



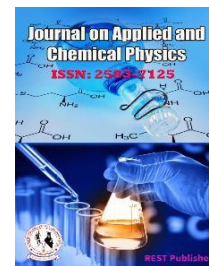
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Evaluating the Performance of Stainless Steel Pipes in the Sugar Industry

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Abstract: In the sugar sector, where they are often utilized to carry corrosive fluids like sugarcane juice, stainless steel pipes serve a critical role. These pipes must endure the demanding operating circumstances, which include being exposed to caustic liquids, high temperatures, and abrasive materials. Stainless steel pipes are the best choice for such demanding applications because they guarantee corrosion resistance, sturdiness, and dependability. However, a thorough investigation and comprehension are required due to issues with corrosion, scaling, and mechanical qualities in the sugar sector. For the sugar business to run effectively and safely, it is crucial to look into the behavior, functionality, and upkeep of stainless-steel pipes in this situation. In the sugar sector, research on stainless steel pipes is very important. Corrosive fluids like sugarcane juice are frequently transported in sugar factories and refineries using stainless steel pipes. To ensure secure and effective operations, it is essential to comprehend the corrosion behavior, scaling propensities, and mechanical characteristics of stainless-steel pipes in this setting. The development of corrosion-resistant materials, efficient cleaning and maintenance techniques, and enhanced piping system design principles can all benefit from research in this field. Such study can contribute to improving the dependability, productivity, and longevity of stainless-steel pipes in this crucial industry by addressing the problems unique to the sugar industry. These samples are put through a number of laboratory procedures, such as corrosion testing using simulated corrosive environments or sugar solutions, scale deposition investigations, and mechanical property evaluations. To study the morphology, content, and corrosion behavior of the pipe materials, advanced analytical techniques may be used, such as scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD), and spectroscopic analysis. Field examinations and monitoring of pipes that are already in use might also yield insightful information. The outcomes of these approaches can direct the creation of efficient corrosion mitigation plans and guidance for the material selection of stainless-steel pipes in the sugar sector. J4 material grade, JSLAUS, 204Cu, 409 M, AISI 304 Yield strength, Ultimate tensile strength, Hardness, % Of elongation, Cost, Corrosion rate AISI 304 material has secured rank 1 when compare to other materials AISI 304 materials has good performance than other materials like J4 material grade, JSLAUS, 204Cu, 409 M so sugar industry use stain fewer steel materials of AISI 304.

Keywords: Ultimate tensile strength, J4 material grade, Yield strength, wasps' method.

1. INTRODUCTION

Alternative projects may be available in the real world, giving you more options. The difficult task of choosing the best alternative falls on the decision maker (DM). The organization's profitability, expansion, and survival in a cutthroat market depend on this choice. Decisions regarding project selection and evaluation must take into account a variety of elements and are crucial for the organization's performance. This style of decision-making entails a number of steps, such as recognizing, taking into account, and evaluating the viability of numerous alternatives. Multi-criteria decision making (MCDM), according to Hwang and Yoon, is a practical method for choosing from a variety of categorized alternatives based on several attributes [1]. Complex technical components can be produced using a single manufacturing process

thanks to a cutting-edge technique called AM using Direct Energy Deposition (DED) is a process. As depicted in Figure 1, the process involves laser melting of a feeding powder supplied by a neutral gas stream to add material progressively. DED has the ability to reduce material waste and increase design diversity by forgoing traditional fabrication methods and adopting a three-dimensional manufacturing approach to manufacturing. However, the uncertainty surrounding the mechanical characteristics of the materials as they are deposited has prevented DED AM from being widely used... "Direct energy deposition (DED)"-produced austenitic stainless steels have been the subject of extensive research. Numerous research has discussed the monotone mechanical behavior, heterogeneous microstructures, and existence of manufacturing flaws brought on by the DED process in the materials. The changes in microstructures in fully dense materials are what cause the variety in mechanical characteristics. It is still unclear how specific microstructural properties, including as strength, ductility, fracture resistance, and fatigue behavior, affect a material's performance [7, 8]. Due to the fact that DED produces the component's shape and material characteristics in the same manufacturing process, it is essential to comprehend how local processing circumstances affect microstructures and mechanical properties [2]. According to a study by Wesley et al. (2012), grade 444 of stainless steel performed better against corrosion than grades 1010 and 304. Sulphanilamide, sulphapyridine, and sulphathiazole were recommended by Singh (2011) as potent anticorrosive chemicals to reduce corrosion in the sugar industry's process equipment. Prado et al. evaluated the impacts of sweet cane juice on the corrosion of carbon steel rolls and welded both austenitic aluminums rolls in 2010. The main wear process, according to Casanova und Aguilar (2008), was silica particles ploughing and piercing off the sugar glucose roller shell. The attributes and Zumelzu et al. conducted a study in 2003 to learn more about the behavior of high-chromium white iron corrosion. Buchanan et al. (2010) conducted an experiment on the abrasion-corrosion effectiveness of Fe-Cr-C shielded metallic arc welding (SMAW) hard sides and plasma-sprayed Fe-Cr-based coatings commonly used in the sugar industry. The study's findings demonstrated that the abrasion-corrosion resilience of SMAW are utilized high Fe-Cr-C coatings was inferior to that of Fe-Cr-based coatings blasted under an arc of electricity when subjected to both sandy and sugarcane juice mixture conditions. In 2007, Panigrahi et al. looked at pitting deterioration in stainless steel evaporator vessels. They proposed a ground-breaking multi-criteria decision-making, or MCDM, method for selecting the optimal material for tubes in the sugar industry to lessen corrosion wear [4]. Sulphur induces the formation of Sulphur elements, which act as pit initiation sites and drastically lower Grade 303 stainless steels resistant to corrosion compared to Grade 304. The stainless-steel grade 303 has good resistance to somewhat corrosive environments. It is important to keep in mind that Grade 303 shouldn't be exposed to maritime environments or other similar settings because the corrosion could lead it to pit quickly. Additionally, the positioning of supplied inclusions Grade 303 stainless steel is a free-machining austenitic stainless steel alloy. It contains higher sulfur content compared to other austenitic stainless steels, which improves its machinability. However, this sulfur addition can have detrimental effects on the corrosion resistance of Grade 303, especially in certain conditions. It is important to consult for particular suggestions on how to use Grade 303 stainless steel in various situations. Consult Atlas Technical Assistance [5]. Due to factors including the necessity to avoid or delay corrosion, take into account life cycle costs, and be environmentally friendly, chromium stainless steels have replaced carbon steels as the material of choice in a variety of structural applications. Ferritin stainless Irons, they are the body Centered cubic crystal have structure and a prominent metallurgical ferrite phase, provide good corrosion resistance and are more affordable than austenitic stainless steels. These steels typically include 10.5% and 30% chromium, Austenite-forming elements Carbon, Nitrogen and Nickel with trace amounts of low chromium grades Ferritin containing Stainless steels are acceptable corrosion resistance and are frequently used in vehicle exhaust systems. In contrast to austenitic steels, completely ferritin structures have Bad low temperature Hardness and low High temperature strength. Due to this, ferritin Stainless steels are typically employed in applications that do not require welding and are thought to have a poorer weld ability [6]. Material selection has become an important task for engineers and industrialists due to advancements in the design and development of machines. There are many different materials accessible today, each with unique properties, uses, benefits, and limits. Design engineers now face a difficult challenge when selecting the best material for a certain application. Designers must now make the best material choice to guarantee product performance, high productivity, and compliance with client criteria. Making the wrong material choice could lead to machine failure, which would cause losses and harm the manufacturing company's reputation [7]. Designers must take into account a variety of material qualities while choosing the best material. Since the selection of materials cannot be dependent on just one factor, it is crucial to understand the criteria. The material selection procedure becomes more difficult when there are multiple critical selection criteria to take into account. It is necessary to give decision-makers direction on how to choose the proper information and the influencing factors using straightforward, methodical, and logical procedures. To find the optimum options for a given application, a methodical and effective approach to material selection is therefore necessary [8]. The existence of corrosion and scale deposits on pipelines poses serious concerns to the petroleum sector. These deposits might result in a decrease in flow area and

