CURRICULUM VITAE

Dr. VINOD KUMAR SINGH
Sr. Assistant Professor
Madanapalle Institute of Technology & Science
#Department of Mechanical Engineering, Kadiri Road, Angallu Village,
Chittoor District, Madanapalle-517325 (A.P.)
M. N.: +919993539637
E-mail id: vinod.1016singh@gmail.com
Skype id: phd12120304

Career Objective:

Highly dedicated and devoted to work for achieving the proposed and desired goal. I ever excel myself by learning everything which comes in my way, which helps me to work in a challenging environment.

Personal Objective:

To attain the greatest height in my life and to give the best out of me in every endeavour.

Educational Qualifications:

Program	Institution/School	CGPA/%	Year of Completion
Ph.D. in Thermal Engineering	IIT Indore	8.33	2017
M.Tech. in Energy System and Pollution	NIT Raipur	9.49	2011
B.E. in Mechanical Engineering	Pt. R.S.S.U. Raipur	8.35	2007
XII	Bhilai Vidyalaya, Bhilai	70.2	2003
X	Bhilai Vidyalaya, Bhilai	69	2001

Major Courses taken in Ph.D. and M.Tech. Program:

- Computational Fluid Dynamics (CFD)
- Principle of Measurements
- Design of Thermal System
- Heat Exchanger Design
- Alternative Fuels and Advance in I.C. Engine
- Conventional Energy Conversion System
- Recent Advances in Heat Transfer
- Computational Numerical Methods
- Non-conventional Energy Sources
- Energy Management
- Energy Pollution and Control
- Noise and Pollution Monitoring Instrumentation

Position of Responsibility:

- **Teaching Assistant** for Heat Transfer, Basic Mechanical Engineering and Heat Transfer Lab in the Discipline of Mechanical Engineering at Indian Institute of Technology Indore. **(January 2013 to August 2017)**

Achievements:

- Received **DST Travel Support** for attending an International Conference (IMPRES 2016) held at Taormina, Sicily, Italy.
- **GATE** score card
- Secured **First Rank** in the Institute level in M.Tech. Program at NIT Raipur.
- Secured **Third Rank** in the college level in B.E. Program at RCET Bhilai.

Computing Skills:

- **Languages:** C, MATLAB
- **Software:** AutoCAD, Polysun

Technical Interests:

- **CO_2 Capture and Sequestration**
- **Adsorption based Gas Storage Systems**
- **Adsorption based Cooling Systems**
- **Thermal Energy Storage Systems**

Projects:

- **Ph.D. Level:** Measurement of CO_2 Adsorption Isotherms and Kinetics of Activated Carbons Suitable for the Development of CO_2 based Adsorption Cooling Systems **(Please refer annexure I)** (**January 2013 to August 2017)**
- **PG Level:** Energy and Exergy Analysis of a Steam Power Plant **(Please refer annexure II)** **(July 2010 to December 2011)**
- **UG Level:**
  - ✓ Thermodynamic Analysis of Catalytic Converter for Vehicular Emission Control of S.I. Engine. **(July 2006 to May 2007)**
  - ✓ Study of Bio-Diesel & Its Application. **(January 2006 to May 2006)**

Professional Experience:

Name of Organization	Position Held	Nature/Type of Work	Period (From - To)
MITS Madanapalle	Sr. Assistant Professor	Teaching/Research	08/01/2018 – Till Date
CCET Bhilai	Assistant Professor	Teaching	03/01/2011-10/12/2012
RCET Bhilai	Lecturer	Teaching	09/08/2008-16/02/2009

Co-Curricular Activities:

- Two weeks vocational training at “**Bhilai Steel Plant**” after 5^{th} semester.
- One-month project-based training at “**Bhilai Steel Plant”** in 51 MW **Power Plant-I** after M.Tech. 3^{rd} semester.

Extra-Curricular Activities:

- Active member of editorial board of college magazine “**EYE**”.
- Participated in Senior UN Information Test.
- Active member of organizing committee of various events at college level.

Publications:

	Published
International Journals (SCI/Scopus)	**8**
International Conferences	**9**
Workshops/Seminars	**9**

Journals: **(January 2013 to Till date)**

1. **Vinod Kumar Singh**, E. Anil Kumar, Measurement and analysis of adsorption isotherms of CO_2 on activated carbon, ***Applied Thermal Engineering*** 97 (2016) 77-86. (I.F. - 4.725)
2. **Vinod Kumar Singh**, E. Anil Kumar, Measurement of CO_2 adsorption kinetics on activated carbons suitable for gas storage systems, ***Greenhouse Gases: Science and Technology*** 7 (1) (2017) 182-201. (I.F. - 1.979)
3. **Vinod Kumar Singh**, E. Anil Kumar, Experimental investigation and thermodynamic analysis of CO_2 adsorption on activated carbons for cooling system, ***Journal of CO_2 Utilization*** 17 (2017) 290-304. (I.F. - 5.993)
4. **Vinod Kumar Singh,** E. Anil Kumar, Thermodynamic analysis of single-stage and single-effect two-stage adsorption cooling cycles using indigenous coconut shell based activated carbon-CO_2 pair, ***International Journal of Refrigeration*** 84 (2017) 238-252. (I.F. - 3.461)

5. **Vinod Kumar Singh,** E. Anil Kumar, B.B. Saha, Measurement of adsorption isotherms, kinetics and thermodynamic simulation of CO_2-CSAC pair for cooling application, ***Energy*** 160 (2018) 1158-1173**.** (I.F. - 6.082)

Scopus/Conference Proceedings:

1. **Vinod Kumar Singh**, E. Anil Kumar, Comparative studies on CO_2 adsorption kinetics by solid adsorbents, ***Energy Procedia*** 90 (2016) 316-325.
2. Reema Saxena, **Vinod Kumar Singh**, E. Anil Kumar, Carbon dioxide capture and sequestration by adsorption on activated carbon, ***Energy Procedia*** 54 (2014) 320-329.
3. **Vinod Kumar Singh**, E. Anil Kumar, Comparative studies on CO_2 adsorption isotherms by solid adsorbents, ***Materials Today Proceedings*** 5 (11) (2018) 23033-23042.

International Conferences:

1. **Vinod Kumar Singh,** E. Anil Kumar, B.B. Saha, Performance evaluation of adsorption cooling system: A comparative study, ICP 2019, Kyushu University, 15^{th}-17^{th} May 2019, Japan.
2. **Vinod Kumar Singh**, E. Anil Kumar, Estimation of thermodynamic properties of CO_2 adsorption on activated carbon, ***6^{th} International Conference on Advances in Energy Research (ICAER 2017)***, IIT Bombay, 12^{th}-14^{th} December 2017, Mumbai, India.
3. **Vinod Kumar Singh**, E. Anil Kumar, Characterization of carbon dioxide adsorption isotherms and kinetics on activated carbon for cooling system, ***IV^{th} International Symposium on Innovative Materials for Processes in Energy Systems 2016 (IMPRES 2016)***, Hotel Villa Diodoro, Taormina, 23^{rd}-26^{th} October 2016, Sicily, Italy.
4. **Vinod Kumar Singh**, E. Anil Kumar, Comparative studies on CO_2 adsorption kinetics by solid adsorbents, ***5^{th} International Conference on Advances in Energy Research (ICAER 2015)***, IIT Bombay, pp. 968-975, 15^{th}-17^{th} December 2015, Mumbai, India.
5. **Vinod Kumar Singh**, E. Anil Kumar, Comparative studies on CO_2 adsorption isotherms by solid adsorbents, ***5^{th} International Conference on Advances in Energy Research (ICAER 2015)***, IIT Bombay, pp. 959-967, 15^{th}-17^{th} December 2015, Mumbai, India.
6. **Vinod Kumar Singh**, E. Anil Kumar, Studies on adsorption isotherm and kinetics of CO_2 by activated carbon, ***International Conference on Polygeneration (ICP 2015)***, Anna University, 18^{th}-20^{th} February 2015, Chennai, India.
7. **Vinod Kumar Singh**, E. Anil Kumar, Studies on CO_2 adsorption by activated carbon, ***International Conference on Environment and Energy (ICEE 2014)***, JNTU Hyderabad, 15^{th}-17^{th} December 2014, Hyderabad, India. (ISBN: 978-93-81212-96-7).

8. Reema Saxena, **Vinod Kumar Singh**, E. Anil Kumar, Carbon dioxide capture and sequestration by adsorption on activated carbon, ***4th International Conference on Advances in Energy Research (ICAER 2013)***, IIT Bombay, pp. 785-793, 10th-12th December 2013, Mumbai, India. (ISBN: 978-81-928795-0-5)
9. **Vinod Kumar Singh**, Rahul Salhotra, Energy and exergy analysis of a 36 MW thermal power plant, ***1st International Conference on Mechanical Engineering: Emerging Trends for Sustainability***, MANIT Bhopal, pp. 1069-1077, 29th-31st January 2014, Bhopal, India.

Citations:

	Google Scholar	Scopus
Total Citations	**260**	**211**
h-Index	**7**	**7**
i10-Index	**7**	**7**

Workshops/Seminars/Short term Courses:

1. Delivered Webinar on “Development of CO_2 based Adsorption Cooling Systems” during 2nd June 2020 at 11:00 AM organized by Department of Mechanical Engineering, Sagar Group of Institution Bhopal.
2. Attended two days International workshop on “**Materials for Energy Conversion and Storage**” during 24th to 25th December 2019 organized by Department of Mechanical Engineering, IIT Tirupati, Tirupati, India.
3. Attended one-week Workshop on “**Electronic Systems for Mechanical Automation & Robotic Technology (eSMART 2019)**” during 20th to 24th May 2019 organized by Department of Mechanical Engineering, NIT Silchar, Silchar, India.
4. Attended one-week Quality Improvement Programme on “**Instructional Design and Delivery System**” during 25th to 29th June 2018 organized by Department of Mechanical Engineering, MITS Madanapalle and NITTTR Chennai, Madanapalle, India.
5. Attended one-week GIAN Course on “**Fundamentals and Applications of Absorption Heat Pumps and Refrigeration Systems**” during 14th to 19th December 2017 organized by Department of Mechanical Engineering, IIT Indore, Indore, India.
6. Attended two-week GIAN Course on “**Adsorption Science and Technology for Cooling and Desalination Applications**” during 11th to 21st September 2017 organized by Department of Mechanical Engineering, IIT Indore, Indore, India.

7. Attended one-week GIAN Course on “**Introduction to Thermal Systems Design**” during 11th to 15th September 2017 organized by Department of Mechanical Engineering, IIT Indore, Indore, India.
8. Attended one-week GIAN Course on “**Second Law Analysis of Thermal Energy Storage Systems**” during 17th to 22nd July 2017 organized by Department of Mechanical Engineering, IIT Indore, Indore, India.
9. Attended two-week GIAN Course on “**Introduction to Heat Pipe Science and Technology**” during 6th to 19nd December 2016 organized by Department of Mechanical Engineering, IIT Indore, Indore, India.

Project:

Project Title: Experimental and theoretical assessment of figures of merit and development of framework for the optimization of modified microencapsulated organic Phase Change Materials (**Submitted**)

Funding Agency: DST Govt. of India (Indo-Israel Collaboration)

Amount: INR 10750000/-

Duration: 2 Years

Designation: Co-PI’s

Personal Profile:

Name:	**Vinod Kumar Singh**
Father’s Name:	Mr. Gokaran Singh
Mother’s Name:	Smt. Prema Devi
Date of Birth:	16th April, 1986
Gender:	Male
Marital Status:	Married
Languages Known:	English, Hindi
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References:

1. **Dr. E. Anil Kumar**
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3. **Dr. Devendra Deshmukh**
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   Email-id: dldeshmukh@iiti.ac.in
   Mobile No.: 9407156827

4. **Prof. Bidyut Baran Saha**
   Professor and Principal Investigator,
   Thermal Science and Engineering Division
   International Institute for Carbon-Neutral Energy Research (WPI-I2CNER)
   Professor, Mechanical Engineering Department Kyushu University
   Adjunct Professor, Kyushu University Program for Leading Graduate School, Green Asia Education Center
   Email-id: saha.baran.bidyut.213@m.kyushu-u.ac.jp
   Tel. No.: +81-92-583-7903

Declaration of Authenticity:

I declare hereby, that the information furnished above is true to the best of my knowledge and belief.

Place: Madanapalle

Date: 02/11/2020

VINOD KUMAR SINGH

Annexure I: Ph.D. Thesis

Title: Measurement of CO_2 Adsorption Isotherms and Kinetics of Activated Carbons Suitable for the Development of CO_2 based Adsorption Cooling Systems.

