A REVIEW ON EXERGY, LIFE CYCLE AND THERMO ECONOMIC ANALYSIS OF SUGAR INDUSTRY

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ABSTRACT

In India Sugar is the second-largest agro-based industry, is a segment of huge prominence to the Indian economy. Thus optimization of the sugar production process for the sake of economic, environmental and energy efficiency should be the prime concern. Exergy analysis can be the best suitable tool along with LCA for the same. A number of studies have been conducted on energy analysis of various food industries especially for sugar industries and throughout the previous decade’s exergy analysis emerges as the best suitable tool for optimization and improvement of the sugar industry. The present study reviews the existing studies on exergy, LCA and thermo economic analysis of Sugar industry.

Key words: Life cycle analysis, thermo Economic analysis of sugar Industry etc.


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1. INTRODUCTION

With an increasing awareness of the environmental impacts and practical limitations associated with the traditional fossil energy carriers, many countries aim to increase the efficiency of the processes using energy, while shifting to more sustainable energy sources. (Fabian Bühler, 2016)

Energy analysis is the traditional method of assessing the way energy is used in an operation involving the physical or chemical processing of materials and the transfer and/or conversion of energy.[1] This usually entails performing energy balances, which are based on the First Law of Thermodynamics, and evaluating energy efficiencies.
This balance is employed to determine and reduce waste exergy emissions like heat losses and sometimes to enhance waste and heat recovery. However, an energy balance provides no information on the degradation of energy or resources during a process and does not quantify the usefulness or quality of the various energy and material streams flowing through a system and exiting as products and wastes.

The exergy method of analysis overcomes the limitations of the FLT. The concept of exergy is based on both the FLT and the SLT. Exergy analysis clearly indicates the locations of energy degradation in a process and can therefore lead to improved operation or technology. The exergy technique for examination defeats the impediments of the FLT. The idea of exergy depends on both the FLT and the SLT. Exergy investigation unmistakably demonstrates the areas of vitality corruption in a procedure and can thusly prompt enhanced operation or innovation. Exergy examination can likewise measure the nature of warmth in a waste stream.[2]

A principle point of exergy investigation is to distinguish significant (exergy) efficiencies and the causes and genuine sizes of exergy losses. (Ibrahim Dincer, 2013) In an exergy analysis, the underlying state is determined, and accordingly it is not a variable. The work yield is boosted when the procedure between two indicated states is executed in a reversible way. In this manner, all the irreversibility are ignored in deciding the work potential. At long last, the framework must be in the dead state toward the finish of the procedure to expand the work yield. In dead express the framework is in thermodynamic harmony with the earth. (Yunus A Cengel)

Efficiencies in view of exergy, dissimilar to those in view of vitality, are dependably measures of the way to deal with genuine ideality, and in this manner give more significant data while surveying the execution of vitality frameworks. Additionally, exergy misfortunes unmistakably distinguish the areas, causes, and wellsprings of deviations from ideality in a system. (Ibrahim Dincer, 2013)

Losses occur when the efficiency of a device or process deviates from the efficiency that would occur if the device or process were ideal. The value of a loss is a measure of this deviation from ideality Exergy losses, on the other hand, do provide quantitative measures of deviations from ideality. In addition, exergy losses allow the location, type, and cause of a loss or inefficiency to be clearly identified. This information is critical for efforts to increase exergy efficiency. The goal of more efficient energy use can be achieved by utilizing exergy analysis as it takes into account locations, types, and real magnitudes of wastes and loss of energy. (Ibrahim Dincer, 2013)

2. EXERGY ANALYSIS IN SUGAR PRODUCTION PROCESS

For better utilization of energy during the sugar production process, it is important to take into account the quantity and quality of energy. It is required to compare the performance of different process plants or units. For this purpose it has been decided to use criteria of performance based on exergy analysis, known generally as exergetic efficiencies. An exergetic effectiveness can likewise be utilized to think about the level of thermodynamic flawlessness of various procedures in a given plant. For the most part, the execution of Sugar creation process is assessed through vivacious execution criteria in view of first law of thermodynamics, including electrical power and warm productivity.

In late decades, the exergetic execution in light of the second law of thermodynamics has found as helpful technique in the plan, assessment, advancement and change of the procedure. The sugar generation stages are considered by different scientists as an open relentless state.
thermodynamic framework in the vitality and exergy investigations. Many researchers (Schneider, 1971, Baloh, 1981; Uze, 1991; Tekin et al., 1992; Leblebici, 1998; Tekin and Bayramoglu, 1998; Cadet et al., 1999) have made some important contributions to this subject. In addition to these, this paper presents a research review covering the energy and exergy analyses of sugar production stages. The Exergy analysis of Sugar production process has been carried out by different researchers is illustrated in Table 1.