potentially the blocking of entire pipeline sections if they are not carefully discovered and monitored. In this work, the effects of simulated seawater on corrosion and scale deposition on a 316L stainless steel elbow were examined using a combination of ultrasonic testing, visual inspection, and spectroscopic techniques. The wall thickness of the elbow pipe was measured by the researchers externally using an ultrasonic thickness gauge. A borehole camera was used for a visual assessment to evaluate the pipe's condition. A sample was taken and subjected to analysis in order to comprehend the morphology and composition of the scale deposit. Various analytical techniques [9]. The results revealed that the presence of scale deposits on the internal wall of the pipe led to a slight increase in wall thickness before the cleaning process. However, after cleaning, a significant reduction of up to 14% in wall thickness was observed, indicating the successful removal of the scale deposits. The researchers used a mix of testing and characterization approaches to get important insights into the corrosion and scale deposition behaviour of the materials. With the aid of these approaches, the researchers were able to compile thorough data regarding the corrosion and scale deposition events that occurred on the materials under investigation the study used Fourier transform infrared spectroscopy (FT-IR) to determine the scales' molecular make-up. The findings showed that the scale deposition on the stainless steel elbow's internal wall caused a modest increase in wall thickness prior to cleaning. However, following cleaning, a noticeable decrease in wall thickness of up to 14% was seen, indicating the successful removal of scale deposits. The researchers learned crucial things about how these materials behave when it comes to corrosion and scale deposition by combining various testing and characterization methodologies. In the petroleum business, this information is useful for creating mitigation and preventative maintenance plans [10]. The findings demonstrated that scale buildup on the pipe's internal wall caused a modest increase in wall thickness prior to cleaning. A maximum 14% drop in wall thickness was seen after cleaning, indicating the elimination of scale deposits. The researchers were able to get important insights into the corrosion and scale deposition behaviour on these materials by combining various testing and characterization methodologies. It is typical to hear pounding noises coming from process vessels or pipelines in sugar mills or refineries. These loud noises frequently cause people to worry about potential equipment damage and provide a safety risk to those around. These hammering noises are puzzling since no discernible mechanical action is associated with them. Those who are unfamiliar with the underlying mechanisms may find this absence of an obvious relationship confusing. Furthermore, it is frequently difficult to locate the precise source of the sound, let alone establish the reason [11]. The findings demonstrated that scale buildup on the pipe's internal wall caused a modest increase in wall thickness prior to cleaning. A maximum 14% drop in wall thickness was seen after cleaning, indicating the elimination of scale deposits. The researchers were able to get important insights into the corrosion and scale deposition behaviour on these materials by combining various testing and characterization methodologies. When the hammering sound occurs from inside a vessel, it is considerably more challenging to locate its source. Before the sound waves can be heard outside, they must pass through the vessel's wall. The sound waves spread over a significant portion of the vessel's wall and may have an impact on the integrated pipework connected to the vessel because the steel walls of the vessel are great sound conductors. As a result, it is quite difficult to identify the exact location of the sound within the vessel. Overall, it might be challenging to pinpoint the origin of these pounding noises in sugar plants or refineries and to comprehend their underlying reasons due to their nature. To successfully address these worries, a thorough examination and investigation are needed [12]. Before the cleaning procedure, the researchers found that the buildup of scale on the pipe's inside surface caused a modest increase in wall thickness. But following the cleaning, they saw a considerable reduction in wall thickness of up to 14%, demonstrating the effective removal of scale deposits. The researchers learned important things about how corrosion and scale deposition behave on these materials by combining testing and characterization methodologies. Through the use of a multifaceted strategy, they were able to examine a variety of factors, including elemental composition using energy-dispersive X-ray spectroscopy (EDS), morphological traits using scanning electron microscopy (SEM), quantitative elemental analysis using X-ray fluorescence (XRF), and determination of the crystalline structure of the scales using X-ray diffraction (XRD). As a result, DED additive manufacturing processes produce microstructures that resemble those in high-energy density welds, particularly laser welds, through localized heating and quick cooling. DED-processed austenitic stainless steels that are then annealed go through recrystallization, which lowers their toughness and strength. It is similar to the recrystallization behavior of wrought stainless steel. Interestingly, DED austenitic stainless steel can display tensile properties that are very similar to those of strain-hardened forged materials despite having unique microstructures. [13].

2. MATERIALS & METHODS

J4 Material Grade: J4 stainless steel is renowned for having outstanding corrosion resistance qualities. It is a member of the ferritic stainless-steel family and has a greater chromium content (usually between 14 and 17%) than other ferritic grades. Because of its improved corrosion resistance due to the increased chromium content, it may be used in a variety of

harsh settings. Where corrosion resistance is crucial, J4 stainless steel is frequently used in kitchen appliances, car trims, and architectural components. Formability and Deep Drawing Capability: J4 stainless steel also stands out for having excellent formability and deep drawing capacity. Compared to other stainless steel grades, it has a reduced work hardening rate, allowing it to go through significant plastic deformation without becoming overly hard.

Julius: Joint Service Lightweight Integrated Suit Technology (JSLIST) Undergarment System is referred to as SLAUS. Military troops wear a protective gear system that offers chemical and biological defence capabilities. The Joint Service Lightweight Integrated Suit Technology (JSLIST) or another outer protective garment is designed to be worn over the JSLAUS to increase comfort and offer additional protection against chemical and biological threats. It is made of specialised materials and consists of an undergarment, an over garment, and integrated socks that act as a barrier against dangerous substances and can withstand permeation.

204Cu: The austenitic family of stainless steel includes the grade 204Cu. It has a low nickel content (about 2-4%) and a high chromium content (approximately 17-19%), making it a more affordable option than stainless steel grades with a greater nickel content. The primary benefit of 204Cu stainless steel is its exceptional corrosion resistance, particularly in areas with moderate corrosive conditions. It is frequently utilized in applications that call for resistance to freshwater, mild acids, alkalis, and atmospheric corrosion. Additionally, 204Cu stainless steel is well suited for numerous fabrication procedures and applications in sectors including architecture, automotive, and food processing thanks to its outstanding formability and weld ability.

409 M: A ferritin stainless-steel grade known as 409 M is frequently used in situations where resistance to corrosion and high temperatures are necessary. In comparison to other ferritin stainless steel grades, it has a larger percentage of chromium (about 10–12%) and a lower amount of nickel (approximately 0.5–1%), which improves its corrosion resistance. The exceptional heat resistance of 409 M stainless steel, which makes it appropriate for applications involving high temperatures like automotive exhaust systems, is one of the material's main features. It can endure extended exposure to hot temperatures without suffering significantly from mechanical properties loss. A cost-effective option for a variety of structural and aesthetic applications where corrosion resistance and heat resistance are crucial considerations is 409 M stainless steel, which also has good formability and weld ability.