Thesis Supervisor: Dr. E. Anil Kumar (Associate Professor, IIT Indore)

Abstract: Adsorption of CO_2 on activated carbons is widely utilized in gas storage systems and adsorption-based cooling systems. Selection of CO_2-activated carbon pairs for gas storage and cooling systems is mainly influenced by adsorption isotherms, adsorption kinetics, thermodynamic properties and operating conditions. The elaborated research work aims at experimental and theoretical studies on CO_2 adsorption of various activated carbons namely Norit RB3 (steam activated rod) (AC1), Norit Darco (100 mesh size) (AC2) and Norit Darco (12×20 US mesh size) (AC3) and coconut shell based activated carbon (CSAC) for the development of CO_2 based adsorption cooling systems.

The numerical simulation is carried out to study the rate of adsorption of the CO_2 gas on activated carbon. A one-dimensional mathematical model is proposed based on the Dubinin's theory of volume filling of micropores, and analyzed along with the unsteady heat transfer. A parametric analysis is carried out to study the effect of various crucial parameters like radius of bed, cooling fluid temperature, initial bed temperature and heat transfer coefficient on the adsorption amount. The results show that lower bed radius is ideal for obtaining high amount of CO_2 adsorbed assuming constant packing density. Also, a high heat transfer coefficient up to 100 W/m^2 K and low cooling fluid temperature of 283 K is necessary for speeding up the process. High initial bed temperature also supports greater adsorption amount under the same conditions.

In the present study, the CO_2 adsorption isotherms of activated carbons are measured using a Sievert's type experimental setup at wide range of temperatures from 273 to 358 K. Experimental data of CO_2 adsorption isotherms is modelled using Langmuir, Tóth, Dubinin-Astakhov (D-A) and modified Dubinin-Astakhov model. Pseudo-saturation pressure of CO_2 plays a significant role in the estimation of thermodynamic properties of supercritical gas adsorption, and it is evaluated using measured adsorption isotherms data. The thermodynamic properties namely isosteric heat of adsorption at surface loading, Gibbs free energy, and entropy are evaluated using classical Clausius-Clapeyron equation and Dubinin-Astakhov model for both subcritical and supercritical phases of CO_2 respectively. Adsorbed phase specific heat capacity, entropy, and enthalpy are also estimated.

The adsorption kinetics of CO_2 on activated carbons (AC1, AC2, AC3 and CSAC) are measured at different supply pressures (1, 5, 10 and 20 bar) and temperatures (298, 308, 318 and 338 K) using volumetric method. Activation energies at different pressures are calculated by fitting the Arrhenius equation to the adsorption kinetics data. Analysis of mechanism of

interaction between CO_2 molecules and adsorbents during the adsorption process is attempted using interparticle and Boyd's diffusion models. It has been found that the film-diffusion is an important rate controlling step in CO_2 adsorption process.

The adsorption-based cooling/heating systems have been paid more attention owing to free of moving parts, simpler control, lesser operational cost and utilization of waste heat. They are non-toxic and eco-friendly as compared to the mechanical vapor compression cooling systems. CO_2 has emerged as a next generation promising refrigerant for an adsorption-based cooling system for the possible applications in commercial/residential cooling, vehicle air-conditioning, and large refrigeration systems. The measured adsorption isotherms data and estimated thermodynamic properties are used for the thermodynamic analysis of single-stage and single-effect two-stage adsorption cooling system. The single-stage CO_2 based cooling system performance parameters in terms of maximum theoretical specific cooling effect (SCE) and coefficient of performance (COP) are estimated for the driving heat source temperature of 80°C at four cooling temperatures of 0, 5, 10 and 15°C with a fixed adsorption/condenser temperature of 25°C. All the four activated carbons are found suitable for developing CO_2-activated carbon pairs-based cooling system. The maximum SCE and COP are obtained as 25.87 kJ/kg and 0.10 respectively.

In addition, the performance of the adsorption cooling cycle in terms of the maximum theoretical SCE and COP of single-effect two-stage adsorption cooling system using CSAC at different driving heat source temperatures (80°C for single-stage and 65°C for single-effect two-stage) and evaporator temperatures (0, 5, 10 and 15°C) is estimated. The maximum values of specific cooling effect and coefficient of performance are obtained as 9.26 kJ/kg and 0.06 for single-stage and 8.85 kJ/kg and 0.04 for single-effect two-stage cooling system respectively.

This thesis presents important data related to experimental measurement and theoretical modelling of CO_2 adsorption isotherms and kinetics of activated carbons. Important thermodynamic properties are estimated from adsorption isotherms and kinetics data. Single-stage and single-effect two-stage adsorption refrigeration cycles are analyzed thermodynamically. The results obtained will add value to the knowledge base of CO_2 adsorption isotherms and kinetics, thermodynamic properties of activated carbons and CO_2 based adsorption cooling systems.

Annexure II: M.Tech. Thesis

Title: Energy and Exergy Analysis of a Steam Power Plant.

Thesis Supervisor: Prof. Rahul Salhotra (Professor, NIT Raipur)

Abstract: This work is based on the application of second law of thermodynamics for energy efficient design and operation of the conventional coal fired power generating stations. The steam power plant has been used for the analysis at both design conditions and at present working conditions. The usual energy analysis evaluates the energy generally on its quantity only. However, the exergy analysis assesses the energy on quantity as well as the quality. The primary objectives of this thesis are to analyze the system components separately and to identify and quantify the sites having larges energy and exergy losses. In addition, the effect of varying the reference environment state on this analysis will also be presented. The aim of the exergy analysis is to identify the magnitudes and the locations of real energy losses, in order to improve the existing systems, processes or components. This thesis deals with an energy and exergy analysis performed on an operating 36 MW unit of steam power plant at power station-1, Bhilai steel plant, Bhilai, India. The exergy losses occurred in the various subsystems of the plant and their components have been calculated using the mass, energy and exergy balance equations.

The comparison between the energy and exergy losses of the individual components of the plant shows that the maximum energy losses of 52.64 MW in occur in the condenser, whereas the maximum exergy losses of 55.52 MW occur in the boiler. On the other hand, the exergy analysis of the plant showed that energy lost in the condenser is thermodynamically insignificant due to its low quality. Energy loss in the boiler system, it was found to be 46.19% and also less than 4% for all other components. In addition, the calculated thermal and exergy efficiency of the power cycle was 33.86% and 30.25%, which is low compared to the modern power plants.

The major source of exergy destruction was the boiler system where chemical reaction in a combustion chamber is the most significant source. Exergy destruction in the combustion chamber is mainly affected by the excess air fraction and the temperature of the air at the inlet. The inefficiencies of combustion can be reduced by preheating the combustion air and reducing the air-fuel ratio. Although the percent exergy destruction and the exergy efficiency of each component in the system changed with reference environment temperature, the main conclusion remains the same; the boiler is the major source of irreversibility in the thermal power plant.

माध्यमिक शिक्षा मण्डल, मध्यप्रदेश, भोपाल

BOARD OF SECONDARY EDUCATION, MADHYA PRADESH, BHOPAL

हाई स्कूल सर्टिफिकेट परीक्षा (10+2) 2001

HIGH SCHOOL CERTIFICATE EXAMINATION (10+2) 2001

प्रमाणपत्र-सह अंकसूची स.क्र./S.No. 011437075

CERTIFICATE-CUM MARKSHEET

MARCH-APRIL-, **2001**

केन्द्र क्रमांक CENTRE NO.	संस्था क्रमांक SCHOOL No.	पंजीयन/नामांकन क्रमांक REGISTRATION/ ENROLMENT NO.	नियमित/स्वाध्यायी REGULAR/ PRIVATE	अनुक्रमांक ROLL NUMBER
93028	931153	9357145	REGULAR	19320697

प्रमाणित किया जाता है कि
CERTIFIED THAT

श्री/श्रीमती/कुमारी : SRI/SMT/KUM VINOD KUMAR SINGH जिनके WHOSE

पिता/पति का नाम श्री : FATHER'S/HUSBAND'S NAME IS SRI GOKARAN SINGH

माता का नाम श्रीमती : MOTHER'S NAME IS SMT PREMA DEVI

तथा जन्मतिथि : AND DATE OF BIRTH IS **16.04.1986** SIXTEENTH APRIL -NINETEEN EIGHTY SIX है

हाईस्कूल सर्टिफिकेट परीक्षा में संस्था/केन्द्र** से सम्मिलित हुए

HAS APPEARED IN THE HIGH SCHOOL CERTIFICATE EXAMINATION FROM **SCHOOL/CENTRE B S P H S SCHOOL SEC 2 BHILAI (DURG)

एवं उनका परीक्षाफल रहा।

AND HAS BEEN DECLARED, PASS IN **FIRST** DIVISION .

उनके द्वारा विषयवार निम्नानुसार प्राप्तांक अर्जित किए गए :-

SUBJECTWISE MARKS OBTAINED BY HIM/HER ARE AS UNDER :-

विषय/SUBJECTS		अधिकतम अंक MAX. MARKS	न्यूनतम उत्तीर्णांक MIN. PASS MARKS		प्राप्तांक/MARKS OBTAINED			विशेष REMARKS
			सैद्धांतिक THEORY	प्रायोगिक PRACTICAL	सैद्धांतिक THEORY	प्रायोगिक PRACTICAL	योग TOTAL	
ENGLISH	(SPECIAL)	100	33	--	044	--	044	
HINDI	(GENERAL)	50	17	--	042	--	042	DISTN
SANSKRIT	(GENERAL)	50	17	--	033	--	033	
MATHEMATICS		100	33	--	087	--	087	DISTN
SCIENCE		100	25	08	046	018	064	
SOCIAL SCIENCES		100	33	--	075	--	075	DISTN
		500					**345**	← महायोग GRAND TOTAL

महायोग शब्दों में : TOTAL IN WORDS : THREE HUNDRED FORTY FIVE ***

प्राचार्य के हस्ताक्षर एवं पद मुद्रा / Seal and Signature of Principal

PRINCIPAL
BHILAI VIDYALAYA
Sector-2 Bhilai

Adm No 16772

(केवल नियमित छात्र/छात्रा के लिए For Regular Students only)
निम्नांकित आंतरिक विषयों में निपुणता प्राप्त की :-
Attained Proficiency in the following internal subjects :-

(1) समाजोपयोगी उत्पादक कार्य Socially useful Productive work.

(2) शारीरिक एवं नैतिक शिक्षा Physical and Moral Education.

Dipali Rastogi

सचिव/SECRETARY

(कृ.पृ.उ.देखें)

छत्तीसगढ़ माध्यमिक शिक्षा मण्डल, रायपुर
CHHATTISGARH BOARD OF SECONDARY EDUCATION, RAIPUR
हायर सेकण्डरी स्कूल सर्टिफिकेट परीक्षा (10+2) 2003
HIGHER SECONDARY SCHOOL CERTIFICATE EXAMINATION (10+2) 2003
FEB-MARCH, 2003

स.क्र. /S.No. 000248174

प्रमाणपत्र–सह–अंकसूची
CERTIFICATE-CUM-MARKSHEET

केन्द्र क्रमांक CENTRE NO.	संस्था क्रमांक SCHOOL NO.	पंजीयन / नामांकन क्रमांक REGISTRATION/ ENROLMENT NO.	नियमित / स्वाध्यायी REGULAR/ PRIVATE	अनुक्रमांक ROLL NUMBER
13026	131153	9357145	REGULAR	21319197

प्रमाणित किया जाता है कि
CERTIFIED THAT

श्री / श्रीमती / कुमारी : SRI/SMT/KUM **VINOD KUMAR SINGH** जिनके WHOSE

पिता / पति का नाम श्री : FATHER'S/HUSBAND'S NAME IS SRI **GOKARAN SINGH**

माता का नाम श्रीमती : MOTHER'S NAME IS SMT. **PREMA DEVI** है

हायर सेकण्डरी स्कूल सर्टिफिकेट परीक्षा में संस्था / केन्द्र से सम्मिलित हुए
HAS APPEARED IN THE HIGHER SECONDARY SCHOOL CERTIFICATE EXAMINATION FROM
** SCHOOL/CENTRE **B S P H S SCHOOL SECTOR-2 BHILAI DURG**

एवं उनका परीक्षाफल रहा।
AND HAS BEEN DECLARED **PASSED IN FIRST DIVISION.**

उनके द्वारा विषयवार निम्नानुसार प्राप्तांक अर्जित किए गए :–
SUBJECTWISE MARKS OBTAINED BY HIM/HER ARE AS UNDER :-

विषय / SUBJECTS	अधिकतम अंक MAX. MARKS	न्यूनतम उत्तीर्णांक MIN. PASS. MARKS		प्राप्तांक / MARKS OBTAINED				विशेष REMARKS
		सैद्धांतिक THEORY	प्रायोगिक PRACTICAL	सैद्धांतिक THEORY	प्रायोगिक PRACTICAL	योग / TOTAL अंकों में	योग / TOTAL शब्दों में	
HINDI (SPECIAL)	100	33	-	068	-	068	SIX EIGHT	
ENGLISH (GENERAL)	100	33	-	056	-	056	FIVE SIX	
MATHEMATICS	100	33	-	063	-	063	SIX THREE	
PHYSICS	100	25	08	056	021	077	SEVEN SEVEN	DISTN
CHEMISTRY	100	25	08	062	025	087	EIGHT SEVEN	DISTN
ADDITIONAL SUBJECT IF ANY ↓	500					351		← महायोग GRAND TOTAL

महायोग शब्दों में : GRAND TOTAL IN WORDS : **THREE HUNDRED FIFTY ONE*****

(केवल नियमित छात्र / छात्रा के लिए For Regular Students only)
निम्नांकित आंतरिक विषयों में निपुणता प्राप्त की Attained Proficiency in the following internal subjects :
(1) समाजोपयोगी उत्पादक कार्य Socially useful Productive work. (2) शारीरिक एवं नैतिक शिक्षा Physical and Moral Education.