Table 1 Exergy Analysis in Sugar Production Process

<table>
<thead>
<tr>
<th>Author</th>
<th>Objective</th>
<th>Methodology</th>
<th>Key Findings</th>
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<tr>
<td>Mustafa Bayrak, Adnan Midilli and Kemal Nurveren, (2003)</td>
<td>Conduct an energy and exergy analyses of sugar production stages in Bor Sugar Plant, Turkey</td>
<td>All calculations were accomplished by employing the first and second law of thermodynamics.</td>
<td>It was found that the exergy losses took place mostly during the processes of sherbet production. Suggested that the irreversibility, generally emerging from the limited temperature contrasts at the sugar creation stages, ought to be diminished to complete all the more effectively the sugar generation process.</td>
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<tr>
<td>H. M. Sahin, A. Acir, T. Altunok, E. Baysal and E. Kocyigit</td>
<td>Analysis of exergy and energy of sugar production process in sugar plant</td>
<td>Sugar production processes considered as a steady state open thermodynamics system and employed the energy and exergy analyses, based on the first and second laws of thermodynamics using operational system data</td>
<td>Lowest values resulted from the degradation of energy quality and irreversibilities during the sub operation of the sugar crystallization process. The rate of the exergy carried by the raw juice should be increased to improve the exergy efficiency and to reduce the degradation of energy quality. Heat exchangers used in all sugar production steps should be suitable for well insulated devices that allow energy exchange between hot and cold fluids.</td>
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<td>Necmettin Sahin, Erkan Kaplan, Mustafa Bayrak, I. Faruk Yaka and Afsin Gungor, 2015</td>
<td>Exergy analysis of Eregli sugar factory</td>
<td>The process is divided into 4 different units in a detailed way and factory-wide including exergy analysis. Exergy analysis of the processes was considered as continuous-flow open systems and the mass.</td>
<td>The factory systems maintenance, repair and renovation have been recommended.</td>
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<tr>
<td>T. Tekçi And M. Bayramoglu, 1998</td>
<td>Exergy Loss Minimization Analysis Of Sugar Production Process From Sugar Beet</td>
<td>Two techniques, namely: approximate optimization analysis and structural analysis is applied to simplify the detailed optimization task.</td>
<td>Presents preliminary results of a detailed study on the minimization of exergy losses in a beet sugar manufacturing plant. It is found that approximate optimization analysis and structural analysis may be used consecutively; AOA screens the most significant factors while SA partitions the factors as ones to be used for preliminary sub-optimization of some specific units, and ones to be used for a complete plant optimization.</td>
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<td>Tolga Taner and Mecit</td>
<td>To determine the best</td>
<td>In this study, the laws of</td>
<td>An overall assessment of the energy</td>
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A Review on Exergy, Life Cycle and Thermo Economic Analysis of Sugar Industry

The cogeneration process from sugarcane bagasse is an alternative way to reduce fossil fuels consumption. As the sugarcane industry generates serious environmental problems, it is considered a major pollutant, which requires alternative solutions to minimize its impacts. Cogeneration is one of the best ways to cope out this problem. Sugar industry utilizes distinctive cogeneration plans to fulfill the plant’s procedure steam request and create surplus power by updating the steam channel parameters. Steam turbines are irreplaceable for cogeneration plants in sugar ventures, consuming energies, for example, bagasse, as technology is all around developed.[5] Thus sugar cane bagasse has strong potential in displacing the fossil fuels and can be extensively used in the boilers and furnaces for power generation. Obviously, this considerable amount of power should be generated efficiently. The previous study done by various researchers for the cogeneration is depicted in table 2.

In most countries, numerous sugar or food production plants driven by fossil fuels like coal, or by other energy resources are in service today. But in recent time, many sugar production companies have paid consideration to process improvement by cogeneration process using by product as fuel but the basic disadvantage are the major air pollutants such as CO₂, SO₂, and NOₓ). Which can be further reduced by optimization. Exergy analysis is a useful tool in such efforts.