AISI 304: The austenitic family of stainless steels includes the widely used AISI 304 grade. Because it contains 8-10.5% nickel and 18-20% chromium, it has high corrosion resistance in a variety of conditions. The flexibility of AISI 304 stainless steel is one of its primary qualities. It is extensively employed in many different fields and applications, such as food processing, chemical processing, building construction, and kitchen appliances. Because of its outstanding weld ability, high strength, and exceptional formability, AISI 304 is a preferred option for both commercial and domestic uses. It is a dependable and long-lasting material for many uses due to its resistance to corrosion from chemicals, moisture, and atmospheric conditions as well as its visual appeal.

yield strength: Yield strength is a mechanical characteristic that gauges how much stress a material can take before irreversibly deforming plastically. It is a crucial factor in figuring out a material's ability to support loads and maintain structural integrity. Through the use of a tensile test, in which a sample of the material is stressed to the point of yield, the yield strength is commonly ascertained. The material goes through a large degree of plastic deformation without any rise in stress near the yield point. The tension necessary to produce this yield point is then used to compute the yield strength.

Ultimate tensile strength: The mechanical parameter known as ultimate tensile strength (UTS) indicates the highest stress that a material can bear before cracking or breaking under strain. It is a crucial factor in determining how strong and long-lasting a material is. The UTS is calculated via a tensile test, in which a sample of the material is stretched to its breaking point under increasing tension. The highest stress applied to the specimen right before it cracks is then used to calculate the ultimate tensile strength. It displays the maximum load that the material in tension is capable of supporting.

Hardness: The ability of a material to resist permanent indentation or penetration is known as hardness. It shows if a substance can endure localized plastic deformation or wear. Various techniques, such as the Rockwell hardness test, Vickers hardness test, or Brignell hardness test, are frequently used to quantify hardness. In these tests, the surface of the material is subjected to a specified force or load, and the size of the indentation that results is measured. The size of the indentation is then used to calculate the hardness value.

% Of elongation: The percentage increase in length of a specimen following a tensile test serves as an indicator of a material's ductility or stretch ability and is known as percent elongation. When a specimen fractures during a tensile test,

the length change is measured and expressed as a percentage of the gauge length to determine the percent elongation. It offers important details on the material's capacity for plastic deformation prior to fracture, demonstrating its capacity to withstand brittle failure and absorb energy. Higher % elongation readings often denote a material's higher ductility and toughness.

Cost: Cost must be taken into account while choosing materials and making decisions. It is essential in figuring out whether employing a specific material in a particular application is practical and profitable. In addition to the price paid initially for a material, the cost of that material also takes into account its processing, production, installation, maintenance, and lifespan expenses. It is crucial to take into account a material's overall value and performance in respect to the particular application when assessing its cost. While some materials may cost more up front, they may have a longer lifespan, require less care, or perform better, which will save money over time. On the other side, cheaper materials may need to be replaced more frequently or repairs, leading to higher overall costs.

Corrosion rate: The term "corrosion rate" describes how quickly a material corrodes or degrades as a result of chemical interactions with its surroundings. Usually, it is expressed as a mass loss per unit area per unit time, such as millimeters per year (mm/year) or inches per year (in/year). The kind of material, the corrosive environment, temperature, humidity, and the presence of pollutants are some of the variables that affect corrosion rate. A shorter lifespan, lessened structural integrity, and higher maintenance costs can result from faster material degradation, which is indicated by higher corrosion rates. In sectors like the oil and gas, maritime, and chemical industries where materials are exposed to harsh conditions, understanding and managing corrosion rates is crucial.

WASPAS Method: In a variety of decision-making contexts, the Weighted Sum Model (WSM) and Weighted Product Model (WPM) Multi-Criteria Decision Making (MCDM) approaches are frequently used. A brand-new MCDM technique called Weighted Aggregated Sum Product Assessment (WASPAS), which combines the WSM and WPM approaches, was proposed by Zavadskas, Tarski's, Antucheviciene, and Zakarevicius in 2012. In comparison to WSM and WPM, they argued that the WASPAS technique provided greater accuracy. The WASPAS technique has been widely used in different research projects ever since it was first introduced. For instance, Stanines, Medineckien, Zavadskas, and Celibates used WASPAS to evaluate the ecological and economic impacts of modernizing multi-dwelling houses [161]. Similar to this, Baguio's, Zavadskas, and Tarski's chose a deep-water port using WASPAS. The WASPAS approach has been used successfully in a variety of decision-making scenarios. The WASPAS approach has been widely used and put to use in many disciplines to improve decision-making. In order to evaluate facade possibilities, Zavadskas, Antucheviciene, Saparauskas, and Tarski's used WASPAS [162], and the same researchers also tested its robustness for evaluating various solutions [163]. In order to assess real-time intelligent sensors for bridge structural health monitoring, Bitarafan, Zoltan, Areli, Zavadskas, and Mahmoudzadeh used WASPAS [164]. To assess the health and safety procedures on building sites, Dues and Antucheviciene used WASPAS [165]. Furthermore, WASPAS was employed by Hashemkhani Zoltan, Achaia, Derakhti, Zavadskas, and Moshed Verandah to examine decision-making in relation to economic challenges from a prospective foresight perspective. Overall, the WASPAS method has gained popularity and shown to be effective in increasing decision-making across a range of fields. Due of its adaptability and efficiency, a valuable tool in numerous research studies [1]. To solve MCDM issues with interval type-2 fuzzy sets (IT2FSs), the researchers in the current study suggest an expanded version of the WASPAS approach. IT2FSs use interval membership values instead of the crisp membership values used by type-1 fuzzy sets, giving linguistic evaluations more freedom. The suggested method incorporates IT2FSs to provide a higher level of knowledge about variables, boosting the decision-making process' intelligence and the precision of evaluating options. The researchers modify the normalization and weighted product model as well as incorporate the ideas and arithmetic operations of IT2FSs to extend the WASPAS approach with them. In addition, a fresh approach is created to determine criteria weights by fusing subjective weights provided by decision-makers with objective weights discovered using an entropy method. The stability of the various criteria weights during the decision-making process is improved by this combination, which guarantees more realistic criteria weights. Overall, the suggested enhanced WASPAS method with IT2FSs provides a better method for MCDM issues, enabling a more thorough assessment of the available options and aiding more precise decision-making [2]. The goal of the research is to suggest a method for choosing process improvement projects that considers uncertainty and the dynamics of evaluations based on important continuous improvement criteria. The method chosen for this study is the Weighted Aggregated Sum Product Assessment (WASPAS) method, which expands on Zadar's fuzzy sets approach by using ordered fuzzy numbers (OFNs). Kolinski, Prokopowicz, and Sleazy (2002, 2003) proposed OFNs as a model in which operations on fuzzy numbers are analogous to operations on real numbers. In order to conduct assessments, the WASPAS technique combines the Weighted Sum Model (WSM) and Weighted Product Model (WPM), as first proposed by Zavadskas, Tarski's, Antucheviciene, and Zakarevicius

