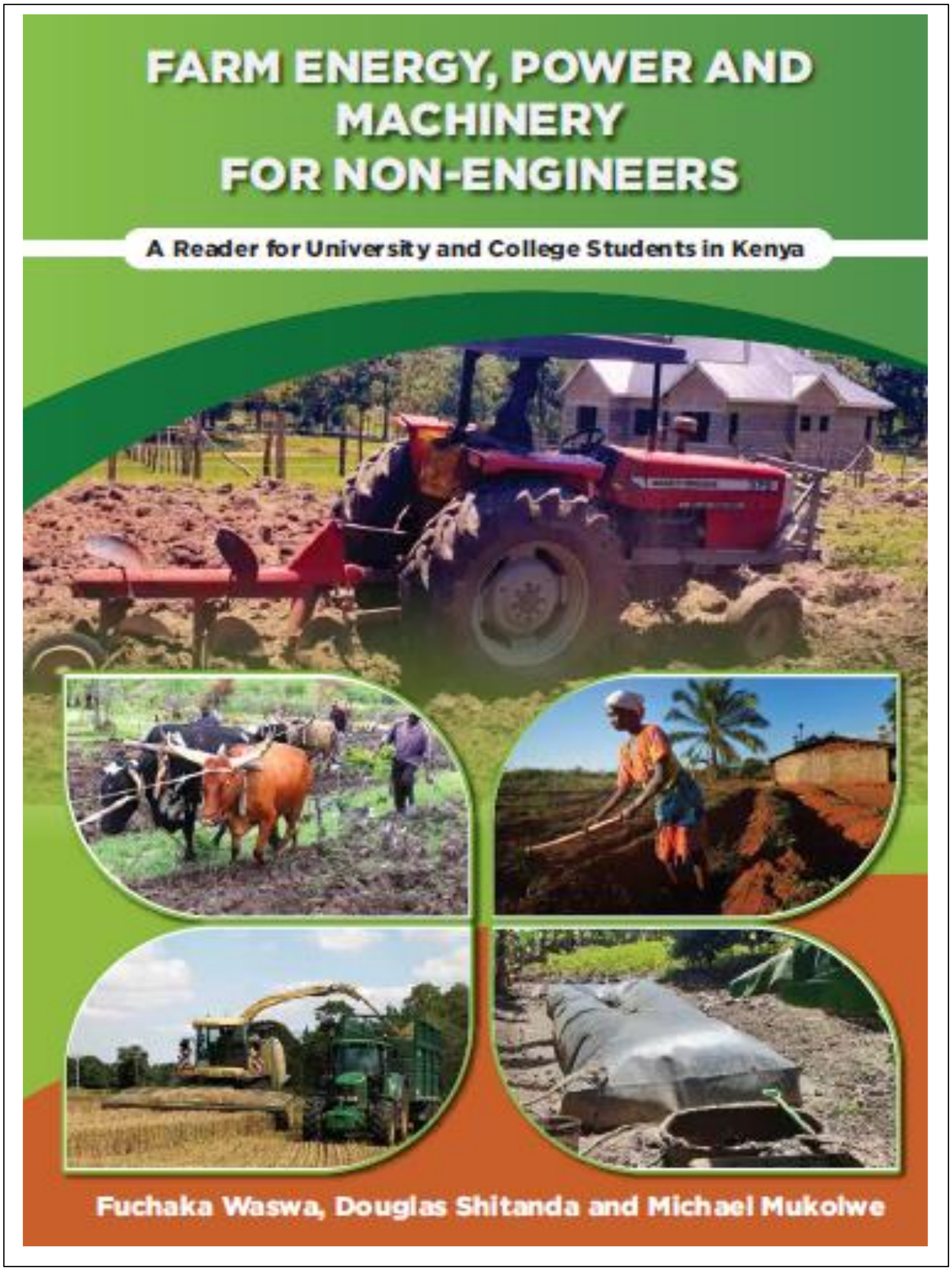
FARM ENERGY, POWER AND MACHINERY FOR NON-ENGINEERS
A Reader for University and College Students in Kenya
Fuchaka Waswa, Douglas Shitanda and Michael Mukolwe

Farm Energy, Power and Machinery for Non-Engineers:

A Reader for University and College Students in Kenya

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Abbreviations

AC	Alternating Current
AE	Agricultural Engineering
AMS	Agricultural Machinery Services
BDC	Bottom Dead Centre
CR	Compression Ratio
DAP	Draft Animal Power
DC	Direct Current
DfE	Designed for the Environment
Diff-Lock	Differential Lock
ECE	External Combustion Engine
EF	Ecological Footprint
EMCA	Environmental Management and Coordination Act
EPRA	Energy and Petroleum Regulatory Authority
GDP	Gross Domestic Product
GHGs	Green House Gases
HD	Heavy Duty Oil
Hp	Horse Power
ICE	Internal Combustion Engine
ILO	International Labour Organisation
kW	Kilowatts
NS	Nano-structural
OHS	Occupational Health and Safety
POPS	Role-over protection Structures
Psi	Pounds per square inch
PTO	Power Take-Off
PTS	Power Transmission System
SAE	Society of Automotive Engineers
SDGs	Sustainable Development Goals
TDC	Top Dead Centre
VI	Viscosity Index

Technical Review

Agriculture is the backbone of economic development in Kenya and contributes over 50% to the Gross Domestic Product (GDP). As such training of agricultural specialists is one of the cogs that drives the country's economy for enhanced human well-being. The role of agricultural engineering in increasing farm productivity cannot also be overemphasized. This is why agricultural engineering as subject is offered to students taking agricultural sciences and related courses. Other professionals who deal with sales, servicing and maintenance of farm machinery, tools and equipment also benefit from knowledge of agricultural engineering, and in particular farm power and machinery. This book provides to this broad goal and has come in handy as it explains sources of farm power and farm machinery in simple terms that are easy to understand by the non-engineers. It also emphasises the use of sustainable energy solutions that have less negative impact on the environment.

Chapters one and two introduce the importance of mechanization and explain the advantages and disadvantages thereof in order for farmers to make informed decisions on the use of machinery. They emphasise in particular the need to promote the hitherto marginalised micro-agricultural mechanization in response to declining farm sizes. Chapter three exposes the reader to an array of energy sources that are available for farm operations and the attendant technology for its effective use. Here-in is a menu from which stakeholders can adopt wholesale or innovate around for sustainable energy solutions at the farm level. Alternative power sources, have been explored. Instructing learners in these sources of energy will lead to their enhanced promotion at the farm level.

Chapter four discusses the need for efficient energy use based on the concept of ecological footprints. This dimension has been generally marginalized in conventional engineering training. With this book, learners and readers can now begin to appreciate the relevance of sustainability thinking in routine farm operations. Further, environmental performance in tandem with international trends will begin being emphasised in engineering training in this part of the world.

Chapter five though seven give details of the farm tractor and associated implements and their maintenance. Being the most popular vehicular machine on the farm, the operating principles of the internal combustion engine and other systems of the general-purpose tractor have been accurately covered in sufficient detail. In a way users of this book will have basic mechanics knowledge necessary for working comfortably with farm machinery.

The last two chapters stress the need for safe keeping of farm machinery and equipment in a designated yard. The learner is also taken through good maintenance and safety procedures in handling of farm machinery. There is also sufficient information on draft animal power and its accessories. The authors' concern with draught animal welfare and appropriate harnessing gear is very commendable, particularly in certain parts of Kenya, where respect of animal welfare still lags behind. The inclusion of occupational health and safety is key in reducing risks and disasters that could arise when machines are not used as per manufacturers' specifications.

Overall, the technical content is accurate and more than sufficient for non-engineers. This book has excellent illustrations and pictures that make it very easy for even beginners to understand and appreciate the role of farm energy, power and machinery in the ever-evolving agricultural sector. The footnotes and bibliography point readers to relevant resource materials that may not be available as hard copies in local universities and colleges. In this information age, the opportunities to explore the internet for learning purposes has been expanded. This book is a welcome resource in university libraries and also those of tertiary institutions.

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Foreword

The role of agriculture in the development agenda of Kenya cannot be overemphasised. The need to produce adequate food in the context of declining land sizes and risk of climate change is a challenge that must be continuously overcome. Timing of operations and efficient use of available farm power and machinery in both intensive and extensive production systems remain key inputs in this endeavour. Equally important is the need to train agricultural experts capable of aligning production and value–addition to sustainable development goals. This book offers university and college students a head-start in this direction. It also bridges the gap in training that has existed for a long time, where-in the competence in farm power and machinery for non-engineers has not been fully maximised.

Most actors at the farm level may not need hard sciences and deep engineering but rather sufficient hands-on skills. This book is appropriate in this regard, and has addressed farm energy, power and machinery under relevant and attractive themes that cover the farm as a system. It is a timely book in higher education training, where-in university and tertiary institutions stand to benefit a lot. The authors have done a splendid job when it comes to simplifying the burden of synthesising and communicating knowledge for different stakeholders who may use this book. I highly recommend this book to all universities and colleges offering agriculture and related programmes. Lecturers, instructors, tutors, technicians, learners and even farmers will find this reader very helpful in routine decision-making and practice as they all endeavour to practice sustainable agriculture and make significant contributions to enhanced human well-being especially at the farm level.

Amb. Simon Nabukwesi, CBS
Principal Secretary (2017-2022)
State Department for University Education and Research

Preface and Acknowledgement

Having studied agriculture and taught it for over 20 years, the authors came to the conclusion that university and college students taking agriculture and agriculture related courses need agricultural engineering courses tailor-made to suit their unique requirements. Whereas engineering students need deep knowledge in engineering designs and operational aspects of farm machinery, non-engineers only need basic knowledge in operation principles of farm machinery, and their accessories. Further, subjecting non-engineers to mathematical aspects of farm power also causes many with little background in mathematics and physics to approach such courses with fear, which ultimately undermines their performance and ultimate passion for farm machinery. This easy to read and understand handbook aims to fill this gap.

The topics, their logical flow and overall design of the book was intentional in order to allow students gradually explore the material based on the first principle learning model. Reflection questions and individual tasks are included at strategic parts/sections of the handbook to enable students to pause and synthesise knowledge. In essence, the book adequately addresses farm energy, power and machinery that are typical in agro-ecosystems of developing countries. Furthermore, it highlights how machinery can be used within the confines of "agriculture that is designed for the environment" (DfE). This dimension is also integrated across chapters as appropriate.

Chapter one allows the learner to explore a variety of basic terms commonly used in agricultural engineering. Chapter two focusses on the need to enhance agricultural mechanisation both in intensive and extensive production systems. Micro-mechanization is particularly a new frontier that has potential to benefit many small-holder farmers

Chapters three expose learners and readers to energy dynamics and options that could be aligned to various farm needs, including aspects of energy use efficiency. Apart from helping to mitigate effects of climate change, energy use efficiency also cuts costs in the long run, thus making the farm profitable. Chapter four is the gist of this book as it focusses on the wonder machine on the farm – the general-purpose tractor. The systems and operational principles of the tractor are addressed in an easy-to-understand way.

To create awareness of the multiple functions of a tractor, accessories that must allow these possibilities are explained in chapter five. In addition, opportunities for combined operations are also described. Chapter six builds the capacity of learners to service and maintain farm machinery so that they could serve users more efficiently (well and for a long time at minimum costs). Chapter seven emphasises the need for a well-planned machinery yard for safe keeping of machinery, their accessories and support systems with fuel storage and garage services.

The critical importance of draft animal power and the commensurate animal welfare needed to sustainably harness this source of power is covered in chapter eight. The authors make a strong case for Kenya to be deliberate in enhancing animal welfare especially oxen and donkeys.

To enhance the safety of farm stakeholders, chapter nine provides a wide array of safety tips when working with machinery. The knowledge of the non-engineer learner on key engineering materials has been boosted in chapter ten. To balance capacity and competence development during the training in farm energy, power and machinery, the authors have in chapter eleven sequenced field exposure and experiences that a well-trained university and college student in agriculture requires. To this extend, training institutions have an obligation to offer requisite infrastructure in pursuit of quality assurance.

The footnotes on various pages, reflection boxes and the bibliography at the end of the book points readers and learners to resource materials necessary for expanding their scope and knowledge in farm energy, power and machinery in the context of sustainable development. Therefore, by interacting with this reader, the learners should be able to:

1. Articulate operational principles of critical energy sources on the farm.
2. Select basic farm machinery and implements for specified tasks.

3. Advise on operational requirements of key farm machinery and especially the general-purpose tractor.
4. Perform basic maintenance of the farm tractor and its accessories.
5. Harness Draft Animal Power at the farm level within animal welfare confines.
6. Monitor and advise on occupational health and safety when working with farm machinery and other implements.
7. Innovate around micro-mechanization towards enhanced farm and land productivity
8. Maintain the momentum of agriculture that is designed for the environment.

To maximise benefits from this Reader, the instructor shall assist the learners explore their individual tasks embedded in the Reader, and also navigate through calculations or computations of his/her choice that are relevant for each section. Few such calculations are intended to enhance the capacity of learners in analytical thinking.

For providing us with the space to explore our academic and publishing passion, we profoundly thank our universities' Management, namely Kenyatta University, Machakos University, and Masinde Muliro University of Science and Technology for the support extended to us. The moral support provided by our families cannot be overemphasised.

Finally, lets us be reminded that tilling the land and adding value to its products is a task humanity was allotted as long as the earth endures. The safe and appropriate use of farm energy, power and machinery is key in the pursuit of national food security and overall environmental performance.

Fuchaka Waswa
Lead Author

1: Basic Terms

There are key terms a non-engineer engaged in agriculture or related courses should be familiar with. As a critical term, engineering can be defined as a scientific field that involves the use of our scientific understanding of the natural world to invent, design, and build things in order to solve societal problems and achieve set development goals. These tangible things (physical capital) that are as a result of engineering include roads, bridges, vehicles, aircrafts, ships, all sorts of machines, tools, equipment and implements, computers and buildings among others.

The United States Engineers Council for Professional Development defines engineering as the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behaviour under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property[1]. A rather loose definition would be the manufacture or assembly of engines, machines and tools for various functions.

Conventionally three categories of engineering dominated the discipline, thus: mechanical engineering, civil and structural engineering and electrical engineering. With time the field has expanded to include agricultural (Biosystems) engineering, chemical engineering, telecommunication and information engineering, medical engineering and environmental engineering among others. Whether these emerging offshoots are recognised as "engineering" is country specific. Suffice is to say that the world of inventions has engineering as its key signature.

For purposes of this reader, the focus shall be mechanical engineering and in particular farm power and machinery. The list below though not exhaustive provides some of the key terms, where-in farm energy, power and machinery find relevance.

[1] https://www.britannica.com/technology/engineering (Accessed on 5th August 2022)

1. **Accessories**: Something extra that improves or completes the thing it is added to; a thing which can be added to something else in order to make it more useful, versatile, or attractive.
2. **Agricultural Engineering:** This is the branch of engineering that applies engineering knowledge in providing solutions to problems faced in agriculture and food production. It is now increasingly being referred to as Biosystems engineering.
3. **Agriculture Designed for the Environment**: Agriculture that is people and environment friendly
4. **Agriculture:** Is the practice of harnessing environmental resources to produce crop and animal products for human well-being
5. **Agro-ecosystem**: An ecosystem devoted to agricultural use
6. **Carbon Neutrality:** Refers to achieving net-zero carbon dioxide emissions.
7. **Competence or skill**: Do-how of an activity
8. **Energy**: The ability to do work
9. **Engineering materials** are used during the construction and fabrication of farm tools, machinery, implements and accessories are referred to as engineering materials
10. **Engineering:** This is the branch of knowledge that applies the principles of natural sciences (physics, chemistry and biology) in provision of solutions to problems that face humankind
11. **Environment:** Sum total of nature and its components (natural and artificial)
12. **Environmental change:** Negative or positive alterations in environmental components (descriptors)
13. **Equipment**: A set of tools or other objects commonly used to achieve a particular objective. Different jobs require different kinds of equipment. An equipment can also be an accessory or an implement.
14. **Facility**: A place, amenity, or piece of equipment provided for a particular purpose, e.g., a garage
15. **Farm Tools**: A variety of pieces of equipment used in farm operations singly or together with other farm machinery
16. **Force**: Is a push or a pull, whether horizontal or vertical or oblique
17. **Fuel:** A substance harnessed for a defined purpose through the process of combustion
18. **Health:** In engineering context, being free from injury and disease

19. **Horse Power (**hp): A horse power is equivalent to 33000 feet (ft) pounds (lb) per minute. I.e., the ability to move a load of 33,000 pounds through a distance of 1 foot in 1 minute. (1 pound (lb) = 454g = 0.454 kg. Therefore 33,000 lb = 14,982 kg, thus ca. 15 tons. Therefore, 1 hp is about 15 tonnes-feet per minute. 1 metric hp = 75 kg metre per second. (I.e., moving 75 kg load through a distance of 1 metre in one second). One horse power = 0.75 kilowatt. An engine developing 100hp can be rated as 75 kW
20. **Implement**: A tool or other piece of equipment that is used for a particular purpose. A tool can also be an accessory
21. **Labour**: A factor of production generally represented by human and social capital
22. **Machinery**: Any equipment, apparatus, hardware, instrument, tool, gadget, vehicle etc. (stationary or mobile), intact or portable used to make work easier.
23. **Matter**: Is any physical substance in general, as distinct from mind and spirit; which occupies space and possesses rest mass
24. **Mechanisation**: The introduction of machines or automatic devices into a process, activity, or place; the action or process of making something mechanical in character; process of changing from working largely or exclusively by hand or with animals to doing that work with machinery.
25. **Physical capital**: Is the technology and physical infrastructure designed and developed by humans for different functions, such as transportation networks, a power grid, sewerage and waste disposal systems, etc.
26. **Power**: Is the rate of doing work, Engine power is measures in horse power or kilowatts.
27. **Quality:** The degree of excellent attribute of an item with regard to its fitness for purpose.
28. **Resource use efficiency:** Using just what is needed and necessary in a given place, context and at a given time**.**
29. **Risk:** Probability of occurrence of a certain event or activity
30. **Safety:** Protected against harm or injury
31. **Speed**: Distance covered per unit time
32. **Torque:** Turning moment of a rotating body and is a product of the force exerted by the body and the perpendicular distance from the centre of rotation
33. **Traction:** Is a force generated between tyre and soil surface that enables a vehicle e.g., tractor to pull loads and move forward.
34. **Work**: Is force applied through a defined distance

2. Development of Agricultural Mechanisation

2.1. Conventional Agricultural Mechanization

Agricultural mechanization refers to the use of machines to perform various farm operations. It includes the use of tractors to till land, plant, harvest farm produce, transport goods and also the use of accessories for other specialised operations. Mechanization plays a key role in extensive as well as intensive agricultural systems, which are key in feeding a rapidly increasing world population. Although the use of improved machinery and tools has increased substantially over the last 50 years, the use of land and labour-saving technologies, has lagged behind in many countries, especially in sub-Saharan Africa.

While it used to take a long time to plant and harvest agricultural products, the use of agricultural machinery has reduced this time and significantly enhanced efficiency of operations. Throughout history, the growing of crops was a matter of human labour and draft animal power. Oxen, horses, and mules pulled ploughs to prepare the soil for seed and hauled wagons filled with the harvest. The rest of the chores required backbreaking manual labour to plant seeds; till, or cultivate, to remove weeds so as to improve the harvest. There was also a complex and arduous task of cutting, collecting, bundling, threshing, and loading of harvests from the farm. People therefore developed tools to ease farming burdens.

The introduction of the internal combustion engine (ICE) at the turn of the 20th century, set the stage for dramatic changes in agricultural production with the tractor being at the centre of action. It was mainly involved in towing and powered the planters, cultivators, reapers, pickers, threshers, combine harvesters, mowers, sprayers and balers. In 1902 a pair of engineers named Charles Hart and Charles Parr introduced a tractor powered by an internal combustion engine that ran on gasoline[2]. The general-purpose tractor is the focus in this reader.

[22] Hart and Parr's company was therefore the first company that was devoted exclusively to making tractors. Copyright © 2021 National Academy of Sciences.

2.2. Advantages of Mechanisation

Mechanisation in agriculture has inherent advantages that include but not limited to the following:

1. Allows investment in large scale farming and hence commercial farming
2. Making work easier thus reducing drudgery
3. Improvement of efficiency and effectiveness of production
4. Reduction of time taken in operations
5. Multiplicity of tasks in a single operation, which saves on time, costs and labour requirements
6. Release of labour for non-agricultural purposes
7. Enhancement of productivity
8. Contraction of the demand for animal labour thus enhancing animal welfare
9. Diversification and multiplication of agricultural production practices
10. It is associated with human capacity and competence development
11. Often results in a shift from subsistence to commercial agriculture
12. Improvement in product quality
13. Reduction in production costs
14. Reduction of field losses (food losses)
15. Attraction of youth into farming, since farming is made to be attractive.

2.3. Disadvantages of Mechanization

Despite the advantages in mechanisation, there are disadvantages, which equally provide humanity with the opportunity to innovate sustainable solutions thereto. These challenges include but are not limited to the following:

1. Displacement of human labour thus causing joblessness
2. Environmental pollution through emission of greenhouse gases (GHGs)
3. The propensity for land degradation through soil compaction and other associated effects.
4. The use of machinery is associated with Occupational Health and Safety (OHS) concerns to mitigate against accidents.

5. Mechanisation is costly in the short term and may be deemed uneconomical in small scale farming systems.
6. Requirement of extra technical skills
7. Machinery use is season based. This reduces the returns on investment of these machines, especially when they are sometimes idle.

2.4. Enhancing Agricultural Mechanization

In order to enhance agricultural production and production efficiency, there is need to invest in mechanisation in agriculture at both extensive and intensive production systems. Some strategies that can contribute to this broad goal include:

1. Educating farmers on the need to accept the change from traditional agriculture to modern systems.
2. Simple and less expensive machines should to be developed for current small-scale based farm operations.
3. Develop more versatile machines – those which can perform different jobs at different seasons of the year – i.e., reduce idleness and loss of money.
4. Teaching farmers to develop the practice of owning and operating farm machines collectively (Chama groups).
5. Governments to establish more Agricultural Machinery Service centres (AMS) and make them more operational for tractor/machinery hire by farmers.
6. Avail credit to farmers for purchasing machinery.

2.5. Micro-Agricultural Mechanization

The existence of fragmented landholdings is a feature of less developed agricultural systems; it is regarded as a major obstacle to agricultural development, since it hinders agricultural mechanization, causes inefficiencies in production, and involves large costs to alleviate its effects. Generally, smallholder farms tend to overuse labour resulting in low productivity, which is also coupled by high labour costs per unit production. This is occurring against the background of demographic shifts in agriculture, whereby labour is becoming increasingly scarce. Lack of access to more modern forms of farm power by smallholder farmers is a key factor that perpetuates labour drudgery, particularly among women (during farm operations like weeding, threshing, shelling and transportation), whilst impeding production and farm output.

One of the main causes of low labour productivity in Sub-Saharan Africa is the lack of appropriate machinery that caters for and suits the requirements of small-scale farms. Thus, the limited adoption of mechanization among smallholder farmers is a direct consequence of the unavailability of appropriate technologies. The challenge of mitigating the effects of low labour productivity among smallholder farmers underscores the importance of adapting mechanization technologies to farm characteristics. Given that predominantly, small scale farms of limited land sizes are a common feature of most regions in Sub Saharan Africa, the introduction of big tractors as a strategy in adaptation of mechanisation may not provide all the solutions. This calls for adoption of agricultural machinery that are manoeuvrable in small holdings such as the two wheeled tractor (Figure 2.1) and generator powered portable maize shellers (Figure 2.2). The motor bike has become the choice vehicle for transporting such shellers. A part from saving time operators earn Kenya shillings per 50kg bag of shelled maize.

Figure 2.1a: A two wheeled tractor coupled to a row planter

Figure 2.1b. Forage cutter with improvised radiator, Lukhuna

Figure 2.2. Portable generator powered maize sheller. Both can fit on a motor bike.

Figure 2.3. Transporting the maize sheller

Value-addition in this design may entail directly linking the sheller to the motor-bike engine through a special PTO system.

Source of picture: Woodland Estate, Naluchira, Kakamega (August 2022).

Effective mechanization contributes to increased production in two major ways: Timeliness of operations and good quality work

2.6. Further Reading

Agricultural Mechanization. http://www.fao.org/3/i6044e/i6044e.pdf (Accessed on 17th July 2021)

3: Sources of Farm Energy

3.1. Overview

All known ecosystems are powered singly or in combination by solar energy, gravity, geothermal energy, wind power, water, fossil fuels, and natural gas. The most readily available is solar. In order to access and utilise the other forms, humans must manipulate the physical environment using various kinds of technology. This necessary perturbation may be associated with diverse and adverse socio-economic and environmental impacts[3]. Ecosystems can therefore be classified based on the sources of energy that power them (Figure 3.1). This classification also illustrates though indirectly the normal traditional to modernity transformation and associated environmental implications. The reader is encouraged to discuss the implications of the arrow to the right in the context of global environmental changes[4].

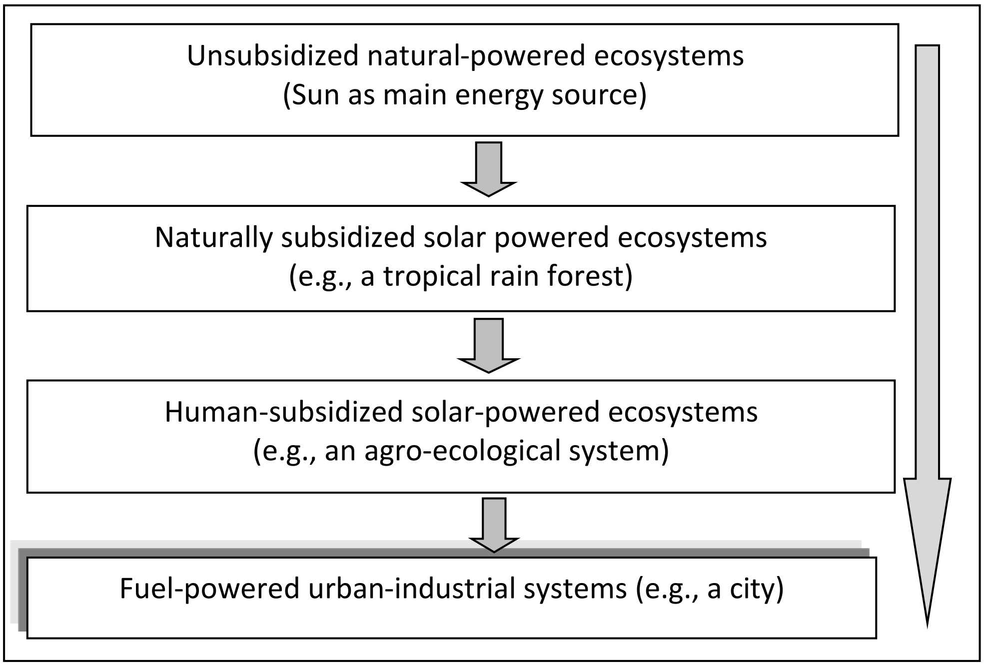

Figure 3.1: Energy based ecosystem classification

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[3] Projects that must be subjected to an environmental impact assessment are outlined in the environmental management and coordination act, 1999 (EMCA, 1999)

[4] Population pressure, pollution, climate change, security, energy crisis, conflict etc.

3.2. Renewable and Non-Renewable Energy

The critical role of farm energy in developing countries cannot be over-emphasised. Two broad categories of energy sources are generally distinguished.

1. **Renewable energy.** This is energy obtained from renewable resources, which are naturally replenished on a human time scale. The main examples include: solar energy, hydro-power, wind energy, geothermal energy, tidal energy and bioenergy. In Kenya relevant information for operating a power plant based on renewable energy may be accessed at https://renewableenergy.go.ke/[5]

2. **Non-renewable energy.** This is energy derived from natural resource that is found beneath the earth, and when consumed, does not replenish at the same speed at which it is used up. As such this energy tends to run out (will not be replenished in our lifetimes or even in many, many years). The main examples are petroleum, natural gas, coal and nuclear energy. In the first three sources (fossil fuels), carbon is the main element. Global economies are heavily reliant on these sources. However due to their potentially severe environmental impacts coupled with geo-politics associated with their supply and demand, the call to shift to cleaner renewable sources is getting louder by the day. Sustainable energy solutions are now a clarion call within sustainable development goals.

An overview of specific energy forms in these two broad categories is the focus of the next section of this chapter.

