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# COMPARATIVE PATHWAY ANALYSIS OF PARAFFIN WAX AND BEESWAX FOR INDUSTRIAL APPLICATIONS

***M. Enamul Hossain[1*], M. Ibrahim Khan[2], Chefi Ketata[3] and M. Rafiqul Islam[3]***

[1]Department of Petroleum Engineering, King Fahd University of Petroleum and Minerals, Dhahran 31261, Kingdom of Saudi Arabia

[2]Energy and Environment System Group, ISEEE University of Calgary ES 602, 2500 University Drive NW Calgary, Alberta, Canada, T2N 1N4

[3]Faculty of Engineering, Dalhousie University-Sexton Campus D510-1360 Barrington Street, Halifax, NS, B3J 2X4

**Abstract**

Laboratory analysis is one of the most powerful tools to make a decision for any field application. There are many factors that influence the experimental results. Therefore, it is necessary to analyse the sustainability of the samples so that the experimental findings can be used directly for the field application where sustainability and environmental issues are the main concern. In general, wax has numerous applications. Today, most of the commercial applications use paraffin wax that is derived from petroleum oil. Even though, historically beeswax had been used for many centuries, paraffin wax has taken over practically all commercial applications. Similar to all other man-produced products, the assumption behind replacing beeswax with paraffin wax is they represent the same chemical that the C – H aliphatic compound. This study conducts an in-depth comparison between paraffin wax and beeswax. This comparison is based on the pathways travelled by these seemingly. The sustainability analysis of beeswax and paraffin wax has been conducted. According to pathway analysis it is found that beeswax and paraffin wax follow opposite pathway. The sustainability assessment of these products evident that one is inherently sustainable and other one is completely unsustainable. This analysis shows the need of studying the pathway prior to selecting a material for commercial applications.

**Keywords:** beeswax; paraffin wax; pathway analysis; reservoir rock; sustainability analysis.

[*] Corresponding author E-mail: menamul@kfupm.edu.sa or dr.mehossain@gmail.com

## 1. Introduction

It is a very important task to accomplish the sustainability analysis of any event (in laboratory to field scale) before going to take any action. The study of sustainability is a formidable research topic and has dominated many issues related to air, water, and land pollution. The petroleum industry is possibly to the most active sector dealing with all levels of pollutions. Petroleum activities also create ecological problems for plants, insects and animals. The petroleum industry and its chemical outlets dominate all industrial applications. However, all these applications assume that chemicals derived from petroleum source and processed through unsustainable means represent the same product that is naturally processed and had been in use for many centuries. The distinction between these two lines of products is obscured because there is no prescribed means to study the long term impact of these products.

Recently, Khan, et al. (2007) studied a pathway analysis of a sustainable and an unsustainable product. They have used a newly developed sustainability criterion to analyze a natural product (i.e., wool fiber) and synthetic product (i.e., polyurethane fiber). Based on the origin, degradation, oxidation and decomposition, they showed wool fiber is sustainable whereas polyurethane is unsustainable. In connection with natural product, Hossain et al. (2010a, 2010b, and 2009a – 2009e) conducted a series of experiments dealing with waterjet drilling technique. They have used paraffin wax and beeswax as a rock sample during the experiment. It is very interesting to investigate which one of the two types of waxes is analogous to the real natural reservoir rock. The present study is an attempt to identify the natural and sustainable wax sample to simulate the rock based on experiment. Hossain et al. (2010a) studied the different important parameters related to waterjet drilling using paraffin wax samples. They introduced empirical relations for depth of penetration (DOP) and rate of penetration (ROP) with drilling time. Both the empirical correlations are linearly related with time. The same experimental procedure and aspects were applied to develop the empirical correlations using beeswax samples (Hossain et al., 2009a). They found that DOP and ROP relations with time are nonlinearly related for this case where beeswax is used as rock samples.

