OPTIMIZATION OF PROCESS PARAMETERS OF REFRIGERATION PROCESS FOR A REFRIGERANT MIXTURE

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This study optimizes refrigeration process parameters for a new refrigerant mixture. Grey relational analysis has been used to find the best process parameters that lead to a higher Coefficient of Performance and lower Compressor discharge temperature, lower Compressor Power, and lower Mass flow rate. A mixture of R152a-R290-R600-R600a is proposed as a refrigerant. The predicted results have been checked with confirmation tests. The results of the confirmation test are the same as the results that were predicted.

Keywords: Optimization; refrigeration process; Coefficient of Performance; Grey Analysis

1. Introduction

Since it was developed about thirty years ago, the Taguchi technique has been utilized in the manufacturing industry to reliably design a product or process with a single quality feature. The Taguchi method has been utilized with great success in the machining and manufacturing industries [1, 2]. In 1982, Dr. Deng put out the idea of using grey analysis as a means of satisfying the mathematical requirements for insufficient, uncertain, and incomplete systems. As its name suggests, grey analysis can optimize the complicated interactions that exist between numerous performance indicators [3], [4]. Vapour compression is the most common refrigeration and airconditioning cycle. Compressor, Condenser, Expansion, and Evaporation complete the vapour compression refrigeration cycle. A refrigerant-based vapour compression refrigeration system improves air refrigeration [17]. It does so near the pressure and temperature of the atmosphere, where it then evaporates. It is considered to be a vapour compression refrigeration system since the evaporator produces low-pressure vapour refrigerant, which is then converted by the compressor into high-pressure refrigerant. Research has been done using a variety of parameters to investigate the performance of the vapour compression refrigeration cycle. The performance of the vapour compression refrigeration cycle is significantly influenced more by the refrigerants. Both heat pumps and refrigeration cycles need the usage of refrigerants, which are typically fluids but can undergo phase transitions at low temperatures. The phase shift from liquid to gas and back again is included in most cycles. For this purpose, a great variety of working fluids are utilized. The choice of refrigerant is completely random. Thermophysical, technological, economic, and environmental issues, together with safety considerations, are what define it [5, 6, 7]. Refrigerants containing chlorofluorocarbons (CFCS) and hydro chlorofluorocarbons (HCFCS) are being phased out in favor of hydrofluorocarbons (HFCS) as a result of rising environmental concerns regarding the depletion of the stratospheric ozone layer and the acceleration of climate change. Due to their different thermo-physical properties, new alternative refrigerants require new refrigeration systems. maintain or improve cycle performance [8], [9], [10]. CFC and HCFC are being phased out of refrigeration due to environmental concerns about ozone depletion and global warming. HFC, HC, and HFC mixtures have replaced R-12 and R-22 [11]. The sun's harmful ultra-violet radiation is blocked by the earth's thin ozone layer. Conventional refrigerants deplete ozone in the upper atmosphere due to chlorine. This increases ultraviolet radiation reaching Earth's surface, causing skin cancer, cataracts, and immune system damage [14].

2. Experimental Apparatus

Figure. 1. Experimental test facility

Figure 1 displays a window air conditioner as well as an environmental chamber. Indoor and outdoor chambers meet BIS: 1391-1992a. The inside space is warmed by a heater with a capacity of 2500 W. Watt meters have an accuracy of 0.5% for measuring a power source. The temperature in the room is kept stable by the fan circulation. The amount of heat that can penetrate panels insulated with PUF is capped at 5% of their capacity. The heat from the condenser is removed by a 2 TR split air conditioner, which then cools the outside chambers. Humidifiers keep chambers humid. The amount of Coriolis refrigerant that flows through mass flow meters is measured. Compressor power is measured by a digital Watt meter with an accuracy of 0.5%. Thermocouples of the J-type are used to monitor temperatures, whereas pressure transducers are used to measure pressures of refrigerants. ALL humidity sensors are linked together through nimble computerized data gathering.

