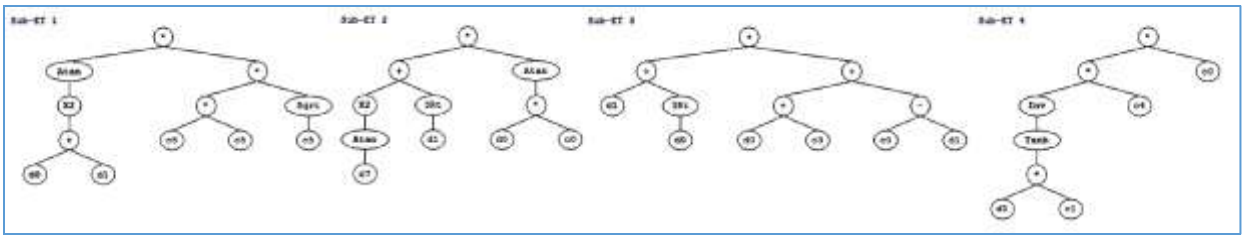

Figure 11. Expression tree of superheated vapor R513A enthalpy

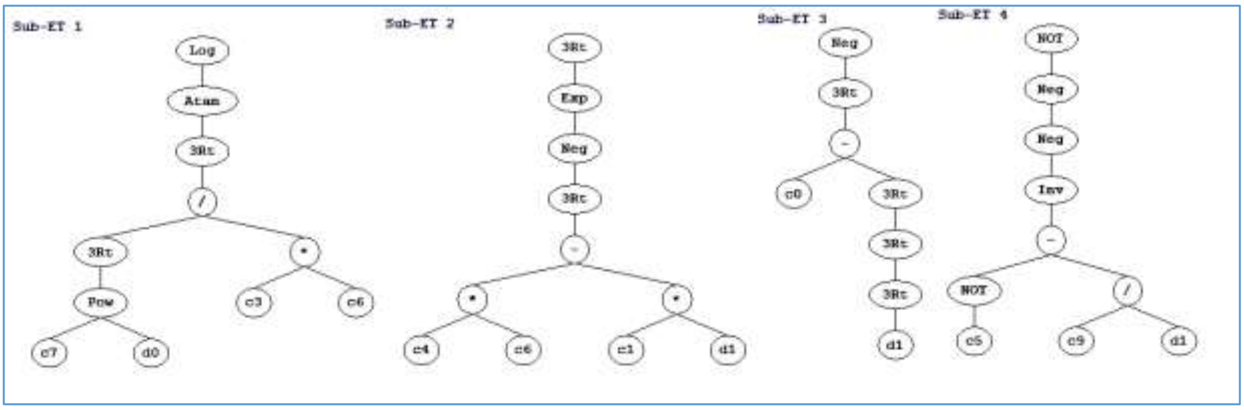

Figure 12. Expression tree of superheated vapor R513A entropy

The results have shown that the GEP model could be considered as an efficient modelling technique for the estimate of thermodynamic properties of refrigerants. Results of this study could be used in areas where you need to quick and accurate estimation of thermodynamic properties of R513A is required.

4. Conclusion

It is essential the properties of refrigerant are determined. In this study, gene expression programming applied to mathematical expression development in an attempt to predict saturation and superheated vapor thermodynamic properties of R513A refrigerant. The determined mathematical expressions are both accurate and straightforward, and they can be effectively used for a wide range when there is a need. In this manner, the thermodynamic analysis has got easy without the need to complex formulas through these determined mathematical expressions.

GEP that used as a tool to find the mathematical equation predicting thermodynamic properties of this refrigerant could be used as an alternative approach for the evaluation of these properties prediction. Using the GEP models for this purpose can assist in obtaining difficult-to-reach refrigerant data.

References

[1]. Calm, J.M.; Hourahan, G., Refrigerant data update, Hpac Engineering, 2007, 79(1): 50-64.

[2]. Calm, J.M., The next generation of refrigerants – Historical review, considerations, and outlook, International Journal of Refrigeration, 2008, 31(7): 1123-1133. doi:10.1016/j.ijrefrig.2008.01.013

[3]. Mohanraj, M.; Jayaraj, S.; Muraleedharan, C., Environment friendly alternatives to halogenated refrigerants—A review, International Journal of Greenhouse Gas Control, 2009, 3(1): 108-119. doi:https://doi.org/10.1016/j.ijggc.2008.07.003

[4]. Sun, J.; Li, W.; Cui, B., Energy and exergy analyses of R513a as a R134a drop-in replacement in a vapor compression refrigeration system, International Journal of Refrigeration, 2020, 112: 348-356. doi:https://doi.org/10.1016/j.ijrefrig.2019.12.014

[5]. Devecioğlu, A.G.; Oruç, V., Characteristics of Some New Generation Refrigerants with Low GWP, Energy Procedia, 2015, 75: 1452-1457. doi:10.1016/j.egypro.2015.07.258

[6]. Dey, P.; Sarkar, A.; Das, A.K., Development of GEP and ANN model to predict the unsteady forced convection over a cylinder, Neural Computing and Applications, 2015, 27(8): 2537-2549. doi:10.1007/s00521-015-2023-8

