NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY
[IJIERT] ISSN: 2394-3696 Website: ijiert.org
VOLUME 9, ISSUE 3, Mar. -2022

MATERIAL OPTIMIZATION AND SELECTION FOR THE DESIGN OF SHELL AND TUBE HEAT EXCHANGER

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ABSTRACT

The efficiency of heat exchanger is dependent on the reliability and durability of its materials used at the design phase. The project is aimed at materials optimization and selection for the design of a shell and tube heat exchanger tube in order to mitigate failure mechanism such as erosion wear, fatigue and fouling resulting from fluid particles. Therefore, the need exists for high performance engineering materials and improved surface engineering application to mitigate the potential degradations due to erosion wear, fouling and fatigue. The material selection process was performed using the Cambridge Engineering Selector Edu-pack software Granta with limit and design constraints such as maximum service temperature 300℃, fracture toughness$\geq$ $30\mathrm{MPa.m}^{0.5}$, elastic limit 120MPa. Materials such as MXT5 Copper TiB_2 composite, molybdenum alloy 363 TZM, molybdenum alloy 362 and tungsten metal (UNS no: R07004) are materials that satisfied the design requirement. The weighed property index method was further used to evaluate candidate materials based on the importance of the material properties. MXT5 Copper TiB_2 (5%TiB_2 volume and 95% pure copper) composite materials were finally proposed as the optimum material for the design of shell and tube heat exchanger tube because of its excellent mechanical properties such as high fracture toughness and impact strength, significant increase in thermal conductivity and low cost.

Index Terms— Optimization, Heat Exchanger, Shell and Tube, Materials

INTRODUCTION

Over the past few decades, there is an increasing demand in the use of heat exchangers as a critical equipment to many processes such as chemical, petrochemical, refinery, oil and gas industries refrigeration, fossil and nuclear power, industries as a result of ever-increasing energy demand. It is therefore important to make the best possible use of energy resources and the utilization of efficient and economical heat exchangers in this endeavor (Rodriguez 1991).

Heat exchangers are a mechanical equipment’s which transfer heat energy (enthalpy) between two fluid streams to prevent hydrate formation, viscosity reduction and breakdown emulsion for separation of oil and gas, at different temperature with maximum rate and minimum investment and maintenance cost (Siva and Chaitanya 2016). The heat exchangers are basically used to reduce the temperature of one process fluid, which is desirable to heat without inter-mixing the fluid, leak or altering the fluid phase (Alex et al nd, and Shravan et al 2011). A typical application consists of heating and cooling of a fluid stream of interest and evaporation or condensation of single or multi-component fluid streams. Heat exchangers are classified based on the transfer process taking place in them. Heat exchangers are major source of problem in many process applications resulting in poor plant availability and efficiency. Therefore, the reliability of heat exchanger is a critical area which requires close attention (Rodriquez 1991).

Among several components of heat exchangers, the tube is the most critical region with regards to failure (Weimin, Yungang and Kong 2017). The tube has been most affected by failure and almost 85% - 90% failure rate of heat exchanger tube is as a result of inlet-end related problems and approximately 80% occur within the first six inches of the inlet-end, this is because, turbulent flow condition changes to laminar flow, and erosive fluid is sharply declined which eventually leads to leakage and tube failure. In the report of NEA/CS NIR (2015) revealed that the common source of failure in shell and tube heat exchanger tube was due to erosion wear, thermal cycling, fouling, and inappropriate material selection.

Hence, the selection of high-performance materials with the combination of appropriate properties at relatively low price is a huge challenge to material engineers. Therefore, to maintain the integrity of engineering structure, it is fundamental that material engineers design a durable and reliable structure, this requires proper understanding of material proprieties and selection in order to minimize the economic losses and material failure caused by erosion wear, fouling and fatigue. To select suitable materials for shell and tube heat exchanger tube design, it is noteworthy for material to meet the material performance criteria which includes, cost, functional requirement, reliability, resistivity to in-service operations and processibility requirement.

LITERATURE REVIEW

Material deterioration in heat exchangers has been a persistent problem in the oil and gas industry. The consequence has led to financial losses and low performance. Hence, have raised the profile of heat exchanger as a critical area of study. Several studies have been carried out with respect to material failure which aimed at proffering lasting solution to material failure in the oil and gas industry.

According to Ibrahim (2012) the deposition and accumulation of undesired material such as scale, algae, suspended solids, soot, dirt, and insoluble salts on the internal or external surface of process material including boiler and heat exchangers is referred to as fouling. According to Müller-Steinhagen 2000, Fouling is not static rather a dynamic process, which changes over time. The progressive deposition of fouling decreases the overall heat transfer (enthalpy) coefficient and increases the overall thermal resistance of heat exchangers.

According to Garrett-Price et al. (1985) stated that refineries based in USA losses more than $2 billion per annual due to heat exchanger fouling, according to Garrett-Price, the overall cost of heat exchangers fouling in most developed nations such as UK, US and Europe are about 0.25% of the national gross national product GNP. For instance, the total cost of heat exchanger fouling in the united stated UK ranges between £8 -14x10 per year and $8 -10x10 per annual for the USA. Furthermore, study conducted by Pritchard et al. (1988) revealed that about 15% of the maintenance cost of an industrial plant is due to heat exchanger and boiler and half is attributed to fouling. In another study conducted by Pilavachi and Isdale (1992) in the European nations shows that the cost of fouling in heat exchanger follows the order of 10 x9 10 ECU and a total 20 – 30% cost is due to increased energy demand. A comprehensive studied conducted by 10 Chaudgane shows the total cost of fouling in the industries of France is about 1 x 10 French Francs per annum (Chaudgane, 1992). Steinhagen et al. (1993) stated that the overall costs of fouling for New Zealand are 0.15% of the New Zealand Gross National Product GDP. In another study conducted by Xu Zhi-Ming et al. (2007) projected the economic consequences of fouling in boiler and turbine is approximately 4.68 billion dollars, which is about 0.169% in china GDP.

The issue with erosion is best addressed first by looking at the real erosion mechanism. Erosion has been defined as the process of mechanical property removal in a material from a target material surface due to the cutting action of the moving particles at high velocity. This form of damage mechanism is influenced by the properties of the eroding particles and condition of impingement (Okonkwo and Adel 2014, Aribo 2014).

