International Journal of Design
Universitas Komputer Indonesia
Journal homepage: https://ojs.unikom.ac.id/index.php/injudes

Heat Exchanger Design for the Production of Water Based Mos2 Nano-lubricant

Hufaidatul Azfa Nurusyifa Ramdaniah, Asep Bayu Dani Nandiyanto**, Risti Ragadhita***, Teguh Kurniawan*****

*,**,***Departemen Kimia, Universitas Pendidikan Indonesia, Indonesia
****Departemen Teknik Kimia, Universitas Ageng Tirtayasa, Indonesia
*Corresponding Email: nandiyanto@upi.edu

ABSTRACTS

This study aims to develop and analysis the design of a heat exchanger (HE) for water-based Mos2 nano-lubricant production using a simple one-pass HE shell and tube type. Specifications of the designed HE are shell length 4.8768 m, shell diameter 0.889 m, tube outer diameter 0.0254 m, and thickness 0.0217 m. The calculation is then performed manually using the Microsoft Excel application. The results showed that the shell and tube HE designs with a one-pass type have laminar flow with an effective value of 95.38 percent and an NTU value of 31.79. This HE designs has a high effectiveness so that it is considered effective for use. This result is very important to maximize the efficiency of shell and tube heat exchange. This HE designs analysis can then be used as a learning tool for the design process, operating mechanism, and HE performance analysis.

ARTICLE INFO

Article History:
Received 12 November 2022
Revised 2 December 2022
Accepted 20 December 2022
Available online 25 December 2022

Keywords:
Effectiveness,
Heat exchanger,
Shell and tube,
Nano-lubricant.

1. INTRODUCTION

A heat exchanger or also known as a heat exchanger (HE) is a device that transfer heat from one fluid to another. Two fluids with different temperatures are separated on the hot side or on the cold side with a separation medium to achieve an optimal thermal temperature (Ma et al., 2015). Because it is used in a variety of industrial applications, HE plays an important role in the efficient use of energy. (Hajatzadeh Pordanjani et al., 2019). The HE consists of a series of thin plates joined by a frame in a position parallel to the plates (Alok Shukla. 2016). One of the most widely used HE is the shell and tube heat exchanger (Selbaş et al., 2006). The properties that determine the capacity of a liquid to transfer heat are: thermal conductivity, kinematic viscosity v, specific heat cp, density and thermal expansion. These properties determine the ability of the liquid to cool the device, namely the coefficient (Bergman, T. L. et al, 2011; Rudramoorthy, R., & Mayilsamy, K., 2010). The advantages of using HE include high thermal efficiency and economic savings (Ma et al., 2015).

Nanoparticle-in-water water-based nano-lubricant was developed as a new type of environmentally friendly lubricant (Rahmati et al., 2014; Spear et al., 2015). Water-based nano-lubricant has many advantages in that it is readily biodegradable (Xie et al., 2019), has low emission values, is environmentally friendly (Sayuti et al., 2014), has good refrigeration (Rahman). et al., 2019), fire resistance and other advantages over conventional emulsions because the base fluid is water. MoS2 nanoparticles are solid lubricants that are widely applied as lubricant additives in various solvents (Aralihalli & Biswas, 2013; Hu et al., 2016). MoS2 is stable below 400 °C and under nanometric conditions it is stable below 300 °C (Wang & Zhang, 2016). Nano-lubricants offer solutions to environmental problems associated with traditional lubricant additives containing sulfur, chlorine, and phosphorous. Nanolubricants show a number of advantages, such as having better stability when suspended in a lubricant compared to micro or macro sized particles (Wang et al., 2009), particles are not retained by the filter (Chou et al., 2010), can form films on various types of surfaces (Spikes, 2015), have relatively good temperature stability, and show limited tribochemical reactions (Chou et al., 2010).

This study describes a systematic summary of research results presented in previously published data, including details of nano-lubricant preparation and production methods and heat exchanger design in mathematical models. Deionized water and MoS2 nanoparticles were used as main ingredients in the production of the MoS2 nano-lubricant.