(2012). According to some reports, the WASPAS approach is more accurate than using either WSM or WPM. The current literature, however, does not take into account OFNs in the fuzzy WASPAS method or combine the aforementioned techniques into a single conceptual framework. In order to close this gap, this study suggests a strategy that integrates the WASPAS method with OFNs, resulting in a more thorough and precise assessment framework for choosing process improvement initiatives [3]. They combine two Multi-Criteria Decision Making (MCDM) methods—Weighted Aggregated Sum Product Assessment (WASPAS) and Criteria Importance Through Inter-Criteria Correlation (CRITIC)—to solve this decision-making process. The weights of the criteria used in the decision-making process are determined using the CRITIC technique. This strategy offers a fair and impartial way to give the criteria weights. To determine the relative importance of the criteria, it takes into account their interactions. The authors hope to create a fair and open framework for allocating weights to the criteria by employing the CRITIC technique. The WASPAS approach will then be combined with these weights to assess the options and determine which time and attendance software is best. It takes into account how strong the contrast and conflict are within the framework of the decision-making dilemma. It falls under the domain of correlation approaches and entails analyzing the decision matrix to discover the data in the standards used to assess the options. To thoroughly rank the options, the WASPAS technique combines the Weighted Sum Model (WSM) and Weighted Product Model (WPM). It offers a structure for combining criteria weights and assessing alternatives according to their effectiveness. The use of the combined CRITIC and WASPAS methodologies in the context of decision making is the primary contribution of this paper to the body of current work. The authors want to improve decision-making and offer a more reliable technique for choosing the best time and attendance software by combining these two approaches [4]. The researchers propose the use of Multi-Criteria Decision Making (MCDM) methodologies to conduct a thorough review of outsourcing tactics that takes into account both qualitative and quantitative factors. The Weighted Aggregated Sum Product Assessment (WASPAS) method, which was recently created by Zavadskas et al. in 2012, is explicitly recommended by them. The WASPAS approach, which involves optimizing a weighted aggregated function, is renowned for its capacity to deliver extremely accurate estimations. It has been successfully used in a variety of decision-making situations, including choosing construction methods, updating homes, and choosing the site of shopping centers. Researchers like Zavadskas and Tarski's (2011) and Kalpaks and Tupenaite (2011) have previously shown the usefulness of MCDM approaches in economic applications. The authors of the current study use the WASPAS technique to evaluate and rank outsourcing options, taking into account a variety of factors and resulting in a more well-informed decision-making process [5]. The weighted aggregated sum product assessment (WASPAS) approach is a Multiple Attribute Decision Making (MADM) technique that was only recently developed by Zavadskas et al. in 2012. By utilizing the benefits of the weighted sum model (WSM) and weighted product model (WPM), it aims to increase the accuracy of ranking alternatives. The WASPAS approach improves ranking accuracy by combining the WSM and WPM. The technique makes use of an ideal combination parameter that is computed throughout the procedure. In the literature, this parameter's precise specifics are covered. The WASPAS method tries to improve the precision of rankings for decision-making purposes and provides a useful approach to MADM challenges [6]. The planning of waste incineration plant construction sites while taking into account ecological, technological, and urban factors is the main topic of this article. The article's main goal is to show how multi-criteria decision methods (MCDM) can be used to address the practical issue of trash incineration plant location while taking sustainability considerations into account. The study suggests using a combined strategy that combines the Weighted Sum Model (WSM) and the Weighted Product Model (WPM), two criteria for optimality. WASPAS, or Weighted Aggregated Sum Product Assessment, is the name of this combination approach. The researchers investigate the applicability and value of this method for choosing construction sites for waste incineration facilities. The authors offer a WASPAS-SVNS modification of the original WASPAS approach, which is based on a single-valued neutrosophic set, to address the issue. The idea of single-valued neutrosophic sets is incorporated into the decision-making process in this extension. The paper's overall goal is to show how the WASPAS-SVNS technique may be used to address the difficulties of site planning for waste incineration plants while taking into account a variety of factors and adding sustainability considerations [7]. In order to analyse multi-criteria decision-making (MCDM) problems employing hesitant fuzzy sets (HFSs), this study proposes an integrated methodology that combines the Weighted Aggregated Sum Product Assessment (WASPAS) method with information measures. By adding HF-aggregation operators and modifying the normalization and weighted product methods, the WASPAS approach is broadened to include HFSs. A group support system (GSS) problem is used as an example to show how well the created method works with real-world MCDM issues. The study demonstrates the method by outlining the solutions to the GSS problem and doing a sensitivity analysis by adjusting the parameter and weights of the established WASPAS method. The proposed strategy is also contrasted with earlier approaches to emphasize the advantages of the outcomes obtained. This comparison is used to verify the efficacy and performance of the integrated method that has been suggested for resolving MCDM issues with HFSs. Overall, the paper intends to offer a thorough and

reliable way for evaluating MCDM issues using HFSs that combines the WASPAS method with information measures, and to demonstrate its applicability and superiority through real-world examples and comparisons with existing methods [8]. This study focuses on Uttara hand, India's sustainable viewpoints. Following is the planned order of the study's remaining components: "Earlier works": This section will offer a thorough analysis of earlier research that is pertinent to the current topic. It will examine the relevant literature and research that has already been done. "Preliminaries": The fundamental ideas and tenets of Fermata fuzzy sets (FFSs) will be covered in this part. It will give you the background knowledge you need to comprehend the sections that follow. The phrase "improved score function and entropy measure within FFSs" refers to the presentation of a novel Fermata fuzzy score function and new entropy measures in the context of FFSs. The purpose of these upgrades is to increase the decision-making process' accuracy and efficacy. The phrase "Proposed FF-WASPAS method for MCDM problems": A novel Fermata fuzzy Weighted Aggregate Sum Product Assessment (FF-WASPAS) model will be introduced in this part. In order to address MCDM issues, the FF-WASPAS method integrates the score function and entropy measures within the FFSs framework. "Case study: healthcare waste disposal location (HCWDL) selection" The choice of where to dispose of medical waste will be the focus of a case study. In this real-world case, the FF-WASPAS method will be used, and the results will be compared to those from other existing methods. "Conclusions": This part will offer the study's summary of its main contributions and findings. Future research directions connected to this work will also be covered. By adhering to this predetermined framework, the study hopes to investigate the sustainable viewpoints of Uttara hand, India, and to suggest a unique FF-WASPAS approach for MCDM issues with FFSs. The practicality and stability of the proposed technique will be discussed in the case study and in comparisons with other approaches [9]. After being created by Zavadskas et al. in 2012, the WASPAS (Weighted Aggregated Sum Product Assessment) method has subsequently been widely applied and expanded in a variety of decision-making settings. The WASPAS method has been used by researchers in a variety of fields to address issues with multi-criteria manufacturing, assess the best locations for solar projects, define outsourcing policies, and handle decision-making issues with hesitant fuzzy soft information. In order to assess real-time smart sensors for basic bridge health evaluation, Bitarafan et al. (2014) developed the WASPAS technique and added the SWARA (Step-wise Weight Evaluation Ratio Analysis) method. The SWARA technique was included to improve WASPAS's capabilities in the decision-making process. Chakraborty and Zavadskas (2014) also used the WASPAS method to a number of multi-criteria manufacturing problems. These included choosing a cutting fluid, an arc welding process, a baking environment, and an electroplating system. In order to address complicated decision-making scenarios including numerous criteria and considerations in the industrial area, the researchers used WASPAS. In order to handle interval-valued intuitionistic fuzzy numbers, Zavadskas et al. (2014) developed an extended version of the WASPAS method and contrasted the outcomes with previous methodologies. Vafaeipour et al. (2014) evaluated the preferred locations for running solar plants using the SWARA and WASPAS techniques. To define outsourcing policies, Lashkar et al. (2014) created an MCDM method based on the WASPAS method and Quantitative Strategic Planning Matrix (QSPM). Comprehensive analyses of MCDM techniques, such as the SWARA and WASPAS methods with fuzzy extensions, were carried out by Martini et al. (2017). They went over the most recent advancements and uses of these techniques. In order to address hesitant fuzzy soft decision-making issues, Peng and Dai (2017) developed three unique methods: WASPAS, MABAC (Multi-Attributive Border Approximation area Comparison), and COPRAS (Complex Proportional Assessment). These studies emphasize the WASPAS method's adaptability and application in diverse decision-making contexts, as well as its efficiency in weighing options and assisting decision-making processes [10]. The current work focuses on the issue of choosing the site of a gas station and suggests a novel methodology that combines the spherical fuzzy Weighted Aggregated Sum Product Assessment (WASPAS) method and the spherical fuzzy Analytical Hierarchy Process (AHP). The study starts off by reviewing the pertinent literature and creating a hierarchy of primary and secondary criteria for the location selection problem. The opinions and preferences of various experts are then gathered with accordance to the criteria. The proposed spherical fuzzy AHP-integrated spherical fuzzy WASPAS approach, which takes into consideration the ambiguity and uncertainty related to the experts' judgements, is used to analyses these viewpoints. The methodology makes it possible to calculate the relevance weights for the factors taken into consideration and to evaluate potential locations using these weights. The study's recommended approach will be used to give a thorough and precise evaluation of the locations of petrol stations. A practical case study is carried out for Istanbul, Turkey, to show how the methodology can be used. The case study's findings demonstrate the usefulness and efficacy of the suggested approach for aiding decision-making procedures for choosing the location of petrol stations [11]. Guyton et al.'s discussion of the criteria for choosing an acceptable Multi-Criteria Decision Making (MCDM) algorithm is lengthy [30]. The Weighted Aggregated Sum Product Assessment (WASPAS) technique stands out among the alternatives because it combines the weighted sum model (WSM) and the weighted product model (WPM) in a novel way. In comparison to the WSM and WPM approaches, the WASPAS

