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Experimental Analysis on the use of Mango nuts as Adsorbents for Solid Adsorption Refrigeration

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Abstract

The performance analysis (stability of desorption and adsorption equilibrium, refrigeration effect and the COP) were determined using MNAC and compared with CAC at 1.0, 0.8, 0.6 and 0.4g/g initial adsorbate capacity under same experimental conditions and were found comparable with each other. MNAC and CAC both exhibited stable desorption and adsorption equilibrium. The refrigeration effect achieved was only suitable for chilling water from 28 - 20, 28- 19, 28- 19.5 and 28- 20^{o}C for MNAC- methanol and 28- 19, 28- 18, 28- 19 28- 19.5^{0}C for CAC- methanol at the studied initial adsorbate capacities, this low performance was linked to vacuum control, low thermal conductivity necessitating low refrigerant desorption quantity with consequent effect on the quantity re- adsorbed at the evaporator that cause cool production. The COPs for MNAC- methanol at the investigated adsorbate capacities were 0.079, 0.044, 0.028 and 0.030. Those for CAC- methanol were 0.074, 0.029, 0.019 and 0.017 respectively, this compared favourably with other works. Mango nuts activated carbon can thus be suitable replacement as activated carbon for adsorption refrigeration application.

Keywords: Methanol, Mango nuts, Experimental analysis, COP, Experimental rig

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1.0 Introduction

One of the global challenges in the contemporary society is the ability to maintain and control quality environment suitable for habiting man especially in developing countries where agricultural by- product generates lot of wastes due to lack of processing know- how. Energy resources and their utilization intimately relate to sustainable development. In attaining sustainable development, there is the need to explore ways of increasing the energy efficiency of processes utilizing sustainable the abundant energy resources. The utilization of renewable energy offers a wide range of exceptional benefits. Mango, *Indicamagnifera*is a major waste in Benue State especially the capital, Makurdi during its harvesting season as farmers from different part of the state finds a ready market in Makurdi. The edible part of mango is the peel and the fibrous material. The pit is not a consumable part of mango and is usually discarded as waste due to lack of local processing technologies. Mango has become and economically important species since its demand domestically and for export has become tremendous.

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A sustainable energy system may be regarded as a cost-efficient, reliable and environmentally friendly energy system that effectively utilizes local resources and networks. In the contemporary trends carbon has been one of the magnificent elements which have revolutionized material science. From carbon we obtain the best porous absorber (activated carbon) with excellent properties for large spectrum of industrial applications. The study of thermally activated adsorption cooling cycle is motivated by two factors, namely the need to switch to ozone-friendly working for refrigeration in the wake of ratification of the Montreal Protocol by several countries and environmental concern in reducing the greenhouse gas emissions in accordance with Kyoto Protocol [1]. Thermally activated adsorption cooling cycles or vapour adsorption refrigeration systems are considered to be the alternatives of conventional vapour compression cycles as they can be driven low temperature heats sources such as industrial waste heat, solar hot water system to mention but a few. Apart from this, the systems are relatively simple to construct, as it has no major moving parts. Electricity may be needed for the pumping of heat source and coolant flow only. Moreover, the heat source temperature can be further reduced as low as 50^{0}C [2]. Thermally powered adsorption systems have drawn the attention as they can reduce greenhouse gas emissions, which are in- line with the recommendations outlined in the Kyoto protocol. The use of chloroflourocarbons (CFC) has become a pressing problem to solve. Adsorption refrigeration cycles are environmentally friendly and rely on the adsorption of a refrigerant gas into an adsorbent at low pressure and subsequent desorption by heating using low- grade heat sources. The adsorbent acts as 'chemical compressor' driven by heat. In its simplest form, an adsorption refrigeration device consists of two linked vessels, one of which contains the adsorbent and the other contains the refrigerant. Adsorption refrigeration systems have the advantage of simplicity in design and construction; there are no moving components, and no solution pumps; they are able to be driven directly by lower primary energy and no need for electricity. Due to its high consumption of the edible part, massive amount of mango nut are disposed causing gradual fermentation and subsequent release of odour [3]. To make better use of cheap and abundant agricultural waste, it is proposed to convert mango nut waste into activated carbon. This conversion will address dual problems of unwanted agricultural wastes been converted into waste been converted to useful, value- added adsorbent and also the use of agriculture by- products to represent potential source of adsorbent which will contribute to solving part of waste management challenges locally.