Table 2 Exergy analysis of cogeneration power plants

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<tr>
<th>Author</th>
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<th>Conclusions</th>
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<tr>
<td>Luciana Faria Saint-Martin Pereira et al, 2013</td>
<td>The exergetic analysis was employed to evaluate the sugar and alcohol plants performance</td>
<td>The method of exergetic analysis of cogeneration in a sugar and alcohol plant was developed and applied to a typical plant</td>
<td>The thermodynamics first law alone does not evaluate the performance correctly. Many exergy is destroyed in the boiler due the combustion irreversibility, explaining the low exergetic efficiency. To improve the system performance a greater attention must be give mainly to the boiler, and next, to the turbo-generator turbine</td>
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<td>Reynaldo Palacios-Bereche et al (2013)</td>
<td>Exergetic analysis of the integrated first- and second-generation ethanol production from sugarcane</td>
<td>Conducted an assessment of the exergy and exergetic cost associated with the ethanol production process from sugarcane biomass, including the route of bagasse enzymatic hydrolysis. In spite of the increase in the exergetic cost of the mainproducts, the global exergetic efficiency is higher for the integrated plant in comparison with the conventional plant, reaching 36.6% in the Best Case, compared to 28.4% for the Base Case.</td>
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<td>Christoffer Lythcke-Jorgensen (2014)</td>
<td>An exergyanalysis is carried out for a modelled polygeneration system in which lignocellulose ethanol production based on hydrothermal pre-treatment is integrated in an existing combined heat and power (CHP) plant</td>
<td>The load in the CHP unit only had a minor impact on the standard exergy efficiency of the ethanol facility during integrated operation. The inclusion of district heating production in the ethanol facility was found to increase the standard exergy efficiency slightly. The efficiency of integrating lignocellulose ethanol production in CHP plants is highly dependent on operation, and it is therefore suggested that the expected operation pattern of such polygeneration system is taken into account when evaluating the potential performance of the polygeneration system.</td>
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<td>S.C. Kamate, P.B. Gangavati, 2009</td>
<td>Exergy analysis of a heat-matched bagasse-based cogeneration plant of a typical 2500 tcd sugar factory, using backpressure and extraction condensing steam turbine is presented.</td>
<td>At optimal steam inlet conditions of 61 bar and 475°C, the backpressure steam turbine cogeneration plant perform with energy and exergy efficiency of 0.863 and 0.307 and condensing steam turbine plant perform with energy and exergy efficiency of 0.682 and 0.260, respectively. Boiler is the least efficient component and turbine is the most efficient component of the plant.</td>
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<td>Pablo Silva Ortiz, Silvio de Oliveira Jr., 2014</td>
<td>In this work via exergy analysis biomass pre-treatment methods to prepare LB for bioethanol production using two typical chemical compositions of sugar cane bagasse are evaluated</td>
<td>Four case studies for the following pre-treatment technologies (A) SE, (B) Organosolv, (C) LHW and (D) SE ± LHW are studied. High exergy values are obtained in all cases of this study (A) 93.2%, (B) 85.4%, (C) 94.1%, and (D) 95.1%, the values of destroyed exergy rate found for the cases analysed using the raw material 2 are high compared to the input bagasse exergy rate, (A) 7.2%, (B) 24.8%, (C) 6.0%, and (D) 5.5%, highlighting the relevance of such processes in the overall exergy efficiency of second-generation bioethanol production routes.</td>
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<td>J. Raghu Ram, Rangan Banerjee, 2003</td>
<td>Energy and cogeneration targeting for a sugar factory</td>
<td>Modified evaporator designs are proposed as it has been found that the existing plant is not the surface zone of the evaporators and the measure of steam being devoured. Exergy losses can be reduced by 48% of its original value if the existing quadruple effect is modified to a</td>
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Luis E. et al 2013

Energy and exergy investigation of a sugar stick bagasse gasifier coordinated to a solid oxide power device in view of a semi balance approach

Develop a comprehensive mathematical model of a bagasse gasification unit integrated with a solid oxide fuel cell, for predicting the system performance using the energy and exergy criteria.

The quasi-equilibrium approach is talked about in view of the trial information from a pilot percolating gasifier for two biomass sources: sugar stick bagasse and rice husk.

3. EXERGY ANALYSIS IN OTHER FOOD PRODUCTION UNIT

The main challenges facing by the food production unit are the major requirement for improved agricultural and postharvest treatment methods and more efficient food production. More efficient food production required less energy and water, and reduces food wastage all over the food chain (Ohlsson, 2014). The total amount of raw materials, water, and energy required along a food chain can be substantial depending on the type of food product produced (Ramirez, 2005). To make the process more efficient exergy analysis can play a major role in the era. Some researchers made their research in this era, are depicted in table 3.