3.3. Sources and Application of Farm Energy

3.3.1. Human Energy

A part from harnessing all other energy types, people are also a critical source of farm power through the various types of work they perform on the farm. Human labour should however be utilised in line with International Labour Organisation (ILO) regulations. The farm is a system with several interdependent components where-in

[55] Energy and Petroleum Regulatory Authority (EPRA, 2022)

occupational safety is key. According to the International Labour Organisation[6] (ILO):

1. The agricultural sector employs an estimated 1.3 billion workers worldwide.
2. In terms of fatalities, injuries and work-related ill-health, it is one of the three most hazardous sectors along with construction and mining.
3. At least 170,000 agricultural workers are killed each year.
4. Millions of people are seriously injured in workplace accidents involving agricultural machinery or poisoned by pesticides and other agrochemicals.
5. Widespread under-reporting of deaths, injuries and occupational diseases in the agricultural sector compromises the real picture.
6. Since much agricultural work is by nature physically demanding, the risk of accidents is increased by fatigue, poorly designed tools, difficult terrain, exposure to extreme weather conditions, and poor general health, associated with working and living in remote and rural communities.
7. Working conditions and operations in agriculture are quite variable: season to season; extensive to intensive; subsistence to commercial; small-scale to large scale; highly-mechanised to rudimentary; out-door to indoor among others. Occupational Health and Safety risks will thus vary accordingly.
8. The most vulnerable groups are found in family subsistence agriculture, in plantations as daily paid labourers, seasonal or migrant workers without land, and, child labourers.
9. ILO defines child labour as work that deprives children of their childhood, their potential and their dignity, and that is harmful to their physical and mental development.
10. Child labour has the following key features:
    a. Is mentally, physically, socially or morally dangerous and harmful to children; and/or
    b. Interferes with their schooling by depriving them of the opportunity to attend school; obliging them to leave school prematurely; or requiring them to attempt to combine school attendance with excessively long and heavy work.

[6] https://www.ilo.org/safework/areasofwork/hazardous-work/WCMS_110188/lang--en/index.htm (accessed on 30th August 2021)

Whether or not particular forms of "work" can be called "child labour," may also vary across individual countries. In this book, child labour shall be understood as described by ILO guidelines together with the International Declaration of Human Rights.

3.3.2. Animal Power

Farm animals are harnessed for work in the context of draft animal power (DAP) Oxen, donkey and horses are commonly used in this regard (Figure 3.2). Welfare of draft animal power is discussed in detail in chapter 8.

Figure 3.2. Using oxen to plough

Draft animal power at the farm level is particularly important in developing countries where the cost of machinery is prohibitive. The use of oxen and donkeys is most popular. However, despite existence of legislation on animal rights and welfare, respect for cases of misuse and mistreatment of animals abound within local communities

3.3.3. Fossil Fuels

Fossil fuel is derived from fossilized remains of organic matter. The main examples are petroleum, natural gas and coal[7]. The main constituents are Carbon and Hydrogen, hence the name hydro-carbons. It is the breakdown of C-H bond through combustion that releases energy as illustrated below:

$$\mathbf{C_xH_y + O_2 \Rightarrow CO_2 + H_2O + Energy}$$

The main examples of fossil fuel are: petroleum and natural gas. Fossil fuels power the world but are a major source of greenhouse gasses especially CO_2 and other oxides of carbon. The role of fossil fuels in

[7] Coal is a dark or brown solid material formed from vegetation, which has been consolidated between other rock strata and altered by the combined effects of pressure and heat over millions of years to form coal seams (Source: https://www.worldcoal.org/coal-facts/what-is-coal-where-is-it-found/) Accessed on 13th April 2022.

global warming and climate change cannot be overemphasised (Figure 3.3).

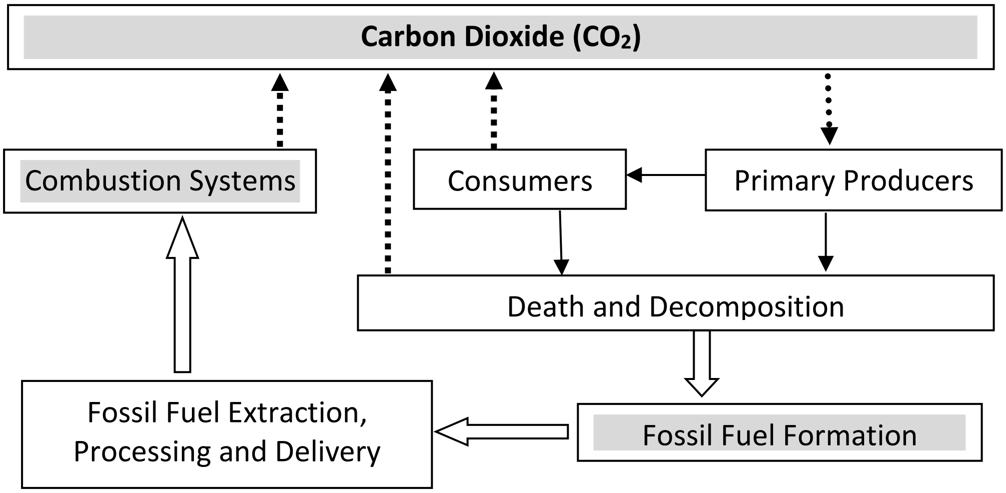

Figure 3.3: A simplified illustration of fossil fuel synthesis

Primary producers (green plants) take in CO_2 to synthesise carbohydrates through the process of photosynthesis. This vegetation can be eaten by secondary consumers, who upon respiration release CO_2 into the atmosphere. When both producers and consumers die, they decompose and contribute to the formation of fossil fuel. Upon extraction and processing through refineries, fossil fuel in the form of different grades of petroleum is used to power different machines largely through combustion process, thereby releasing CO_2. Today innovations in efficient use of fossil fuels to reduce CO_2 emission (pursue carbon neutrality) is key in global environmental dialogue[8]. Similarly, innovations in favour of green (clean) energy alternatives are in top gear. The agricultural farm cannot be left behind in this endeavour.

> ***Future Trends:*** Globally, the quest for energy security and the risk of climate change highlights the need for a transition to a low-carbon, high efficiency and environmentally friendly energy system.

[8] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (Accessed on 08-03-22)

3.3.4. Biomass Energy

Biomass energy is the energy captured from the sun through photosynthesis and stored in biological matter. Its forms include: wood fuel (firewood), briquettes, crop residues, animal waste, biofuels (biogas, bioethanol and biodiesel) among others. It is the most dominant energy source in rural agro-ecosystems, and has direct connection to agriculture and the well-being of households. Biomass energy also has a direct bearing to greenhouse gas emissions and hence global warming and climate change. Some examples of biomass energy are outlined below:

3.3.4.1. Wood Fuel (firewood)

Firewood is the traditional and most popular source of energy in rural households and majorly used for cooking. In-door air pollution is a major problem associated with its use. Although the traditional 3-stone cook stove has been in use from time immemorial, improved[9] cook stoves are gradually gaining popularity as more efficient appliances for the use of wood fuel. Reliance on wood fuel is however a major threat to forest cover and hence biodiversity conservation. This calls for energy options that enhance achievement of the 10% threshold, while mitigating global warming and climate change.

3.3.4.2. Briquettes

These are special charcoal produced from densification of waste plant materials like coffee husks, maize cobs and stalks, sugarcane bagasse, and sawdust[10]. These briquettes can either be carbonized or non-carbonized.

3.3.4.3. Biogas

This is the gas generated from the anaerobic digestion of biomass especially animal wastes (cow dung, chicken droppings etc.), human excreta and plant wastes. Biogas is composed of methane (CH_4), carbon dioxide (CO_2), and traces of hydrogen sulphide (H_2S) and water vapour. To commercialise methane generation calls for guaranteed production of adequate volumes, purification and

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[9] Are designed to enhance efficiency in fuel wood combustion and also reduce indoor air pollution from smoke.

[10] Waudo S and Waswa F. (**2024**). Value-Addition in Biomass for enhanced Household Energy Security in Navakholo Sub-County, Kenya. Journal of the Kenya National Commission for UNESCO. https://doi.org/10.62049/jkncu.v4i1.52

liquefaction into standardised LPG containers. Research by Wachera (2017)[11] in central Kenya showed that only two dairy cows under zero grazing system are sufficient to supply a typical small-scale biogas digester with required raw material. As such, most rural households have the potential to expand their energy options in this way. The initial cost involved is however the main disincentive.

While figure 3.4a illustrates a design that integrates animal waste and human excreta as raw materials, most popular designs are singly powered by animal dung. The other potential of biogas for domestic energy supply lies in the use of biodegradable kitchen wastes (Figure 3.4 b). The slurry from biogas digester forms very good organic fertilizer.

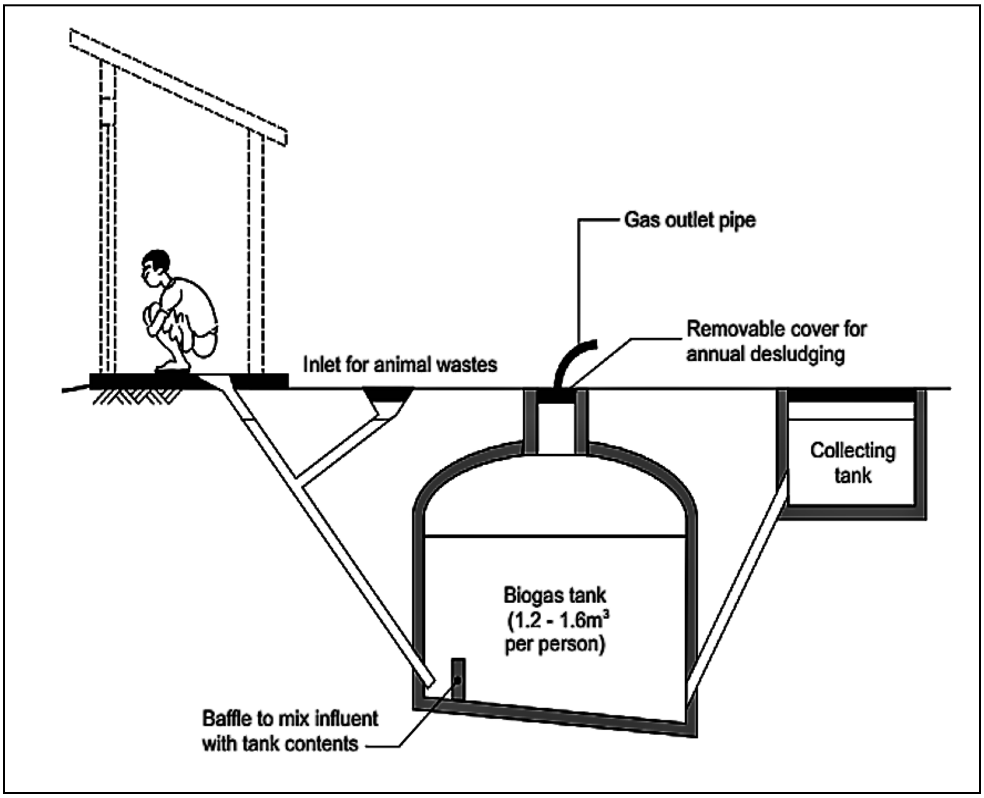

Figure 3.4a. Biogas digester fed from raw material from a toilet and animal waste

[11] Wachera R W and Waswa F. 2017. Enhancing Energy Access and Soil Fertility Management through Biogas Technology in Smallholder Dairy Production Systems in Nyeri County, Kenya. *International Journal of Agriculture and Environmental Research* (3) 5: 3691-3708. ISSN: 2455-6939

Currently domestic toilets are also being designed as bio-digesters to supply methane as an energy buffer for households.

> The concept of eco-toilets where-in biogas gas is generated from human faecal waste in urban centres, has greatly enhance public health in slum areas. Kibera slum in Nairobi makes an excellent case study.

Figure 3.4b. A Demo-biogas plant powered by biodegradable kitchen wastes at AMIRAN[12] Head Office, Nairobi Kenya. Photo was taken during the peak of Covid-19 pandemic

3.3.4.4. Saw Dust

Due to scarcity of firewood, rural households are increasingly turning to burning saw dust in specialised gasifiers for cooking purposes (Figure 3.5). Saw dust can also be combined with other material like waste paper, charcoal dust and cow dung, and turned into more efficient composite energy balls. Research to establish the appropriate

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[12] https://www.baltoncp.com/amirankenya/agribusiness/home-biogas/ (Accessed on 08-03-22)

combinations and relative amounts is needed. In Kenya a lot of saw dust generated from timber mills goes to waste, when an additional value chain to manufacture saw dust energy balls for cooking or saw bust briquettes can be created.


Figure 3.5. Saw dust gasifier. Note the dense parking and energy loss

Future Trend:
The next frontier in biomass energy research is value-addition just as it is done for crop and animal commodities.

3.3.4.5. Biofuels

Biofuels are liquid fuels obtained from biomass materials (selected plants/crops). These fuels are usually blended with petroleum fuels, but they can also be used on their own. Two types of biofuels are generally distinguished; bioethanol and biodiesel.

Bioethanol

Bioethanol is fuel sourced from carbohydrate-based crops through the process of ethanolic fermentation. The most popular bioethanol crops include sugarcane and maize. The United States is the world's largest producer of ethanol, having produced over 13.9 billion gallons in 2020. Together, the United States and Brazil produce 84% of the world's ethanol. The vast majority of U.S. ethanol is produced from corn, while Brazil primarily uses sugarcane[13].

[13] https://www.statista.com/statistics/281606/ethanol-production-in-selected-countries/ (Accessed on 5-3-22)

Biodiesel

Biodiesel is fuel extracted from oil crops using extraction equipment (machinery). The most popular biodiesel crops include Jatropha, palm kernel oil, linseed, and canola oil among other seed-based oils. By 2019 Indonesia was the leading producer of biodiesel followed by the USA, Brazil and Germany in that order as global champions in biodiesel. No African country appears in the top ten producers of biodiesel[14].

Discussion Question

1. Using examples explain the meaning of the term bioenergy
2. Which crops or plants can be harnessed for biofuel production in Kenya?
3. Should Kenya till land for biofuel production or for food security?
4. Explain the potential of arid and semi-arid lands in future production of biofuels.

3.3.5. Electrical Energy

3.3.5.1. Overview

Electric energy is generated by the flow of electrons in a circuit. The following are the salient issues in electrical energy:

1. Electric potential is measured in volts and it is this pressure that causes an electric current (measured in amperes) to flow through a conductor.
2. Electric pressure (voltage) is provided by a dynamo or generator. Mechanical rotation of a dynamo in a magnetic field causes an electric current to be produced.
3. In a battery, two suitable yet dissimilar materials are situated in a chemical (electrolyte). Since there is an electric pressure (charge) between the two materials, a current (electrons) will flow if the 2 materials are connected by an external wire.
4. While a battery can be recharged (i.e., reversible changes in the electrolyte), the same is not possible in a torch. The changes in the chemical material in a torch keep happening until the torch dies, thus necessitating replacement of the batteries (dry cells)

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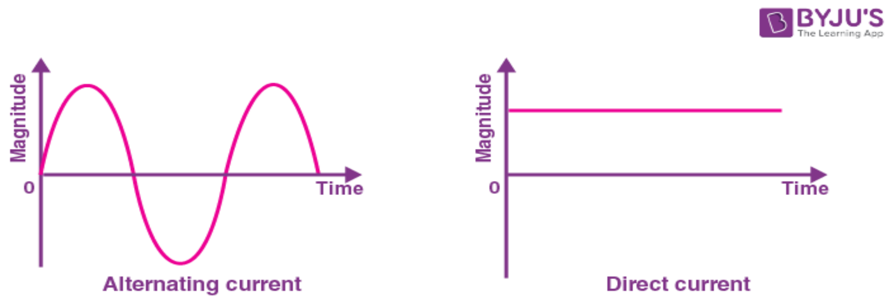
[14] https://www.statista.com/statistics/271472/biodiesel-production-in-selected-countries/ (Accessed on 5-3-22)

5. Specific materials act as conductors (current can flow through them). Those which cannot are called insulators or non-conductors.
6. Two types of current exist: Direct Current (DC) – the flow is continuously in one direction e.g., from the battery. Alternating Current (AC) - current that changes its magnitude and polarity (direction) at regular intervals of time (Box 1). AC is supplied to pieces of equipment using 3 wires; thus: Power is transmitted by the hot (live) wire (Red). The neutral wire is connected to the earth and provides a return path for the current in the hot wire (i.e., the reversed flow at completion of one cycle). The third wire that is also connected to the earth is linked to the metallic parts of the equipment to mainly eliminate electric shock hazards. AC is used mostly in homes and offices because its generation and transport across long distances is a lot easier and energy loss with distance is much less.
7. No material will conduct a current without some resistance, which is measured in ohms. This resistance manifests itself as heat, which is a sign that power is being wasted. A conductor with high resistance makes a good electric heater. Water heaters operate based on this heat generated from resistance.
8. A circuit is the complete pathway of current flow from generator through appliance and back to source of pressure.
9. A fuss along an electric current is a safety valve to cut off excessive current that can cause damage. The fuse is generally a thin wire designed to carry a limited current only. The fuse (wire) melts to break the circuit any time the current exceed this limit.

Box A: Direct Current (DC) and Alternating Current (AC)



Source: https://byjus.com/jee/alternating-current/ (Accessed on 25-01-23)

To Note:

1. The time interval between 2 successive cycles is the period
2. Number of cycles or periods per second is the frequency
3. The maximum voltage or current in both directions is the amplitude

3.3.5.2. Measuring Electric Power

1. Electric pressure is measured in volts, which is the pressure of electric current at source. The higher the voltage, the more dangerous is the electric power and the greater is the flow of current assuming constant resistance.
2. Rate of flow (current) is measured in amperes
3. Resistance is measured in ohms and is inversely proportional to amperes.
4. If high voltage (pressure) is accompanied with less current flow, then the resistance is high and vice versa.
5. Electric power is measured in watts. Since most machines use large number of watts, kilowatts (kW) is used to make figures more convenient (1000 Watts = 1 kW).
6. Quantity of power consumed is measured in kilowatts. 1 unit = 1000 watts = 1 kW
7. 1000 watts used for 1 hour is called 1kilowatt-hour (1 kWhr)
8. Total cost = kilowatts x time (hrs) x cost per unit [Appliance watts x time)/1000] x unit cost

3.3.5.3. The Transformer

The transformer is characterized as follows:

1. When a current is passed through a conductor, an electric field or region is produced round that conductor. If a second conductor is placed in that field, any changes in the field or any change in the position of the second conductor will induce an electric current in the second conductor. This is called *electromagnetic induction* and it is used in the electric starter motor and in ignition systems of engines.
2. Transformers step up the voltage in the secondary circuit. Transformers have two coils called primary and secondary windings. If the secondary winding has more turns than the primary windings, the voltage is increased and current in decreased and vice versa.
3. The relationship between voltage, current, and resistance is described by **Ohm's law;** thus: the current (***i)*** flowing through a

circuit is directly proportional to the voltage (***v***), and inversely proportional to the resistance (***r***).

4. *Hence:* ***i=v/r***
5. Thus: if voltage is increased, the current will increase. But, if resistance is increase, then the current will decrease.

Colour Coding

1. Because electricity from the mains can be dangerous, colour coding is used to quickly enhance safety. In order to make sure that the correct wires are attached to the correct terminals when appliances are being connected to the mains, each wire has a different-coloured insulation. Thus:

a. **RED** is used for the live part of the circuit and switches should always be incorporated in this wire.
b. **BLACK** is used for the neutral part of the circuit
c. **GREEN** is used for the earth line. It allows would be dangerous current to escape to the earth rather than cause damage like electric shocks and or electrocution

3.3.5.4. Electricity-based Energy Sources

The conventional energy sources that generate electricity for work include:

Hydro-Power

Hydro-power is electricity generated when falling water is used to turn turbines in a magnetic field thus generating electricity based on the left-hand rule[15]. Generated electricity is stepped up using transformers and distributed using power cables. Most dams are multi-purposes with hydro-power as a major function. Micro-hydropower stations can be constructed on several scattered water falls within the country.

A typical hydro-power station is as illustrated in figure 3.6. Water falls through a head (height) to a turbine, which then rotates in a magnetic field, thus generating electricity. This is the basis of a generator or dynamo. The headlights of a bicycle at night work on this principle. Huge hydro-power stations like *Kindaruma* dam in Kenya supply the national grid. The potential for small hydropower power stations on

[15] Availability of any 2 of the following items/components, will automatically yield the 3rd: Motion, magnetic field and electric current.

many rivers is high. To leverage on this opportunity calls for policy changes that would cut on costs and liberalise power generation and supply.

Reflection Question:

1. Document the multi-purpose projects that generate electricity in your country
2. How much power does each dam generate?
3. Assess the negative socio-economic and environmental impacts of multi-purpose projects like dams.

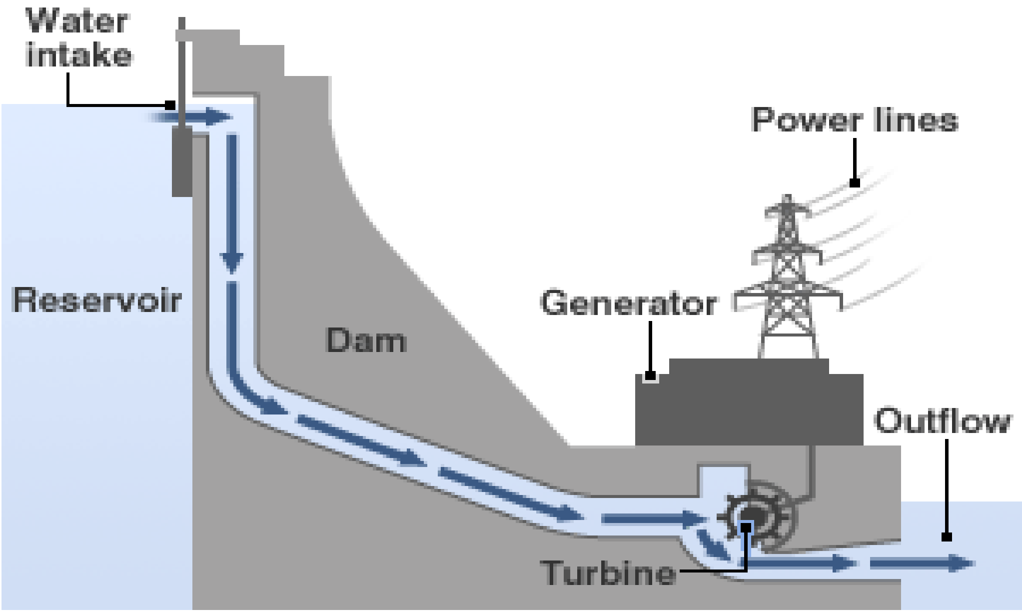


Figure 3.6: Illustration of hydro-power generation (Source: http://news.bbc.co.uk/2/shared/spl/hi/sci_nat/06/global_energy/html/hydrowind.stm (Accessed 14-02-2022)

Geothermal Energy

As the name suggests, geothermal energy is energy generated from below the earth. Water in confined acquirers is heated by underlying hot rock, which is in turn heated by magma. When a well is sunk into this confined acquirers, the hot water gushes to the surface under pressure. The vapour from is harnessed to spin (rotate) a turbine, which causes motion within a magnetic field to generate electricity. Hot water deposits are the most common sources of steam and hence the geothermal energy. Kenya is famous for this form of energy at Olkaria in Naivasha[16] within the hell's gate region. A schematic representation of geothermal energy system is provided in figure 3.7.

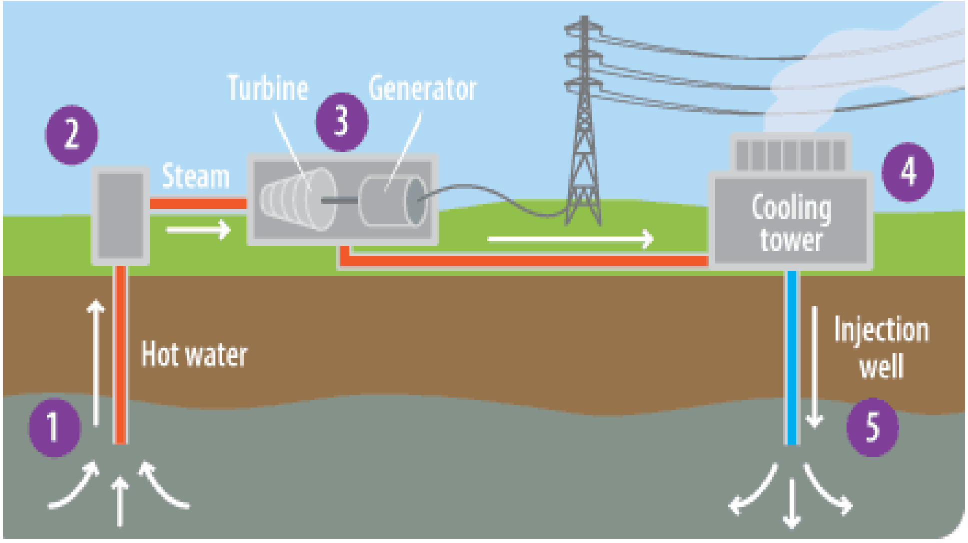


Figure 3.7: Illustration of geothermal energy generation (source: https://archive.epa.gov/climatechange/kids/solutions/technologies/geothermal.html) Accessed 0n 14-02-2022

Solar Power

Solar power is electricity obtained from the sun through photovoltaic technology. Solar cells trap the sun's energy and transform it into electricity (Figure 3.8). For mega solar plants, the scarcity of land has necessitated the installation of solar panels on water bodies like lakes. Just like hydro-power, solar power has wide applications. Among the public universities in Kenya, Kenyatta University has one of the largest solar plant[17] with a capacity of 100 kilowatts. This project was funded by the French government in partnership with French solar solutions provider, Urbasolar at a cost of about US$0.15 million.

[16] Geothermal resources in Kenya are located within the Rift Valley with an estimated potential of between 7,000 MW to 10,000 MW spread over 14 prospective sites (Source: https://renewableenergy.go.ke/technologies/geothermal-energy/#:~:text=Geothermal%20resources%20in%20Kenya%20are,spread%20over%2014%20prospective%20sites.&text=This%20makes%20geothermal%20a%20very,electricity%20generation%20in%20the%20country) Accessed on 14-02-2022

[17] http://www.ku.ac.ke/ku/item/675-ksh17m-solar-pilot-project-commissioning-at-ku

The future of global energy security is shifting to electric cars, which necessitates construction of charging stations powered by solar energy[18].

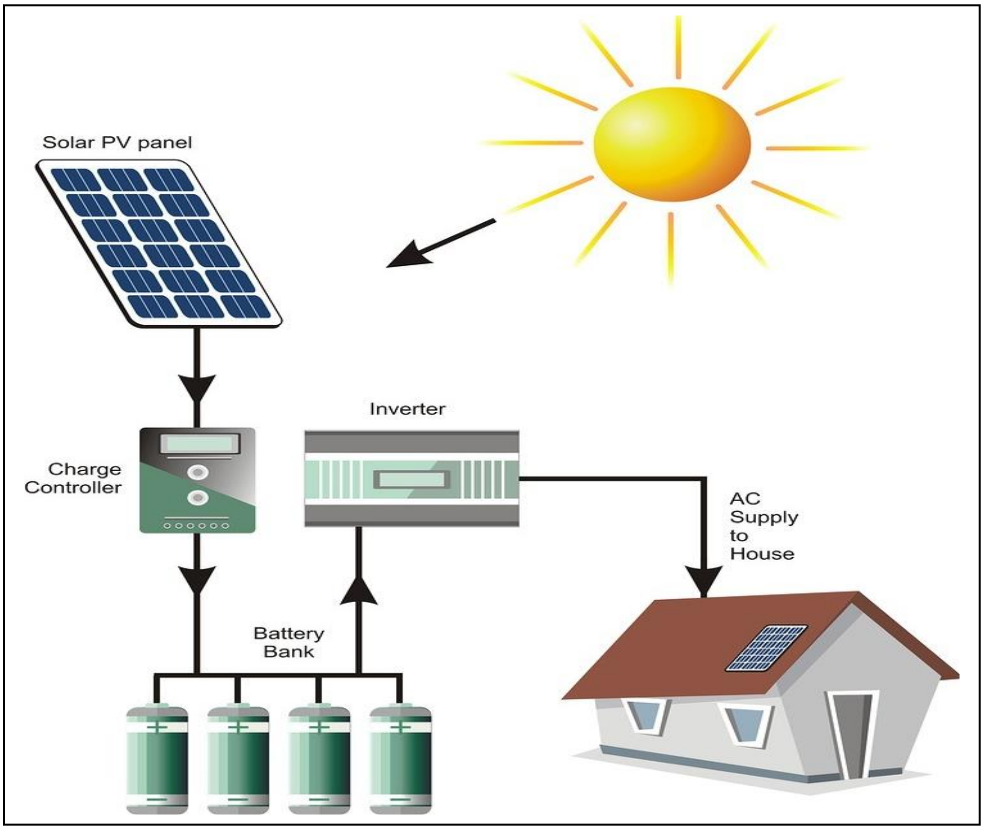


Figure 3.8: Solar energy generation and harnessing for water pumping Source: https://www.indiamart.com/proddetail/solar-off-grid-power-plant-2kw-19806716548.html (Accessed 04-12-2022)

Wind Power

Wind power is electric energy harnessed from wind currents. However, the power is sporadic and uncertain in many areas. Wind causes the turbines to rotate, which in turn causes rotation of coil in a magnetic field thus generating electricity (Figure 3.9 a). Nowadays, turbine towers are becoming taller to capture more energy, since winds generally increase as altitudes increase. At higher heights

[18] https://www.afrik21.africa/en/kenya-kengen-installs-a-charging-station-for-electric-vehicles-in-nairobi/ (Accessed on 11th April 2023)

above the ground, wind can flow more freely, with less friction from obstacles on the earth's surface such as trees, other vegetation, buildings, and mountains. Rotor diameters too have increased in recent times. In the USA, the average rotor diameter in 2021 was 127.5 meters! (Figure 3.9 b).

