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Experimental Investigation on use of Molecular Sieve4A as Desiccant in Heatless Desiccant Air Dryer

A.J. D'souza
Gujarat Technological University, Ahmedabad

P. K. Brahmbhatt
Government Engineering College, Dahod

Corresponding Author A.J. D'souza.

Abstract

Many applications, such as power tools such as air hammers, drills, and wrenches, pneumatic machine operations, painting, coating, moulding, and sandblasting, require dry compressed air. Moisture in compressed air, even in little amounts, can cause damage to the final products. As a result, removing moisture from compressed air is particularly desirable. A heatless desiccant air dryer can be used to accomplish this. The usage of solid desiccant molecular sieve 4A in a heatless air dryer with a capacity of 10 CFM is investigated in this research. The efficiency and rate of moisture removal were found to be 81% and 39.58 gm/hour respectively. With the use of neural designer, a neural network created artificially was utilized to forecast the dew point temperature in a heatless air dryer over a longer period of time. The heat generated throughout the packed bed during the adsorption process was also investigated. Because the changeover cycle duration was kept low, there was no need to cool the bed externally.

Introduction

The use of traditional vapour compression air conditioning systems has been linked to major environmental issues such as greenhouse gas emissions, ozone layer depletion, and global warming. Desiccant-based air conditioning technology can be seen as a promising environment-friendly and green technology solution to lessen the negative environmental consequences of typical air-cooling systems. Zero ozone depletion potential (ODP) and global warming potential (GWP) are achieved using desiccant-based cooling systems. A 13 percent reduction in carbon dioxide emissions was recorded in a comparison study between the vapour compression system and desiccant-based cooling technology. Considering desiccant-based cooling is a thermally heat-driven system, it enables the use of low-grade waste heat and renewable energy sources such as solar energy. [1]. Desiccant based dehumidification has huge potential as air dehumidification is a crucial aspect for increasing durability of products because dry air is used for improving the process, product or conditions in large industries such as food production, pharmaceutical production, industrial chemicals production etc. It is also required in goods storage, packaging equipment rooms, organic plant, inorganic products and hygroscopic raw materials storage. Many pneumatic applications require dry compressed air to perform various mechanical functions. [2]. Compressors are frequently utilized in pneumatics for a variety of applications. They compress atmospheric air or gas, which consists of saturated water droplets. Instrumentation, air system infrastructure, and the ultimate product could be damaged by these concentrated water droplets in their saturated state.[1]. As a result, moisture-free compressed air is preferred. Air dryers are one of the methods for removing moisture from compressed air. The needed dewpoint, or the temperature at which air will saturate with moisture, is used to build compressed air dryers. Condensation is inevitable when the temperature of the air falls below or equals the dewpoint. It's been proposed that when the dewpoint drops, so does the amount of moisture in the air. [2]. An air dryer's primary function is to remove moisture from compressed air. Refrigeration, regenerative, deliquescent, and membrane air dryers are broadly classified on the basis of the integration of the technology used to achieve moisture removal [2]. The high-temperature compressed air passes through the refrigerant drier, where it is cooled. The saturated water droplets condense when the temperature drops, and they are subsequently evacuated from the compressed air drier. However, the dewpoint temperature of this dryer is restricted to a maximum of +2°C [3]. Desiccant dryers can thus be used in applications where the dew point temperature is typically between -40°C and -100°C [3]. Single tower deliquescent and twin tower regenerative desiccant dryers are two types of desiccant dryers. The following are the several types of twin tower regenerative closed loop desiccant dryers: Blower Heater Non-Purge (BHNP) with/without water cooling pumps, Compressed air Heater Purge (CHP), Blower Heater Purge (BHP), and Pressure Swing Heater-less (PSH) are all often employed in industries that demand extremely dry air in the -40°C to -100°C pressure dew point range. Sensitive electronics, food production, pharmaceuticals, and hospital surgical air all need this exceedingly dry air [1]. The regeneration process employed to replenish the saturated desiccants is what sets these dryers apart. For moisture removal, methods include using selective additional equipment such as a blower, heater, purged compressed air, or a combination of these equipment. Twin tower regenerative desiccant dryers have two identical towers loaded with solid adsorbents, as the name implies. The first tower is filled with moisture-laden compressed air, which is absorbed by the solid adsorbents. The moisture-laden compressed air is diverted to the second tower once the first tower hits saturation, while the first tower regenerates. This cycle produces dry compressed air.[1].To lower the moisture content of compressed air, heatless air dryers use solid adsorbents in the form of granules such as silica gel, activated alumina, and zeolites (molecular sieve). [4][5]

