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Inherent Occupational Health Assessment for Alternative Hydrogen Synthesis Pathways

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Abstract

Hydrogen is one of the most investigated topics in energy transition due to its sustainability and vast applicability. However, it has health and safety challenges like any other chemical process. Most attention focuses on this fuel production's technology and economic potential with some work related to its safety impact. This study conducts an occupational health hazard assessment on two hydrogen synthesis routes at the design research and development stage. This study compares the outcomes to find the healthiest Hydrogen production route. This research leveraged the Inherent Occupational Health Index (IOHI) as the assessment to measure the health challenges peculiar to each production route. Three different index calculation types additive, average, and worst case are used to achieve the comparison. The information used in the evaluation is available at the R&D design stage. The study shows that both synthesis routes assessed steam methane reforming and coal gasification fall under the hazardous category of the IOHI index standard. But steam methane reforming has a lower IOHI index standard value of 16 than coal gasification 17.7. Therefore, although both synthesis routes are hazardous and pose occupational health risks to workers, steam methane reforming is a better alternative for hydrogen production from a health perspective.

Keywords: Inherent Health; Health Hazard; Research and Development; Hydrogen Synthesis; Worker’s Health.

1.0 INTRODUCTION

Rapid global economic and development growth has led to increased demand for energy [1]. The global energy demand increased by 2.2% in 2017 and is estimated to keep that exponential growth till 2050 [2]. A significant portion – approximately 85%– of this energy is supplied with fossil fuel. However, such unsustainable energy sources are projected to be exhausted in the next 60 years if we continue to exploit them at this rate [3]. Furthermore, the by-product of greenhouse gases (GHG) from fossil fuels has been reported to exacerbate the effects of climate change and global warming–taking it above 4°C– [2]. Part of the proposed solutions to address this runaway global warming is the Paris agreement of 2015. The world leaders have agreed to keep the temperature rise significantly below 2°C and limit global warming to 1.5°C above the pre-industrial levels [4]. As a signatory to this accord, Malaysia pledges to reduce GHG emissions by 45% by 2030 relative to 2005 [5]. This pledge is an arduous task requiring the strongest will from all the stakeholders involved.

However, given the abundance of hydrogen and its unique properties, such as the ability to produce water as the only by-product, the ability to synthesize hydrogen from a variety of naturally occurring materials, and the focus on hydrogen production technologies, hydrogen presents a potential for rapid development and a greener future [6]. These listed properties have made hydrogen an attractive alternative to fossil fuels and a potential panacea to Earth's energy problems.

But, despite these favorable characteristics, the synthesis process of hydrogen comes with health and safety challenges like any other chemical process. In fact, given the need for new technologies to democratize the industry, many researchers suggest it will introduce novel health and safety challenges to the energy industry [6]. Not much work has been done to study the occupational health aspects of hydrogen fuel synthesis routes, especially at the early research and development stage. As a result, many workplaces' health and safety challenges are unknown. Protecting workers' health is one of the most crucial factors to consider while selecting processes. Therefore, it is vital to conduct hazard and risk assessments as early as feasible, beginning with the R&D stage, for better worker protection and more effective risk management.

Knowing these hazards and risks is crucial in protecting workers from exposure to potential health threats associated with the synthesis process. Furthermore, it is vital to understand these hazards and risks as part of the screening process for determining which hydrogen synthesis technique poses the least risk to employees' health. Therefore, this work aims to address this by applying the proven method proposed by [7] to investigate the occupational health hazards in two different hydrogen production pathways.

2.0 METHODOLOGY

This study aims to quantify the occupational health risks in two hydrogen generation process designs using Hassim & Hurme's methodology [7]. Hassim & Hurme created this method to aid users in selecting chemistry pathways based on the health risk associated with various process paths. The methodology considers specific quantitatively calculated parameters representing the Inherent Occupational Health Index (IOHI) to quantify the health risk. The IOHI comprises all aspects that could substantially impact one's health [8]. The methodology is meant to be used during the design research and development stage. The earliest stages of the design phase are the best time to implement this concept [9]. As a result, the chosen pathways are constrained by the information available during the R&D phase. A higher IOHI rating (also known as a penalty) indicates that the procedure poses a more significant risk to occupational health. As a result, when evaluating different process technologies to discover which approach would describe the most substantial damage to workers' health and find feasible solutions, methodologies like the IOHI are helpful.

