Techno Economic Analysis of Online and Closed Loop Transformer Oil Purification System for Offshore Oil and Gas Platform

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Abstract.
The focus of this research is to conduct techno-economic analysis for investment on purification system of transformer oil in offshore oil and gas industry. The challenges of the purification system are the design shall be appropriate for limited space area, no production disruption (works online), and conducted without discharging from the pipe / transformer system in accordance with regulations. The methodology of this research is conducting literature study and review to previous researches and using existing contract data and manufacturer’s offering which applied in oil & gas industry of Indonesia. The result is the most appropriate purification system is the combination of filtration – degassing & dehydration – filtration methods, 70 cm x 70 cm x 125 cm in dimension. The investment is good in economic value which indicated by IRR value 25.24%, NPV IDR 2,425,529,703, and payback period 4.35 years.

Keywords: techno-economy, oil transformer, purification system, closed loop, online, offshore oil and gas

1. Introduction
Transformer is an electrical equipment to step up and step down the Alternating Current (AC) voltage. Every industry requiring electrical power utilize transformer as main electrical equipment which shall be maintained properly to assure the production and operations sustainable. One of the main part which shall be maintained is transformer oil which has function as isolation and cooling agent.

After certain period of operating time, the transformer oil has decreased in quality specification due to the presence of contaminants such as: water content, acid, dissolved gas, and sludge. To prevent the transformer failure due to bad oil condition, the oil shall be replaced with new oil. The oil replacement resulted into the used oil which categorized as hazardous and toxic substances – B3 [1].

The quantity of hazardous and toxic substance due to used oil (called used oil) is different depending on the production capacity of the industry. For the case study taken at offshore upstream oil and gas industry on Java Sea, the quantity of used oil was 19.47 ton on 2018 and 19.34 on 2019. The quantity of used oil is one of parameter of environmental performance of oil and gas industry assessed by Ministry of Environment and Forestry of Republic of Indonesia (KLHK). Therefore, the used oil shall be processed or purified so that the quantity can be reduced significantly. Furthermore, the transformer used oil purification will increase the profit due to the budget saving in purchasing new oil and payment to third party for used oil disposal process.

The transformer oil purification in offshore oil and gas industry face some challenges. The first challenge is the limited space area on offshore platform. The purification system shall be compacted and
appropriate for limited space area. The second is no redundancy in transformer operations so that the purification process shall be conducted in energized condition to assure no production and operations disruption (called *online*). The third is the capacity of transformers are small which are 200 up to 3000 kVA. The smaller transformer capacity means the smaller oil volume. Failure in operational or design of oil purification will cause in decreasing oil volume drastically in the energized transformer and caused shutdown.

The fourth challenge is regulation of KLHK which state that any processing which introducing hazardous and toxic substances into work area need special permission into KLHK. It means that any hazardous and toxic substance processing plant out of system is prohibited in oil and gas industry [2]. Therefore, the purification system shall be conducted without discharging out of the transformer oil system or pipe (called *closed loop*).

The objective of this research is to conduct the design of online and closed loop transformer oil purification system which appropriate for offshore oil and gas industry which has characteristic small transformer capacity between 200 up to 3000 kVA. The second objective is to analyse the economic value of the oil transformer purification investment in term of IRR, NPV, and payback period.

2. Transformer Oil

Transformer oil has two (2) function in transformer which are as a coolant to prevent overheat and as a dielectric isolation between the windings to prevent short circuit. In its early era, transformer oil was defined as mineral oil which is very refined and stable at high temperatures and has excellent insulating properties [3]. However, in recent studies several types of vegetable oil or organic ester oil have been used as an alternative to mineral oil. This is because vegetable oil has several advantages over mineral oil such as less risk of fire, coming from renewable materials, etc. [4].

Currently, transformer oil which commercially used is produced from wax free naphthenic mineral oil [5]. The use of this type is due to its advantages in terms of good pour point at low temperature, good thermal cooling capacity, low cost, high efficiency, and easy market availability [4]. However, in addition to several advantages, mineral oil has several disadvantages, including: it is not biodegradable so that it has the potential to pollute the environment, the risk of burning is high, and the potential for scarcity in the future along with the scarcity of crude oil as its raw material [6].