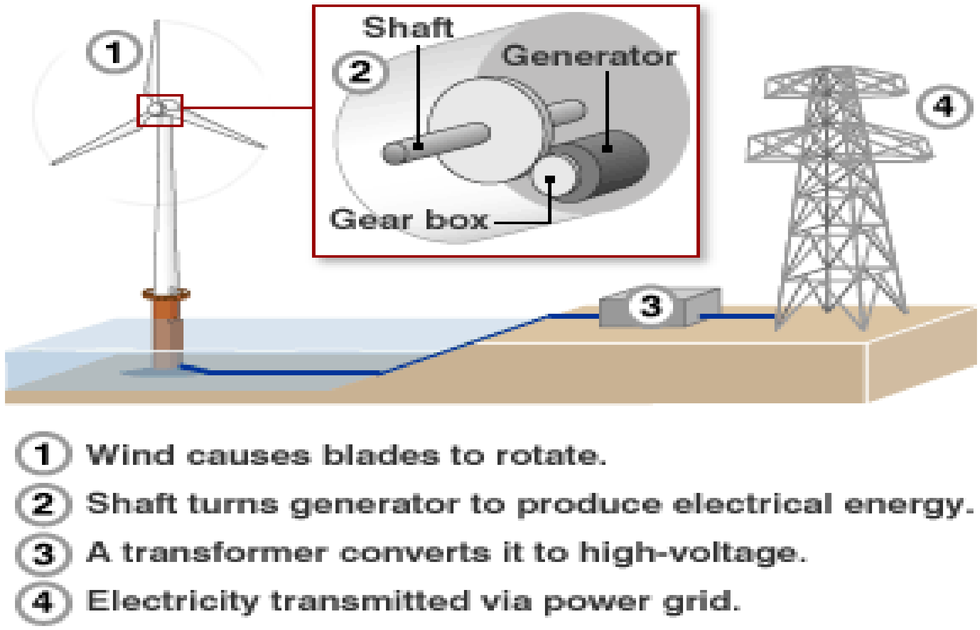


Figure 3.9(a). Illustration of a wind power system (Source: http://news.bbc.co.uk/2/shared/spl/hi/sci_nat/06/global_energy/html/hydrowind.stm (Accessed 14-02-2022)

As an example, in farm application, a windmill converts kinetic energy of the wind into mechanical energy to do various activities such as pumping water (Figure 3.9 c). On the other hand, a wind farm is a cluster of wind turbines in a favourable geographic location for purposes of generating electricity. The largest wind farm in Kenya is located at *Loiyangalani* in Marsabit County[19]. It has the potential to generate 310 megawatts of electrify.

[19] The Lake Turkana Wind Power project is the largest in Africa and is made up of 365 turbines, each having a capacity of 850 kilowatts. It is located 600 kilometres from Nairobi in the Loiyangalani District, Marsabit County. Construction of the facility started in October 2014 and it began full commercial operations in March 2019 (Source: https://www.cnbc.com/2019/07/22/the-biggest-wind-farm-in-africa-is-officially-up-and-running.html) Accessed on 12-02-2022

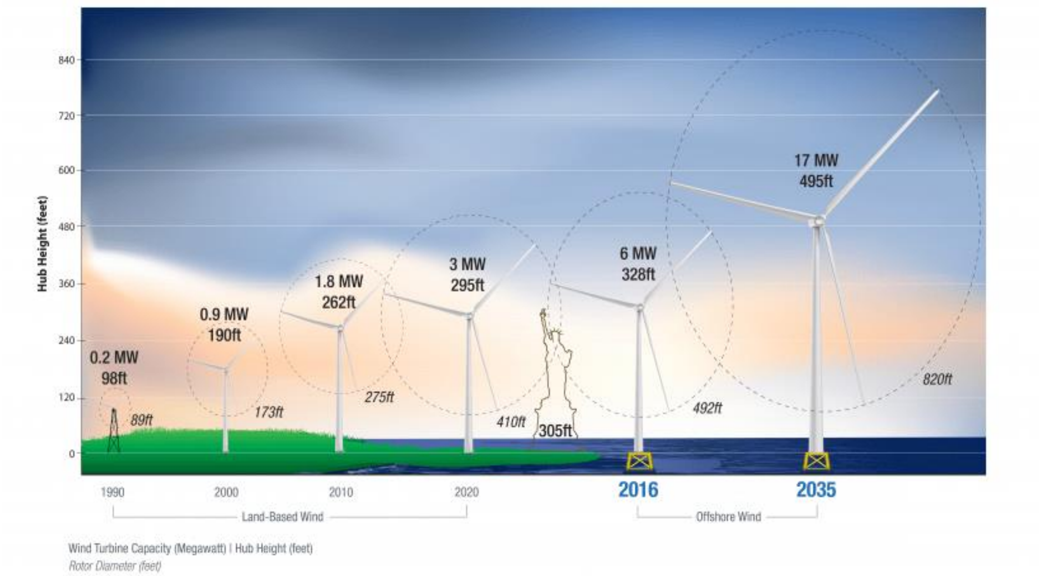


Figure 3.9(b). Illustrating turbine height and rotor diameter (Retrieved on 4th October 2022 from: https://www.energy.gov/eere/articles/wind-turbines-bigger-better)

Figure 3.9(c). Lake Turkana Wind Power Project. Largest wind farm in Africa. Source: https://www.dailysabah.com/energy/2019/07/20/kenya-launches-biggest-wind-farm-in-africa-providing-one-fifth-of-energy-demand (Accessed on 29-11-22)

Nuclear Power

Nuclear energy is derived from the fission of radioactive elements and in particular Uranium 235 isotope. Fission reaction (splitting of atoms through bombardment from free neutrons results into the production of other neutrons, protons and heat energy (Figure 3.10).

The energy generated is given by Einstein's equation, thus:

$$E = MC^2$$

Where:

E = Energy generated
M = Mass of radioactive material
C = Speed of light

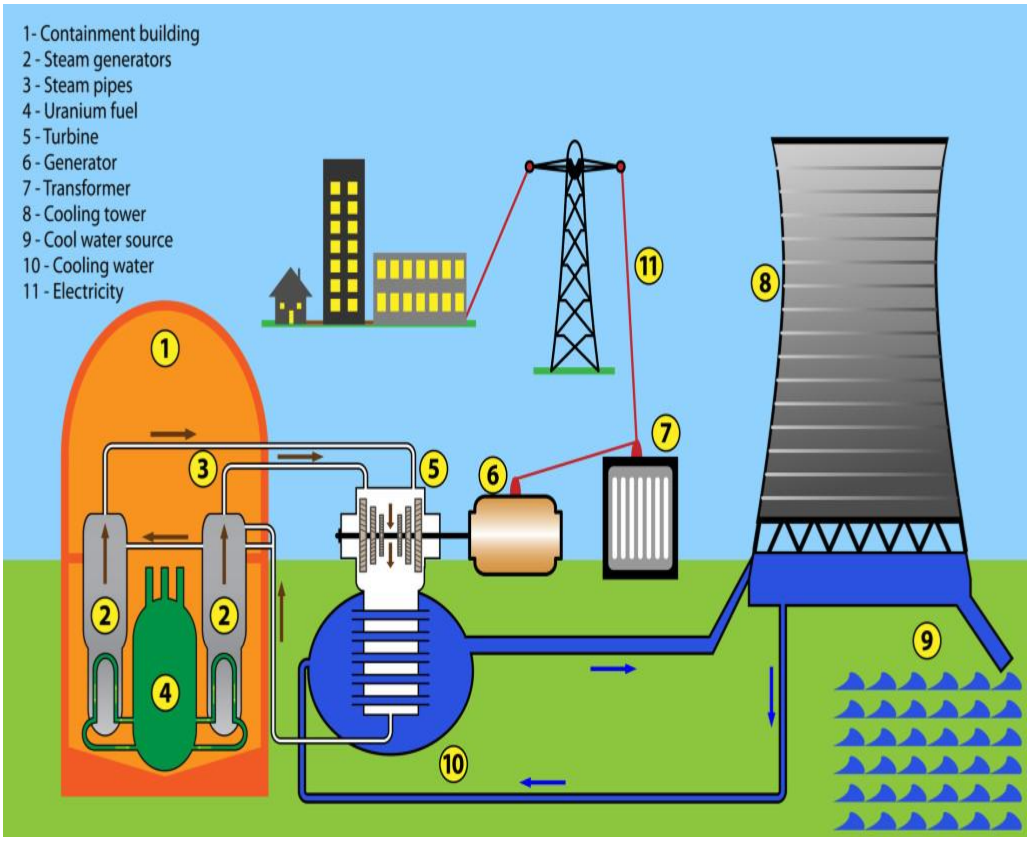


Figure 3.10: Illustration of a nuclear energy plant (Source: https://kidspressmagazine.com/science-for-kids/misc/misc/nuclear-energy.html) Accessed 14-02-2022

Although nuclear energy is clean and very reliable, it is associated with high risks including nuclear radiation and hazardous nuclear wastes.

The Chernobyl nuclear disaster in Ukraine[20] is an example to keep learning from.

Most countries are decommissioning their nuclear plants in favour of renewable and cleaner energy sources. International treaties also exist to limit possession and use of nuclear weapons. The International Atomic Energy Agency (IAEA) is responsible for monitoring and overseeing the restrictions

Ocean Power

The potential of ocean power lies in the flow of tides, movement of waves and ocean currents. These waves and currents must be harnessed to drive turbines and generate electricity. Since the waves are irregular, this energy is also intermittent and therefore less reliable. This may explain why it is relatively untapped.

Individual learning tasks	1. Read the material on *renewable energy* sources provided at the indicated hyperlink 2. Explain the relative applicability of these energy sources on a typical rural farm 3. Do some literature review on how electricity can also be obtained from decommissioned damp sites by use of special generators

Reflection:

Both renewable and non-renewable energy sources can be made more environment friendly through their efficient use and behavioural changes in their composition patterns

[20] https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/chernobyl-accident.aspx (accessed on 08-03-22)

3.4. Strategies for Farm Energy Management

3.4.1. The Energy Pyramid

With today's increasing energy prices, the agricultural sector must invest in new innovations to save energy on the farm. Energy actions typically increase in cost and complexity as one moves along the energy demand and supply pathway. The conventional audit starts from conservation activities to energy-efficiency measures and finally to alternative energy (Figure 4.1). An audit of the current energy consumption on a farm should help us recommend better ways to save energy through more efficient behaviours and use of equipment, best energy choices, their cost, energy efficiency measures, and alternative energy options (Gulkis, 2009). The complexity of energy actions typically increases up the pyramid

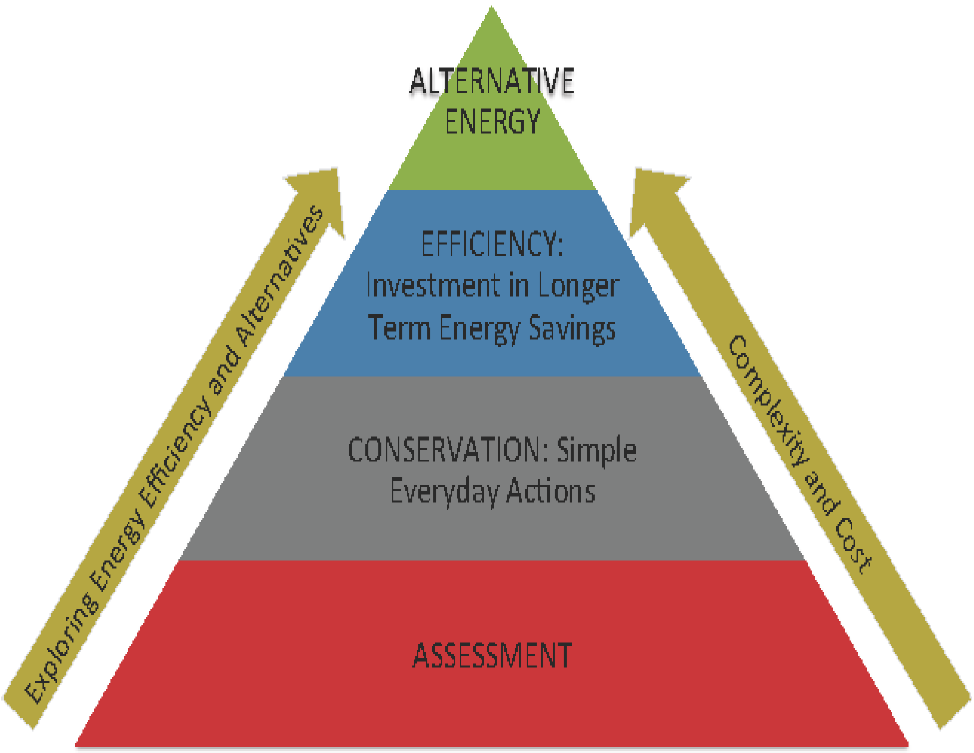


Figure 3.11. The Energy Audit Pyramid
Source: https://energizeohio.osu.edu/farm-energy-management
(Retrieved April 18, 2024)

3.4.2. Ecological Footprint and Energy Use Efficiency

The Ecological Footprint[21] (EF) estimates the area of environmental resource required to support our consumption patterns (food, goods, services, housing, and energy) and assimilate our wastes on an annual basis. It is expressed in "global hectares" (gha) or "global acres" (ga), which are standardized units that take into account the differences in biological productivity of various ecosystems impacted by your consumption activities. The bigger the area the more the pressure on the environment; and the less efficient is the production system. Energy is a critical resource for the global economy. Its demand is increasing, while supply is declining; hence its importance in sustainable development (SD) agenda and dialogue around the world.

3.4.3. Reducing Carbon[22] and Energy Footprint on the Farm

Reducing carbon and energy footprint on the farm and other human activities should now be the norm and not the exception in this era of sustainability thinking. This can be done at the farm level using among others the following strategies:

Use of cleaner transport in farm operations

1. Avoid allowing your motorized machinery to idle. If you'll be waiting for more than 30 seconds, turn off the engine (except in traffic).
2. Have your vehicle serviced regularly to keep the emission control systems operating at peak efficiency. Check your car's air filter monthly, and keep the tires adequately inflated to maximize gas mileage.

Addition of energy-saving features to your farm

1. Install LED bulbs in all your home light fixtures-but remember, compact fluorescents contain mercury, so look for low-mercury models and be sure to dispose of old bulbs safely through your local hazardous waste program.
2. Weather-proof your home. Make sure your walls and ceilings are insulated, and consider double-pane windows. Eliminate drafts with caulking, weather strips, and storm windows and doors.

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[21] For details visit: https://www.footprintnetwork.org/our-work/ecological-footprint/

[22] Carbon footprint is the amount of CO_2 emissions associated with all the activities of a person or other entity (Source: https://www.britannica.com/science/carbon-footprint)

3. Insulate your water heater. Switch to a tank-less water heater, so your water will be heated only as you use it.
4. Choose energy efficient appliances like improved cook stoves

Adoption of energy-saving habits

This intervention is hinged upon behavioural changes that bolster resource stewardship, such as:

1. Making use of power equipment only when necessary and choosing green electricity
2. Putting off lights during the day
3. Activate instant shower heaters only when necessary and for a short period.

> Visit the nearest market centre and familiarise yourself with the different types of improved cook stoves and what sets them apart.

3.4.4. Further Reading

1. Atlas of Africa Energy Resources. UNEP 2017. https://www.icafrica.org/fileadmin/documents/Publications/Africa_Energy_Atlas.pdf (Accessed 0n 12-02-2022)
2. Energy in Developing Countries. https://www.princeton.edu/~ota/disk1/1991/9118/9118.PDF (Accessed on 12-02-2022)
3. International Renewable Energy Agency (IRENA): https://www.irena.org/-/media/Files/IRENA/Agency/Data-Statistics/2-Overview-of-renewable-energy.pdf?la=en&hash=6B78D45E6E3D67409D05F7FAB38D638A4F9ACB55 (Accessed July, 2021)
4. WHO. Reducing your carbon footprint. https://www.who.int/world-health-day/toolkit/dyk_whd2008_annex1.pdf

4. Tractors and Principles of Internal Combustion Engines

4.1. Tractors as Wonder Machines on the Farm

A machine is a thing that is created by people to make work (task) easier. It is a tool or invention which multiplies the effect of human effort. It can be a mechanically, electrically, *or electronically operated device for performing a task.* Machines can therefore be applied across many task areas. Accordingly, agricultural machinery are structures and devices used in farming (agriculture). Many types occur: from hand tools, power tools and tractors, and the countless kinds of farm implements that they tow or operate. Tractors are however the conventional vehicular machinery on the farm. It is a farm vehicle that coverts chemical energy from fossil fuel into mechanical energy to do work. It has the ability of replacing at least 10 horses for a farm task. And unlike the horses, there is no need for rest. This comparison of the horse equivalence for a machine is a precursor of the concept of horse power (Hp). This is however possible when attention is given to lubrication and supply of fuel.

Different types of tractors are designed for different tasks. Common types have been described by among others Shippen and Turner (1966)[23] and include:

1. Walking type tractor. This tractor is usually fitted with two wheels only. The direction of travel and its controls for field operation is performed by the operator, walking behind the tractor
2. General purpose tractors (30 – 100kW)
3. Crawlers (Track laying tractors)
4. Heavy wheeled tractors (100 – 500kW)
5. Caterpillars. Mainly used in earth movement operations

Tractors are also named based on the implement attached to them for specific functions. Both the vehicle and the implement attached to it qualify to be called machines, because they make work easier by

[23] Source: Shippen J.M and Turner J.C. 1966: Basic Farm Machinery. Volume 1. Pergamon, Oxford. Unless otherwise stated all subsequent images in this part of the book have been obtained from this same book.

multiplying human effort. Some specific examples in this case include:

1. Rough Terrain Vehicles (RTVs): specially designed to navigate rough and uneven terrain. Similarly, All Terrain Vehicles (ATVs) also called quad bikes are a simple way of moving around larger farms and are much more efficient than tractors
2. Harvesters for both above and below ground farm produce
3. Sprayers including simple knap sack prayers or boom sprayers.
4. Planters: Used for planting/drilling seeds
5. Transplanters: used for transplanting seedlings from one place to another
6. Tillage machines/implements: Ploughs, Cultivators, Harrowers, Furrowers and Ridgers etc.
7. Leveler: Is a tractor implement used to make the soil more levelled, smooth and surface obtained, enabling it to create a moist environment for crops and reducing consumption of fertilizers, seeds, chemical and fuel.
8. Grain Millers: Grinding grain into flour
9. Cutters such as Mowers, Power saws and Brush cutters (also called a brush saw or clearing saw) which is a powered tool used to trim weeds, small trees, and other foliage not accessible by a lawn mower. Various blades or trimmer heads can be attached to the machine for specific applications
10. A sawmill or lumber mill is a facility where logs are cut into lumber
11. Balers for packaging hay into bales
12. Grabber: Is a useful attachment for tractors used to grab or hold a large amount of items, which makes this farm task more efficient. E.g sugarcane grabber makes loading harvested cane very easy, fast and efficient.
13. Trailer: for transporting heavy loads of materials or equipment around a farm. It can be easily connected to a tractor via a coupling mechanism or hitch, allowing it to be towed with ease.
14. Backhoe: Is used for digging holes or doing small excavations (Figure 4.1a)

Figure 4.1a. Backhoe

15. A Loader (Figure 4.1b). The loading assembly at the front is operated based on hydraulic principles. Similarly a Telehandlers (boom lifts) (Figure 4.1c) are used for tasks like lifting hay bales and moving heavy loads

Figure 4.1b. A Telehandler

Figure 4.1c. A Loader

For purposes of this book, emphasis is put on the general-purpose tractor (Figure 4.1d). Most tractors including the general-purpose model are powered by internal combustion engines (**ICE**). Steam engines were powered by external combustion engines[24] (**ECE**)

[24] An external combustion engine is a heat engine where an (internal) working fluid is heated by combustion of an external source, through the engine wall or a heat exchanger. The fluid then, by expanding and acting on the mechanism of the engine produces motion and usable work (https://www.engineeringchoice.com/external-combustion-engine/) Accessed on 12-02-2022. As an example, a steam engine derives its heat from fuel consumed outside the cylinder.

Figure 4.1d. The general-purpose tractor with a mounted disc plough in rest position

The essential parts of a tractor engine are arranged in such a way as to allow a series of events (operation cycles) to occur. Key components include:

1. Camshaft: Regulates opening and closing of valves
2. Connecting rod: Connects piston to crankshaft
3. Crankcase: Houses the crankshaft and its accessories. It has a crankcase breather that prevents build-up of pressure in the crankcase.
4. Crankshaft: Its rotation moves the pistons up and down in the cylinder (Figure 4.2)
5. Cylinder head: Seals off the top of the cylinder
6. Cylinder: receives fuel for burning
7. Exhaust valve: Allows exit of exhaust gases (CO_2 CO, vapour, heat)
8. Flywheel: Is fitted to the crankshaft to assist it maintain uniform turning (rotation).
9. Inlet (Induction) valves: Allow entry of fuel-air mixture (Petrol engine) or air (diesel engine) into cylinder
10. Piston: moves up and down the cylinder

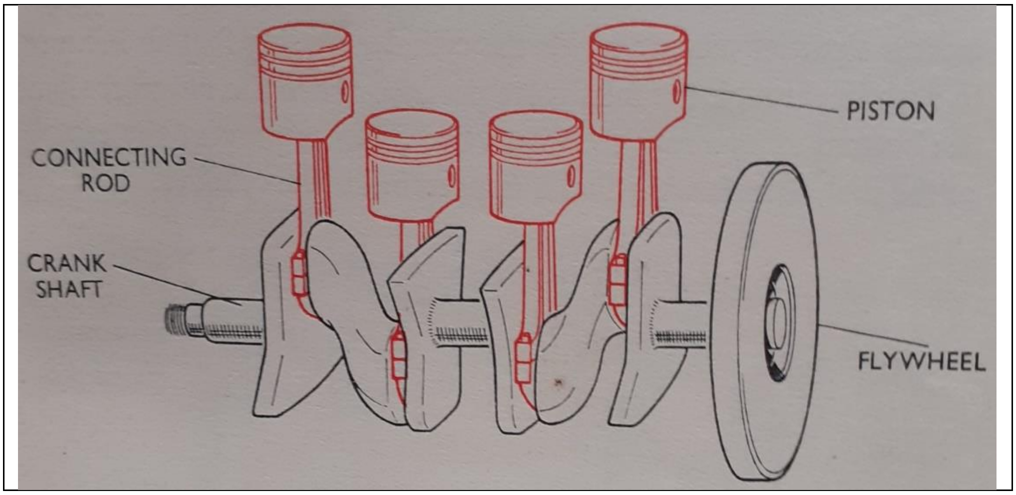

Figure 4.2: Arrangement of pistons on crankshaft (Source: Shippen and Turner, 1966)[25]

Most tractor engines operate on a 4-stroke cycle. The internal combustion engine[26] is a form of heat engine because heat energy produced during burning of fuel is changed into mechanical energy to yield a push, pull, lift, rotary motion. Common fuels used are petrol and diesel for spark ignition and compression ignition respectively.

Vertical cylinder orientation is most common; though horizontal orientation exists. Where an engine has several cylinders, the arrangement is multiplied so that all connecting rods are attached to one crankshaft having the required number of cranks along its length. The basic cycle (1-2-3-4) takes place independently in each cylinder of the engine. As such in a multi-cylinder engine, each cylinder with requisite components should be considered as an independent mechanical unit.

Timing gears connect the crankshaft, camshaft, piston and valves, thus effecting their timed operations, when either a thrust is applied on the piston or flywheel is rotated.

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[25] Shippen J.M and Turner J.C. 1966: Basic Farm Machinery. Volume 1. Pergamon, Oxford

[26] Along with gasoline or diesel, ICE can also utilize renewable or alternative fuels like natural gas, propane, biodiesel or ethanol. They can also be combined with hybrid electric powertrains to increase fuel economy or plug-in hybrid electric systems to extend the range of hybrid electric vehicles (https://www.energy.gov/eere/vehicles/articles/internal-combustion-engine-basics) Accessed on 12-02-2022)

Air or air/fuel mixture enters the cylinder [induction stroke (1)] when the inlet valve opens. Compression stroke (2) follows when both inlet and out valves are closed. Stroke 3 is the power stroke, which happens when the compressed fuel/air mixture or air alone is ignited, expands rapidly and pushes the piston downwards.
For being connected to the crankshaft via the piston rod, the crankshaft rotates and the rotary motion is transmitted to the wheels or power take off (PTO) through a system of gears. Through the resultant motion, the desired work is done,

Individual task	Visit the transport yard or department of mechanical engineering in any institution and seek to visually acquaint yourself with the tractor and its accessories.

4.2 (i). The 4-Stroke Spark Ignition Engine

A stroke is a one-direction movement of the piston in the cylinder. Spark ignition (SI) is so called because an electric spark is required to ignite either petrol air mixture or vaporising oil in the cylinder to initiate the first power stroke.
The 4-strokes of a spark ignition engine are described in the YouTube link[27] below and illustrated in figure 4.3.

Induction Stroke

In the induction/intake stroke:

1) The inlet valve is open
2) The exhaust valve is closed
3) The piston moves down creating a partial vacuum above it.
4) Partial vacuum created sucks in the fuel/air mixture
5) When the piston reaches the design bottom of its stroke (bottom dead centre (BDC), the inlet valve closes to prevent mixture from escaping.

[27] https://www.youtube.com/watch?v=8dAbcbAJRw8, https://www.youtube.com/watch?v=8avKPNgVbX0 (Retrieved February 27, 2024)

Compression Stroke

In the compression stroke:

1) Both valves are closed.
2) Piston moves upwards compressing the fuel/air mixture into a small space at the top of the cylinder. Top Dead Centre (TDC) is traditionally the position of an internal combustion engine's piston when it is at the very top of this compression stroke
3) This space is usually provided by having the underside of the cylinder head suitably shaped (i.e., slightly concave)

Power Stroke

In the power/combustion stroke:

1) Both valves are still closed.
2) Piston is at the top of the compression stroke (Top Dead Centre TDC)
3) A spark released from the spark plug ignites the mixture, which therefore burns and expands forcing the piston downwards thus providing the inception power (rotary motion of the crankshaft). The firing order is the order/sequence in which cylinders are on power stroke. It varies according to the number of cylinders.
4) A sparking plug has a metal body which is screwed into the cylinder head. An electrode running through its centre carries the current. The second electrode at the bottom is the earth. The spark occurs when the current jumps from the centre electrode to the earth electrode.

Exhaust Stroke

In the exhaust stroke:

1) Inlet valve is closed.
2) Exhaust valve is open
3) Piston moves upwards, thus pushing burnt gases (CO_2 and H_2O_g) out into the atmosphere.

Reflection Questions

1. Explain the possible causes of a smoking engine
2. What does bluish exhaust fume communicate?
3. What does a sooty exhaust pipe communicate?

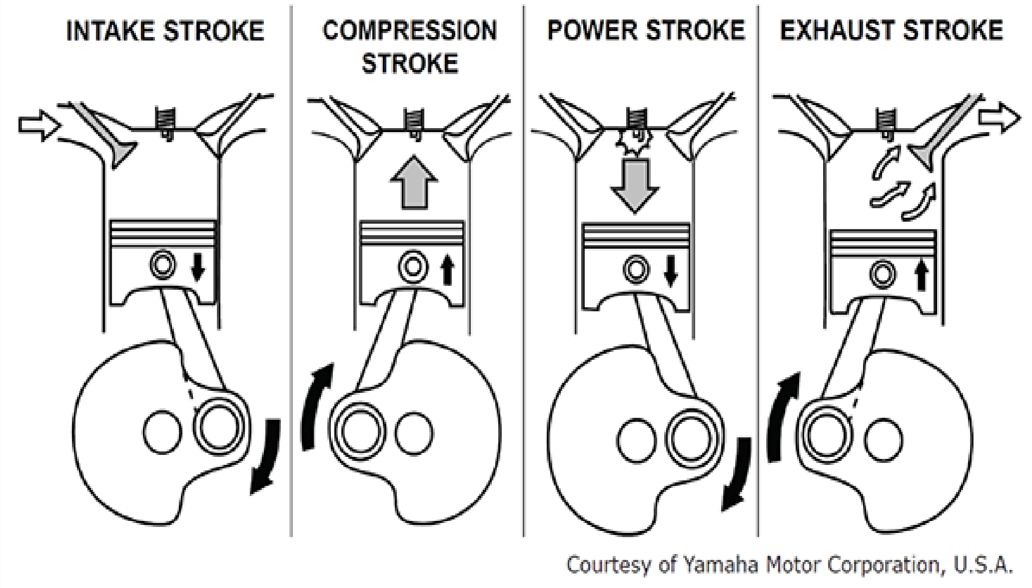


Figure 4.3: Illustrated 4-stroke spark ignition engine cycle
(Source:Universal Technical Institute
https://www.uti.edu/blog/motorcycle/how-4-stroke-engines-work
(Accessed 15-02-2022)

To Note:

1. Firing order is the sequence in which each cylinder is on power stroke ("working stroke")
2. Most tractors have 3, 4 or 6 cylinders in line. Typical firing orders are: [1,2,3]; [**1,3,4,2 OR 1,2,4,3**]; [1,5,3,6,2,4 or 1,4,2,6,3,5] respectively
3. The more the number of cylinders the more the combinations of firing order.
4. Firing order is so sequenced in order to permit smooth and even rotation of the crankshaft, thus reducing engine vibrations.
5. Because the power stroke occurs once in every cycle of 4 strokes, the engine tends to vibrate.
6. A flywheel is thus fitted on the crankshaft to ensure smooth turning during the three non-power strokes through its momentum.

