 Egypt. J. Chem. **Vol. 65,** No. SI:13, pp. 635 - 643 (2022)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Eco-Friendly Thermal Insulator from Agricultural Wastes and Chitosan

CrossMark

Eman M. Gabr *, Enas I. Arafa, Aziza S. El-Tabei

Egyptian Petroleum Research Institute (EPRI) / http://w.ww.epri.sci.eg /Processes Development Department /Cairo/ Egypt

Abstract

Application of thermal insulation for building and industrial sectors is a radical technique for minimizing energy losses and limit greenhouse gasses emissions GHG. The safety recycle of accumulated wastes and environmental burdens is another effective technique for GHG control. In this work we fabricated eco-friendly thermal insulation using agricultural and industrial wastes. The raw materials used are Corn Cob and Sugarcane bagasse; Chitosan as clean adhesive is used too. Many Processes are required for fabrication, beginning with washing, and drying. Then grinding and stiffing took place. Compression process with hydraulic piston converts crushed raw into disc samples with 6mm. thickness and 10 cm. diameters. To define best sample composition and optimum conditions; many samples are prepared, and many Standard Examinations have done. The best sample Composition is 14 gm. of (40% corn cobs & 60% Bagasse) and additives of (10 gm. Chitosan, 2gm. Synthetic polymer and thin layer of Aerogel painting). This sample got least thermal conductivity of 0.04 W/mk; it guarantees low surface temperature of 38ºC for insulated hot fluid pipes. Thermal performance of this composition is perfect represented in slow decomposition at high temperatures. Mechanical tests through (SEM and Contact angles Analysis) proved sample quality. These results clarified the possibility of converting the sample from laboratory scale to commercial production scope. This product can contribute for realizing zero energy losses for building and industrial sectors, which is the 21th century goal.

Key Words: Agricultural Wastes Recycle; Chitosan; Climate Change; Thermal Insulation; Zero energy losses

1- Introduction

In 2015, most countries issued Sustainable Development Goals (SDGs) to protect the planet and ensure prosperity. Many goals of this plane concerned with citizen's health, clean energy and climate change [1].Clean energy with least emissions is the direct way for climate change mitigation and public health improvement. Industry, Electricity production and building sectors are responsible for around 60% of green-house gasses GHG emissions [2].Energy management technique has economic and environmental impacts. While this technique reduces cost; it guarantees least fuel consumption with least harmful emissions [3].Application of thermal insulation is a prime axis of energy management technique; where zero heat losses for industrial and building sectors became the 21th century goal. While applying insulations limit energy consumption and GHG; it improves safety, economically and operability factors[4-6].

While energy management in presence of thermal insulation realizes (SDGs); wastes management and recycling infrastructure are the major challenges facing (SDGs).

For semi agricultural country; the annually estimated amount of dry agricultural wastes is 26 million tones. As example; for every kg of corn harvested, 0.186 kg of Corn Cob(CC) are produced .Similarly, 1 kg of sugarcane bagasse (SB) is obtained for every 3.5 kg of sugar cane processed. These wastes are environmental burdens and should be beneficially utilized rather than being buried or being burned with dangerous healthy impact.

Bagasse and corn cobs are lignocelluloses' compounds which are composed of cellulose, hemicelluloses, lignin and low concentrations simple sugars, lipids, proteins, water and ash.

*Corresponding author e-mail: dremangabr@hotmail.com; (Eman M. Gabr).

Receive Date: 21 August 2022, **Revise Date:** 01 September 2022, **Accept Date:** 04 September 2022
First Publish Date: 04 September 2022
DOI: 10.21608/EJCHEM.2022.157536.6827

The composition of these dry wastes has high thermal stability and resistance for dissolution and hydrolysis: so, recycle these wastes into thermal insulators is a promising idea [7-13].

Recycle of industrial wastes has good environmental impact. Chitin is the main waste of seafood companies around the world; where it is the remains of shrimp and crabs processing. Chitin is a natural abundant waste; used to produce chitosan by deacetylation process. Chitosan is a safely adhesive material. This Chitosan is copolymers composed of glucosamine and N-acetyl glucosamine and marked by its nontoxicity, biocompatibility, and biodegradability [14, 15].