The present paper two different working pairs, methanol-MNAC (Mango Nut Activated Carbon) and methanol- CAC (Commercial Activated Carbon- ISO 9001:2000), known to be of high adsorptive property, the both were compared to determine the suitability and possible replacement of locally produced MNAC as potential source of activated carbon for solid adsorption refrigeration.

2.0 Materials and Methods

The success of an adsorption/ desorption refrigeration cycle depends on the quality of the activated carbon used. To achieve this objective, a developed experimental rig, Fig 1, was first pressurized by pumping through the vacuum valve, 5 to detect leakages. After this procedure, the system is evacuated using a suction pump through the vacuum valve, 5 during which all other valves are opened (valves 1, 2, 3, and 4). After evacuating the system, valve 5 is shot for the rest of the experiment. In order to further analyse the characteristics of the MNAC which was locally manufactured with $CaCl_2$ at optimized conditions with high surface area and carbon yield, as well as low ash content byKwaghger*et al*[4], it was necessary to measure a digital weighing balance desorption and adsorption characteristics of methanol-MNAC pair and compare their behaviour with methanol-commercial activated pair known to be suitable for refrigeration purpose, measure the refrigeration effect (or the cooling effect) and the coefficient of performance[5].

As seen in Figs. 1 and 2, and the generator, of mass 2300g which was immersed in 2000g of water was filled with 250g of methanol and 250g of activated carbon in the first instance (masses of both MNAC and CAC were later varied subsequently). The water was heated using a hot plate with variable heat input control and the energy caused the temperature of the generator to rise which was measured with the dial temperature gauge. Consequently, the pressure of the refrigerant in the generator alsorised, the changes in pressure was measured with dial pressure gauge. Valves 1, 2, 3, and 4 were closed while the generator was heated. As heat was added, the increases in temperature of the generator as well as the generated weight of methanol were recorded at intervals of 15miutes. When the pressure of methanol in the generator reaches typical desorption pressure (between 12- 15kPa). Valve 1 which connects the generator to the condenser was then opened for the methanol vapour to escape and be condensed. The desorbed refrigerant vapour then flow through the condenser pipe which was air cooled. Valve 2 which connects the condenser to the evaporator/ receiverwas then opened to accommodate the condensed vapour in the evaporator/ receiver which was thermally insulated. Valves 2 and 3 were closed while generation process took place. The process continued until the temperature of the adsorbent reached the desorption temperature of about 100^{o}C. Valve 2, connecting the evaporator/ receiver to the condensing pipe was then shut and that of the methanol vapour return line, valves 3 and 4 were opened to allow the pressure of methanol in the evaporator/ receiver drop. When the temperature of the adsorbent in the generator as well as the pressure of the methanol in the evaporator dropped, the adsorbent re- adsorbed the refrigerant from the evaporator. During the return cycle, the weight loss of the refrigerant as it evaporates, temperatures at generator and evaporator/ receiver was measured after every 30 minutes. The cooling effect was obtained from refrigerant evaporation during the adsorption process as the temperature dropped in the insulated evaporator/ receiver. The produced MNAC and the CAC were subjected through this experimental procedure with the mass of the both activated carbons adjusted (250, 200, 150, and 100g) to give initial adsorbate capacity of 1, 0.8, 0.6 and 0.4 g/g respectively.

