Comparation of the impact of selected technical gases on properties of a pneumatic flexible coupling

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Abstract. An important part of the oscillating mechanical drives are flexible shaft couplings. The special use of the pneumatic flexible coupling is possibility to serve as mechanical drives tuners. Being examined in tuners mechanical drives there is also a research focus on the impact of industrial gases on the change of dynamic characteristics of pneumatic couplings. The paper investigates five different industrial gases, namely: air, helium (He-4.6), a mixture of propane and butane gas (C3H8+C4H10), argon (Ar) and nitrogen (N2) to see how these gases affect the dynamic characteristics of pneumatic flexible shaft coupling with marking 4-2/70 T-C.

Keywords: pneumatic flexible coupling, industrial gases, change of a pressure

1 Introduction

In technical operations, mechanical drives are used for a drive and coordination of technology. An inseparable part of the mechanical drives is considered to be a mechanical coupling. One of the important groups of the mechanical couplings is flexible coupling. Its significance lies in the fact that they are only ones capable of protecting the mechanical drive from a resonance [1-3]. Within the group of flexible couplings, there are so-called torsional vibration tuners. These are special flexible couplings in which the properties can be changed and the resonance can be regulated [4-7]. One of such special flexible coupling is a pneumatic flexible coupling [8-11].

The pneumatic flexible coupling contains a flexible space that can be filled with gas. By changing the pressure of a gaseous medium it can significantly influence the properties of a pneumatic flexible shaft coupling as well as mechanical properties of the whole mechanical system in which the given coupling is included [12-13].

The aim of the paper is to investigate the impact of five industrial gases on properties of a flexible pneumatic coupling. This paper presents the impact of air, helium, nitrogen, argon and mixture of propane and butane gas and follows a change of damping ability of the coupling. Damping is one of the essential dynamic characteristics of flexible couplings. Damping characteristic as a dynamic characteristic of a coupling is used mainly in the transition of the mechanical drive in resonance area. In resonance area, one of parameters

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that affect the efficiency of the pneumatic flexible coupling is a speed of fulfillment, respectively a speed of a change of a pressure of gaseous medium in the pneumatic flexible coupling´ s chamber [14].

2 Material and methods

The pneumatic flexible coupling which has been used for research was developed in our Department and it was marked as 4-2 / 70T-C (see Fig. 1).

Fig. 1. Pneumatic flexible coupling 4-2/70 T-C

For the purposes of our research, we used the pneumatic flexible shaft coupling marked as 4-2 / 70 T-C. To transfer a torque, it uses four flexible two-bellows pneumatic members that are evenly located around the circumference, serving as a flexible space. The distance of these flexible spaces from the centre of rotation of the coupling is 83.5 mm. A height of the flexible space in neutral position is 90 mm and diameter is 70 mm. Allowable maximum deformation of the flexible space is 25 mm and it allows the maximum twisting of the coupling of 11.5 °. These flexible spaces are anchored to steel flanges and they are joined together.

For research of damping of pneumatic flexible coupling, five industrial gases have been used. The gases are commercially available and generally used in various industries.

As first investigated gas was the air. The air is a mixture of gases (78.084 % nitrogen N2, 20.947% Oxygen O2, 0.934 % argon Ar, 0.033 % carbon dioxide CO2 and 0.002 % other gases). The air is contained in the atmosphere; it is non-flammable and easily available.

The second type of used gas is helium. On Earth, helium occurs only very rarely. The Earth's atmosphere is found in the upper layers only. Small amount can be found in the natural gas from which it is obtained by process of freezing. Rarely, helium rises from cracks in the Earth ground. Due to its extremely low density and its inert characteristic, helium is used for filling balloons and airships to replace flammable hydrogen gas. A significant disadvantage is its relatively high price. Moreover, helium atom has very small diameter and it easily diffuses through solid materials, and thus the losses occurs [15, 16]. For purposes of our measurements, we used helium marked as HE-4.6. The technical gas contains 99.996 % helium.

The third used gas is a mixture of propane and butane; in detail the percentage ratio of 50% propane and 50% butane. Normally, the propane- butane is considered to be a gas, but rather easily can be removed by cooling or pressing to liquid state. In the liquid state it occupies only 1/260 of its gaseous volume. We used the gas because of its higher density than air, despite its negative and that is its flammability.