2. METHOD

2.1. Manufacturing of MoS2 Nano-lubricant

MoS2 nanoparticles (99.8%, 100nm), triethanolamine (TEA, 98%), oleic acid (OA, 98%), glycerin (98%), sodium dodecylbenzenesulfonate (SDBS), sodium polyacrylate (PAAS) are materials used in the production of MoS2 nano-lubricant. TEA and OA were used to obtain triethanolamine oleate (Deka et al., 2018), which is a good surfactant having both hydrophilic and lipophilic fractions (Hafiz & Abdou, 2003). The addition of glycerin can increase the viscosity of the liquid and increase the stability of the dispersion. SDBS is an excellent anionic surfactant and corrosion inhibitor (Kellou-Kerkouche et al., 2008). PAAS is applied as a thickening agent in nanolubricants (Kong et al., 2017). The temperature of the nano grease should be controlled at 50-70°C. Higher temperatures will cause the organic additives to break down, while lower temperatures will accelerate the growth of bacteria and damage the nanolubricant. The nanolubricant was prepared using the flow chart shown in Figure 1.

Fresh MoS2 nano fat was prepared by a two-step method by dispersing the nanoparticles in deionized water. As the Fig. 1 shows. TEA and OA were mixed in deionized water, heated to 80 °C and stirred for 10 minutes with a temperature-controlled magnetic stirrer to obtain triethanolamine oleate. Glycerin is added to the triethanolamine oleate solution cooled to 25°C and stirred for 10 minutes. SDBS and PAAS were added to the solution and the magnetic stirrer was operated sequentially for 15 minutes to obtain an alkaline solution. Finally, the nanoparticles were added to the alkaline solution and stirred for 15 minutes (Yanan et al., 2020). Figure 2 describes the HE design for MoS2 nanolubricant production. The physical and thermal properties of the fluids used are listed in Table 1.

2.2. Mathematical models for designing a heat exchanger

The assumptions used for the characteristics of the fluids operating in the HE is shown in Table 2. Several assumptions are used for the HE shell-and-tube design. The heating fluid used in this study is mineral oil, while a mixture of ethylene glycol and water is used as the cooling fluid. The hot fluid inlet at 80°C and outlet at 62°C. The cold fluid inlet at 20°C and outlet at 25°C. The mineral oil flow rate is 19.63 (kg/s) and the ethylene glycol flow rate is 5.55 (kg/s). In the data collection process regarding the standard Tubular Exchanger Manufacturers Association (TEMA) specification is used as the standard method and thermal analysis in the form of manual calculations using basic Microsoft Office applications based on Equations 1 – 15. the calculated heat exchange parameters are shown in Table 2.

To measure the energy transferred (Q) some variables need to be determined, as mentioned below.

$$Q_{in} = Q_{out} \tag{1}$$

$$m_c \times Cp_c \times \Delta T_c = m_h \times Cp_h \times \Delta T_h$$

Where, Q is the energy transferred (Wt), m is the mass flow rate of the fluid (Kg/s), Cp is the specific heat, and ΔT is the fluid temperature difference (°C).

To calculate the LMTD the result has to be determined using the eq. 2.

$$LMTD = \frac{(T_{hi}-T_{Ci})(T_{ho}-T_{Co})}{ln\frac{(T_{hi}-T_{Ci})}{(T_{ho}-T_{Co})}} \tag{2}$$

Where, T_{hi} is temperature of the hot fluid inlet (°C), $T_{ho}$is temperature of the hot fluid outlet (°C), T_{Ci} is temperature of the cold fluid inlet (°C), and $T_{Co}$is temperature of the cold fluid outlet (°C).

To measure the heat transfer field area (A), it has to be determined using the eq. 3.

$$A = \frac{Q}{U_d \times \Delta T_{LMTD}} \quad (3)$$

Where Q is the energy transferred (W) U_d is the overall heat transfer coefficient, and ΔT_{LMTD} is the logarithmic mean temperature difference (F).

To determine the Number of tube (Nt) use the eq. 4.

$$Nt = \frac{A}{L \times \mathrm{a}''} \quad (4)$$

Where, A is the heat transfer area (ft^2), L is the Length of tube, and a″ is the outer surface area (ft/ft^2).