2.1 Grey Analysis

The concept of grey analysis was initially introduced many decades ago, but it has only just begun to see widespread application. Evaluation of complicated projects with insufficient data can be accomplished through the use of grey analysis. In order to prepare the raw data for a subsequent analysis, grey analysis demands that the data be preprocessed into quantitative indices.

2.2 Grey Relational Coefficient and Grade Calculation

In grey relational analysis, grey relational generation normalizes experimental outcomes between 0 and 1. Grey relational analysis looks at correlations between variables. The next step is to calculate the grey relational coefficient by making use of the outcomes of the experiments that have been normalized. This will demonstrate the relationship between the results that were desired and the results that were actually achieved. The calculation for the grey relational grade involves taking the coefficients for each performance attribute and averaging them out. The grey relational grades are used to evaluate a number of different performance aspects. The performance characteristic optimization is made easier to understand thanks to these techniques, which focus on the gray relational grade. The parameters of the process that have the highest grey relational grade are the ones that should be used.

ANOVA is used to identify statistically significant process parameters. GRA and ANOVA could predict the optimal process parameter combination.

3. Result and discussion

3.1 Data preprocessing

Several distinct sequence formats are utilized throughout the grey relational analysis process. The arrangement of the data obtained from an experiment is what constitutes a sequence. The sequence that is used for reference is referred to as the reference sequence. The reference sequence consists of the maximum coefficient of performance, the minimum compressor discharge temperature, the maximum compressor power, the minimum mass flow rate, and the minimum pressure ratio. In the vast majority of situations, the number 1 is considered to be the point at which the reference sequence gets underway. When conducting grey relational analysis, the initial step is to preprocess the data. In this stage, we will attempt to normalize the raw data so that it may be evaluated in the most efficient manner possible. Because the range and unit of one data collection could be different from those of other data sets, preprocessing of the data is often required in order to account for this possibility. Data preprocessing is required whenever the sequence scatter range is excessively vast, or whenever the directions of the target in the sequence are distinct from one another. Data preparation is the process of transforming the initial sequence into a sequence that is comparable to other sequences. This process is called data normalization. The sequence that is used to compare one set of data with another is referred to as a comparable sequence. In most cases, what people mean when they talk about comparable sequence is the normalised value of the data.

Tables 1 and 2 display the S/N ratio and normalised results for the Coefficient of Performance and Compressor discharge temperature, Compressor power, Mass flow rate, and Pressure ratio, respectively, after undergoing preliminary data processing.

The best normalised results should be equal to one, and the larger normalised results correspond to better performance.

Table 1. S/N ratio for experimental results of performance Characteristic

COP	Tdc	CP	MFR	PR
11.032	-36.765	0.156	36.473	-10.732
11.081	-36.823	0.201	36.356	-10.577
11.054	-37.046	0.212	36.245	-10.446
11.134	-37.287	0.221	36.125	-10.317
11.135	-37.439	0.228	36.012	-10.153
11.356	-36.232	0.456	37.985	-11.413
11.376	-36.411	0.492	37.904	-11.245
11.387	-36.657	0.517	37.814	-11.101

11.456	-36.878	0.538	37.727	-10.932
11.445	-37.040	0.564	37.634	-10.805
11.351	-35.665	0.465	38.124	-11.753
11.386	-35.875	0.502	38.047	-11.595
11.421	-36.084	0.538	37.973	-11.412
11.452	-36.283	0.575	37.891	-11.271
11.482	-36.482	0.603	37.807	-11.103
10.783	-36.123	-0.094	37.254	-9.965
10.795	-36.324	-0.085	37.134	-9.828
10.795	-36.534	-0.085	37.004	-9.687
10.793	-36.738	-0.085	36.868	-9.572
10.783	-36.937	-0.095	36.723	-9.425
11.135	-36.953	0.254	36.161	-10.882
11.158	-37.125	0.273	36.053	-10.732
11.175	-37.304	0.292	35.938	-10.577
11.192	-37.467	0.308	35.825	-10.424
11.202	-37.638	0.317	35.702	-10.264