Solid and liquid desiccants are the most common types of desiccants. Compared to liquid desiccants, solid desiccants have the following advantages: a) No leakage, b) Minimal or non-existent corrosion and environmental problems, and c) Minimal upkeep (Grossman and Johannsen, 1981). Solid desiccants are porous structure materials that adsorb water by a variety of methods such as chemical adsorption onto pore walls, sequential layered physical adsorption of water molecules, or capillary condensation into pores [4]. Solid desiccants finds its application in desiccant wheels[5], [6],[7],[8],[9], heat pumps[10]and heat exchanger [11];[12]. Using artificial neural networks [13]; [14]many solid desiccant systems have been analyzed. However, limited literature is available on heatless air dryer. No previous study of solid desiccant dryers has included a full analysis of a heatless air dryer employing compressed air using molecular sieve 4A as desiccant, to the knowledge of the authors'. The current experimental study on the use of molecular sieve 4A in a Heatless Desiccant Air Dryer has been motivated by this. The moisture removal rate and effectiveness have been calculated. The effect of heat of adsorption across the packed bed is carried out. With the use of neural designer, an artificial neural network is developed to validate the experimental findings. The utmost dryness that may be achieved in a heatless air dryer utilizing solid desiccant molecular sieve 4A is determined. The pore size of a 4A molecular sieve is 4Å or 4angstrom. Any molecule greater than 4 Å, it does not adsorb. It is sodium forms of the type A crystal structure. Moisture is removed from liquefied and gaseous materials using a molecular sieve 4A.

Sr No	Properties	Molecular Sieve 4A
1	Bed Crushing strength	21N
2	Particle Size	1.6-2.7mm
3	Tapped bulk density	792 kg/m^3

Table 1. Properties of molecular sieve 4A used for experimentation.

System Description

The performance of activated alumina and molecular sieve 13x will be investigated using a twin tower pressure swing heatless air dryer. Compressed air containing moisture passes via a carbon filter, then an after filter, and finally tower A, where the desiccant adsorbs moisture. A dewpoint metre is used to determine the dryness of compressed air. Desiccant in a saturated state is regenerated by passing fractional dry compressed air through tower B. The time it takes to transfer between towers is kept at 5 minutes. To switch the airflow from tower A to tower B, a timer and a solenoid valve are utilised.

In order to construct and operate a heatless air dryer, it is necessary to evaluate the moisture content of the compressed air. The moisture content of compressed air entering the dryer can be determined using the following method:

$$W = 593.335 \times e^{(0.05486 \times t_g)} \times P(-0.81452) \qquad (1)$$

It's safe to presume that the desiccant bed is capable of absorbing all of the moisture. Using an 8-hour cycle length for the dryer's daily use. The amount of moisture removed per cycle can be expressed in the following way:

$$M = \frac{QcW}{24} \qquad (2)$$

The water vapour capacity of a desiccant is usually expressed as the mass of water vapour adsorbed per unit mass of desiccant.

$$V = \frac{\text{Mass of water vapour adsorbed}}{\text{Mass of Desiccant}} \qquad (3)$$

As a result, the volume is calculated, and the towers for the heatless air drier for 10 CFM compressed air is designed[15].The experimental setup is depicted in the diagram below:

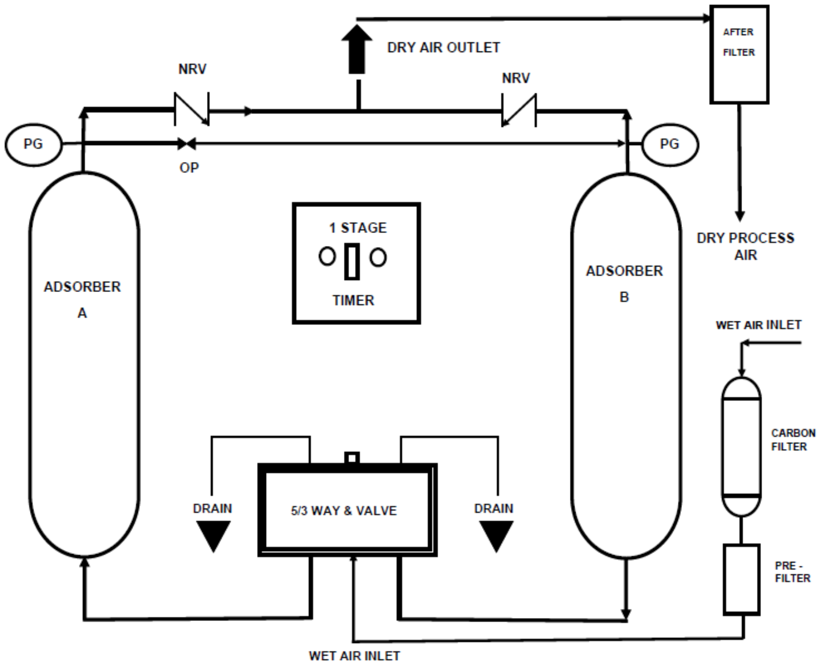


Fig 2: Experimental test rig diagram.

Experimentation procedure

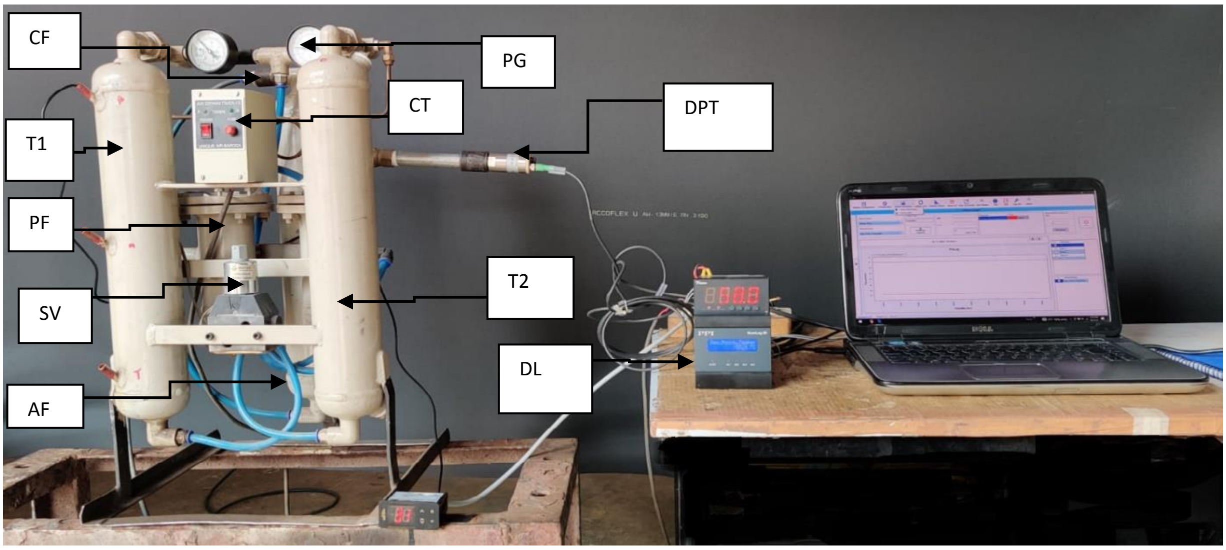


Fig. 3 Detailed view of the experimental set up

PG: Pressure Gauge	DPT: Dew Point Transmitter
CT: Control Timer	DL: Data Logger
HD: Heatless Air Dryer	T2: Tower B
SV: Solenoid Valve	T1: Tower A
AF: After Filter	PF: Pre-Filter
CF: Carbon Filter	

This experiment uses a heatless desiccant air dryer (also known as a pressure swing regenerative dryer) with a 10-cfm capacity. The air is compressed by the compressor, which has a pressure of 7 bar. It is initially passed through an activated charcoal filter to remove any oil from the compressed air. Because oil can be adsorbed by the solid desiccant, the desiccant can become inactive. The air then passed through a pre filter with a filtration efficiency of 5 microns after passing through the activated carbon filter. The air enters the desiccant tower A or B, depending on the operating condition, after passing through the pre filter.