To calculate the surface are of heat transfer in tube (a_t), it can be determined by the eq. 5.

$$a_{s,t} = N_{s,t} \frac{a'_{s,t}}{n} \quad (5)$$

Where, a'_t is the flow area in the tube (m^2) and n = the number of passes. The result of a'_t will use to calculate mass flow rate of water in tube (G_t)

$$G_{s,t} = \frac{m_{h,c}}{a_{s,t}} \quad (6)$$

These two values were needed to calculate the Reynolds number. The Reynolds number can be determined by using Eq. 7, where μ is the dynamic viscosity of the fluid in the tube.

$$Re_{s,t} = \frac{di_{s,t} \times G_{s,t}}{\mu} \quad (7)$$

Prandtl Number (Pr) in the tube can be determined by using Eq. 8, where K is the thermal conductivity of the tube material.

$$Pr = \left(\frac{C_p \times \mu}{K}\right)^{\frac{1}{2}} \quad (8)$$

The value of Reynolds number and Prandtl number was used to determine the Nusselt number (Nu).

$$Nu = 0.023 \times {Re_{s,t}}^{0.6} \times Pr^{0.33} \quad (9)$$

Actual Overall Heat Transfer Coefficient (U_{act}) can be determined by using eq. 10.

$$U_{act} = \frac{1}{\frac{1}{h_i} + \frac{\Delta r}{k} + \frac{1}{h_o}} \quad (11)$$

Where, h_i is inside heat transfer coefficient, h_o is outside heat transfer coefficient, and Δr is wall thickness. To measure the hot and cold fluid rate, it has to be determined using the eq. 12 as mentioned below.

$$C_h = m_h Cp_h \quad (12)$$

Where, C_h is hot fluid rate (W/K), $Cp_h$is specific heat capacity (J/Kg K), and m_h is mass flow rate of hot fluid (Kg/s). this calculation also applied to calculate the cold fluid rate.

$$C_c = m_c Cp_c \quad (13)$$

When, C_c is cold fluid rate (W/K), $Cp_c$is specific heat capacity (J/Kg K), and m_c is mass flow rate of cold fluid (Kg/s). this result used as C_{min}.

Number of heat transfer units, NTU can be determined by using Eq. 14.

$$NTU = \frac{U \times A}{C_{min}} \quad (14)$$

Heat exchanger effectiveness, ε can be determined by using Eq. 15.

$$\varepsilon = \frac{Q_{act}}{Q_{max}} \times 100\% \quad (15)$$

$$Q_{max} = C_{min}(T_{hi} - T_{ci}) \quad (16)$$

Q_{act} is actual energy transferred, T_{hi} is temperature of the hot fluid inlet and T_{ci} is temperature of the cold fluid inlet.

Required data such as operating conditions and heat exchanger specifications are taken from the results of literature review and calculations. operating conditions And The heat exchanger specifications are shown in Table 2.