2.1. Transformer Oil Contaminant

Transformer oil degrades during its operating life due to a combination of heat, electrical, chemical, mechanical, environmental factors etc. These factors reduce the dielectric capability of the transformer oil so that the probability of failure of the transformer increases. The main causes of oil contamination are electrical disturbances and thermal decomposition. The contaminant can come from external and internal. The external contaminant is moisture/water content and the internal contaminant are dissolved gas, acidity, and sludge which presence due to the degradation of oil and isolation paper [7].

2.1.1. Water Content / Moisture

The presence of even a very small percentage of the oil can affect the dielectric properties of the oil and transformer insulating paper. When the transformer is filled with oil, the oil moisture will be absorbed by the insulation paper (due to the hygroscopic nature of the insulation paper) so that the insulation paper will be more easily degraded and its useful life will be reduced. Water in transformer oil can come from the atmosphere. The source of the atmosphere can be through inhalation of silica gel and leaks in equipment such as insulation cracks, poor gasket conditions, exposed man hole covers, etc.

2.1.2. Dissolved Gas

Due to the thermal and electrical tension, isolation paper and transformer oil are decomposed and cracked. The cracking produces some gases which can reduce the heat dissipation and oil transformer dielectric strength. The produced gasses due to cracked transformer oil are hydrogen (H2), methane (CH4), acetylene (C2H2), ethylene (C2H4), and ethane (C2H6). Whereas produced gasses due to cracked isolation paper are carbon monoxide (CO) and carbon dioxide (CO2).
2.1.3. Acidity
Like most industrial oils, transformer oil is oxidized under the influence of excessive temperature and oxygen. When there are small metal particles acting as a catalyst, transformer oil will experience an increase in the amount of acid due to the formation of carboxylic acids. The worst thing that will happen is a blockage in the oil flow so that the transformer is not cooled properly and worsens oil damage. In addition, the presence of acids in this oil will damage the insulation paper and shorten the service life of the transformer.

2.1.4. Sludge
The continuous operations of transformer oil for a long period cause the oil to be decomposed and produce sediment. In principle, deposits are formed as a result of oxygen exposure during heating and produce large, heavy, dark deposits that eventually clog the coolant ducts in the transformers. This deposit will attack the cellulose of the transformer winding and form a layer on the winding thereby reducing the effectiveness of heat reduction. If this happens, the transformer windings will have a higher temperature than it should be and will cause the transformer to fail more quickly.

The earlier presence of deposits in transformer oil is the appearance of peroxides, organic acids, alcohols, aldehydes, ketones, and other aromatic compounds, especially those with polarity functional groups. These compounds attack the transformer components such as paper, iron, and copper which then form an intermediate product in the oil which will polymerize together to form a solid material called sludge. Sludge tends to settle in locations with the warmest and coldest temperatures on the transformer.

2.2. Purification Methods
Purification or recondition of used oil is the process of returning used oil to "new oil" by removing chemical impurities, heavy metals, dissolved gases, and impurities. Used oil is recycled in the oil purification / reconditioning system. The used oil is tested first to determine suitability for purification and develops a system depending on the impurities. There are a number of different oil purification processes. Used oil treatment generally involves the following processes, or a combination thereof, depending on the facility.

2.2.1. Natural Sedimentation
The natural sedimentation process is carried out based on the separation and discharge of water from the bottom of the transformer container which is carried out naturally, with the condition that the transformers must be removed from the system (offline) for 24 hours. After that, the oil will be pumped out to a higher level, the water will be removed from the bottom, followed by cleaning and refilling the transformer oil. This method requires a long time with unsatisfactory results when compared to the required specifications [8].

2.2.2. Filtration
Filtration is a process used to separate solids from liquids or gases using a filter media. In used oil, filtration can be of several types with the most widely used type is the principle of oil circulation through a series of filters and absorbents with a medium such as filter paper. This process can also occur in other processes such as adsorption [9].