Argon was the fourth used gas. Argon is used in welding such as pure gas or in a mixture with carbon dioxide or nitrogen. Argon gas is heavier than the air. The most important chemical characteristic of argon is its inertness, which makes it an ideal protective gas even at the temperatures necessary in metallurgy or welding arc light. Argon is obtained in an ammonia production from hydrogen and air nitrogen, where it is actually a waste. 1 m^3 of air contains 9.3 litres of argon. Argon can also be produced from the air. Oxygen binds with red hot copper, nitrogen is bonded to a metal magnesium or calcium as nitride and the remainder of the crude argon contains about 0.25% of other rare gas, which are separated from the argon by fractional distillation, absorption and desorption of the fractional carbon.

The last used gas was nitrogen. Nitrogen is non-flammable gas without colour and odor. It is slightly lighter than air. Nitrogen is so-called inert gas and its treated is very difficult with other chemical compounds. With the exception of oxygen, chlorine and fluorine, nitrogen is presented as more electronegative element, so the compound can be considered as nitrides of the elements [17].

Argon, helium and nitrogen are non-toxic, but non-supportive of life. Their different physical properties can be seen in Table 1.

Table 1. Basic physical properties of individual gases

	helium He	air O_2+N_2	propane-butane C_3H_8+C_4H_{10}	argon Ar	nitrogen N_2
Specific gas constant r [J kg-1 K-1]	2079	287.04	163.39	208.49	296.75
Gas density [kg.m-3] (15° C)	0.176	1.276	2.145	1.76	1.234
Molecular weight [kg kmol-1]	4.003	28.966	50.102	39.944	28.016

On Fig. 2 is shown a gas density of the individual gases. It can be seen that the greatest value is achieved by a mixture of propane and butane 2.145 $kg.m^{-3}$. Argon, nitrogen and the air achieved lower values and the lowest value of 0.176 $kg.m^{-3}$ is achieved by helium. A similar course is shown in Fig. 3 where molecular weights of the gases are visible. The maximum value 50.102 $J.kg^{-1}.K^{-1}$ also achieved a mixture of propane and butane and then sequentially followed by argon, air and nitrogen with the lowest value 4.003 J.kg is again helium.

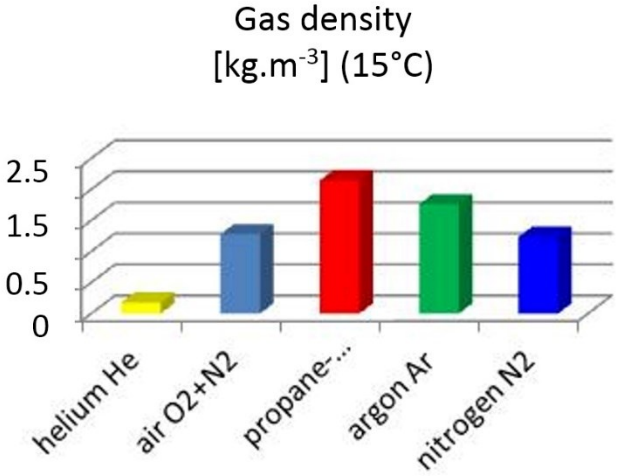

Fig. 2. The density of the gas

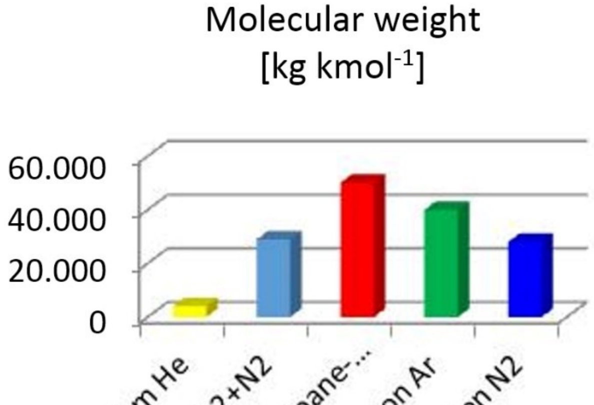

Fig. 3. The molecular weight of the gas

The change can be evident in value of a specific gas constant. Completely, the highest value is achieved by helium gas. It is a value of 2079 J.kg^{-1}.K^{-1}. Other gases have values of a specific gas constant much lower. Lowest value of 208.49 J.kg^{-1}.K^{-1} has argon. It is value almost 10 times lower than helium. The air and nitrogen have approximately 7 times lower value than helium (the air has 287.04 J.kg^{-1}.K^{-1} and nitrogen has 296.75 J.kg^{-1}.K^{-1}. A mixture of propane and butane has approximately 13 times lower value of specific gas constant and that is 163.39 J.kg^{-1}.K^{-1} shows in Fig. 4.