4.2 (ii). The 4-Stroke Compression Ignition Engine

Compression ignition (CI) is the mechanism used in diesel engines. Diesel engines are stronger because higher pressure and thrusts take place within them. Instead of fuel/air mixture being taken into the cylinder, air alone enters and is compressed to about 1000°F[28]. The volume of air is reduced by about 16 times its original volume. Compared to the spark ignition, compression reduces the mixture to about 7-8 its original volume. At the power stroke, a spray of diesel is injected into the compressed air setting it on fire. The burning fuel expands rapidly and thrusts the piston downwards, which in turn causes the crankshaft to rotate, thus effecting the working (Power) stroke.

A key feature of diesel engines is the Compression Ratio (CR). This is the ratio of volume of air at maximum induction stroke (i.e., Bottom Dead Centre-BDC) to volume of air at maximum compression (i.e., Top Dead Centre-TDC). A ratio of $30cm^3$ to $5cm^3$ (6:1) means induction volume has been reduced by a factor of 6.
Generally, diesel engines use higher compression ratios than petrol engines, because the lack of a spark plug means that the compression ratio must increase the temperature of the air in the cylinder sufficiently to ignite the diesel.
The apparent superior power of diesel engines is attributed to their higher CR than that of petrol engines. This higher apparent power in diesel engines is due the greater volume of air that is heated during the power stroke. This volume can be further increased by the inclusion of a turbocharger (Figure 4.4) to allow more air into the combustion chamber.

Observation

1. The apparent popularity of Subaru cars in Kenya is partly attributed to this turbo-charging effect.
2. Any machine where power is generated by combusting hydro-carbons can have a turbo-charging system within its inherent design.

[28] (°F – 32) × 5/9 = °C; e.g. 1000°F = 538°C

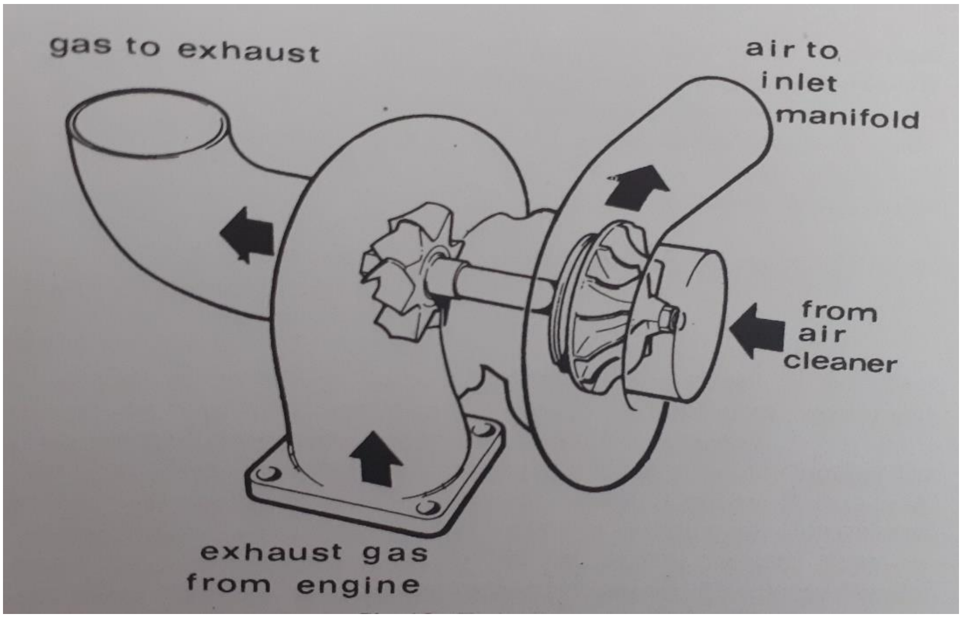


Figure 4.4: Illustration of a turbo-charger (Source: Bell, 1983)

Turbochargers are mostly used in engines that demand high performance. Before leaving the engine, exhaust gasses under high pressure is harnessed to drive a turbine that sucks extra air from the air cleaner to the inlet manifold. More air into the engine means maximised combustion of the fuel and thus enhanced engine performance.

To Note:

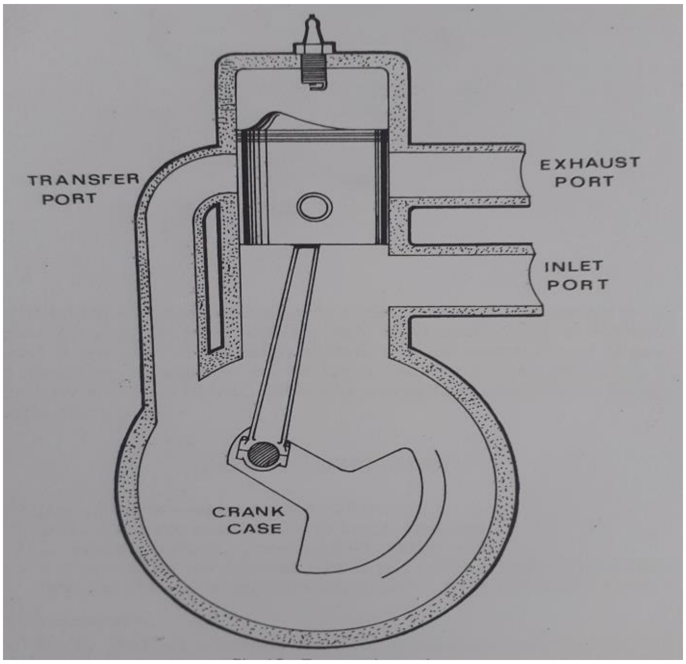
Starting or running problems of engines are frequently caused by fuel or ignition faults. If the fuel is adequate and the carburettor clean check the following ignition faults before calling the mechanic:

1. *Stuck open, shut, dirty or pitted contact breaker points*
2. *Loose terminals*
3. *Broken or loose king lead*
4. *Damp and or cracked distributor cap*
5. *Dirty spark plugs*
6. *Discharged battery*

4.3. The 2-Stroke Spark Ignition Engine

A 2-stroke engine provides power for small machines or light duty machines such as hand-powered hedge trimers, chain saws, small rotary cultivators, grass cutters and power saws (Figure 4.5). The design of the engine enables the Induction and Compression strokes to occur simultaneously (C-I); and the Power and Exhaust strokes likewise (P-E) (Figure 4.6).

Figure 4.5. A 2-sroke engine power saw



Note:

Deflection piston

Position of the exhaust port, inlet port and transfer port relative to the movement of the piston.

Figure 4.6: Illustration of a 2-stroke spark ignition engine (source: Bell, 1983)

The stages for each stroke are described below.

Stroke 1:

In this stroke:

1) Piston moves upwards on a **COMPRESSION** stroke, thus closing the transfer port and exhaust port.
2) This upward stroke also uncovers the intake port
3) Partial vacuum created in the crankcase causes fuel/air mixture to rush in through the inlet port thus simultaneously effecting the **INDUCTION** stroke.

Stroke 2:

In this stroke:

1) When the piston is at the top of compression stroke, a spark is introduced, igniting the mixture. The resultant explosion pushes the piston down thus effecting the **POWER** stroke.
2) As the piston moves down, it uncovers the exhaust port, thus allowing burnt gases to escape, hence **EXHAUST** stroke.
3) This downward movement of the piston uncovers the transfer port while at the same compressing the mixture in crankcase, thus allowing new mixture to enter above the piston through the transfer port in readiness for next compression stroke.

Note that:

1. In the 1st stroke, induction and compression of air-fuel mixture occurs. In the 2nd stroke, power and exhaust occurs.
2. The piston is shaped in such a way as to deflect the incoming fuel/air mixture into the combustion chamber so that it does not mix with the exhaust gases escaping from the opposite side. This phenomenon is referred to as ***scavenging.*** Figure 4.7 shows the different piston crown configurations that enhance scavenging.
3. The crankcase is airtight and does not contain any oil. Engine lubrication is by oil mist (i.e. oil is mixed with the petrol). As such always add oil to the petrol in the correct proportion.
4. A 2-stroke engine is air-cooled. The cooling fins must be kept clean to prevent overheating.

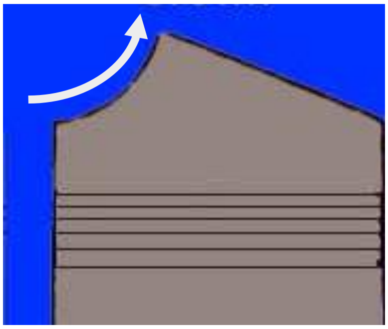


Figure 4.7: Piston head shape showing dorection of deflection (Source: https://carbiketech.com/piston-design-functions/) Accessed on 04-12-2022. NB: The one on the left would fulfil the deflection requirements in a 2-stroke internal combustion engine

Individual learning task	Navigate through relevant sites on the internet to: 1. View the firing order in Internal Combustion Engine 2. View other shapes of piston heads 3. Understand the function of the piston and piston rings.

4.4. Cooling Systems

Internal combustion engines operate on the principle of combusting hydrocarbons (fossil fuel) where in heat is a major by-product of the power stroke. Thousands of power strokes will undoubtedly generate too much heat which if not removed could cause engine damages like melting engine components. The cooling system prevents overheating thus maintaining optimum working temperature for the engine to function well. The common problems of the cooling system are:

1. Water pump failure
2. Leaky radiator hoses
3. Radiator leaks
4. Thermostat failures

There are two types of cooling systems in heat engines

4.4.1. Air Cooled System

In an air-cooled system;

1. Only air is used to carry away excess heat.
2. A blast of air is directed around the cylinder and cylinder head, both of which are finned to increase surface area for more air and trapping of heat energy.
3. The blast of air is created by a blower fan to the engine flywheel, which is encased to extend over and around the cylinder.
4. The rotating blower draws in air, which takes away the heat
5. Air cooling is used in small single cylinder engines e.g mowers.
6. For bigger machines, air cooling alone will not be enough. A more elaborate and efficient system would be needed to effect engine cooling, hence the water-cooled system.

4.4.2. Water Cooled System

The water-cooled system is used by most multi-cylinder engines because it is more efficient. It uses both air and water to effect cooling. The radiator is the main house of the cooling water. The engine cylinders are completely surrounded by a water jacket, which also extends to the cylinder head. An outlet from the cylinder head is connected to the top of the radiator. From another outlet at the bottom of the radiator, a hose connection is taken to the water jacket surrounding the cylinder (Figure 4.8).

Note that:

1. Based on figure 4.8, the Radiator matrix (H) is designed to provide the largest possible surface area to maximise on air intake. Hot water circulates within it and transfers heat to the air current passing through its tubes.
2. The fan (G) behind the radiator and in front of the engine is driven by a fan belt from the engine crankshaft. The fan creates a zone of low pressure, which causes air from outside to rush in.
3. The Impeller driven by the fan shaft rotates thus aiding in water flow up from the bottom tank of the radiator.

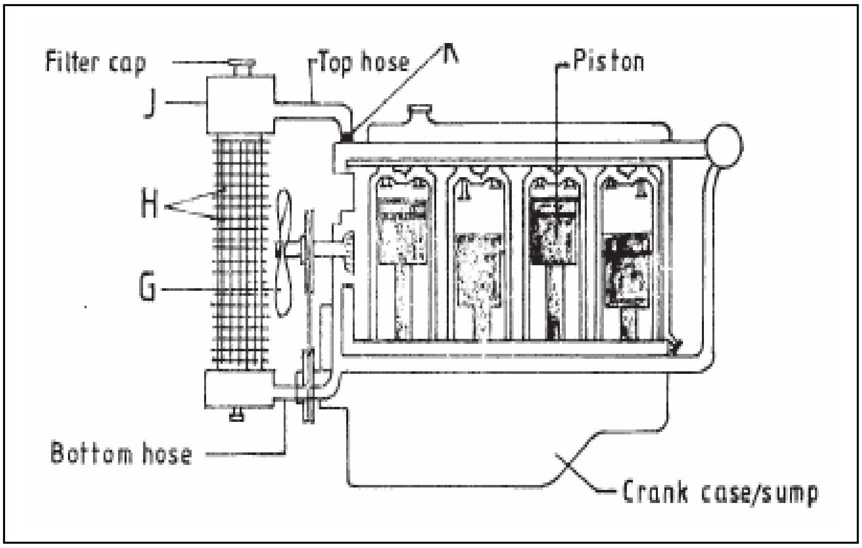


Figure 4.8: Layout of a water-cooling system (Source: https://www.atikaschool.org/agriculturetopicalquestions/the-cooling-system-of-a-tractor-engine (Accessed on 14-02-2022)

4. For being less dense than cold water, heated water rises up into the radiator header tank (J), and is replaced with cold water from the bottom of the radiator through a process called *Thermo-syphon* (i.e water flow caused by a temperature gradient).
5. A thermostat is fitted into the outlet pipe connecting the cylinder head to the top of radiator. It restricts the flow of water to the radiator until an efficient working temperature is attained. Very useful in winter or cold weather.
6. Volume of water within the cylinder block is much less than that within the whole cooling system. Accordingly, restricted flow causes rapid warming up from cold.
7. The thermostat operates automatically and triggers fan rotation when engine temperature climbs above expected value.
8. In very cold weather (winter), a *radiator blind or shutter* can be fitted to the tractor to control the air in-flow through the radiator and help the engine to warm-up quickly.
9. Since freezing water expands and could crack the engine block, anti-freeze is added to prevent this from happening.
10. A coolant can also be used to raise the boiling point and prevent over-heating.
11. For more reading visit the hyperlink on water cooling system

Care of the Cooling System

1. Check radiator water level daily in hot weather and top as appropriate
2. Flush the cooling system routinely to clear any sediments
3. Keep the outside of radiator clear of dirt and chaff
4. Maintain the correct fan belt tension
5. Check for leaks and make sure hose connections are tight.
6. Ensure the thermostat is functioning and not stuck shut.

Individual learning task	1. Explain any design similarities between the radiator and the bee honey comb. 2. Explain the possible causes of over-heating? 3. Why may water be drained from the engine during winter period? 4. At what part and stage of cooling system is heat transfer by (a) conduction, (b) convection and (c) radiation?

4.5. Lubricating System

4.5.1. Overview of Lubrication System

The aim of the lubrication system is to put a film of oil between two working metal surfaces in contact in order to reduce friction, hence tear and wear. This enhances the durability of parts and smooth working of the equipment/part/machine. Since friction is not 100% removed, lubricating oil also helps to cool the metals. Friction should however NOT be reduced at clutch and brake systems since grip should be maximised

4.5.2. Lubricating Oil

Lubricating oil, sometimes simply called lubricant/lube, is a class of oils used to reduce the friction and wear between moving mechanical components that are in contact with each other. Lubricating oil is used in motorized vehicles, where it is known specifically as motor oil, engine oil, and transmission fluid.

Properties of Engine Lubricating Oil

The lubricating oil should;

1) Provide a film of proper thickness between the bearing surfaces under all conditions of operation.
2) Remain stable under changing temperature conditions.
3) Not corrode the metal surfaces.

Functions of Lubricating Oil

In internal-combustion engines, lubricating oil serves several functions as outlined below:

1) Reduces tear and wear by preventing metal-to-metal contact between moving parts.
2) Controls friction between load-bearing surfaces
3) Reduces corrosion by coating metal parts and by flushing debris from between moving parts.
4) Dampers mechanical shock in gears.
5) Forms a seal on the walls of the cylinders.
6) Limits the temperature by carrying away heat from fluid friction and combustion of fuel.

4.5.3. Categories of Lubrication Oils

Three main categories occur today:

Mineral Lubricating Oils

Mineral oils are lubricating oils refined from naturally occurring crude oil. They are the most commonly used type because of the low cost of extracting the oils from crude oil. Additionally, mineral oils can be manufactured to have varying viscosity. This makes them useful in a wide range of applications.

Synthetic Oil

Synthetic oils are lubricating oils that are chemically manufactured. It consists of chemical compounds that are artificially made. Synthetic lubricants can be manufactured using chemically modified petroleum components rather than whole crude oil, but can also be synthesized from other raw materials. The base material, however, is still overwhelmingly crude oil that is distilled and then modified physically and chemically. Synthetic oil is used as a substitute for petroleum-refined oils when operating in extreme temperature. Synthetics oils typically outperform conventional motor oils in providing more protection by;

1) Keeping the engine cleaner
2) Offering greater protection against engine wear
3) Flowing better at low temperatures
4) Protecting better at high temperatures
5) Protecting critical turbocharger parts

Detergent Oils

These are oils that contain additives (i.e., additions over and above the base oil (crude oil). The additives prevent the formation of carbon and deposits inside an engine, by holding in suspension the sticky particles, which would otherwise settle on pistons; piston rings, cylinder walls etc. resulting in increased wear.

Soot and carbon are produced when fuel and lubricating oil burn within the engine. These are held in the engine oil giving it the black colour, which is however no indication that the oil requires changing[29]. Heavy Duty oil (HD) is oil that is fully detergent (i.e., has additives that prevent formation of sticky deposits as well as prevents oxidation and corrosion in the engine). Changing from conventional to detergent oil requires procedural "flushing" of the engine.

To Note:
Because the shaft inside a turbocharger can spin upwards of 200,000 revolutions per minute, it's critical that your motor oil get to that shaft and lubricate it properly and very quickly. Conventional oils can break down faster under these conditions and leave deposits on the turbocharger components, which can lead to failure. Here is where HD oil becomes very useful.

[29] To change oil, stick to service schedule, either mileage or engine working hours as appropriate

4.5.4. Classification of Lubricating Oils

Classification of lubrication oil is based on their VISCOSITY (i.e. thickness and resistance to flow of the oil). This system was adopted by the American Society of Automotive Engineers (SAE[30]). A suitable grade of oil is always recommended by the manufacturers of specific engines. The classification of the oils is as given below.

1) SAE oils of numbers 10, 20, 30, 40 are generally engine oils (Light oils that are easily flow).
2) SAE 50, 70, 90 are gear and transmission oils (Heavier oils)
3) SAE 120 and 140 are very thick oil and used in bearings.

To Note:

1. Lower numbers correspond to low viscosity (i.e., oils are thin and easy to flow)
2. High numbers correspond to high viscosity (i.e., oils are thick and relatively not easy to flow)

4.5.5. Viscosity Index

1. The Viscosity Index (VI) is a dimensionless (unit-less) number that represents how the *viscosity* of a hydraulic fluid changes with temperature. It is a measure of how well a fluid can protect its *viscosity* during changes in temperature.
2. The lower the VI, the more the viscosity is affected by changes in temperature.
3. Better oils should have a high VI (i.e., the viscosity is not easily affected by changes in temperature. The oil remains relatively stable at high temperature).

4.5.6. Types of Lubricating Systems

There are two main types of lubricating systems; splash feeding and forced feeding.

Splash Feed lubrication

Splash lubricating system is generally used in small single cylinder air cooled engines. Lubrication is achieved by oil splash, done by a dipper provided at the connection between the piston rod and

[30] For history, visit https://www.sae.org/about/history

crankshaft. When the engine is running, the dipper dips into a narrow trough of oil beneath and throws (splashes) the oil up on the working parts. As such it is important to keep the oil levels in the oil sump at the correct positions. A Dip Stick is used to check of the oil level.

Forced Feed Lubrication

In forced feed lubrication, a pump is used to force oil to the required parts. When the engine is running, the gear pump, which is driven by the camshaft, draws in oil and pumps it to the external oil filter. From the filter, the oil travels through oil galleries and drillings to lubricate necessary engine parts. The oil is stored in an oil sump from which it is pumped.

4.5.7. Contaminants of Engine Lubricating Oil

Contaminants of engine oil include:

1. **Dust and Grit:** These are mainly from the environment
2. **Fuel:** Small amounts of fuel may leak past the pistons and mix with oil when the engine is operating below its correct working temperature.
3. **Sludge:** Is formed from carbon, water and other substances produced when fuel is burnt in an engine.
4. **Soot and carbon:** These contaminants come from the combustion of the oil. Some carbon and soot may be washed down into the sump causing further contamination.
5. **Wear particles:** These come from the friction wear of the engine.
6. **Water:** Produced when fuel is burnt and from condensation.
7. **Unburnt fuel:** It seeps down past the piston and into the oil sump. Correct engine temperature ensures complete vaporization of fuel to prevent this possibility.
8. **Engine heat:** (excessive temperature). This causes a gradual breakdown of the structure of lubricating oil.

To minimize oil contamination, oil filters are fitted within the system to prevent most of the contaminants from reaching the working parts of the engine. Oil that has served for the recommended mileage should be changed, together with the oil filter.

To Note:

1. Lubricating oils of different viscosities can be blended. This ability to blend makes some oils to be very useful.
2. Full Synthetic Motor Oil: Is ideal for vehicles that demand peak level performance and high levels of lubrication.
3. Conventional Motor Oil: Is the most commonly used type of oil
4. Synthetic Blend Motor Oil: Offers the best of both worlds
5. High Mileage Motor Oil: Suitable for heavy duty engines

Individual learning task
Visit the transport yard or any petrol station and request to: 1. Examine the physical characteristics of used engine oil 2. Understand how used engine oil and filters are disposed based on National Environment Management Authority (NEMA) standards 3. At what section of the cooling system does transfer of heat occur by (i) Conduction, (ii) Convection and (iii) Radiation?

4.6. Tractor Fuel System

4.6.1. Overview of Key Components

Air Cleaner

1) It prevents dirt and dust from being taken into the engine.
2) The pre-cleaner has vanes that cause air swirl, which throws out heavier dirt particles.
3) Tractors use oil bath air cleaners
4) The dust-laden air must pass through the oil where most of the dust is trapped.

Fuel Filter

1) One to several fuel filters are used to filter the fuel as it pumped from the lift pump to the injection pump.
2) The fuel injection pump is designed with the precision to deliver very small quantities of fuel into the diesel engine.
3) With time, the fuel filter elements become choked with dirt, which necessitates their servicing and replacement at recommended mileage or engine working hours as the case may be.

Fuel Injector
The purpose of the fuel injector is to inject small quantities of fuel into the compressed air in the cylinder of diesel-based engines.

Fuel Pump
The fuel pump forces or pushes fuel through its design pathways to the cylinder for combustion.

4.6.2. Diesel Engine Fuel System

The job of the fuel system is to ensure that a diesel engine requires a precise amount of clean fuel injected into each cylinder at the correct time, in an atomised form. Fuel from the fuel tank also passes through a series of filters to trap all unwanted solid particles and hold them as sediment in a sediment bowl.
A typical layout of the fuel system of a diesel engine is shown in figure 4.9. By virtue of the layout, a fuel lift pump is often necessary to push the fuel along. Instead of a carburettor, fuel injectors are used to introduce fuel into compressed air in the cylinders.
Air in the fuel system causes misfiring and will stop the engine. This air must be removed through a process called bleeding the fuel system (see later sections)

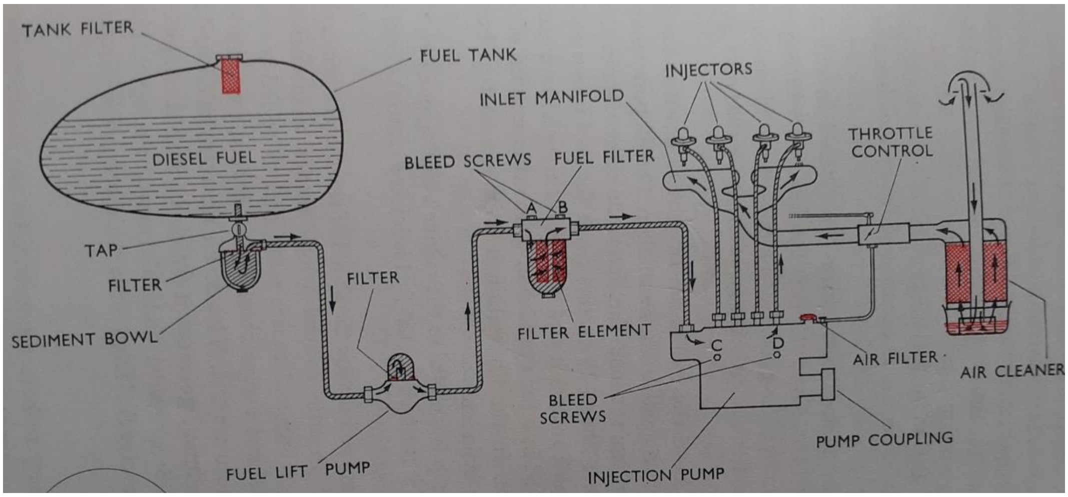


Figure 4.9. Layout of a fuel system of diesel engine (Source: Shippen and Turner, 1966)[31]

[31] Source: Shippen J.M and Turner J.C. 1966: Basic Farm Machinery. Volume 1. Pergamon, Oxford)

Air Cleaners
Tractors may have either an oil bath air cleaner or a dry element air filter.

1. Oil bath Air Cleaner
The oil bath air cleaner is preceded with a dome-shaped pre-cleaner designed to remove any large particles like chaff through a swirling mechanism. Pre-cleaned air then passes through the oil bath where dust removal starts. A gauze above the oil bath becomes impregnated with oil when the engine is running. Dust is trapped by the oil in this gauze as the air is sucked towards the cylinders. When the engine is not running, the oil collects into the oil bath and any dirt in it settles at the bottom of the bath (Figure 4.10)

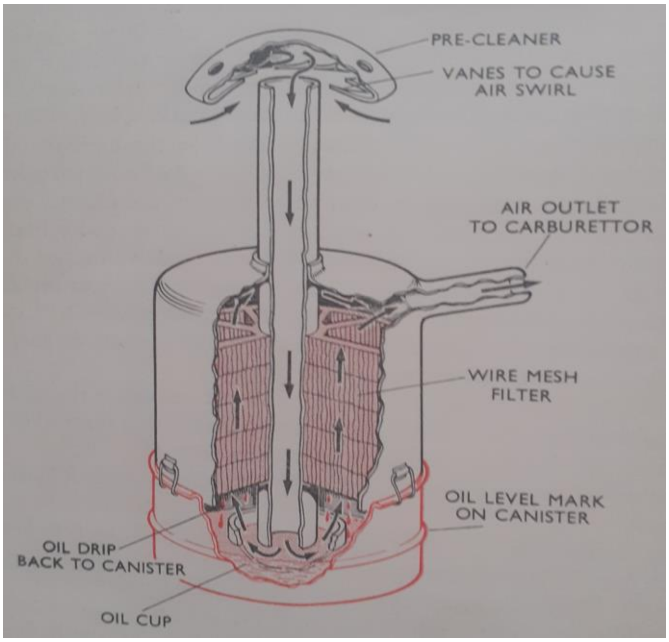


Figure 4.10

Oil bath air cleaner

(Note the direction of air flow)

Source: Shippen and Turner, 1966

2. Dry Air Cleaner
No oil is used. Air passed through a thick paper or filter element on its way to the cylinders. Dust is trapped there-in. This element is often cleaned by gently tapping it or blowing compressed air (air under correct pressure – 30 psi) through it, which removes dust. Most cars use dry air cleaners.

4.6.3. Petrol Engine Fuel System

Fuel flows from the tank through a tap to the carburettor float chamber. A small needle valve controlled by the float keeps the fuel in float chamber at the correct level. The float chamber of the carburettor maintains a constant level of fuel. The brass float rises as fuel feeds into the chamber and closes the needle valve once the chamber is full. As fuel is used, the brass float falls opening the needle valve to allow more fuel in (Figure 4.11).

Petrol flows from the float chamber into a small tube (main jet) in a pipe which carries the air to the engine from the cleaner. At the main jet, the size of this ait pipe is reduced with an insert called venturi. The reduced diameter of the pipe increases the velocity of air as it passes through it, which causes the fuel to be drawn from the main jet thus effecting the fuel-air mixing before the mixture is sucked into the cylinders. The process of air-fuel mixing at the venture is called **carburation**[32].