2.2.3. Adsorption
The adsorption process is the process of attracting a substance to another substance and the substance will be held firmly on the surface. The "attractant" substance in the adsorption process is called an adsorbent. Most of the contaminants in oil, including water, are polar in nature and are readily attracted by adsorbents. The adsorbent material that is often used is fuller's earth / attapulgite clay. Attapulgite clay has been shown to provide satisfactory results for purifying transformer oils due to its ability to neutralize acids, absorb polar compounds, and purify oil [10].
2.2.4. *Degassing & Dehydration*

Degassing is the process of removing dissolved gases while dehydration is the process of removing water content in transformer insulating oil. The used oil will be heated first and then treated under vacuum pressure. In this condition, the water vapor point is significantly lowered and the separation of water from the oil is carried out. Degassing can also be done through an atomization process by spraying oil into the particles to change the solubility of the gas. This method is a very efficient method that is widely applied for the purification of used oil. The main drawback of this method is the need to heat the oil in the refining process. Increasing the temperature of the insulating oil above 65 °C, then drying in a vacuum, causes the loss of the oil fraction which is essential for good insulating oil quality. At lower temperature or vacuum, drying efficiency decreases rapidly [8].

2.2.5. *Neutralization & Additive*

The process of adding additives serves to reduce the acidity of used oil by adding an alkaline substance. Substances such as Pd-MoSe2, Rh-MoSe2 have been proven to be used to reduce CO, H2 and C2H2 gas in transformer oil [11] [12]. In addition, the use of dimethyl aniline (DMA), trichloroethylene (TCE), and TiO2 nanoparticles additives has been tested and it is concluded that these three additives in certain concentrations can increase the dielectric strength of naphthenic transformer oil with the most optimal effect on TiO2 nanoparticles with an increase of up to 39.4% [13].

3. **Methodology**

The entire research methodology is shown in the flow chart schematic in Figure 1 which describes below:

3.1. *Collecting Contaminant Data*

Transformer oil contaminant data collection is by taking samples (sampling) in the field which are then tested for the types of contaminants in the laboratory. Sampling is taken by two (2) way which are using glass syringe for Dissolved Gas Analysis (DGA) test and using bottle for non-DGA. Samples of used transformer oil will be taken to the laboratory to perform a number of tests to obtain contaminant data. Each test refers to the standards applicable in the electricity and oil and gas industry. The types of testing and standard testing methods are listed in table 1.

![Figure 1. Methodology of Research](image-url)

| Table 1. Laboratory Test for Transformer Oil |
|---------------------------------------------|
| **Test Parameter** | **Method Standard** |
| Oil Quality Analysis | Water Content | IEC 60814 |
| | Acidity | IEC 62021-2 |
| | Breakdown Voltage | IEC 60156 |
| | Colour | ASTM D1500 |
| Dissolve Gas Analysis | Hydrogen (H2) | ASTM D3612-B |
| | Methane (CH4) | ASTM D3612-B |
3.2. Selection of Purification Method
The process of selecting a transformer oil purification method must meet two main criteria, namely the system must be able to run online and closed loop. The online means the purification method must be able to run without the need to turn off the transformer so that it does not shutdown the operations. Meanwhile, the closed loop is defined as the purification process which is carried out onsite and integrated into the transformer system without the need to remove transformer oil from the closed system. There are 5 purification method that will be tested as stated in section 2.2.

In this study, the process of selecting a transformer oil purification system used an integrative literature review method. The methodology in the integrative literature review consists of four (4) phases, namely design, conduct, analysis, and structuring and writing reviews [14].

3.3. Design Purification System
The design of this transformer oil purification system is a combination of various selected methods according to the contaminants that have been carried out by previous laboratory tests. The method of determining the purification system design uses literature review and market assessment methods of commercialized transformer oil purification products.

The next step is to calculate the required purification system operating conditions for offshore oil and gas field transformers. The operating conditions of the purification system in the form of oil flowrate to undergo this purification will determine the duration of purification for each transformer. In general, purification in offshore oil and gas fields must be carried out in no more than 8 hours. This is because this purification system is required to be carried out continuously without interruption and is not allowed to be done at night. The calculation of the operating conditions of transformer oil purification will be used to determine the dimensions of the most appropriate purification system for offshore oil and gas fields. The consideration of the dimensions of this purification system will be adjusted to the conditions of the offshore oil and gas field which are relatively dense and there is no large empty space.

3.4. Economic Analysis
The economic analysis in this research is by evaluating the IRR, NPV, and payback period using Ms. Excel. The input data used the actual contract value at upstream offshore oil and gas industry in the case study.

