



THE PERFORMANCE EFFECTS OF SOLID WASTE FROM BAGASSE ON INCREASED OIL RECOVERY

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ABSTRACT

Aims: This study aims to determine the synthesis of bagasse to form surfactants and evaluation of the performance of the sample to increase oil yield. Indonesia generates very large amounts of solid waste, without recycling or adequate management efforts to preserve the environment. Bagasse emerged as one of the most abundant biomass due to the operations of large plantations and factories. Furthermore, previous studies showed extensive uses in the fields of compost, animal feed, bioethanol energy, paper, and reinforced building materials. **Methodology and Results:** Lignin was extracted from bagasse to process sodium lignosulfonate surfactant (SLS surfactant). The synthesis was characterized several times, and certain examples showed significant HLB values, as a function of emulsion builder. This condition in the oil reservoir is required to reduce interface stress (IFT) and friction in the movement of particles. Another analyses involves the assessment of core flooding of specific synthetic core and crude samples. **Conclusion, significance and impact of study:** The results confirm the ability of surfactant bagasse to increase oil recovery, namely the HLB value of 11.6. The results also show the surfactant classification with the ability to form a middle-phase emulsion in order to increase petroleum products. Therefore, bagasse as solid waste has a performance effect on the process of increasing petroleum production.

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1. INTRODUCTION

Solid waste refers to material residues from the extraction of the juice or during processing. These composites are of no significant socio-economic or environmental value, and therefore, are known causes of pollution. In addition, common sources include sugar, pulp, paper, rayon, plywood, nuclear waste, fruit, fish or meat preservation.

Generally, solid wastes are particularly high in organic content and are heterogeneous, with varying physical and chemical characteristics depending on the original sources. The composition comprises yard waste, food scraps, plastics, wood, metal, paper, rubber, leather, batteries, inert substances, textiles, paint containers, crushed building objects, and several complex materials. Therefore, proper fractionation and sorting are needed prior to processing (Husseterialsin, 2018). Furthermore, solid waste from agricultural activities is classified as organic materials, e.g. straw and majority generated during harvest seasons are burned or used as fertilizers (Poluakan, *et al.*, 2018; Siami, *et al.*, 2019).

Recycling has become more important in recent times, but organic residues deserve special attention. Only about 50% of waste in developing countries are decomposed for use as fossil fuel alternatives. However, the success of resource and energy recovery programs are based on precise information on particle quantity. This forms the basis for effective technology adoption in selected areas (Selvam, 2016).

Indonesia is considered an agricultural hub, with intense efforts to advance the sector. Sugarcane occurs as one of the potential commodities being developed (Yani, 2012). This grassy plant, including Monocotyledonae and Glumiflorae, is only cultivated in regions with tropical climates. The morphological characteristics include the shape of the cone stems, stacking arrangement, with a slightly flattened cross section, yellowish-green stems and leaves. In addition, the stems possess a thin wax layer, and forms portions of 3-4 rows each, width of 4-6 cm, and curved leaves below ½ length. Furthermore, sugarcane stalks are used to produce sugar, where the juice formed the primary product and ingredient. The squeezing process into a sweet liquid also produces bagasse as a solid waste. Figure 1 shows the piles of trash from the stems are commonly generated by sugarcane juice drink traders.

Similarly, solid waste produced in large volumes by sugar factories on a daily basis are stacked as garbage, and are practically employed as boiler fuels. However, due to limited storage, heaps of bagasse are placed outside, and possibly results in certain health hazards,

particularly to the eyes. Also, without proper handling, various kinds of respiratory diseases tend to occur (Yani, 2012). Subsequent un-utilized waste materials are usually piled around a mill or on a factory scale arranged in the form of block cubes. During sugarcane processing, 90% bagasse, 5% molasses, and 5% water are generated. The negative impact tends to be extensive without adequately managing the resulting waste. Therefore, substantial storage facility is required due to the bulky characteristics, although most factories dispose waste by open dumping (Syafrudin, 2007).