Expecting growing of Global waste by 2050 is 70% with sever influence of climate change. So.

treatment different wastes 'types and recycle them into useful product as thermal insulation has eco and economic impacts. For industrial unit, application insulation for hot pipes improves enhanced efficiency and safety adding to protecting sensitive electronics and limiting noise pollution. Subsequently estimation of global industrial thermal insulation market is 9. 9 Billion US$ by 2027.While in buildings sector; the prime goal is realizing zero energy losses by insulation application with optimum conditions [16-20].

The objective of this work:

Fabrication of eco- friendly' insulators by recycling of the wastes (agriculture& industrial).Then evaluation these insulations sheets by thermally, mechanically, and economically tests. Application of fabricated insulation sheet for industrial or building sectors realize the (SDGs); through reduction of energy demand and protect environment.

2. Thermal insulating materials

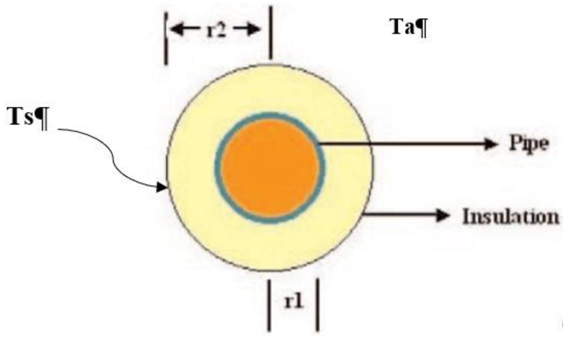
Thermal insulating materials are poor conducting material, which have low thermal conductivity factors. There are two types of insulation materials; the first one is organic insulations. This type

Is composed of hydrocarbon polymers; commercially products named as Thermocol (Polystyrene formed). The second type is inorganic insulations which formed in fibrous, granular and powder. This type is composed of siliceous/aluminous/calcium materials; commercially products named as Mineral wool, Calcium silicate [21, 22].

2.1 Importance of insulation application

Application of thermal insulation is a radical solution to minimize energy losses and consequently limit GHG emissions. As an example, for an industrial unit, has pipelines with radius (r1) passed hot streams of 200 ºC. Due to poor thermal conducting of insulators; Application of piping insulation reduces surface temperature (Ts) from 200 ºC to 50 ºC. Change of pipe dimensions where radius will be (r2) . Ambient temperature is (Ta), heat losses for unite area is (S) . Subsequently surface heat losses (Hs) reduced in percentage of 93% compared to non-insulated pipe as shown in figure (1) and according to equations 1-5. Which; realizes less rate of fuel combusted (Hf) with less operating cost (Cf).

This simple example approved economic and eco benefits of thermal insulation application for industrial unit. On the other hand; limiting of energy losses for building in presence of insulation; controls load of both heating and cooling systems [23- 27].



¶

Figure (1) Piping Thermal Insulation

$S = [10 + (Ts-Ta) / 20] * (Ts – Ta)$ (1)

$Hs = S * A$ (2)

$A = 2\pi * r * L$ (3)

$Hf = Hs \times \text{Annual operating hours} / NHV*{}^{\eta}b$ (4)

$Cf = Hf * U\,Cf$(5)

Where:

S:	Surface heat loss in kCal/hr m2	NHV:
	Net heating value of fuel kCal/kg	
Ts:	Hot surface temperature in °C	${}^{\eta}b$:
	% Boiler efficiency	
Ta:	Ambient temperature in °C	
r1,r2:	Radius of pipe before & after insulation m	
Hs:	Total heat loss kCal/hr	Hf:
	Equivalent Fuel losses kg/y	
Cf:	Annual cost of heat losses $/y	
U Cf:	Cost of fuel mass unite $/kg	

3. Materials and Experimental methods

All raw materials used in this work are accumulated wastes and environmental burdens.

3.1 Agricultural wastes

Processed Corn Cob (CC) and sugarcane bagasse (SB) are the main components of thermal insulators. Materials processing passed through many stages:

- Washing of Bagasse and corn cobs then drying in an oven at a temperature of 80°C for 60 minutes to avoid bacteria and fungi growth.
- Grinding the dried wastes by a powerful grain mill.
- Sifting the milling products into particle size less than 0.6 mm. As particle size of grinding wastes decrease; cohesion ability of samples increases.