2.1 Case Studies

The IOHI is applied to alternative process routes for hydrogen production to demonstrate the method. [3] summarized 14 different ways for synthesizing hydrogen, including some technologies that are well developed and available commercially and others that are under research and development stages. Two commercially available or matured synthesis routes are selected for this study based on the information available for assessment. The routes are Steam Methane Reforming (SMR) and Coal Gasification. The following sections discuss the selected processes.

2.1.1 Hydrogen Production via Steam Methane Reforming

Steam methane reforming (SMR) is the most widely used and commercially available hydrogen production technique. It is also the most cost-effective option. The process involves converting methane to a synthesis gas that consists of CO, CO_2, and H_2 using steam (H_2O) as a reactant.

In an endothermic process, methane reacts with steam in the presence of a nickel-based catalyst to produce a synthesis gas composed mainly of carbon monoxide and hydrogen. Methane feed heats up in the reformer and then flows through a desulfurization vessel, where Hydrogen Sulfide, H_2S, is absorbed on a solid absorbent. The desulfurized gas combines with the steam and is superheated in a feed preheat coil. In the reformer vessel, the mixture travels via a reforming catalyst-filled tube. The reformer's controlled external firing provides the heat for the reaction. The following is how the reaction occurs:

$$CH_4 + H_2O_{(g)} \rightarrow CO + 3H_2 \quad (1)$$
$$(Catalytic\ steam\ reforming, 800 - 1000°C, 5 - 35\ bar)$$

The synthesis gas is delivered to the high-temperature shift reactor (HTS), which uses a copper-promoted iron-chromium catalyst to transform carbon monoxide and water into hydrogen and carbon dioxide. The process gas cooler/steam generator cools the synthesis gas leaving the reformer. The reaction is temperature-sensitive, and the process shifts to reactants as the temperature rises. Maximum CO conversions are usually governed by equilibrium irrespective of reaction pressure since moles have no fluctuations [10]. The reaction is as follows:

$$CO + H_2O_{(g)} \rightarrow CO_2 + 3H_2 \quad (2)$$
$$(Water - gas\ shift\ reaction, 200 - 450°C)$$

The shift reactor effluent is cooled by a condensing water heater, a boiler feed water (BFW) preheater, and a gas trim cooler. A condensate separator separates the extra condensate from the cooler stream. To obtain a 99.99 percent hydrogen purity, the shifted synthesis gas is delivered to a pressure swing adsorber (PSA) hydrogen purification system to remove unwanted by-products (CO_2, H_2O, CH_4, and CO). The PSA off-gas is transferred to the reformer to assist in reform by providing some of the necessary fuel. Figure 1 depicts a process flow diagram of a typical SMR process.