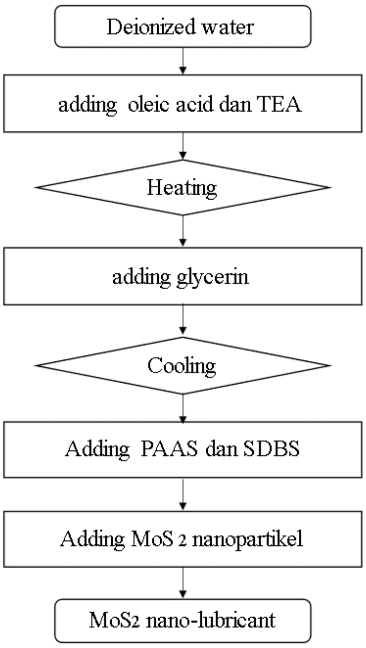

Fig. 1. Schematic method of manufacturing MoS_2 nano-lubricant

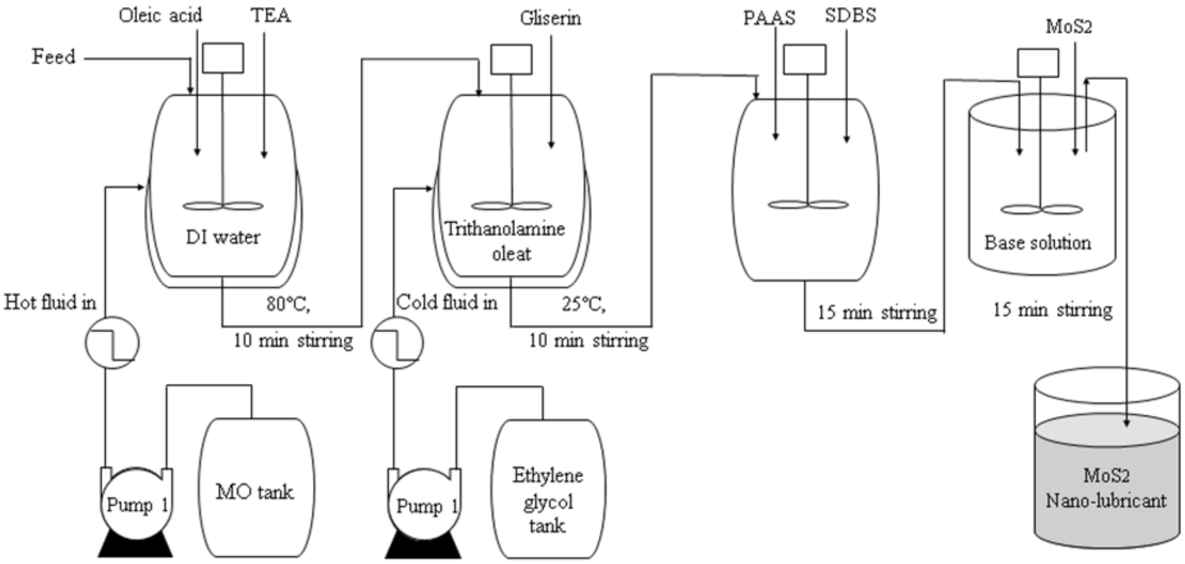

Fig. 2. Process flow diagram of manufacturing MoS_2 nano-lubricant

3. RESULTS AND DISCUSSION

3.1. Engineering Perspective

The production of MoS2 nano-lubricant has several advantages because the lubricant can be recycled. Water-based MoS2 nano lubricants are proven to have excellent reusability characteristics. The use of recycled MoS2 nano-lubricant greatly reduces lubricant consumption and waste water disposal. In addition, it is very important in saving resources, protecting the environment and reducing costs. In this study, several assumptions and conditioning were used based on the illustration of the MoS2 nano-lubricant production process shown in Fig. 2. Based on these assumptions and operating condition in table 2, it was shown that the HE designs resulted in an effectiveness of 95.38%.

The concept of HE design is used to calculate the difference between temperature of hot fluid inlet and cold fluid inlet with a visible effect on the outlet temperature. The value of Q in the shell and tube HE types design was 772754.58 W with the Reynolds number in the tube is 0.44 and in the shell 20.7 which is lower than 2300, so the type of flow that occurs in the shell is the laminar flow. Type of the shell and tube HE is single tube pass, type E, square tube layout and baffle type single segmental. The NTU number of this operating condition is 31.79.

The effectiveness this heat exchanger design is high when the temperature condition of hot fluid inlet is 80°C and outlet 62°C. This HE effectiveness determined by the actual heat transfer rate divided with the maximum possible heat transfer rate. The total performance of HE is determined by the density, viscosity, thermal conductivity and specific heat of the working fluid. The magnitude of the effectiveness value of this HE designs indicates that this design is suitable for the production of MoS2 nano-lubricant.

Table 1. Physical and thermal properties of the fluid.

	Hot Fluid **Mineral oil at 80°C** (Nadolny & Dombek, 2017)	**Cold fluid** **Ethylene glycol at 25°C** (Yaws, C. L., 1999)
Thermal conductivity λ ($W \cdot m^{-1} \cdot K^{-1}$)	0.126	0.256
Viscosity v ($mm^2 \cdot s^{-1}$)	3.43	17.645
Heat specific c_p ($J \cdot kg^{-1} \cdot K^{-1}$)	2187	2433
Density ρ ($g \cdot l^{-1}$)	832	1110
Thermal expansion β (K^{-1})	0.00080	0.00057

Table 2. Specification of shell and tube heat exchanger and operating condition for mineral oils and ethylene glycol fluid based on calculation result