4. Result & Discussion
4.1. Sampling & Oil Transformer Contaminant
Sampling was carried out on 8 transformers in the offshore oil and gas in the Java Sea, Indonesia as shown in figure 2 and 3, and the results are presented in table 2. Based on the laboratory test results, the most dominant contaminant that exceeds the specification standard limit is dissolved gas. Meanwhile, water content contaminants have begun to show a tendency to be at the specification threshold. Over time of operation, water content will increase and exceed specification limits. Meanwhile, the acidity contaminants appear quite stable and do not affect the quality of the transformer oil.
Table 2. Contaminants of Oil Transformer for Offshore Oil & Gas Industry

|                         | Standard | Trafo 1 | Trafo 2 | Trafo 3 | Trafo 4 |
|-------------------------|----------|---------|---------|---------|---------|
| Capacity (kVA)          | -        | 2000    | 2000    | 1120    | 1000    |
| Oil Volume (L)          | -        | 4050    | 1974    | 1173    | 617     |
| Water Content (mg/kg)   | ≤ 40     | 19      | 12      | 18.3    | 26.2    |
| Acidity (mg OH/g)       | ≤ 0.3    | 0.01    | 0.01    | 0.01    | 0.02    |
| Breakdown Voltage (kV)  | ≥ 30     | 52.9    | 69      | 51.9    | 34.1    |
| Total Dissolved TDCG    | ≤ 720    | 49      | 4700    | 1027    | 777     |

4.2. Selection of Purification Methods

Based on literature study for five (5) purification methods in section 2.2, the result is presented below:

- **Natural Sedimentation**
  
The sedimentation process must be operated in a separate transformer from the electrical system (de-energized / offline) for a minimum of 24 hours. By gravity, water and sediment will fall to the bottom position of the transformer. After 24 hours, the transformer oil will be completely pumped out, the water and sediment below will be removed, then the oil will be added back. This processing is open (open loop) because it requires a separate oil storage from the transformer system [8].

- **Filtration**
  
  Filtration is based on the principle of fluid (oil) circulation through a series of filter and absorbent media such as filter paper. The oil circulation can be conducted part by part of the oil (not all together) so that the transformer can continue to operate with the minimum oil requirements in the transformer 50% (online). The filtration system can be connected to the transformer oil input and output system through the pipe so that oil never comes out of the system / pipe (closed loop) [15].

- **Adsorption**
  
  The principle of the adsorption method in transformer oil purification is to use an adsorbent solid medium (most commonly attapulgite clay). This adsorbent will be placed into a closed pressure vessel. The crude oil that has been preheated will be passed through a pressure vessel containing the adsorbent and will be processed within 1.5 hours to absorb water and acid contaminants in the crude oil. This system can be run completely without removing transformer
oil from the system (closed loop). This adsorption method can be carried out online with a minimum requirement of 50% oil in the transformer [10].

- **Degassing & Dehydration**
  The principle of degassing & dehydration is to heat the dirty oil first and then spray it into a vacuum chamber at a certain temperature. The degassing & dehydration process is carried out in a closed cycle without removing oil from the system (closed loop). This degassing & dehydration method can be conducted online with a minimum requirement of 50% oil in the transformer [16].

- **Neutralization & Additive**
  The neutralization process and the addition of new additives were tested on a laboratory scale, which means they are carried out outside the transformer system (open loop). There was not found a single literature and commercial products using the neutralization method and the addition of additives that can be combined in a closed loop in a transformer oil system. This neutralization & additive method can be done online with a minimum requirement of 50% oil in the transformer [17].

Based on a literature study of these five (5) methods, results are obtained as in table 4.2 which states that the methods that meet the online and closed loop requirements are filtration, adsorption, and degassing & dehydration. The natural sedimentation method must be carried out offline and open loop, while the neutralization method & additives in used transformer oil have just been tested in the laboratory so that they cannot meet the closed loop requirements.

### 4.3. Design Purification System

Literature study was conducted into previous researches for the combination of filtration, adsorption, and degassing & dehydration method. The options are shown below:

- **Option 1 [3]**
  The design of transformer oil purification system Option 1 is a combination of primary filtration, heating up to 65 °C, fine filter, degassing & dehydration using vacuum chamber, and finalized by final filtration.

- **Option 2 [16]**
  The design of transformer oil purification system Option 2 is a combination of pre-filter, heating up to 70 °C, fine filter, continuing in the adsorption chamber to conduct adsorption using fuller’s earth or alumina, and finalized by degassing & dehydration using vacuum chamber.