A comparative study of paraffin wax and beeswax samples are completed based on different parameters related to drilling activities (Hossain et al., 2009b). They also developed empirical correlation on thermal exposure time with DOP and ROP for both paraffin wax and beeswax respectively (Hossain et al., 2010b). It shows that paraffin wax has the linear relationship whereas beeswax has the nonlinear relationship. They also showed the nonlinearity of beeswax by another empirical relation on DOP and ROP with gap distance between drill bit tip and sample top surface (Hossain et al., 2009b). Based on the parameters related with drilling operations, the cited works of Hossain et al. (2010a, 2009a, and 2009b) established the beeswax as a natural waxy material that can be used to simulate reservoir rock matrix. However, these papers did not complete the sustainability analysis of beeswax and paraffin wax based on pathway.

A process is truly sustainable and environment friendly when both the process and source are sustainable. This study uses paraffin wax and beeswax as the representations of artificial and natural products and offers in-depth pathway analysis. This study classifies that only natural products are sustainable.

## 2. Methodology

A scientific analysis of paraffin wax and beeswax was carried out based on its structure, manufacturing and processing. Detailed analyses of their pathways were carried out along with their comparative characteristics. A recently proposed sustainability model (Khan, 2006) is applied for evaluating the sustainability of paraffin wax and beeswax. In addition, a laboratory analysis of strength test was also investigated. A compressive testing machine, Versa-Tester 30 M, CT 744 was used for the strength tests.

## 3. Experimental Samples

Uniaxial compression tests were performed on beeswax and paraffin wax samples, which had a diameter of 2” (50.8mm) and a length of 5” (127mm) (see Figures 1). The length-to-diameter ratio is 2.5. The stress rate was applied within the limits of 0.5 –1.0 MPa/s.

a) Paraffin wax b) Beeswax

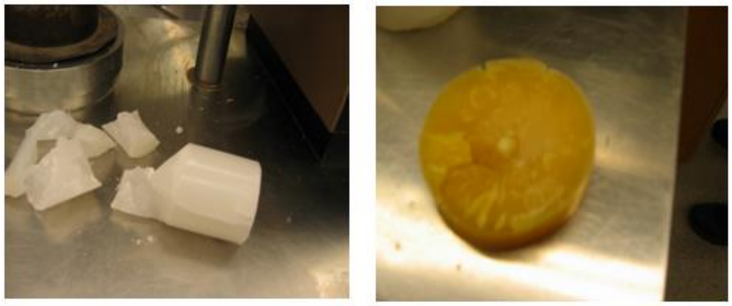
Figure 1. Wax samples for uniaxial compressive strength test (represented from Hossain et al., 2009f).

## 4. Test Results after Load

Microstructural weakening begins when any load (compressive or tensile) is applied to any material. Therefore, the impact of load on rock samples is essential to get the proper information during the drilling activities. Figure 2 shows the fracture nature of paraffin wax and beeswax after applying uniaxial compressive load. Paraffin wax shows the broken pieces where lots of fractures took place during the strength test. However, beeswax has no broken pieces whereas fine micro fractures developed.

Figure 3 shows the stress-strain curve for paraffin wax in room temperature. Hossain et al. (2009f) explained how stress-strain varies with the applied load. They also showed the variation of different mechanical properties. Using the best fit regression analysis, the curve trend of paraffin wax that has ostensibly linear can be mathematically expessed by an empirical relation. The trend line for stress ($\sigma_p$) with strain ($\varepsilon_p$) is presented by Eq. (1).

$$\sigma_p = 509.8\, \varepsilon_p - 2.812 \tag{1}$$



a) paraffin wax b) beeswax

Figure 2. Wax samples after uniaxial compressive strength test.