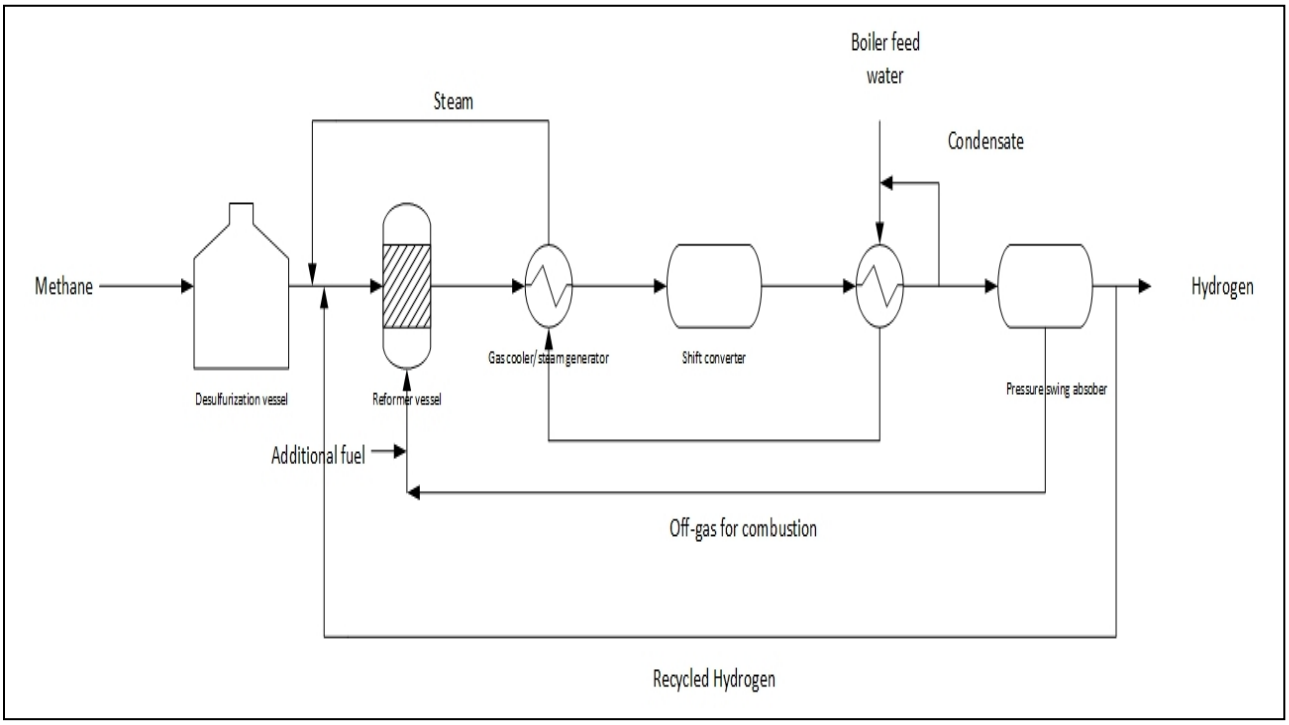

Figure 1. Process flow diagram of typical steam methane reforming (adopted from [11])

2.1.2 Coal Gasification Process

Gasification is another mature method used to produce hydrogen fuel. It is a sequence of thermochemistry transformation processes that converts coal into gas. First, coal is reacted (partially oxidized) with oxygen and steam in a gasifier. Next, it is converted to synthesis gas or syngas, a carbon monoxide and hydrogen mixture at a high temperature and moderate pressure. The significant primary reaction for coal gasification in industrial hydrogen production is provided in the equation below. Gasification chemistry is highly complicated and involves several chemical reactions. These chemical reactions are summarized in Table 1.

$$C_nH_m(coal) + nH_2O \rightarrow nCO + \left(n + \frac{m}{2}\right)H_2 \qquad (3)$$

Most gasification processes consist of four steps: coal preparation, coal gasification, synthesis of gas cleaning, and gas beneficiation. These procedures usually contain a lot of steps.

Lignite, sub-bituminous, bituminous, and anthracite coal are the four types of coal. As long as the coal has been suitably pre-treated, all four forms of coal can be gasified. The drying (for high moisture coal - anthracite), partial oxidation (for caking coal), crushing, and sizing of coal are all part of the pre-treatment process [12].

Coal gasification is next after coal pre-treatment. The pre-treated coal is fed into a gasification reactor. The reaction of coal gasification is endothermic. The reaction of oxygen and steam in coal creates a combination of carbon monoxide and hydrogen in the reactor. The chemical reaction typically occurs at a temperature of around 1000°C or more to achieve the necessary reaction rate. The devolatilization of the feedstock (coal) and the breaking of weaker chemical bonds occurs as the feedstock temperature rises in the gasifier. In the early phases of gasification, this produces volatile gases such as tars, oils, phenols, and hydrocarbon gases [13]. In most situations, these compounds react further to produce H_2, CO, and CO_2. The fixed carbon interacts with oxygen (O_2), steam, CO_2, and H_2 during devolatilization to contribute to the final gas combination [13].