method has the benefit of being mathematically simple and producing more accurate findings. These features make the WASPAS technique an effective tool for making decisions on algorithm selection issues. The WASPAS technique also takes into account the initial information's related uncertainty, which is frequently conveyed linguistically. The neutrosophic set environment [31], which enables the modelling of imprecision, indeterminacy, and inconsistent decision-making processes, is used to resolve this ambiguity. Decision-makers can choose an appropriate MCDM algorithm for their particular problem domain by using the WASPAS approach and taking into account the neutrosophic set environment [12]. Since its 2012 introduction, in academic literature, the Weighted Aggregated Sum Product Assessment (WASPAS) method has grown significantly in favor. It has become the method of choice over others, including the Weighted Sum Model (WSM) and the Weighted Product Model (WPM), thanks to its capacity to deliver a more precise and thorough performance evaluation, leading to a more dependable composite solution. Additionally, substantial research has been done on leveraging fuzzy sets to extend the WASPAS approach. Fuzzy sets can be used in decision-making processes to take uncertainty and ambiguity into account. Fuzzy sets make the WASPAS method more flexible and capable of managing complex decision-making situations with erroneous information. In fact, the WASPAS technique has undergone a number of improvements to improve its ability to handle ambiguous and inaccurate input. These additions consist of single-valued neutrosophic sets, interval-valued intuitionistic fuzzy sets, and interval type-2 fuzzy sets. These fuzzy set extensions make it possible to handle the ambiguity and imprecision that come with language expressions when evaluating them. Incorporating ambiguity and uncertainty into decision-making requires the use of fuzzy sets. The development of membership functions that can precisely capture the specificity and uncertainty connected to the assessed criteria is made possible by fuzzy sets. Pythagorean fuzzy sets, in contrast to intuitionistic fuzzy sets, enable specialists to give membership and non-membership degrees that may sum up to values higher than. This adaptability in how membership and non-membership are expressed has been successful in helping people solve multi-attribute decision-making issues. The WASPAS technique has proven to be helpful in decision-making processes, as have its fuzzy set extensions such Pythagorean fuzzy sets. These approaches offer more accurate and subtle evaluations across a range of fields. The WASPAS technique helps decision-makers better capture and handle uncertainty, ambiguity, and expert preferences by adding fuzzy sets, resulting in more well-informed and trustworthy decision outputs [13].

3. RESULT AND DISCUSSION

TABLE 1. Stainless Steel Pipe in Sugar Industry

Material	Yield strength	Ultimate tensile strength	Hardness	% Of elongation	Cost	Corrosion rate
J4 material grade	382	728	98	48	112	0.16
JSLAUS	420	790	97	58	210	0.31
204Cu	415	795	96	55	120	0.05
409 M	270	455	78	32	184	0.4
AISI 304	256	610	86	60	89	0.01

Table 1 evaluates five stainless steel pipe materials for sugar industry applications based on six key performance criteria. Mechanical Strength: JSLAUS leads in both yield strength (420 MPa) and ultimate tensile strength (790 MPa), indicating superior load-bearing capacity. 204Cu shows similar performance (415/795), while the J4 material grade lags behind at 382/728. AISI 304 and 409M show moderate strength, with 409M being the weakest at 270/455. Hardness and Wear Resistance: The J4 material grade achieves the highest hardness (98), offering superior resistance to surface wear, which is crucial for abrasive sugar processing environments. JSLAUS and 204Cu have comparable hardness (97/96), while AISI 304 (86) and 409M (78) are softer. Ductility: AISI 304 offers the highest elongation (60%), allowing for significant deformation before fracture, which is beneficial for thermal expansion and installation flexibility. JSLAUS (58%) and 204Cu (55%) offer good ductility, while 409M's low 32% makes it susceptible to brittle failure. Cost-Performance Balance: AISI 304 offers the best value at the lowest cost (89) and has excellent corrosion resistance (0.01) making it highly suitable for the acidic environments of sugar processing. 204Cu offers the second-best corrosion resistance (0.05) at a moderate price (120). Despite its lower price, the poor corrosion rate (0.4) of 409M makes it unsuitable for long-term service.