Figure 1 Bagasse waste from sugarcane juice drink traders (Marzuki, 2017)

The remains from these activities are abundant, but not optimally utilized. Moreover, without proper treatment, these materials transform into solid waste leading to pollution. Furthermore, bagasse is flammable due to the constituent of water, sugar, fiber, as well as microbes, and therefore ferments and releases heat on accumulation. As a result, cases of bagasse fire have been reported in several sugar factories, while others burn the excess garbage. Also, fire occurs due to the bagasse fermentation process, as shown in the Figure 2.



Figure 2 Fire of the Djombang Baru Sugar Factory, East Java (Rosul, 2019)

The deposited bagasse are actually potentials for further processing into valuable materials (Adiguna, 2020). These products include bio briquettes, synthetic matter e.g., furfural, particle-board, compost, and animal feed, as well as for other purposes. Therefore, intense efforts are necessary in handling bagasse, in order to generate enhanced value, ecologically and economically (Bursatriannyo, 2016).

Previous studies on solid waste utilization in various industries have been extensively reported, including the use of palm oil waste for manhanase enzyme production, tofu dregs for antibiotic media components, bagasse for cellulose, nanocellulose, and a mixture to yield silica gel, as well as organic fertilizer. Indonesia's high sugar production rates have contributed significantly to abundant bagasse yield. In addition, molasses is a minor waste also obtained, particularly in the separation of low-grade syrup. The sugar in the syrup no longer crystallizes due to the presence of sucrose fractions, including glucose and fructose. Furthermore, 100 g of molasses, comprises 29.40 g sucrose, 11.92 g glucose, 12.79 g fructose, fats, vitamins and minerals. In Indonesia, molasses is dominantly applied as alternatives to animal feed (Rochana, 2004) and raw material in producing mono sodium glutamate (MSG) (Isnaeni, 2019). There is also an innovative product called KrisBu, commonly known as bagasse chips (Sholahuddin, 2019). Moreover, processed feed, MSG and chips serve as food or raw materials to livestock and humans. Furthermore, certain treated waste materials, termed oriented strand board (OSB), a board panel with an orientation direction similar to plywood, have been reported (Angelo, 2019). PTPN XI East Java also proved the success of bagasse processing into particle

board, used as a soundproof (Karenina, 2018), in addition to multi-purpose box for storing household items (Li-An'Amie, 2014). These boards and bricks are employed in building materials, while the processed products, including briquettes, bioethanol, and activated charcoal are extremely valuable to the energy sector. A number of research data on waste utilization to form bioethanol (Hermiati, 2010), activated charcoal (Wijayanti, 2009; Shofa, 2012) and briquettes (Dharma, 2017; Leni, 2019), are also readily available.

The sugarcane bagasse waste is synthesized into useful products for the petroleum industry, including surfactants believed to increase yield in enhanced oil recovery (EOR) process (Setiati, 2017). In addition, the surfactants are usually produced from petrochemical compounds (fossil fuel derivatives) and oleo chemicals (vegetable and animal oil derivatives) (Fleurackers, 2014). Based on environmental issues and sustainable development, most industries are essentially inclining towards the use of alternative sources with similar properties, but eco-friendly tendencies. In nature, certain compounds are obtained from living materials with equivalent characteristics as surfactants, and therefore, are eventually termed biosurfactants (Renung, 2015). These biodegradable substances are classified into two based on raw material sources. The first group is due to the metabolism of microorganism cells, while the second is acquired from natural ingredients by chemical processes. Moreover, the compounds occur naturally, especially in hygiene products. Furthermore, surfactant represents the surface-active agent due to the ability to reduce water surface tension. In addition, the molecules generally exist in two fragments, including hydrophile and lipophile (hydrophobic), with a charged or polar portion (Figure 3). Therefore, the first tends to hydrophilic (akin to water), while second, consisting of long or nonpolar hydrocarbon chains, are hydrophobic (repel water).