- Compression of prepared wastes took place through hydraulic compressor with pressure force of 2000 kN. This process converts the wastes into discs or sheets to increase sample's ability for handling and facilitate samples evaluation.

3.2 Industrial Wastes

Chitosan is clean adhesive and eco-friendly binder; used as additives in insulators fabrication. Extraction of chitosan from crustacean shells waste is done through many stages: firstly, washing the wastes with water and drying under vacuum, then grinding took place. Secondly, shells powder is soaked in 1M of NaOH for 24 h then washing and drying took place. Thirdly, shells powder is demineralized using 1 M HCl, then deproteinized using 1 M NaOH, and discolored using Oxalic acid to get treated chitin powder. Finally, deacetylation of the chitin powder using 50% NaOH is repeated to get higher degree chitosan. Summary of extraction stages is shown in figure (2) [28, 29].

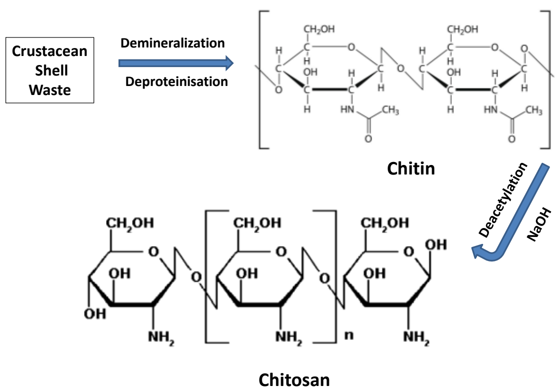


Figure (2) Extraction Stages of Chitosan from Crustacean Shell Wastes

3.3 Supplementary materials and Additives

To improve insulation samples performance; some materials are added**.**

3.3.1 Natural polymer

To increase grinding cohesion through compression process; we add chitosan to the samples. Chitosan marked as green adhesive due to its biosafety, film-forming ability, and water barrier. Adding of chitosan to samples in different ratios took place to evaluate the effect of chitosan percentages on samples performance.

3.3.2 Synthetic polymer

To modify samples strength and facilitate these samples handling and application; small portion of poly vinyl acetate (PVA) is added. Presence of chitosan as naturally binder; limits percentage of PVA in samples' composition to 8%. This limitation has good environmental impact [30].

3.3.3 Coating Layer

Due to high thermal efficiency of Aerogel and its high price as thermal insulation; we prepared Aerogel at laboratory and coated samples with thin layer of it. This coating has good effect on samples performance physically and thermally, with low added cost.

Aerogel Preparation Steps:

- We prepare Aerogel in laboratory using Tetraethyl Orthosilicate A.R [TEOS] (commercially imported through Alpha Chemica Organization)with Batch Number [TE 409].
- Adding ethanol in same ratio of TEOS with stirring for 10 minutes. Then adding small portion of ammonia [NH4OH] with stirring for 5 minutes. See figure (3).[31 - 34]

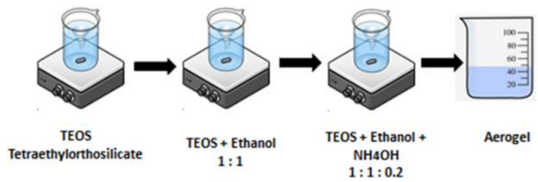


Figure (3) Laboratory Preparation of Aerogel

3.4 Initial Evaluation of Samples Performance

3.4.1 Thermal Evaluation

- Thermal conductivity factor indicates insulation efficiency of samples, where low values guarantee least energy losses.
- Estimation of samples' thermal conductivity is done with the laboratory instrument following Lee theory.

3.4.2 Cohesion Evaluation of Samples

Samples' hardness and cohesion strength are tested using DUROMETER STAND /Model 470/PTC/ USA industrial. Testing method is ASTMD 2240 Standard applying conditions of Shore A and 1 kg load. Samples with good performance have high cohesion strength.

4. Results and Discussion

4.1 Defining Optimal Wastes Ratio of Sample

1. Samples preparation in different Corn bobs to Bagasse ratio (0% to 100%); with constant amount of chitosan 5 gm as binder material and defined sample thickness of 6 mm.
2. Mechanical and thermal tests help us to define optimal ratio which is 40% corn & 60 % bagasse which realize highest cohesion strength factor and least thermal conductivity as shown in figure (4).