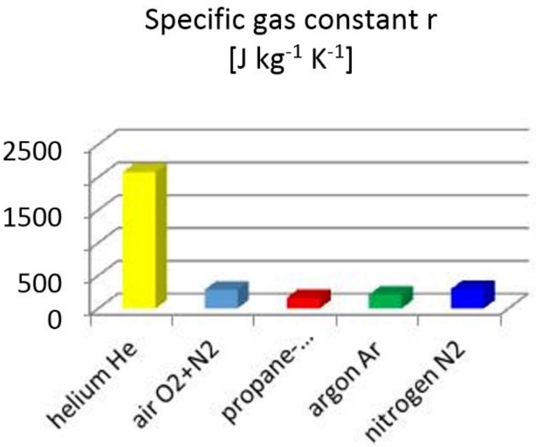

Fig. 4. The specific gas constant

3 Results and discussions

The first examined parameter was the needed time of fulfilment of the flexible coupling´s spaces. The reference time to which the other times were compared was the time of filling the spaces with the air (marked as t_{air}). Against this reference value will determine the ratio of time during fulfilment by any other gas. The interesting thing is the ratio of the time for the fulfilment of the flexible spaces to the flexible pressure limit, respectively; any pressure change in the flexible space is still the same.

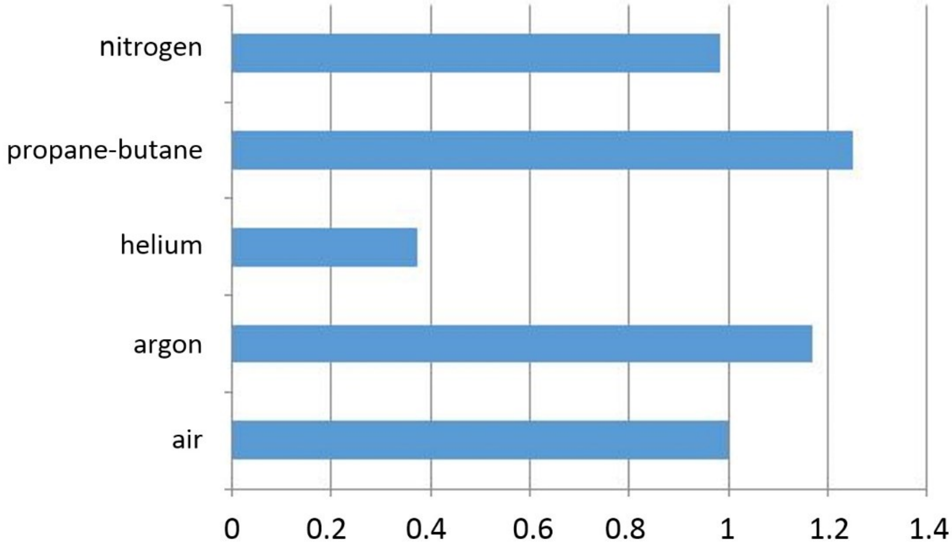

Fig. 5. Time comparison of pneumatic flexible coupling 4-2/70 T-C pressuring on required pressure using different gases

Figure 5 shows the relative values of fulfilment time of the flexible spaces for different gases. The smallest ratio and therefore the fastest fulfilment of flexible space are by helium gas. In order to pressurize the flexible space to a certain pressure, the time of fulfilment by helium is 0.372 times shorter than those ways in which we are pressurizing the flexible space by the air. This means, $t_{he} = 0.372.t_{air}$. If we use the nitrogen contained in the air, so time $t_{nitrogen} = 0.98.t_{air}$ will be almost the same as the time required to pressurize by the air. The use of argon gas that is extracted and denser than air, we have found that the time to fill the flexible space at a certain pressure is greater $t_{ar} = 1.17.t_{air}$. The longest pressurizing time took a mixture of propane and butane. This mixture is densest and it has the highest molecular weight and the lowest value of a specific gas constant and thus pressurizing the flexible space to the final pressure takes 1.25 times longer than achieve the desired pressure change by the air. It applies to $T_{Pro\text{-}Btut} = 1.25.t_{air}$.