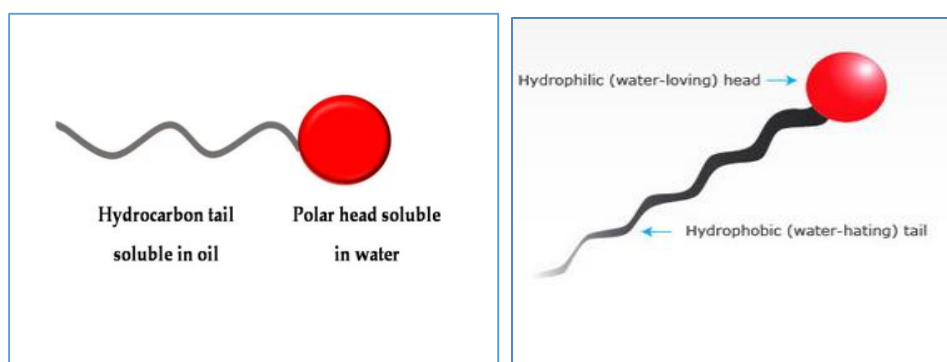


Figure 3 The molecular structure of the surfactant (Santos, 2016)

According to Schramm (2000), hydrophilic groups attract water molecules in solution, while hydrophobic particles exhibit repulsion. On dissolving in water, the hydrophilic portion binds to water, while the hydrophobic constituents tend towards the surface. However, adding lesser amounts of surfactant to an immiscible two-phase mixture, e.g., oil and water, emulsifies into a stable liquid.

The hydrophile-lipophile balance (HLB) refers to one of the parameters with a key role in the surfactant mechanism, and is used to determine the emulsion type (Sheng, 2011). Figure 4 shows the dynamic morphology of micro emulsions is generally evaluated by the HLB of the surfactants. The figure also reveals three kinds of classifications, based on hydrophilic and lipophilic values. A type O/W (Winsor I) is formed mainly in the lower or water phase at greater hydrophilic value compared to lipophilic. Meanwhile, W/O (Winsor II) type micro emulsion occurs in the upper or oil phase at lesser hydrophilic value than lipophilic. Furthermore, sufficient surfactant mechanism requires the ability to develop a middle phase emulsion, therefore the surfactants are expected to be partially soluble in the water and the oil phases, otherwise called a Winsor III emulsion type (Sandersen, 2012).

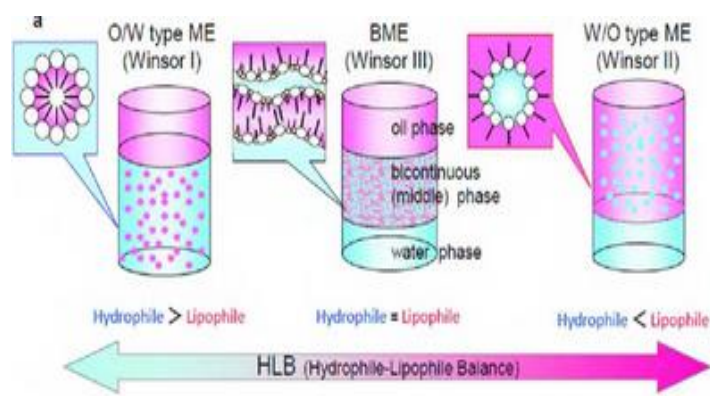


Figure 4 Microemulsion classification based on the HLB value (Kunitake, 2012)

The HLB calculation is evaluated using the formula (Nobel, 2011)

$$HLB = 20 * (Mh) / (Ml + Mh)$$

With Mh = the molecular weight of the hydrophilic group

Ml = the molecular weight of the hydrophobic or lipophilic group

According to Nobel (2011) recommended HLB value occurs in the range of 1 – 28, as shown in

Table 1. The results are possibly matched with the range of HLB values, therefore the surfactant function is confirmed accurate.

Table 1 Suggested HLB values (Akzo Nobel, 2011)

Application	HLB values
Defoaming of aqueous systems	1 - 3
W/O emulsification	3 - 6
Wetting	7 - 9
O/W emulsification	8 - 28
Solubilization	11 - 18
Detergency and cleaning	12 - 15

Apart from Akzo (2011), HLB has also been researched by Myers, (2006) and is obtained by calculating the value for various regions of the molecule, ranging from 0 - 20. A value of zero corresponds to the total hydrophobic molecules, while 20 indicates the particle comprising hydrophilic components (Table 2). This estimate is employed to ascertain surfactant properties. Consequently, higher HLB value tends to enhanced hydrophilic surfactant and solubility in water, otherwise known as O/W (Oil in Water) emulsion, while lower estimates indicate the surfactant is a W/O (Water in Oil) emulsion, with added solubility in oil.