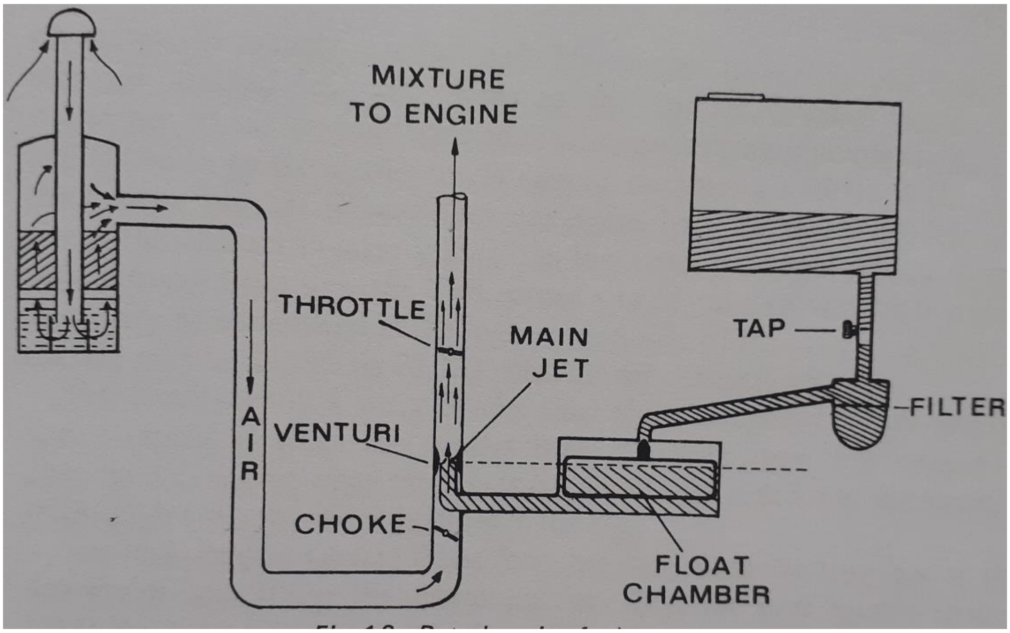


Figure 4.11. Layout of a carburettor system (Source: Bell, 1983)

[32] For details visit: https://www.mecholic.com/2018/09/what-is-carburation-factors-affecting.html

Conventional air-fuel proportion is 15 parts of air to 1 part of fuel by weight to maximise on combustion of the hydro-carbon. An engine will not develop full power when running on a weak mixture (very little fuel)-(17:1 and above). Similarly, when the mixture is rich (too much fuel) e.g 12:1, petrol wastage occurs causing build-up of carbon around the valves and combustion space.

Excess deposits reduce engine efficiency. Black smoke from exhaust pipe may be indicative of a rich mixture, while blue smoke indicates burning of engine oil. For 2-stroke engines, blue smoke will be released when too much oil is mixed with the fuel. Fuel and a little oil are mixed in a 2-stroke engine because the fuel comes into contact with moving components frequently, hence the need to offer lubrication that allows for smoother strokes. 2-stroke engines have no oil sump and independent lubrication system yet pistons must be lubricated for their smooth movement during the strokes. Also note that by its design, the oil in the fuel lubricates the piston and cylinder lining before the power stroke. This mixture also serve the added purpose of heat transfer hence engine cooling[33].

Most cars today run on Electronic Fuel Injection (EFI) system rather than having carburettors. From the bottom of the float chamber, the fuel is fed through a jet discharge tube in a restricted part of the induction pipe called *venturi.* On induction stroke, air rushing into cylinder must pass through the venturi in which the jet discharge tube is situated.

The choke valve controls the amount of air coming into the carburettor. When it is closed or partly closed, the air intake is restricted so that mixture contains a higher proportion of fuel.

The throttle valve controls the supply of fuel/air mixture into the engine cylinder. For cars the throttle valve is connected to the accelerator pedal and for tractors on the governor and hand control. To reduce speed, close or partly close this valve. For tractors, the governor helps to maintain a constant speed of the tractor once that speed has been set by the hand control

[33] https://www.quora.com/Why-do-we-add-petrol-with-oil-to-a-two-stroke-engine (Retrieved February 27, 2024)

Air-Petrol mixture Flow Dynamics at the Venturi

The discharge (Q) of a fluid in a closed conduit is always the same at any section of the conduit. The only thing that changes when the cross-section area (A) of the conduit is varied is the flow velocity (V).

Accordingly: Discharge (Q) = volume (V_o)/time (t)

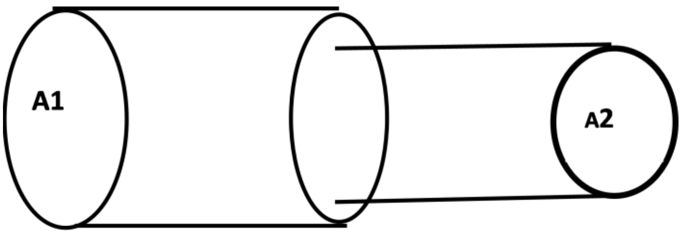
At any section of a conduit: $Q_1=Q_2=Q_n$

Where:

1, 2 and n represent different cross-section areas of the conduit. Discharge (Q) is also the product of cross section area (A) and flow velocity (V) as illustrated in Box A. For the same closed conduit:

$$Q_1=Q_2=Q_n = A_1V_1 = A_2V_2=A_nV_n$$

Box A: Illustrating the relationship: $A_1V_1 = A_2V_2 = Q$



1. Area (A) = πr^2
2. Volume (V_o) = Ah = $\pi r^2 h$
3. Discharge (Q) = Volume/time = $V_o/t = \pi r^2 h/t$ (height can also be distance d)
4. Velocity (V) = distance/time =d/t; thus: d= Vt
5. Since Volume (V_o) = Ah = $\pi r^2 h$; and h=d, then V_o) = Ah = $\pi r^2 d$ = Ad
6. Therefore, discharge Q = Vo/t = Ad/t = AVt/t = AV
7. Since discharge is the same at any point along the conduit: Q1=Q2=Q3
8. Therefore, $A_1V_1 = A_2V_2 = A_nV_n$
9. At the Venturi, the reduced area of conduits (A) is compensated with increased flow velocity (V), which helps in atomizing (mixing the fuel and air)

Individual learning task	Assuming that r_1=14 cm, r_2 = 7 cm and Q = 45cm^3/min: Calculate flow rate at the venturi (V_2) in litres/min

4.6.4. Bleeding the Fuel System

When air gets into the fuel system, the smooth flow of fuel is interrupted causing the combustion process to be disrupted. The flow of fuel can be completely stopped leading to stalling of the engine and hence the vehicle. Therefore, the system must be bled to rid it of air. The air pockets cause air locks the same way it happens in closed water conduits (pipes). The airlock causes the engine to run erratically and eventually stops. Bleed screws are appropriately included in the design to enable removal of air pockets in a process called bleeding. The screws are opened as per the engines' recommended procedure. A frothy flow of fuel during bleeding is suggestive of presence of air locks. Bleeding must be done until the flow of fuel is continuous and uninterrupted.

Air gets into the fuel system when:

1. The driver allows fuel in the tank and all fuel lines to run dry
2. Servicing is done on the fuel system.

Bleeding (removal of air) may also be done on the braking and hydraulic systems.

4.6.5. Handling of Diesel Fuel Tank on the Farm

The fuel system is very sensitive to the smallest dirt or dust particles. Clean handling of fuel is critical and must start where the fuel is stored. To ensure clean fuel, the following must be ensured.

1. No galvanised iron tank is used because diesel tends to remove Zinc coatings thus contaminating the fuel.
2. The tank is stationed on a raised platform to allow easy filling of the tractor.
3. The tank is designed to slope to the rear to allow sediment to collect away from the outlet.
4. A sludge tap is fitted at the rear part of the tank to drain off the sediment at intervals.
5. A downturned air entry pipe is fitted at the top of the tank to prevent entry of dirt but allow air in while fuel is drawn off.

6. The pipe through which the tank is filled is covered with a screw cap.
7. A filter is fitted to the tank at the end of the refuelling pipe.
8. The valve on the refuelling pipe is kept covered in the box beneath the tank.

> ***Reflection:***
> In pursuit of increased environmental performance, the machinery world has moved away from carburettors, to electronic fuel injection, hybrid systems and now electricity powered machines

4.7. The Electrical and Ignition Systems

4.7.1. The Electrical System

The electrical system supplies electrical power to operate various electrical components such as lighting, horning, indicators etc. For motor vehicles, the electrical system is also used to control opening and closing of doors, windows, radios, music systems, horn and wipers.

Electrical power is supplied and stored in the battery. The battery functions based on the principle of electrolysis, where the electrolyte is often sulphuric acid (H_2SO_4). Batteries store direct current (DC). The acid strength weakens when the battery is discharging, hence the need to keep charging it. Also because of the heavy demands on the battery, made by the various electrical circuits on the tractor, it is necessary to keep the battery charged. An alternator or dynamo is used to generate the current for charging the battery. It is driven by the fan belt (Figure 4.12).

For the alternator, it is the magnet that rotates around the coil. For the dynamo (generator), the coil rotates within a stationary magnet assembly. Electricity is generated when there is motion of the electric coil in a magnetic field based on faraday's principle of electromagnetic induction.

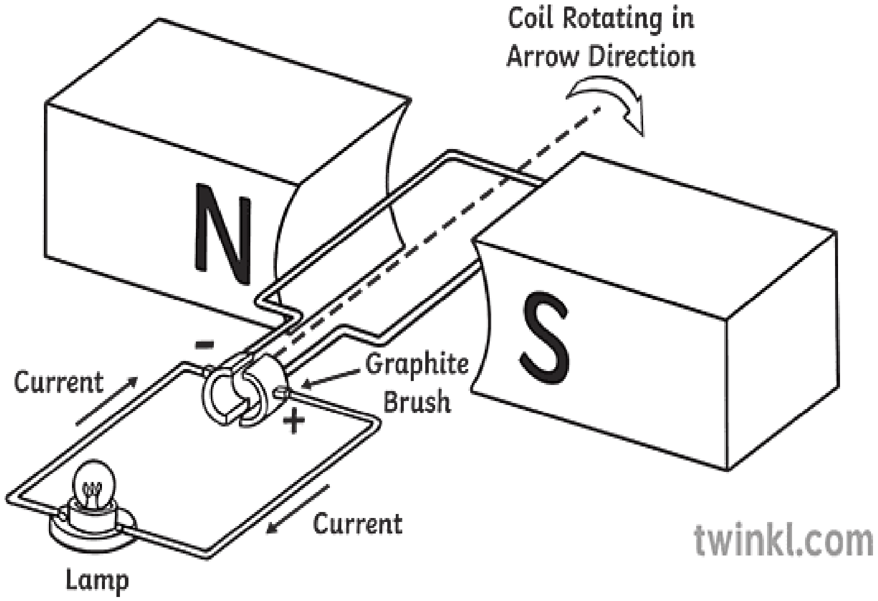


Figure 4.12. A simplified dynamo.
(Source: https://www.twinkl.com.kw/illustration/dynamo-dc-generator-diagram-labelled-edexcel-question-science-secondary-bw-rgb (Accessed on 14-02-2022)

4.7.2. The Ignition System

The ignition system is used to start (ignite) the engine. The spark needed for this purpose can be provided either by a Battery and Coil or Magneto Ignition.

4.7.2.1. Coil Ignition

The battery supplies the initial (Primary) current to operate the system. Batteries function on the principle of electrolysis where distilled/battery water dissociates into hydrogen and hydroxyl ions thus generating an electric current (flow of electrons). The conventional components of coil ignition are as illustrated in figure 4.13.

To Note:

1) When the ignition switch is turned on, the current from the battery (primary circuit) creates a magnetic field in the coil windings.
2) Contact breaker points are opened by the CAM, breaking the primary circuit and causing the high voltage (secondary current) to be induced in the secondary circuit (the same way a transformer works), which takes the current at high voltage (strength) into the spark plug.
3) The electrical spark which ignites the air-fuel mixture takes place across the points of a spark plug, which protrudes into the combustion chamber, where the air-fuel mixture is compressed.
4) The spark must jump across the points (centre electrode and earth electrode) against the high pressure within the cylinder.
5) The 12V battery on its own cannot cause this to happen. The voltage must be increased to 7-10,000 to actualise this jump.
6) This increase in voltage is achieved by use of a high-tension ignition coil.

To ensure effective and efficient performance, the battery;

1) Must be kept clean and dry externally
2) Must be adequately topped-up with distilled water (the cell plate within the battery must be covered). Today zero-maintenance batteries exist for cars.
3) Must have the terminals tight and free from corrosion. A smear of petroleum jelly on the terminals will help prevent corrosion.
4) Must be rigidly fixed in position to avoid movement/shaking and hence spillage of electrolyte and or its damage altogether.
5) Must always be kept in a state of charge.

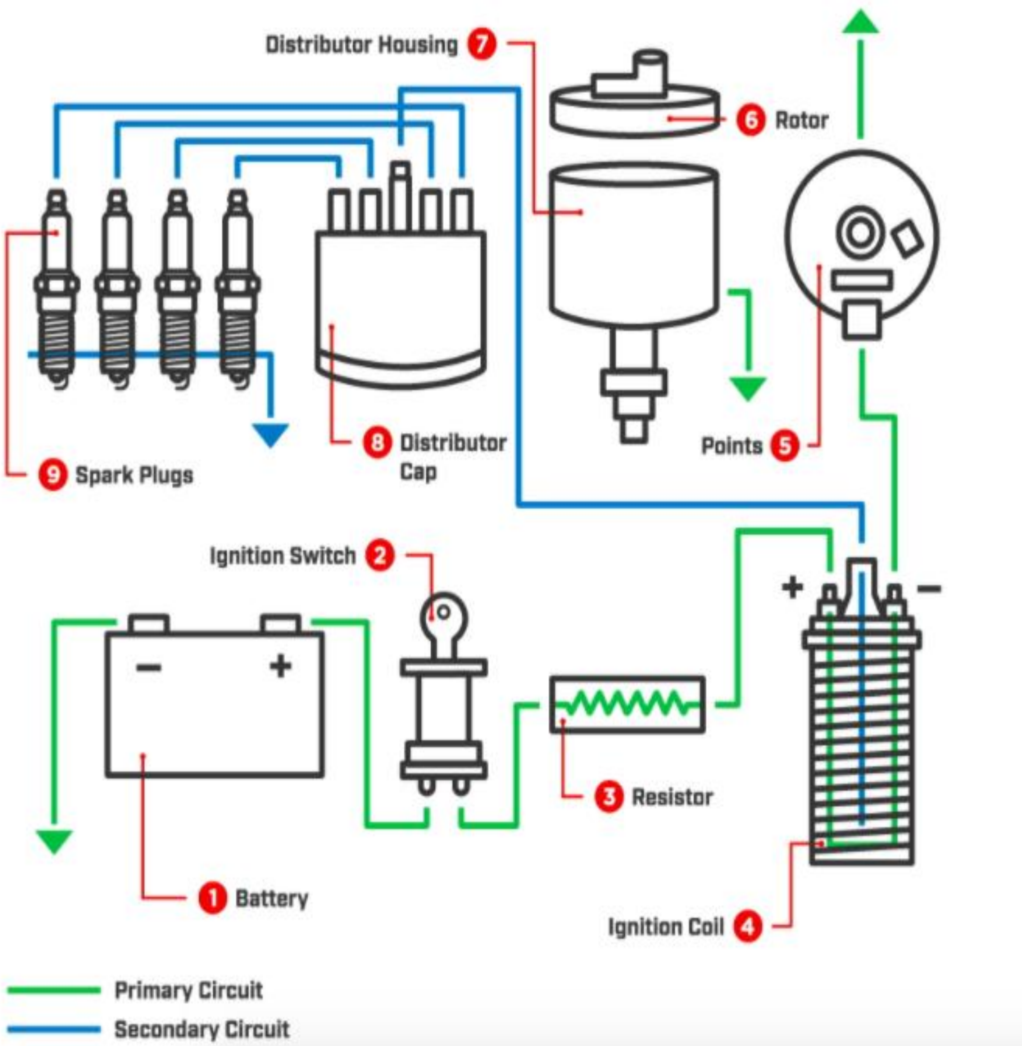


Figure 4.13. Conventional arrangement of coil ignition
Source: https://www.championautoparts.com/Technical/Tech-Tips/How-Ignition-Systems-Work.html) Accessed on 14-02-2022

4.7.2.2. Magneto Ignition.

For magneto ignition;

1) Instead of the initial primary current coming from the battery, it is induced[34] when an electric conductor (the coil) is rotated in a magnetic field by the timing gears. A flywheel magneto (mainly

[34] For the science, read more about electromagnetic induction.

used with single-cylinder engines) is built into the engine flywheel. It carries a magnet which is rotated a round a stationary coil (conductor) thus producing the initial low voltage current (provided by the battery in a coil ignition system). Alternatively, electricity is produced when an electric conductor (coil) is rotated in a magnetic field.

2) This generation is based on the "left hand rule" where-in having any 2 components among motion, magnetic field and electricity, the third is automatically the outcome. In magneto there is rotation of a magnetic field around a coil, which yields electricity.
3) The low voltage is stepped up like in the case of battery and coil ignition to enable creation of a spark with enough strength to jump across the plug points in the compression chamber. The resulting power stroke causes the engine to run.
4) It is the power stroke that initiates rotary movement of the crankshaft, and finally the wheels via the transmission system.

To Note:

1. In both systems, the condenser serves the purpose of absorbing the current, which tends to jump across the contact breaker points.
2. The Dynamo is driven by the engine and supplies direct current (DC) to the battery to restore its power, by rotating armature (coil) between two permanent (stationary) magnets. The voltage output is low and constant.
3. Alternators supply AC current, by rotating a magnetic field in a stationary armature (coil) to generate an AC, having a higher and variable voltage output.
4. .Dynamos have a commutator and brushes to convert the AC voltage generated to DC voltage, while alternators use diodes to convert AC to DC.
5. Dynamos are less efficient and heavier than alternators, while alternators are more efficient and lighter than dynamos.

Individual learning task	You wake up one day and realise your tractor can not ignite at all. Outline the possible causes

4.8. The Power Transmission System

4.8.1. Overview

The Power Transmission System (PTS) is meant to transfer the power developed by the engine to the driving wheels and vary the torque and direction of rotation of the ground wheels, in order for the tractor to work. The circular movement of the crankshaft is transmitted through the clutch, gearbox, driveshaft, differential, and axles extending to the wheels.

The PTS is also used to reduce the engine speed as desired. The rear wheels (Driver wheels) drive the front wheels (driven wheels) for a 2-wheel rear wheel drive (RWD) tractor. A complex system of gears is used to achieve these functions (Figure 4.14).

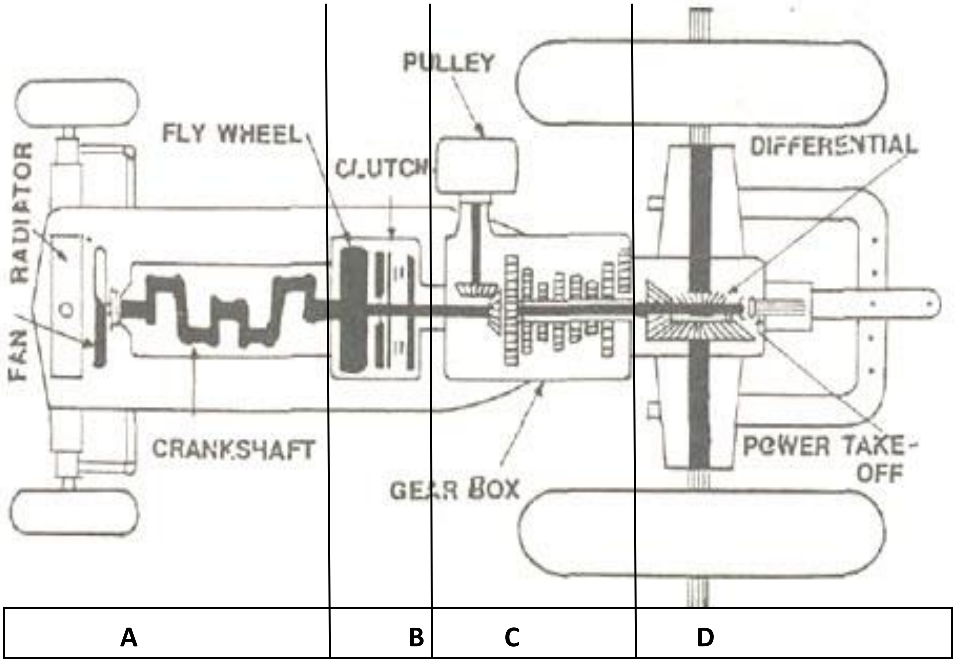


Figure 4.14a. Illustration of the tractor transmission system[35] (where A=Engine Block; B=Clutch Assembly; C=Gear Box; D=Differential unit)

[35] Source: Tractor systems and controls: http://ecoursesonline.iasri.res.in/mod/page/view.php?id=126225http://ecoursesonline.iasri.res.in/mod/page/view.php?id=126225) Accessed on 14-02-2022

1. In Front Wheel Drive (FWD) vehicles, the front wheels pull the machine.
2. In Rear Wheel Drive (RWD) Vehicles, the rear wheels push the machine.
3. In All Wheel Drive (AWD) both the front and rear wheels do the pulling and pushing.
4. A 2-wheel drive vehicle can be changed into a 4-wheel drive vehicle using a system of gears. For maximised traction in tractors, 4-wheel mode is engaged.

4.8.2. Major components of the Power Transmission System

4.8.2.1. The Clutch

1) It is the first unit in the transmission system.
2) It engages and disengages the drive (Main shaft) from the engine and enables the driver to move off smoothly.
3) It provides the means of connecting the engine to the tractor's gearbox and power from engine to Power Take off (PTO) shaft.
4) The clutch works on the principles of friction. When two friction surfaces are bought in contact with each other and pressed together, they are united due to the friction between them. If one is rotates, the other will also rotate.
5) The main clutch assembly is bolted to the engine flywheel (the driving component). The driven member is the pressure plate. This is mounted on the transmission shaft. The clutch plates are between the two members. With the exception of the clutch plate, all the clutch components must turn (rotate) with the flywheel and by extension crankshaft and hence the drive shaft as long as the clutch is engaged.
6) The pressure plate is designed and arranged in such a way that on releasing the clutch, it pushes the clutch plate onto the flywheel, gripping them and thus allowing both to rotate at the same speed.
7) The linear arrangement must thus be: ***Flywheel-Clutch Plate-Pressure Plate***
8) The rotary motion of the crankshaft is transmitted to the wheels via a series of gears and other specialised assemblies as outlined in the next section.

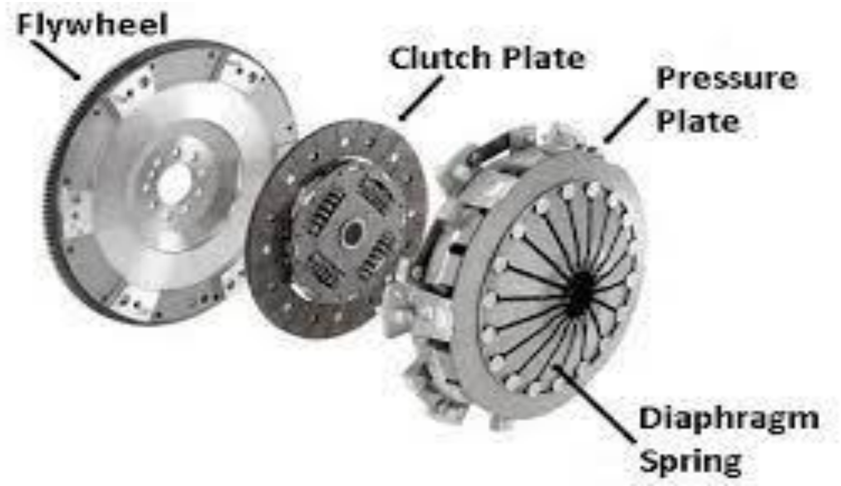


Figure 4.14b. Clutch Assembly
Source: https://www.theengineerspost.com/what-is-clutch/
(Retrieved 5th October, 2023)

When must the clutch be disengaged?

i. When starting the engine
ii. When stopping the vehicle
iii. When shifting the gears, and
iv. When idling the engine.

4.8.2.2. The Gear Box

1) This is the second unit in the transmission system.
2) The main purpose is to reduce the speed of the drive from the engine crankshaft before the drive is applied to the rear wheels.
3) Throughout the transmission system, the input speed of the engine crankshaft is reduced in stages to give a suitable forward speed to the tractor.
4) This is achieved when a smaller gear drives a larger gear. The reverse (a bigger gear driving a smaller gear) results into increase in speed.
5) Reduced speed along the transmission system makes the power of the engine more easily applied to the work that the tractor may be doing. The last speed reduction unit occurs between the

differential and the half shafts that finally rotate/drive the rear wheels.

6) The gear box therefore enables operator to choose alternative speeds.
7) The speed ratio (**driver to driven** gears) can also be altered easily and conveniently as required.
8) Suitable pairs of gears are meshed together to provide the necessary speed ratios between the engine and the rear wheels.
9) The operator selects the desired number of speed ratios by moving the appropriate gears into position (**1-2-3-4-5-R**), where speed increases with gear number. Reverse gear is conventionally given as R. The gear box provides the means to reverse the tractor.
10) Low (heavy) gear is obtained when the drive gear is smaller than the driven gear. This effects high torque but low speed.
11) High (light) gear occurs when the drive gear is bigger than the driven gear. Torque is reduced as speed is increased.
12) The terrain conditions determine the choice of gear to engage – whether low or high. Situations that may necessitate low gear include:
    a. Rough terrain
    b. Pulling heavy load
    c. Slowing down
    d. Steep decent or steep rise
    e. Overcoming high resistance during ploughing
13) The gear box also allows the drive wheels to be stopped without having to stop the engine e.g., balancing on a steep gradient.

4.8.2.3. Gears and Belt Drivers

A gear wheel has a number of teeth cut around the circumference. If two gears wheels have their teeth meshed together, and one of them rotates, the other must also rotate but in the opposite direction. The speed at which they rotate will be in direct proportion to each other. If the two gear wheels have the same number of teeth, they will rotate at the same speed. If the drive gear has 16 teeth and the driven gear 32 teeth, the gears will have a speed ratio of 2:1 because whilst the drive gear has made one complete revolution, the driven gear will have made half a revolution. To match one revolution of the driven (32 teeth gear), the drive gear must revolve twice, hence the 2:1 ratio.

Whenever a small gear wheel drives a large one, the large one will rotate at a slower speed. If a large gear drives a small gear wheel, the small one will rotate faster to "catch up" (Figure 4.15a). Fitting an idler gear makes no difference to the speed ratio of the two outside gears as long as they are of the same size. It merely changes the direction of rotation so that the 2 gears now rotate in the same direction (Figure 4.15a and b).

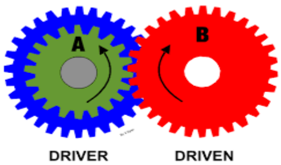
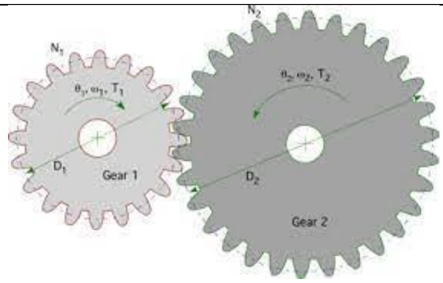
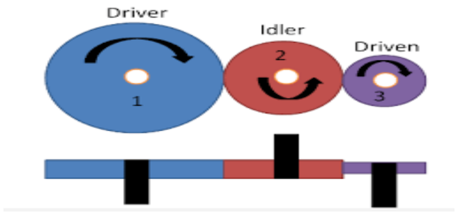
	When gears with equal number of teeth are in mesh, the Speed ratio is 1:1 Direction of rotation is opposite
	Gears in mesh have a speed ratio. 2:1 speed ratio implies a smaller drive gear in mesh with a larger driven gear, hence reduction in speed. A 1:2 speed ratio implies a larger drive gear in mesh with a smaller drievn gear, hence increase in speed at the final drive..
	Idler gear between any 2 gears makes the gears to rotate in the same direction. The speed ratio will depend on the difference in size between the idler gear and the other gears.

Figure 4.15a. Illustration of meshing of gears
Watch how [manual gearing and transmission occurs]() at the hyperlink shown above.

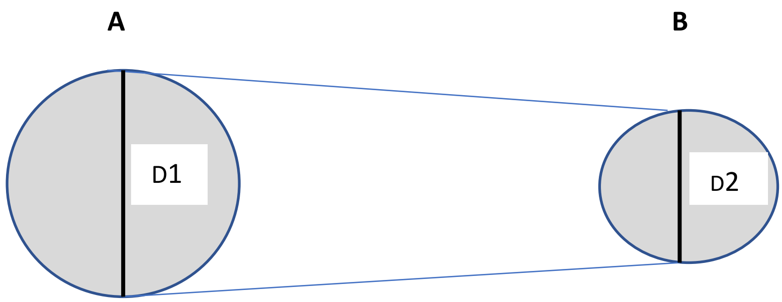


Figure 4.15b. Direction of pulley rotation is the same. Crossing the belt will cause them to rotate in opposite direction

If the bigger pulley (A) of diameter D_1 (Figure 4.15b) turns through 1 revolution, the belt will move a distance of πD_1, which will thus turn the smaller pulley (B) of diameter D_2 through same distance of πD_1. Since the distance round pulley B is πD_2, this pulley B will turn through $\pi D_1 / \pi D_2$, revolutions, which equals D1/D2.
Thus: the speed of the driven pulley (B) = speed of the driving pulley (A) x D_1/D_2. Hence: A/B = D2/D1
Thus:

$$\frac{\text{Speed of driving pulley}}{\text{Speed of driven pulley}} = \frac{\text{Diameter of driven pulley}}{\text{Diameter of driving pulley}}$$

Similarly, the action of gears in mesh is similar to a series of levers or pulleys, thus:

$$\frac{\text{Speed of driving gear (A)}}{\text{Speed of driven gear (B)}} = \frac{\text{No. of teeth on driven gear (B)}}{\text{No. of teeth on driving gear (A)}}$$

A gear with 15 teeth drives a gear with 75 teeth. If the speed of the driving gear is 55 rpm, calculate the speed of the driven gear.