प्राचार्य के स्याही से हस्ताक्षर एवं पद मुद्रा
Seal and Signature of Principal in Ink

Sr. Principal
Bhilai Vidyalaya, Sector-2

सचिव / SECRETARY

(कृ.पृ.उ.देखें)

पं. रविशंकर शुक्ल विश्वविद्यालय, रायपुर (छ.ग.)

Pt. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR C.G.

Grade Sheet

BE I-SEMESTER Examination Feb-March 2004

Roll No 46432

En No. NN/25909

Name VINOD KUMAR SINGH

Father's Name GOKARAN SINGH

Mother's Name Smt. PREMA DEVI

A.R.(E) Pt.R.S.S.U.

Center Name RUNGTA COLLEGE OF ENGG.& TECHNOLOGY.DURG.

Subject	L	T	P	Credit	GA	GP	CP
LANGUAGE(PROFESSIONAL COMM.IN ENGLISH	2	1	0	3	BC	7	21
ENGG.CHEMISTRY	2	1	2	4	BB	8	32
ENGG.PHYSICS	3	1	2	5	BB	8	40
MATHEMATICS	3	1	0	4	BB	8	32
ENGG.MECHANICS	3	1	2	5	CC	6	30
BASIC ELECTRICAL ENGG.	3	1	2	5	BC	7	35
ENGG.GRAPHICS-I	0	0	4	2	AA	10	20
WORKSHOP PRACTICE-I	0	0	4	2	AA	10	20
GENERAL PROFICIENCY	2	0	0	2	AA	10	20
Grand Totals				32			250

	SEM1	SEM2	SEM3	SEM4	SEM5	SEM6	SEM7	SEM8
SPI	7.81	*	*	*	*	*	*	*

Date :

Dy. Registrar
Pt. Ravishankar Shukla University

Registrar
Pt. R.S. Shukla University, Raipur (C.G.)

पं. रविशंकर शुक्ल विश्वविद्यालय, रायपुर (छ.ग.)

Pt. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR (C.G.)

Grade Sheet

BE II-SEMESTER Examination August - 2004

Roll No. 46432
Enrollment No. NN 25909

Name VINOD KUMAR SINGH
Father's Name GOKARAN SINGH
Mother's Name Smt. PREMA DEVI

Center Name RUNGTA COLLEGE OF ENGG.& TECHNOLOGY,DURG.

Subject	L	T	P	Credit	GA	GP	CP
INTRODUCTION TO COMPUTING	2	1	0	3	AB	9	27
ENVIRONMENT & ECOLOGY	2	1	2	4	AB	9	36
ENGINEERING PHYSICS-II	3	1	2	5	BB	8	40
MATHEMATICS-II	3	1	0	4	CC	6	24
ENGG.THERMODYNAMICS	3	1	2	5	CC	6	30
BASIC ELECTRONICS	3	1	2	5	BC	7	35
ENGG.GRAPHICS-II	0	0	4	2	AA	10	20
WORKSHOP PRACTICE-II	0	0	4	2	AA	10	20
GENERAL PROFICIENCY	2	0	0	2	AA	10	20
Grand Totals				32			252

	SEM1	SEM2	SEM3	SEM4	SEM5	SEM6	SEM7	SEM8
SPI	~~7.87~~	~~*~~ 7.87	*	*	*	*	*	*

Date : 27 NOV 2004

Section Officer (Exam.)
Pt. R.S.U., RAIPUR

Registrar
Pt. R.S. Shukla University, Raipur (C.G.)
J. S. D. (Exam.)
Pt Ravishankar Shukla University
RAIPUR (C. G.)

पं. रविशंकर शुक्ल विश्वविद्यालय, रायपुर (छ.ग.)

Pt. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR (C.G.)

Grade Sheet

BE SEM.- III MECHANICAL ENGG. January - 2005

Roll No.	46432	**Name**	VINOD KUMAR SINGH
Enrollment No.	NN 25909	**Father's Name**	GOKARAN SINGH
		Mother's Name	Smt. PREMA DEVI

Center Name RUNGTA COLLEGE OF ENGG.& TECHNOLOGY,BHILAI

Subject	L	T	P	Credit	GA	GP	CP
COMPUTER GRAPHICS	2	1	3	5	AB	9	45
MATERIAL SCIENCE	2	1	0	3	BB	8	24
STRENGTH OF MATERIALS	3	1	0	4	AB	9	36
FLUID MECHANICS	3	1	3	6	BB	8	48
MANUFACTURING SCIENCE-I	3	1	3	6	BC	7	42
MATHEMATICS-III	3	1	0	4	CC	6	24
MATERIAL TESTING	0	0	3	2	AA	10	20
GENERAL PROFICIENCY	2	0	0	2	AA	10	20
Grand Totals				32			259

	SEM1	SEM2	SEM3	SEM4	SEM5	SEM6	SEM7	SEM8
SPI	*	*	8.09	*	*	*	*	*

Date : 20/04/2005

O. S. D. (Exam.-Semo.)
Pt. Ravishankar Shukla University
RAIPUR (C.G.)

Registrar
Pt. R.S. Shukla University, Raipur (C.G.)

पं. रविशंकर शुक्ल विश्वविद्यालय, रायपुर (छ.ग.)

Pt. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR (C.G.)

Grade Sheet

B.E. SEM. 4TH MECHANICAL ENGG. MAY.2005

Roll No.	46432	**Name**	VINOD KUMAR SINGH
Enrollment No.	NN 25909	**Father's Name**	GOKARAN SINGH
		Mother's Name	Smt. PREMA DEVI

Center Name RUNGTA COLLEGE OF ENGG.& TECHNOLOGY,BHILAI

Subject	L	T	P	Credit	GA	GP	CP
MECH.MEASUREMENTS & METROLOGY	2	1	3	5	AB	9	45
MANUFACTURING SCIENCE-II	2	1	0	3	BC	7	21
APPLIED THERMODYNAMICS	3	1	3	6	BB	8	48
ADVANCE STRENGTH OF MATERIALS	3	1	0	4	BC	7	28
KINEMATICS OF MACHINE	3	1	3	6	BB	8	48
NUMERICAL ANALYSIS &COMPUTER PROG.(C,	3	1	3	6	BB	8	48
GENERAL PROFICIENCY	0	0	0	2	AA	10	20
Grand Totals				32			258

	SEM1	SEM2	SEM3	SEM4	SEM5	SEM6	SEM7	SEM8
SPI	*	*	*	8.06	*	*	*	*

Date : 24/10/2005

O. S. D. [Exam.-Secre.]
Pt. Ravishankar Shukla University
Registrar
Pt. R.S. Shukla University, Raipur (C.G.)

पं. रविशंकर शुक्ल विश्वविद्यालय, रायपुर (छ.ग.)

Pt. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR (C.G.)

Grade Sheet

B.E SEM.-5TH MECHANICAL ENGG. NOV.2005

Roll No. 46432
Enrollment No. NN 25909

Name VINOD KUMAR SINGH
Father's Name GOKARAN SINGH
Mother's Name Smt. PREMA DEVI

Center Name RUNGTA COLLEGE OF ENGG.& TECHNOLOGY,BHILAI

Subject	L	T	P	Credit	GA	GP	CP
MANAGEMENT SCIENCE	2	1		3	AB	9	27
INTERNAL COMBUSTION ENGINE	2	1	3	5	BB	8	40
TURBO MACHINERY	3	1		4	AB	9	36
MACHINE DESIGN-I	3	1	3	6	BB	8	48
DYNAMICS OF MACHINE	3	1	3	6	BB	8	48
FLUID MACHINERY	3	1	3	6	AB	9	54
GENERAL PROFICIENCY				2	AA	10	20
Grand Totals				32			273

	SEM1	SEM2	SEM3	SEM4	SEM5	SEM6	SEM7	SEM8
SPI	*	*	*	*	8.53	*	*	*

REMARKS

Date : 04/04/2006

O.S.D. (Exam.)
Pt. Ravishankar Shukla University
RAIPUR (C.G.)

Registrar
Pt. R.S. Shukla University, Raipur (C.G.)

पं. रविशंकर शुक्ल विश्वविद्यालय, रायपुर (छ.ग.)

Pt. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR (C.G.)

Grade Sheet

B.E.SEM.-6TH MECHANICAL ENGG. MAY.2006

Roll No. 46432
Enrollment No. NN 25909

Name VINOD KUMAR SINGH
Father's Name GOKARAN SINGH
Mother's Name Smt. PREMA DEVI

Center Name RUNGTA COLLEGE OF ENGG.& TECHNOLOGY,BHILAI

Subject	L	T	P	Credit	GA	GP	CP
PROJECT MANAGEMENT & BUSINESS MANAGE	2	1		3	BB	8	24
INDUSTRIAL ENGINEERING	2	1		3	BC	7	21
PRODUCT DEVELOPMENT	3	1		4	BC	7	28
MACHINE DESIGN-II	3	1	3	6	AB	9	54
ENERGY CONVERSION SYSTEM	3	1	3	6	BB	8	48
OPERATION RESEARCH	3	1	3	6	AA	10	60
COMPUTER AIDED DRAFTING			3	2	AB	9	18
GENERAL PROFICIENCY				2	AA	10	20
Grand Totals				32			273

	SEM1	SEM2	SEM3	SEM4	SEM5	SEM6	SEM7	SEM8
SPI	*	*	*	*	*	8.53	*	*

REMARKS

Date : 21/11/2006

Deputy Registrar (Exam.)
Pt. Ravishankar Shukla University
RAIPUR (C. G.)

Registrar
Pt. R.S. Shukla University, Raipur (C.G.)

पं. रविशंकर शुक्ल विश्वविद्यालय, रायपुर (छ.ग.)

Pt. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR (C.G.)

Grade Sheet

B.E. SEM. -7TH MECHANICAL ENGG. JAN.2007

Roll No. 46432
Enrollment No. NN 25909

Name VINOD KUMAR SINGH
Father's Name GOKARAN SINGH
Mother's Name Smt. PREMA DEVI

Center Name RUNGTA COLLEGE OF ENGG.& TECHNOLOGY,BHILAI

Subject	L	T	P	Credit	GA	GP	CP
AUTOMOBILE ENGINEERING	2	1	3	5	AB	9	45
HEAT & MASS TRANSFER	3	1	3	6	BB	8	48
COMPUTER AIDED DESIGN	3	1	3	6	AB	9	54
ENTREPRENEURSHIP	2	1		3	AB	9	27
QUALITY CONTROL & MAINTENANCE ENGG.	3	1		4	AB	9	36
PROJECT SEMINAR			7	4	AA	10	40
GENERAL PROFICIENCY				2	AA	10	20
Grand Totals				30			270

	SEM1	SEM2	SEM3	SEM4	SEM5	SEM6	SEM7	SEM8
SPI	*	*	*	*	*	*	9.00	*

REMARKS

Date : 20/04/2007

JRGond
Registrar
Pt. R.S. Shukla University, Raipur (C.G.)
Assistant Registrar (Exam.)
Pt. Ravishankar Shukla University
RAIPUR (C. G.)

पं. रविशंकर शुक्ल विश्वविद्यालय, रायपुर (छ.ग.)

Pt. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR (C.G.)