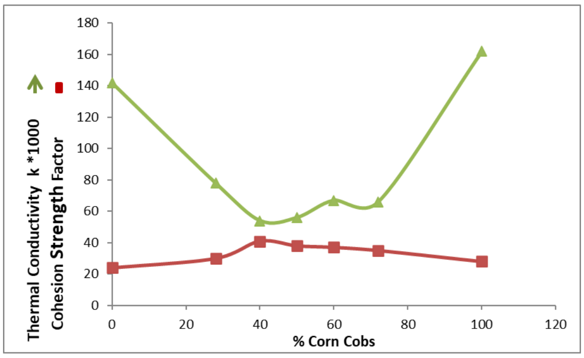


Figure (4) Effect of % Corn on Samples Specifications

4.2 Effect of Samples Additives

- Study the effect of adding chitosan to samples in increasing quantities7.5gm and 10 gm.
- Study the effect of adding synthetic polymer with small portion on samples performance.
- Study the effect of painting samples with thin layer of Aerogel; beside thermal and mechanical advancement of samples it improves fire retarded and water resistivity.

4.3 Samples tests

Many tests have done to define the best sample conditions

4.3.1 Scanning Electron Microscope [SEM]

- The Instrument used is **ZEISS- EVO15 (United Kingdom Fabrication)** Imaging and analytical excellence on insulators samples. Testing of material quality or failure mechanism of samples.
- Results of SEM Analysis on different samples conditions are shown in figure (5). As shown in figure 5[A & B]; Samples of 100% Bagasse or 100 % Corn Cob are weak performance with respect to coherence and strength. That's proved mixing of Bagasse and Corn Cob improves of samples quality
- Study effect of chitosan ratio and study effect of aerogel coating are presented in SEM results of figure 5 [C,D,E,F,G,H and I].Sample figure 5[G] with composition of (40% corn cobs & 60% Bagasse) and additives of (10 gm. Chitosan- 1% Synthetic polymer and thin layer of Aerogel coating) is the highest material quality. Where, good particles compact took place. This composition is candidate to fabricate eco- friendly thermal insulation sheets.

4.3.2 Thermal stability Test using [TGA]

Thermo-gravimetric Analyzers [TGA] Instruments is used to examine samples 'stability factor by determination the characteristics of a substance through a change in mass and examination the decomposition rate of insulation material. The instrument used for this test is SHIMADZU-TGA-50 Series-Japanese industrial with heating rate 10 deg /minute under nitrogen atmosphere. As shown in figure (6); the three samples of agricultural wastes are thermally stable with slowly decomposition at high temperature.Sample10; which has Chitosan content of 10 gm.is the highest stability one. Figure (7); show the effect of adding Synthetic polymer and Aerogel coating. The most stable sample is 10sA; which composition are(40% corn cobs & 60% Bagasse) and additives of (10 gm. Chitosan, 1% Synthetic polymer and thin layer of Aerogel).

