Chapter 2
Background Theory

2.1 Distributed generation

Distributed generation (DG) generally refers to small scale (1-50 kW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include, but are not limited to synchronous generators, induction generators, reciprocating engines, microturbines, combustion gas turbines, fuel cells, solar photovoltaic’s, and wind turbines. DG can be used to generate a customer’s entire electricity supply; for peak shaving (generating a portion of a customer’s electricity onsite to reduce the amount of electricity purchased during peak price periods); for standby or emergency generation (as a backup to Wires Owner's power supply); as a green power source (using renewable technology); or for increased reliability. In some remote locations, DG can be less costly as it eliminates the need for expensive construction of distribution and/or transmission lines.

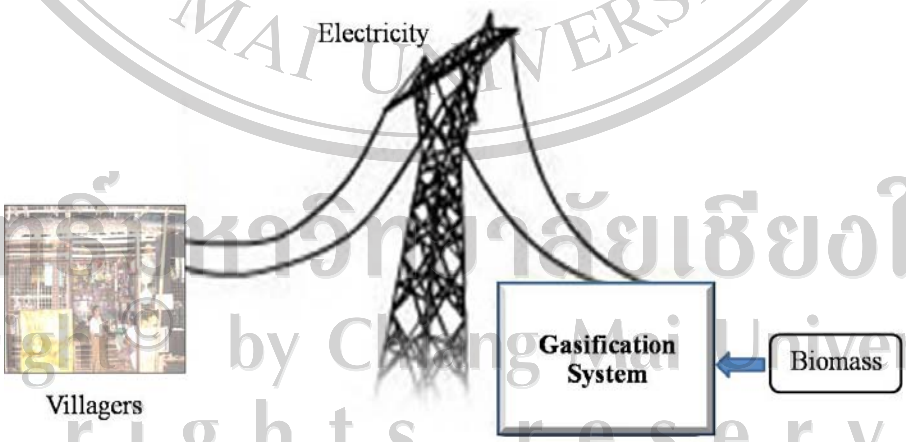

Figure 2.1 Small Distributed Generation for villagers

Benefits of DG include:

- A lower capital cost because of the small size of the DG (although the investment cost per kVA of a DG can be much higher than that of a large power plant).
- Reduction of the need for large infrastructure construction or upgrades because the DG can be constructed at the load location.
- If the DG provides power for local use, it may reduce pressure on distribution and transmission lines.
- With some technologies, produces zero or near-zero pollutant emissions over its useful life (not taking into consideration pollutant emissions over the entire product lifecycle i.e. pollution produced during the manufacturing or after decommissioning of the DG system).
- With some technologies such as solar or wind, it is a form of renewable energy.
- Can increase power reliability as back-up or stand-by power to customers.
- Offers customers a choice in meeting their energy needs.
- There are no uniform national interconnection standards addressing safety, power quality and reliability for small distributed generation systems.
- The current process for interconnection is not standardized among provinces.
- Interconnection may involve communication with several different organizations
- The environmental regulations and permit process that have been developed for larger distributed generation projects make some DG projects uneconomical.
- Contractual barriers exist such as liability insurance requirements, fees and charges, and extensive paperwork.

2.2 Gasification

Gasification refers to a thermochemical conversation of carbonaceous solid fuel into a gaseous energy medium by adding an oxidizing agent (air, oxygen, water vapour). If air or oxygen is used, the oxidization reactions can supply the heat necessary for converting the endothermic stages: so external energy supply is not necessary. The product is a mixture of combustible and non-combustible gases, liquids and solids. The principal combustible gas components are CO and H_2. Other include CH_4**,** but in small proportions. The final product composition will depend on operating conditions, the gasifier and the fuel type.

The process in the gasifier can be broken down into different stages:

- Drying Zone
- Pyrolysis Zone
- Combustion Zone
- Reduction Zone

2.2.1 Drying Zone

Solid fuel is introduced into the gasifier at the top. As a result of heat transfer from the lower parts of the gasifier, drying of wood or biomass fuel occurs in the bunker section.

The water vapour will flow downwards and add to the water vapour formed in the oxidization zone. Part of it may be reduced to hydrogen and the rest will end up as moisture in the gas.