Particulate removal, tar and oil removal, gas quenching and cooling, and acid gas removal are the four gas cleaning activities used to prepare syngas for combustion or further beneficiation. Carbon monoxide (CO), carbon dioxide (CO_2), hydrogen, methane (CH_4), hydrogen sulfide (H_2S), nitrogen (if the air is the oxygen source), water (H_2O), and several minor and trace components can all be found in the synthesis gas exiting the gasifier. The gasification technology utilized determines the presence of these components. The minor and trace elements are removed from the synthesis gas to prescribed amounts useable in downstream processing [13]. The particle removal process' principal goal is to remove coal dust, ash, and tar aerosols from the unprocessed gas. During tar, oil removal, and gas quenching and cooling, contaminants such as ammonia are scrubbed from natural product gas using aqueous or organic scrubbing liquors. Acid gases such as H_2S, COS, CS_2, mercaptans, and CO_2 are removed from the synthesis gas using an acid gas removal process. In most acid gas removal techniques, the acid gases are absorbed in a solvent and stripped, resulting in a nearly pure acid gas waste stream with little hydrocarbon carryover.

The synthesis gas enters the water-gas shift reactor for further hydrogen production. The WGS reaction is exothermic and requires a lower temperature for CO conversion. During the shift conversion process, H_2O and a fraction of CO catalytically combine to produce additional CO_2 and H_2 in the WGS reactor. Typically, combustion and gasification are conducted first in a reactor in a conventional approach. Because the combustion reaction is swift, the operating temperature in the combustion zone is ≥1200°C; as the hot gas mixture moves further into the gasification zone, the temperature drops to ≥700°C. The decrease in temperature depends on the type of gasification reactor employed. Also, depending on the type of reactor used, a pressure of typically 30 bar or more is required [14]. Then, the synthesis gas is introduced into another reactor with an operating temperature below 450°C for CO conversion (shift conversion). Maximum CO conversions are usually governed by equilibrium independent of reaction pressure [10]. Leftover CO and H_2 in the product gas react in a methanation reactor to create CH_4 and H_2O after passing through an absorber for CO_2 removal. Figure 2 shows a process flow diagram of a conventional gasification process.