Rosenfend and Kiefner 2006, stated that progressive localized damage depends on fluctuating stress or strain of material and such stress or strain are locally characterized by structural discontinuities, geometry, notches surface irregularities, defects or metallurgical non-homogeneities. They further stated that fatigue phenomenon is not static hence categories the process of occurrence into three distinct stages namely crack initiation, crack growth propagation and final fracture. However, Kachanov 1958, studied the continuous damage phenomenon for metal creep fracture in one dimension. The study revealed the historical beginning of material progressive damage modelling taking place before macroscopic fracture. The study suggested that material damage can only manifest if at least one crack or cavity is present at the microscopic scale.

METHODOLOGY

MATERIAL SELECTION PROCESS AND TECHNIQUES

Material selection is a significant process in the development and design process of engineering structures. Impropriate or inferior material selection may cause failure. Selecting optimal material for any engineering structure or component it is important to consider the operational requirement in which it is employed. Hence, selecting material that best justify the requirement of the design and give maximum performance, relatively low cost, manufacturing process is the goal of optimum product design. In recent past, conventional materials are being replaced with new material and these set of high-performance materials are in the increase both in types, sizes and numbers.

MATERIAL PERFORMANCE INDICES

The design of mechanical structural element is determined by three parameters namely; Functional requirement (the physical function to transmit and thermal energy), the geometry (shape), and the properties of the material of which it is made, including its cost. The performance of the element can be described by an equation with the general form (Ashby method 2015).

The derivation of the performance indices for a shell and tube heat exchanger tube required first determining the hoop stress or the circumferential stress of the tube material. Edwards (2008) provided the specification for a classical Shell Tube Heat Exchanger tube with internal diameter 0.670in (r = 0.00851m) and wall thickness of 0.65in (0.00277m). Therefore, the Hoops Stress for a thin-walled material is calculated as;

$$\text{Hoop stress} \quad \sigma = \frac{\Delta p . r}{t} \qquad (3.1)$$

$$\sigma = \frac{3.8 \text{ x } 10\text{Pa x } 0.00851\text{m}}{0.00277\text{m}} \qquad (3.2)$$

$$\sigma \quad = 120\text{MPa}$$

The performance indices of any engineering component are mathematical expression derived to guide the selection process for the material

Therefore, Heat flux is obtained as

$$q = -k\frac{\Delta T}{t} \qquad (3.3)$$

Where ΔT is the temperature change across the surface from fluid 1 into the wall ($\Delta T = T_1 - T_2$). k, Is the thermal conductivity of the wall (thickness) and Q is the total heat energy flow, considering, a heat exchanger with n number of tubes of length L, the area A = 2πrLn.

The tube wall thickness must possess sufficient strength to resist the pressure difference Δp between the inside and outside. It is desirable that the maximum allowable stress in the wall is lower than yield strength of the material in which the tube is made.

i.e. $\sigma = \frac{\Delta p.r}{t} \leq \sigma_y$,

$$t = \frac{\Delta p.r}{\sigma_y} \qquad (3.4)$$

Substituting equation (3.4) for t in (3.4) to eliminate t, hence equation 3.2 becomes

$$q = \left(\frac{\Delta T}{r\Delta p}\right)\left(k.\sigma_y\right) \qquad (3.5)$$

The material index is an integral part of equation 3.5 with all material properties
Hence, heat flow per unit area is maximized by maximizing:

$$M_1 = \frac{q}{A} = k\sigma_y \qquad (3.6)$$

Hence to maximized heat flux q the material index must be maximized.
Taking logarithm of both sides,

$$\log\sigma_y + \log k = \log M_1 \qquad (3.7)$$

$$\log\sigma_y = -\log k + \log M_1 \qquad (3.8)$$

$$y = mx + c. \qquad (3.9)$$

Thus, a log-log plot of σ_y against k, with a slope m = -1 gives the required materials.
Performance Index derivation to maximize heat flow per unit mass (Minimu**m** Weight Exchanger)
Function: STHE tube,
Objective: Minimize weight of STHE tubes,
Constraints: 1. Support pressure difference Δp across tube wall,
2. Withstand circumferential stress σ_y across tube wall.
Free Variable: 1. Material choice
2. Tube-wall thickness, t

The total mass, M, of the STHE tubes is given as:

$$M = \rho V = \rho AL \qquad (3.5)$$

Where ρ is the density of the tube material.
The rate of heat transfer,

$$q = -k\,A\,\frac{\Delta T}{t} \qquad (3.6).$$

Substituting (3.6) for A in (3.5) yields:

$$M = \rho * L\left(\frac{qt}{k\Delta T}\right) \qquad (3.7)$$

The tube wall thickness must be sufficient enough to withstand the pressure Δp between the inside and outside. This requires that the stress in the wall remain below the elastic limit of the material;

i.e. $\sigma = \frac{\Delta p.r}{t} \leq \sigma_y$

$$t \geq \frac{\Delta p.r}{\sigma_y} \qquad (3.8)$$

Substituting (3.8) for t in (3.7) yields

$$M = \frac{\rho * q}{k\Delta T} * \left(\frac{\Delta p.r}{\sigma_y}\right) * L$$

$$\frac{M}{q} = \frac{\rho}{k\Delta T} * \left(\frac{\Delta p.r}{\sigma_y}\right) * L \quad \text{Or}$$

$$\frac{M}{q} = \frac{\Delta p}{\Delta T} * \frac{\rho}{K\sigma_y} * r$$

Or,

$$\frac{q}{M} = \frac{\Delta T}{\Delta p} * \frac{K\sigma_y}{\rho} \frac{1}{r} \qquad (3.9)$$

Thus, to minimize weight (or mass) per unit heat transfer energy m/q it requires we Minimize $\left({}^{\rho}/k\sigma_y \right)$ or maximize heat transfer per unit mass ${}^{q}/_{M}$, by maximizing $k\sigma_y/\rho$

Thus, a log-log plot of σ_y against ${}^{\rho}/_{k}$ on a slope m = -1 gives the required materials.

Performance Index to maximize internal crack size by inspection:

Function: Shell and Tube Heat Exchanger tube.

Constraints: 1. Support pressure difference Δp across tube wall,
2. Withstand hoop stress σ_y across tube wall

Objective: Maximize internal crack size by inspection.

Free Variable: 1. Material choice,
2. Tube-wall thickness, t.