- **Option 3 [18]**
  The design of transformer oil purification system Option 3 is a combination of filtration, degassing & dehydration using vacuum chamber, then finishing treatment by adsorption and finalized by final filter.

| Table 3. Contaminants of Oil Transformer for Offshore Oil & Gas Industry |
|-----------------------------------------------|
| **Option 1** | **Option 2** | **Option 3** |
| **Water Content (mg/kg)** | 7 | 6 | 59.72 | 32.46 | 35.4 | 12 |
| **Acidity (mg OH/g)** | 0.014 | 0.014 | 0.299 | 0.01 | 0.38 | 0.02 |
| **Breakdown Voltage (kV)** | 90 | 91 | 25 | 34 | 33.4 | 70 |
| **Total Dissolved Combustible Gas-TDCG (ppm)** | 53 | 1 | 190.62 | 23.82 | 0.253* | 0.001* |

*for option 3, TDCG was not evaluated. To evaluate the chemical contaminant, the author used relative permittivity ($\varepsilon_r$)
These options were assessed for their suitability to the types of contaminants for the transformer oil in the upstream oil and gas industry as listed in table 2. The contaminants detected in Table 2 are dominant in water content and TDCG. Therefore, the transformer oil purification design system option 1 was chosen because it is the most appropriate to the minimum requirements of the contaminants to be removed. The detail schema for purification system option 1 is shown in figure 4.

Based on table 2, data shows that the largest volume of oil is in transformer 1 with a capacity of 2000 kVA and an oil volume of 4050 litres. Therefore, the design of the transformer oil purification system for the upstream oil and gas industry must be able to accommodate a minimum of online and closed loop transformer oil purification for transformers with the largest volume. If it is required that the purification work be completed in a day (8 hours), the system design must have a minimum flow rate of 4050 L/8 hours = 8.4375 litres per minute.

Based on the analysis of commercial products on the market, a product design was obtained using the purification system of option 1 (filtration - degassing & dehydration - filtration) with a flow rate of 10 litres/minute. The product has dimensions of 70 cm x 70 cm x 125 cm and weight 170 kg.

4.4. Economic Analysis

Economic analysis is carried out on the first option transformer purification system. The input data used are contained in table 4. The CAPEX used is the manufacturer’s offer in 2019 so that the value in the installation year, namely 2020, will be escalated with an inflation rate of 3.99%.

| Parameter            | Value                  | Reference                  |
|----------------------|------------------------|----------------------------|
| CAPEX                | IDR 1,795,907,300      | Market Assessment          |
| Depreciation         | 20 years               | Assumption                 |
| Inflation Rate       | 3.99%                  | Bank Indonesia 2015-2019   |
| OPEX                 | 2% of CAPEX            | (Seider, 2019) [19]        |
| B3 Disposal Tariff   | IDR 2,800,000/ton      | Case study’s contract value|
| New Oil Tariff       | IDR 30,568,156,425/ton | Case study’s contract value|
| Used Oil Quantity    | 19 ton / year          | Case study’s data          |
| Interest of Debt     | 10%                    | Assumption                 |

Based on free cash flow calculations, the value of Interest Rate of Return (IRR) is 25.24% and Net Present Value (NPV) is IDR 2,425,529,703. These IRR and NPV values indicate that this investment is profitable and worth executing. The payback period for this investment is 4.35 years.
5. Conclusion
Used Oil of transformer at offshore oil and gas industry which have capacity 200 to 3000 kVA can be reduced significantly by conducting onsite purification. The most appropriate purification system to conduct online and closed loop purification at limited space area at offshore is the combination of filtration – degassing & dehydration using vacuum chamber – final filtration as shown in figure 4. The dimension of purification system design is 70 cm x 70 cm x 125 cm and weight 170 kg. Based on economic analysis, the investment of transformer oil purification in offshore oil and gas is profitable. It is indicated value of IRR 25.24%, NPV IDR 2,425,529,703, and payback period 4.35 years.