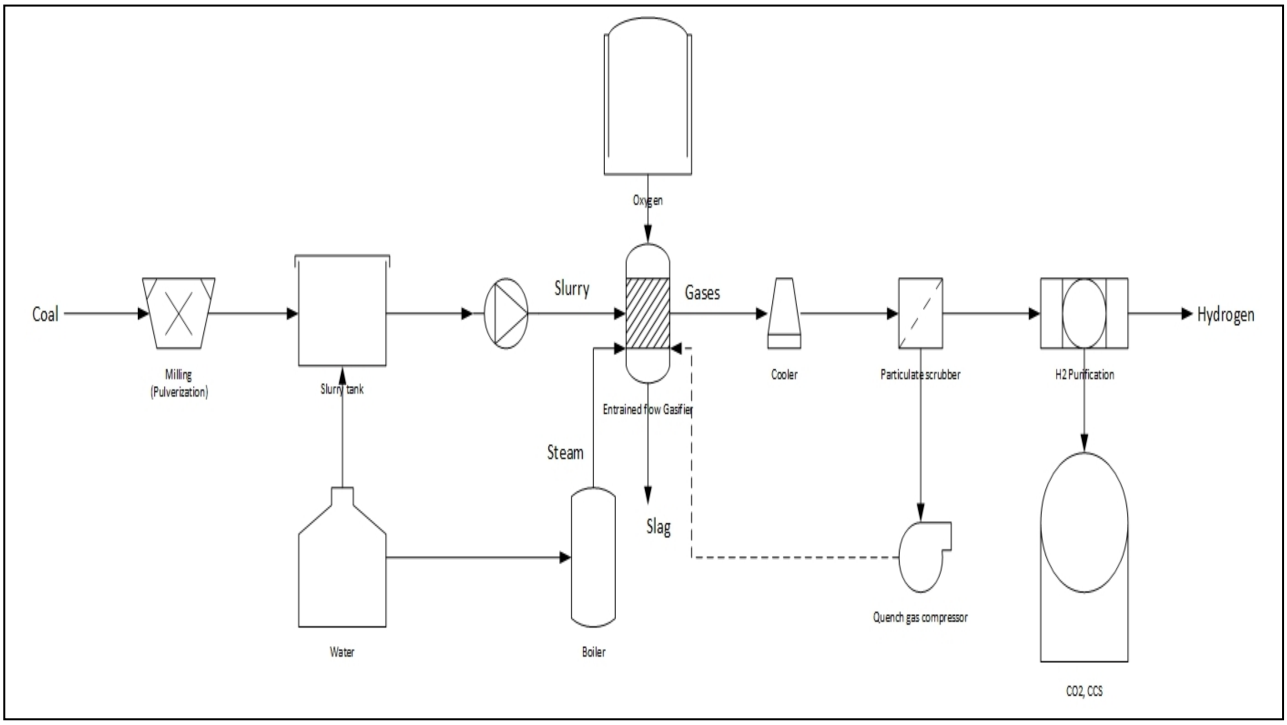

Figure 2. Process flow diagram of conventional gasification process (Adopted from [15])

Table 2. Gasification reaction chemistry

Reaction No.	Reaction	Reaction Description
R1	$C + \frac{1}{2}O_2 \leftrightarrow CO$	Carbon gasification with oxygen
R2	$C + O_2 \leftrightarrow CO_2$	Carbon combustion with oxygen
R3	$C + CO_2 \leftrightarrow 2CO$	Carbon gasification with carbon dioxide
R4	$C + H_2O \leftrightarrow CO + H_2$	Carbon gasification with steam
R5	$C + 2H_2 \leftrightarrow CH_4$	Carbon gasification with hydrogen
R6	$CO + H_2O \leftrightarrow H_2 + CO_2$	Water-Gas Shift reaction
R7	$CO + 3H_2 \leftrightarrow CH_4 + H_2O$	Methanation reaction

2.2 Assessment method for the occupational health hazards

To assess the inherent occupational health hazards, an approach that quantifies and offers an index on the health hazard for a given process is required. The information needed to conduct this assessment comes from the process reaction chemistries and the properties of the chemicals present. As previously stated, the Steam Methane Reforming Process and the Coal Gasification Process are the two processes examined in this study.

This research aims to assess the inherent occupational health risks associated with two different hydrogen production processes to determine the most practical for hydrogen production from a health hazard perspective. The Inherent Occupational Health Index (IOHI) is used in this study. This index describes the inherent occupational health hazard in the processes. The following equation determines the IOHI for each process:

$$I_{IOHI} = I_{PPH} + I_{HH} \tag{4}$$

I_{PPH} stands for Index for Physical and Process Hazards. It assesses all factors based on the ability of materials or chemicals to expose workers to chemicals, i.e., the likelihood of employees' exposure to chemicals as a result of the physical properties of the substances. The Index for Health Hazards, I_{HH}, on the other hand, examines the number of chemical hazards to human health when exposed to them and the health impacts and risks connected with that exposure.

The physical and process hazard index (I_{PPH}) is derived by adding all elements or sub-indexes that potentially raise the risk of injuries or health impacts directly or indirectly [7], [8]. These factors are process operation mode (I_{PM}), material phase (I_{MS}), volatility (I_V), operating pressure (I_P), temperature (I_T), and corrosiveness (I_C). All stated factors are given a value representing a penalty between zero to three (0-3) to quantify the level of physical and process hazards except corrosiveness, with penalties between zero to two (0-2). This penalty for corrosiveness is due to being less likely than the others to produce direct chemical exposure. The process condition determines process mode, temperature, and pressure subindices. The higher the risk or probability of a process condition causing health damages, the larger the penalty assigned to such process condition [7]. At the same time, the corrosiveness, material phase, and volatility of the process reaction step are penalized depending on the most dominant or maximum hazardous chemical. [7] provides thorough descriptions of these parameters. The following formula calculates the I_{PPH}:

$$I_{PPH} = I_{PM} + I_P + I_T + \max(I_{MS}) + \max(I_V) + \max(I_C) \tag{5}$$

The Health Hazard Index is calculated by adding two factors: Exposure limits (I_{EL}) and R-phrase (I_R). These two factors describe the level of chemical hazard to human health on exposure. The workers' health risks determine the severity of the penalty assigned. The higher the risk of threat to worker's health, the greater the penalty. The I_{EL} provides information on the long-term health risks of chemicals that employees are exposed to at work. I_R defines the type of health effect, acute or chronic toxicity that the chemical may have. Except for chronic toxicity effects, penalties attributed to both factors vary from zero to four (0-4) because it is assumed that the toxicity risks of the chemicals provide the most significant health danger to the exposed workers. The most dangerous chemical in the process step penalizes both factors. [7] provides thorough details on how the factors are created and how penalties are assigned to each parameter. The following formula calculates the I_{HH}:

$$I_{HH} = I_{EL} + I_R \tag{6}$$

The methodology described above is a reliable and straightforward way of assessing occupational health hazards in chemical processes at the design stage. The method does not require complex calculations. It is flexible and can be used without the need for an expert. All information required is available at the design stage. It is a handy tool for decision-making regarding occupational health hazards. Hassim & Hurme presented a method for calculating the IOHI that is very detailed [7].

2.2.1 Index Calculation

Other instances of index computation methodologies are used in this study to provide diverse perspectives on index-based assessment methods and the method's flexibility. The index-based method typically has an additive structure, which means that the index values of all subprocesses are added together to produce the overall index for the route [7]. One advantage of the index's additive character is that it reflects the process's complexity, which undoubtedly increases the chances of leaks, fugitive emissions, and other accidents [7]. However, its additive nature may exaggerate this characteristic, and processes with more reaction steps tend to have the worst index value.

Other index calculation methods were used, including average-type and worst-case calculations. The average-type analysis eliminates the additive effect. This elimination is achieved by dividing the overall IOHI score by the number of reaction steps. In the worst-case scenario, the routes' maximum sub-index penalties are added together [7].

Using other index-based calculation approaches in assessing the selected hydrogen synthesis route is vital because coal gasification has three or seven reaction steps depending on the calculation method used. Only three (R2, R3, & R6) of the seven reaction steps or subprocesses in the coal gasification pathway connect to the actual production of hydrogen. Other reaction steps or subprocesses are not considered in this assessment because the steam methane reforming pathway has just two reaction steps/subprocesses that lead to the actual production of hydrogen. Generally, the coal gasification route is not a safe and healthy route for hydrogen production because of the occupational health hazards associated with it, such as exposure to coal dust, noise, fires from possible spontaneous combustion of coal, inhalation of the products of combustion, or gaseous toxicants, etc. [16]. Given the nature of the additive index under consideration, it's best to limit this evaluation to the reaction steps/subprocesses that contribute to the actual production of hydrogen.

Finally, the processes are ranked using Hassim & Hurme's IOHI standard [7]. The IOHI standard intends to assist users in determining the level of health risk in a process. The standard offers practicable hazard measures and has four classifications: safe, moderately safe, moderately hazardous, and hazardous. The IOHI standard comes in handy for users who intend to assess the level of risk in a particular process with no intention of comparison. The standard also compares alternative processes based on the calculated IOHI value. In this study, the IOHI compares the level of health risk in the selected alternative H_2 production techniques using just the additive-type calculation to demonstrate its use. To rank the considered processes under the categories indicated, the route IOHI index value is divided by the number of reaction steps in each pathway.

3.0 RESULTS AND DISCUSSION

This section presents the evaluation results of inherent occupational health hazards in hydrogen production for two processes: Steam Methane Reforming and Coal Gasification. The IOHI assessment parameters evaluate each hydrogen synthesis route subprocess. The routes are represented by the process reaction chemistries for both processes. Equations (1) and (2) are used to assess SMR and reactions R2, R3, and R6 for coal gasification. Table 2 shows a summary of the penalties assigned to each reaction step.

Table 3. Summary of the penalty allocated to the H_2 subprocess by the Inherent Occupational Health Index calculation

Route/Step	I_{PPH}						I_{HH}		*IOHI*
	I_{PM}	I_{MS}	I_V	I_C	I_T	I_P	I_{EL}	I_R	
Steam Methane Reforming	1								
(7)		2	3	1	3	1	2	4	16
(8)		2	3	1	3	0	2	4	15
Coal Gasification	1								
R2		3	3	1	3	1	4	3	18
R3		3	3	1	3	1	4	4	19
R6		2	3	1	3	0	2	4	15

3.1 Results

3.1.1 Calculation of the IOHI using the Additive-type method

The additive-type approach, as previously indicated, adds up the subprocess indexes. Table 3 displays the results of the additive-type analysis. The coal gasification route has a higher index value than steam methane reforming, as seen in the table. As previously stated, this is due to the number of subprocesses involved in coal gasification (three). Moreover, even though both H_2 synthesis routes share reaction chemistry—the water-gas shift reaction— the reaction step had a significant impact on both the physical and process hazard index and the health hazard index for coal gasification.