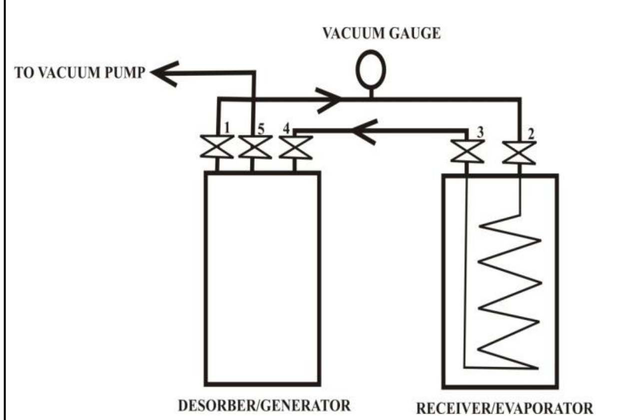

Fig 1: Schematic of the Experimental Rig

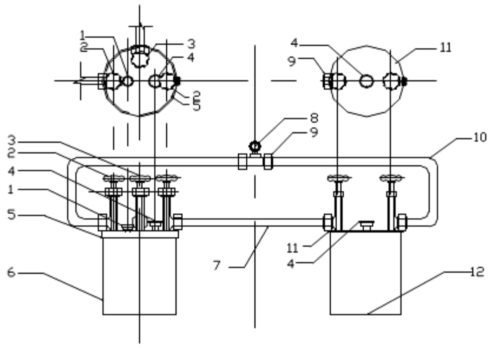

Fig. 2: Assembly of the Experimental Rig

1. Dial pressure gauge 2. Flow control valve 3. Vacuum control gauge 4. Dial thermometer 5. Generators cover 6. Generator 7. Refrigerant return valve 8. Vacuum gauge 9.Connector nut 10. Condenser pipe 11. Receiverscover 12. Receiver (Evaporator)

2.1 Refrigeration effect analysis

Desorption and adsorption characteristics of the both MNAC and CAC was analysed and the effect on cool production compared. Usually, the characteristics of any cool production device are described by its cooling effect and the coefficient of performance[5].

$$COP = \frac{Q_c}{Q_{in}} \quad (1)$$

Where:

$$Q_c = L(\Delta x) - C_{pm}(T_{a1} - T_{a2}) \quad (2)$$

$$Q_{in} = Q_{sen} + \Delta H$$

$$Q_{sen} = m_w C_{pw}(T_i - T_f) \quad (3)$$

Q_c = the useful cooling (kJ/kg) of adsorbent

Q_{in} = the heating output per kilogram of adsorbent (kJ/kg)

Q_{sen} = sensible heat needed to heat the adsorbent and its containing vessel to the maximum temperature (kJ/kg)

Δx = the refrigerant concentration change (g/g)

$$\Delta x = x_{conc} - x_{dil} \quad (4)$$

x_{conc} = adsorption capacity before desorption (g/g)

x_{dil} = adsorption capacity after desorption (g/g)

C_{pm} = specific heat capacity of refrigerant 2.554(kJ/kgK)

L= latent heat of vaporisation of methanol (1102kJ/kg)

ΔH = isosteric heat of sorption of methanol (1480.75kJ/kg)

3.0 Results and Discussion

3.1 Result

The obtained experimental result for the both MNAC-methanol and CAC- methanol pairsis presented in Tables 1- 13

TABLE 1: AVERAGE AMOUNT OF DESORBED REFRIGERANT AT 1g/g INITIAL ADSORBATE CAPACITY

Time (mim)	Weight of Desorbed Refrigerant (g)	
	MNAC	CAC
15	8	9
30	32	33
45	87	92
60	149	152
75	185	186
90	200	202
105	207	209
120	208	210

TABLE 2: AVERAGE AMOUNT OF DESORBED REFRIGERANT AT 0.8 g/g INITIAL ADSORBATE CAPACITY

Time (mim)	Weight of Desorbed Refrigerant (g)	
	MNAC	CAC
15	8	8.5
30	30	31
45	72	74
60	120	124
75	143	149
90	162	169
105	168	179
120	174	181

TABLE 3: AVERAGE AMOUNT OF DESORBED REFRIGERANT AT 0.6g/g INITIAL ADSORBATE CAPACITY

Time (mim)	Weight of Desorbed Refrigerant (g)	
	MNAC	CAC
15	7.5	7
30	29	30
45	48	51
60	79	83
75	92	97
90	99	101
105	128	131
120	132	136

TABLE 4: AVERAGE AMOUNT OF DESORBED REFRIGERANT AT 0.4g/g INITIAL ADSORBATE CAPACITY

Time (mim)	Weight of Desorbed Refrigerant (g)	
	MNAC	CAC
15	7.5	6.5
30	28	29
45	42	45
60	61	63
75	72	75
90	79	79
105	81	84
120	81	87

TABLE 5: AVERAGE AMOUNT OF REFRIGERANT ADSORBED AT 1g/g INITIAL ADSORBATE CAPACITY

Time (min)	Weight of Adsorbed refrigerant (g)	
	MNAC	CAC
390	11	9
360	55	53
330	99	103
300	117	120
270	125	132
240	139	143
210	148	152
180	159	163
150	170	171
120	183	185
90	197	192
60	200	201
30	208	210

TABLE 6: AVERAGE AMOUNT OF REFRIGERANT ADSORBED AT 0.8g/g INITIAL ADSORBATE CAPACITY

Time (min)	Weight of Adsorbed refrigerant (g)	
	MNAC	CAC
390	13.5	15
360	20	24
330	41	47
300	54	57
270	58	62
240	67	66
210	74	77
180	87	86
150	100	98
120	122	121
90	125	128
60	128	131
30	132	136