Grade Sheet

B.E.SEM.-8TH MECHANICAL ENGG. APRIL-2007

Roll No. 46432 **Name** VINOD KUMAR SINGH

Enrollment No. NN 25909 **Father's Name** GOKARAN SINGH

Mother's Name Smt. PREMA DEVI

Center Name RUNGTA COLLEGE OF ENGG.& TECHNOLOGY,BHILAI

Subject	L	T	P	Credit	GA	GP	CP
ENGINEERING ECONOMICS	3	1		4	AB	9	36
REFRIGERATION & AIR CONDITIONING	4	1	3	7	BB	8	56
POWER PLANT ENGINEERING	4	1		5	BB	8	40
MACHINE TOOL DESIGN	3	1		4	AB	9	36
ROBOTICS MECHATRONICS	4	1		5	BC	7	35
PROJECT SEMINAR			8	4	AA	10	40
GENERAL PROFICIENCY				2	AA	10	20
Grand Totals				31			263

SEM	CP	CREDIT
First	250	32
Second	252	32
Third	259	32
Fourth	258	32
Fifth	273	32
Sixth	273	32
Seventh	270	30
Eighth	263	31

SPI - 8.48

CPI - 8.35

RESULT PASS 1ST WITH HONOURS

Date : 28/06/2007

JRGond

Registrar

Pt. R.S. Shukla University, Raipur (C.G.)

Assistant Registrar (Exam.)

Pt. Ravishankar Shukla University

RAIPUR (C. G.)

क्रम संख्या - 46432 ROLL No. 46432

पं. रविशंकर शुक्ल विश्वविद्यालय रायपुर

PT. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR

बैचलर ऑफ इंजीनियरिंग
(BACHELOR OF ENGINEERING)

प्रमाणित किया जाता है कि

विनोद कुमार सिंह

ने 2006 में इस विश्वविद्यालय की बैचलर ऑफ इंजीनियरिंग परीक्षा प्रथम श्रेणी में ऑनर्स सहित उत्तीर्ण की। उन्हें आज मैकेनिकल इंजीनियरिंग में बैचलर ऑफ इंजीनियरिंग की उपाधि प्रदान की जाती है।

This is to certify that

Vinod Kumar Singh

having passed the **Bachelor of Engineering** Examination of 2007 of the University in the First Division, With Honours is admitted today to the Degree of the **Bachelor of Engineering** in Mechanical Engineering.

रायपुर, दिनांक
Raipur, Dated 10 JAN 2008
Issued on.... 31 JUL 2008

(LAKSHMAN CHATURVEDI)
कुलपति
KULPATI

NATIONAL INSTITUTE OF TECHNOLOGY RAIPUR (C.G.) 492 010

Master of Technology (Two Year Post Graduate Course)

FIRST SEMESTER EXAMINATION JULY 2009

MARK SHEET

CSVTU SCHEME

NAME: VINOD KUMAR SINGH
FATHER'S NAME: SHRI GOKARAN SINGH
MOTHER'S NAME: SMT. PREMA DEVI

SPECIALIZATION: ENERGY SYSTEM AND POLLUTION
DEPARTMENT: MECHNICAL ENGINEERING

ROLL NO.: 08229008
ENROLLMENT NO.: 080820

SUBJECT	E.S.E. MARKS		C.T. MARKS		T.A. MARKS		TOTAL MARKS		GRADE	GRADE POINT	CREDITS EARNED
	MAX	OBT	MAX	OBT	MAX	OBT	MAX	OBT			
Conventional Energy Conversion System	100	69	20	18	20	18	140	105	A	9	4
Non-Conventional Energy Sources	100	58	20	18	20	18	140	94	B+	8	4
Computation Method In Energy Systems	100	83	20	17	20	19	140	119	A+	10	4
Envirnmental Pollution & Control	100	81	20	16	20	18	140	115	A	9	4
Lab-I	75	69			75	66	150	135	A+	10	2
Lab-Ii	75	66			75	71	150	137	A+	10	2
Elective-I (Recent Advances In Heat Transfer)	100	44	20	18	20	18	140	80	B	7	4

CUMULATIVE PERFORMANCE

MAXIMUM MARKS	OBTAINED MARKS	DIVISION	CPI
1000	785	Honours	8.83

TOTAL: 1000 785

MARKS IN WORDS: SEVEN HUNDRED EIGHTY-FIVE

RESULT: PASS

SPI: 8.83 CREDITS EARNED:24

ABBREVIATIONS

- * Reappearance
- G Grace
- ABS Absent
- ESE End Semester Exam
- CT Class Test
- TA Teacher Assessment
- SPI Semester Performance Index
- CPI Cumulative Performance Index
- F Indicates failure in the Subject(s)

Prepared By

Checked By

Date 16-Dec-2009

Controller of Examination

DEAN (Academics)

NATIONAL INSTITUTE OF TECHNOLOGY RAIPUR (C.G.) 492 010

Master of Technology (Two Year Post Graduate Course)

SECOND SEMESTER EXAMINATION NOV. - DEC. 2009

MARK SHEET

CSVTU SCHEME

NAME: VINOD KUMAR SINGH
FATHER'S NAME: GOKARAN SINGH
MOTHER'S NAME: PREMA DEVI

SPECIALIZATION: ENERGY SYSTEM AND POLLUTION
DEPARTMENT: MECHANICAL ENGINEERING

ROLL NO.: 08229008
ENROLLMENT NO.: 080820

SUBJECT	E.S.E. MARKS		C.T. MARKS		T.A. MARKS		TOTAL MARKS		GRADE	GRADE POINT	CREDITS EARNED
	MAX	OBT	MAX	OBT	MAX	OBT	MAX	OBT			
Non-Convention Energy Systems	100	87	20	18	20	18	140	123	A+	10	4
Energy Management	100	78	20	17	20	17	140	112	A	9	4
Heat Exchanger Design	100	91	20	17	20	18	140	126	A+	10	4
Lab-I (Energy Lab)	75	72			75	70	150	142	A+	10	2
Lab-Ii (Pollution Lab)	75	68			75	67	150	135	A+	10	2
Elective-Ii (Noise And Pollution Monitoring Instrumentation)	100	68	20	19	20	19	140	106	A	9	4
Elective-Ii (Material Handing System)	100	59	20	14	20	18	140	91	B+	8	4

CUMULATIVE PERFORMANCE			
MAXIMUM MARKS	OBTAINED MARKS	DIVISION	CPI
2000	1620	Honours	9.08

TOTAL: 1000 835

MARKS IN WORDS: EIGHT HUNDRED THIRTY-FIVE

RESULT: PASS

SPI: 9.33 CREDITS EARNED:24

ABBREVIATIONS
- * Reappearance
- G Grace
- ABS Absent
- ESE End Semester Exam
- CT Class Test
- TA Teacher Assessment
- SPI Semester Performance Index
- CPI Cumulative Performance Index
- F Indicates failure in the Subject(s)

Prepared By	Checked By		Controller of Examination	DEAN (Academics)

Date 19-Jul-2010

NATIONAL INSTITUTE OF TECHNOLOGY RAIPUR (C.G.) 492 010

Master of Technology (Two Year Post Graduate Course)

THIRD SEMESTER EXAMINATION APRIL - MAY 2010

MARK SHEET

CSVTU SCHEME

NAME: VINOD KUMAR SINGH
FATHER'S NAME: GOKARAN SINGH
MOTHER'S NAME: PREMA DEVI

SPECIALIZATION: ENERGY SYSTEM AND POLLUTION
DEPARTMENT: MECHANICAL ENGINEERING

ROLL NO.: 08229008
ENROLLMENT NO.: 080820

SUBJECT	E.S.E. MARKS		C.T. MARKS		T.A. MARKS		TOTAL MARKS		GRADE	GRADE POINT	CREDITS EARNED
	MAX	OBT	MAX	OBT	MAX	OBT	MAX	OBT			
Design Of Thermal System (C)	100	80	20	16	20	18	140	114	A	9	4
Preliminary Work On Disseratation	100	88			100	93	200	181	A+	10	14
Seminar					20	18	20	18	A+	10	2
Elective-Iv (Alter. Fuel & Adv. In Internal Combus. Engine)	100	82	20	18	20	20	140	120	A+	10	4

TOTAL: 500 433

MARKS IN WORDS: FOUR HUNDRED THIRTY-THREE

RESULT: PASS

SPI: 9.83 **CREDITS EARNED:24**

CUMULATIVE PERFORMANCE

MAXIMUM MARKS	OBTAINED MARKS	DIVISION	CPI
2500	2053	Honours	9.33

ABBREVIATIONS
- * Reappearance
- G Grace
- ABS Absent
- ESE End Semester Exam
- CT Class Test
- TA Teacher Assessment
- SPI Semester Performance Index
- CPI Cumulative Performance Index
- F Indicates failure in the Subject(s)

Prepared By | Checked By

Date 22-Oct-2010

Controller of Examination

Dean (Academics)

NATIONAL INSTITUTE OF TECHNOLOGY RAIPUR (C.G.) 492 010

Master of Technology (Two Year Post Graduate Course)

FOURTH SEMESTER EXAMINATION DECEMBER 2011

MARK SHEET

CSVTU SCHEME

NAME: VINOD KUMAR SINGH
FATHER'S NAME: GOKARAN SINGH
MOTHER'S NAME: PREMA DEVI

SPECIALIZATION: ENERGY SYSTEM AND POLLUTION
DEPARTMENT: MECHANICAL ENGINEERING

ROLL NO.: 08229008
ENROLLMENT NO.: 080820

SUBJECT	E.S.E. MARKS		C.T. MARKS		T.A. MARKS		TOTAL MARKS		GRADE	GRADE POINT	CREDITS EARNED
	MAX	OBT	MAX	OBT	MAX	OBT	MAX	OBT			
Dissertation + Seminar	300	290			200	190	500	480	A+	10	23
MARKS IN WORDS: FOUR HUNDRED EIGHTY						**TOTAL:**	**500**	**480**	**CREDITS EARNED:**		**23**

RESULT: PASS

SPI: 10.00

STATEMENT OF MARKS AND CUMULATIVE PERFORMANCE

SEMESTER	I	II	III	IV	GRAND TOTAL	
MAXIMUM	1000	1000	500	500	MAXIMUM	OBTAINED
OBTAINED	785	835	433	480	3000	2533
SPI	8.83	9.33	9.83	10.00	PERCENTAGE: 84.43 %	
CPI	8.83	9.08	9.33	9.49	RESULT	
DIVISION	Honours	Honours	Honours	Honours	PASSED WITH HONOURS	

ABBREVIATIONS

- G Grace
- ABS Absent
- ESE End Semester Exam
- CT Class Test
- TA Teacher's Assessment
- SPI Semester Performance Index
- CPI Cumulative Performance Index
- F Indicates failure in the Subject(s)

Prepared By	Checked By	Date 09-Jan-2012	Controller of Examination	Dean (Academics)

(For details of Grading System and other rules see overleaf)

Roll No. : 08229008 **Enroll. No. :** 080820

राष्ट्रीय प्रौद्योगिकी संस्थान रायपुर

NATIONAL INSTITUTE OF TECHNOLOGY RAIPUR

छत्तीसगढ़, भारत

CHHATTISGARH, INDIA

मास्टर ऑफ़ टेक्नोलॉजी

MASTER OF TECHNOLOGY

प्रमाणित किया जाता है कि **विनोद कुमार सिंह** ने वर्ष **2011** में इस संस्था द्वारा आयोजित **मास्टर ऑफ़ टेक्नोलॉजी** की परीक्षा **एनर्जि सिस्टम एण्ड पॉल्यूशन** में विशिष्टता सहित **मेकेनिकल इंजीनियरिंग** विभाग से **ऑनर्स सहित** उत्तीर्ण की, इन्हें **मास्टर ऑफ़ टेक्नोलॉजी** की उपाधि प्रदान की जाती है।

This is to certify that **VINOD KUMAR SINGH** having passed the **MASTER OF TECHNOLOGY** examination with specialization in **ENERGY SYSTEM & POLLUTION** from the Department of **MECHANICAL ENGINEERING** of this institute **WITH HONOURS**, in the year **2011**, is being awarded the degree of **MASTER OF TECHNOLOGY.**

कुल सचिव
Registrar

निदेशक एवं अध्यक्ष, अभिषद
Director &
Chairperson, Senate

अध्यक्ष, शासी निकाय
Chairman
Board of Governors

रायपुर, 19 मई 2012
Raipur, 19 May 2012

भारतीय प्रौद्योगिकी संस्थान इन्दौर
INDIAN INSTITUTE OF TECHNOLOGY INDORE

सत्र ग्रेड रिपोर्ट / SEMESTER GRADE REPORT

दिनांक / Date: July 17, 2013

छात्र / छात्रा का नाम Student's Name	रोल नं. Roll No.	सत्र Semester	वर्ष Year	विभाग कोड Deptt. Code
Vinod Kumar Singh	**12120304**	Spring 2013	1	ME