The stress, required to cause fast fracture from an internal crack size of 2a in a material of fracture toughness $K_{1c}$is given by:

$$\sigma = \frac{K_{1c}}{\beta\sqrt{\pi a_c}} \qquad (3.15)$$

Where β is a geometry factor $\approx$1.

To maximize pressure containment, the yield stress of the material σ must remain below the elastic limit σ_y of the material,

i.e. $$\sigma \leq \sigma_y = \frac{\Delta p.r}{t} = \frac{K_{1c}}{\beta\sqrt{\pi a_c}} \qquad (3.16)$$

Although the pressure is limited by the fracture toughness K_{1c} of the material, this is not a “failsafe” performance index. A safer performance index would be to calculate the crack size that is just larger than the thickness of tube material when subjected to its “yield stress before break” σ_y. This would enable the crack size to safely dispense the pressure and/or be discovered during inspection

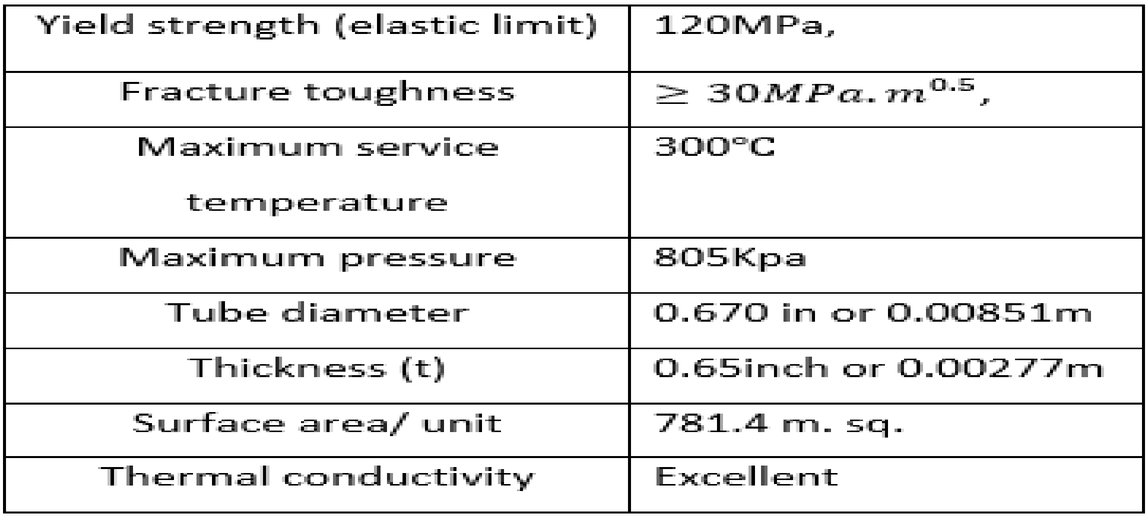
i.e

$$a_c = 2a \geq t = \frac{1}{\beta\pi}\left(\frac{K_{1c}}{\sigma_y}\right)^2 \qquad (3.17)$$

To maximize a_c, we need to maximize $\left(K_{1c}/\sigma_y\right)^2$, which can be obtained by a log-log plot of K_{1c} against σ_y on a slope of m=1.

In-service condition and design limit of a shell and tube heat exchanger’s material.

(Ashby 2015, Greuning 2006, Edward 2008).



Yield strength (elastic limit)	120MPa,
Fracture toughness	$\geq 30 MPa.m^{0.5}$,
Maximum service temperature	300°C
Maximum pressure	805Kpa
Tube diameter	0.670 in or 0.00851m
Thickness (t)	0.65inch or 0.00277m
Surface area/ unit	781.4 m. sq.
Thermal conductivity	Excellent

ASHBY CAMBRIDGE ENGINEERING SELECTOR CES EDU PACK SOFTWARE

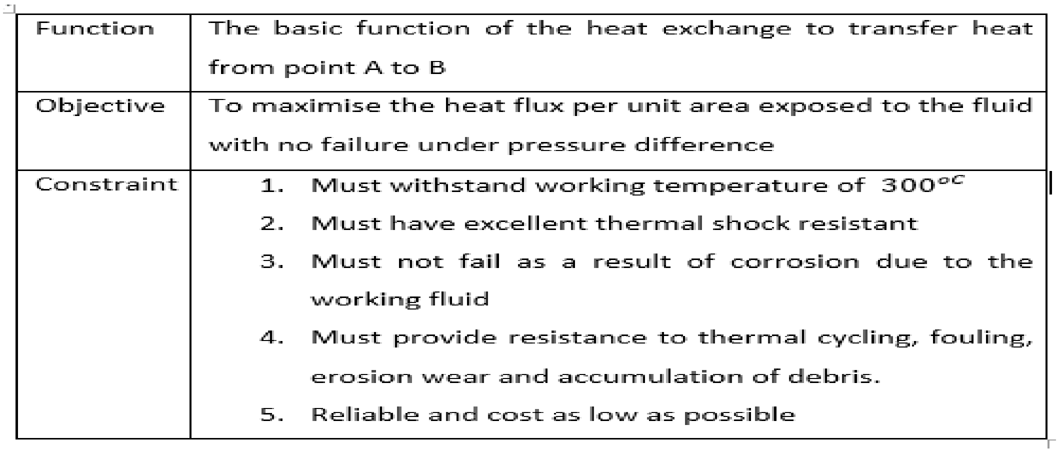
Engineering design required a profile of material properties in order to function optimally Ashby (2011). Nevertheless, this is idealistic for material to have exact profile of desired material properties to meet the material profile. This simply implies that; material property trade-offs are important so as to obtain the requirement of the overall and most appropriate candidate material. Ashby (2011), further defined the transition stages, as the requirement for engineering designs to be translated into constraint and objectives, which are used to classify materials. The established constraints can be used in the material database to screen for potential candidates. These screened materials are represented in graphical chart the design performance index. It is noteworthy that; no material selection process or technique can ultimately give a perfect material selection.