The towers are entirely packed with desiccant, and steel straps are attached at the tower apertures to ensure that no desiccant particles are transported over into the compressed air stream. Filling the tower with desiccant material adsorbs the moisture in the compressed air and dries it out. The dry air is now discharged from the tower. Purge air is a fraction of this dry air that is routed via thin tube to the tower-B for the regeneration process. The remaining air is transferred to the output line via a non-return valve (also known as a check valve), where it is passed to the after filter, which eliminates dust particles introduced by the desiccant (desiccant particles). Clean, compressed, and dry air is produced.

The purge air is delivered from the top to the tower-B. The bottom of tower-B is maintained open to the atmosphere, resulting in decreased pressure in the tower-B. The desiccants are regenerated by the dry compressed purge air. The cycle has now shifted. The tower-B receives compressed air while the tower-A is regenerated. After a 5-minute delay, this cycle reverses direction.

A timer is connected to the solenoid valve, which controls the motion of the 5/2 direction control valve, to control this cycle. The direction of compressed air (towards tower-A or tower-B) and the opening of tower-A or tower-B are controlled by this 5/2 control valve.

Instrumentation

During the experiment, the following instruments were used to measure various factors such as dew point temperature, relative humidity, dry bulb temperature, wet bulb temperature and pressure.

1) Dew point Meter (Accuracy: $\pm$0.5˚C)
2) Hygrometer (Accuracy: $\pm$2%)
3) Pressure gauge (Range: 25 kg/cm^2, Accuracy: 0.25kg/cm^2)
4) Data logger

Uncertainty Analysis:

The goal of this research is to determine the air humidity ratio and adsorption rate. Two variables, namely dew point temperature (T) and relative humidity (Ø), have a significant impact on the air humidity ratio and adsorption rate. Let w_R be the result's uncertainty and w_t, $w_\emptyset$ denote variable's the uncertainties. The root of the sum square is used to calculate the uncertainty[16]. Then the uncertainty in the result is expressed as

$$w_R = \left[\left(\frac{\partial w}{\partial T}\, w_t\right)^2 + \left(\frac{\partial w}{\partial \emptyset}\, w_\emptyset\right)^2\right]^{\frac{1}{2}} \qquad (4)$$

where

- Temperature measurement uncertainty, w_t : ± 0.5˚C
- Relative humidity measurement uncertainty, $w_\emptyset$: ± 2 %

The air humidity ratio and adsorption rate percentage calculations have 0.28 percent and 0.21 percent errors, respectively.

Performance parameters

Calculating the moisture removal rate and efficacy of the desiccant dehumidifier to evaluate its performance. The following equation is used to find the rate of moisture removal to the surface of the desiccant from the air:

$$\Delta m = ma(W_{in} - W_{out}) \qquad (5)$$

Where,

- ma = the mass flow rate of the compressed air at the inlet of the dehumidification tower,
- W_{in} , W_{out} = the compressed air humidity ratios at the input and output, respectively.

The dehumidification tower's effectiveness (εDW) is calculated as the ratio of the change in real air humidity ratio to the highest feasible change in humidity ratio.

$$\varepsilon_{DW} = \frac{(W_1 - W_2)}{(W_1 - W_{2\,ideal})} \qquad (6)$$

where,

- The ideal humidity ratio of the air stream at the desiccant dehumidifier's exit is W_{2ideal}. The value of W_{2ideal} is set to zero by presuming that the air is totally dehumidified at this stage.[17]

Artificial Neural network

A neural network model is made up of several filtering components known as neurons. Weights serve as communication channels that connect them. In a basic ANN model, there is an input layer. A simple ANN model consists of an input layer, an output layer, and at least one hidden layer. The input method and the network setup both influence layer selection. A basic neural network model consists of synapses or connecting links, a summing node with a squashing function, and an externally provided bias to boost or lower the net input of the activation function. The network's performance is determined by the weights and biases values in each neuron. The network must be taught to create the required output using input data sets. The weights are adjusted to minimise the discrepancies between the ANN and experimental outputs. This technique is repeated until the error function is no longer functional.[13]