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6. References
[1] J. G. Speight, The Chemistry and Technology of Petroleum, Boca Raton: Taylor and Francis Group, 2014.
[2] KLHK, "Peraturan Menteri Lingkungan Hidup No 18 Tahun 2009 Tentang Tata Cara Perizinan Limbah Berbahaya dan Beracun," KLHK, Jakarta, 2009.
[3] S. Salvi and A. P. Paranjape, "Study of Transformer Oil Filtration Machine," International Research Journal of Engineering and Technology (IRJET), pp. 2471-2474, 2017.
[4] J. Rouabe, L. M Barki, A. Hammami, I. Jallouli and A. Driss, "Studies of Different Types of Insulating Oils and Their Mixtures as an Alternative to Mineral Oil for Cooling Power Transformers," Heliyon 5, 2019.
[5] N. S. A. Japar, M. A. A. Aziz and M. N. Razali, "Formulation of Fumed Silica Grease from Waste Transformer Oil as Base Oil," Egyptian Journal of Petroleum 28, pp. 91-96, 2019.
[6] R. Liao, J. Hao, G. Chen, Z. Ma and L. Yang, "A Comparative Study of Physicochemical, Dielectric and Thermal Properties of Pressboard Insulation Impregnated with Natural Ester and Mineral Oil," IEEE Transactions on Dielectrics and Electrical Insulation, 2011.
[7] S. Salvi and P. A. Paranjabe, "Study of Transformer Oil Purification," SSRG International Journal of Electrical and Electronics Engineering (SSRG - IJEEE), pp. 16-19, 2017.
[8] I. Macuzic and B. Jeremic, "Modern Approach to Problems of Transformer Oil Purification," Tribology in Industry, pp. 39-44, 2002.
[9] G. Wahdaniyah, P. T. Prasetyo, A. Setiabudi and T. R. Biyanto, "Purification of Transformer Oil in PT. PJB UP Paiton," International Journal of Engineering Sciences & Research Technology, pp. 91-94, 2016.
[10] IEEE-Std.637, "IEEE Guide for the Reclamation of Insulating Oil and Criteria for Its Use," American National Standard Institute, New York, 2007.
[11] H. Cui, D. Chen, Y. Zhang and Z. Zhang, "Dissolved Gas Analysis in Transformer Oil Using Pd Catalyst Decorated MoSe2 Monolayer: A First-Principles Theory," Sustainable Materials and Technologies 17, 2019.
[12] Y. Zhang, X. Sun, S. Tan, T. Liu and H. Cui, "Adsorption Characteristic of Rh-doped MoSe2 Monolayer Toward H2 and C2H2 for DGA in Transformer Oil Based on DFT Method," Applied Surface Science 487, pp. 930-937, 2019.
[13] Y. Z. Lv, Y. Ge, Z. Sun, L. Wang, M. K. Niu, M. Huang, C. R. Li, B. Qi and J. S. Yuan, "Effects of Additives on Dielectric Strength og Naphthenic Transformer Oil," Journal of Molecular Liquid 271, pp. 1-7, 2018.
[14] R. Palmatier, M. Houston and J. Hulland, "Review Articles: Purpose, Process, and Structure," *Journal of the Academy of Marketing Science*, pp. 46, 1-5, 2018.

[15] G. Wahdaniyah, P. T. Prasetyo, A. Setiabudi and T. R. Biyanto, "Purification of Transformer Oil in PT PJB UP Paiton," *International Journal of Engineering Sciences & Research Technology*, pp. 91-94, 2016.

[16] L. M. Adesina, K. Saadu and G. A. Ajenikoko, "Transformer Oil Regeneration as a Panacea for Electric Power Utility Company’s Equipment Optimization," *International Journal of Recent Technology and Engineering (IJRTE)*, pp. 2160-2167, 2019.

[17] Y. Z. Lv, Y. Ge, Z. Sun, L. Wang, M. K. Niu, M. Huang, C. R. Li, B. Qi and J. S. Yuan, "Effects of Additives on Dielectrics Strength of Naphthenic Transformer Oil," *Journal of Molecular Liquids 271*, pp. 1-7, 2018.

[18] A. H.-Z. Z. I. F. . A. S. F. G. A. B. L. Safiddine, "Transformer oil reclamation by combining several strategies enhanced by the use of four adsorbents," *The Institute of Engineering and Technology*, pp. 1-7, 2017.

[19] W. D. Seider, J. D. Seader, D. R. Lewin and S. Widagdo, Product and Process Design Principles: Synthesis, Analysis, and Evaluation, Hoboken: John Wiley & Sons, Inc., 2009.