Description	**Type/value**
Type of heat exchanger	Single tube pass, type E shell and tube heat exchanger
Mineral oil inlet temperature (°C)	85
Mineral oil outlet temperature (°C)	62
Ethylene glycol inlet temperature (°C)	20
Ethylene glycol outlet temperature (°C)	25
Tube outside diameter, do (mm)	25.4
Tube inner diameter, di (mm)	21.74
Pitch, (mm)	31.75
Total tube number, N	497
Total Heat Transfer Surface Area in Tube (m^2)	0.0922
Mass Flow Rate of Fluid in Tube ($kg/m^2.s$)	212.84
Reynold Number in Tube	0.44
Prandtl Number in Tube	59535
Nusselt Number in Tube	0.50
Tube layout	Rotated square
Shell inner diameter, Ds (mm)	990.60
Shell thickness, ds (mm)	3.20
Total Heat Transfer Surface Area in shell (m^2)	0.3925
Mass Flow Rate of Fluid in shell ($kg/m^2.s$)	14.14
Reynold Number in Shell	20.70
Prandtl Number in Shell	167696.42
Nusselt Number in Shell	37.49
Baffle type	Single-segmental
Baffle spacing, B (mm)	247.65
Initial Heat Transfer Rate (W)	772754.58
Logarithmic Mean Temperature Difference (°C)	10.15
Area of Heat Transfer (m^2)	596.31
Mineral oil mass flow rate (kg/s)	19.63
Ethylene glycol mass flow rate (kg/s)	5.55
Mineral oil heat rate (W/K)	42,930.81
Ethylene glycol heat rate (W/K)	13,503.15
HE Effectiveness (%)	95.38
Number of Transfer Unit	31.78

4. CONCLUSION

In summary, HE designs with shell and tube and single pass types have various specifications. The results of the single pass type HE shells and tube design have a specification of shell length of 4.8768 m, pipe inside diameter of 0.0254 m, shell diameter of 0.0217 m and thickness of 0.000889 m. This type of HE design is laminar flow. The effectiveness of HE is 95.38% and NTU is 31.79. This HE designs has a high effectiveness so it is considered effective for use. This result is very important to maximize the efficiency of the shell and tube heat exchanger. Therefore, the results of the analysis lead to information that will help optimize the single-pass shell-and-tube HE models.

ACKNOWLEDGMENTS

We acknowledged Bangdos Universitas Pendidikan Indonesia.

REFERENCES

Alok Shukla. (2016). Economic Heat Exchanger Is?. Global Journals of Research in Engineering, 16(1), 17–23.

Aralihalli, S., & Biswas, S. K. (2013). Grafting of Dispersants on MoS2 Nanoparticles in Base Oil Lubrication of Steel. Tribology Letters, 49(1), 61–76. https://doi.org/10.1007/s11249-012-0042-5

Bergman, T. L., Bergman, T. L., Incropera, F. P., Dewitt, D. P., & Lavine, A. S. (2011). Fundamentals of heat and mass transfer. John Wiley & Sons.

Chou, R., Battez, A. H., Cabello, J. J., Viesca, J. L., Osorio, A., & Sagastume, A. (2010). Tribological behavior of polyalphaolefin with the addition of nickel nanoparticles. Tribology International, 43(12), 2327–2332. https://doi.org/10.1016/j.triboint.2010.08.006

Deka, B., Sharma, R., Mandal, A., & Mahto, V. (2018). Synthesis and evaluation of oleic acid based polymeric additive as pour point depressant to improve flow properties of Indian waxy crude oil. Journal of Petroleum Science and Engineering, 170, 105–111. https://doi.org/10.1016/j.petrol.2018.06.053

Flynn, A. M., Akashige, T., & Theodore, L. (2019). Kern's Process Heat Transfer. John Wiley & Sons.

Hafiz, A. A., & Abdou, M. I. (2003). Synthesis and evaluation of polytriethanolamine monooleates for oil-based muds. Journal of Surfactants and Detergents, 6(3), 243–251. https://doi.org/10.1007/s11743-003-0268-z

Hajatzadeh Pordanjani, A., Aghakhani, S., Afrand, M., Mahmoudi, B., Mahian, O., & Wongwises, S. (2019). An updated review on application of nanofluids in heat exchangers for saving energy. Energy Conversion and Management, 198, 111886. https://doi.org/10.1016/j.enconman.2019.111886

Hu, K. H., Xu, Y., Hu, E. Z., Guo, J. H., & Hu, X. G. (2016). Rolling friction performance and functional conversion from lubrication to photocatalysis of hollow spherical nano-MoS2/nano-TiO2. Tribology International, 104, 131–139. https://doi.org/10.1016/j.triboint.2016.08.029