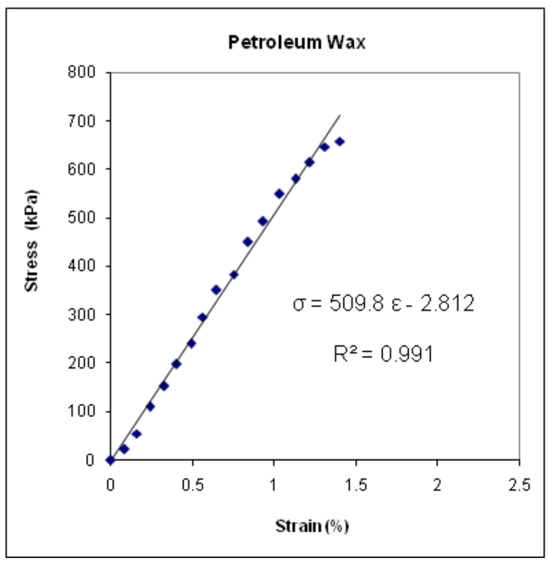



Figure 3. Stress variation with strain for empirical relation based on paraffin wax (redrawn from Hossain et al., 2009f).

Figure 4 presents the stress-strain curve for beeswax in room temperature. Hossain et al. (2009f) explained the stress-strain variation and different loads during the strength test. They also explained how stress-strain varies nonlinearly. Beeswax has no regular shape and pattern of the conventional stress-strain curve. The behavior of the curve is similar to natural materials, which can be used as a rock sample in laboratory to simulate rock in field scale. The non-linear trend of the natural wax that has complex features can be mathematically explained by an empirical relationship. The trend line for stress ($\sigma_b$) with strain ($\varepsilon_b$) is shown by best fit regression analysis, which is shown in Eq. (2).

$$\sigma_b = -120.1\ \varepsilon_b^2 + 456.4\ \varepsilon_b + 92.33 \quad (2)$$

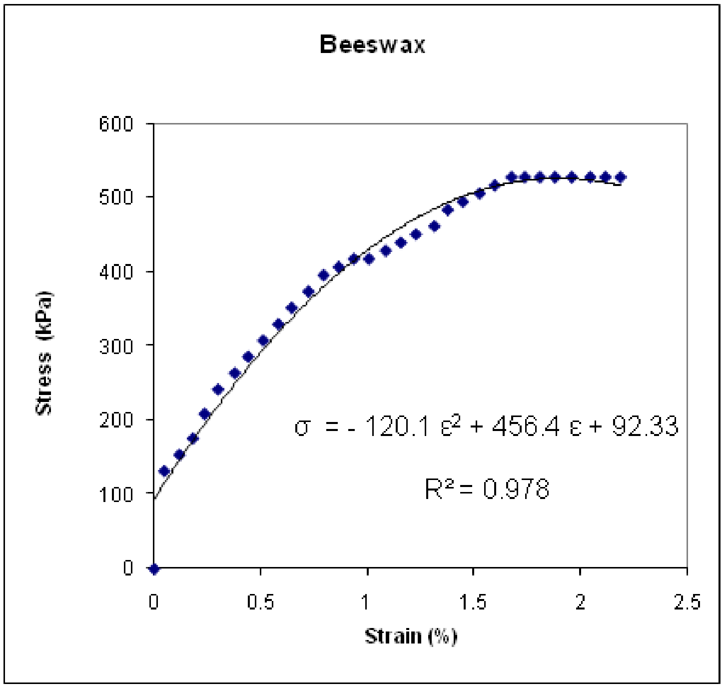



Figure 4. Stress variation with strain for empirical relation based on beeswax (redrawn from Hossain et al., 2009f).

## 5. Why Materials Pathway Travelled Is Important

The shape and properties of any phase (i.e., solid, liquid or gas) materials depend on its origin and its pathway travelled with time. The present status of materials is directly related to time factor. Therefore, the pathway analysis is important for any material characterization. Just looking at the end products it is hard to assess whether a product is sustainable or not. As a result, we need a pathway analysis for knowing the path it travels. The pathway analysis tells us about the actual environmental cost of a product. There are many other tools to evaluate products, such as Life Cycle Assessment (Bergerson and Lave, 2004; Bergerson and Keith 2006; Joule and David, 2006), Environmental Impact Assessment (Beanlands and Duinker, 1984), Cumulative Effect Assessment ((Duinker and Greig, 2006), and toxicity test (Gulec, and Holdway, 1999). However, all of these assessments do not tell the hidden cost and time or duration factors of a material. Only recently, Khan (2006a) introduced time factor as most important criterion in the sustainability assessment and sustainable technology development. This pathway analysis gives a clear picture of a material about its environmental burden and sustainability status (Khan et al., 2007). A comparison of paraffin wax and beeswax is exhibited in Table 1. It shows that how these two products are different though it has almost similar composition.