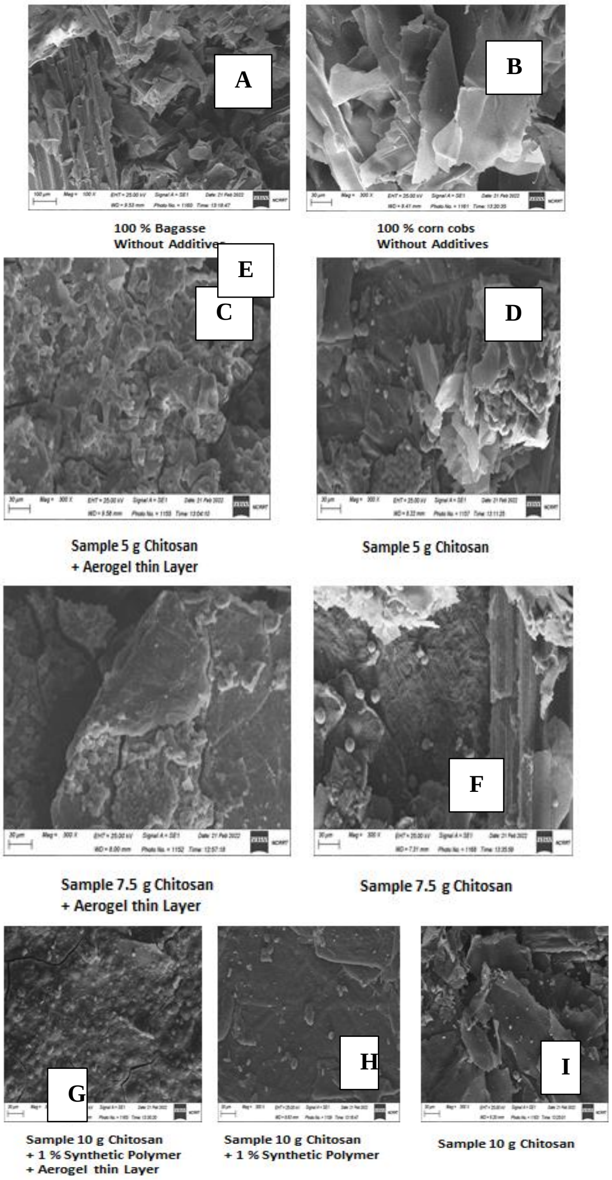


Figure (5) SEM Analytical Results

4.3.3 Water Resistivity Test

Water resistivity of samples is tested by defining the water contact angle (WCA).Where; this angle value change according to samples composition and additives. The Specifications of used apparatus are (Attention

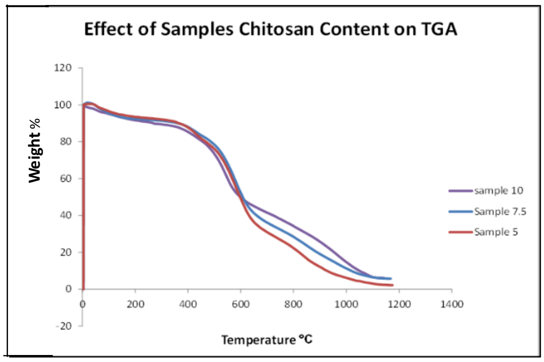


Figure (6) TGA Analysis Results of Samples Chitosan Content

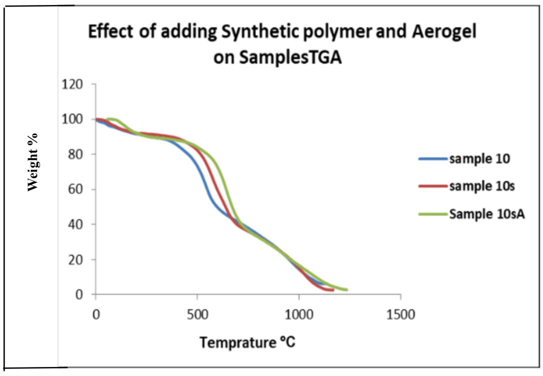


Figure (7) Defining of best sample according to thermal stability

Theta Optical Tensiometer / Biolin Scientific Company/ Finland). Increasing angle value indicates less water absorption of sample surface and consequently good mechanical performance of sample. Water resistivity indicators of different samples' composition are:

- Samples of 100% Bagasse or 100% Corn cobs wastes have low contact angles (ranged between 83º- 94º) .
- Adding 5gm. of chitosan; the highest contact angle was 112.8º.
- Adding 7.5gm. of chitosan; the highest contact angle was 113.4º.
- The sample of high-water resistivity has contact angle of 121.24º. This sample conditions are ratio of Corn cobs & Bagasse (40%:60%) and additives of (10 gm. Chitosan, 1% PVA and Aerogel layer). Figure of results in details is presented in Appendix[A]

5. Results and interpretation

Many tests have done for samples to examine their quality. Due to effect of samples' compositions on their efficiency; defining the best composition is required. Sample contents of: 14gm. Corn cobs & Bagasse (40%:60%) and additives: (10 gm. Chitosan, 1% PVA and Aerogel layer) has the best thermal-mechanical performance with good water resistant.