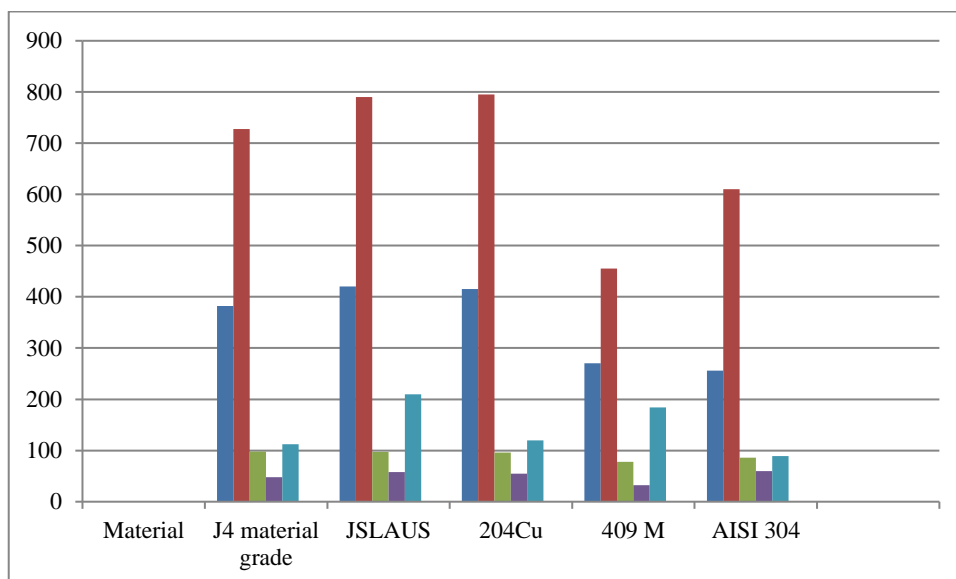


FIGURE 1. Stainless Steel in Sugar Industry

Figure 1 This comprehensive visual comparison of five stainless steel materials used in sugar factory piping systems simultaneously displays six performance parameters for the J4 material grade, JSLAUS, 204Cu, 409M, and AISI 304. The most striking feature is the dominance of the ultimate tensile strength values, represented by the tallest red bars. JSLAUS, 204Cu, and the J4 material grade approach 790-800 MPa, clearly demonstrating their superior structural capabilities compared to 409M and AISI 304, which peak at 450-610 MPa. The dark blue bars representing yield strength follow a similar pattern. JSLAUS leads at 420 MPa, closely followed by 204Cu and the J4 material grade in the 380-415 range, while AISI 304 and 409M lag significantly behind at 250-270 MPa. This indicates that they will undergo permanent deformation at much lower stress levels. The medium-range properties, shown in purple (hardness) and green (percentage elongation), are in the 30-100 range. Here, except for the notably lower measurement of 409M, the hardness values are relatively consistent across all materials. Furthermore, the percentage elongation values show the superior ductility of AISI 304 at around 60%. The short bars representing cost (cyan) and corrosion rate (orange) are barely visible at this compressed scale, but they represent important practical considerations—the very short orange bar for AISI 304 indicates exceptional corrosion resistance, while its short cyan bar shows cost-effectiveness. This visual representation effectively illustrates the fundamental trade-off between mechanical strength properties and economic-corrosion performance. It shows that while higher-grade materials like JSLAUS and 204Cu offer superior strength properties, AISI 304 provides an optimal balance for applications where corrosion resistance and cost are prioritized over maximum mechanical strength.

TABLE 2. Performance Value

Material	Yield strength	Ultimate tensile strength	Hardness	% Of elongation	Cost	Corrosion rate
J4 material grade	0.90952	0.91572	1.00000	0.66667	0.79464	0.06250
JSLAUS	1.00000	0.99371	0.98980	0.55172	0.42381	0.03226
204Cu	0.98810	1.00000	0.97959	0.58182	0.74167	0.20000
409 M	0.64286	0.57233	0.79592	1.00000	0.48370	0.02500
AISI 304	0.60952	0.76730	0.87755	0.53333	1.00000	1.00000

Table 2 This normalized performance transforms raw material properties into relative performance values (0-1 scale), where 1.0 represents the best performance in each category, enabling direct multi-parameter comparison. Superior in Strength: JSLAUS achieves perfect yield strength (1.00) and near-perfect tensile strength (0.99), ranking first in mechanical strength. 204Cu matches this, possessing perfect tensile strength (1.00) and excellent yield strength (0.99). The J4 material grade closely follows with strong performance in both these metrics (0.91). Exceptional in Hardness: The J4 material grade delivers maximum hardness (1.00), with JSLAUS (0.99) and 204Cu (0.98) closely matching it. This group exhibits superior wear resistance compared to 409M (0.80) and AISI 304 (0.88). Compromise in Ductility: Paradoxically, 409M achieves

perfect ductility (1.00) despite its lower strength, indicating easy deformation. The other materials sacrifice ductility for strength, with values ranging from 0.53-0.67. Crucial Economic-Corrosion Balance: AISI 304 dominates with perfect scores in both cost-effectiveness (1.00) and corrosion resistance (1.00), two factors critical for the long-term sustainability of the sugar industry. 204Cu offers a reasonable corrosion performance (0.20) at a good price (0.74), while JSLAUS's poor price rating (0.42) and weak corrosion resistance (0.03) severely limit its practical value. Strategic Insight: This normalization reveals the significant advantage of AISI 304 in operational stability, while higher-strength materials, although performing better mechanically, fail economically for general applications.

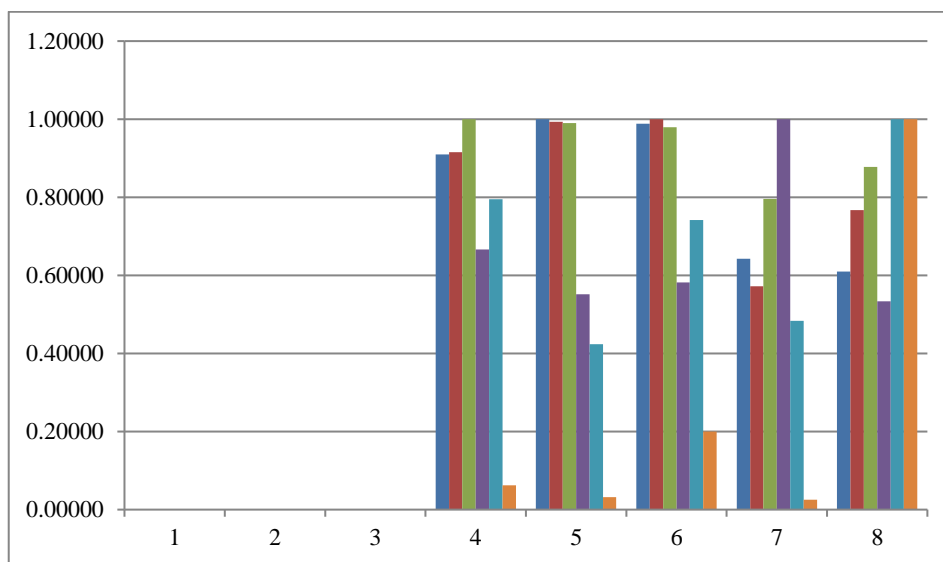


FIGURE 2. Performance Value

Figure 2 grouped bar chart provides a comprehensive visualization of the normalized performance values of six material properties for five different stainless steel materials used in sugar industry applications. Here, each color series represents a unique material, and the 4-8 positions on the x-axis correspond to different performance parameters measured on a scale of 0-1.2. The chart reveals a notable tri-modal distribution pattern, where the performance values are clustered in three distinct zones: a high-performance zone (0.9-1.0), a moderate-performance zone (0.5-0.7), and a scattered low zone. This indicates that, due to inherent metallurgical trade-offs, the materials consistently excel in some properties while compromising on others. The most striking feature is the dense clustering of bars at positions 4-6, where several series (specifically the blue Series1, orange Series2, and gray Series3) reach near-perfect values of 0.9-1.0. These likely represent mechanical strength properties such as tensile strength, ultimate tensile strength, and hardness. This demonstrates that the high-grade stainless steel types compete very closely in structural performance capabilities. In contrast, positions 7-8 show significantly higher variability; here, the bars are scattered between 0.4 and 1.0. These may represent parameters such as percentage elongation and cost, where the materials exhibit considerable differences based on their specific metallurgical compositions and manufacturing processes. The yellow Series 4 and purple Series 5 bands show significant strength at these later stages, suggesting that some materials sacrifice a degree of mechanical strength to improve flexibility or economic factors.