The use of CES selector Granta play an important role in material selection. This method uses charts to present potential materials based on their performance indices with a material database called material universe and CAMPUS plastics. This database has general materials instead of brand name and the values allocated are not specified. The values are within a particular range to include all the materials available of this type. A section is provided to include the suppliers of each possible material selection so that purchase can be efficiently carried out or information can be gotten directly from them if needed. The varieties of materials contained in the material universe are polymers, ceramics, metals and alloys and lastly composites. There are about 3700 materials available in the CES basic edition database. As technology increases more materials are discovered in different sizes and shapes which are now available in the selector except Aerogels, Nano materials, textiles and “smart”

RESULTS AND DISCUSSION

Material selection for mitigating failure due to erosion, fouling and fatigue in a shell and tube heat exchanger was performed using the Cambridge Engineering Selector CES Edu-pack 2017 software. The material selection was carried out using advance level 3 of the CES Granta software, and the following results (plots) were obtained from the CES Granta, yield strength vs thermal conductivity, yield strength vs Density/thermal conductivity, fracture toughness vs yield strength, maximum temperature vs water (salt), fracture toughness vs price, thermal conductivity vs price and yield strength vs. young’s modulus. The following are required for the tube and baffle plate materials.

Translation of Design Criteria for the STHE Tube.



Function	The basic function of the heat exchange to transfer heat from point A to B
Objective	To maximise the heat flux per unit area exposed to the fluid with no failure under pressure difference
Constraint	1. Must withstand working temperature of 300^{oC} 2. Must have excellent thermal shock resistant 3. Must not fail as a result of corrosion due to the working fluid 4. Must provide resistance to thermal cycling, fouling, erosion wear and accumulation of debris. 5. Reliable and cost as low as possible

MATERIAL SELECTION FOR A TUBE IN A SHELL AND TUBE EXCHANGER

In the level 3 of the CES, advanced materials (high performance materials) were obtained from material universe for the tube in shell and tube heat exchanger such as ceramics and glass/non-technical ceramics 39, technical ceramics 171, hybrids: composite/foams/honeycombs/natural material 322, metal and alloys/ferrous/alloy steel 193, carbon steel 121, stainless steels 190, micro alloy and high strength steel 21, refractory alloys/molybdenum 6 and tungsten 17. At this level, the tree selection tool is used to eliminate materials from 3968 to 33.

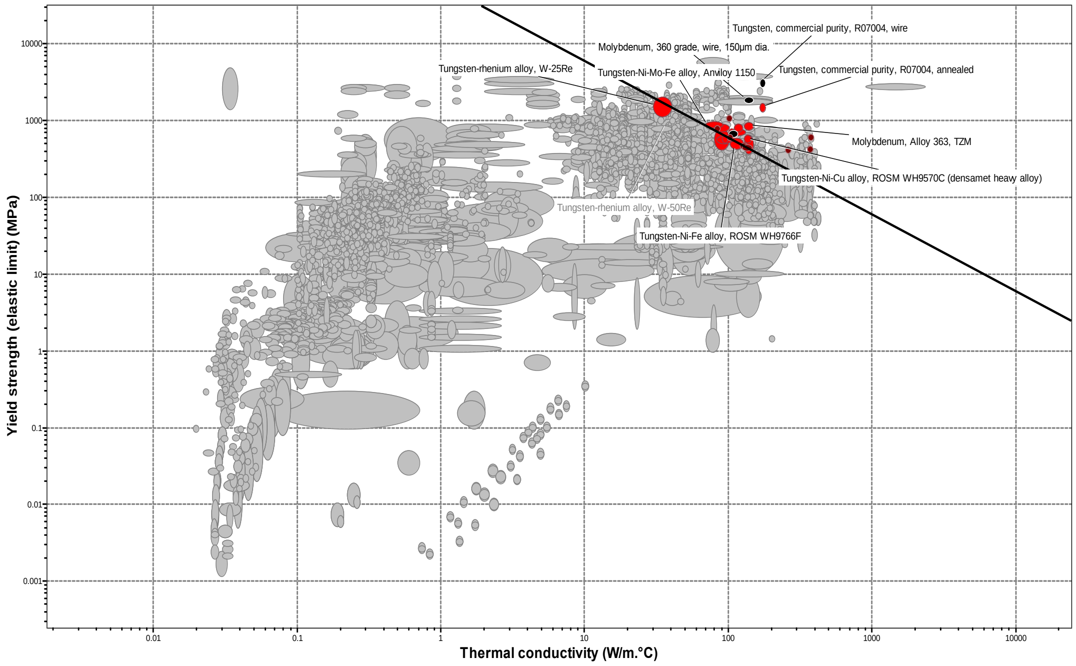
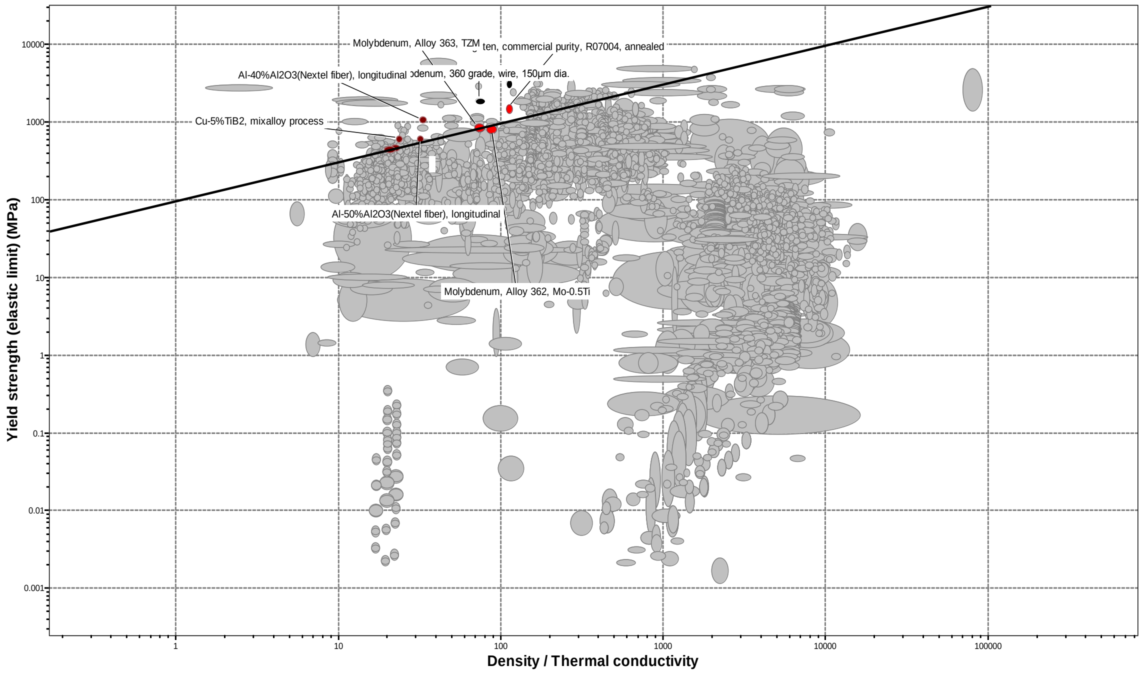