कार्यक्रम / Programme: **Ph.D.**
विभाग / Department: **Mechanical Engineering**

पाठ्यक्रम कोड Course Code	पाठ्यक्रम नाम Course Name	पाठ्यक्रम अंक Course Credit	अर्जित ग्रेड Grade Obtained
ME 601	Principles of Measurements	4.0	AB
ME 618	Computational Fluid Dynamics (CFD)	3.0	BC
ME 798	Seminar Course	2.0	AB

चालू सत्र प्रदर्शन Current Semester Performance			संचित प्रदर्शन Cummulative Performance		
कुल पंजीकृत अंक Total Credit Registered	ग्रेड प्वाइंट Grade Points	एसपीआई SPI	कुल पंजीकृत अंक Total Credit Registered	ग्रेड प्वाइंट Grade Points	सीपीआई CPI
9.0	75.0	8.33	9.0	75.0	8.33

उप कुलसचिव (शैक्षिक)
Deputy Registrar (Academic)

Dy. Registrar (Academic)
IIT Indore

भारतीय प्रौद्योगिकी संस्थान इन्दौर
शैक्षणिक विभाग
खण्डवा रोड, सिमरोल इन्दौर - ४५३ ५५२ मध्यप्रदेश, भारत

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Khandwa Road, Simrol, Indore - 453 552, Madhya Pradesh, India

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PROVISIONAL DEGREE CERTIFICATE

This is to certify that

Vinod Kumar Singh

Roll no. 12120304

has successfully completed all the prescribed requirements for award of the degree of

Doctor of Philosophy (Ph.D.)
in
Mechanical Engineering

of the Institute securing a CPI of 8.33 out of the maximum CPI of 10.00
on **October 23, 2017.**

The title of his thesis is:
"Measurement of CO_2 Adsorption Isotherms and Kinetics of Activated Carbons Suitable for the Development of CO_2 based Adsorption Cooling Systems"

The degree shall, however, be conferred at the next convocation subject to the ratification by the Senate and Board of Governors of the Institute.

P. Sant — 27/10/17

Date: October 27, 2017
Place: Indore

Dy. Registrar, Academic Affairs

Dy. Registrar (Academic)
IIT Indore

MADANAPALLE INSTITUTE OF TECHNOLOGY & SCIENCE
(UGC - AUTONOMOUS)

PROCEEDINGS No. MITS/Estt./H.R/Appt.271/2017-18, Dated: 08/01/2018

Appointment Order

In pursuance of the Selection Committee's report dated 22.12.2017, Dr. Vinod Kumar Singh, S/o. Shri Gokaram Singh, resident of Bhilai is appointed as a Sr. Assistant Professor – 2 in the Department of Mechanical Engineering in this institute and he will be paid gross salary of Rs. 1,08,726/- p.m. as per AICTE VII Pay Scale.

In order to provide stability to the career of the selected applicant and enable him to complete the projects he may handle, a minimum service of 2 years is stipulated. However, probation will be only for a period of one year. If the applicant desires to leave, he needs to give two month's prior notice or pay 2 month's salary in lieu of notice period.

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- He shall abide by the rules & regulations of the college.

He shall report to duty on 08.01.2018.

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To
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EXPERIENCE CERTIFICATE

This is to certify that **Mr. Vinod Kumar Singh was** working in **Christian College of Engineering & Technology**, Bhilai as **"Assistant Professor"** in the **Department of Mechanical Engineering** of this institution from **03.01.2011 to 10.12.2012.**

This certificate is being issued on his request for his own accord.

M.V. 11/12/12

Dr.M.Venu Gopala Rao,
Director

Director
Christian College
of Engg. & Tech., Bhilai
Pin : 490026

11/12

List of Publications

List of Journal Publications:

1. **Vinod Kumar Singh,** E. Anil Kumar, Measurement and analysis of adsorption isotherms of CO_2 on activated carbon, ***Applied Thermal Engineering*** 97 (2016) 77-86. (I.F. - 3.771) (ISBN No.: 1359-4311)
2. **Vinod Kumar Singh,** E. Anil Kumar, Measurement of CO_2 adsorption kinetics on activated carbons suitable for gas storage systems, ***Greenhouse Gases: Science and Technology*** 7 (1) (2017) 182-201. (I.F. - 1.991) (ISBN No.: 2152-3878)
3. **Vinod Kumar Singh,** E. Anil Kumar, Experimental investigation and thermodynamic analysis of CO_2 adsorption on activated carbons for cooling system, ***Journal of CO_2 Utilization*** 17 (2017) 290-304. (I.F. – 5.503) (ISBN No.: 2212-9820)
4. **Vinod Kumar Singh,** E. Anil Kumar, Thermodynamic analysis of single-stage and single-effect two-stage adsorption cooling cycles using indigenous coconut shell based activated carbon-CO_2 pair, ***International Journal of Refrigeration*** 84 (2017) 238-252. (I.F. – 3.233) (ISBN No.: 0140-7007)
5. **Vinod Kumar Singh,** E. Anil Kumar, B.B. Saha, Measurement of adsorption isotherms, kinetics and thermodynamic simulation of CO_2-CSAC pair for adsorption chiller application, ***Energy*** 160 (2018) 1158-1173. (I.F. – 4.968) (ISBN No.: 0360-5442)

List of Conference Proceedings:

1. **Vinod Kumar Singh**, E. Anil Kumar, Comparative studies on CO_2 adsorption kinetics by solid adsorbents, ***Energy Procedia*** 90 (2016) 316-325. (ISBN No.: 1876-6102)
2. **Vinod Kumar Singh**, E. Anil Kumar, Comparative studies on CO_2 adsorption isotherms by solid adsorbents, ***Materials Today Proceedings*** 5 (11) (2018) 23033-23042. (ISBN No.: 2214-7853)
3. Reema Saxena, **Vinod Kumar Singh**, E. Anil Kumar, Carbon dioxide capture and sequestration by adsorption on activated carbon, ***Energy Procedia*** 54 (2014) 320-329. (ISBN No.: 1876-6102)
4. **Vinod Kumar Singh**, E. Anil Kumar, Estimation of thermodynamic properties of CO_2 adsorption on activated carbon, **Springer Proceedings in Energy**. (Accepted)

List of International Conferences based on Ph.D. Thesis:

1. **Vinod Kumar Singh**, E. Anil Kumar, Estimation of thermodynamic properties of CO_2 adsorption on activated carbon, ***6th International Conference on Advances in Energy Research (ICAER 2017)***, IIT Bombay, 12th-14th December 2017, Mumbai, India.
2. **Vinod Kumar Singh**, E. Anil Kumar, Characterization of carbon dioxide adsorption isotherms and kinetics on activated carbon for cooling system, ***IVth International Symposium on Innovative Materials for Processes in Energy Systems 2016 (IMPRES 2016)***, Hotel Villa Diodoro, Taormina, 23rd-26th October, Sicily, Italy.
3. **Vinod Kumar Singh**, E. Anil Kumar, Comparative studies on CO_2 adsorption kinetics by solid adsorbents, ***5th International Conference on Advances in Energy Research (ICAER 2015)***, IIT Bombay, pp. 968-975, 15th-17th December 2015, Mumbai, India.
4. **Vinod Kumar Singh**, E. Anil Kumar, Comparative studies on CO_2 adsorption isotherms by solid adsorbents, ***5th International Conference on Advances in Energy Research (ICAER 2015)***, IIT Bombay, pp. 959-967, 15th-17th December 2015, Mumbai, India.
5. **Vinod Kumar Singh**, E. Anil Kumar, Studies on adsorption isotherm and kinetics of CO_2 by activated carbon, ***International Conference on Polygeneration (ICP 2015)***, Anna University, 18th-20th February 2015, Chennai, India.
6. **Vinod Kumar Singh**, E. Anil Kumar, Studies on CO_2 adsorption by activated carbon, ***International Conference on Environment and Energy (ICEE 2014)***, JNTU Hyderabad, 15th-17th December 2014, Hyderabad, India. (ISBN: 978-93-81212-96-7).
7. Reema Saxena, **Vinod Kumar Singh**, E. Anil Kumar, Carbon dioxide capture and sequestration by adsorption on activated carbon, ***4th International Conference on Advances in Energy Research (ICAER 2013)***, IIT Bombay, pp. 785-793, 10th-12th December 2013, Mumbai, India. (ISBN: 978-81-928795-0-5)
8. **Vinod Kumar Singh**, Rahul Salhotra, Energy and exergy analysis of a 36 MW thermal power plant, ***1st International Conference on Mechanical Engineering: Emerging Trends for Sustainability***, MANIT Bhopal, pp. 1069-1077, 29th-31st January 2014, Bhopal, India.

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Research Paper

Measurement and analysis of adsorption isotherms of CO_2 on activated carbon

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A B S T R A C T

In the present work CO_2 adsorption isotherms of a commercially available activated carbon, Norit Darco type obtained from lignite granular material, were measured. Adsorption isotherms were measured at different temperatures 298 K, 308 K, 318 K and 338 K and over a pressure range of 0–45 bar using Sievert's type experimental setup. Experimental data of CO_2 adsorption isotherms were modelled using Langmuir and Dubinin–Astakhov (D–A) isotherm models. Based on coefficient of correlation and normalized standard deviation it was found that D–A isotherm model was well suited with the experimental data of CO_2 adsorption isotherms. The important thermodynamic properties viz., limiting heat of adsorption at zero coverage, entropy, Gibbs free energy and isosteric heat of adsorption as a function of surface coverage were evaluated using van't Hoff and Clausius–Clapeyron equations. These thermodynamic properties were indicating that CO_2 uptake by activated carbon is a physisorption phenomenon. The adsorption isotherms data and the thermodynamic parameters estimated in the present study are useful for designing of an adsorption based gas storage systems.

1. Introduction

Development of modern civilization has led to rapid utilization of fossil fuels. As a consequence emission of carbon dioxide (CO_2) has substantially increased. CO_2 is released to atmosphere as a component in flue gases emitted by power plants, gas processing industries, refineries, chemical and petrochemical industries, iron and steel industries and cement industries. These industries are mainly responsible for anthropogenic CO_2 emissions [1]. The International Panel on Climate Change (IPCC) estimates that average CO_2 concentration level may rise to 570 ppm by the year 2100 causing an increase in mean sea level height from the reference of 38 cm and the rise in mean global average temperature of about 1.9 °C [2,3]. Several approaches have been suggested and implemented for reducing the concentration level of CO_2 in the environment: (1) improve the energy efficiency, (2) reduce the CO_2 emission by expanding non-fossil fuels like hydrogen, nuclear energy and renewable energy, (3) capturing the CO_2. The most suitable approach among these is capturing CO_2 from power industries [4].

Adsorption is considered as the most promising and versatile technique among other available processes likes absorption, cryogenic separation, membrane separation and micro algal bio fixation for CO_2 separation. The advantages are reduction in cost of CO_2 separation, increased CO_2 carrying capacity, lower regeneration energy requirements and minimum pressure drop [5,6]. According to the literature, the activated carbons are one of the most appropriate aspirants for CO_2 separation/capture, adsorption capacity of CO_2 being dependent on the adsorbent qualities viz., surface area, pore structure and the properties of surface chemistry [7,8]. Activated carbons are inexpensive and insensitive to moisture. They exhibit high surface area, high CO_2 adsorption capacity and thermal stability [9,10]. Physical adsorption on activated carbons has been widely used for the applications of separation and purification of gases and adsorption based gas storage systems [11,12]. To design and develop these systems, it is important to determine the adsorption isotherms and isosteric heat of adsorption of the adsorbate–adsorbent pairs.