SMR is ranked one and has an IOHI value of 32. SMR is a healthier H_2 synthesis route or less dangerous than coal gasification, even though both use fossil fuels as raw material. SMR is the most extensively utilized and least expensive method for producing hydrogen at the moment. It also has the advantage of being highly efficient and having a low operational and production cost. This finding adds to its benefits by demonstrating a healthier hydrogen production route than coal gasification, which is already a complex procedure. SMR has a low physical and process hazard, I_{PPH}, and a low health hazard, I_{HH}, compared to coal gasification. Although starting a steam methane reformer is one of the most dangerous procedures, it has fewer reaction steps than coal gasification, which has more reaction steps and offers a greater health risk in addition to the complexity of its operation. In addition to the impact of the reaction step/subprocess on the index value, both H_2 synthesis routes use chemicals with greater I_V and I_T penalties, indicating that they contain high-volatility chemicals. They also employ high operating temperatures, which could endanger workers' health; coal gasification, on the other hand, is more dangerous due to its more significant number of subprocesses.

Table 4. Hydrogen routes Inherent Occupational Health Index values (additive-type)

Route/Step	I_{PPH}	I_{HH}	I_{IOHI}	Ranking
Steam Methane Reforming	20	12	32	1
Coal Gasification	32	21	53	2

3.1.2 Calculation of the IOHI using the Average-type method

The average I_{IOHI}, I_{PPH}, and I_{HH} indexes are calculated for each process route to limit the influence of subprocesses on the final index result [7]. Compared to coal gasification, SMR has the lowest average IOHI value, as indicated in Table 4. The result implies that SMR is a healthier pathway for H_2 generation for average-type calculations. The index value difference between SMR and coal gasification is only 1.7—with SMR and coal having IOHI values of 16 and 17.7, respectively. Although the difference in I_{PPH} values for both routes is slight (0.7), when compared to the I_{HH} value, SMR is somewhat healthier or less hazardous in terms of process and physical hazard. As a result, SMR is ranked as the healthiest method in terms of physical and process hazards and health hazards, implying that it poses less of a risk of worker exposure and harm than coal gasification.

For the average-type analysis based on the IOHI value and rank, coal gasification, the least healthy route for additive-type calculations, continues to be the least healthy route for hydrogen production. It is also the route with the highest scores for both Physical and Process hazards, I_{PPH}, and Health hazards, I_{HH}, indicating the most significant risk of exposure and harm. The additive-type calculation implies that the route is the overall unhealthiest option with the highest risk of an occupational health hazard.

Table 5. Hydrogen routes Inherent Occupational Health Index values (average-type)

Route	Average I_{PPH}	I_{PPH} rank	Average I_{HH}	I_{HH} rank	Average I_{IOHI}	I_{IOHI} rank
Steam Methane Reforming	10	1	6	1	16	1
Coal Gasification	10.7	2	7	2	17.7	2

3.1.3 Calculation of the IOHI using the Worst case-type method

The route index is the sum of the route's highest sub-index penalties, according to the worst-case analysis [7]. The process's worst possible hazard is thought to be represented by the sub-index with the highest penalty. This calculation technique could prevent the same "worst chemical" from being penalized in many subprocesses [7].

According to Table 5, coal gasification is the most dangerous approach regarding I_{IOHI} value for the worst-case calculation, followed by steam methane reforming. Surprisingly, the I_{PPH} values for both channels are nearly identical, indicating that they have the same worst-case potential for exposure danger. However, their maximum potential for harm, Max.I_{HH}, differs by a factor of two, with coal gasification obtaining the highest index value, indicating that it poses the most significant health risk.