Fig.3.4 Graph of yield strength against thermal conductivity Figure 3.4 is a plot of yield strength (elastic limit) against thermal conductivity with a slope (M) = -1 obtained from the performance indices using the limit selection tool. The chart shows that material that passed the limit test have high ratio of yield strength to thermal conductivity ($^{\sigma_y}/_{k}$). The requirement for STHE of tube is that material must be thermal shock resistance and the maximum allowable stress in the tube wall must remain below the elastic limit of the material to prevent deformation of the material.

Figure 4.2 is a graph of elastic limit against the ratio of density to thermal conductivity with a slope of M= 0.5. The further reduces the material grid from 25 to 10. See appendix 4.3. The plot also shows that material generally the survived the limit test have high yield strength but low ratio of density to thermal conductivity. However, tungsten commercial purity has high ratio of density to thermal conductivity and yield strength while Al (2124)-20%SiP MMC powder and Al (2124)-15%SiP MMC powder has both low ratio of density to thermal conductivity and yield strength (elastic limit) when compared to other materials.



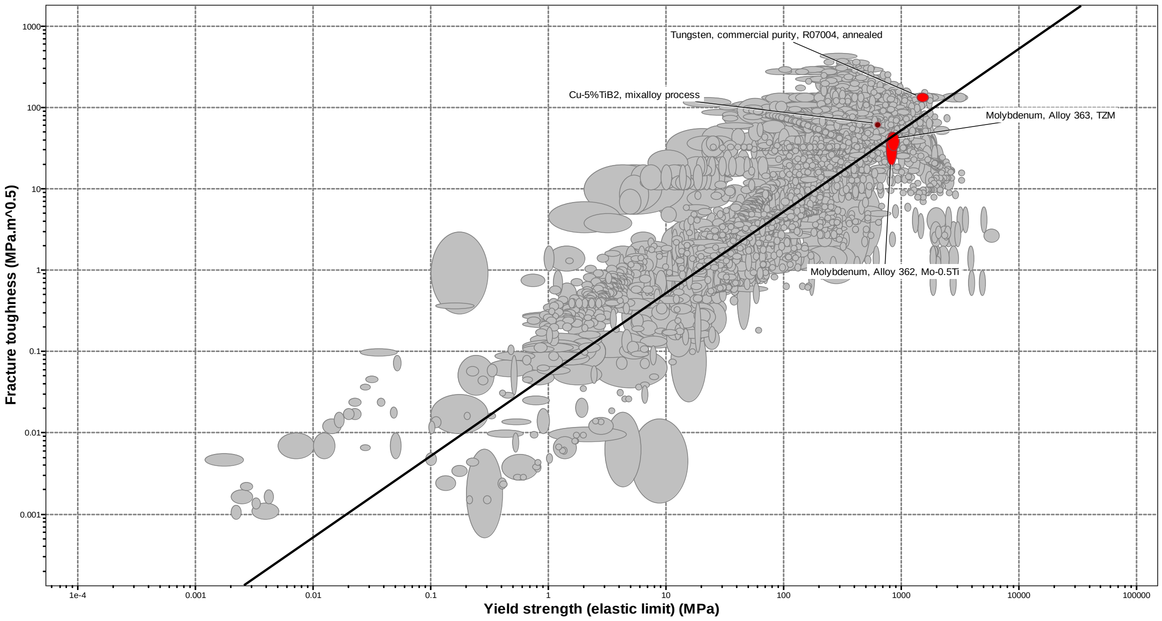


Figure 4.3. Is a graph of fracture toughness against yield strength with a slope of M= 1. Materials that survived the limit test includes such as Cu-5%TiB2 mix alloy process, Molybdenum alloy 362, 363, Mo-0.5Ti, and tungsten, commercial purity. Generally, the graph indicates that all the materials have both high yield strength

and fracture toughness. However, material like tungsten commercial purity have the highest fracture toughness and yield strength followed by Cu %5TiB2 while molybdenum alloy contains the lowest fracture toughness and yield strength when compared to other materials.

In the plot, shown in Figure 4.4. The maximum service temperature against sea water resistance is about1400^{oc}. The graph also shows that materials are acceptable in salt water using alloy database such as Cu-5%TiB2, molybdenum 363, molybdenum 362 and tungsten commercial purity. Materials like molybdenum alloy offers the highest service temperature resistance to sea water while Cu-5%TiB2 offered the least service temperature resistance at a service temperature of 440^{oc} which is above the limit for the maximum service temperature the tube. The requirement for the tube is that material must be corrosion resistance hence the said material can be used for the design of a tube.

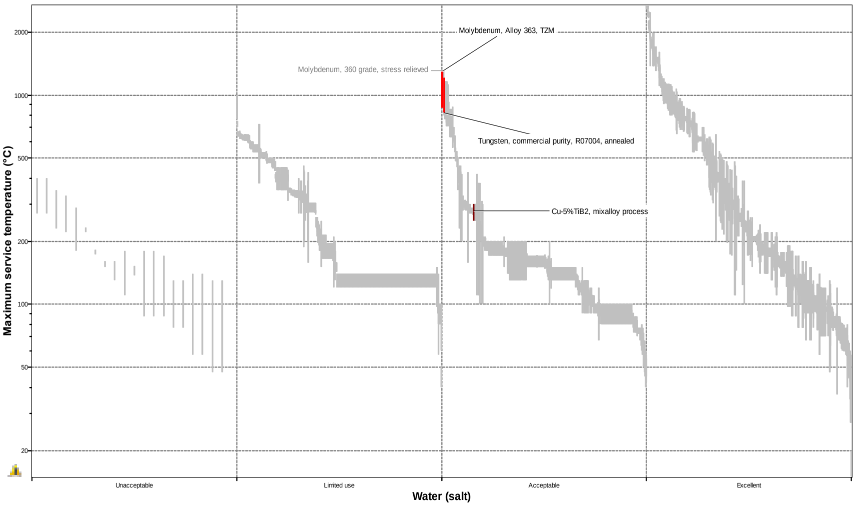


Fig. 4.4 Graph of maximum service temperature against water (salt)

As shown in figure 4.5. Tungsten commercial purity R07004 annealed have high fracture toughness and cost than Cu-5% TiB2 and molybdenum, alloy 363 TZM. It is thus, evident in the graph that materials with high fracture toughness will have high price. The material requirement for the STHE of tube is to have a relatively cheap material with high fracture toughness. Arguably, engineering material should not be subjected to cost rather material performance.