**Table 1. Basic Difference between beeswax and paraffin wax**

| | Paraffin wax | Beeswax |
|---|---|---|
| Type | tasteless and odorless white translucent solid | Testy, good odor, yellow, brown, or white bleached solid |
| Composition | solid aliphatic hydrocarbons of high molecular weight such as $C_{36}H_{74}$. Its molecular formula is $C_nH_{2n+2}$ | myricyl palmitate, cerotic acid and esters, and some high-carbon paraffins. |
| Diversity | There is no diversity. | Highly diverse. Complex process of synthesis very little is known so far. It's different segments like different monomers |
| Functionality | Single-functional just as plastic | Multifunctional such as for the protection of organisms, supplies of nutrients, |
| Adaptability | It is non-adjustable and non-adoptable and can not change itself life the natural products do. | It can adapt with the changes in different conditions, such as temperature, humidity, light intensity. It protects itself and protects the organism where it grows. |
| Time factor | Non-progressive. It does change with time | It is regressive and changes according to time for example it degrades by time |
| Perfectness | It creates all kind of problem. From carcinogenic products to unknown product | It is perfect and does not create problem. Instead solve the problem. |
| Melting point | 47°C to 65°C | 62°C to 65°C |
| Density (g/cm$^3$) | 0.88 to 0.94 | 0.95 |

## 6. The Paraffin Wax Pathway

Figure 5 shows the paraffin wax pathway. In this study, the pathways of paraffin wax are categorized into six main steps. All six steps are shown in Figure 5. In the suitable environmental condition, dead plants are transformed into hydrocarbon deposits in natural way. These hydrocarbons sources are explore and exploit by different development phases. In this process, different toxic chemicals and unsustainable techniques/process are used which causes many environmental impacts through releasing gaseous, liquid, and solid wastes (Khan and Islam, 2007b). This toxic inputs and outputs are shown in Figure 5. After production, the hydrocarbons are upgraded in the refinery by using many toxic catalysts where final paraffin wax is produced as product (Khan and Islam, 2007). This whole process creates environmental problems and uses many toxic substances.

## 7. Health Hazard of Paraffin Wax

Paraffin wax is known to numerous health hazards. Paraffin wax contains up to 11 carcinogenic compounds (Website 1). Health hazards are normally noticed when it is mixed with perfume and are compounded with chemical fixatives, synthetic glosses and bleached cotton wicks. Paraffin wax that coats the skin clogs the pores and interferes with skin's ability to eliminate toxins, promoting acne and other disorders. It slows down skin function and cell development, resulting in premature aging. Any mineral oil derivative can be contaminated with cancer causing PAH's (Polycyclic Aromatic Hydrocarbons). One must note that toxins are released all the time, irrespective of actual burning of the wax. This is because oxidation is a continuous process in the natural environment. Table 2 shows health hazard issues of paraffin wax.

**Table 2. Different potential health hazard effects**

| | Description | |
|---|---|---|
| Toxicology[1] | Toxicity to humans, including carcinogenicity, reproductive and developmental toxicity, neurotoxicity, and acute toxicity[2], Prolonged contact may lead to irritation | |
| Potential health effects[3] | Eye | Solid material is not expected to be an eye irritant; however, contact with molten wax may cause thermal burns. Vapours from molten wax may cause watering of the eyes. |
| | Skin | Solid material is not expected to be a skin irritant; however, skin contact with molten wax may cause thermal burns. No harmful effects from skin absorption are expected |
| | Inhalation (Breathing) | Vapours emitted from molten wax are expected to have a low degree of irritation by inhalation. However, at elevated temperatures, vapours are irritating and may cause headache, nausea and dizziness. Such exposures are extremely unlikely in normal use. |
| | Ingestion (Swallowing) | Irritation of mucous membranes[4]. Acts as a laxative and may cause diarrhoea |
| | Signs and Symptoms | Effects of overexposure may include irritation of the nose and throat |
| | Chronic | Inhalation of vapours at elevated temperatures and ingestion are the routes of entry into the body. The product defeats the skin and prolonged or repeated skin contact may contribute to dermatitis. |
| | Ventilation | Working area should be well ventilated. Local exhaust (e.g., dust collection system) should be employed as appropriate to minimize dust level in the working area. |
| | Ecotoxicity[2] | Toxicity to aquatic organisms |