Saha et al. [13] measured CO_2 adsorption isotherms of different adsorbents such as activated carbon fiber of type A-20 and activated carbon powder of type Maxsorb III at different temperatures. They have found that the CO_2 adsorption capacity decreased with increase in temperature from −18 to 80 °C. Garcia et al. [14] measured CO_2 adsorption isotherms on phenol-formaldehyde resin-based activated carbon at three different temperatures 298 K, 318 K and 338 K. They have observed that the CO_2 adsorption capacity dropped from 440.14 to 264.08 mg/g as the temperature increased from 298 to 338 K. CO_2 adsorption isotherms on Kureha carbon at different temperatures (298–323 K) showed that the adsorption capacity dropped from 462.15 to 374.12 mg/g with increase in temperature from 298 to 323 K as reported by Yu et al. [15]. Siriwardane et al. [16] and Zhang et al. [17] performed comparative studies of CO_2 adsorption isotherms on activated carbon and zeolite at 298 K; they observed lower CO_2 adsorption capacity of ac-

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Original Research Article

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Measurement of CO_2 adsorption kinetics on activated carbons suitable for gas storage systems

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Abstract: The adsorption kinetics of CO_2 on three commercially available activated carbons namely Norit RB3 (steam activated rod) (RB3), Norit Darco 100 mesh size (Darco 100 mesh), and Norit Darco 12 × 20 US mesh size (Darco 12 × 20) are measured using Sievert's apparatus at different supply pressures (1, 5, 10, and 20 bar) and temperatures (298, 308, 318, and 338 K). Extracts of experimental results of CO_2 adsorption kinetics are used for mathematical modelling using different standard models, such as pseudo-first order, pseudo-second order, Elovich, and intra-particle diffusion kinetics models. The adsorbate-adsorbent interactions and kinetics behavior of CO_2 adsorption on adsorbents are deduced from the best-fitted kinetics model. Based on coefficient of correlation and normalized standard deviation, it has been found that pseudo-second order kinetics model very well suits with the experimental data of CO_2 adsorption kinetics. Activation energies at different pressures are calculated by fitting the Arrhenius equation to the adsorption kinetics data. Analysis of the mechanism of interaction between CO_2 molecules and adsorbents during the adsorption process is attempted using interparticle and Boyd's diffusion models. It has been found that the film-diffusion is an important rate controlling step in CO_2 adsorption process. © 2016 Society of Chemical Industry and John Wiley & Sons, Ltd.

Keywords: activated carbons; activation energy; CO_2 adsorption; diffusion coefficient; kinetics models

Introduction

In recent years, the level of carbon dioxide (CO_2) concentration in the atmosphere has been increasing continuously at an approximate rate of 2 ppm (parts per million) per year due to the consumption of heavy fossil fuels as reported by the Inter-Governmental Panel on Climate Change (IPCC).[1] CO_2 is considered to be a major greenhouse gas (GHG) released from various industries, that is responsible for global warming and climate change. Carbon capture and sequestration is suggested as one of the options to reduce the anthropogenic emission of CO_2.[2,3] Compared to other available processes like absorption, cryogenic, and membrane separation, adsorption is considered to be a promising solution for CO_2 separation due to a lower regeneration energy requirement, enhanced CO_2 carrying capacities, faster reaction rates, and minimum pressure drop, etc.[4–6] Recent literature[7–9] shows that activated carbons are one of the important candidates for CO_2 separation as they are inexpensive and insensitive to moisture. These materials also exhibit fast kinetics, high surface area and pore size distribution, high CO_2 adsorption capacity, and thermal stability. Physical adsorption on

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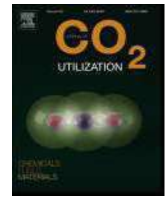

Experimental investigation and thermodynamic analysis of CO_2 adsorption on activated carbons for cooling system

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ABSTRACT

In the present study, the adsorption isotherms of CO_2 on three commercially available activated carbons are measured for possible application in cooling systems. The adsorption isotherms are measured using a Sievert's type experimental setup at various temperatures from 273 to 358 K. Experimental data of CO_2 adsorption isotherms is modelled using Dubinin-Astakhov model. Pseudosaturation pressure of CO_2 plays a significant role in the estimation of thermodynamic properties for supercritical gas adsorption, and it is evaluated using adsorption isotherms data. The thermodynamic properties namely isosteric heat of adsorption at surface loading, Gibbs free energy, and entropy are evaluated using classical Clausius-Clapeyron equation and Dubinin-Astakhov model for both subcritical and supercritical phase of CO_2 respectively. Adsorbed phase specific heat capacity, entropy, and enthalpy are also estimated. These thermodynamic properties are used for the thermodynamic analysis of CO_2-AC based adsorption cooling system. The cooling system performance parameters like specific cooling effect (SCE) and coefficient of performance (COP) are estimated for the driving heat source temperature of 80 °C at four cooling temperatures of 0, 5, 10 and 15 °C with a fixed adsorption/condenser temperature of 25 °C. All the three activated carbons are found suitable for developing CO_2-AC based cooling system. The maximum SCE and COP are obtained as 25.87 kJ/kg and 0.09 respectively.

1. Introduction

Activated carbons are found more suitable for adsorption of carbon dioxide (CO_2) compared to other solid adsorbents. They exhibit high adsorption capacity, fast kinetics, high surface area, better pore size distribution and thermal stability [1–5]. They are also inexpensive and insensitive to moisture. Adsorption of gases or vapors onto activated carbons is widely utilized in different applications like separation and purification of gases, gas storage systems, adsorption-based heating and cooling systems, cryo-coolers and energy storage systems [6–10]. Functioning of these applications are mainly influenced by selection of adsorbate/adsorbent pair, adsorption isotherms, adsorption kinetics, isosteric heat of adsorption, entropy generation, specific heat capacity and internal energy of adsorbent. Several researchers have studied the adsorption isotherms and pore size distribution of many adsorbate/adsorbent pairs using traditional methods. But the characterization of any adsorbate/adsorbent pair is incomplete without information on the thermodynamic properties like isosteric heat of adsorption, entropy, specific heat capacity, adsorbed phase volume, Gibbs free energy, and internal energy. While designing any gas storage system or adsorption-based heating/cooling system, knowledge of the above mentioned properties helps in achieving high level of confidence.

Hill [11,12] and Everett [13] developed theoretical models for physical adsorption systems using solid adsorbent, and then Guggenheim [14] described a general approach for modelling of physical adsorption systems with exchanging of heat and work. Young and Crowell [15] investigated the thermodynamic properties of solid adsorbents and suggested that two new variables: surface area and spreading pressure are necessary in the case of physical adsorption. Myers [16] estimated the thermodynamic properties such as Gibbs free energy, enthalpy and entropy using adsorption isotherms data. He has concluded that the specific heat capacity on porous adsorbents of both, adsorbed phase and gaseous phase are equal. Further, Chakraborty et al. [17] investigated that the thermodynamic properties of $CaCl_2$-silica gel/water pair and activated carbon/CH_4 pair.

For the adsorption process, CO_2 molecules get attracted and accumulated in the pores of the adsorbent surface with phase transformation. The transformed phase of the CO_2 molecules is

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Thermodynamic analysis of single-stage and single-effect two-stage adsorption cooling cycles using indigenous coconut shell based activated carbon-CO_2 pair

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ABSTRACT

The CO_2 adsorption pressure concentration isotherms of indigenous coconut shell based activated carbon are measured using Sievert's type experimental setup. The thermodynamic properties viz. isosteric heat of adsorption at surface loading, Gibbs free energy, entropy and specific heat capacity are estimated using measured adsorption isotherms data. These measured adsorption isotherms data and thermodynamic properties are used for the thermodynamic analysis of single-stage and single-effect two-stage adsorption cooling system. The performance of the adsorption cooling cycle in terms of the maximum theoretical specific cooling effect and coefficient of performance at different driving heat source temperatures (80 °C for single-stage and 65 °C for single-effect two-stage) and evaporator temperatures (0, 5, 10 and 15 °C) is estimated. The maximum values of specific cooling effect and coefficient of performance are obtained as 9.26 kJ kg^{-1} and 0.06 for single-stage and 8.85 kJ kg^{-1} and 0.04 for single-effect two-stage cooling system respectively.

Analyse thermodynamique des cycles de refroidissement à adsorption mono-étagés et bi-étagés à simple effet fonctionnant avec un couple constitué de charbon actif à base de noix de coco indigène et de CO2

Mots clés : Cycle de refroidissement à adsorption ; Charbon actif à base de noix de coco ; Propriétés thermodynamiques ; Simulation thermodynamique

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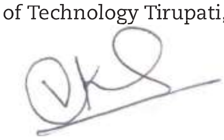

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Comparative Studies on CO_2 Adsorption Kinetics by Solid Adsorbents

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Abstract

Adsorption kinetics of carbon dioxide (CO_2) on activated carbon (Norit RB3 type steam activated rod) and zeolite 5A (Si/Al = 1.33) are compared at various temperatures (298, 308, 318 and 338 K) and supply pressures (1, 5, 10 and 20 bar). Sievert's type experimental setup is used for adsorption kinetics measurement. The experimental data is subsequently modelled using pseudo first and second order kinetics models, which revealed that the pseudo second order kinetics model well fitted the CO_2 adsorption kinetics data than pseudo first order kinetics model. The rate constants and activation energies of CO_2 adsorption on activated carbon and zeolite 5A are estimated. It is found that at 1 bar supply pressure, the rate of CO_2 adsorption on zeolite 5A is more than that of the activated carbon, while at higher pressure, the rate of CO_2 adsorption on the activated carbon is greater than the zeolite 5A due to large surface area and pore volume. Activation energies are calculated at different pressures by fitting the Arrhenius equation to the adsorption kinetics data. It is observed that the activation energies of activated carbon are slightly more than that of the zeolite 5A.

Peer-review under responsibility of the organizing committee of ICAER 2015

Keywords: Activation energy; Activated carbon; Adsorption kinetics; Carbon dioxide; Zeolite 5A

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Carbon Dioxide Capture and Sequestration by Adsorption on Activated Carbon

Reema Saxena[a], Vinod Kumar Singh[a], E. Anil Kumar[a,*]

[a]*Discipline of Mechanical Engineering, Indian Institute of Technology Indore, Indore, M.P.- 453446, India*

Abstract

Activated Carbon (AC) materials was selected as suitable adsorbent for the carbon dioxide (CO_2) capture and a numerical analysis was carried out to study the rate of adsorption of the gas on ACs. A one dimensional mathematical model was proposed based on the Dubinin's Theory of Volume Filling of Micropores, and analyzed along with the unsteady heat transfer. A parametric analysis was carried out to study the effect of various crucial parameters like radius of bed, cooling fluid temperature, initial bed temperature and heat transfer coefficient on the adsorption amount. The results show that lower bed radius was ideal for obtaining high amount of CO_2 adsorbed assuming constant packing density. Also, a high heat transfer coefficient up to 100 $Wm^{-2}K^{-1}$ and low cooling fluid temperature of 283 K was necessary for speeding up the process. High initial bed temperature also supports greater adsorption amount under the same conditions.

Selection and peer-review under responsibility of Organizing Committee of ICAER 2013

Keywords: Activated carbon; Bed radius; Carbon dioxide capture and sequestration; Mathematical model; Unsteady heat transfer

1. Introduction

Large scale development of modern civilization has led to very fast depletion of fossil fuel energy resources. Especially the exponential increase in consumption of fossil fuel has resulted in emission of CO_2 in a huge quantity. Severe environmental issues like global warming and climate change are the result of emissions from fossil fuel

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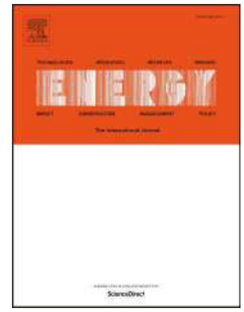

Adsorption isotherms, kinetics and thermodynamic simulation of CO2-CSAC pair for cooling application

Vinod Kumar Singh, E. Anil Kumar, Bidyut Baran Saha

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Comparative Studies on CO_2 Adsorption Isotherms by Solid Adsorbents

Vinod Kumar Singh [a], E. Anil Kumar [a]

Show more

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Abstract

The present study provides the necessary thermodynamic data required for the design of CO_2 based adsorption systems using the activated carbon (Norit type RB3 steam activated rod) and zeolite 5A (Si/Al = 1.33). In this work, the CO_2 adsorption isotherms of activated carbon and Zeolite 5A are studied at different temperatures (298, 308, 318 and 338 K) and pressures (0-30 bar) using a Sievert's type experimental setup. Experimental data of CO_2 adsorption isotherms on adsorbents are modelled using Langmuir and Freundlich isotherm models. The coefficient of correlation and normalized standard deviation are estimated, which revealed that the Freundlich isotherm model is well suited to the experimental data of CO_2 adsorption isotherms than Langmuir model. The thermodynamic parameters are estimated and these parameters indicated that the adsorption process is spontaneous, exothermic and physisorption in nature. Isosteric heat of adsorption and limiting heat of adsorption are calculated using the Clausius-Clapeyron and van't Hoff equations respectively.