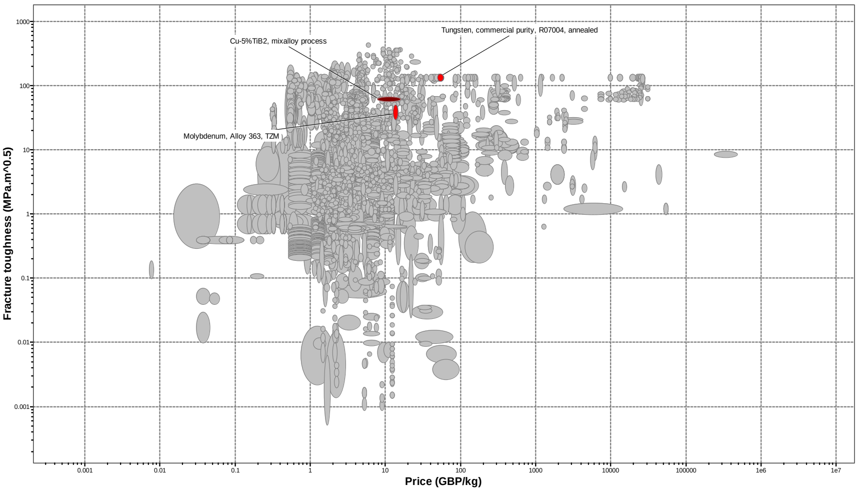


Fig. 4.1 Graph of Fracture Toughness against Price.

Figure 4.6 is a graph of thermal conductivity against price. The graph shows that Cu-5%TiB2 alloy is preferred to other material since it has high thermal conductivity and relatively cheap price compared to Tungsten commercial purity R07004 annealed and molybdenum, alloy 363 TZM. The material requirement for STHE of tube is to obtain a material with excellent thermal conductivity with less cost implication.

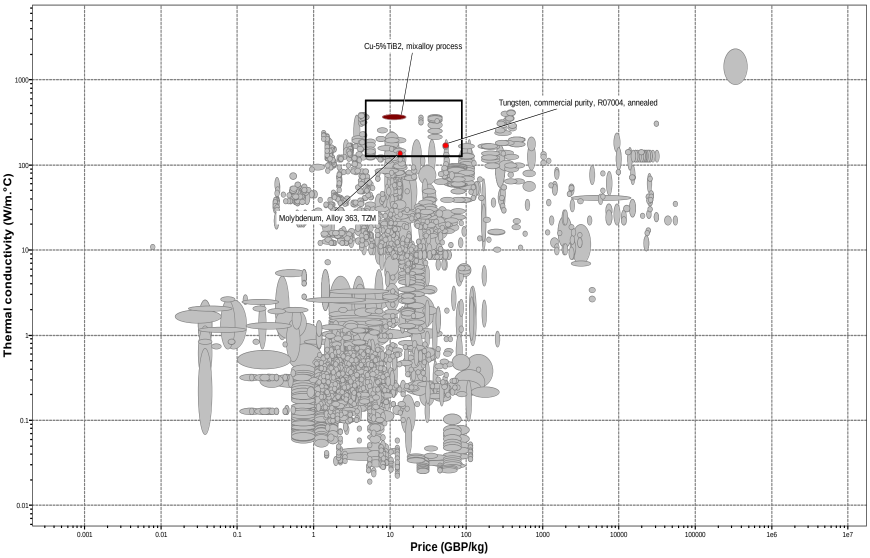


Figure 4. 2 is a graph of thermal conductivity against price

As shown below in figure 4.7. Tungsten commercial purity R07004 annealed has a very high yield strength and relatively low young's modulus* thermal expansion coefficient. Thus, making Tungsten commercial purity R07004 annealed preferred to other materials.

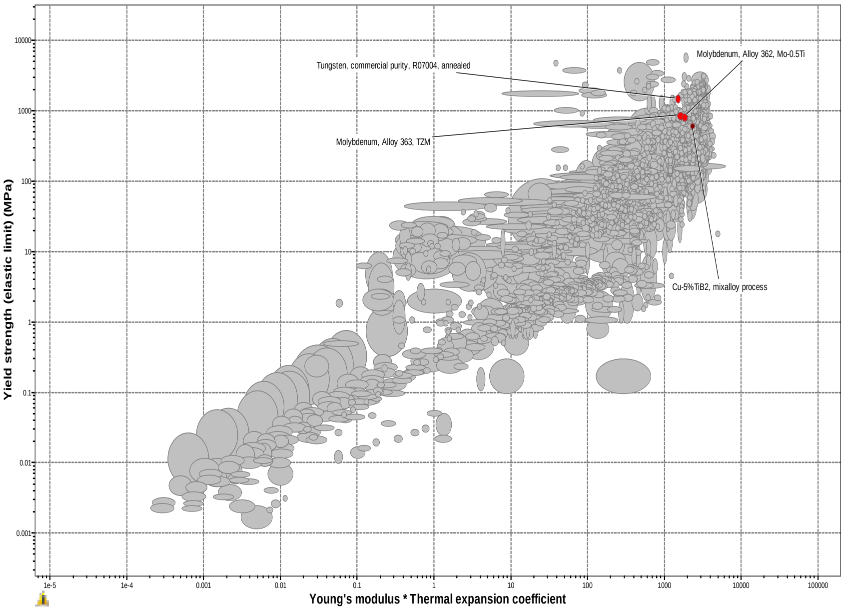


Figure 4. 3 Graph of yield strength versus young's modulus*thermal expansion coefficient

MATERIAL EVALUATION AFTER SCREENING AND RANKING

The evaluation candidate material process involves the collection of detailed information about a particular candidate material, so as to ascertain if candidate material meets design criteria and could be used for the purpose. Therefore, the evaluation of the individual candidate material will involve material properties, application, manufacture process, material availability and cost implication. The materials that survived the after screening and ranking of materials the following: MXT5 copper TIB2 composite, Molybdenum, Alloy 363 TZM, Tungsten metal (UNS no: R07004) and Molybdenum, Alloy 362.