55/B = 75/15

> B = 55x15/75 = 11 rpm

An electric motor, fitted with a 5 cm pulley and turning at 1400 rpm drives a hammer mill fitted with a 7 cm pulley. At what speed will the hammer mill rotate?

4.8.2.4. The Differential System

The functions of the differential system are to:

1) Change the direction of the drive from the crankshaft and main shaft to the wheels (i.e. 90°).
2) Cause a further reduction in the speed of the drive transmitted to the left and right (half) shafts (Axles)

3) Enable rear wheels to rotate at different speeds when turning corners. (The differential thus differentiates/varies the speed of the half shafts).
4) The differential lock (Diff-Lock) cuts out the action of the differential thus causing both the half shafts to lock and rotate at the same speed. The tractor then moves in a straight line and cannot turn at a corner.
5) The diff-lock also makes it impossible for one wheel to spin, which allows the tractor to easily overcome difficult terrain conditions like in muddy conditions.

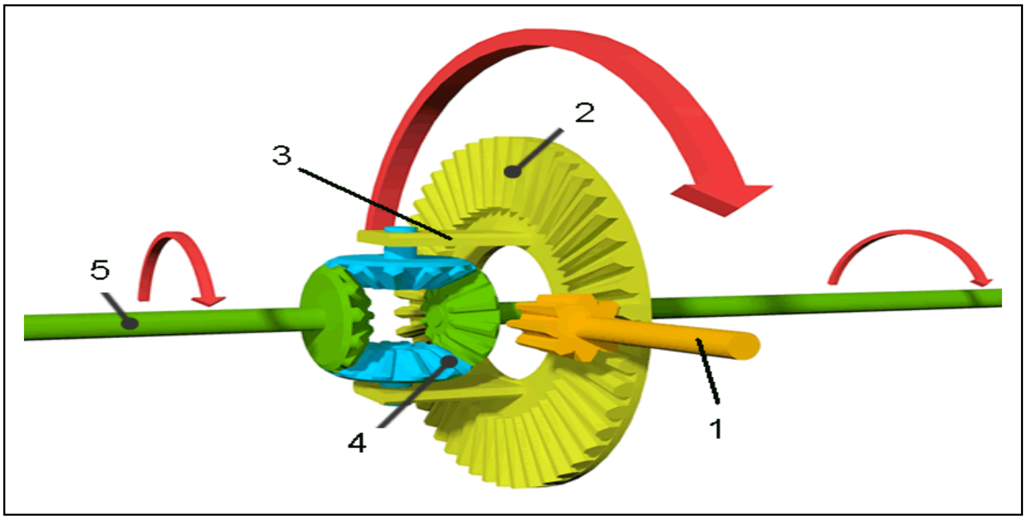


Figure 4.16: Illustration of a conventional differential System
Source:
http://ecoursesonline.iasri.res.in/mod/page/view.php?id=126234
(Accessed on 11-11-2022)

Watch the hyperlink indicated to learn more how the differential works.

The main components of the differential system (Figure 4.16) are listed below:

1. Input pinion gear
2. Crown wheel gear
3. Differential cage
4. Differential star
5. Differential axle (sun) gear

To Note:

1) The differential drive ring gear is also called the crown. The axle shafts are also called the half shafts. They transmit power to the left and right wheels.
2) When ploughing, one wheel may be on firm ground while the other on the furrow ground where resistance to wheels may be more. This may cause differential spinning of the wheels.
3) A differential Lock (Diff-Lock) is a devise used to lock the differential unit so that the wheels rotate at the same speed making the tractor to travel in a straight line. As such a tractor cannot turn corners on a differential lock.
4) The crown and pinion are two components (bevel gears) used to change the direction of the drive from the engine (main shaft) through 90° to the wheels; and also, reduction in speed of main shaft. The axles on which the wheels are secured will thus rotates slowly compared to the drive shaft.
5) The small bevel pinion on the output shaft from gearbox drives the larger crown wheel.
6) When a small gear drives a larger one, there is always reduction in speed.

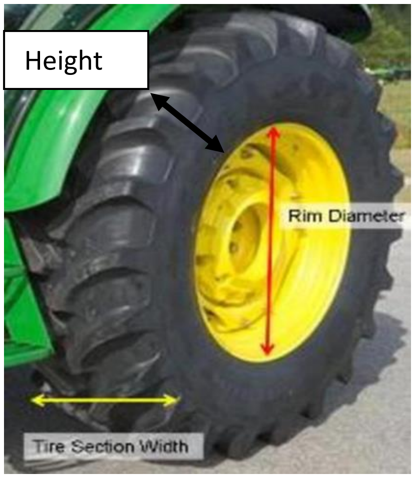
4.9. Wheels, Tyres and Brakes

4.9.1. Wheels and Tyres

Modern tractors have pneumatic wheels. Some farmers use steel wheels fitted with lugs, when field conditions are difficult.
On a general-purpose tractor;

1. The rear wheels are mostly the drive (driver) wheels because they are powered by the engine. The front wheels are called idler wheels (driven wheels) and by them, the tractor is steered in various directions, as long as the diff-lock is not engaged.
2. Grip is a necessary requirement for tyres and can be achieved through use of wide tyres on the rear wheels. This helps to improve grip because a large area of tyre is in contact with the field surface.
3. The size of the tyre is stamped on the tyre wall, thus:
    a. The wheel diameter (d) is the diameter of inner rim of the wheel.
    b. The wheel width (w) is the distance from one wall side to the other.

c. The wheel height is the distance of tyre from rim edge to where the measurement of tyre width starts.
d. For instance, a 12x36 inch tyre means it is 12 inches in width and can fit a rim of 36 inches. Similarly, a 10-16.5 tyre is 10” wide and fits a 16.5” rim. A 18x8.50-8 tyre is 18” inches tall; 8.5” inches wide, and mounts correctly on an 8” diameter rim (Figure 4.17).
e. Therefore, for a 2-variable nomenclature, the 2 figures represent width and rim diameter respectively. For a 3-variable branding the order is: height-width-rim.



This tyre is 18 inches tall, 9.5 inches wide and fits correctly on a rim of diameter 8 inches

Figure 4.17. Understanding nomenclature of tyre sizes

To Note:

1. A tyre is made in different casing thickness or layers or ply, hence the concept of ply[36] rating, which means the number of layers (fabric or canvas material) onto which is mounted the rubber tread. A 6 ply means 6 layers of fabric or canvas.
2. Despite the ply rating and treads, SLIP (i.e., failure to grip) could still occur depending on field conditions.
3. Tyres must be kept at the correct working pressure. Tyre pressures were formerly given in pounds per square inch (psi).

[36] The thickness and strength of plywood is based on the same concept.

Today they are given in bars or kg/cm^2. 1 bar = 14.7 psi, which also approximates $1kg/cm^2$.

4. Wheel Track settings are also possible and more common for front wheels on the general-purpose tractor.
5. Fronts wheels should have the same recommended pressure in both wheels to prevent the tractor from pulling towards the side of low-pressure tyre.
6. Counter weights can be fitted on rear wheels to improve penetration and adhesion (grip) and hence traction. Weights can also be fitted on front wheels or at the front of the tractor to counter rear load and thus prevent the tractor from lifting up from the front (tipping over backwards).
7. High tyre pressure reduces tractive efficiency.
8. Ballasting tractor tyres with water is a cheap way of adding weight to enhance penetration and adhesion. The normal ratio of water to air is 75:25. This also reduces bounce on rough road. The water must contain some $CaCl_2$ to protect it from frost.
9. The distance between front wheels can be varied. Wider space corresponds to better stability. Varying this width also helps the tractor to fit in different crop spacing requirements without damaging the crops.

4.9.2. Reduction of Wheel Slip

Wheel slip occurs when the force applied to a tyre exceeds the traction available to that tyre. As a consequence, the wheel rotates (spins) but there is no traction of the vehicle. To achieve traction and hence do work, wheel slip, which cannot be removed 100%, must be reduced using various interventions as outlined below:

1. Ensuring correct wheel pressure. Generally low tyre pressure increases the surface area of tyre in contact with soil, hence better traction. However very low tyre pressure can result in tyre damage. Tyre pressure is given either in pounds per square inch (psi) or bars or $kg/cm^{2.}$ 1 bar = 14.7 psi. A tyre pressure of 1 bar will be about 15 psi which is also about 1 kg/cm^2.
2. Using tyres of correct sizes and pattern of treads.
3. Use of wheel strakes. These have spikes which dig into the soil to increase grip.
4. Use of wheel girdles fitted entirely around the tyre.
5. Use of metal weights on rear wheels.

6. Use of spade lug wheels. These are metal wheels having around their entire perimeter steel lugs which bite into the ground, thus improving traction.
7. You may engage the diff-lock
8. Ballasting of rear wheels (75% water: 25% air) is a simple way of adding weight. The water must have some CaCl added to protect it from frost.

4.9.3. Tractor Weights

1. Besides ballasting, weights can be added at the front or on the rear wheels to enhance grip (traction).
2. Weights can be bolted to each front wheel or carried in a front mounted weight tray. Front weights are needed to counterbalance the weight of a heavy rear-mounted implement. Otherwise, the tractor could tip backwards.
3. Weights made of cast iron discs can be bolted to rear wheels to enhance grip. Each disc has a known weight

4.9.4. Wheel Brakes

Regardless of the design, the principle of braking is to force a stationary component into contact with a rotating component resulting into stoppage.

a. Internal Expanding shoe Brakes:

1. The brake drum secured to the driving shaft turns with the rear wheels. When the brake is applied, the pedal linkage turns the cam and the brake shoes are forced outwards, forcing the linings on the shoes to grip the rotating brake drum and thus slowing or stopping the tractor. The brake pad/lining are the stationary components.
2. For the external contracting brakes, the brake band having a brake lining contracts inwardly onto a rotating drum, thus stopping the wheels.

b. Disc Brakes

The principle of disc plates is to separate the drive from going into the differential shaft which is driving the tractor.

c. Independent Braking

Brakes of tractors can normally be operated independently of each other, as dictated by work and terrain conditions. The same left wheel and right wheel brakes can be latched together so that both brakes operate at one time if necessary.

d. Hand brake
This overrides the pedals when the tractor is parked. It's a parking brake.

Worn out brake pads and brake linings should be replaced as part of maintenance practice.

4.9.5. Tractor Steering

There are three ways of steering the wheels:

1. **Manual steering:** Steering is through mechanical linkages.
2. **Power Steering:** Manual steering is assisted by a miniature hydraulic system whose pump is driven by the fan belt. When this system fails, the tractor reverts to manual steering.
3. **Hydrostatic Steering:** There is no conventional steering linkage from the steering wheel to the wheels. A system of engine-driven oil pump does the job. It is not possible to steer the tractor if the hydrostatic system develops a fault.

Individual task	1. Ensure you are familiar with both the external contracting mechanism and the internal expanding mechanism 2. Learn about Wheel Track Setting next time you visit the machinery yard.

4.10. Hydraulic System, Hitches and Draw Bar

4.10.1. Hydraulic System

The hydraulic system converts hydraulic energy into mechanical energy for the tractor to raise or lower implements (Figure 4.18). The system also supplies power to operate external rams and hydraulic motors. The basic components of the hydraulic system are:

1. Hydraulic pump
2. Hydraulic cylinder and piston
3. Hydraulic tank
4. Control valve
5. Hope pipe and fittings
6. Lifting arms.

Hydraulic system is popularly applied in:

1. Construction of civil infrastructure like roads and reservoirs
2. Loading purposes
3. Braking systems, and
4. Tillage operations.

Figure 4.18: Application of hydraulic system in sugarcane loading at Woodland Estate, Naluchira, Kakamega, Kenya

In terms of operation, the basic principle is Pascal's law, which states that in a closed hydraulic system, the pressure exerted on the walls is the same everywhere in the system. As such any force applied to a confined fluid is transmitted uniformly in all directions throughout the fluid regardless of the shape of the container, effecting the same pressure everywhere in the system (Figure 4.19). Thus $P_1=P_2=P_3 = P_n$ (Where 1, 2, 3 and n represent different surface areas of the same conduit).

1) Pressure (P) is the quotient of Force (F) and area (A) i.e., P=F/A.
2) For instance, applying 5-units of force on a small piston of 1-unit square area means P=F/A = 5/1 = 5. Thus, for every 1-unit square area beneath the ram, there is also 5 units of pressure (P=F/A); thus: F=PA.
3) If the second piston has an area 10 times that of the first, the force on the second piston is P_2A_2 = 5x10 = 50 (Note that $P_1=P_2$). Recall that the pressure is the same everywhere in that conduit.
4) If the ram moves by 1 unit height, volume displaced will be Area x Height = 10 x1 = 10 cubic units.

5) The same volume will be pushed down by the piston in the left part of the system. Thus 10 =Area (1) x Height (h). h = V/A = 10/1 -10. That means the piston will move through a distance (height) of 10 units to effect a 1 unit distance (height) of the ram.
6) The ratio of movement is the same as the ratio between the weights (force) applied to the ram and to the piston thus 50:5 thence 10:1, as well as between the cross-section areas of the ram and piston – 10:1.
7) If such a system had an inbuilt non-return valve to prevent the oil being pumped in from a sump from flowing backwards, each time the piston is forced down, it would be possible to lift a weight progressively higher.
8) A hydraulic jack works on the same principle.
9) Lifting and lowering of implements attached to the tractor hydraulic system works on the same principle.
10) The hydraulic pump is operated by suitable gears, connected with the engine.

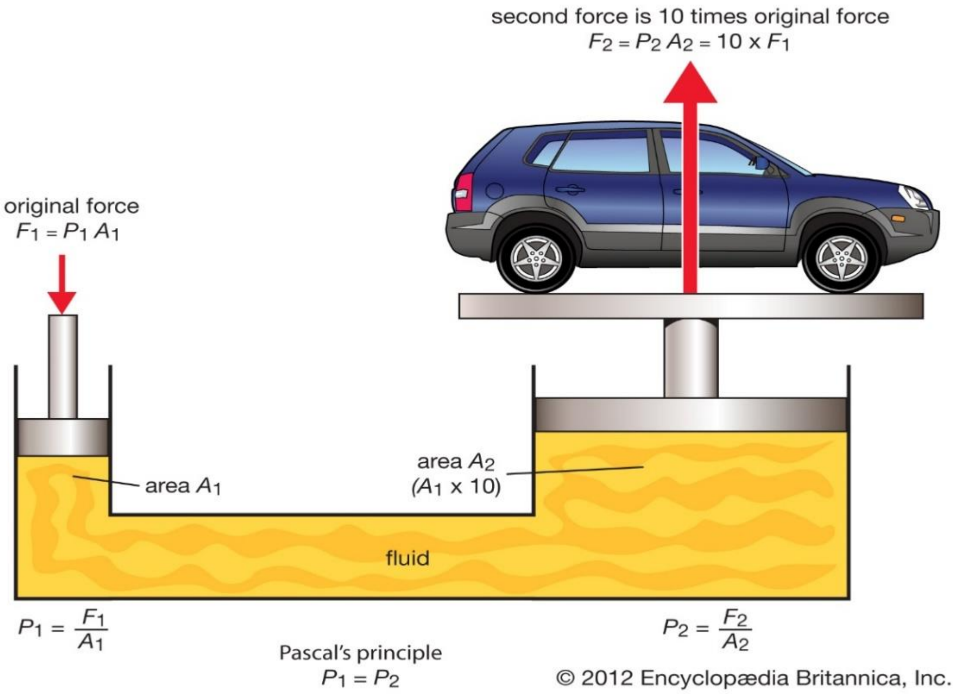


Figure 4.19: Illustration of Pascal's law
(Source: https://www.britannica.com/science/Pascals-principle)
Accessed on 14-02-2022

4.10.2. Hitches

There are 3 types of Hitches for general purpose tractors (Figure 4.20 a-c).

4.10.2.1. The 3-Point Linkage

The 3-point linkage (or three-point-hitch) is a standardised system to attach implements that need to be lifted or lowered depending on the field operations e.g., a Plough to tractors (Figure 4.21). They comprise of three movable arms assembled in a triangle or 'A' formation, and are controlled by the hydraulic system allowing lifting, lowering and tilting. Three-point linkage systems are designed to shift the weight of the implement, such as a plough, to the tractor providing the tractor more traction. The 2 lower arms are used to attach an implement to the tractor and are used by the hydraulic system to raise an implement. The top link provides stability and prevents implement hitting tractor when lifted (i.e., stops the implement tipping backwards or forwards).

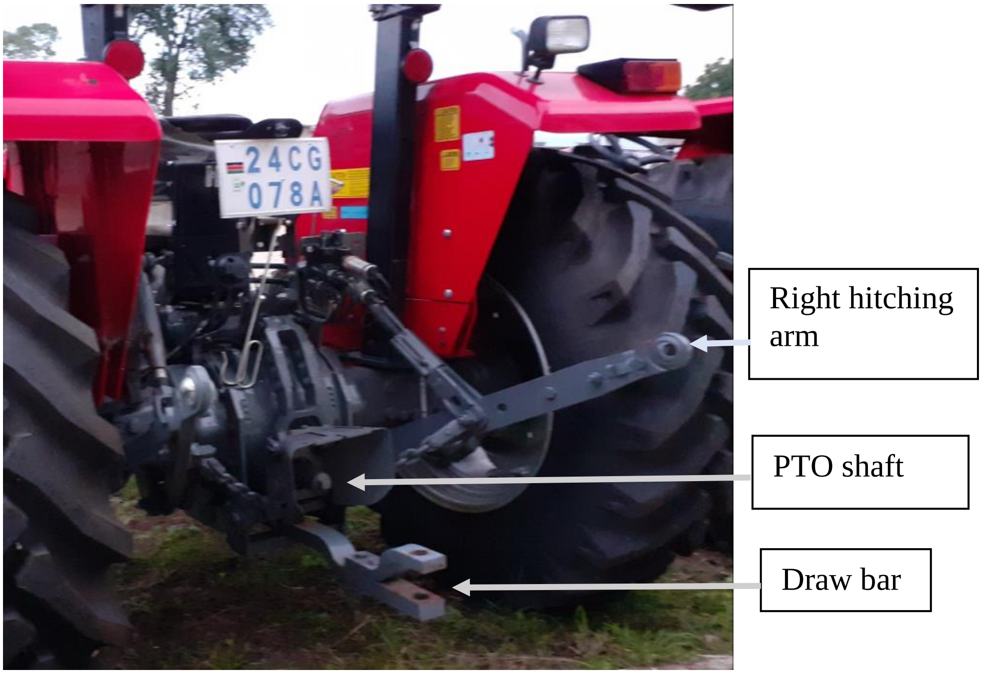


Figure 4.20 a. Hitching arms, drawbar and PTO shaft

4.10.2.2. Pick-Up Hitch

The pick-up hitch is the point of attachment for towing trailers and is operated by hydraulics but does not use engine power to work. It is used to improve manoeuvrability of the implement.

4.10.2.3. The Draw Bar and Drawbar Pin

The draw bar is permanently fixed to the underside of rear of the tractor. As the name suggests, it can be used to draw an implement having wheels (point of attachment for pulled implements). It is not operated by hydraulic system.

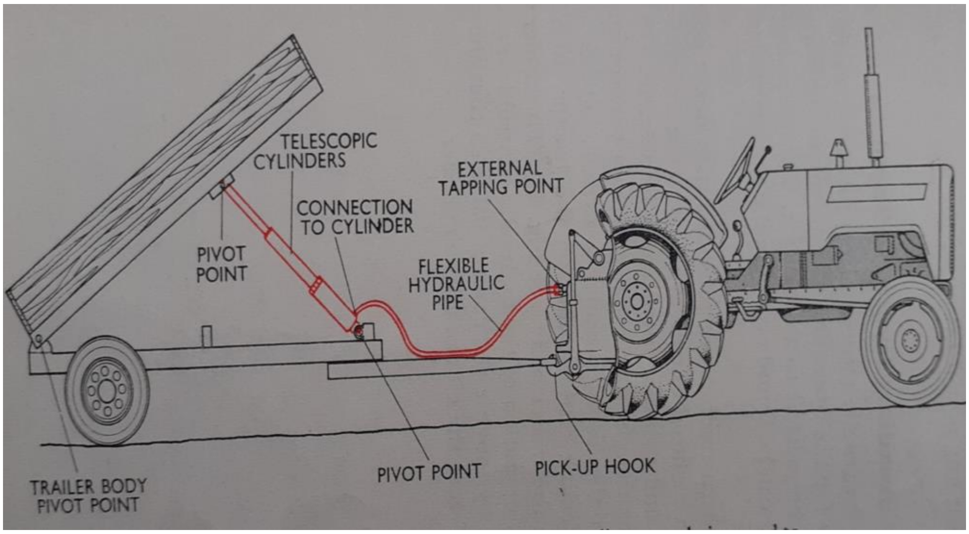


Figure 4.20 b: Pick up Hitch Source: Shippen and Turner, 1966)

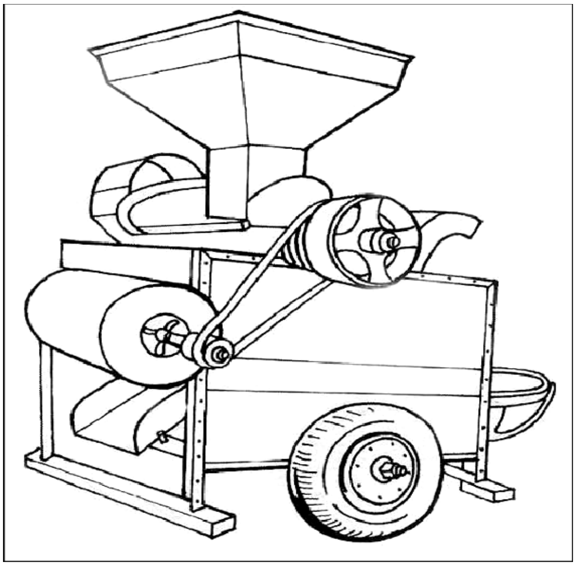
4.11. The Power Take-Off Shaft

As the name suggests, the power take off (PTO) shaft takes power from the main shaft for applications other than traction. The PTO can be controlled (engaged or disengaged) by an independent clutch or dual clutch system. The clutch pedal must be pushed down before engaging the PTO drive. The PTO system enables a tractor to operate other implements while it's stationary or even when in motion (Figure 4.21a and b). The PTO must have design guards to cover the top and sides of the splined shaft as a safety precaution. The PTO system consists of:

1. **PTO drive shaft:** Part of the lay shaft of the tractor gear box.
2. **PTO gears:** These gears connect or disconnect the PTO shaft from the lay shaft of the tractor's gearbox.
3. **PTO Shaft:** The rod that transmit power to implements

Individual learning task	Explain the pathway of power transfer from the engine to the PTO. Which tasks on the farm can be achieved by harnessing the PTO?

Figure 4.21a. Harnessing the PTO shaft for maize shelling. Source: https://www.intechopen.com/chapters/79507 (Accessed on 29-11-22)



A power operated Maize Sheller can comprise a closed metal drum structure driven by a 12 hp diesel engine. This power can also be tapped from the PTO of a tractor.
Electric power can also be used. The grains are removed from the cob due to the rubbing action between pinions (rotating spikes) and corns

Figure 4.21b: A maize Sheller assembly (Source: https://www.researchgate.net/figure/Power-operated-Maize-Sheller_fig2_242233927) accessed on 11th July 2022

5. Tractor Implements and Accessories

5.1. Introduction

All accessories are implements but not all implements are accessories. Tractors can do for us different jobs/work depending on the requisite accessory. These equipment/implements are attached on either the draw bar or hitches or PTO shaft.

Based on the type of hitching tractor drawn implements are classified as:

a. Trailed type implement
b. Semi-mounted implement and
c. Mounted implement

5.1.1. Trailed or Pull type implement

The trailed implements are attached to the tractor’s drawbar and they are not raised or lowered. The implement trails the tractor as it moves since they are heavy and are usually provided with wheels for easy hitching to the back of tractor and better stability, e.g., a trailer.

5.1.2. Semi-mounted implement

These types of implements are attached to the tractor’s 2-point linkage. Due to their weight, they are normally provided with wheels to help in performance and transportation of the machine. The implements can be raised or lowered using the hydraulic system of the tractor. Examples of these implements include the disc harrow, seed drill (Figure 5.2 -5.5)

5.1.3. Fully Mounted implement

A fully mounted implement is one which is attached to the tractor through a hitch linkage in such a manner that it is completely supported by the tractor when in raised position. The implement can be controlled directly by the tractor steering unit. As such they have no own wheels. Standard one gang ploughs are good examples.

Figure 5.1. Tractor mounted seed planter

Figure 5.2 Tractor mounted disc harrow

5.3 Mounted cultivator

5.4 Mounted ripper

5.5. A 2-gang saucer-shaped semi-mounted disc harrower (Source: Bukura College Machinery Yard, Kakamega)

Rather than have single operation units, combined operation units exist. Besides maintaining efficiency, they also save on time and costs. As an example, furrowing, seeding, manure/fertiliser application, seed covering and firming of ground can be done in a single operation. The reduction from 5 individual events to 1 combined event equally results into reduction in soil compaction, labour costs and fuel costs. Multiple cultivation events can be done in a single operation (run) using an implement specifically designed for that purpose. For example: furrowing (A), seed drilling (B), manure application (C), seed covering (D) and ground firming (E) can be done in a single operation as illustrated in figure 5.6. Calibration of the entire assembly is necessary before actual operations are done.

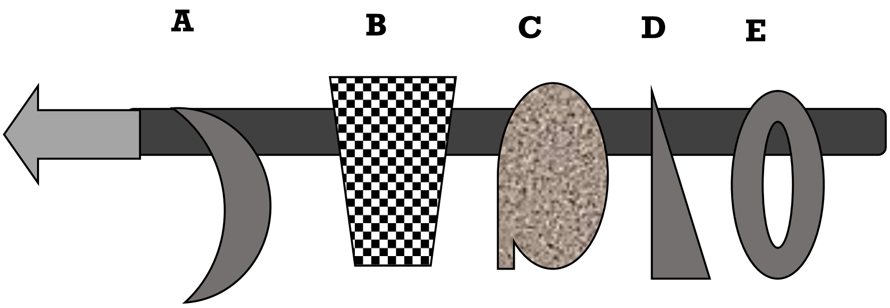


Figure 5.6a: Illustrated multi-purpose seeder (The arrow indicates the direction of pulling)

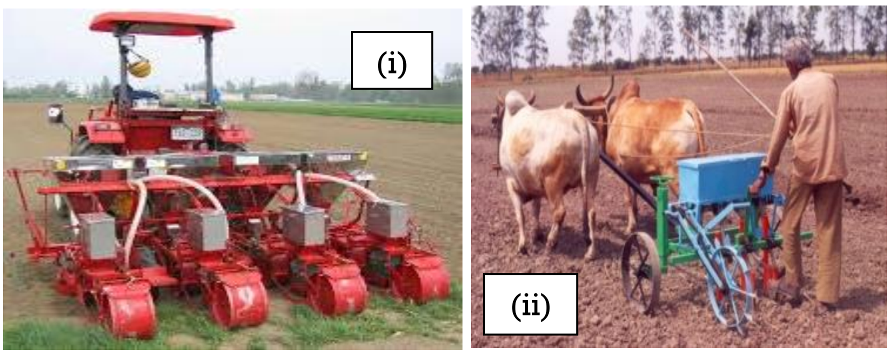


Figure 5.6b: (i) Tractor mounted multipurpose air seeder (Source: Research Gate, 2022) (ii) Animal drawn seeder (Source: www. aicrp.icar.gov.in/fim/salient-achievements/sowing-and-planting-equipment)

Since the land sizes are ever decreasing, the scope for increasing the speed or width of existing implements is less feasible. Hence, reducing the number of passes by combining two or more field operations with the use of combination tillage implements may provide better solution.

In a single run the combined tillage tool performs primary as well as secondary tillage operations.

5.2. Tilling Systems and Operations

Tillage is the mechanical manipulation of soil in order to provide conditions favourable for crop growth. These include:

1. Develop or produce a suitable/desirable soil structure or tilth
2. Control weeds or remove unwanted crops
3. Loosen soil for better aeration and water retention
4. Incorporate into the soil crop remains, fertilizers, manure etc.
5. Leave a rough surface so that soil erosion is minimized

Essentially the action of tillage is to change the ratios of the soil components on volume basis. For example, for loamy soil, before tillage the soil, water and air contents are 55, 42, and 3%. After tillage this becomes 43, 33, and 24% respectively.

Depending on the amount of crop residue left on the soil surface, tillage practices generally fall into three main categories:

1. Conservation tillage
2. Reduced (minimum) tillage
3. Conventional tillage

Within the conventional type, the following tillage practices can be distinguished:

1. Primary tillage: Is the initial major soil working operation that disturbs the soil in such a way that it can be subsequently processed into a condition suitable for germination of seed when planted.
2. Secondary tillage: This involves later operations that work soil at a shallower depth so as to turn it into a suitable seedbed for planting.
3. Tertiary tillage: This entails any other operation that may be needed to address specific or unique field requirements like furrowing, ridging etc.