Sources: http://physchem.ox.ac.uk/MSDS/PA/paraffin.html[1]
http://www.pesticideinfo.org/Detail_Chemical.jsp?Rec_Id=PC34867[2]
http://www.prochemicals.com[3]
http://www.jtbaker.com/msds/englishhtml/p0121.htm[4]

## 8. The Beeswax Pathway

Seven different phases of beeswax pathways are presented in Figure 6. In these phases, honeybees produce wax using truly natural process by utilizing enzymes in digestion, metabolism and other complex biological process. However, the paraffin wax production is conducted in the chemical processes which completely follow opposite direction comparing with beeswax. In the beeswax, real bees' enzymes are used, but in the refinery toxic catalysts mainly containing heavy metals are used. Considering Figures 5 and 6, we can say that these two products are similar in functionally, but pathways are completely opposite. One is truly natural and another one is completely anti-natural.

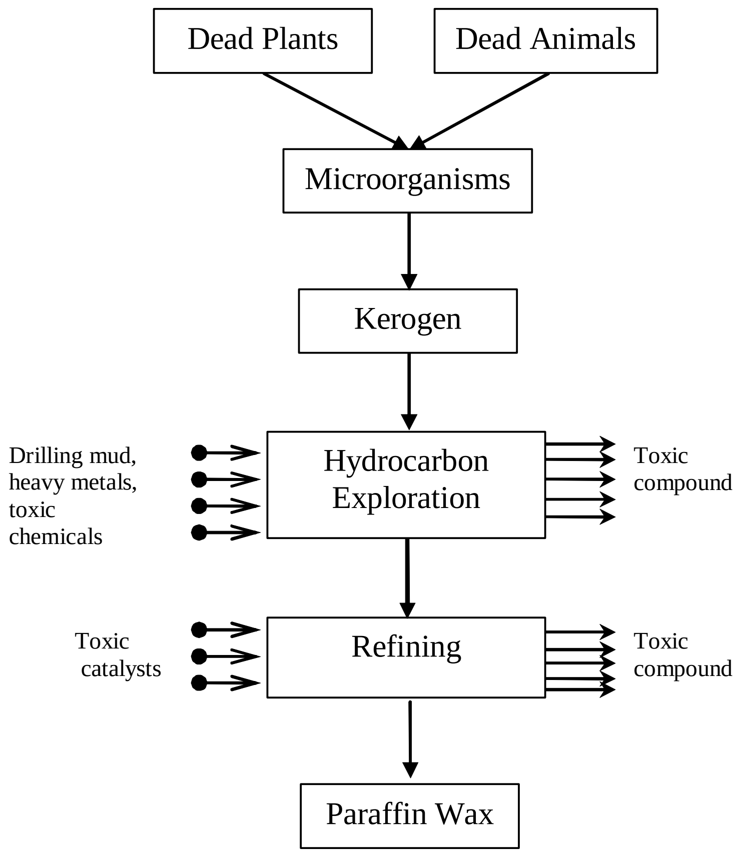



Figure 5. Paraffin wax pathway.