TABLE 7: AVERAGE AMOUNT OF REFRIGERANT ADSORBED AT 0.6g/g INITIAL ADSORBATE CAPACITY

Time (min)	Weight of Adsorbed refrigerant (g)	
	MNAC	CAC
390	12	20
360	39	33
330	54	67
300	99	107
270	107	111
240	121	118
210	129	123
180	135	130
150	140	152
120	151	160
90	160	168
60	174	173
30	174	181

TABLE 8: AVERAGE AMOUNT OF REFRIGERANT ADSORBED AT 0.4g/g INITIAL ADSORBATE CAPACITY

Time (min)	Weight of Adsorbed refrigerant (g)	
	MNAC	CAC
390	8	7
360	10	11
330	21	23
300	37	39
270	39	42
240	42	49
210	51	57
180	59	63
150	67	75
120	75	79
90	78	82
60	80	85
30	81	87

TABLE 9: TEMPERATURE CHANGES IN THE GENERATOR AT THE STUDIED ADSORBATE CAPACITIES IN THE GENERATOR FOR MNAC

Time (min)	Temperature increase in the generator (^{0}C)			
	1	0.8	0.6	0.4
15	35	34	36	37
30	43	39	42	44
45	55	49	53	55
60	62	57	60	62
75	73	69	71	70
90	82	81	80	79
105	94	92	93	89
120	100	101	101	100

TABLE 10: TEMPERATURE CHANGES IN THE GENERATOR AT THE STUDIED ADSORBATE CAPACITIES AT THE GENERATOR FOR CAC

Time (min)	Temperature increase in the generator (^{0}C)			
	1	0.8	0.6	0.4
15	35	36	36.5	37
30	45	50	49	51
45	56	56	60	71
60	64	69	69	79
75	72	80	84	85
90	84	85	90	98
105	96	98	98	100
120	100	100	101	101

TABLE 11: REFRIGERATION EFFECT AT THE EVAPORATOR OF THE STUDIED ADSORBATE CAPACITIES USING MNAC

Time (min)	Temperature changes in the evaporator (^{0}C)			
	1	0.8	0.6	0.4
30	28	28	28	28
60	28	27	28	28
90	27	27	27	27.5
120	27	26	26	27
150	26	25	26	26
180	25	25	25	25
210	24	24	24	25
240	23	23	23	23
270	22	21	22	22
300	21	21	21	22
330	21	20	20	20.5
360	20	19	20	20.5
390	20	19	19.5	20

TABLE 12: REFRIGERATION EFFECT AT THE EVAPORATOR FOR THE STUDIED ADSORBATE CAPACITIES USING CAC

Time (min)	Temperature changes in the evaporator (^{0}C)			
	1	0.8	0.6	0.4
30	28	28	28	28
60	27	28	29.5	28
90	26	27	27.5	27
120	26	26	26	26
150	25	25	25	27
180	24	24	23.5	26
210	23	23	23	23.5
240	22	22	22	23
270	21	21	21	22
300	21	20	20.5	21
330	20	19	20	20
360	20	19	19	20
390	19	18	19	19.5

TABLE 13: COEFFICIENT OF PERFORMANCE FOR THE USED ACTIVATED CARBONS AT THE STUDIED ADSORBATE INITIAL CAPACITIES

Activated Carbon	Coefficient of Performance			
	1	0.8	0.6	0.4
MNAC	0.079	0.044	0.028	0.030
C1AC	0.074	0.029	0.019	0.017