The neural network represents the predictive model. In Neural Designer, neural networks allow deep architectures, a class of universal approximators. All input parameters such as flow rate, relative humidity, pressure etc have been kept constant. The ANN model predicts the outlet dew point temperature over a period of time. The figure below depicts a graphical representation of the network architecture. It contains the following layers:

- Scaling Layer with 1 neurons (yellow)
- Perception layer with 3 neurons (blue)
- Perception layer with 1 neuron (blue)
- Unscaling layer with 1 neuron (red)
- Bounding layer with 1 neuron (purple)

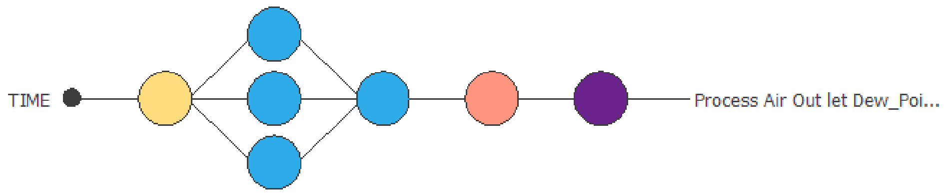
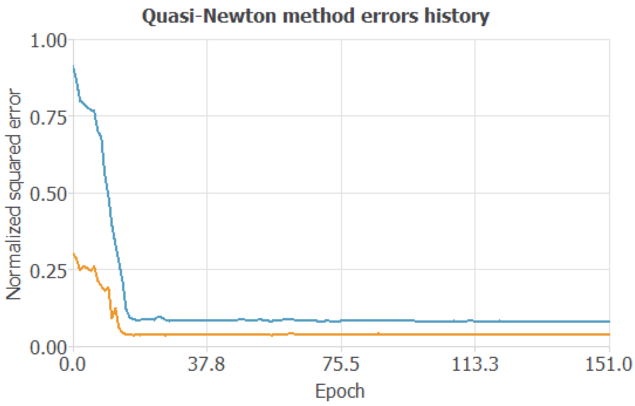


Fig 4: Graphical representation of the neural network architecture.

Results and discussion

The training and selection error in each iteration are depicted in the graph below. The training error is shown by the blue line, while the selection error is represented by the orange line. The starting training error is 0.909671, and after 151 epochs, the final value is 0.0810398. The selection error starts at 0.301985, and after 151 epochs, the ultimate value is 0.0378647.



	Value
Training error	0.081
Selection error	0.0379
Epochs number	151

Fig 5: Plot depicting training and selection error.

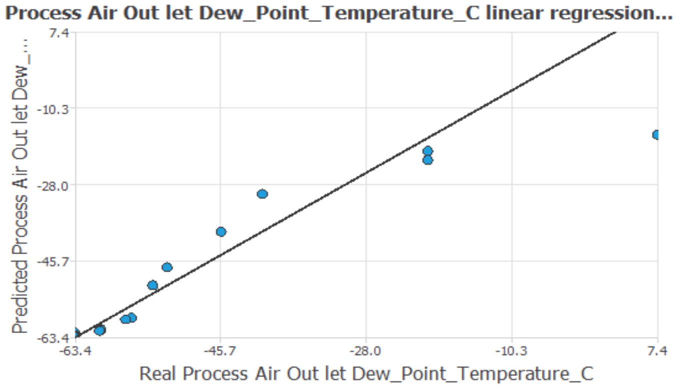
The lowest, maximum, averages, and standard deviations of the errors between the neural network and the testing samples in the data set are measured by the errors statistics. They are a useful tool for determining a model's quality. The absolute and percentage errors of the neural network for the testing data are shown in the table below, together with their lowest, maximum, mean, and standard deviations.

	Minimum	**Maximum**	**Mean**	**Deviation**
Absolute error	0.000469208	23.9746	0.61919	2.60824
Relative error	6.62723e-6	0.338624	0.00874563	0.0368395
Percentage error	0.000662723	33.8624	0.874563	3.68395

Table 2,digressions of the absolute and percentage errors of the neural network for the testing data

A linear regression analysis between the scaled neural network outputs and the associated targets for an independent testing subset is the traditional way for testing a model's loss. For each output variable, this approach yields three parameters. The y-intercept would be 0 for the first two parameters a and b, correlating to it. If the correlation coefficient is 1, then the outputs of the neural network and the targets in the testing subset are perfectly correlated.