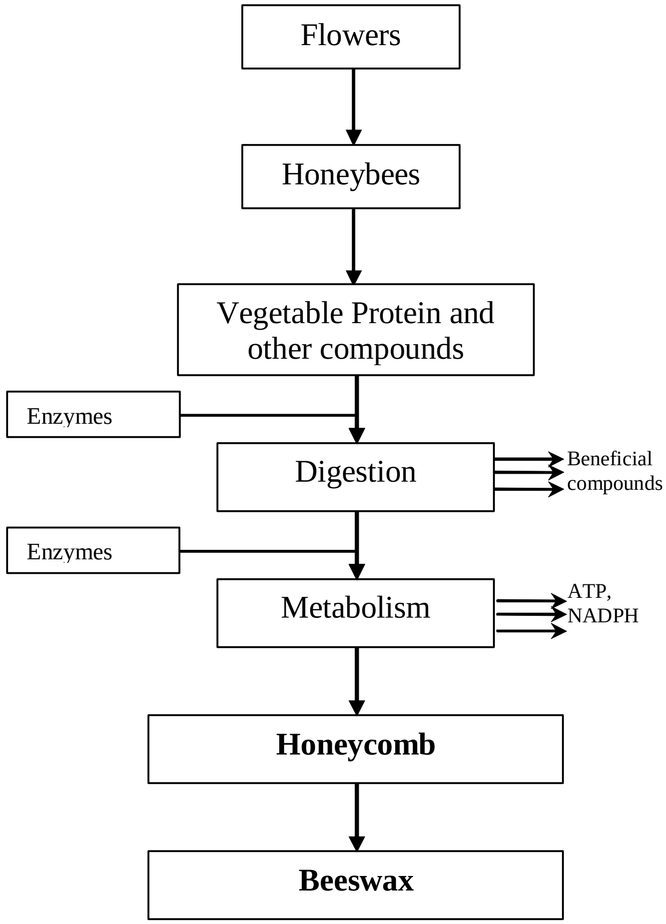



Figure 6. Beeswax pathway.

## 9. Sustainability of Beeswax and Paraffin Wax

Sustainability can be assessed only if a product, material or technology emulates nature. In nature, all functions or techniques are inherently sustainable, efficient and functional for an unlimited time period. In other words, as far as natural processes are concerned, 'time tends to Infinity'. This can be expressed as t or, for that matter, $\Delta t \rightarrow \infty$.

By following the same path as the functions inherent in nature, an inherently sustainable products or process can be developed (Khan and Islam, 2007a). The 'time criterion' is a defining factor in the sustainability and virtually infinite durability of natural functions. Figure 7 shows the direction of nature-based, inherently sustainable technology, as contrasted with an unsustainable technology. The path of sustainable technology is its long-term durability and environmentally wholesome impact, while unsustainable technology is marked by $\Delta t$ approaching 0. Presently, the most commonly used theme in technology development is to select technologies that are good for t = 'right now', or $\Delta t = 0$. In reality, such models are devoid of any real basis (termed "aphenomenal" by Khan, 2006a and 2006b) and should not be applied in technology development if we seek sustainability for economic, social and environmental purposes.

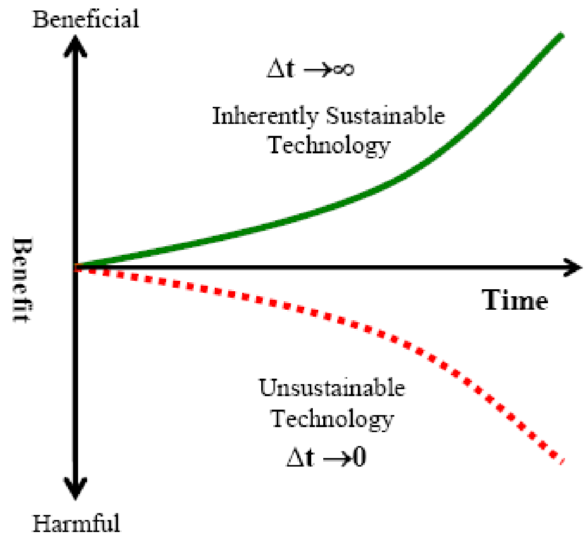



Figure 7. Direction of sustainable/green technology (redrawn Khan, 2006a).