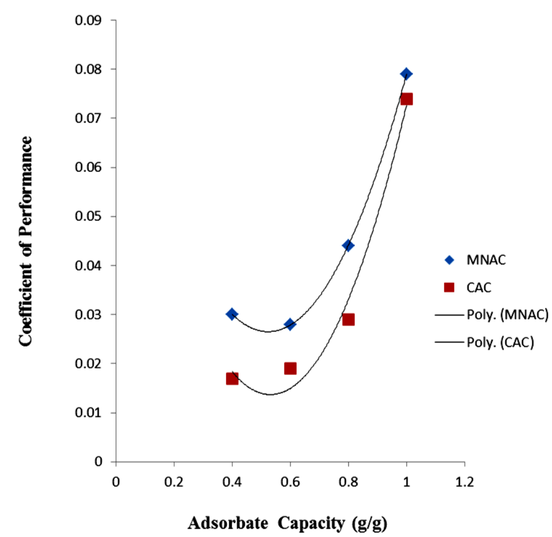

Fig. 3: Variation of COP with the Adsorbate Capacity

3.2 Discussion

The efficiency of an adsorption/ desorption refrigeration system is influenced by the choice of adsorbate/ adsorbent pair [7]. To further analyse the performance characteristics of the developed MNAC- methanol, it was necessary to measure the desorbing and adsorbing characteristics of the pair, the refrigeration effect and the coefficient of performance and compare with the CAC- methanol pair adjudged to be suitable for refrigeration purposes as reported by Li et al.,[5].During heat addition at the generator, the refrigerant is released by the activated carbon which is subsequently collected at the in the evaporator. When heat addition is stopped, the desorbed refrigerant is re- absorbed back in the generator. For good characteristics of a refrigeration system, the quantity of the desorbed refrigerant should be same as that of the refrigerant re- adsorbed in the generator thereby establishing stable desorption and adsorption equilibrium. In the present work, desorption and adsorption equilibrium was established for both MNAC and CAC at all the studied adsorbate initial capacities as seen in TABLES 1- 4 and 5-8respectively. Almost same quantity of refrigerant that was desorbed was re-adsorbed. TABLES 1- 4 and 5- 8 shows that although equilibrium was attained, longer duration was required for the adsorption process than the desorption process. Similar trend was reported by Li et al.,[5]. Anyanwu, [8] observed that the amount of refrigerant desorbed increase with increase in time and temperature while a reverse trend is observed during the desorption process. TABLES 1- 4 shows that in 120min, 208, 174, 132 and 81g of methanol were desorbed by MNAC and 210, 182, 136 and 87g were desorbed by CAC with the same quantity of heat applied at the generator. Desorption and adsorption processes for both MNAC and CAC have common trends as observed in TABLES 1- 4 and 5- 8 respectively at all the initial adsorbate capacities studied. Temperature changes at the generator during desorption process for both MNAC and CAC are shown in TABLES 9 and 10 respectively. When heat intensity is increased, the value of COP does not increase synchronously, conversely the COP of the system decreases by some degree. This reason can be explained as follows: heat addition is used for both adsorbent sensible heat and metallic sensible heat. When the heat intensity increases, the adsorbent maximum desorbing temperature increases too. There is an optimum desorbing temperature value and when the desorbing temperature becomes greater than the optimum temperature, the amount of desorbed refrigerant mass become weaker. This means that most of heat intensity is used for metallic sensible heat; this will cause the COP of the system to decrease. Nevertheless, the cooling effect of the adsorption refrigerator will increase with the increase of heat intensity. However, there is a minimum value of heat beyond which the cooling effect begins to drop because the amount of desorbed refrigerant, when evaporated, is just assured for providing cooling to evaporator [9]. Little discrepancies from the in behaviour of the developed system in terms the quantity of the desorbed and adsorbed refrigerant (real situation) from theoretical situation could be due to experimental reality, the process of desorption and adsorption do not take place isobarically in real situation [10]. The variations in pressure could probably be from little leakages from the system. During the adsorption phase, as seen in TABLES 5- 8, about 197, 118.5, 162 and 73g were re- adsorbed by MNAC and 201, 121, 161 and 80g were re- adsorbed by CAC in 390 minutes at the studied adsorbate capacities respectively. Longer durations of the adsorption process could probably be due poor heat transfer property of the activated carbons used. This shows that almost the same amount that was desorbed at the generator was re- adsorbed. However, the results indicate that adsorbing and desorbing characteristics of the activated carbon- methanol from both MNAC and CAC are quite stable, since the desorbed refrigerant in the desorption process was almost completely adsorbed in the adsorption process. Similar observations were reported by Li et al., [5]; Wang et al.,[6] using methanol- activated carbon/ ethanol- activated carbon and methanol- activated carbon/ ammonia- activated carbon respectively. Based on the desorbing and adsorbing characteristics of the MNAC and CAC- methanol, one can compare the effect of the system with the two working pairs. Usually the characteristics of an adsorption refrigeration system are described by the refrigeration effect (cool effect in the evaporator) and the coefficient of performance. The refrigeration effect achieved was the reduction of the initial temperature of water by from 28- 20, 28- 19, 28- 19.5 and 28- 20 ^{o}C for MNAC and from 28- 19, 28- 18, 28- 19, and 28- 19.5^{o}C for CAC respectively at the studied adsorbate capacities as seen in TABLES 10 and 11. This low cooling effect could be due to the fact that, the quantity of methanol desorbed was not significant to cause ice production. Leite et al,[10] reported that the quantity of ice production (cooling effect) depends to a large extent on the quantity of desorbed refrigerant. The refrigeration effect achieved could only be utilised for cooling water required for domestic applications. This low cooling effect could be due to the fact that the quantity of methanol evaporated was not sufficient to cause ice formation also the difficulty in achieving a perfect vacuum could be responsible for this low performance. Also, high condensing pressures, above 20^{0}C could be responsible for the poor refrigeration effect. When condensing temperature is below 20^{0}C, the system could even produce ice of over 10kg [9].