TABLE 3. Weightages

Material	Yield strength	Ultimate tensile strength	Hardness	% Of elongation	Cost	Corrosion rate
J4 material grade	0.166	0.166	0.166	0.166	0.166	0.166
JSLAUS	0.166	0.166	0.166	0.166	0.166	0.166
204Cu	0.166	0.166	0.166	0.166	0.166	0.166
409 M	0.166	0.166	0.166	0.166	0.166	0.166
AISI 304	0.166	0.166	0.166	0.166	0.166	0.166

Table 3 weighting scheme proposes a uniform distribution method, in which the six performance criteria (yield strength, ultimate tensile strength, hardness, percentage elongation, cost, and corrosion rate) are assigned equal importance values of 0.166 (representing 16.6% or approximately 1/6) across all five stainless steel materials evaluated for sugar industry piping applications. This equal weighting approach, summing to 1.0 or 100%, represents a democratic multi-criteria decision-making framework that considers mechanical properties, economic factors, and corrosion resistance as equally important for material selection, avoiding any inherent bias towards strength, durability, or cost-effectiveness. The consistent value of 0.166 across all materials and all parameters indicates a standardized evaluation method that can be used in the initial stages of material assessment before domain-specific adjustments are made based on specific application requirements. This approach ensures that a material cannot achieve a superior overall ranking by excelling in only one or two categories and failing in others, but instead requires balanced performance across all dimensions. However, this equal weighting may not reflect real-world priorities in sugar industry applications, where corrosion resistance and cost typically hold disproportionate importance due to the highly acidic processing environment and long-term operational economics, while maximum tensile strength may be less critical for typical piping systems operating below material failure limits. This method provides a neutral basis for objective comparison, but it would benefit from adjusted weightings that reflect actual operational priorities, such as increasing the importance of the corrosion rate to 0.30-0.35 and reducing the emphasis on certain mechanical properties to better align with practical sugar industry requirements.

TABLE 4. Weighted normalized decision matrix

Material	Yield strength	Ultimate tensile strength	Hardness	% Of elongation	Cost	Corrosion rate
J4 material grade	0.15098	0.15201	0.16600	0.11067	0.13191	0.01038
JSLAUS	0.16600	0.16496	0.16431	0.09159	0.07035	0.00535
204Cu	0.16402	0.16600	0.16261	0.09658	0.12312	0.03320
409 M	0.10671	0.09501	0.13212	0.16600	0.08029	0.00415
AISI 304	0.10118	0.12737	0.14567	0.08853	0.16600	0.16600

Table 4 weighted normalized decision matrix represents the final analysis stage. In this, the normalized performance values of each material have been multiplied by their respective weights (0.166 per criterion) to generate weighted scores that enable a comprehensive material ranking for sugar factory piping applications. This table, when examined across all six criteria, reveals significant performance differences with values ranging from 0.00415 to 0.16600; higher numbers indicate better weighted performance in each category. JSLAUS dominates in the mechanical strength categories, achieving the maximum weighted scores in tensile strength (0.16600) and near-maximum scores in ultimate tensile strength (0.16496) and hardness (0.16431), confirming its leading position in structural performance. However, it shows significant weaknesses in cost (0.07035) and corrosion resistance (0.00535), which severely limits its practical feasibility. The J4 material grade exhibits balanced mechanical performance in strength (0.15098/0.15201) and hardness (0.16600), and moderate cost-effectiveness (0.13191), although its corrosion resistance score (0.01038) is a concern for acidic sugar processing environments. Conversely, AISI 304, despite having moderate mechanical properties, receives excellent weighted scores in the two most critical categories: cost (0.16600) and corrosion resistance (0.16600). Its overall weighted performance in these economic and durability factors significantly outweighs the strength advantages of the higher-grade materials. The 409M material shows poor overall performance, scoring lowest in strength and corrosion resistance categories, and only scoring highly in ductility (0.16600), which offers limited practical value. This matrix effectively demonstrates that, when equal importance is given to all criteria, AISI 304 emerges as the optimal choice by excelling in the factors that determine long-term operational success and total cost of ownership in corrosive sugar factory applications.

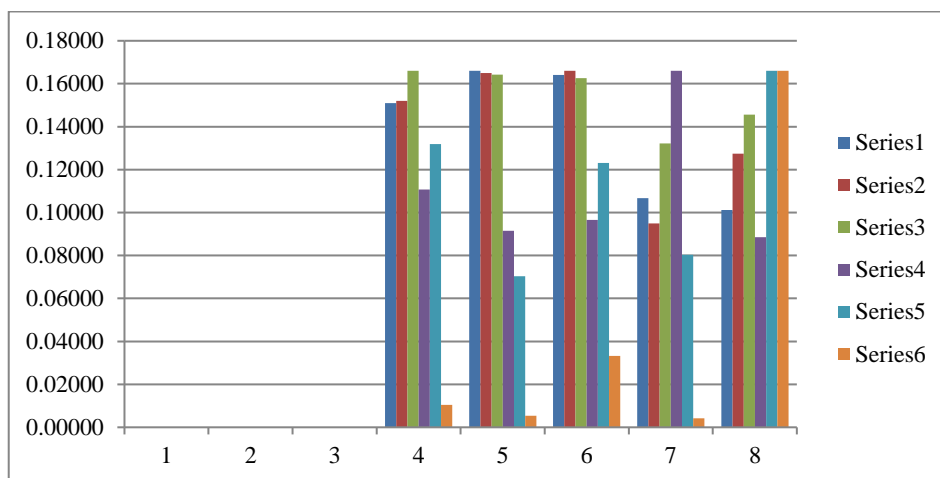


FIGURE 4. Weighted Normalized Decision Matrix

Figure 4 Weighted normalized decision matrix of stainless steel industry used in sugar industry of j4 materials grade, JSLAUS, 204cu, 409 M, AISI 304 which are yield strength, ultimate tensile, hardness, cost, corrosion rate.