Table 2 Value of HLB and its application (Myers, 2006)

HLB Value Range	Application
2 – 6	W/O emulsion
7 – 9	Wetting agent
8 – 18	O/W emulsion
3 – 15	Detergent
15 – 18	Solubilization

In the event where water is mixed with oil, the soluble hydrophobic molecules (tail) exit the water phase, and penetrates into the oil, while the hydrophilic group (head) dissolves and remains in the water phase. This is a surfactant alignment to modify the surface properties at the water/air or water/oil interface. Subsequent increase in concentration instigates the hydrophobic (oil-like) groups to form micelles, where each consists of several monomers, with

varying shape. However, there is no formation at lower concentrations. The surfactant tends to accumulate on the surface as the solution mingles with the oil phase. Eventually, the oil-like and water-like groups tend to dissolve in the oil and water phases, respectively. Under these conditions, the phase interface tension appears to decline. Therefore, the primary function of the surfactant is to reduce the oil-water surface tension.

2. RESEARCH METHODOLOGY

This research utilizes samples of crude oil, surfactant bagasse, and brine. The core flood apparatus, with synthesis cores, was utilized to commence the performance analysis of the surfactant bagasse in the enhanced oil recovery process. Also, the composite served as an injection fluid after successful characterization and compatibility. Furthermore, core flood assessments were conducted at four varied surfactant concentrations, termed 1.5%, 3%, 4%, and 4.5%, as well as brine at 5,000 ppm, 10,000 ppm, 20,000 ppm, and 40,000 ppm (Setiati, 2017).

The best core flood results are used as reference for further investigation, including component testing using NMR (Nuclear Magnetic Resonance). Based on the NMR, constituents of the surfactant bagasse monomer structure are visible therefore the HLB (Hydrophilic - Lipophilic Balance) value is also possible to calculate. This flow is indicated in Figure 5.

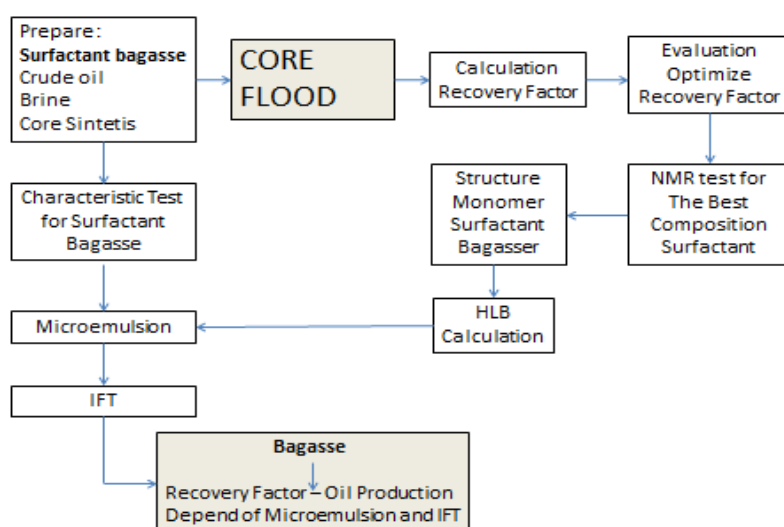


Figure 5 Microemulsion classification based on the HLB value (Kunitake, 2012)

3. RESULTS AND DISCUSSION

Several injections at various surfactants and brine concentrations were conducted in the core flood experiment. Furthermore, there is need to ascertain the core surfactant bagasse parameters in the enhanced oil recovery. Table 3 represents the six best injection results, and the core flood outcome showed the highest recovery factor of 9.50% occurred in SLS surfactant injection at varied surfactant concentration of 3% and brine salinity of 10,000 ppm. Under this condition, the middle phase emulsion formed extends to 7.50%, while the interfacial tension measured up to 1.68 mN/m.