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<tr>
<td>Majid Jafaryani et al, 2015</td>
<td>Exergy analysis of an industrial-scale yogurt production plant</td>
<td>Exergy balance equation and exergetic efficiency definition</td>
<td>The main contributors to the exergy destruction of the entire plant were in descending order of importance: boiler &amp; air compressor combination of the steam generator (12484.88 kW), ice-water tank &amp; agitator combination of the above-zero refrigeration system (2900.59 kW), and pressure reducer of the steam generator (731.82 kW).</td>
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<td>Mohamad Mojarab Soufiyan et al, 2016</td>
<td>Comprehensive exergy analysis of a commercial tomato paste plant with a double-effect evaporator</td>
<td>Using energy and exergy balance equations, all components of the plant were investigated exclusively and their exergetic parameters were figured on the premise of genuine operational information.</td>
<td>Over 82% of the total destroyed exergy in the plant occurred in the boiler combination as the main component wasting exergy. Exergy idea and its augmentations could be filled in as a capable evaluation procedure to improve the plan and execution of numerous impact vanishing frameworks utilized in sustenance industry.</td>
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<tr>
<td>D.A. Fadare et al, 2010</td>
<td>Energy and exergy analyses of malt drink production in Nigeria</td>
<td>Exergy balance equation and exergetic efficiency definition</td>
<td>Exergy losses in the system can be reduced by increasing the capacity of the pasteurizer unit which will in turn reduce the load on the boiler. Process heat integration between the pasteurizer and other units in the packaging group operation can also help to improve the energy efficiency of the system.</td>
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<td>Z. Sogut, N. Ilten, Z. Oktay, 2010</td>
<td>Energetic and exergetic execution assessment of the fourfold impact evaporator unit in tomato paste production</td>
<td>Performance of quadruple effect evaporator unit (QEEU) by using exergy analysis based on actual operational data</td>
<td>Main reason to get relatively lower exergy efficiency arises from no insulation. Insulation of the pipes and the heat exchangers is very crucial to improve energy and exergy efficiency for such industrial systems. The highest exergy destruction occurs</td>
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The procedure for applying the exergy analysis food chains as proposed by Filippos K. Zisopoulos, 2015 can be subdevied in 7 steps i.e.1. Defining the system boundaries of the food process or chain; 2. Finding out the reference environment, which directly or indirectly affect the local environmental circumstances; 3. Conduct a mass flow analysis; 4. Define and calculate thermodynamic indicators; 5. Interpret the results; 6. Propose and assess possible amendments/developments; 7. Interconnect the consequences.

In food production system water and energy are the prime considerations. Some researchers did there study to improve the scenario, Lee and Okos (2011) assessed positively different food production unit that reduces water and energy consumption, while Alamilla-Beltran et al. (2011) acknowledged developing food processing technologies with encouraging solicitations such as electro permeabilization, Plasma activation, Plasma etching, Plasma modification, and radiofrequency heating, between others.

From the literature it can be concluded that in the food chain industry there will be need of avoiding the waste generation by minimizing or re-using, in such a way that the whole raw materials are transformed into prized and useful products, reducing the exergy destruction during processing and utilizing the renewable energy sources as an alternative of fossil sources.
4. LIFE CYCLE ASSESSMENT ALONG WITH EXERGY ANALYSIS OF FOOD INDUSTRY

For ecological considered development, natural and ecological indicators are gradually emerges as necessary tools (Gong and Wall (2001)). As there is depletion in resources available naturally of our environment it gains more importance by day to day. To overcome this scenario Life Cycle Assessment (LCA) have become popular as they found out the ecological problems in the production processes. In sugar industry as there is need of improving the efficiency there is also a need of making process more sustainable and in this way some researchers make their contribution by considering the Life Cycle Analysis along with Exergy Analysis are tabulated in Table 4.