6. Laboratory Model of Piping Insulation

- To Examine the efficiency of eco-friendly insulators; we designed a laboratory model. It consists of Carbon-steel pipe with 30 cm. Length & 10 cm. Diameter.
- At beginning Surface Temperature of pipe was 24ºC.Outlet hot steam of laboratory heating mantle was passing through pipe for 60 minutes. In this case, surface temperature of pipe before insulation was 80 ºC
- After wrapping the pipe with samples of prepared insulation in 6 mm thickness; outlet hot steam of laboratory heating mantle was passing through pipe for 60 minutes. Where, surface temperature of pipe after insulation was 38 ºC.
- This model proved mechanical and thermal efficiencies of eco-friendly insulators; where minimizing of surface temperature guarantees reduction of energy losses, less fuel combusted, workers safety and perfect process control.
- This model confirmed the possible transition of insulators sheets from laboratory scale to manufacturing scope.
- Piping model and results are shown in Appendix[B].

Conclusion

Mixture of grinding agricultural wastes in presence of chitosan as green and clean adhesive can be recycle into eco - friendly thermal insulators. Standard Examination and laboratory model proved that the best conditions of this insulator are composition of 14 gm. (40% corn cobs & 60% Bagasse) and additives of (10 gm. Chitosan, 1% Synthetic polymer and thin coat of Aerogel).Where it is the highest material quality, good water resistivity and high cohesion strength. Thermal performance of this composition is perfect represented in slow decomposition at high temperatures. While low thermal conductivity of 0.04 W/mk is the most important achievement. That means our fabricated thermal insulation is competitor to marketable insulations. These results proved the possibility of commercially production of eco- friendly insulation to apply for industrial or building sectors. Where, minimizing energy losses and limiting GHG emissions through Insulations applications; are direct ways for climate change mitigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Nomenclature

S	Surface heat loss in kCal/hr m2	**NHV**	Net heating value of fuel kCal/kg
Ts	Hot surface temperature in °C	**ηb**	% Boiler efficiency
Ta	Ambient temperature in °C	**r1**	Radius of pipe m
Hs	Total heat loss kCal/hr	**r2**	Radius of pipe after insulation m
Hf	Equivalent Fuel losses kg/y	**WCA**	Water contact angle**.**
Cf	Annual cost of heat losses $/y	**CC**	Corn Cob
U Cf	Cost of fuel mass unite $/kg	**SB**	sugarcane bagasse

References:

1. United Nations, based on the latest available data and estimates as of June 2021: https://unstats.un.org/sdgs
2. Sudeepa Kumari,"Clean Energy: Key to a Sustainable Future".2021.ENVIS RP: Geodiversity& Impact on Environment eISSN: 0974 – 1356,Vol.25 (3)
3. United Nation Industrial Development Organization"Practical Guide forImplementing anEnergy ManagementSystem"Printed in AustriaV.15-07781—November 2015—650
4. DanielaSova, Mariana Domnica Stanciu ,Sergiu Valeriu Georgescu"Design of Thermal Insulation Materials with Different Geometries of Channels".Polymers 2021, 13, 2217. https://doi.org/10.3390/polym13132217.
5. Alexey Zhukov, Tatiana Konovaltseva, Ekaterina Bobrova,Ekaterina Zinovieva."Thermal insulation: operational properties and methods of research"MATEC Web of Conferences 251, 01016 (2018) https://doi.org/10.1051/matecconf/201825101016
6. Gabr E. M. & Mohamed S. M. " Energy management model to minimize fuel consumption and control harmful gas emissions"International Journal of Energy and Water Resources (2020) 4:453–463.**https://doi.org/10.1007/s42108-020-00085-2**
7. Safenaz Shaaban and Mahmoud Nasr "Agricultural Wastes-To-Green Energy in Egypt".(2018) Advance in Biotechnology & Microbiology.V.8 issue 5DOI: 10.19080/AIBM.2018.08.555750
8. Diego Juela, Mayra Vera, Christian Cruzat, Ximena Alvarez and Eulalia Vanegas." Adsorption properties of sugarcane bagasse and corn cob for the sulfamethoxazole removal in a fixed-bed column.Open Access Sustainable EnvironmentResearch.(2021).V.31issue 27,1 – 14 https://doi.org/10.1186/s42834-021-00102-x
9. Athi-enkosi Mavukwana "Development of a Simulation Model for Gasification of South African Solid Waste: Waste Tyres and Agricultural Residue.Master in Technology Degree.2016. University of Johannesburg.
10. Sarita Cândida Rabelo,Aline Carvalhoda Costa,Carlos EduardoVazRosse "Sugarcane: Agricultural Production, Bioenergy and Ethanol, Chapter 17 - Industrial Waste Recovery" Science-direct .2015, https://doi.org/10.1016/B978-0-12-802239-9.00017-7
11. Benallel, A. Tilioua, M. Ettakni, M. Ouakarrouch, M. Garoum, M. Ahmed Alaoui Hamdi, Design and thermophysical characterization of new thermal insulation panels based on cardboard waste and vegetable fibers, Sustainable Energy Technologies and Assessments, 48 (2021) 101639.
12. Š. Hýsek, M. Podlena, H. Bartsch, C. Wenderdel, M. Böhm, Effect of wheat husk surface pre-treatment on the properties of husk-based composite materials, Industrial Crops and Products, 125 (2018) 105-113.
13. - S. Liuzzi, C. Rubino, F. Martellotta, P. Stefanizzi, C. Casavola, G. Pappalettera, Characterization of biomass-based materials for building applications: The case of straw and olive tree waste, Industrial Crops and Products, 147 (2020) 112229.
14. M Faisal, A Elhussieny, K A Ali, I Samy and N M Everitt "Extraction of degradable bio polymer materials from shrimp shell wastes by two different methods" The 4th International Conference on Advanced Applied Sciences. Materials Science and Engineering 464 (2018) 012004,IOP Publishing.**https://doi:10.1088/1757-899X/464/1/012004**
15. Teli M.D., Javed Sheikh."Extraction of chitosan from shrimp shells waste and application in antibacterial finishing of bamboo rayon"International Journal of Biological Macromolecules 50 (2012) 1195– 1200.
16. Heba Elbasiouny, Bodor A. Elbanna, Esraa Al-Najoli, Amal Alsherief,Shimaa Negm, Esraa Abou El-Nour, Aya Nofal and Sara Sharabash "Agricultural Waste Management for Climate Change Mitigation: Some Implications to Egypt" Waste Management in MENA Regions,2020.Springer Water, https://doi.org/10.1007/978-3-030-18350-9_8
17. - Buratti, C.; Belloni, E.; Merli, F. Water vapour permeability of innovative building materials from different waste. Mater. Lett. 2020, 265, 127459.
18. - C. Lacoste, R. El Hage, A. Bergeret, S. Corn, P. Lacroix, Sodium alginate adhesives as binders in wood fibers/textile waste fibers bio- composites for building insulation, Carbohydrate polymers, 184 (2018) 1-8.