Table 3 Value of HLB and its application (Myers, 2006)

Salinity (ppm)	Surfactant Concentration (%)	Middle Phase Emulsion (%)	IFT (mN/m)	RF SF (%)
5,000	1.5	1.25	6.81	7.00
10,000	1.5	10.00	2.73	9.25
10,000	3.0	7.50	1.68	9.50
20,000	1.5	5.00	4.13	8.55
40,000	1.5	6.00	4.11	1.80
40,000	4.0	0.00	2.72	1.16

Furthermore, with the formation of the middle phase emulsion, the interfacial tension (IFT) also decreased, therefore the oil grains migrated more easily. As the IFT becomes low, the capillary pressure declined, and the oil grains are pushed, moving between the gaps in the rock grains.

To strengthen the successful condition of the bagasse surfactant performance, there is need to perform component structure test contained in the bagasse surfactant, as the next analysis involved characterization using NMR spectroscopic measurements. This NMR spectroscopy was employed to identify the organic compound structure. The results of the ¹HNMR, ¹³C NMR spectrum analysis and 2D spectrum showing the correlation between carbon-hydrogen atoms in the molecular structure of the surfactant bagasse are displayed in the Table 4.

Table 4 Value of HLB and its application (Myers, 2006)

Group	Component	Number
Lipophilic Groups	= CH -	3
	- CH ₂ -	3
	- CH ₃	2
Hydrophilic Groups	- SO ₃ Na	1
	- OH	3

Based on the number of atoms in the bagasse surfactant component, the HLB value is estimated. The results of the HLB calculation are as follows:

$$M_h = (\text{SO}_3\text{Na}) + (\text{OH}) \times 3 = (32 + 48 + 23) + 51 = 154$$

$$M_l = (\text{CH}) \times 3 + (\text{CH}_2) \times 3 + (\text{CH}_3) \times 2 = 111$$

Based on the result of the molecular weight calculation in the hydrophilic and lipophilic groups, Figure 4 shows the hydrophilic value appears greater than the lipophilic. Therefore, the type of emulsion formed is a microemulsion type O/W (Winsor I), implying the occurrence is more pronounced in the lower or water phase. The hydrophilic and lipophilic molecular weight values are then included in the HLB calculation formula: $\text{HLB} = 20 \times (M_h) / (M_l + M_h) = 20 \times 154 / (111 + 154) = 11.62$

In reference to Table 1 (Azko, 2011), the value of HLB = 11.62, is categorized as O/W emulsification in a range of 8–28, and solubilization at 11-18. This connotes the bagasse surfactant is able to dissolve and establish an emulsion between oil and water. Based on Table 2 (Meyers, 2006), the HLB value of 11.62 is included in the O/W emulsification category in the 8-18 range, indicating the ability to develop suspensions. Also, with a surfactant of 1.5% - 3%, emulsion possibly occurs, as proven in the observation phase test at 7.50 - 10%. However, the blend in the bagasse surfactant injection system of 9.50%, was able to reduce IFT to 1.68 mN/m. The results of this research are supported by the emulsion formation theory, where due to the decline in surfactant compound on the water surface and the cohesion effect between water molecules, the surface tension tends to also decrease. Therefore, surfactants are known to reduce interfacial tension by absorbing water-oil (Schramm, 2000). Furthermore, surface active molecules (surfactant) exhibited polar and non-polar groups. As the substance is

dispersed in water at lower concentration, the surfactant molecules are absorbed on the surface to form a monomolecular layer, therefore leading to a declined interface tension in order to encourage easy movement of the oil grains. As a result, the bagasse surfactant was known to reduce the interface tension in the crude oil injection system, therefore increasing petroleum yield.

4. CONCLUSION

Based on the results and discussion, bagasse as solid waste shows a fairly good performance in the Enhanced Oil Recovery (EOR) process. Lignin from bagasse has the potential to become a surfactant, which in fact has the ability to form emulsions, which causes a decrease in interfacial tension. In addition, the decline triggers the ease of movement of oil. In conclusion, bagasse as solid waste shows a significant contribution to the EOR process.