Previous Next

Keywords

Activated carbon; *Adsorption isotherms*; *Carbon dioxide*; *Thermodynamic properties*; *Zeolite 5A*

Special issue articles Recommended articles Citing articles (0)

Estimation of Thermodynamic Properties of CO_2 Adsorption on Activated Carbon

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Abstract: *The objective of the present study is to measure the adsorption isotherms of CO_2 on activated carbon at different temperatures from 273 to 358 K and pressure up to the saturation pressure of assorted temperature using a Sievert's type experimental setup. Extracts of experimental data of CO_2 uptake are correlated to the Langmuir and Tóth adsorption isotherm models. The Tóth adsorption isotherm model is well suited to the experimental data of CO_2 uptake. The essential thermodynamic properties are evaluated using an experimental data of CO_2 uptake. In this work, the CO_2 uptake and isosteric heat of adsorption of CO_2 on the activated carbon are obtained and compared with other available activated carbons and it is found that the results are a good agreement of present measured result. These thermodynamic parameters are useful for designing of any adsorption based gas storage and cooling systems.*

Keywords: Activated carbon, Carbon dioxide, Isotherm model, Saturation pressure, Thermodynamic properties.

1. INTRODUCTION

The rapid development of modern civilization and the increasing living standard have led to an exponential increase in energy consumption. As a consequence, environmental pollution has become a serious problem. Among the various effects of environmental pollution, global warming has been a critical one. Worldwide, many researchers are seeking ways to reduce the anthropogenic emission of CO_2. Adsorption is selected as the most versatile and promising process among other available processes like adsorption, cryogenic, membrane and micro algal bio-fixation for CO_2 separation. The advantages are lower regeneration energy requirements during desorption process, increased CO_2 carrying capacity, reduction in the cost of CO_2 separation and minimum pressure drop [1, 2]. According to the published literature, the activated carbons are an appropriate candidate for CO_2 separation, the amount of CO_2 adsorbed being reliant on the adsorbent qualities such as surface area, pore structure and the properties of surface chemistry [3-8]. They exhibit high CO_2 adsorption capacity, high surface area, thermal stability, inexpensive and low cost [9, 10]. Physical adsorption on activated carbon is widely utilized for various applications like adsorption based gas storage systems, adsorption based heating and cooling systems, separation and purification of gases, cryocoolers and energy storage systems [11-15]. Functioning of these applications is required to accurate information of adsorption isotherms data and isosteric heat of adsorption helps in achieving a high level of confidence.

Many researchers [7, 8, 16-20] have measured the adsorption isotherms of CO_2 on commercially available activated carbons at different temperatures and pressure conditions using a volumetric method. They have observed that the adsorption temperature increases with the decrease in CO_2 uptake and have also noticed that the isosteric heat of adsorption varies with an increase in surface loading due to an energetically heterogeneous surface of the adsorbent. Two points have been observed from available literature: first, the CO_2 adsorption isotherms of activated carbon at a wide range of temperatures and pressures (up to saturation pressure of assorted temperatures) have not yet been estimated. Secondly, the vital thermodynamic properties like the heat of adsorption at zero and surface loading, entropy and Gibbs free energy of the activated carbon at different adsorption temperatures and equilibrium pressures are not available.

The aim of the present study is to measure the adsorption isotherms of activated carbon for the probable development of an adsorption based cooling system. The adsorption isotherms of CO_2 on activated carbon are measured at various temperatures from 273 to 358 K and pressures (up to saturation pressure of assorted temperatures) using the volumetric method. The measured adsorption isotherms data are fitted with Langmuir and Tóth adsorption model. Further, the thermodynamic properties viz. heat of adsorption at zero loading and surface loading, Gibbs free energy and entropy are extracted from the measured isotherms data.

2. EXPERIMENTAL SECTION

The description of physical properties, material characterization of activated carbon and procedure for adsorption isotherms measurement are briefly discussed in this section.

2.1 ADSORBENT/ADSORBATE USED

In this study, the commercially available activated carbon (Norit Darco 100 mesh size) is procured from Sigma Aldrich. The BET surface area, total pore volume and average pore diameter are evaluated using a BET analysis and the

Characterization of Carbon Dioxide Adsorption Isotherms and Kinetics on Activated Carbon for Cooling System

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1. Introduction

The rapid development of modern civilization and increasing living standard has lead to exponential increase in energy consumption. As a consequence, environmental pollution has become a severe problem. Among the various effects of environmental pollution, global warming has been a critical one. Worldwide, many researchers are seeking ways to reduce the global warming. Conventional refrigeration units have always act as an important source for global warming. Methods like, replacing Hydro Chloro Flouro Carbon (HCFC), with Hydro Flouro Carbon (HFC) refrigerants also, could not have significant effect on global warming. It is projected that refrigeration and air conditioning units would contribute approximately 9-19% of total greenhouse gas emission in 2050 [1]. On the basis of reliability and ecofriendliness, adsorption based cooling systems seem to be feasible solution. Many researchers have reported about various natural and low global warming potential refrigerants including water, ammonia, methanol, ethanol and HFO-1234ze. Solar energy or low grade energy like, waste heat can be used as driving media for adsorption based cooling systems. Adsorption based cooling system like water/zeolite, water/silica gel and ammonia/activated carbon are already commercialized. The main hindrances of these systems are poor systems performance, bulkiness of adsorbents and low heat transfer rate inside the adsorber/desorber bed.

With very low values of global warming potential and ozone layer depletion potential, carbon dioxide (CO_2) has emerged as an appropriate refrigerant for adsorption based cooling system for the possible applications of commercial/residential cooling, vehicle air-conditioning and large refrigeration systems. CO_2 is a non-toxic and non-flammable natural refrigerant. As an adsorbent, activated carbon has received considerable attention due to its suitable properties like, high surface area, large pore size distribution, high adsorption capacity, fast kinetics and thermal stability etc.

The objective of the present article is to measure the adsorption isotherms and kinetics of CO_2/activated carbon pair for the probable development of an adsorption based cooling system. The adsorption isotherms of CO_2 on activated carbon are measured at various temperatures from 0 °C to 75 °C and over a pressure range of 0 to 95 bar using a Sievert's type experimental setup. CO_2 adsorption kinetics is also evaluated at different supply pressures (1, 5, 10 and 20 bar) with same adsorption temperatures respectively. The adsorption isotherm parameters are correlated using a Dubinin-Astakhov (D-A) isotherms model with volume correction. Further, the values of isosteric heat of adsorption and specific heat capacity are extracted for the assorted CO_2/activated carbon isotherms data. Also the apparent activation energies for different supply pressures at different temperatures are evaluated. In addition, the coefficient of performance (COP) and specific cooling effect (SCE) of cooling system are simulated for different driving heat source temperature ranging from 30 °C to 90 °C, evaporator temperature of 0 °C, 5 °C, 10 °C and 15 °C and cooling source temperature of 25 °C.

Keywords: Activated carbon, Adsorption, CO_2, Cooling system, Isotherms, Kinetics

2. Experimental Section

2.1 Material

In this study, the commercially available activated carbon (Norit Darco 100 mesh size) is procured from Sigma Aldrich. The BET surface area, total pore volume and average pore diameter are evaluated using BET analysis and the respective values are 876.45 m^2/g, 0.73 cm^3/g and 3.33 nm. The elemental contents and average particle size of the adsorbents are evaluated using an Elemental analysis and SEM instrument respectively.

2.2 Experimental procedure

The details of experimental setup, adsorption cell design and data reduction for adsorption isotherms measurement is given in author's recent article [2]. The adsorption isotherms and kinetics of

Comparative Studies on CO_2 Adsorption Isotherms by Solid Adsorbents

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Abstract

The present study provides the necessary thermodynamic data required for the design of CO_2 based adsorption systems using the activated carbon (Norit type RB3 steam activated rod) and zeolite 5A (Si/Al = 1.33). In this work, the CO_2 adsorption isotherms of activated carbon and Zeolite 5A are studied at different temperatures (298 K, 308 K, 318 K and 338 K) and pressures (0-30 bar) using a Sievert's type experimental setup. Experimental data of CO_2 adsorption isotherms on adsorbents are modelled using Langmuir and Freundlich isotherm models. Coefficient of correlation and normalized standard deviation are estimated, which revealed that the Freundlich isotherm model is well suited with the experimental data of CO_2 adsorption isotherms than Langmuir model. The thermodynamic parameters are estimated and these parameters indicated that the adsorption process is spontaneous, exothermic and physisorption in nature. Isosteric heat of adsorption and limiting heat of adsorption are calculated using the Clausius-Clapeyron and Vant' Hoff equations respectively.

Keywords: Adsorption Isotherms; Carbon dioxide; Isosteric heat of adsorption; Thermodynamic properties.

1. Introduction

Development of modern civilization has led to rapid utilization of fossil fuels. As a consequence CO_2 concentration level has continuously increased year by year. CO_2 is an important greenhouse gas released from various industries like power plants, gas processing industries, cement industries, iron and steel industries, etc. is responsible for global warming and climate change [1]. Carbon capture and sequestration is one of the options to reduce the anthropogenic emission of CO_2. Physical adsorption is considered as the most suitable technique for CO_2 separation due to lower regeneration energy requirement, increased CO_2 carrying capacity, faster reaction rates and minimum pressure drop etc. when compared with other processes like absorption, cryogenic and membrane separation. Property data like adsorption isotherms and isosteric heat of adsorption is very essential for the design of any adsorption system. Adsorption processes based on solid adsorbents are widely used for room and moderate temperature applications mainly using inorganic porous materials such as activated carbon and zeolite due to large surface area, porosity, surface chemistry, easy to design pore structure, availability and lower cost [2].

Saha et al. [3, 4] and Himeno et al. [5] performed the CO_2 adsorption isotherms on different activated carbons at various temperatures. They have found that the CO_2 adsorption capacity decreased with increase in adsorption temperature. Singh et al. [6] measured the CO_2 adsorption isotherms on Darco type activated carbon at different temperatures and pressure range of 0-45 bar. They have observed that the CO_2 adsorption capacity decreased with increase in adsorption temperature from 298 to 338 K. Garcia et al. [7] and Yu et al. [8] measured the CO_2 adsorption isotherms on activated carbons at different adsorption temperatures. They have also found that the adsorption capacity dropped from 440.14 to 264.08 as the temperature increased from 298 to 338 K and 462.15 to 374.12 mg/g with increase the adsorption temperature from 298 to 323 K respectively. Lee et al. [9] performed the CO_2 adsorption isotherms on zeolite 13X and zeolite 13X/activated carbon at various temperatures with low pressure range of 0-1 bar. They have observed that at low pressure the amount of CO_2 adsorbed on zeolite 13X is higher than that of activated carbon. Liu et al. [10] measured the CO_2 adsorption isotherms on zeolite 5A at different temperatures (303 to 423 K) with a pressure range of (0-1 bar). They have observed that the adsorption capacity of CO_2 adsorbate is more as compare to N_2 adsorbate.

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Comparative Studies on CO_2 Adsorption Kinetics by Solid Adsorbents

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Abstract

Adsorption kinetics of carbon dioxide (CO_2) on activated carbon (Norit RB3 type steam activated rod) and zeolite 5A (Si/Al = 1.33) are compared at different temperatures (298 K, 308 K, 318 K and 338 K) and pressures (1 bar, 5 bar, 10 bar and 20 bar). Sievert's type experimental setup is used for adsorption kinetics measurement. The experimental data on activated carbon and zeolite 5A are subsequently modelled using a pseudo first and second order kinetics model, which revealed that the pseudo second order model well fitted the CO_2 adsorption kinetics data than pseudo first order model. The rate constants and activation energies of CO_2 adsorption on activated carbon and zeolite 5A are estimated. It is found that at 1 bar supply pressure, the rate of CO_2 adsorbed on zeolite 5A is more than that of the activated carbon, while at higher pressure, the rate of CO_2 adsorbed on the activated carbon is greater than the zeolite 5A due to large surface area and pore volume. Activation energies on activated carbon and zeolite 5A are calculated at different pressures by fitting the Arrhenius equation to the adsorption kinetics data. It is observed that the activation energies of activated carbon are slightly more than that of the zeolite 5A.

Keywords: Activation energy; Activated carbon; Adsorption kinetics; Carbon dioxide; Zeolite 5A.