Table 2 Normalization of the experimental results of performance Characteristics

COP	Tdc	CP	MFR	PR
0.390	0.503	0.410	0.348	0.473
0.414	0.413	0.436	0.298	0.538
0.434	0.316	0.449	0.248	0.593
0.448	0.213	0.462	0.195	0.648
0.459	0.116	0.474	0.143	0.714
0.786	0.716	0.795	0.950	0.165
0.831	0.626	0.846	0.920	0.242
0.872	0.529	0.885	0.887	0.308
0.910	0.432	0.910	0.855	0.385
0.945	0.329	0.949	0.820	0.440
0.803	1.000	0.808	1.000	0.000
0.855	0.903	0.859	0.972	0.077
0.907	0.806	0.910	0.945	0.165

0.955	0.710	0.962	0.915	0.231
1.000	0.613	1.000	0.885	0.308
0.003	0.787	0.000	0.674	0.791
0.014	0.690	0.013	0.624	0.846
0.014	0.587	0.013	0.571	0.901
0.010	0.484	0.013	0.516	0.945
0.000	0.381	0.000	0.456	1.000
0.493	0.374	0.513	0.211	0.407
0.524	0.284	0.538	0.163	0.473
0.548	0.187	0.564	0.110	0.538
0.572	0.097	0.590	0.058	0.604
0.586	0.000	0.603	0.000	0.659

3.2 Grey Relational Coefficient and Grey Relational Grade

A grey relational coefficient is generated after the data have been preprocessed in order to express the relationship between the ideal and real normalized experimental outcomes. The following is an expression that can be used for the grey relational coefficient:

$$\varepsilon_{ij} = \frac{min_i min_j \left|x_i^o - x_{ij}\right| + \varsigma max_i max_j \left|x_j^o - x_{ij}\right|}{\left|x_i^o - x_{ij}\right| + \varsigma max_i max_j \left|x_i^o - x_{ij}\right|} \quad (1)$$

$$= \frac{\Delta_{min} + \varsigma\Delta_{max}}{\left|x_i^o - x_{ij}\right| + \varsigma\Delta_{max}} \quad (2)$$

where xi^o is the ideal normalized results for the i^{th} performance characteristics
and V is the distinguishing coefficient, which is defined in the range
0 £ V ³1.

Since there are too many relational coefficients to compare directly, further data reduction employs average-value processing to transform each sequence into its mean. Mean is also referred to as the relational grade.grey relational analysis formation equation mentioned in equation 3.

$$a_j = \frac{1}{n}\sum_{i=1}^{n} \xi_{ij} \tag{3}$$

where j represents the grey relational grade for the jth experiment, and N represents the total number of performance attributes.

In this particular instance, the grey relational grade is used to indicate the degree of correlation that exists between the reference sequence and the comparability sequence.

The L25 orthogonal array grey relational grades for each trial are presented in Table 3. When the grey relational grade is greater, it implies that the experimental result is closer to the ideal normalised value. Experiment number 15, which received the highest grey relational grade, possesses the many performance qualities that are superior to those of the other 25 experiments.

Table 3 Grey Relational Coefficient & GRG for output responses

COP	**Tdc**	**CP**	**MFR**	**PR**	**GRG**
0.450	0.502	0.459	0.434	0.487	0.460
0.460	0.460	0.470	0.416	0.520	0.465
0.469	0.422	0.476	0.399	0.552	0.468
0.475	0.388	0.481	0.383	0.587	0.470
0.480	0.361	0.488	0.368	0.636	0.475
0.700	0.638	0.709	0.909	0.374	0.685
0.747	0.572	0.765	0.862	0.397	0.711
0.797	0.515	0.813	0.816	0.419	0.737
0.848	0.468	0.848	0.775	0.448	0.763
0.901	0.427	0.907	0.735	0.472	0.796
0.718	1.000	0.722	1.000	0.333	0.737
0.775	0.838	0.780	0.948	0.351	0.758
0.843	0.721	0.848	0.901	0.374	0.791
0.918	0.633	0.929	0.854	0.394	0.834
1.000	0.564	1.000	0.813	0.419	0.880
0.334	0.701	0.333	0.605	0.705	0.435
0.336	0.618	0.336	0.571	0.765	0.431
0.336	0.548	0.336	0.538	0.835	0.428