Another parameter examine in research was a damping pneumatic coupling. The measurements were realized by means of which was determined the damping ***b***. Dynamic measurements were carried out for all five gases. The pneumatic flexible coupling was placed in the measuring device. By the method of free oscillations were determined values of damping ***b***. An example of such measurements for the investigated gas at a pressure of 500 kPa is shown in Figure 6.

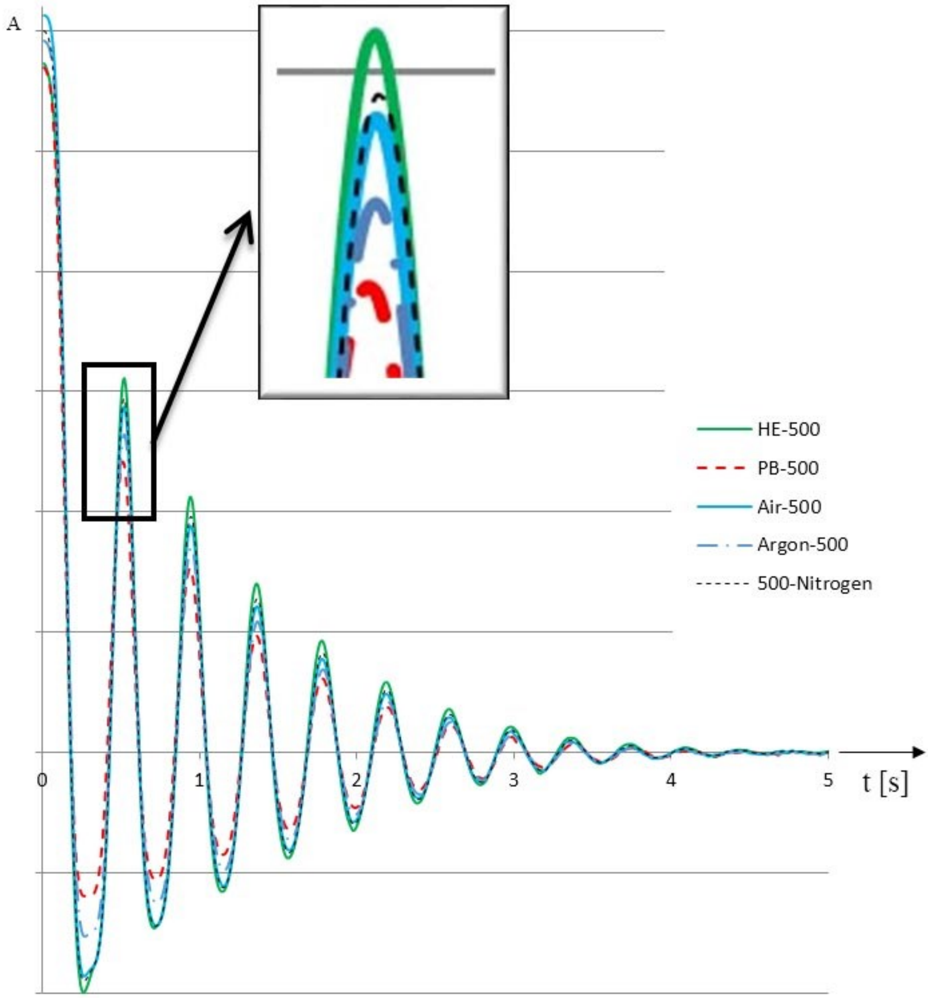

Fig. 6. Measurement at 500 kPa by using of five different gases using a method of free oscillation

The experiments were carried out on pneumatic shaft coupling which was gradually pressurized at the pressure range from 100 to 600 kPa. Subsequently, all examined gases were used in order: air, helium, propane-butane, argon and nitrogen. From the measured data were determined a damping value in the pressure range from 100 kPa to 600kPa for all investigated gases. The result damping values are shown in Figure 7.