TABLE 5. Preference Score and WASPAS Coefficient

Preference Score	Preference Score	WASPAS Coefficient
0.721943	0.550972	0.636458
0.662556	0.443074	0.552815
0.745535	0.662263	0.703899
0.584287	0.391884	0.488085
0.794759	0.777101	0.78593

Table 5 WASPAS (Weighted Aggregated Sum Product Assessment) analysis table displays three crucial columns that integrate comprehensive material evaluation: two different preference scores and a final WASPAS coefficient representing the optimal ranking metric for selecting stainless steel materials in sugar industry applications. The first preference score column shows values ranging from 0.584287 to 0.794759, with AISI 304 receiving the highest score (0.794759), followed by 204Cu (0.745535), J4 material grade (0.721943), JSLAUS (0.662556), and 409M significantly lagging behind (0.584287). This indicates their relative overall performance when equally weighted across all six criteria. The second preference score column, calculated using a different WASPAS methodology, shows a wider range from 0.391884 to 0.777101, maintaining the same ranking order but with a more pronounced differentiation between materials, again confirming the superiority of AISI 304 (0.777101) and the inadequacy of 409M (0.391884). The final WASPAS coefficient represents a harmonized assessment combining both calculation methods, yielding values between 0.488085 and 0.78593, with AISI 304 firmly leading at 0.78593, exhibiting 61% better performance than the worst material (409M at 0.488085). This ranking of material grades confirms that, despite lower mechanical strength properties, the exceptional performance of AISI 304 in corrosion resistance and cost-effectiveness makes it the optimal choice for sugar industry piping. Following closely is 204Cu (0.703899) as a viable alternative, offering superior strength with acceptable corrosion performance, while premium strength materials like JSLAUS (0.552815) and J4 material grade (0.636458) rank lower due to their inferior corrosion resistance and higher costs, which outweigh their mechanical advantages in this specific application context.

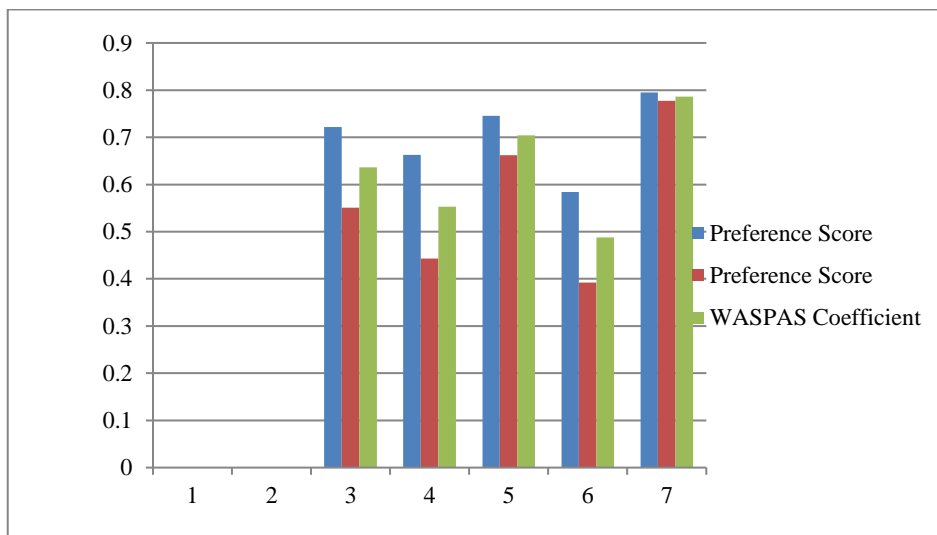


FIGURE 5. Preference Score and WASPAS Coefficient

Figure 5 Shows the graph of performance score and wasps coefficient of stainless steel industry used in sugar industry of j4 materials grade, JSLAUS, 204cu, 409 M, AISI 304 which are yield strength, ultimate tensile, hardness, cost, corrosion rate.

TABLE 6. Rank

WASPAS Coefficient	RANK
0.63645767	3
0.552814565	4
0.703898716	2
0.488085079	5
0.78592973	1

Table 6 Shows the wasps coefficient and rank of stainless steel industry used in sugar industry of j4 materials grade, JSLAUS, 204cu, 409 M, AISI 304 which are yield strength, ultimate tensile, hardness, cost, corrosion rate.

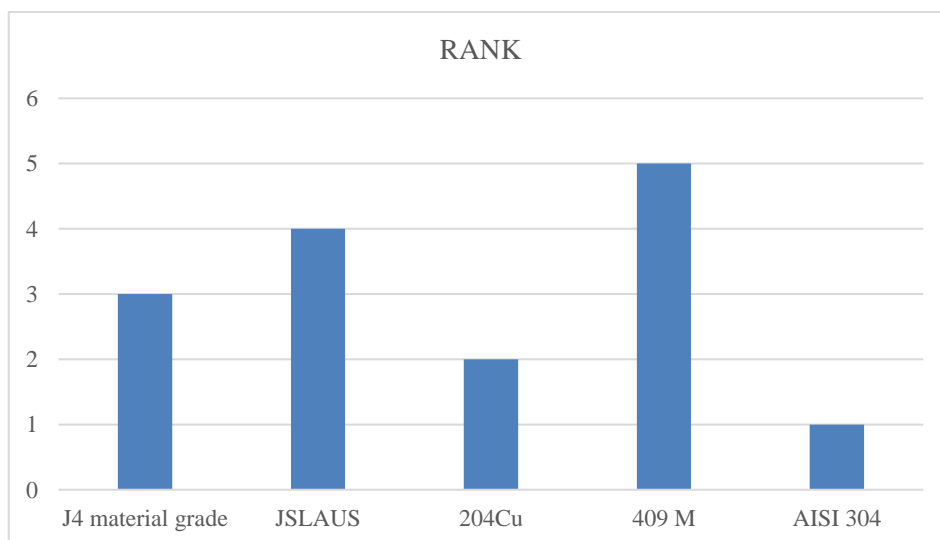


FIGURE 6. Rank

Figure 6 shows the graph of the wasp as coefficient and rank of stainless steel industry used in sugar industry of j4 materials grade, slabs, 204cu, 409 m, anise 304 which are yield strength, ultimate tensile, hardness, cost, corrosion rate.

4. CONCLUSION

As a result of their critical role in the transfer of corrosive fluids, stainless steel pipes have become a vital component of the sugar industry. Stainless steel pipes are widely used because of their remarkable corrosion resistance, toughness, and dependability in challenging operating settings. The understanding of stainless steel pipe behavior in the sugar industry has substantially improved thanks to advances in research and development. The performance of stainless steel pipes can be improved by carefully considering corrosion, scaling, and mechanical qualities. The information gleaned from these experiments has aided in the creation of successful corrosion mitigation techniques, such as the application of surface treatments or coatings and the choice of suitable stainless steel grades. The findings demonstrated that scale buildup on the pipe's internal wall caused a modest increase in wall thickness prior to cleaning. A maximum 14% drop in wall thickness was seen after cleaning, indicating the elimination of scale deposits. The researchers were able to get important insights into the corrosion and scale deposition behavior on these materials by combining various testing and characterization methodologies. The production of deposits that can clog pipe sections, lower flow efficiency, and raise maintenance costs has been minimized by study on scaling tendencies. To reduce scaling problems and guarantee uninterrupted operations, techniques like correct fluid conditioning and routine cleaning have been investigated. To assure the structural integrity and longevity of stainless steel pipes, mechanical qualities like tensile strength, hardness, and toughness have also been studied. The design and execution of reliable pipe systems have benefited from an understanding of the impacts of operational factors, temperature variations, and mechanical stresses. Increased output, operational effectiveness, and safety have resulted from the sugar industry's adoption of stainless steel pipe technology. Based on the useful knowledge gleaned from research endeavors, manufacturers, engineers, and operators can choose materials, set up maintenance plans, and take design issues into account. The significant study on stainless steel pipes used in the sugar sector has, in general, improved pipe performance, decreased downtime, and raised cost effectiveness. These developments have strengthened stainless steel pipes' status as the go-to option for fluid transmission in the corrosive and demanding environment of the sugar industry.

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