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<tr>
<td>Maylier Pérez Gil et al 2013</td>
<td>Life cycle assessment of the cogeneration processes in the Cuban sugar industry</td>
<td>A combination of nine steam generators model with eight turbo generators was analyzed, for a total of 72 alternatives, using the Eco-indicator 99 and the software Sima-Pro.</td>
<td>The reduction of process emissions to the air, water and soil had a favorable effect on the categories of carcinogenesis, radiation, Eco toxicity and land use. The category of Human Health damages reached higher impacts in the cogeneration stage, which represented about 80% of the total environmental impact of the process. It was evidenced that the largest contribution to this category was the emissions of particulate material from bagasse combustion.</td>
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<td>Conteras Moya, Rosa Domínguez et al , 2013</td>
<td>Exergetic analysis in cane sugar production in combination with Life Cycle Assessment</td>
<td>In this work, Exergetic Life Cycle Assessment was combined with a traditional LCA of cane sugar production process developed previously by Conteras et al. (Conteras et al., 2009), for assessing four different alternatives for byproducts valorization of the cane sugar process.</td>
<td>The environmental benefits of producing alcohol, biogas, animal food and fertilizers from the sugar production by-products were documented. The combination of both tools contributes with the environmental profile of the process and results thermodynamically rigorous of resources consumption, its renewability and hence the process sustainability.</td>
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<td>João Paulo Macedo et al 2014</td>
<td>Comparative analysis of electricity cogeneration scenarios in sugarcane production by LCA</td>
<td>The method used in this study aimed to provide an understanding and a model of the electrical and thermal energy production and the environmental impacts of conventional vapor power systems which operate with a Rankine cycle</td>
<td>Reheating and regeneration concepts were found to be considerably effective in improving the energy and environmental performance of cogeneration systems by burning sugarcane bagasse. For the evaluated categories, the results indicate that the proposed modifications are favorable for increasing the efficiency of the thermodynamic cycle and for decreasing the environmental impacts of the product system.</td>
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<tr>
<td>M. Genc, S. Genc, Y. Goksungur,2017</td>
<td>Exergy Analysis of Wine Production: Red Wine Production Process as a Case Study</td>
<td>The mass, energy, and exergy balance equations are applied to the system of interest to</td>
<td>The total exergy destruction of the overall system without waste stream was found to be 344.08 kW The total exergy destruction of the</td>
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Determine exergy destruction and efficiencies in which the system is at steady-state and steady-flow process.

Overall system with waste stream was calculated as 2692.51 kW. The thermal efficiency of the overall system was determined as 57.2% while the exergy efficiency was calculated as 41.8%.

5. EXERGO ECONOMIC ANALYSIS

For optimum working analysis and design optimization the technique should combine the thermodynamic as well as economic considerations. Most of the research in this era shows that the best way of optimization is to depend the cost accounting on the thermodynamic or exergy analysis.

The thermo-economic analysis done by various researchers based on exergy methods is shown in Table 5. Exergy-based cost analysis permitted the credentials of a decrease in the production charges of sugar, ethanol and electricity as a significance of an improved exergy presentation of the energy conversion processes inside the production stages, mostly in the cogeneration plant. (Luiz Felipe Pellegrin et al 2011), such reduction in turn clues to higher incomes for the system.

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<tr>
<td>Eduardo Rafael Barreda Del Campo et al 1998</td>
<td>Thermo economic analysis of Sugar Mill</td>
<td>Two different cost attribution methods, the extraction method and the equality method are used to evaluate the exergetic and monetary (operational) costs of each flux within the system, especially the steam and generated power</td>
<td>The costs of the electricity and the steam produced were evaluated considering the costs of equipment acquisition, fuel and makeup water, using two methods of cost assignment. The costs of the steam supplied to process vary significantly, depending on the state of the steam and the process used to bring it to the state</td>
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<tr>
<td>Adriano V. Ensinas et al 2006</td>
<td>Optimization of Thermal Energy Consumption in Sugar Cane Factories</td>
<td>The methodology proposed is used to evaluate the cost of the steam consumed by the factory and the optimal design of the evaporation system as well as the juice and syrup heaters network</td>
<td>A thermo monetary enhancement of warm vitality utilization in a sugar creation process searching for the base ventures and operation costs . The evaporation system represents the largest part of the total cost of the factory in thermal energy consumption</td>
</tr>
<tr>
<td>Luiz Felipe Pellegrini, Silvio de Oliveira Junior, 2011</td>
<td>Consolidated creation of sugar, ethanol and power: Thermo monetary and natural examination and enhancement</td>
<td>A general model to the sugar and ethanol production processes is developed based on data supplied by a real plant, and an exergy analysis is performed. A discussion is made about the variables that most affect the performance of the processes. Then, a procedure is presented to evaluate</td>
<td>Besides adding a new revenue to the mill, the generation of excess electricity improves the exergo-environmental performance of the mill as a whole</td>
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6. CONCLUSIONS

The Review paper is based on exergy analysis, cogeneration, LCA and Thermo economic analysis considering food industry and Sugar Industry as a base. This review recognizes numerous points of care for Exergy Analysis to increase recognition in the food industry. Energy and exergy efficiency plays a vital role for any industry especially for food industry and shows the importance of second law analysis in performance optimizing. Cogeneration is the solution for energy optimization for Sugar Industry. Exergy is a valuable thought in economics and Environmental concern for the sugar industry in India. In macroeconomics, exergy offers an approach to lessen asset consumption and ecological pulverization by utilizing an exergy impose. There is necessity of more research in change of plant operation and vitality productivity of sugar industry in India, as the greater part of the examination is completed for different nation’s plant generally for Brazil.

REFERENCES


A Review on Exergy, Life Cycle and Thermo Economic Analysis of Sugar Industry