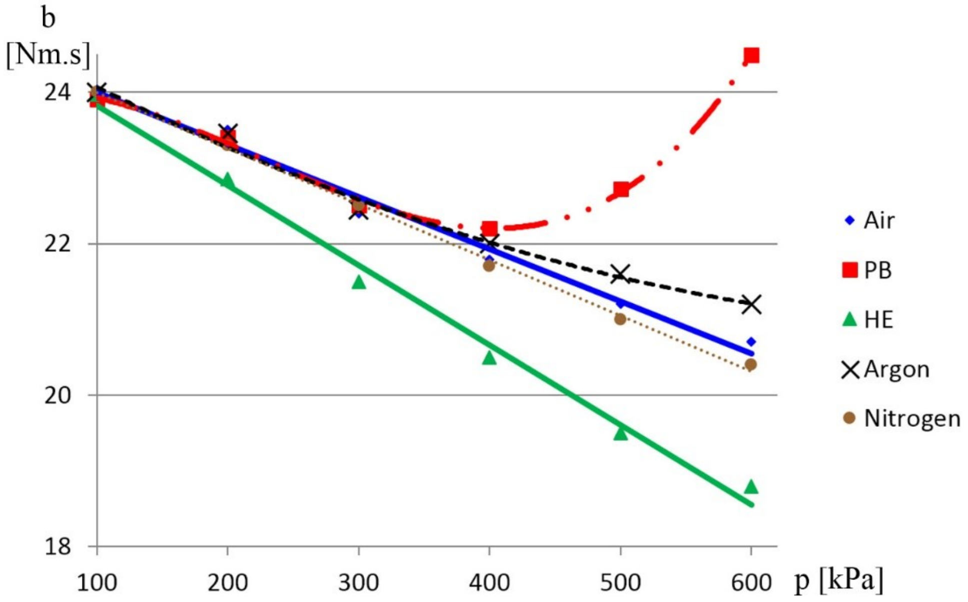

Fig. 7. Damping **b** values of pneumatic flexible coupling, in the range of pressure 100 to 600 kPa and using different gases

Fig. 7 presents the changes in damping of couplings using all investigated gases. At a pressure of 100 kPa, a type of gas is not so substantial as to all gases are approximately the same value 24Nm.s. The amount of gas in flexible coupling is low, so they do not show significant change in physical properties of gases. Gradually with increasing pressure in the coupling, properties of gases will begin to show a change of damping values of the pneumatic coupling. The flexible space filled with Helium, gradually lowers the damping while at maximum pressure 600kPa achieve the lowest value of all the gases of 18.8 Nm.s. In dependence on the pressure, the flexible space filled with the air decrease a damping value 20.7Nm.s at the minimum pressure at 600kPa. Argon and nitrogen have similar physical properties than the air and therefore the damping is similar. Gradually reduce its value depending on the pressure, whereby with a pressure of 600kPa shall nitrogen reach a value of damping 20.4Nm.s and argon 21.2Nm.s. The damping value using a mixture of propane and butane is gradually decreased up to 22.2Nm.s at pressure of 400kPa and then starts to increase to a maximum value 24.49Nm.s at a pressure of 600kPa.

Conclusions

Gaseous medium is very important part of the pneumatic flexible couplings. The type of gaseous medium and its different physical properties such as molecular weight, density gas, and specific gas constant as well as other properties can change and influence the damping of pneumatic flexible couplings. In the concrete, the paper describes pneumatic flexible shaft couplings marked as 4-2/70T-C which has been developed in our department and located in Laboratory at our department where it also performed all measurements.

The selection of gas used in pneumatic flexible coupling will have an impact on time to fulfil the pneumatic flexible couplings. The fastest pressure changes can perform the coupling filled with the gas with the lowest density and that is helium. The longest time needed to change the pressure of pneumatic flexible coupling is reached with a mixture of propane and butane that is in our case the gas with the highest density of all used gases.

Type of gas used in pneumatic flexible couplings affects its damping value. Low pressure did not reveal the change in damping values by using a variety of different gases. The differences in damping values began arise with increasing pressure. The pneumatic flexible coupling reached the lowest values during pressurization with helium. On the other hand, the highest value of damping, the pneumatic flexible coupling reached by fulfilment with a mixture of propane and butane. The pneumatic flexible couplings filled the air, argon, nitrogen achieve the damping value almost the same due to the fact that their physical properties are likely the same.