2.2.2 Pyrolysis Zone

At temperature above 250°C, the biomass fuel starts pyrolysing. The pyrolysis reactions are not well known, but one can summarise that large molecules (such as cellulose, hemicelluloses and lignin) break down into medium size molecules and carbon (char) during the heating of feedstock. The pyrolysis products flow downwards into the hotter zones of the gasifier. Some will be burned in the oxidization zone, and the rest will break down to even smaller molecules of hydrogen, methane, carbon monoxide, ethane, etc: if they are remaining in the hot zone long enough.

If the residence time, in the hot zone is too short or temperature too low, then medium size molecules can escape and will condense as tar oil.

2.2.3 Combustion Zone

A combustion (oxidization) zone is formed at the level where oxygen (air) is introduced. Reactions with oxygen are highly exothermic and result in a sharp rise of the temperature up to 1200-1500°C.

As mentioned above, an important of the oxidization zone, apart from heat generation, is to convert or oxidize virtually all condensable product from the pyrolysis zone. In order to avoid cold spots in the oxidization zone, air inlet velocities and the reactor geomentry must be well chosen.

Generally two methods are employed to obtain an even temperature distribution:

- reducing the cross sectional area at a certain height of the reactor ("throat concept")
- spreading the air inlet nozzles over the circumference of the reduced cross area.

Oxidation or combustion is described by the following chemical reactions:

$$C + O_2 \rightleftharpoons CO_2 \quad (-\ 393\ \text{MJ/kg mole}) \qquad (2.1)$$

$$2\ H_2 + O_2 \rightleftharpoons 2\ H_2O \quad (-\ 242\ \text{MJ/kg mole}) \qquad (2.2)$$

2.2.4 Reduction Zone

The reaction products of the oxidization zone move downward the reduction zone. In this zone the sensible heat of the gases and charcoal is converted as much as possible into chemical energy of the producer gas.

The end product of the chemical reaction that takes place in the reduction zone is a combustible gas which can be used as fuel gas in burners. After dust, condensed tars and moisture removal and cooling the gas is suitable for use in engines.

The following reactions take place in the reduction zone.

$$C + CO_2 \rightleftharpoons 2\ CO \quad (+173\ \text{MJ / kmol}) \qquad (2.3)$$

$$C + H_2O \rightleftharpoons CO + H_2 \quad (+131\ \text{MJ / kmol}) \qquad (2.4)$$

$$CO_2 + H_2 \rightleftharpoons CO + H_2O \quad (-\ 41\ \text{MJ / kmol}) \qquad (2.5)$$

$$C + 2\ H_2 \rightleftharpoons CH_4 \quad (-\ 75\ \text{MJ / kmol}) \qquad (2.6)$$

$$CO + 3\ H_2 \rightleftharpoons CH_4 + H_2O \quad (-\ 205\ \text{MJ / kmol}) \qquad (2.7)$$

Equation (2.3) and (2.4), which are the main reaction of reduction show that reaction requires heat. Therefore the gas temperature will decrease during reduction.

Reaction (2.5) describes the so-call water-gas equilibrium.

Gasifiers are classified as follows:

- Updraft gasifier
- Downdraft gasifier
- Crossdraft gasifier
- Fluidized bed gasifier
- Other types of gasifiers

Updraft gasifier

The common type of a counter current gasifier is a vertical reactor where the feed stock is entered from the top.