0.336	0.492	0.336	0.508	0.901	0.425
0.333	0.447	0.333	0.479	1.000	0.426
0.497	0.444	0.506	0.388	0.457	0.479
0.512	0.411	0.520	0.374	0.487	0.488
0.525	0.381	0.534	0.360	0.520	0.496
0.539	0.356	0.549	0.347	0.558	0.507
0.547	0.333	0.557	0.333	0.595	0.512

3.3 Analysis of Results using Response Table and Response Graph

Different processing parameters' effects on grey relation quality can be isolated using an orthogonal design of experiments. The mean grey relational grade can be determined for refrigerant levels one, two, three, four, and five by taking the average of the grades obtained in the experiments numbered one through five, six through ten, eleven through fifteen, and twenty-one through twenty-five (Table 3). The mean of the grey relational grade can be derived in a similar fashion for each processing parameter (evaporator temperature and condenser temperature). In addition, the overall mean for the grey relationship grade is presented in table 4.

Table 4 Response table for the grey relational grade

Input parameter	**Grey relational grade**				
	Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Refrigerant	0.4670	0.738	0.799	0.4288	0.4967
Evaporator temperature (Te)	0.5591	0.507	0.842	0.5998	0.6177
Condenser temperature (Tc)	0.6010	0.590	0.567	0.58268	0.5877
Total mean of the grey relational grade = 0.587					

The impacts of the input parameters are shown in grey relational grade graphs. The progression of the factor from level 1 to level 5 is depicted in the grey relational grade graph as a change in the response. Both the response graph and table illustrate the best possible values for the operational parameters. Figure 2 presents a graph illustrating the grey relationship grade.

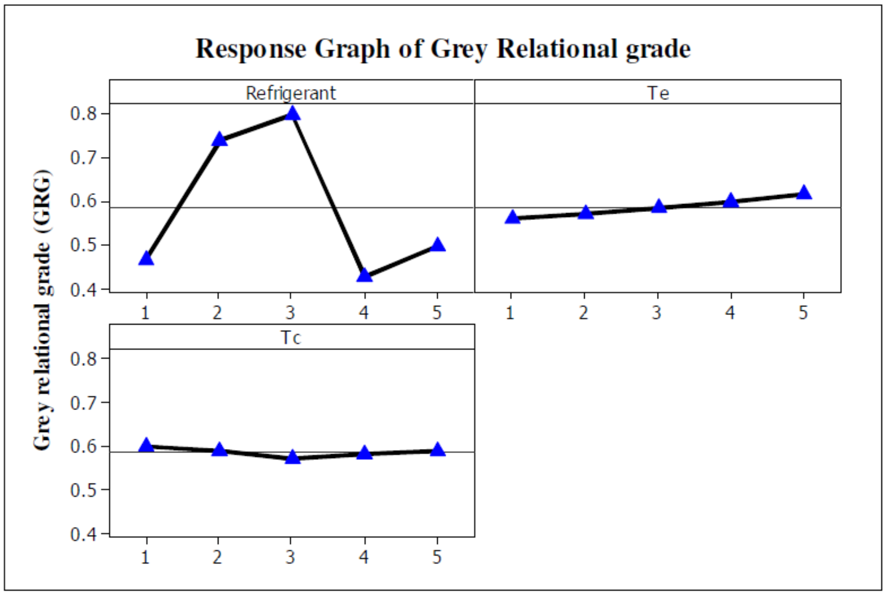

Figure 2. Grey relational grade graph

3.4 Analysis of Results using Statistical Analysis of Variance

The purpose of the analysis of variance (ANOVA) is to conduct research into the input parameters of a process to determine which ones have a significant influence on the performance characteristics of that process. This is achieved by dividing the overall variability of the grey relational grades, which is calculated as the sum of the squared deviations from the overall mean of the grey relational grade, into the contributions made by each input parameter as well as the error. The overall variability of the grey relational grades is determined by the sum of the squared deviations from the overall mean of the grey relational grade. Because of this, it is possible to obtain reliable measurements of the overall variability of the grey relational grades.