Considering pure time, so to speak (or time tending to Infinity) in terms of sustainable technology development raises thorny ethical questions. This 'time tested' technology will be good for Nature and good for human beings. The main principle of this technology will be working towards, rather than against natural processes. It would not work against nature or ecological functions. All natural ecological functions are truly sustainable in this long-term sense. We can take a simple example of an ecosystem technology (natural ecological function) to understand how it is time-tested.

In nature, all plants produce glucose (organic energy) through utilizing sunlight, $CO_2$ and soil nutrients. This organic energy is then transferred to the next higher level of organisms which are small animalss (zooplankton). The next higher (tropical) level organism (high predators) utilize that energy. After the death of all organisms, their body mass decomposes into soil nutrients which again take plants to keep the organic energy looping alive. This natural production process never dysfunctions and remains for an infinite time. It can be defined as a time tested technique. All natural products and materials are time tested.

Figure 8 shows the increasing environmental cost and benefits of sustainable products or technology. In this study, the studied materials paraffin wax and beeswax can be similarly analyzed following the figures of Figure 4. Beeswax is a natural product and completely followed the natural pathways. However, the paraffin wax followed the opposite direction of beeswax. Its natural path was disturbed by different artificial processes. As result, both are similar products, but one is sustainable and other one travelled unsustainable path. Khan et al. (2007) find the similar results in case of synthetic polyurethane and sheep wool. According to them sheep wool is sustainable products and polyurethane is unsustainable product.

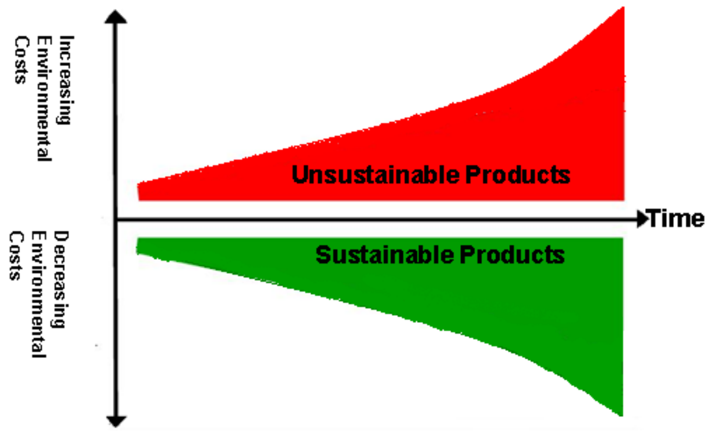



Figure 8. comparative environmental costs of a sustainable and an unsustainable technology (after Khan and Islam, 200b).

## 10. Conclusion

In this study, two homologous products paraffin wax and beeswax are studied. According to functionality and usages, these products are similar. However, evaluating the pathway analysis, it is found that these two products travel complete opposite pathways. Beeswax follows truly natural path, and paraffin wax follows completely anti-natural path. The physical analyses of paraffin wax and beeswax showed that beeswax follows natural pathway on the other hand paraffin wax follows anti nature path. The drilling parameters behaviors also follow the same principle. According to sustainability analysis it is found that one is sustainable and other one is unsustainable. Based on the above discussion, it can be concluded that beeswax is sustainable and paraffin wax is not sustainable. This finding supports the observation of researchers who discovered that paraffin wax releases toxins, some of which can cause cancer and other ailments.

## Nomenclature

| | | |
|---|---|---|
| *DOP* | = | depth of penetration, mm, $[L]$ |
| *ROP* | = | rate of penetration, mm/h, $[L/t]$ |
| t | = | time, s, $[t]$ |
| $\Delta$t | = | very small time fraction, s, $[Lt]$ |
| $\sigma_b$ | = | stress for beeswax samples, kPa, $[M/Lt^2]$ |
| $\varepsilon_b$ | = | strain rate for beeswax, %, |
| $\sigma_p$ | = | stress for paraffin wax samples, kPa, $[M/Lt^2]$ |
| $\varepsilon_p$ | = | strain rate for paraffin wax, %, |

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