The following chart illustrates the linear regression for the output process air dew point temperature. Each circle represents a predicted value versus the actual one. The grey line indicates the best linear fit. Fig. 6 shows the output anticipated by the ANN and that obtained through experiments are in good agreement.



	Value
Intercept	4.9639835
Slope	1.0792556
Correlation	0.96014774

Fig 6: Comparisons of the ANN predictions for outlet dew point temperature with experimental results.

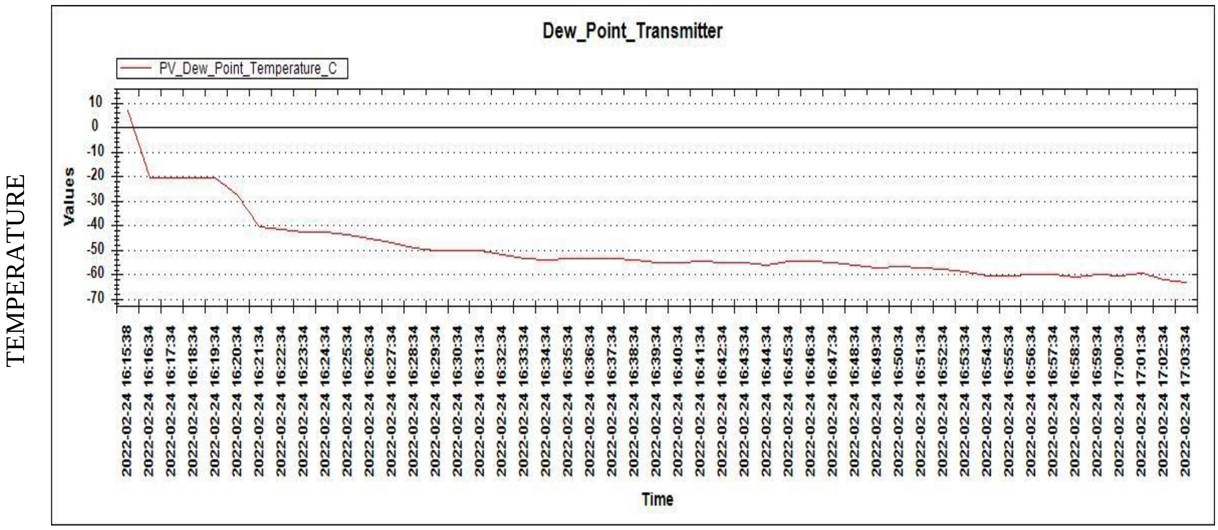


Fig 7: Molecular Sieve 4A Dew point temperature v/s time plot

Fig 7 depicts the experimental results obtained using molecular sieve 4A as the desiccant.

It can be clearly seen that the maximum dewpoint achievable is around -60 °C over period of 60 minutes. The maximum attainable dewpoint achieved was -63°C. The ANN predicted -64°C achievable dew point for a period of 900 minutes. The moisture removal rate and effectiveness obtained were 39.58 gm/hour and 81% respectively.