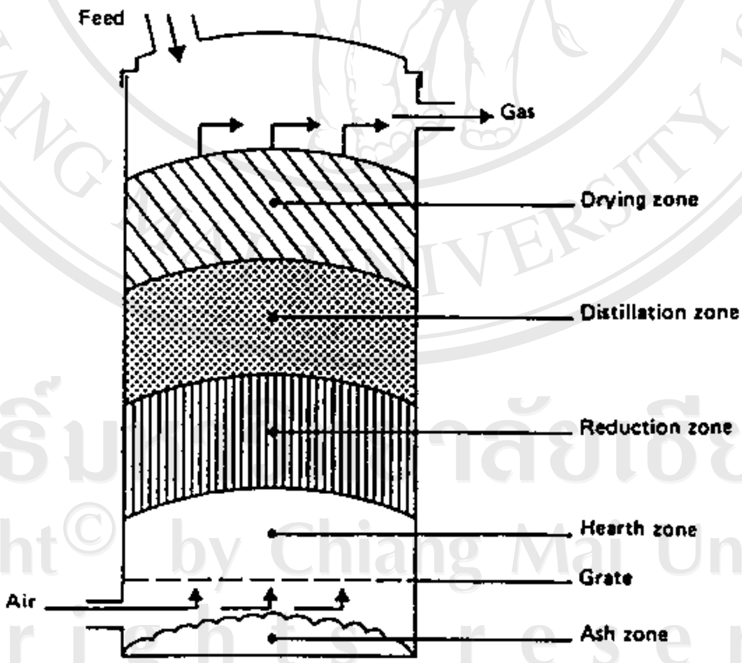

Figure 2.2 Updraft gasifier

The directions of fuel flow and gas flow being opposed, separate reaction zones formed in the reactor. The gas rises inside the reactor and leaves at the top section, which is why this type is also designated as updraft gasifier. Counter-current gasifiers have the advantage that they do not require any special fuel preparation thus allowing the gasification of a wide range of biomass types with different particle size and moisture contents. Through forced convection, the gas heated by oxidation in a bottom zone rises and transfers heat to fuel and the gas leaves the gasifier with a relatively low temperature, which indicates a high gasification efficiency of this process. The drawback of it results from volatile matter produced in the pyrolysis zone, which is carried in the rising gas steam. In consequence, the gas produced by the updraft gasifiers contains a considerable amount of tar compounds. Hence it is more suitable for direct heating than engine operation. Figure 2.2 shows a schematic diagram of updraft gasifier.

Downdraft gasifier

In a co-current gasifier, fuel and gas move in the same direction. The palletized biofuel, at first dried and pyrolyzed nearly in the absence of air in the upper zones reaches further down the very hot oxidization zone, from where, changed into char and ash, it falls into reduction zone. The gases mainly produced in the pyrolysis zone are heated to fairly more than 1000°C in the oxidation zone. In this process, high-tar gaseous compounds in the gas are to a great extent converted into low tar components, which then react with the char in the subsequent reduction zone producing additional gas. The gas issues from the bottom reactor section, hence the other designation of downdraft gasification. In contract to counter-current gasification, the heat transfer between biofuel and gas in co-current gasification is low, so the exit gas has a relatively high temperature.

There is also a higher tendency of slag formation in co-current than in counter current gasifiers because of the high temperature in the oxidization zone. A uniform temperature distribution within the individual reactor zones and a well-formed preciousness to gas of the char layer are decisive factors for the gas quality. Co-current gasifiers therefore make greater demand on the fuel preparation with regard to size and moisture content. The major advantage of downdraft gasifiers is that the gas produced contains far less tar products and other high-boiling compounds than the gas from updraft gasifiers. Figure 2.3 shows a schematics diagram of downdraft gasifier.

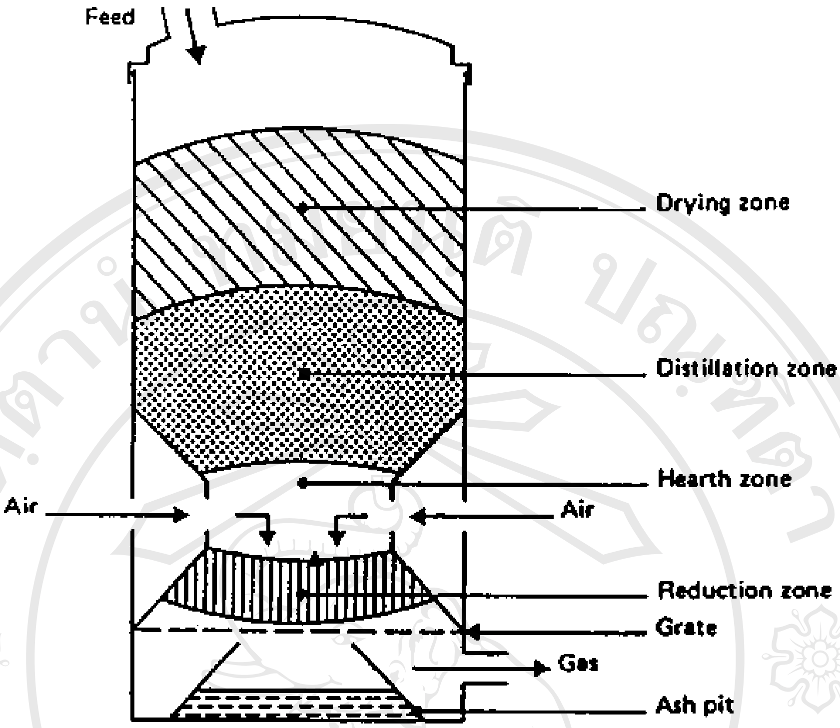

Figure 2.3 Downdraft gasifier

The advantages of downdraft gasification are:

• Up to 99.9% of the tar formed is consumed, requiring minimal or no tar cleanup

• Minerals remain with the char/ash, reducing the need for a cyclone

• Proven, simple and low cost process

The disadvantages of downdraft gasification are:

• Requires feed drying to a low moisture content (<20%)

• Syngas exiting the reactor is at high temperature, requiring a secondary heat recovery system

• 4-7% of the carbon remains unconverted

For a relatively small size gasifier, it is normally of downdraft gasifier type.

Crossdraft gasifier

Crossdraft gasifiers, schematically illustrated in Figure 2.4 are an adaptation for the use of charcoal. Charcoal gasification results in very high temperatures (1500°C and higher) in the oxidation zone which can lead to material problems. In crossdraft gasifiers insulation against these high temperatures is provided by the fuel (charcoal) it self.

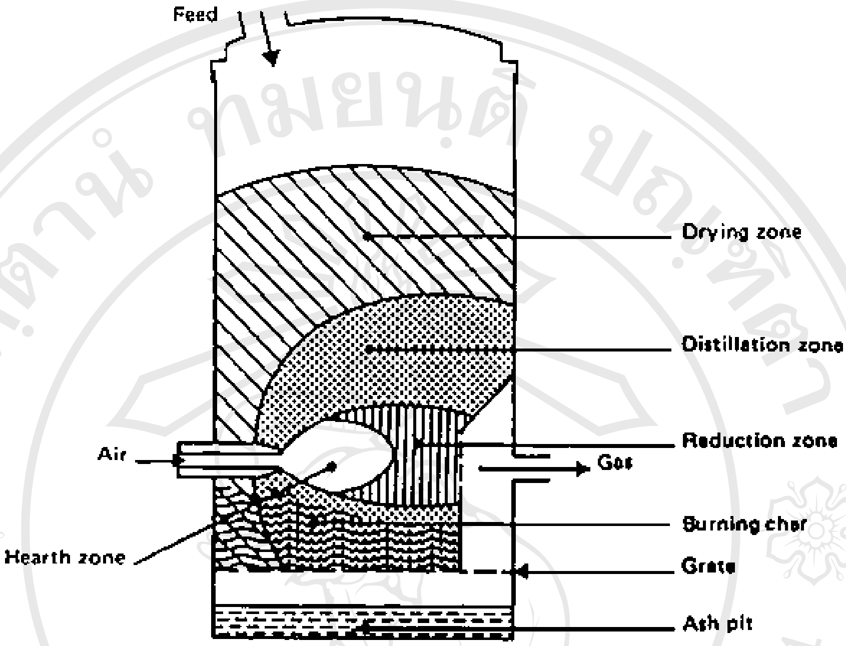

Figure 2.4 Crossdraft gasifier

Advantages of the system lie in the smaller scale which it can be operated. Installation below 10KW (shaft power) can under certain conditions be economically feasible. The reason is the very simple gas cleaning train (only a cyclone and a hot filter) which can be employed when using this type of gasifier in conjunction with small engines.

A disadvantage of crossdraft gasifiers is their minimal tar converting capabilities and the consequent need for high quality (low volatile content) charcoal.

It is because of the uncertainly of charcoal quality that a number of charcoal gasifiers employ the downdraft principal, in order to maintain at least a minimal tar cracking capability.

Fluidized bed gasifier

The operation of both updraft and downdraft gasifiers is influenced by the morphological, physical and chemical properties of the fuel. Problems commonly encountered are; bunker flow, slagging a extreme pressure drop over the gasifier.