DECISION MATRIX OF MATERIALS

A decision matrix are analytical tools used systematically to identify and analyze material that is optimally suitable for the application. In this method, the materials properties are required to make a material suitable for the application are assigned number 0 -1 relatives to the overall material properties importance. The decision matrix approach used to select optimal material is known as weighted property index method.

WEIGHTED PROPERTY INDEX METHOD WPIM.

The weighted property index method is often used in material selection when there are lots of important property to be ranked (compare and evaluate). The ranking is done in an order of most important property to the least by assigning a value known as weight factor. The weight factors are indications of the importance of the specific property. The property values for individual material are normalized by a scaling factorα.

$$\text{Scale prop.}\beta = \frac{Numerical\ value\ for\ material\ \ property\ *\ 100}{maximum\ value\ in\ the\ list}$$

For a low property value such as of cost, corrosion loss and fatigue etc., a minimum value is more preferable and the lowest value is rated as 100. Therefore, the scaled factor is given as

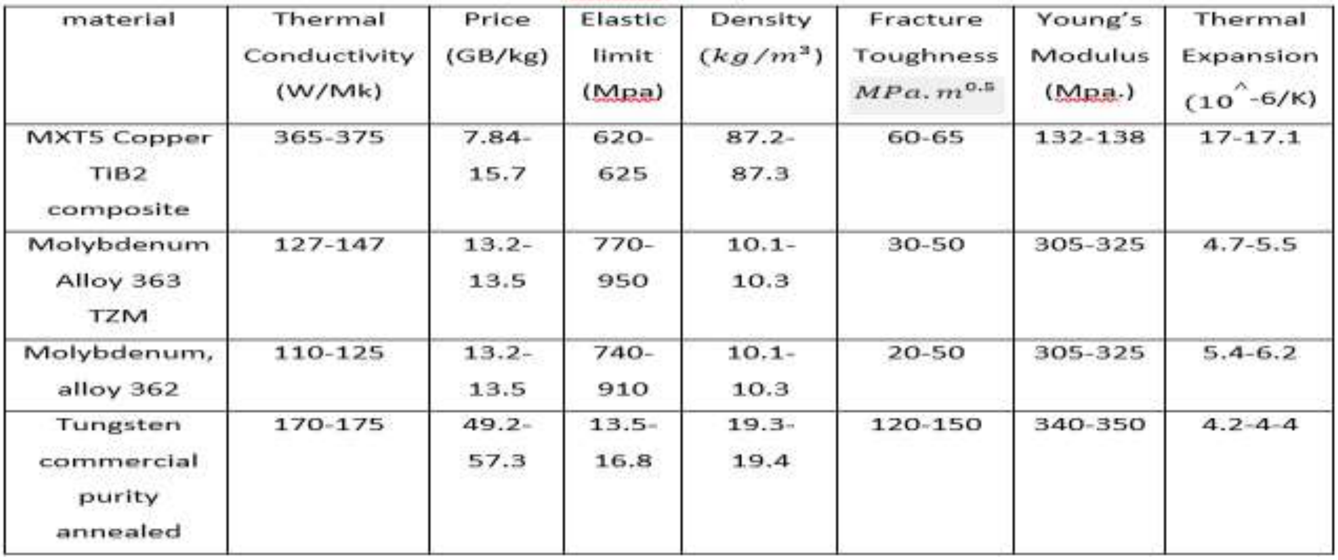
$$\text{Scaled property } \beta = \frac{\text{minimum value in the list}*100}{\text{numerical value of property}}$$

The total number of positive decision $N = \frac{n(n-1)}{2}$

Material Performance index (γ) is calculated as $\gamma = \sum \beta\ \alpha$

Table 4.3 as shown below is a list of material properties for the STHE of tube. It is an indication of the weight factor of candidate material property

Table 4.3 MATERIAL PROPERTIES (CES Granta 2017).

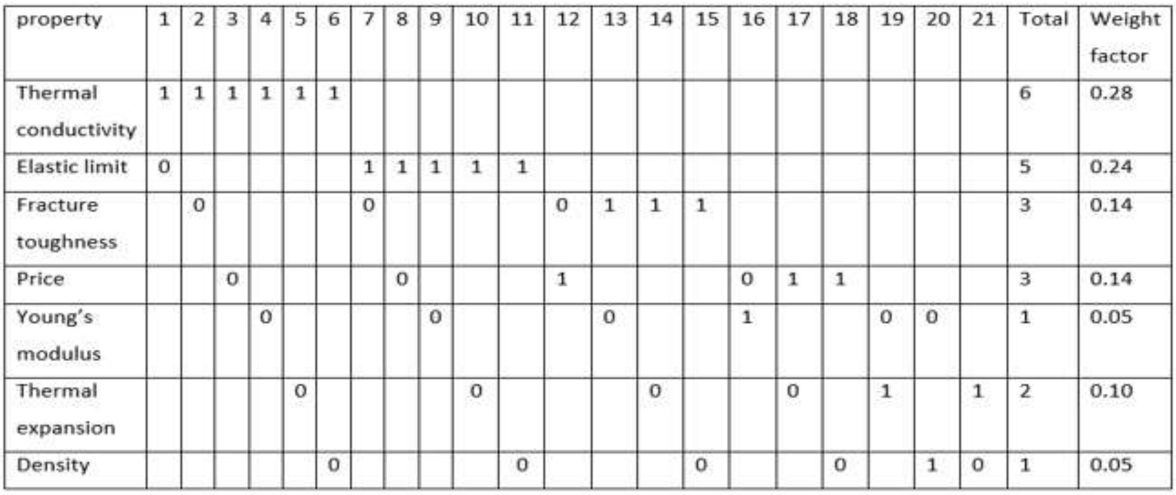


material	Thermal Conductivity (W/Mk)	Price (GB/kg)	Elastic limit (Mpa)	Density (kg/m^3)	Fracture Toughness $MPa.m^{0.5}$	Young's Modulus (Mpa.)	Thermal Expansion (10^-6/K)
MXT5 Copper TiB2 composite	365-375	7.84-15.7	620-625	87.2-87.3	60-65	132-138	17-17.1
Molybdenum Alloy 363 TZM	127-147	13.2-13.5	770-950	10.1-10.3	30-50	305-325	4.7-5.5
Molybdenum, alloy 362	110-125	13.2-13.5	740-910	10.1-10.3	20-50	305-325	5.4-6.2
Tungsten commercial purity annealed	170-175	49.2-57.3	13.5-16.8	19.3-19.4	120-150	340-350	4.2-4-4

Table 4.3 show a list of material properties for a heat exchanger tube. This shows the weight factor of candidate material property. The property of each material is compared to one another to know which material is most important. The most important material property is assigned with 1 and the less important one 0. The total of

each property is determined by dividing the positive decision number in order to calculate the weight factor.