Kellou-Kerkouche, F., Benchettara, A., & Amara, S. (2008). Effect of sodium dodecyl benzene sulfonate on the corrosion inhibition of Fe-1Ti-20C alloy in 0.5M H2SO4. Materials Chemistry and Physics, 110(1), 26–33. https://doi.org/10.1016/j.matchemphys.2008.01.005

Kong, L., Sun, J., Bao, Y., & Meng, Y. (2017). Effect of TiO 2 nanoparticles on wettability and tribological performance of aqueous suspension. Wear, 376–377, 786–791. https://doi.org/10.1016/j.wear.2017.01.064

Ma, Z., Mehos, M., Glatzmaier, G., & Sakadjian, B. B. (2015). Development of a Concentrating Solar Power System Using Fluidized-bed Technology for Thermal Energy Conversion and Solid Particles for Thermal Energy Storage. Energy Procedia, 69, 1349–1359. https://doi.org/10.1016/j.egypro.2015.03.136

Nadolny, Z., & Dombek, G. (2017). Thermal properties of mixtures of mineral oil and natural ester in terms of their application in the transformer. E3S Web of Conferences, 19, 01040. https://doi.org/10.1051/e3sconf/20171901040

Rahman, S. S., Ashraf, M. Z. I., Amin, A. N., Bashar, M. S., Ashik, M. F. K., & Kamruzzaman, M. (2019). Tuning nanofluids for improved lubrication performance in turning biomedical grade titanium alloy. Journal of Cleaner Production, 206, 180–196. https://doi.org/10.1016/j.jclepro.2018.09.150

Rahmati, B., Sarhan, A. A. D., & Sayuti, M. (2014). Morphology of surface generated by end milling AL6061-T6 using molybdenum disulfide (MoS2) nanolubrication in end milling machining. Journal of Cleaner Production, 66, 685–691. https://doi.org/10.1016/j.jclepro.2013.10.048

Rudramoorthy, R., & Mayilsamy, K. (2010). Heat and mass transfer. Pearson Education India.

Sayuti, M., Sarhan, A. A. D., & Salem, F. (2014). Novel uses of SiO2 nano-lubrication system in hard turning process of hardened steel AISI4140 for less tool wear, surface roughness and oil consumption. Journal of Cleaner Production, 67, 265–276. https://doi.org/10.1016/j.jclepro.2013.12.052

Selbaş, R., Kızılkan, Ö., & Reppich, M. (2006). A new design approach for shell-and-tube heat exchangers using genetic algorithms from economic point of view. Chemical Engineering and Processing: Process Intensification, 45(4), 268–275. https://doi.org/10.1016/j.cep.2005.07.004

Spear, J. C., Ewers, B. W., & Batteas, J. D. (2015). 2D-nanomaterials for controlling friction and wear at interfaces. Nano Today, 10(3), 301–314. https://doi.org/10.1016/j.nantod.2015.04.003

Spikes, H. (2015). Friction Modifier Additives. Tribology Letters, 60(1), 5. https://doi.org/10.1007/s11249-015-0589-z

Wang, X., Li, X., & Yang, S. (2009). Influence of pH and SDBS on the Stability and Thermal Conductivity of Nanofluids. Energy & Fuels, 23(5), 2684–2689. https://doi.org/10.1021/ef800865a

Wang, X., & Zhang, Y. (2016). Tuning the structure of MoO 3 nanoplates via MoS 2 oxidation. Philosophical Magazine Letters, 96(9), 347–354. https://doi.org/10.1080/09500839.2016.1223366

Xie, H., Dang, S., Jiang, B., Xiang, L., Zhou, S., Sheng, H., Yang, T., & Pan, F. (2019). Tribological performances of SiO2/graphene combinations as water-based lubricant additives for magnesium alloy rolling. Applied Surface Science, 475, 847–856. https://doi.org/10.1016/j.apsusc.2019.01.062

Yanan, M., Jianlin, S., Jiaqi, H., Xudong, Y., & Yu, P. (2020). Recycling prospect and sustainable lubrication mechanism of water-based MoS2 nano-lubricant for steel cold rolling process. Journal of Cleaner Production, 277, 123991. https://doi.org/10.1016/j.jclepro.2020.123991

Yaws, C. L. (1999). Chemical properties handbook. McGraw-Hill Education.