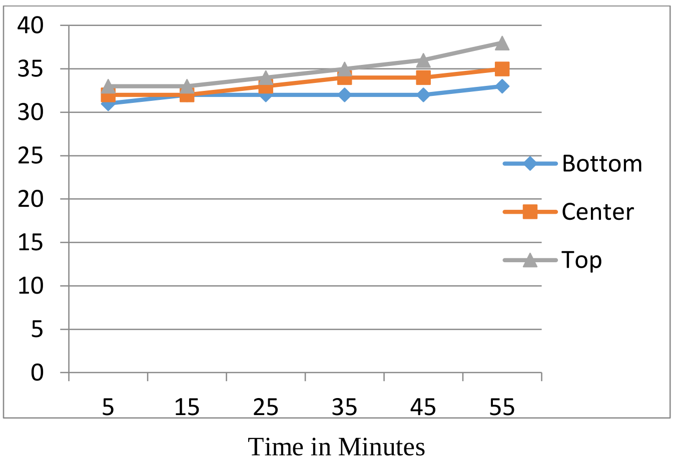


Fig 8: Temperature gradient along the packed bed in the adsorption tower

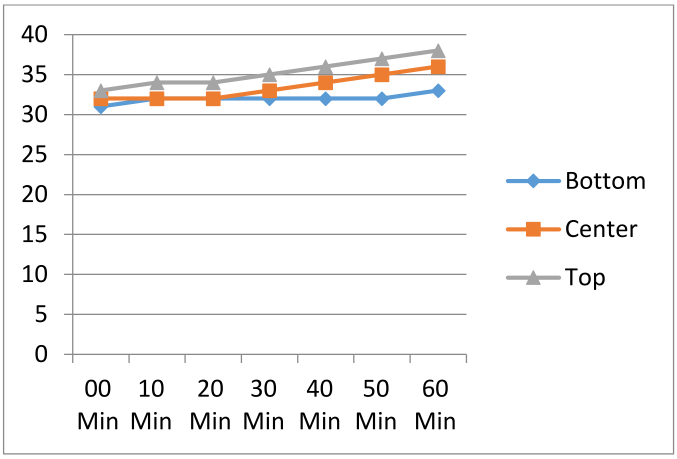


Fig 9: Temperature gradient along the packed bed in the regeneration tower

The temperature along the length of the bed is pretty uniform, as can be shown in Figs. 8 and 9. The heat emitted during the adsorption process is indicated by an increase in the temperature of the solid desiccant. When the bed was filled with molecular sieve 4A, however, the highest temperature differential of T= 7°C was found. As a result, it was determined that cooling the packed bed from the outside was not necessary. Overheating of the desiccant can impact the rate of adsorption, but due to the short cycle time, this was avoided.

Conclusion

An experimental test rig was developed to investigate the performance of the molecular sieve 4A desiccant in the heatless air dryer. Moisture removal rate and effectiveness of the dehumidifier are considered as performance indicators. The experimental runs were used to train a neural network using a neural designer to predict the outlet dew point temperature over a period of time. The heat of adsorption released in the packed during adsorption and regeneration process was also investigated. The following conclusions can were drawn from the above work:

- The experimental investigation using molecular sieve 4A as the desiccant in heatless air dryer gave moisture removal rate and effectiveness of 39.58 gm/hour and 81% respectively. Both the performance parameters indicated that molecular sieve 4A can be used as a desiccant in heatless air dryer for efficient adsorption of moisture from compressed air.
- The experimental results indicated outlet dewpoint temperature of -63°C for 60 minutes trial time and the ANN model predicted -64°C for 900 minutes trial time. The results indicate the accuracy of the model was satisfactory and coincided with the experimental data. Hence use of ANN can be effectively used to predict the outlet dew point temperature saving a lot of engineering effort, time and funds.
- The performance of the ANN model is measured using the correlation coefficient (R) and the mean square error (MSE). The ANN model performs well statistically, with a correlation coefficient of 0.96 that is very close to unity, and MSE values for ANN training and predictions that are very low when compared to the range of experiments evaluated for a heatless air dryer.
- Heat of adsorption released during adsorption and regeneration process was experimentally investigated throughout the bed. The results indicate that owing to the short cycle time externally cooling the packed bed was not needed.

This work reveals that the molecular sieve 4A can be effectively used as a desiccant in heatless air dryers without the need for externally cooling the packed bed. Provided the cycle time for switching the adsorption and regeneration process is kept short. The use of ANN to predict the output of heatless dryer with a high degree of accuracy proved to be a good alternative to the exhaustive experimental study for long period of time. More parameters can be investigated with the help of ANN to evaluate the performance of a heatless air dryer saving both time and money.

Nomenclature

M= Total moisture adsorbed, kg

t = Temperature, $^\circ C$

P = Pressure, MPa

c = Drying cycle, hours

W = Water content of gas, kg/10^6 Std m^3

V = Volume, m^3

D= Bed Diameter, m

Q = Gas flow rate, 10^6 Std m^3/day

Subscripts

B = Bed

V= Vessel

g = Gas

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