Table 4.4



property	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total	Weight factor
Thermal conductivity	1	1	1	1	1	1																6	0.28
Elastic limit	0						1	1	1	1	1											5	0.24
Fracture toughness		0					0					0	1	1	1							3	0.14
Price			0					0				1				0	1	1				3	0.14
Young's modulus				0					0				0			1			0	0		1	0.05
Thermal expansion					0					0				0			0		1		1	2	0.10
Density						0					0				0			0		1	0	1	0.05

In this case, material with very high thermal conductivity is required in order to maximize the heat transfer from the hot stream fluid to cold stream fluid. Hence thermal conductivity is regarded as the most important property see table 4.4. Furthermore, high strength material is also needed to withstand pressure differential between primary side and secondary side thus the elastic limit of the material is ranked the second most important property. Fracture toughness is another important property which determines material resistance to fracture. More also cost is another important property which affect the choice of material. Salt water is also very important since it determine the corroding nature of the material.

Material	Thermal Conductivity (W/Mk)	Price (GB/kg)	Elastic limit (Mpa)	Density (kg/m^3)	Fracture Toughness	Young's Modulus (Mpa.)	Thermal Expansion (10^-6/K)	Total (Performance Index)
	0.28-0.28	0.14-0.14	0.24-0.24	0.05-0.05	0.14	0.05	0.10	1.0
MXT5 Copper TiB2 composite	28	2.23-3.84	19.32-15.79	14	2.5-2.16	3.88-3.94	5	56.79
Molybdenum Alloy 363 TZM	9.8-10.98	3.76-3.29	24	1.62-1.65	1.25-1.66	8.97-9.20	1.38-1.61	30.6
Molybdenum, Alloy 362	8.44-9.33	3.76-3.29	23.06-22.98	1.62-0.14	0.83-1.66	8.97-9.20	1.58-1.81	37.40
Tungsten Commercial Purity Annealed	13.04-13.06	14	0.42	3.1-3.11	5	10	1.24-1.28	28.5

FINAL MATERIAL SELECTION

Table 4.5 is provided with candidate material in the order from highest total weighted properties to the lowest. The use of weighted property index method was ranked according to the importance of the properties required. The material that was found to be the best suitable to mitigate erosion, fatigue and fouling is MXT5 Copper TiB_2composite.

CONCLUSION

The optimization and selection of material was carried out using the Ashby material selection strategy and Cambridge Engineering Selector CES Granta Edu-pack 2017 package to proposed and justify high performance materials to mitigate failures that are associated to tube in a shell and tube heat exchangers in oil and gas industry. A material selection strategy for mitigating tube failure in shell and tube heat exchanger was present in this project. The material selection process involves the four phases of Ashby's materials selection method. The first phase translated the design requirement in terms of functions, objectives, constraints and free variables. The material performance indices were derived to express constraints and objectives for material selection in CES Edu-pack Granta. The material performance indices and constraints were used to screen and rank materials in CES.

Firstly, the translation of the design criteria consists of a list of criteria expressed as constraint (maximum service temperature > 300C; $\text{fracture toughness} \geq 30\text{MPa.m}^{0.5}$, excellent resistance to corrosion (salt water), resistance to thermal shock and cycling.

Secondly, the objectives maximize the heat flux and minimise the cost.

Thirdly, Cambridge Engineering selector CES Granta 2017 software selection tools can be used to eliminate and screen candidate material.

Fourthly, the ranking of material was done based on the objective. The results obtained shows that the following material survived or meet the set requirements. The materials include MXT5 Copper TiB_2Composite, Molybdenum, and Alloy 363 TZM. Tungsten metal (UNS no: R07004), Molybdenum, alloy 362.

Fifthly, However, the decision matrix method was used to decide the final material based on weighted property index method. The final selection process shows the most suitable material that can used to reduce the failure mechanism that are related to thermal cycling (fatigue), erosion wear, and fouling in a shell and tube heat exchanger tube. Hence, MXT5 Copper TiB_2Composite material was selected as the optimal material due to the highest performance index.

The following conclusion drawn from this project are listed below;

1. The use of high-performance materials significantly reduced failure mechanism in heat exchangers and other oil and gas related components.
2. MXT5 Copper TiB_2composite is selected as the best material because of it high fracture toughness and impact strength to avoid fast fracture. According to Murugesh et al 1991 and Diamond, kirk and Briggs 1983, the relative hardness of the particles and target material are not the only parameter in determining erosion rate but their fracture toughness. The high value of toughness plays a significant role to erosion wear phenomena.
3. The choice of material is significantly by influenced environmental factors in addition to high thermal conductivity and ability to resist thermal shock (MXT5 copper TiB_2composite, 5%TiB_2 volume and 95% copper volume).
4. Furthermore, MXT5 copper TiB_2 composite was selected due to it high density and relatively high elastic limit in order to obtain a stiff and strong material.
5. Not forgetting cost, MXT5 copper TiB_2 composite is relatively cheap.

In summary, after properly analyzing the results obtained from the various chart in the CES package. MXT5 copper TiB_2composite was selected because it has excellent mechanical property which also has the potential to mitigate the effect of thermal cycling, erosion wear mechanism and fouling in shell and tube heat exchangers. Thermal cycling, fouling and erosion damage phenomena are the common source of failure that are associated with heat exchangers and tube section. Hence to mitigate these failure mechanisms, it is important to verify the basic contributory factors such as particle size, flow velocity, flow direction and turbulence etc.

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