The coefficient of performance (COP) is the amount of cooling achieved by a refrigeration machine per unit of heat supplied. The COP for the MNAC was 0.079, 0.044, 0.028 and 0.030, while that of CAC was 0.074, 0.029, 0.019 and 0.017 at 1, 0.8, 0.6 and 0.4g/g initial adsorbate capacities respectively as seen in TABLE 13. This range was indeed close and could obviously be due to the fact that both activated carbons have common desirable characteristics such as surface area and carbon yield including affinity for each other [8]. It was however observed that the COP of MNAC was slightly higher than that of CAC at all the initial adsorbate capacities investigated as seen in TABLE 13 and Fig. 3. This could be due to the fact that the

MNAC has higher surface area and lower ash content ($2437.99m^2/g$ and 2.25%) than the surface area and ash content of CAC (950- $1500m^2/g$ and 3%). The COP obtained in the study compared favourably with that obtained by Anyanwu and Ezekwe, [11]; Boubakri, et al.,[12]. The low COP could be due to the difficulty in vacuum control of the system as loss of vacuum tends to deteriorate systemperformance and hence the COP [13]. This loss of vacuum in a good mechanically sealed system may be caused by formation of unwanted gases from the decomposition of methanol especially when in contact with metallic materials used for constructing the system thus catalysing the decomposition reaction [14]. Contact thermal resistance could also be responsible for low COPs of adsorption systems. The adsorbent is installed inside a definite shape of metal; the metal accepts heat energy from the water to heat the adsorbent in order to release the refrigerant. Due to the existence of thermal contact resistance between the adsorbent and the metal surface, there is a great temperature gradient which reduces the heat transfer effect from the metal surface to the adsorbent [9]. According to Li and Wang, [9] revealed that when the value of thermal contact resistance decrease by half, the COP and the ice production increase by nearly 30%. Smoother surface could reduce the contact thermal resistance. Another reason for the low COPs is that, suitable adsorbent for adsorption applications are inherently porous so as to adsorb large amounts of adsorbate. However their thermal conductivities are low which affect the COP of any adsorption cooling device. Li and Wang, [9] established that when thermal conductivity increase from in the range $0.02 \leq k_e \leq 2.0$ the COP and the desorbed refrigerant mass and the cooling effect increase steadily. The thermal conductivity value of adsorbents is usually $1.0Wm^{-1}K^{-1}$ and when this value is exceeded, better performance results are achievable [9]. In order to improve on the performance characteristics of adsorption cooling systems, Gacciolaa and Restuccia, [15] suggested that incorporation of metallic spheres or strips in to the adsorbents could increase performance. Another possibility in the low performance characteristics could be that linked to similar observations of Li and Wang, [9]. They reported that as the mass of the adsorbent decrease through the reduction of the initial adsorbate capacities, the COP and the cooling effect decrease. This is because packing density is affected by thermal conductivity in the adsorbent. Another reason for the low values of COPs could be due to the high condensing temperatures for both MNAC and CAC pairs. Li and Wang, [9] observed that when condensing pressures are below 20^0C, the values of COP could exceed 0.15.

4.0 Conclusion

Experimental rig has been successfully developed and used to test the performance of the MNAC produced with $CaCl_2$-methanol and CAC- methanol pairs.Performance characteristics experiments in terms of stability of adsorption and desorption equilibrium, refrigeration effects and COP were carried out with the developed rig using MNAC-methanol pair and a standard CAC- methanol pair. The result obtained with MNAC- methanol pair favourably compared with the standard CAC- methanol and works of other researchers.

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