5.3. Tillage Implements (Ploughs)

Design implements (ploughs) are available to suit the kind of tillage desired. Both single gang, multiple gangs and reversible ploughs are available for use. The two main ploughs types are the Disc plough and mouldboard plough.

5.3.1. Disc Plough

The disc plough is an implement that uses a rotating concave disc to lift, pulverize and partially invert the soil (Figure 5.7).

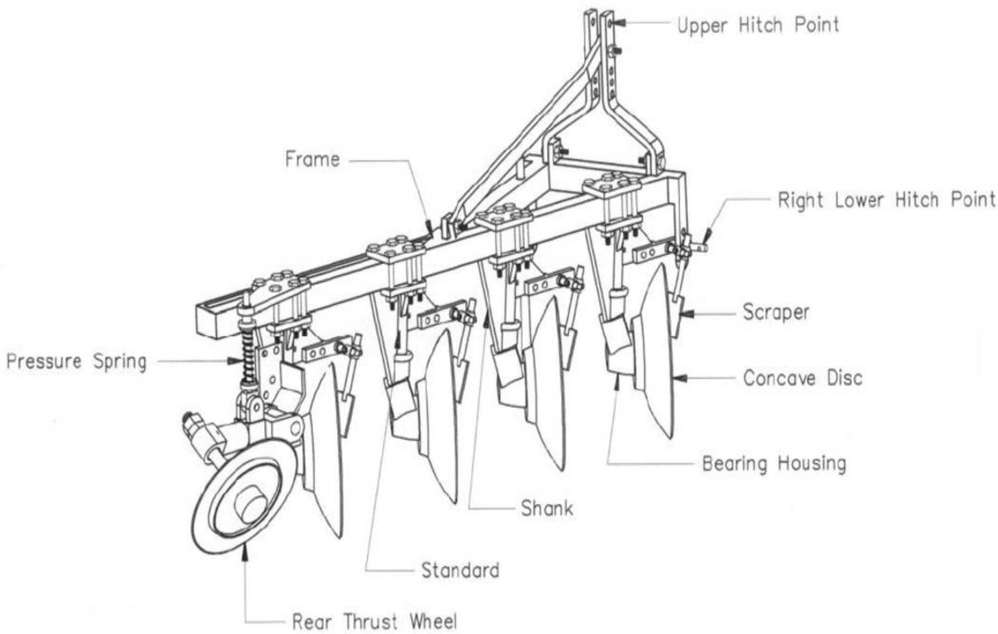


Figure 5.7 One gang disc plough.
Source: https://www.semanticscholar.org/paper/To-Assess-the-Impact-of-Disc-Plough-Weight-and-on-Tanimola-Oyekunle/00a99716045b79c8db7a67da2a4a0b61b392339a (Retrieved on 1st November 2022)

It easily cuts trash and rolls over obstructions. It is best adapted for:

1. Hard, dry soils where M/B has penetration problems
2. Sticky soils where M/B cannot scour well
3. Loose soils

4. Soils containing obstructions e.g., roots
5. Areas where deep ploughing is desirable

The disc plough pulverises more than inverts the soil. It can be a one-gang plough or several gangs' plough.

5.3.2. The Mould Board Plough

The mouldboard plough (Figure 5.8 and 5.9) is a primary tillage implement whose main function is to piece, cut a rectangular furrow slice, lift it and invert the furrow slice to cover the trash. It thus bringing new soil onto the surface while covering crop residue and other material.

The size of the plough bottom is the width of furrow it is designed to cut. Single mould ploughs are popular with draft animal power. For tractors, multiple board ploughs make more economic and technical sense.

The plough is best suited for areas with soft soils (temperate zones) that are not sticky, hard or loose, and in a field with minimum of obstructions.

The key components of a mouldboard plough are:

1. **Share:** It is that part of the plough bottom which penetrates into the soil and makes horizontal cut below the surface thus initiating the lifting and turning of the furrow slice.
2. **Mould board:** It is the curved part which continues the lifting and eventual turn of the slice. Some amount of pulverization of the soil slice also occurs.
3. **Landside:** It is the flat plate which presses against the furrow wall and prevents the plough from lateral swinging and and absorbs the side forces from the turning furrow slice.
4. The rear part of land side is called heel which slides on the bottom of the furrow
5. **Skim:** This is fitted on disc coulters to remove a small amount of the top corner of the furrow slice, throw it into the previous furrow. This ensures that all surface trash is buried and the furrow joints are sealed. Also known as a jointer

6. **Frog:** It is the part to which the share, landside and mouldboard are attached.
7. **Coulter:** Its purpose is to make a vertical cut thus separating the furrow slice from the un-ploughed land, and also cut trash and ensure proper coverage
8. **Tail piece:** It is an adjustable extension, which can be fastened to the rear of the mould board to help in turning the furrow slice

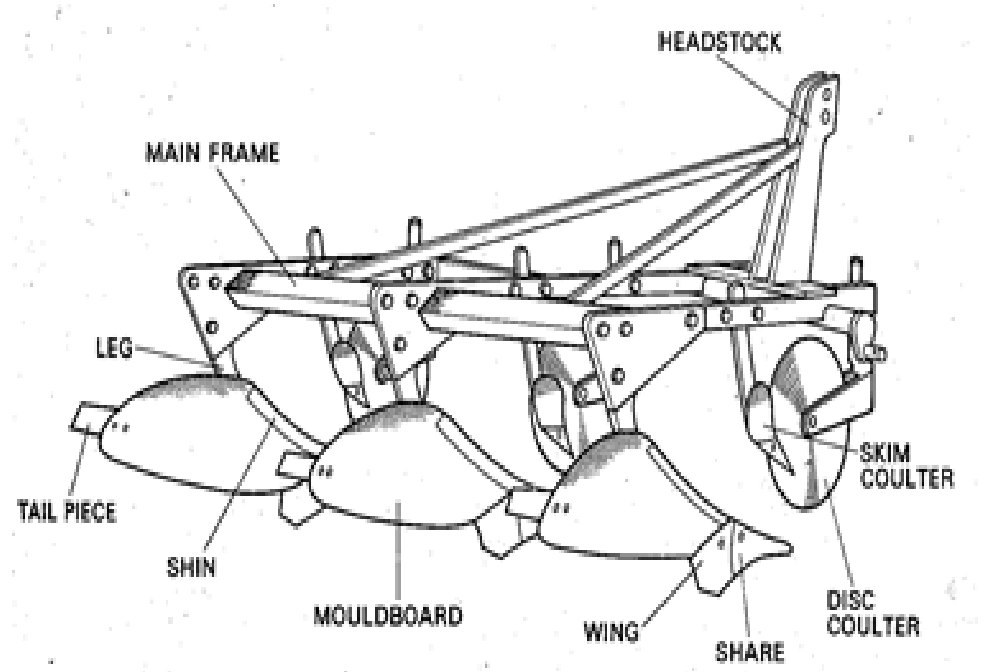


Figure 5.8. Tractor mounted mouldboard plough

In other plough designs, a reversible mouldboard or disc plough (Figure 5.10 become more relevant. Such a plough has left and right-handed discs or mouldboards thus allowing the tractor driver to work up and down in the same furrow. The soil can be thrown in the same direction regardless of the direction of travel. The turnover mechanism may be manual, mechanical or hydraulic. Further:

1. The plough is heavier and more expensive than the right-handed plough but leaves a level surface.
2. The time needed to mark out the field is minimal.
3. They are suitable for small and irregular fields.

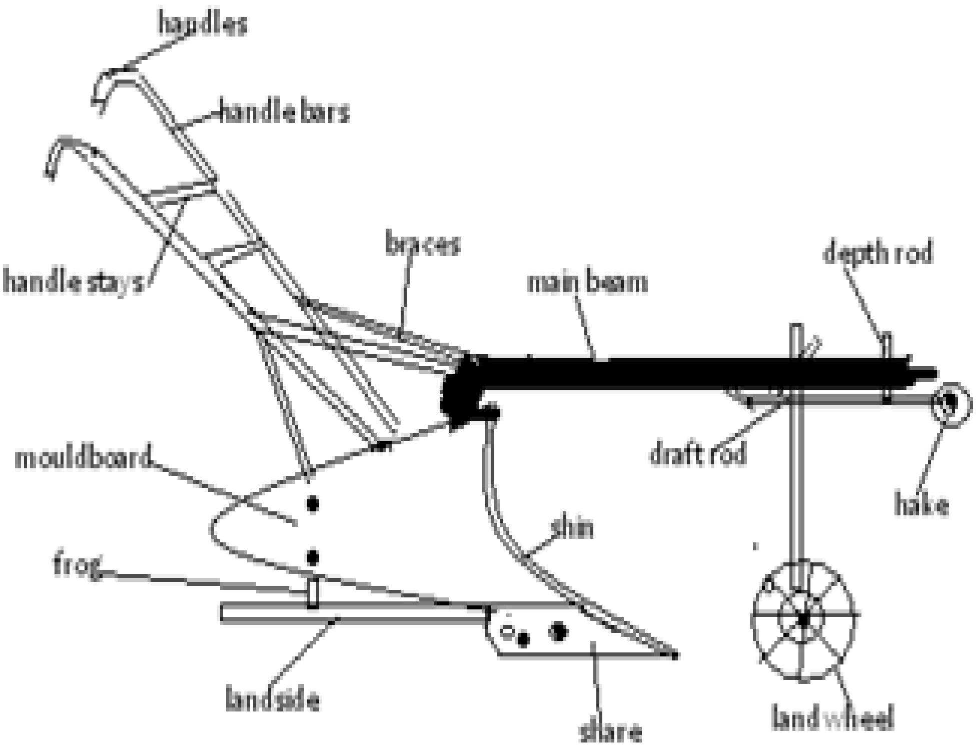


Figure 5.9 Animal drawn Mouldboard plough. Source: https://www.easyelimu.com/high-school-notes/agriculture/agriculture-form-4-notes/item/2094-farm-power-and-machinery (Retrieved on 1st November 2022)

Figure 5.10. A reversible mouldboard plough (Source: https://used.russells.uk.com/russellgroup/groundused/agriculture/reversible-ploughs) Accessed on 17-05-23)

To Note:

1. The more the discs on a gang, the more the ploughed area in a single run.
2. Oxen drawn mouldboard ploughs conventionally have only one mouldboard, otherwise the load would overwhelm the animals.

5.3.3. Maintenance of Ploughs

The key aspects in this regard are:

1. Greasing all lubrication points every day during the ploughing season.
2. Changing all soil engaging parts when they are worn especially the shares.
3. Keeping nuts and bolts tight at all times
4. At the end of the season, replace any broken items, coat bright parts with a rust preventing solution and store under cover

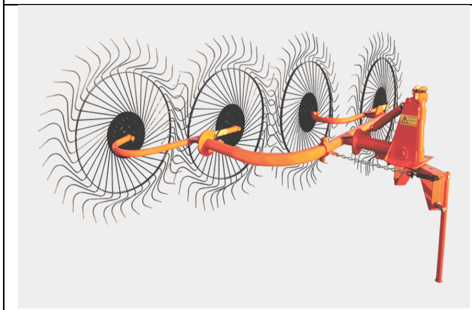
5.4. Safety Precautions

Your safety and health as a machine operator cannot be compromised at all times. When working with ploughs pay attention to among others the following:

1. Exercise care when attaching the plough to the tractor
2. When an **integral** or **mounted** plough is raised, there is possibility of instability. Tipping is likely and the steering becomes "light". One has to watch out
3. Never kneel or sit under a plough held in the raised position, even when fitting shares or making adjustments.
4. Do not dismount when the tractor-implement combination is in motion.
5. Be careful of sharp edges when adjusting nuts, bolts etc.
6. Ensure nobody is standing near a reversible plough before the tripping turnover mechanism has been actuated

5.5. Other tasks for Mounted Implements

Other mounted implements for different tasks are outlined below (Figures 5.11, 5.12, 5.13 and 5.14).

 Figure 5.11. Manure spreader	 Figure 5.12. Ground crop sprayer[37]
 Figure 5.13. Hay rake	 Figure 5.14. Transport trailer

5.5.1. Drills

A drill consists of a box or hopper carried on wheels with a feed mechanism, which delivers grain to the seed tubes. Planters and seeders operate by this mechanism for planting operations. For combined drills, the hopper is much larger and divided into 2 parts: one for seed and the other for fertiliser. Planting and fertilizer application are achieved in one pass. Equipment design must suit intended purpose. Calibration of planters is necessary in order to achieve the required planting (sowing) rate and density.

5.5.2. Manure and fertiliser distributors

Manure and fertiliser distribution can be done by farmyard and manure spreaders. Combined shredding and spreading mechanism

[37] Google and compare this to a boom sprayer

are used to distribute the material. Slurry spreaders can on the other hand spread slurry on land with special irrigation equipment using a pump, pipeline system and slurry guns which spray the liquid on the land.

5.5.3. Mowing Machinery

Cutters and Shredders are farming implements used to “cut or shred” unwanted weeds or other vegetative growth. Mowers are used to cut grass and other upright crops.

5.5.4. Hay Preparation Machinery

Hay making machinery including Balers, Silage making machinery

5.5.5. Ground Crop Sprayers

The design sprayer is mounted on the tractor to a height above the crop. Crop line spacing must be done with prior knowledge of the equipment for spraying. Alternatively, the tractor must be designed with the possibility of varying the width of both wheels.

5.5.6. Transportation

Transport on the farm can be done by either a trailer mounted on a tractor or a pick or lorry.

5.5.7. Harvesting Machinery

A wide range of crops can today be harvested by machines. Suffice is to note that such machines must be designed specifically for the crop in question. For example, a huller (also called rice husker) is a kind of agricultural machinery that hulls rice. A cotton harvester is a machine that automates cotton harvesting.

A combine harvester on the other hand is a machine that "combines" several operations critical at the harvesting stage (Figure 5.15). It does the following sequential work types in a single run (operation):

1. It cuts the crop
2. It conveys the crop to the threshing (separation/winnowing) mechanism
3. It sorts (separates) the grain or seed from the straw and chaff, and delivers it to a transport vehicle driving strategically along.

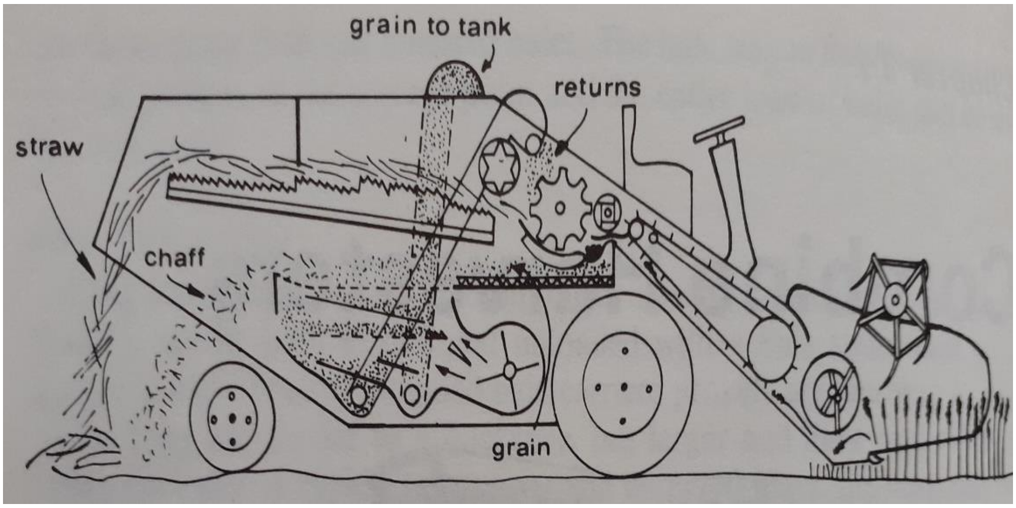


Figure 5.15: Illustration of grain flow in a combine harvester (Source: Bell 1983)

Combine harvesters are self-propelled and have a range of forward and reverse speeds to suit both field and road conditions. Crops grown on large scale especially cereals (wheat, maize, barley and rice) are popularly harvested using combine harvesters. Root crops can also be harvested using a combine harvester. As an example, in a potato harvester, the processes involved are basically:

1. Digging and removal of the potatoes from the soil
2. Lifting and conveying the potatoes to a cleaner
3. Removing the soil and other foreign materials, and
4. Conveying the potatoes to a carrier or packaging system (Figure 5.16)

The design should ensure zero damage to the physical appearance of the potatoes.

Reflection:

Critically examine the combine harvester in the context of agriculture designed for the environment?
What possibilities exist for combined operations within draft animal power systems?

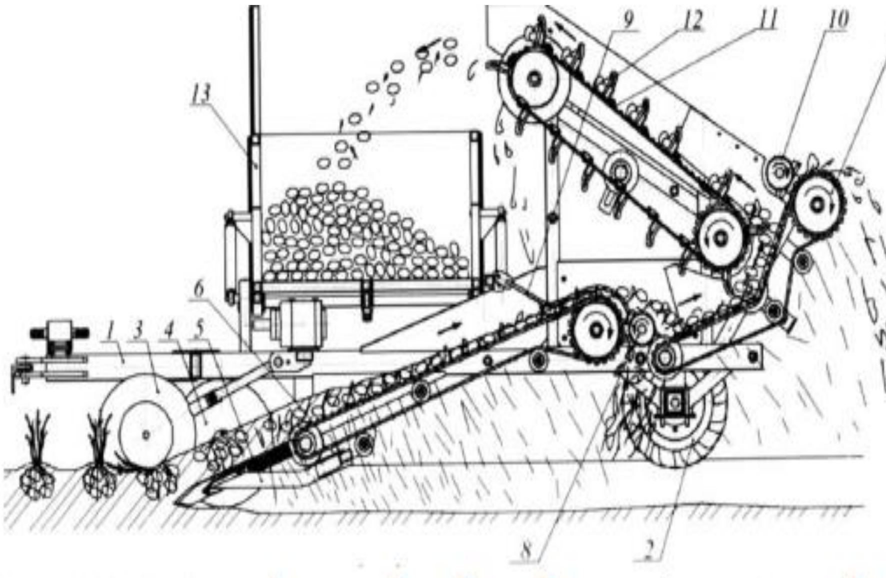


Figure 5.16: Potato combine harvester (Source: Bell 1983)

5.6. Other Farm Machinery and Implements

The multiplicity of farm operations necessitates availability of a wide range of machinery. In addition to the machinery and accessories discussed in preceding sections, students are urged to take time and familiraise with other machinery/equipment such as:

1. Briquetting machinery
2. Choppers can be designed to chop fodder like Napier grass into desired sizes.
3. Concreting, moulds and brick making equipment
4. Roller mills: Used for crushing or flattening grain. Roller mills are also used in sugarcane milling factories
5. Food Mixers: Are designed to mix 2 or more food types
6. Grain driers.
7. Hammer Mills: They pulverize dry grain into desired sizes. A typical example is a maize mill.
8. Ridgers and rotary tillers
9. Roller Mills: Are used to crush or flatten grain
10. Spraying machinery/equipment

Boomless verses Boom Spraying

Besides tillage, spraying is also the other most frequent farm operation. While simple portable hand sprayers are common on small sized farms, spraying crops on large scale farms will require specially designed sprayers that can be mounted on a suitable vehicle like a tractor. This requirement introduces the innovation of a Boomless Sprayer and a Boom Sprayer.

Boomless Spraying

A boomless sprayer will generally have one or two nozzles that are pointed sideways in opposite directions, or tilted up slightly to achieve a wider spray pattern as compared to ordinary hand operated sprayers. Boomless sprayers are great for small, fast jobs with minimal fuss. Boomless sprayers are versatile and can take on the tougher more complicated sprayer jobs. They're perfect for ditches and rough uneven terrain, around objects like poles and fences.

In case you have an orchard of common trees like citrus fruits or apple among others, a Boomless Sprayer allows you to get in and around the trees, save you a lot time, and reduce the likelihood of damaging a boom arm. Further, boomless sprayers are also great for mosquito spraying if you have stagnant water in your yard

Boom Spraying

A boom sprayer on the other hand is designed to cover much larger area and in more efficient way. It usually has multiple spray nozzles spread out along arms (booms), pointed directly down.

By virtue of their sizes and weight, they are often semi-mounted implements. They generally run closer to the ground meaning that they're less affected by the wind. Therefore, the spraying is more accurate and much easier to track what has been sprayed and what hasn't.

Due to the width of the boom, Boom Sprayers also allow you to spray a larger area in a shorter amount of time, therefore saving you time and money on big spraying jobs. They are perfect for field spraying large areas, particularly even terrain. If your property is prone to wind in specific seasons then a boom sprayer can be set up to help you reduce chemical drift and reduce your environmental footprint.

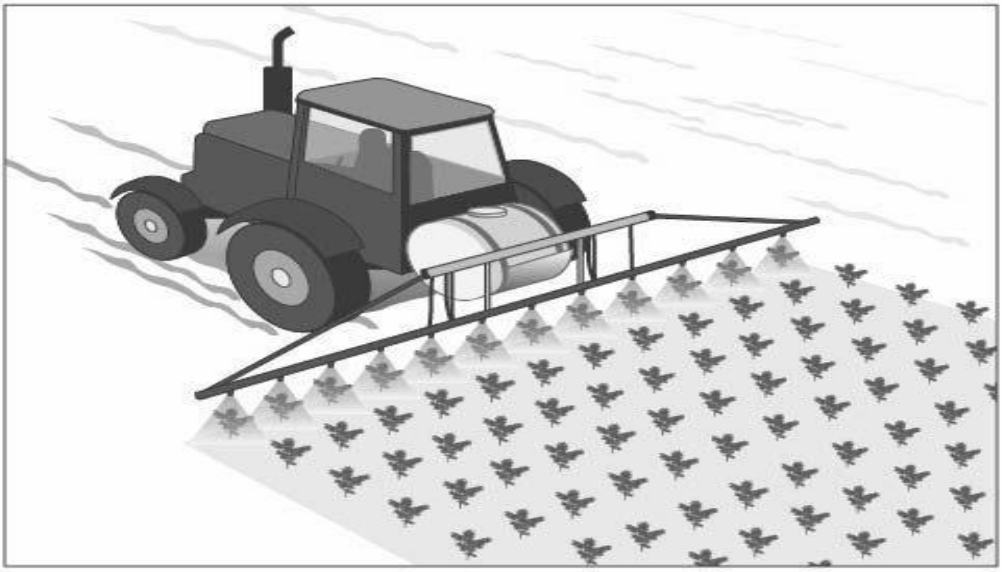


Figure 5.17. Illustration of a boom sprayer (Retrieved on 21st November 2022 from: https://www.no-tillfarmer.com/articles/11446-why-you-should-recalibrate-your-boom-sprayer-this-spring)

The Pivot Irrigation System
Are used to irrigate very large tracts of land and are designed with clearance that accommodates different crops. Two types are generally used (Figure 5.18)

1. A fixed center pivot system
Centre pivot irrigation (also called water-wheel irrigation or circle irrigation) involves sprinklers that rotate and water crops in a circle around the central pivot[38]. The irrigation system is attached to a stationary pivot point in the middle of the field. This is where the water enters the pivot pipes, and where the control panel is located. A electric motor on each wheeled tower enables the structure to move autonomously around the pivot point like the hand of a clock resulting into a circular irrigation pattern

[38] https://www.twl-irrigation.com/what-is-centre-pivot-irrigation/ (Retrieved April 20, 2024)

2. Lateral move system

It works on a similar principle although its motorized wheeled towers drive in straight lines, while the water is drawn from a supply ditch that runs parallel to the field.

Figure 5.18. Part of a centre pivot irrigation. See videos on the hyper link and also at footnote[39] below for in-depth learning.

[39] https://www.youtube.com/watch?v=DE3tJzL-LT0; https://www.youtube.com/watch?v=2bILpvH3EuQ (Retrieved April 20, 2024).

6. Maintenance of the Farm Tractor

6.1. Overview

If the tractor is to serve us well, it must receive routine maintenance based on the manufacturer's guidelines/manuals/instructions. Normally, servicing attention to various parts/components is recommended at intervals during the working life of the tractor. Some items may require attention daily while others after specific hours of tractor use. Therefore, a record of hours worked is necessary. This is often entered into a tractor's record book.

Most tractors are fitted with an instrument called "a proof meter" which records among others the engine operating hours, which then guides the operator on the service needed. Generally, a tractor is subjected to maintenance based on the number of hours it has performed its function.

6.2. Servicing/Maintenance Scheme for a Diesel Tractor

Tractor operation hours are a reflection of the time the tractor systems have been running, thus subjected to tear and wear. In-line with these, tractor maintenance intervals are classified into:

1. Daily checks
2. 50-hour checks
3. 200-hour checks
4. 600-hour checks
5. 1000-hour checks

6.2.1. Daily Attention Checks

The following daily checks MUST be carried out.

1. Oil level in the oil sump and top as appropriate
2. Water level in the radiator and top as appropriate
3. Oil level in the oil bath air cleaner and clean out dirt
4. Lubricate steering linkages with grease gun
5. Brakes to ensure they are working
6. Hitching points to ensure they are intact
7. Adequacy of fuel
8. Tire pressure to ensure they are adequately inflated and not leaking

6.2.2. Service after Every 50 hours

The following service **MUST** be carried out after every 50 hours.

1. Remove the air cleaner oil container and also the filter and clean as appropriate
2. Check the oil level in the gearbox and top up as appropriate
3. Check oil level in the rear axle and fill up to recommended mark on dipstick
4. Lubricate front and rear wheel bearings
5. Lubricate clutch cross-shaft
6. Lubricate brake pedal shaft
7. Check tyres and inflate to correct pressures
8. Top up battery with distilled water if not maintenance free and clean the battery terminals

6.2.3. Service after Every 200 Hours

The following service MUST be carried out after every 200 hours.

1. Remove and clean engine air breather filter
2. Drain the engine lubricating oil and refill the sump with new oil
3. Remove the engine external oil filter element, wash out the bowl and refit a new element
4. Lubricate the generator
5. Check the oil level in the steering box
6. Drain and flush cooling system

6.2.4. Service after Every 600 Hours

The following service **MUST** be carried out after every 600 hours.

1. Remove the diesel fuel filter element, wash out the bowl and fit a new element
2. Remove the fuel injectors and replace with a service set

6.2.5. Service after Every 1000 Hours

The following service **MUST** be carried out after every 1000 hours.

1. Drain the gear box lubricating oil and refill the sump with new oil
2. Drain the rear axle lubricating oil. Remove and clean the hydraulic pump filter screen and magnetic filters. Replace the filters and refill the sump with new oil.

6.2.6. Other Procedures in Routine Servicing of Tractors

1. Adjustment of brakes
2. Adjustment of clutch pedal movement
3. Adjustment of fan belt tension
4. Keeping the tractor clean
5. Checking the tightness of nuts and bolts
6. Checking for any leakages
7. Checking accessories for any loose parts and fix accordingly
8. Cleaning accessories after use and parking neatly and safely
9. Greasing as appropriate to prevent rusting

6.2.7. Maintenance of Tractor Implements
Cleaning after use, greasing as appropriate, tightening loose nuts and bolts, replacing worn out parts etc

Best Practice Tip:

A professional farmer privileged to have machinery, should not wait for the statutory working hours before inspecting his/her machinery and implements. Before and after work, a quick check is advisable in order to fix defects that occur randomly

7. Machinery Yard

7.1. Machinery Storage

A machinery yard is a place on a farm where machinery and their accessories are kept and or stored and collected each time they have to be used. The yard as a land use should therefore be designed to accommodate all different types of machines and vehicles available at a given farm (Figure 7.1). The buildings must be designed to suit this use and, in all cases, ensure occupational safety and health. Equipment for maintenance and servicing of machinery should be in place. In addition, offices and stores for personnel and spare parts are a must on a progressive farm.

Figure 7.1: A modern machirey yard
Source: https://www.dreamstime.com/photos-images/machinery-yard.html (Accessed on 14-02-2022)

A farm machinery storage facility is important for the following reasons:

1. *Higher equipment trade-in value*: Machinery dealers tend to allow farmers more value on housed machinery compared to non-housed machinery.
2. *Greater convenience:* The equipment is generally located at one place and under one roof.
3. *More security*: This is important especially if the farm is in a remote location.
4. *Better aesthetics*: The farmstead looks more appealing to passers-by and to the family that lives there.
5. *More capacity needed*: In most cases, Often, new equipment is larger than what it replaces and simply too big for the old storage unit.
6. *Greater use:* The structure for machinery storage often is incorporated into a structure also intended to store seed, pesticides, and fertilizer or to house a modern farm shop.
7. *Better tax management*: In a good year, the real cost of machinery storage can be substantially cushioned.