The overall sum of the squares, denoted by SS(t), can be disassembled into its component pieces, which are known as the sum of the squared deviations owing to each input parameter and the sum of the squared error, respectively. It is possible to use the percentage contribution made by each input parameter to the total sum of the squared deviation SS(t) in order to evaluate the significance of the influence that a change in input parameter has on performance characteristic. This evaluation may be done in order to determine whether or not a change in input parameter has a positive or negative impact. In addition, the Fisher's F test can be used to determine whether input factors have a significant impact on the performance characteristic that is being analysed. This is one more application of the test that has been developed by Fisher. In a situation that is more usual, the performance characteristic will be significantly influenced by the change in the input parameter if F is a value that is quite high. Table 5 provides a summary of the results of the analysis of variance performed on performance characteristics.

Table 5. Results of ANOVA

Parameters	Degree of freedom	Sum of square	Mean square	F	Contribution (%)
Refrigerant	4	0.5785	0.1446	209.47	96.5
Te	4	0.0107	0.0026	3.88	1.69
Tc	4	0.0026	0.0006	0.94	0.43
Error	12	0.0082	0.0006		1.38
Total	24	06001			100

ANOVA shows that refrigerant is the most important parameter, affecting performance most.

3.5 Validation Tests

The third step, which comes after determining the best level, consists of predicting and verifying the performance improvement of air conditioners with a capacity of 1 TR compared to the initial parameter setting. It is vital to complete the parameter design by performing a validation test. The predicted mean grey relational grade is computed using this expression when the following conditions are optimal:

$$\hat{\eta} = \eta_m + \sum_{i=1}^{n} (\overline{\eta}_i - \eta_m)$$

where η_m	- total mean of the grey relational grade,
$\overline{\eta}$	- mean grey relational grade corresponding to ith significant factor on the jth level in Table 4
n	- number of significant factors that affect the multiple performance characteristic

The expected mean at the optimal settings is found to be 0.845

Table 6 compares the predicted and actual performance of 1 TR capacity air conditioners for multiple performance characteristics using optimal process parameters.

Table 6 Improvement in grey relational grade after the validation Experiment

	Initial process parameters	Optimal process parameters	
		Prediction	**Experimental**
Setting level	A1B1C1	A3B5C1	
Coefficient of Performance	3.574	-	3.75.
Compressor discharge temperature	68.4	--	65.7
Compressor Power	0.979	--	0.931
Mass flow rate	0.01501	-	0.01268
Pressure ratio	3.	-	3.55
Grey relational Grade	0.460	0.845	0.892
Improvement in grey relational grade: 0.431			

According to the confirmation experiment, the optimal parameters are refrigerant at level 3, evaporator temperature at level 5, and condenser temperature at level 1. The confirmation experiment results at the optimal level (A3B5C1) show that Coefficient of Performance is improved from 3.574 to 3.750, compressor discharge temperature is decreased from 68.4°C to 65.7°C, compressor power is reduced from 0.979 to 0.931, mass flow rate is decreased to 0.01268 from 0.01501, and pressure ratio is slightly increased from 3.44 to 3.55. This optimization technique clearly improves the 1 TR capacity air conditioner system's multiple performance characteristics.

4. CONCLUSION

Process parameters that lead to a higher Coefficient of Performance and lower Compressor discharge temperature, lower Compressor Power, and lower Mass flow rate is predicted. The predicted results have been checked with confirmation tests. The results of the confirmation test are the same as the results that were predicted. The confirmation result shows that the grey relational grade has gotten a lot better for the 1 TR air conditioning process. The analysis of variance showed that Refrigerant is the most important parameter for improving the process's multiple performance characteristics. The temperature of the evaporator and the temperature of the condenser have less of an effect on the output responses. The best conditions found in this study will help to improve the process of cooling 1 TR of space.

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Received date: 05-10-2022

Revised date: 01-07-2023

Accepted date: 25-08-2023