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REFERENCES

- Adiguna, A.W. 2020. Pemanfaatan Abu Ampas Tebu Limbah Pabrik Gula Cinta Manis Kabupaten Ogan Ilir Sebagai Additive Beton. *Sainmatika: Jurnal Ilmiah Matematika dan Ilmu Pengetahuan Alam*. 17(1). Juni 2020. DOI 10.31851/sainmatika.v17i1.3383.
- Akzo Nobel. 2011. HLB & Emulsification, <http://surface.akzonobel.com>.
- Angelo, C., A.P. Setiawan, and J.F. Poilot. 2019. Penelitian Ampas Tebu sebagai Material Pembuatan Papan Unting. *Jurnal Intra*. 7(2): 511-514.
- A. Selvam and J. Wong, Waste Management and Sustainability: An Introduction, Book, 2016. <https://www.researchgate.net/publication/311869732>.
- Bursatriannyo. 2016. Diversifikasi Pemanfaatan Ampas Tebu, Pusat Penelitian dan Pengembangan Perkebunan-Indonesian Centre of Estate Crops Research and Development. *Warta Litbangtri*. 22(2).

- Dharma, U.S., N. Rajabiah, and C. Setyadi. 2017. Pemanfaatan Limbah Blotong dan Bagase menjadi Biobriket dengan Perekat Berbahan Baku Tetes Tebu dan Setilage. *Jurnal Teknik Mesin, Univ. Muhammadiyah Metro, TURBO*. 6(1). URL: <http://ojs.ummetro.ac.id/index.php/turbo>.
- Fleurackers, S. 2014. Biosurfactants Versus Chemically Synthesized Surface-Active Agents. *Biosurfactants: Production and Utilization-Processes, Technologies, and Economics*. 159: 37.
- Hermiati. 2010. Pemanfaatan Biomassa Lignoselulosa Ampas Tebu untuk Produksi Bioetanol. *Jurnal Litbang Pertanian*. 29(4).
- Hussein, I., Abdel-Shafy, and Mona S.M.M. 2018. Solid Waste Issue: Sources, Composition, Disposal, Recycling, and Valorization. *Egyptian Journal of Petroleum*. 27(2018): 1275–1290. journal homepage: www.sciencedirect.com.
- Isnaeni. 2019. Limbah Ampas Tebu dan Tahu Jadi Komponen Media Produksi Antibiotika, Unair News, <http://news.unair.ac.id/2019/10/16/limbah-ampas-tebu-dan-tahu-jadi-komponen-media-produksi-antibiotika/>.
- Karenina. 2018. Kreatif! Ampas Tebu Bisa Jadi Produk Berdaya Guna, Hasilnya Buat Kagum. <https://pontianak.tribunnews.com/2018/06/06/kreatif-ampas-tebu-bisa-jadi-produk-berdaya-guna-hasilnya-buat-kagum?page=2>.
- Kunitake, M. Sakata K. and T. Nishimi, Mesostructured Polymer Materials Based on Bicontinuous Microemulsions, Kumamoto University, 2012.
- Li-An'Amie, N. L., & Nugraha, A. 2014. Pemanfaatan Limbah Ampas Tebu melalui Desain Produk Perlengkapan Rumah. Institut Teknologi Bandung. *Product Design*. 3(1): 180028.
- Marzuki. 2017. Banyak Ampas Tebu Tidak Pergunakan Hanya Dibakar. *Steemit*. <https://steemit.com/aceh/@marzuki88/banyak-ampas-tebu-tidak-pergunakan-hanya-dibakar-c8dbc6837fe17>.
- Maulinda, L., H. Mardinata, Jalaluddin. 2019. Optimization of Making Briquettes Based on Sugarcane Waste Using the RSM Method, *Jurnal Teknologi Kimia, Unimal*. 8(1) :1- 97. Mei 2019.
- Myers, D., Surfactant Science and Technology. New Jersey: Wiley Interscience, 2006.
- Poluakan, L. C., Purwaningrum, P., Indrawati, D. 2018. Environmental Risk Considerations in the Development of Solid Waste Facility: Case Study Rawa Kucing Solid Waste Facility, Tangerang City. *Indonesian Journal of Urban and Environmental Technology* 1(2): 124-136 DOI : 10.25105/urbanenvirotech.v1i2.2822
- Reningtyas, R., Reningtyas and Mahreni. 2015. Biosurfaktan. *Eksergi*. XII(2): 12-22.