Table 6. Hydrogen routes Inherent Occupational Health Index values (worst case-type)

Route	Max. I_{PPH}	I_{PPH} rank	Max. I_{HH}	I_{HH} rank	Max. I_{IOHI}	I_{IOHI} rank
Steam Methane Reforming	11	1	6	1	17	1
Coal Gasification	12	2	8	2	20	2

3.2 Comparison of Results

The findings suggest that coal gasification is the most dangerous method of producing H_2 fuel, based on all three types of index calculations utilized in this study. The I_{PPH}, I_{HH}, and I_{IOHI} are all significantly different in the additive-type calculation results. It means that coal gasification is considerably more hazardous to employees than steam methane reforming and provides a greater risk of occupational health hazards in terms of exposure and harm. It's plausible to claim that this is due to the influence of reaction steps, given the nature of additive-type calculations. As previously said, the more reaction steps we have in a process, the more hazardous that process becomes from the standpoint of additive-type measures, reflecting this study's findings.

Although coal gasification is the unhealthiest pathway for H_2 production in both the average-type and worst-case type calculation techniques, the difference in the I_{PPH} value for both calculation forms is slight—0.3—based on the results. After removing the influence of the reaction steps, the result demonstrates that both methods have about the same level of physical and process hazards, i.e., the possibility of chemical exposure among employees during the production process. This outcome isn't surprising given the relatively high working temperatures necessary in the pathways and the volatile chemicals involved. The health hazard, I_{HH}, for steam methane reforming is the same for both calculation techniques. In summary, the number of health hazards posed to employees by both synthesis processes is about the same for both average-type and worst-case estimations.

Each calculation approach assesses the health hazards of the alternative H_2 processes from various angles [7]. According to the results obtained, all calculation methods give the same results, SMR has a ranking of one, and coal gasification has a scale of two in all calculation approaches. Each method has a unique way of presenting potential health risks from various angles. The additive method, for example, demonstrates how a process's complexity affects the number of threats; the average method shows the average hazards of route steps, and the worst-case method shows the process's worst aspect from a health standpoint [7]. The average and worst-case calculation approaches are recommended if the emphasis is not on the influence of the number of process steps [7]. They allow for a more thorough examination of the route's characteristics.

3.3 Standard for the Inherent Occupational Health Index

Based on the final IOHI score, the additive-type calculation is employed for the IOHI standard. Both synthesis pathways fall into the hazardous category, offering a risk of health problems, according to Table 6. However, coal gasification has a higher I_{IOHI} score. Although both processes are risky, coal gasification is more dangerous than steam methane reforming, according to the findings.

Table 7. Results of the assessment based on Hydrogen Routes Standards (for additive calculation).

Routes	No. of steps	Routes I_{IOHI}	I_{IOHI}/steps	Status
Steam Methane Reforming	2	32	16	Hazardous
Coal Gasification	3	53	17.7	Hazardous

The focus of this research was entirely on the synthesis routes for the two chosen hydrogen processes. Future research could focus on assessing the inherent occupational health of several types of raw materials used in H_2 generation via steam reforming and coal gasification to determine the healthiest raw material for each route and compare all materials and paths.

4.0 CONCLUSION

According to the case study findings, the chemicals utilized in the processes and the operating conditions play a critical role in determining inherent occupational health hazards. The chemical's material phase interferes with the index's value, volatility, exposure limit, R-phrase, and equipment operating conditions (temperature, pressure, and operating mode).

Furthermore, for additive-type calculation, the number of reaction steps in the processes substantially impacts the IOHI value. The index calculated in the two hydrogen production processes shows that industries can assess inherent occupational health hazards during the R&D stage of process design. The Inherent Occupational Health Index method utilized in this study showed to be a simple yet effective method of evaluating occupational health. The IOHI method can be applied early in the R&D phase of the process.

When contrasted, both synthesis pathways explored in this work are judged hazardous, i.e., they are neither healthy nor safe hydrogen generation routes. In addition, neither path adheres to the inherent occupational health concept. This conclusion is due to high working temperatures and pressures and the chemical or raw material properties. Although both synthesis routes are hazardous and pose occupational health risks to workers, steam methane reforming is a slightly better alternative for hydrogen production from a health perspective, given it has a lower Inherent Occupational Health Index standard value.

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