19. Zhejin Li, Peng Sui, Xiaolei Yang, Hongcui Dai,Pan Long,Yuanquan Chen "Balancing GHG mitigation and food security through agricultural recycling systems: Case studies in the North China Plain"Journal of Cleaner Production. volume 157, 20 July 2017, Pages 222-231
20. LINDEBERG J.D."STATE OF RECYCLING – Q1 2021 Managing change in a resource-constrained world." RRS pages 1-26. JDL@RECYCLE.COM.
21. Irina Smirnova, Pavel Gurikov." Aerogel production: Current status, research directions, and future opportunities". The Journal of Supercritical Fluids 134 (2018) 228–233.https://doi.org/10.1016/j.supflu.2017.12.037
22. Report-linker. "Global Industrial Thermal Insulation Industry". July 2020. https://www.reportlinker.com/p05112905/?utm_source=GNW
23. Insulation Outlook." Top 10 Reasons to Insulate". http:// Insulation.org./about-insulation/
24. Uruthira Kalapathy, Andrew Proctor, and John Shultz."Silicate Thermal Insulation Material from Rice Hull Ash". Ind. Eng. Chem. Res. 2003, 42, 1, 46 – 49. https://doi.org/10.1021/ie0203227
25. Xiaojun Liu, Xin Chen and Mehdi Shahrestani "Optimization of Insulation Thickness of External Walls of Residential Buildings in Hot Summer and Cold Winter Zone of China"Sustainability 2020, 12, 1574; doi:10.3390/su12041574
26. Jailani, S. (2019). PPT course, syllabus. Syllabus, insulation and refractories, bureau of energy efficiency. www.Slide share /Salman Jailani.net. Accessed Jan 2020.
27. Michal Ganobjaka, Samuel Brunnera, Jannis Wernerya."Aerogel materials for heritage buildings: Materials, properties and case studies". Journal of Cultural Heritage, 42 (2020) p.81–98. https://doi.org/10.1016/j.culher.2019.09.007
28. Xuedong Xi, Antonio Pizzi, Hong Lei, Bengang Zhang, Xinyi Chen, Guanben Du. "Environmentally friendly chitosan adhesives for plywood bonding". International Journal of Adhesion & Adhesives 112 (2022) 103027. https://doi.org/10.1016/j.ijadhadh.2021.103027
29. Urška Vrabič Brodnjak, Dimitrina Todorova, Mirjam Leskovšek."Viscoelastic and physical Properties of Paper from Softwood and Hardwood Pulp with Addition of Chitosan and Rice Starch". Journal of Science & Technology for Forest Products and Processes. September 7,2020, NO.6
30. World Health Organization, Regional Office for Europe. "Chemical policy and programs to protect human health and environment in a sustainability perspective". Report of a WHO Meeting Bonn, Germany 4-5 July 2016
31. Nilofar Asim, Marzieh Badiei, Mohammad A. Alghoul, Masita Mohammad, Ahmad Fudholi, Md Akhtaruzzaman, Nowshad Amin, Kamaruzzaman Sopian."Biomass and Industrial Wastes as Resource Materials for Aerogel Preparation: Opportunities, Challenges, and Research Directions".Ind. Eng. Chem. Res. 2019, 58, 38, 17621 –17645 https://doi.org/10.1021/acs.iecr.9b02661
32. Gen Hayase, Kazuyoshi Kanamori, Kentaro, Abe, Hiroyuki Yano, Ayaka Maeno, Hironori Kaji, Kazuki Nakanishi. "Polymethylsilsesquioxane–Cellulose Nanofiber Biocomposite Aerogels with High Thermal Insulation, Bendability, and Superhydrophobicity".ACS Appl. Mater. Interfaces 2014, 6, 12, 9466–9471.https://doi.org/10.1021/am501822y
33. Huiran Jin, Xinyu Zhou, Tingting Xu, Chenye Dai, Yawei Gu, Shan Yun, Tao Hu, Guofeng Guan, Jing Chen. "Ultralight and Hydrophobic Palygorskite-based Aerogels with Prominent Thermal Insulation and Flame Retardancy". ACS Appl. Mater. Interfaces 2020, 12, 10, 11815–11824.https://doi.org/10.1021/acsami.9b20923
34. Zengwei Liu, Jing Lyu, Dan Fang, and Xuetong Zhang. "Nanofibrous Kevlar Aerogel Threads for Thermal Insulation in Harsh Environments". ACS Nano 2019, 13, 5,5703–5711 https://doi.org/10.1021/acsnano.9b01094

Appendices
Appendix [A]

[a] Bagasse100%   [b] corn cobs 100%

[c] Bagasse and corn cobs Chitosan (5gm.)   [d] Bagasse and corn cobs Chitosan (5gm.) + s. polymer   [e]Bagasse and corn cobs Chitosan (5gm.) + s. polymer + A

[f] Bagasse and corn cobs Chitosan (7.5gm.)   [g] Bagasse and corn cobs Chitosan (7.5gm.) + s. polymer   [h] Bagasse and corn cobs Chitosan (7.5gm.)+ s. polymer+ A

[i] Bagasse and corn cobs Chitosan (10gm.)   [j] Bagasse and corn cobs Chitosan (10gm.) + s. polymer   [k] Bagasse and corn cobs Chitosan (10gm.)+ s. polymer+ A

Effect of samples Composition on water Resistivity
Best Sample is [k] which has the highest contact angle

Appendix[B]

Laboratory Model of Piping Insulation

(I)

(II)

(III)

(IV)

Surface temperature of pipe changed from 80°C before insulation to 38 °C after it. This result approved fabricated insulation quality and guarantees reduction of energy losses by percentage of at least 50 %