In conclusion we can state that the type of gas as well as its physical properties can greatly influence the damping of flexible pneumatic couplings and thus influence the properties of mechanical drives in which these pneumatic flexible couplings are included.

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References

1. J. Kuľka, M. Mantič, M. Kopas, E. Faltinová, D. Kachman, *Heuristic optimization approach to selecting a transport connection in city public transport*. Open Engineering **7** (1), 1-5, ISSN 2391-5439 (2017)
2. J. Kuľka, E. Faltinová, M. Kopas, M. Mantič, *Diagnostics and optimisation of crane track durability in metallurgical plant.* Diagnostyka **17**, 41-46 (2016)
3. L. Jakubovičová, P. Zavadinka, J. Jakubovič, *Transport Duty Cycle Measurement of Hybrid Drive Unit for Mixing Drum*. Adv. Intell. Syst. Comput. **393**, 219-224 (2016)
4. J. Homišin, M, Urbanský, *Partial Results of Extremal Control of Mobile Mechanical System*. Diagnostyka **16** (1), 35-39 (2015)
5. L. Jakubovičová, M. Sága, M. Vaško, *Numerical study of influence of mutual slewing of roller bearing rings on the principal stresses at contact area*. Scientific Journal of Silesian University of Technology - Series Transport **84**, 83-91 (2014)
6. M. Sága, M. Vaško, P. Pecháč, *Chosen Numerical Algorithms for Interval Finite Element Analysis*. Procedia Engineering **96**, 400-409 (2014)
7. J. Zapoměl, V. Dekýš, P. Ferfecki, A. Sapietová, M. Sága, M. Žmindák, *Identification of Material Damping of a Carbon Composite Bar and Study of Its Effect on Attenuation of Its Transient Lateral Vibrations*. International Journal of Applied Mechanics **7** (6), (2015)

8. P. Czech, *Identification of Leakages in the Inlet System of an Internal Combustion Engine with the Use of Wigner-Ville Transform and RBF Neural Networks*. 12th International Conference on Transport Systems Telematics Location: Katowice Ustron, Poland, Telematics in the Transport Environment, Communications in Computer and Information Science **329**, 414-422 (2012)
9. H. Madej, P. Czech, *Discrete Wavelet Transform and Probabilistic Neural Network in IC Engine Fault Diagnosis*. Eksploatacja i Niezawodnosc - Maintenance and Reliability **4**, 47-54 (2010)
10. P. Czech, *Diagnosis of Industrial Gearboxes Condition By Vibration and Time-Frequency, Scale-Frequency, Frequency-Frequency Analysis*. METALURGIJA **51** (4), 521-524 (2012)
11. Ł. Konieczny, R. Burdzik, J. Warczek, P. Czech, G. Wojnar, J. Młyńczak, *Determination of the effect of tire stiffness on wheel accelerations by the forced vibration test method*. J. Vibroengineering **17**, 4469-4477 (2005)
12. P. Czech, G. Wojnar, R. Burdzik, J. Konieczny, Ł. Warczek, *Application of the discrete wavelet transform and probabilistic neural networks in IC engine fault diagnostics*. J. Vibroengineering **16**, (2014)
13. R. Grega, (et al.): *The chances for reduction of vibrations in mechanical system with low-emission ships combustion engines*. International Journal of Maritime Engineering. **157** (A4), 235-240 (2015)
14. J. Homišin, P. Kaššay, M. Puškár, R. Grega, J. Krajňák, M. Urbanský, M. Moravič, *Continuous tuning of ship propulsion system by means of pneumatic tuner of torsional oscillation*. International Journal of Maritime Engineering: Transactions of The Royal Institution of Naval Architects **158** (A3), A231-A238
15. M. Dehdashti-Jahromi, H. Farrokhpour, *Effect of helium nanoclusters on the spectroscopic properties of embedded SF6: Ionization, excitation and vibration*. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy **173**, 772-782 (2017)
16. Shanping Lu, Wenchao Dong, Dianzhong Li, Yiyi Li, *Numerical study and comparisons of gas tungsten arc properties between argon and nitrogen*. Computational Materials Science **45** (2), 327-3352 (2009)
17. J. Sunarso, S.S. Hashim, Y.S. Lin, S.M. Liu, *Membranes for helium recovery: An overview on the context, materials and future directions*. Separation and Purification Technology **176**, 335-383 (2017)