1. Introduction

Nowadays global warming and climate change is the major challenges all over the world. Carbon capture and sequestration is suggested as one of the options to reduce the greenhouse gas emissions. Physical adsorption on porous solid adsorbents is widely used for different applications like water treatment, adsorption based cooling system, gas storage and purification and separation of flue gases [1]. Published data of several researchers [2-6] on CO_2 adsorption isotherms of various solid adsorbents at different temperatures reveals that the amount of CO_2 adsorbed decreases significantly with increase in adsorption temperature owing to low binding forces between the adsorbate-adsorbent interactions. Shen et al. [7] measured CO_2 adsorption isotherms and kinetics on pitch-based activated carbon beads at different temperature (303 to 423 K) with a pressure range of 0-1 bar. They have suggested that the designing of any gas storage system requires the knowledge of adsorption isotherms and kinetics data for increasing the adsorption capacity. Balsamo et al. [8] reported that the adsorption rate increases with increasing CO_2 gas pressure, but with increasing temperature the adsorption rate decreases. Zhang et al. [9] measured the adsorption isotherms and kinetics of CO_2 on activated carbon and zeolite 13X at different temperatures (298 K, 308 K, 318 K and 328 K) and pressures up to 30 bar. They have observed that the adsorption rate of zeolite 13X is more at lower pressure than activated carbon whereas at high pressure the adsorption capacity is higher in activated carbon than that of zeolite 13X.

Most of the researchers studied adsorption capacity of solid adsorbents by measuring adsorption isotherms, a few researchers studied the CO_2 adsorption kinetics on solid adsorbent. Adsorption kinetics is useful for better understanding the phenomenons involved during adsorbent-adsorbate reaction and also to estimate the time require to complete the adsorption process. Adsorption process time is one of the criteria to select the solid adsorbents used in gas storage and adsorption based cooling system. The motivation of the present work is to compare the adsorption kinetics of CO_2 on activated carbon and zeolite 5A at different temperatures (298 K, 308 K, 318 K and 338 K) and pressures (1 bar, 5 bar, 10 bar and 20 bar). The rate constant and activation energies of CO_2 on activated carbon and zeolite 5A at different pressures and temperatures are also estimated.

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Studies on Adsorption Isotherm and Kinetics of CO_2 by Activated Carbon

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Keywords: Activated Carbon, Adsorption Isotherm, Carbon dioxide, Kinetics.

Abstract:

Emission of carbon dioxide gas into environment is the main reason for global warming. Information of adsorption isotherm and adsorption kinetics of pure CO_2 gas is required for planning the adsorption process of a new material that can be scaled-up to large capacity. In this work, adsorption isotherms of pure CO_2 on activated carbon are measured at different temperatures (298 K, 308 K, 318 K and 338 K) and pressures from 0 to 45 bar and kinetics are measured in a wide range of pressures (1bar, 5 bar, 10 bar and 20 bar) at different temperatures (298 K, 308 K, 318 K and 338 K) using a volumetric method. The thermodynamic parameters are estimated and these parameters indicated that the adsorption process is spontaneous and exothermic in nature and physisorption is the dominant mechanism for CO_2 adsorption. In addition, the adsorption activation energy for CO_2 on activated carbon decreased with the increase of pressure. The structural information, surface chemistry, chemical composition and thermal behaviour of the activated carbon are studied.

Introduction

Carbon dioxide (CO_2) is an major greenhouse gas released from power industries, gas processing industries, refineries, chemical and petrochemical industries, iron and steel industries and cement industries [1,2]. The CO_2 removal from industrial emissions has become essential in the fight against global warming and climate change [3]. Scripps Institute of Oceanography recently observed that as the CO_2 concentration increased from 315 ppm in March 1958 to 398 ppm in January 2014 resulting in increase in global average temperature by 0.6 to 1°C. The International Panel on Climate Change (IPCC) estimates that, average CO_2 concentration may rise to 570 ppm by the year 2100 causing a rise of about 1.9°C and 3.8 m in the global average temperature and mean sea level respectively [4]. Consequently the most recommending alternative to alleviate the effect of CO_2 on the world climate is to capture the CO_2 from industries [5,6].

Adsorption is considered as a most proposing and versatile technique among other processes likes absorption, cryogenic separation, membrane separation and micro algal bio fixation for CO_2 separation. It shows the advantages like reduction in cost of CO_2 capture, increased CO_2 carrying capacity, lower regeneration energy requirements, faster reaction rates and minimum pressure drop [7-9]. Songolzadeh et al. [10] is reported that the cost of CO_2 capture is reduced by using an adsorption technique. Among the properties expected in a

Studies on CO_2 Adsorption by Activated Carbon

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Abstract: Carbon dioxide (CO_2) removal from industrial emissions has become essential in the fight against climate change. In the present study, adsorption on activated carbon is selected as a reasonable solution for CO_2 separation because it is simple and relatively less costly when compare to other available CO_2 separation techniques. The objective of this work is to study the CO_2 adsorption and kinetics by commercially available activated carbons namely NORIT type RB3 steam activated rod. The adsorption isotherms and kinetics curves are measured using volumetric method at different temperatures (298 K, 308 K and 318 K) and pressures (0 to 45 bars). The structural information, surface chemistry and thermal behaviour of the adsorbent sample are characterized by X-ray powder diffraction (XRD), infrared spectroscopy (IR), elemental analysis (EA), field emission scanning electron microscopy (FESEM), energy dispersive X-ray spectroscopy (EDX) and thermogravimetric analysis (TGA).

Keywords: Activated carbon; CO_2 separation; Isotherms; Kinetics

1. Introduction

The World's energy consumption has been continuously increasing at a vigorous rate in recent year because of population growth and economic development. Due to increasing emission amounts of CO_2 from fossil fuel combustion and enhancement of the greenhouse effect, the carbon capture and storage (CCS) have attracted increasing attention. Reducing the anthropogenic emission of CO_2 has recently become a political and technological priority. One approach is CCS in which CO_2 is sequestered to reduce its concentration in the atmosphere; another is the development of renewable and clean energy sources, or energy carriers, in order to reduce our dependence on fossil fuels, such as petroleum and coal, which contribute significantly to global CO_2 emissions [1].

CO_2 is considered to be the major greenhouse gas (GHG) contributing to global warming [2]. The International Panel on Climate Change (IPCC) estimates that, average CO_2 concentration may rise to 570 ppm by the year 2100 causing a rise of about 1.9°C and 3.8 m in the global average temperature and mean sea level respectively [3].

Adsorption is considered as a reasonable solution. It shows the advantages like reduction in cost of CO_2 capture, increased CO_2 carrying capacity, lower regeneration energy requirements, faster reaction rates and minimum pressure drop [4, 5]. Reduction in cost of CO_2 capture by using adsorption technique is recently reported by Songolzadeh et al. [6]. Among the properties expected in a good adsorbent, fast adsorption kinetics is one of the most important criterions for selection of the proper adsorbent [7, 8].

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Carbon Dioxide Capture and Sequestration by Adsorption on Activated Carbon

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Abstract: *Carbon dioxide (CO_2) emissions are believed to be a major contributor to global warming. As a consequence large anthropogenic CO_2 sources worldwide will eventually be required to implement CO_2 capture and sequestration (CCS) technologies to control CO_2 emissions. Adsorption is then chosen as the preferred technique due to its relatively simple and cost-effective design. Activated Carbon (AC) materials are selected as suitable adsorbents for the CO_2 capture and a numerical analysis is carried out to study the rate of adsorption of the gas on ACs. A one dimensional mathematical model is proposed based on the Dubinin's Theory of Volume Filling of Micropore, and analyzed along with the unsteady heat transfer. A parametric analysis is carried out to study the effect of various crucial parameters like thickness of bed, cooling fluid temperature, supply temperature and heat transfer coefficient on the adsorption amount. The results show that lower bed thickness is ideal for obtaining high amount of CO_2 adsorbed assuming constant packing density. Also, a high heat transfer coefficient up to 100 $Wm^{-2}K^{-1}$ and low cooling fluid temperature of 283 K is necessary for speeding up the process. High initial bed temperature also supports greater adsorption amount under the same conditions.*

Keywords: AC, Bed thickness, CCS, Mathematical model, Unsteady heat transfer

1. INTRODUCTION

With the rapid development of modern civilization, the widespread use of fossil fuels within the current energy infrastructure is considered as the largest source of anthropogenic emissions of CO_2, which is largely responsible for global warming and climate change [1, 2]. In fact, more than 30 billion tons of CO_2 are added to the atmosphere every year. Moreover, the emission of CO_2, one of the major greenhouse gases, may have contributed to urban smog, acid rain, and health problems [3].

Since the beginning of the industrial revolution around 1850 to 2013, the average atmospheric concentration of CO_2 has increased from 280 to 397 parts per million (ppm) and as a result, the average global temperature has increased between 0.6°C and 1°C in the same time period [4]. The International Panel on Climate Change (IPCC) predicts that, by the year 2100, the atmosphere may contain up to 570 ppm CO_2, causing a rise in the mean global temperature of around 1.9°C and an increase in mean sea level of 3.8 m [5]. Continued uncontrolled greenhouse gas emissions may contribute to sea level increases and species extinction. There is an emerging understanding that CCS technology offers a way of using fossil fuels while reducing CO_2 emissions by 85% or more, while CCS is not the 'silver bullet' that in and of itself will solve the climate change problem, it is powerful addition to the portfolio of technologies that will be needed to address climate change [6].

CCS is actually a suite of technologies to carry out three operations: capture of CO_2 emitted from industrial and energy-related sources before or after combustion, compressing it, and injecting it deep underground in secure geological formations, its disposal by a method that will 'permanently' isolate it from the atmosphere. There are three approaches to CO_2 capture: pre-combustion, post-combustion and oxy-fuel combustion [7].

Post-combustion capture offers some advantages as existing combustion technologies can still be used without radical changes on them. This makes post-combustion capture easier to implement as a retrofit option (to existing power plants) compared to the other two approaches. Therefore, post-combustion capture is probably the first technology that will be deployed [8]. There are several post combustion gas separation and capture technologies being investigated, namely; (a) absorption, (b) adsorption, (c) cryogenic separation, (d) membrane separation and (e) micro algal biofixation. Adsorption may be considered as a competitive solution, it is basically divided into two fold such as, adsorber beds (Alumina, Zeolite and AC) and regeneration methods (Pressure, Temperature, Vacuum and Electric swing). Its major advantage is to reduce the cost of CO_2 capture by designing durable sorbents with efficient materials handling schemes, increased CO_2 carrying capacity, lower regeneration energy requirements, faster reaction rates and minimum pressure drop. However, the application of adsorption from either technology, require easily regenerable and durable adsorbents with a high CO_2 adsorption capacity. It has recently been reported that the cost of the CO_2 capture can be reduced by using this technology [9].

Selection of the proper adsorbent is the most crucial step when designing a new adsorption process. For CO_2 recovery in the process considered here, a material is needed that will selectively adsorb CO_2 in the presence of CO. Because the process requires that we also produce CO_2 during the blow down step, we need a material for

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Energy and Exergy Analysis of a 36 MW Thermal Power Plant

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Abstract

In the present work, the energy and exergy analysis performed on an operating 36 MW thermal power plant at power station-I, Bhilai Steel Plant, Bhilai, India is presented. The primary objectives of this paper are to analyze the system components separately and to identify and quantify the sites having larges energy and exergy losses. Energy losses have mainly occurred in the condenser where 52.64 MW is lost to the environment while only 55.52 MW has been lost from the boiler. In addition, the calculated thermal and exergy efficiency based on the lower heating value of fuel was 33.86% and 30.25%. For a moderate change in the reference environment state temperature, no drastic change was noticed in the performance of major component and the main conclusion remained the same; the boiler is the major sources of irreversibilities in the power plant.

Keywords: Efficiency, Energy, Environment, Exergy, Losses

1. Introduction

The power industry is pillar of the national economic development, so its sustainable development level is a symbol of a country's comprehensive national strength. Analysis of power generation systems is of scientific interest due to continuously increasing energy demand and depreciate fossil fuel resources and also essential for the efficient utilization of energy resources. The researchers, throughout the world, have made considerable efforts to understand the economics of power generation as reported by Lee, C.C. and Miketa, A. et al. (2005).

Efficient power generation requires improvement and modifications in the power generation system. This requires accurate thermodynamics analysis of thermal systems for design and optimization purposes. The most commonly used method for analysis of an energy conversion process is the first law of thermodynamics. The first law of thermodynamics states that when observe at the system and surroundings together, the total amount of energy will remain constant. The first law treats the different forms of energy as equivalent and does not decide the difference in quality between, among others, mechanical and thermal energy as stated by Bejan, A. (1988) and Moran, M.J. et al. (1998). Exergy is defined as the maximum reversible work obtained as a system interacts with an equilibrium state. Exergy is generally not conserved as energy but destructed in the system. Exergy destruction is the measure of irreversibility that is the cause of performance loss.

Therefore, an exergy analysis assessing the magnitude of exergy destruction identifies the location, magnitude and source of thermodynamic incapability in a thermal system as described by Moran, M.J. et al. (1998) and Song, T.W. et al. (2002). Exergy analysis based on the first and second law of