7.2. Factors affecting Siting of Machinery Yards

1. *Noise management*: The location distance from the main house should be far enough away to protect the living area from noise and large machinery traffic, but close enough for security.
2. *Security:* This should be a major consideration in site selection and building orientation.
3. *Privacy*: Plan location of farm machinery storage such that valuable equipment is not visible from the main road and away from prevailing winds.
4. *Convenience*: The storage building should be near the farm workshop to facilitate equipment servicing.
5. *Space:* Ideally, the building should be big enough so that any piece of equipment can be moved in, stored, and moved out without having to disturb any other piece of equipment. However, most farmers cannot justify that kind of "luxury."
6. *Drainage:* As with any farm building, the machinery storage should be on high ground with good drainage. The floor should be at least 12 inches above the existing grade to insure drainage away from the building.

7. *Use Specific:* Machinery storage should *never* be combined with livestock housing due to high moisture levels leading to corrosion problems. Machinery should also not be combined with fodder storage because of fire hazard.

7.3. Planning the Machinery Storage Facility

Like any other farm structure, the machinery storage facility or yard needs planning before its establishment. The following are some of the salient considerations when planning a machinery storage facility:

1. *Decision on what to store*: - This involves planning the storage facility based on past and present operations of the farm i.e., the projections on what the farm will be doing and the requirements
2. *Estimation of floor space requirements:* The floor space required for each particular item to be stored depends on various factors. To determine minimum total storage area, one should work with the specific equipment to be housed, both current and future and use actual dimensions for current equipment.
3. *Decision on building type and configuration: -* Unless there is a scenario whereby site limitations or aesthetic considerations dictate otherwise, there are many choices for building style and width-length combinations.
4. *Determination of machinery-access door size and location: -* The size of machinery will determine the position and size of access ways. For instance, big tractors such as self-propelled combines are machinery most likely to need plenty of head room.
5. *Analysis of building efficiency: -* The final step in planning a specific machinery storage building is to check out the compatibility of the building (size, shape, type, and door sizes and locations) with the machinery to be manoeuvred and stored in it.

Individual task	Visit the machinery or transport yard in any institution or workstation and: 1. Explore the different types of machinery and implements stored there. 2. Explain the logic behind its arrangement and storage pattern

7.4. Workshop

7.4.1. Farm Workshop Tools

Every farm has a requirement to carry out machinery maintenance and repairs. Accordingly, a workshop and an array of workshop tools and equipment are required[40]. The extent of workshop equipment varies considerably from farm to farm, varying from the very basic, required by farmers with few machines, to a complete workshop, required by highly mechanised farms and contractors. The tools found in a farm workshop are classified into two categories - farm tools and workshop tools.

Farm Tools

These are the class of farm workshop tools that reduce the amount of effort employed in farming operations. By extension these tools also increase and improve production. Farm tools are classified into:

1. Cutting tools e.g., cutlass, sickle, axe, knife, shears, pruning saw, secateurs, pickaxe/mattock, *pangas*
2. Digging tools e.g., hoes, fork *jembes*, spades
3. Carrying tools e.g., watering cans, wheelbarrow, sprayers
4. Gathering tools e.g., trowels; shovel, spades, hay/manure fork, rakes

Workshop tools

These are the class of farm workshop tools that reduce the amount of effort employed in workshop operations, mainly repair of equipment, fabrication of equipment etc. Additionally, these tools also increase and improve production. Workshop tools are classified into:

1. Laying out and measuring tools e.g., Spirit Level; Try Square Tape Measure; Steel Tape
2. Striking tools e.g., Sledges, Hammers, Mallet
3. Cutting tools e.g., Drills, Reamers, Chisels, Planes, Hand Drills (Mechanical or Power-driven) Ordinary wood saw, Hacksaw etc.
4. Holding tools e.g., Pliers, Vices and Clamps, Nuts, Screws, Screw drivers, Spanners, Allen Keys
5. Sharpening and grinding tools e.g., Files

[40] Nkurunziza. P.C 1985. Farm Structures, Tools and Machinery. Oxford University Press East and Central Africa)

7.4.2. Farm Workshop Operations

The common farm workshop operations include;

1. Servicing and Repairs
2. Painting
3. Engine overhaul
4. Performance and material testing
5. Joinery/Welding
6. Equipment assembly/dismantling
7. Foundry works
8. Cleaning
9. Cutting
10. Motor winding

7.4.3. Fabrication of Basic Farm Tools

Fabrication of basic farm tools can be done through;

1. Electric welding
2. Gas welding
3. Moulding
4. Machining
5. Riveting
6. Bolting
7. Pressing
8. Bending
9. Joinery
10. Cutting

Some of the processes commonly used for fabrication are electric welding and gas welding. For more knowledge on this visit the hyperlinked reference on the same.

Learning Tasks:

Identify as many farm and workshop tools and indicate their functions using the template below:

Crop Production, Protection and Commodity Processing		
SN	Tool	Function
Animal Production, Protection and Commodity Processing		
SN	Tool	Function
Agricultural Structures		
SN	Tool	Function
Soil and Water Conservation/Management		
SN	Tool	Function

8. Welfare Issues in Draft Animal Power

8.1. Overview of Draft Animal Power

In the agricultural setup, draft animal power (DAP) is the use of domesticated animals mainly horses, donkeys, mules and oxen (mostly bulls) to do work. Animal are made to pull a variety of farm implements and or equipment to do various work such as transportation, processing and ploughing. For maximum output and safety, the animal or pairs of animals should therefore be attached/linked to the accessory using appropriate harnesses.

A harness is a set of straps and fittings by which a horse or other draught animal is fastened to a cart, plough, etc. and is controlled by its driver. Harnesses are designed to suit specific animal breeds. For example, a harness of a donkey will not work on an ox. The anatomy of the animal dictates the harness design to ensure maximum comfort safety and output as the animal works.

As expected, each animal must be trained to accept and work with its design harness. A yoke is a key component of a harness for oxen in most rural areas. Figure 8.1 shows harnessing of animal power.

A yoke is a wooden beam normally used between a pair of oxen or other animals to enable them to pull together on a load when working in pairs. Some yokes are fitted to individual animals.

The wide range of yoking types falls into two main categories, those tied to the **horns** of the animal and those taking power mainly from the **withers** (i.e., the part of the back that is over the shoulders, directly above the first thoracic vertebra. In Zebu (*Bos indicus*) cattle the withers are immediately in front of the hump).

Typical primary tillage in rural farming systems is done by yoked oxen (mostly bulls). Two people are normally required on the minimum: Animal supervisor and plough person. Tillage depth should be appropriate to balance rooting depth requirements and welfare of animals. Tillage when land is newly harvested reduces the power requirements and the burden on the oxen.

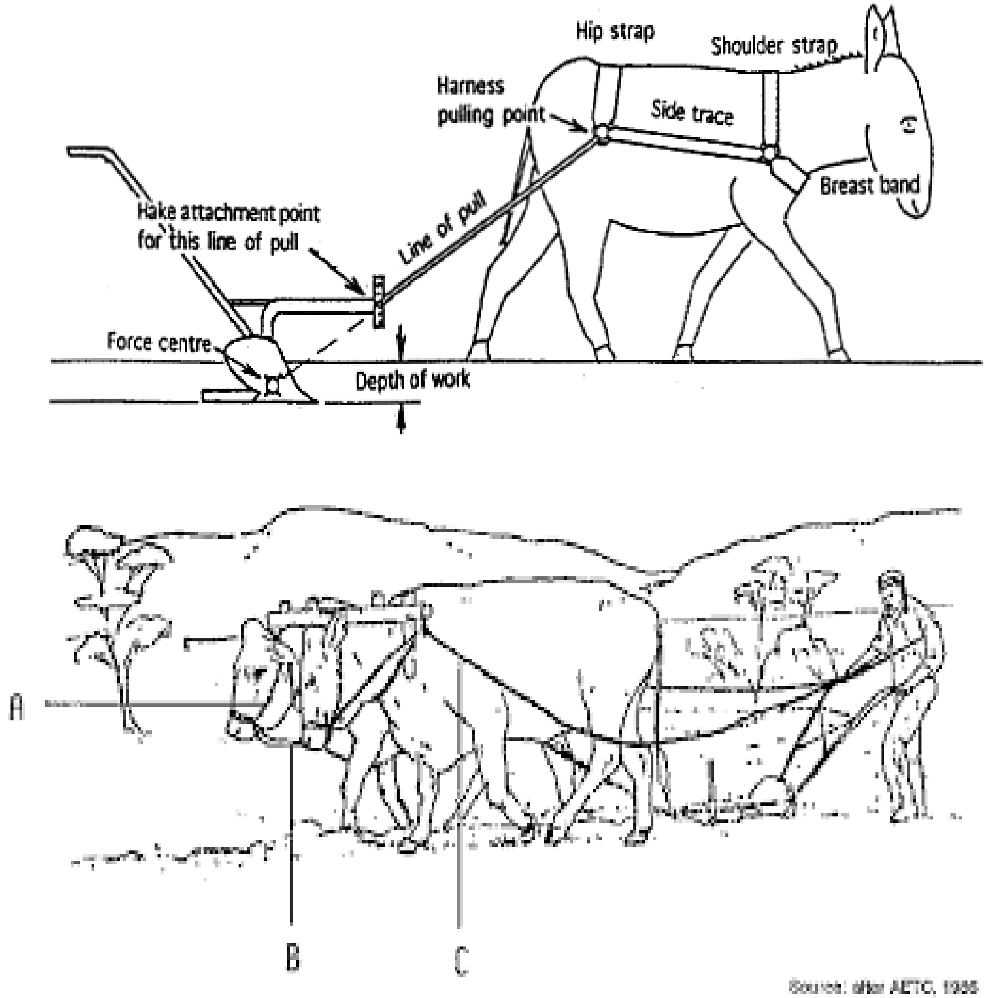


Figure 8.1: Harnessing of draft animal power (A-C are different types of straps). (Source: Accessed June 2021 from: https://teca.apps.fao.org/teca/es/technologies/4483)

Further Reading

Draft animal power. http://www.fao.org/fileadmin/user_upload/ags/publications/draugth_ap_overview.pdf

8.2. Overview of Animal Welfare

Animal welfare refers to the state of the animal. The treatment that an animal receives is covered by other terms such as animal care, animal husbandry, and humane treatment. Protecting an animal's welfare means providing for its physical and mental needs. Criteria for the assessing the welfare of working farm animals (equids and livestock) can be based on among others the following factors:

1. **Behaviour** that could be indicative of pain, anxiety or stress.
2. **Morbidity**, i.e., incidence of disease, illness, lameness, injuries or post-procedural complications, may be a direct or indirect indicator of the animal welfare status
3. **Mortality i.e., death**, like morbidity, may be a direct or indirect indicator of the animal welfare status. Depending on the context, causes of mortality should be investigated as well as temporal and spatial patterns of mortality and possible relationship with husbandry and handling practices.
4. Poor or changing **body condition or physical appearance** may be an indicator of compromised animal welfare and health and scoring systems help to provide objectivity.
5. **Poor human-animal interactions** can lead to or be caused by improper handling. This may include bad driving and inappropriate restraint methods, or the misuse of whips and sticks, and can result in fear and distress.
6. Complications due to **management practices** such as castration and hoof care, are commonly performed in working equids to facilitate handling and improve human safety and animal welfare.
7. **Lameness,** defined as any alteration of the horse's gait can also manifest in such ways as a change in attitude or performance. These abnormalities can be caused by pain in the neck, withers, shoulders, back, loin, hips, legs or fee
8. **Fitness to work** is the state or condition of being physically sound and healthy, especially as a result of exercise and proper nutrition, to perform work well.

8.3. Critical Items for Animal Welfare Needs

For draft animals to serve at their best, there is need to pro-actively consider their welfare[41], so that the state in figure 8.2 does not occur. Critical welfare issues to consider are outlined below:

1. Providing effective shelter
2. Management of diseases and injuries
3. Handling and management practices
4. Ability to interpret behaviour in the context of animal welfare.
5. Consideration on end of working life. When working animals need to be slaughtered, recommended guidelines should be followed to avoid the equids suffering a prolonged and painful death by abandonment, neglect or disease or acute, painful death such as being eaten by wild animals.
6. Appropriate workloads
7. A properly designed, well-fitted and comfortable harness allows the working animal to pull the equipment to the best of its ability, efficiently and without risk of pain or injuries.
8. Suitable diet.
9. Farriery and handlers should routinely clean and check the hooves of the working equid before and after work. Hoof trimming and shoeing of working equids should only be performed by persons with the necessary knowledge and skills.

[41] KENDAT in partnership with Brooke East Africa implements the Heshimu Punda (Respect the Donkey) Programme which aims at improving the welfare of working donkeys in Kenya (https://kendat.org/heshimu-punda-programme/)

<table>
<tr>
<td>Individual learning task</td>
<td>


Figure 8.2. “Overwhelmed beast of burden[42]” Source: https://www.change.org/p/organisation-save-donkey-from-abuse (Accessed on 17th July 2021)

1. How do you feel when you see such images or encounter such events?
2. Why are some people and especially Africans violent against animals?
3. What should be done to enhance animal welfare in your country?
4. Why do legal provisions on animal welfare appear toothless in Kenya?
5. Outline the welfare requirements befitting other domesticated animals and birds (dogs, poultry, cats)
6. Explain the practical steps you will take to enhance the welfare of draft animals at your home?
</td>
</tr>
</table>

[42] Caption title is the authors’ and not the originator of the picture.

9. Occupational Health and Safety on the Farm

9.1. Overview

The farm is a system with several interdependent components wherein safety is key. Although it's the life-line of most households in rural communities around the world, farming is one of the most hazardous occupations. Only one in 10 workplaces are farms, yet they account for one quarter of all work-related deaths. Children under 15 years and adults over 65 years are more likely to be injured or killed on farms than other age groups. Similarly, males are more likely to be injured than females.

Farm injuries and illness at the farm can be reduced by evaluating the risks and minimising them. Accidents can be prevented through better farmer and worker education, making sure equipment is well maintained and has adequate safety features, having safety procedures in place, and training every worker and family member about potential dangers and their risks. According to the International labour Organisation[43]:

1. The agricultural sector employs an estimated 1.3 billion workers worldwide
2. In terms of fatalities, injuries and work-related ill-health, it is one of the three most hazardous sectors along with construction and mining
3. At least 170,000 agricultural workers are killed each year.
4. Millions more agricultural workers are seriously injured in workplace accidents involving agricultural machinery or poisoned by pesticides and other agrochemicals.
5. Widespread under-reporting of deaths, injuries and occupational diseases in the agricultural sector compromises the real picture
6. Since much agricultural work is by nature physically demanding, the risk of accidents is increased by fatigue, poorly designed tools, difficult terrain, exposure to extreme weather conditions, and poor general health, associated with working and living in remote and rural communities

[43]. Source: https://www.ilo.org/safework/areasofwork/hazardous-work/WCMS_110188/lang--en/index.htm (Accessed 0n 30th August 2021)

7. Working conditions and operations in agriculture are quite variable: season to season; extensive to intensive; subsistence to commercial; small-scale to large scale; highly-mechanised to rudimentary; out-door to indoor etc. OHS risks will thus vary accordingly.
8. The most vulnerable groups are found in family subsistence agriculture, in plantations as daily paid labourers, seasonal or migrant workers without land, and, child labourers.

9.2. Common Hazards at the Farm Level

Although every farm is different, hazards common to most farms include:

1. **Animals: I**njuries inflicted by animals can include bites, kicks, crushing, ramming, trampling, and transmission of certain infectious zoonotic diseases such as giardia, salmonella, ringworm and leptospirosis; even death from being gouged by bulls.
2. **Agro-chemicals**: Pesticides and herbicides can cause injuries such as burns, respiratory illness, poisoning and even death.
3. **Confined spaces:** These include silos, water tanks, milk vats and manure pits. They may contain unsafe atmosphere, which can cause poisoning or suffocation
4. **Electricity:** The dangers include faulty switches, cords, machinery or overhead power lines. Electrocution is a common risk where live transmission lines are exposed to both people and animals.
5. **Heights: -** Falls from ladders, rooftops, silos and windmills are a major cause of injury
6. **Machinery:** Hazards include tractors without roll-over protection structures (ROPS), power Take-Off (PTO) shafts, chainsaws, augers, motorbikes and machinery with unguarded moving parts
7. **Noise pollution:** Noise from livestock, machinery among others can cause hearing impairment.
8. **Vehicles:** Crashes or falls from motorbikes, two-wheel and quad bikes, tractors and horses can result in major injuries
9. **Water:** Drowning can occur in as little as five centimetres of water. Reservoirs like dams, lakes, ponds, rivers, channels, tanks, drums and creeks are all hazards. Young children are particularly at risk

10. **Weather:** Hazards include floods, droughts, hurricanes, cyclones, tornadoes, sunburn, heat burns, dehydration and hypothermia.

9.3. Tips on making your Farm a Safer Workplace

1. Regularly walk around your farm to assess potential dangers.
2. Consult with farm safety advisers on what should be done
3. Create a safe play area for children away from hazards.
4. Everyone working on the farm should be properly educated on farm risks and trained in first aid.
5. Keep all equipment in good working condition
6. Store dangerous items behind locked doors.
7. Replace dangerous chemicals with less toxic types
8. Audit injuries and near-misses to pinpoint areas for improvement.
9. Consult with other farm stakeholders on how to improve safety, including a safety plan that includes ways to identify hazards and minimise potential risks.
10. Always use appropriate personal protection gear or equipment (PPE)[44], such as machinery guards and shields, helmets, gloves, goggles or breathing apparatus (Figure 9.1)
11. Make sure everyone understands and uses safety procedures.
12. All machines must be operated by trained personnel
13. All chemicals and equipment must be used based on manufacturers manual and safety guidelines.
14. Every farm must have a first aid facility and ready transport (ambulance) in case of emergency treatment. For an emergency plan see suggestions in the next section below.

[44] PPE varies based on the task at hand, and not every job requires the same equipment. Examples of PPE are eye protection, hearing protection, feet protection, respiratory protection, gloves and full body suits. The hazards determine what PPE you will need. To figure out what you need, begin with a walkthrough of the facility you're working in to develop a list of potential hazards. The workplace should be periodically reassessed for any changes in conditions, equipment or operating procedures that could affect occupational hazards

Some suggestions for an emergency plan include:

1. Making sure that there is easy access to a suitable and well-stocked first aid kit.
2. Making sure that at least one person on the farm is trained in first aid.
3. Keeping emergency numbers and correct addresses next to the telephone. If you or someone else needs to call 000, they need the correct address.
4. Planning routes to the nearest hospital – make sure it has an emergency department.
5. Regularly talking through your emergency plan with your family and other workers.
6. Making sure that children understand what to do in an emergency situation.

9.4. Safety Tips for Using Farm Machinery

To be safe when using farm machinery, the following tips[45] are worth considering:

1. **Read the Manual:** A manual has specific health and safety advice for that piece of machinery. Even if you've used similar implements before, it's well worth re-familiarising yourself with safety advice and putting it into practice.
2. **Maintain your Equipment Properly:** Poorly maintained farm implements can become hazardous. Adhere to maintenance guidelines such as cleaning, lubrication, fluid levels etc.
3. **Use the Right Implement for the Right Job: -** Don't be tempted to use farm implements for jobs they're not designed for. Incorrect use could result in malfunctions and injury.
4. **Wear the Correct Safety Gear: -** Your manual should provide advice on suitable protective gear. The basics include eye and ear defenders, hand protection and safety boots.
5. **Make sure you get help as appropriate: -** While small farm equipment may be easy to handle by yourself, larger and heavier implements will need a least one extra pair of hands. Don't risk an injury because you don't ask for help.

[45] https://www.farmtechsupplies.com/2017/02/15/farm-machinery-safety-tips/ (Accessed on 18th August 2021)

6. **Start-up Compact Tractors Sitting in the Seat: -** Always sit in the seat to start the tractor, once it's running smoothly you can get down to attend to the job.
7. **Do not enter the Danger Zone between Tractor and Implement: -** When the engine is running never enter the area between the tractor and the implement.
8. **Plan Jobs Beforehand: -** It's a good idea to walk a field before you start work to make sure you know whether there are any hidden hazards. Potholes, stakes, boggy areas and rocks could all cause damage to your equipment, and in turn damage to you.
9. **Operate Engines in Well-Ventilated places: -** Make sure covered areas are well ventilated so that engine fumes can dissipate easily.
10. **Keep Children Away from Machinery: -** Children should always be supervised around any farm implements. Children over 14 who wish to help on the farm should be given proper training and instruction, and closely supervised.

Individual task
1. Briefly discuss the safety concerns associated with a typical large commercial farm 2. Read the Occupational safety and Health Act 2007 from the link provided and outline how occupational health and safety can be enhanced and safeguarded when dealing with machinery

9.5. Further Reading

1. ILO. Safety and Health in Agriculture https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_110193.pdf
2. ILO. What is child labour: https://www.ilo.org/ipec/facts/lang--en/index.htm (accessed on 30th August 2021).
3. Universal Declaration of Human Rights, https://www.un.org/en/about-us/universal-declaration-of-human-rights (Accessed on 30th August 2021)
4. THE OCCUPATIONAL SAFETY AND HEALTH ACT, 2007. https://www.health.go.ke/wp-content/uploads/2015/09/OSH%20Act%202007.pdf (Accessed 22nd June 2021)

10. Overview of Engineering Materials

10.1. Definitions and Classifications

Michael F. Ashby[46] defined materials as the food of design. As such, the materials that are used during the construction and fabrication of farm tools, machinery, implements and accessories are referred to as engineering materials. These materials can be broadly classified into the following categories:

1. Metals
2. Polymers
3. Plastics
4. Biological materials
5. Inorganic e.g stones and sand
6. Ceramics
7. Composite Materials
8. Nano-materials.

10.2. Metals

Metals[47] are elemental substances that readily give up electrons to form metallic bonds and are good conductors of electricity and heat. Metals can be ferrous or non-ferrous.

Ferrous Metals

Ferrous metals contain mainly iron (Fe). Iron is the most important metal in industrialized countries. The alloy steel is very important in construction works needing much strength.

Non-ferrous Metals

Non-ferrous metals are other metallic materials that do not contain iron. Some examples include copper (Cu) or aluminium (Al).
Most metals have high melting points. All except mercury are solids at room temperature. Other important basic properties of metals are:

[46] https://www.globalspec.com/reference/30818/203279/chapter-3-engineering-materials-and-their-properties (Accessed on 13-02-2022)
[47] Introduction to Metals. https://www.uobabylon.edu.iq/eprints/publication_3_26810_199.pdf (Accessed on 13-02-2022)

1. **Lustrous:** Having the quality of reflecting light from its surface and can be polished (shinning property)
2. **Malleable:** Can be bent or hammered into shape without shattering.
3. **Ductile:** Can be drawn out into a long wire without snapping or breaking.
4. **Brittle:** They shatter when bent or hit
5. **Sonorous:** Produce a typical sound when they are struck.
6. **Reactivity:** Some metals undergo a chemical change by themselves or with other elements, and release energy. Potassium and sodium are the most reactive metals. They react violently with air and water.

To Note:
An alloy is a metal produced when two or more pure metals are melted together to form a new metal whose properties are quite different from those of original metals. Steel, for example, is a mixture of iron and small amounts of carbon and other elements; a combination that is both strong and easy to use. Stainless steel is the result of adding chromium to steel. Brass is an alloy obtained by mixing copper and zinc, while and bronze is obtained by mixing copper and tin. Both alloys are easy to shape and beautiful to look at. Most competition medals are made from these alloys.

10.3. Polymers

Polymers are classified into three categories: thermoplastic[48] polymers, thermosetting[49] polymers and elastomers[50] (also referred to as rubbers). Polymers have very large molecular structures. Most plastic polymers are light in weight and are soft in comparison to metals. Polymer materials have typically low densities and may be extremely flexible and widely used as insulators, both thermal and electrical. Typical examples of polymers are polyesters, phenolics, polyethylene, nylon and rubber.

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[48] Are plastic polymers that become pliable or mouldable at a certain elevated temperature and solidifies upon cooling. Are popular due to their user-friendly safe processing, and they can be melted, shaped and cooled into a dimensionally stable part in a matter of seconds.
[49] A thermosetting polymer or plastic is a polymer that irreversibly becomes hard when heated.
[50] An elastomer is a polymer with viscoelasticity (having both viscosity and elasticity) and very weak inter-molecular forces, generally having low Young's modulus. Rubber is a good example.

10.4. Biological Materials

Biological materials are materials originated from living things. Leather, limestone, bone, horn, wax and wood among others are biological materials. Wood is fibrous composition of hydrocarbon, cellulose and lignin and is used for many purposes. Apart from these components a small amount of gum, starch, resins, wax and organic acids are also present in wood. Wood can be classified as soft wood or hard wood. Fresh wood contains high percentage of water. To dry it out, seasoning is done. If proper seasoning is not done, defects such as cracks, twists, bending, wrapping and surging may occur. Wood plays a very important role in construction of agricultural structures. As a biological material, leather is obtained from the skin of animals after cleaning and tanning operations.

10.5. Inorganic Materials

In this category are stones, sand, cement, soil among others that are key construction materials for buildings and roads on the farm

10.6. Ceramics

The word ceramic is derived from the Greek word *keramikos*. It covers inorganic non -metallic materials which are formed by the action of heat. Clays, bricks, cements, glass are examples of important ceramics. Ceramics are classified as crystalline compounds between metallic and non-metallic elements. They are most frequently oxides, nitrides and carbides.

10.7. Composite Materials

A composite is a composition of two or more materials in the first three categories, e.g., metals, ceramics and polymers that has properties from its constituents. Large number of composite materials have been engineered. Few typical examples of composite materials are clad metals, fibre glass, reinforced plastics and cemented carbides among others. Fibre glass is a most familiar composite material, in which glass fibres are embedded within a polymeric material.

10.8. Nanomaterials

Nanomaterials[51] are defined as solids having microstructural features in the range of 1–100 nm in at least in one dimension. A nanometre (nm)

[51] Nanomaterials are materials with at least one external dimension that measures 100 nanometres (nm) or less or with internal structures measuring 100 nm or less. Source: https://www.nanowerk.com/what-are-nanomaterials.php (Accessed on 5-3-22)

is a unit of length that is equivalent to one billionth of a metre ($1x10^{-9}$ m) These materials have outstanding mechanical and physical properties due to their extremely fine grain size and high grain boundary volume fraction. They are used to build very tinny and complex structures.

Learning Activity
Survey the university farm, including the machinery yard and align available machinery, implements, tools and accessories to the main engineering materials that form their basic structure.

10.9. Further Reading

Michael F. Ashby and David R. H. Jones. 2012. Engineering Materials 1 An Introduction to Properties, Applications, and Design Fourth Edition (http://materialstandard.com/wp-content/uploads/2019/06/AshbyEngineering-Materials-1.pdf) accessed on 13-02-2022

11. Aligning Farm Power and Machinery to Sustainability Agenda

Environmental changes occur as a result of both natural and human activities. Development policy today seeks to balance economic, social and environmental goals within and across generations. This is the essence of sustainability thinking. In this last chapter the focus is the contribution of farm power and machinery on environmental changes and how the same can be mitigated in pursuit of sustainable development (Table 11.1). As such, farm power and agricultural mechanization should contribute to the attainment of sustainable development goals (Figure 11.1)

Table 11.1. Indicators of environmental changes

	Environmental Changes	**+ / -**
Farm Power and Machinery	1. Poverty	
	2. Water Crisis	
	3. Energy Crisis	
	4. Land Degradation	
	5. Desertification	
	6. Pollution	
	7. Global Warming and Climate Change	
	8. Ozone Depletion	
	9. Deforestation	
	10. Loss of Biodiversity	
	11. Conflicts, Insecurity and War	

Farm Power & Machinery

1. No Poverty
2. Zero Hunger
3. Good Health and Well-being
4. Quality Education
5. Gender Equality
6. Clean Water and Sanitation
7. Affordable and Clean Energy
8. Decent work and economic growth
9. Industry, Innovation and Infrastructure
10. Reduced Inequalities
11. Sustainable Cities and Communities
12. Responsible Consumptinand Production
13. Climate Action
14. Life Below water
15. Life on Land
16. Peace Justice and strong institutions
17. Partnerships for the Goals

Figure 11.1. Agricultural Mechanization and SDGs.

Discussion Question

Using practical examples discuss emerging and other possible innovations that would deliver energy options and machinery designed for the environment

12. Field Experience

For enhanced competence development, the following field and practical experiences are recommended:

Field and or Practical Items
1. Exposure to Solar Farm, Wind Farm, Biogas Digester, Geothermal Station, Hydropower station
2. Exposure to Agricultural Engineering Workshop 3. Key tools and Equipment relevant for agricultural purposes 4. Procedures and safety guidelines in workshops
5. Tractor parts and components 6. 4-stroke and 2-stroke Internal Combustion Engines
7. Draw Bar and Hitches 8. PTO and its applications 9. Implements and Accessories
10. Wheels, traction, balancing and alignment, tractor weights (front weights, rear wheel weights, ballasting)
11. Tractor Maintenance Requirements 12. Audit of a Machinery Yard
13. Draft Animal Power (Donkeys, Oxen)
14. Safety Procedures when working with Machinery
15. Basic self-help mechanics
16. Basic tractor driving skills (Theory and tilling experience)

To Note:

1. Experienced technicians to be used
2. Class size to be appropriate for enhanced hands-on experience.
3. Adequate time to be allocated.

Attachment

Attachment opportunities should also offer learners as much hands on as possible experience with different types of farm energy, machinery, accessories and implements.

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