[7]. Mota-Babiloni, A.; Makhnatch, P.; Khodabandeh, R.; Navarro-Esbrí, J., Experimental assessment of R134a and its lower GWP alternative R513A, International Journal of Refrigeration, 2017, 74: 682-688. doi:10.1016/j.ijrefrig.2016.11.021
[8]. Yıldırım, R.; Yıldız, A., Evaluation of Performance of HFC-R134a/HFO-1234yf Binary Mixtures Used as Refrigerant in a Heat Pump System, El-Cezeri Journal of Science and Engineering (ECJSE), 2020, 7 (3): 1440-1449. doi: 10.31202/ecjse.734445
[9]. Su, W.; Zhou, S.; Zhao, L.; Zhou, N., Vapor–Liquid Equilibrium Prediction of Refrigerant Mixtures with Peng–Robinson Equation of State and Binary Interaction Parameters Calculated Through Group Contribution Model, International Journal of Thermophysics, 2020, 41(2): 1-24.
[10]. Dikmen, E.; Şencan Şahin, A.; Deveci, Ö.; Akdağ, E., GWP Değeri Düşük Soğutucu Akışkanların Kullanıldığı Kaskad Soğutma Sisteminin Karşılaştırmalı Performans Analizi, El-Cezeri Journal of Science and Engineering (ECJSE), 2020, 7 (1): 338-345. doi: 10.31202/ ecjse.630262
[11]. Hamza, A.; Khan, T.A., Comparative Performance of Low-GWP Refrigerants as Substitutes for R134a in a Vapor Compression Refrigeration System, Arabian Journal for Science and Engineering, 2020, 45: 5697-5712. doi:10.1007/s13369-020-04525-3
[12]. Özen, D.; Yağcıoğlu, K., Thermodynamic and Exergy Analysis of an Absorption Cooling System for Different Refrigerants, El-Cezeri Journal of Science and Engineering (ECJSE), 2020, 7(1): 93-103. doi: 10.31202/ecjse.594641
[13]. Chemours Company: https://www.chemours.com/Refrigerants. 2017.
[14]. Harasami, F.; Akhgar, S.; Javan, M.; Shiri, J., Investigating the effect of previous time on modeling stage–discharge curve at hydrometric stations using GEP and NN models, ISH Journal of Hydraulic Engineering, 2017, 23(3): 293-300. doi:10.1080/09715010.2017.1308278
[15]. Kaboli, S.H.A.; Fallahpour, A.; Selvaraj, J.; Rahim, N.A., Long-term electrical energy consumption formulating and forecasting via optimized gene expression programming, Energy, 2017, 126: 144-164. doi:10.1016/j.energy.2017.03.009
[16]. Sharifi, S.S.; Rezaverdinejad, V.; Nourani, V., Estimation of daily global solar radiation using wavelet regression, ANN, GEP and empirical models: A comparative study of selected temperature-based approaches, Journal of Atmospheric and Solar-Terrestrial Physics, 2016, 149: 131-145. doi:10.1016/j.jastp.2016.10.008
[17]. Najafi-Marghmaleki, A.; Tatar, A.; Barati-Harooni, A.; Mohammadi, A.H., A GEP based model for prediction of densities of ionic liquids, Journal of Molecular Liquids, 2017, 227: 373-385. doi:10.1016/j.molliq.2016.11.072
[18]. Dikmen, E.; Ayaz, M.; Gül, D.; Şencan Şahin, A., Gene expression programming approach for the estimation of moisture ratio in herbal plants drying with vacuum heat pump dryer, Heat Mass Transfer, 2016, 53: 2419–2424. doi:10.1007/s00231-017-1998-3
[19]. Kaya, H., Paralel Bağlı Vorteks Tüplerinin Performansı için Yapay Sinir Ağları Analizi, El-Cezeri Journal of Science and Engineering (ECJSE), 2020, 7(3): 1509-1517. doi.org/10.31202/ecjse.774448
[20]. Sattar, A.M.A.; Gharabaghi, B., Gene expression models for prediction of longitudinal dispersion coefficient in streams, Journal of Hydrology, 2015, 524: 587-596. doi:10.1016/j.jhydrol.2015.03.016
[21]. Ferreira, C., Gene expression programming: A new adaptive algorithm for solving problems, Complex Systems, 2001, 13(2): 87-129.

[22]. Hoseinian, F.S.; Faradonbeh, R.S.; Abdollahzadeh, A.; Rezai, B.; Soltani-Mohammadi, S., Semi-autogenous mill power model development using gene expression programming, Powder Technology, 2017, 308: 61-69. doi:10.1016/j.powtec.2016.11.045

[23]. Mesbah, M.; Soroush, E.; Rostampour Kakroudi, M., Predicting physical properties (viscosity, density, and refractive index) of ternary systems containing 1-octyl-3-methyl-imidazolium bis (trifluoromethylsulfonyl) imide, esters and alcohols at 298.15 K and atmospheric pressure, using rigorous classification techniques, Journal of Molecular Liquids, 2017, 225: 778-787. doi:10.1016/j.molliq.2016.11.004