- Rochana. 2004. Pengaruh Pemberian Ransum yang Mengandung Ampas Tebu Hasil Biokonversi oleh Jamur Tiram Putih (*Pleurotus ostreatus*) terhadap Performans Domba Priangan. *JITV*. 9(3).
- Rosul, A. 2019. Tumpukan Ampas Tebu PG Djombang Baru Terbakar, Ini Penyebabnya. <https://jatimtimes.com/baca/192432/20190428/132000/tumpukan-ampas-tebu-pg-djombang-baru-terbakar-ini-penyebabnya>.
- Sandersen, S. B. 2012. Enhanced Oil Recovery with Surfactant Flooding. Denmark: Center for Energy Resources Engineering - CERE.
- Santos, D., Rufino, R., Luna, J., Santos, V., and Sarubbo, L. 2016. Biosurfactants: Multifunctional Biomolecules of the 21st Century. *International Journal of Molecular Sciences*. 17(3): 401.
- Schramm, L., Surfactant: Fundamentals and Application in the Petroleum Industry. Cambridge: University of Cambridge, 2000.
- Setiati, R., Synthesis and Characterization of Sodium Lignosulfonate from Bagasse: The Effects of Concentration and Salinity toward the Performance of Oil Injection in Core. Ph.D Thesis. Bandung Institute of Technology (ITB). Bandung, Indonesia, 2017.
- Sheng, J. L. 2011. Chemical Flooding. Dalam Modern Chemical Enhanced Oil Recovery, page. 239-335. Oxford: Elsevier.
- Shofa, Pembuatan Karbon Aktif Berbahan Baku Ampas Tebu dengan Aktivasi Kalium Hidroksida, Teknik Kimia, Universitas Indonesia, 2012.
- Sholahuddin, I. 2019. Pemanfaatan Potensi Lokal Ampas Tebu Menjadi Keripik sebagai Upaya Meningkatkan Kesejahteraan dan Perekonomian Keluarga. Kompasiana.com. <https://www.kompasiana.com/irfansholahuddin/5c6620f7ab12ae196148aca7/pemanfaatan-potensi-lokal-ampas-tebu-menjadi-keripik-sebagai-upaya-meningkatkan-kesejahteraan-dan-perekonomian-keluarga?page=4>.
- Siami, L., Sotiyorini, T., Janah, N. 2019. Municipal Solid Waste Quantification And Characterization In Banyuwangi, Indonesia. *Indonesian Journal of Urban and Environmental Technology* 2 (2): 189-200. DOI :10.25105/urbanenvirotech.v0i0.4359.
- Syafrudin, A.D.A. 2007. Studi Pengelolaan Limbah Pabrik Gula (Studi Kasus Pabrik Gula Pt. Kebon Agungdi Trangkil Pati). *Jurnal Presipitasi*. 2(1). Maret 2007, ISSN 1907-187X.
- Wijayanti, R., Arang Aktif dari Ampas Tebu sebagai Absorben pada Pemurnian Minyak Goreng Bekas. Departemen Kimia, Fakultas Matematika dan Ilmu Pengetahuan Alam, Institut Pertanian Bogor. Bogor, Indonesia, 2009.
- Yani, M., I. Purwaningsih, M.N. Munandar. 2012. Penilaian Daur Hidup (Life Cycle Assessment) Gula pada Pabrik Gula Tebu. *E-Jurnal Agroindustri Indonesia*. 1(1): 60-67. Juli 2012. <http://tin.fateta.ipb.ac.id/journal/e-jaii>.