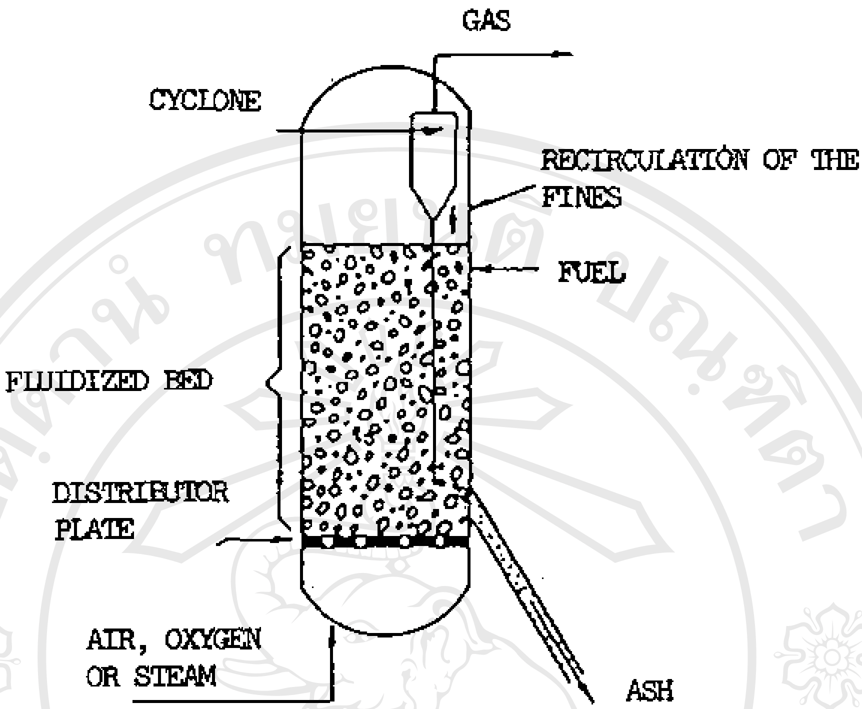

Figure 2.5 Fluidized bed gasifier

A design approach aiming at the removal of the above difficulties is the fluidized bed gasifier, illustrated schematically in Figure 2.5.

Air is blown through a bed of sand particles at a sufficient velocity to keep these in a state of suspension. Air velocity is as larges as 7-10 m ⁄s. The bed is originally externally heated and the feedstock is introduced as soon as a sufficiently high temperature is reached. The fuel particles are introduced at the room of the reactor, very quickly mixed with the bed materials and almost instantaneously heated up to the bed temperature. As a result of this treatment the fuel is pyrolysed very fast, resulting in a component mix with a relatively large amount of gaseous materials. Further gasification and tar conversion reactions occur in the gas phase. Most system are equipped with and internal cyclone in order to minimize char below out as much as possible. Ash particles are also carried over the top of the reactor and have to be removed from the gas stream if the gas is used in engine application.

Other types of gasifiers

A number of other biomass gasifier systems (double fired, entrained bed, molten bath), which are partly spin-offs from coal gasification technology, are currently under development. In some cases these systems incorporate unnecessary refinements and complications, in others both the size and sophistication of the equipment make near term application in developing countries unlikely. For these reasons they are omitted from this account.

2.3 Biomass resources

2.3.1 Rice husk

Rice is by far the staple food of Myanmar and the major agriculture resource in terms of area, volume and income. In 2007-2008, Myanmar produced 30 million Mt of paddy. Rice hulls accounted for 20% of paddy production on a weight basis, meaning that nearly 6 million Mt of rice hulls were produce in 2007-2008. Annual production of paddy in Myanmar is given Table 2.1.

Rice husk is composed of water, vaporizing materials by heat and inorganic materials. The water content in the rice husk is about 10 wt% and it depends on the drying condition. After drying perfectly, rice husk is composed of about 63 wt% of vaporizing material, 20 wt% of carbon and 17 wt% of ash. Main component in ash is SiO_2. Then, carbonized rice husk includes about 55 wt% of carbon and 40 wt% of SiO_2. A carbonized rice husk has so large specific surface area as 330 m^2/g. A rice husk looks as show in Figure 2.6.

Figure 2.6 Rice Husk

Table 2.1 Annual production of paddy.

(Ref: http://www.moai.gov.mm/statistics.htm#LAND%20POTENTIAL)

Year	Production (000' Mt)
1992-93	14,837
1993-94	16,760
1994-95	18,195
1995-96	17,953
1996-97	17,676
1997-98	16,654
1998-99	17,078
1999-00	20,126
2000-01	21,324
2001-02	21,916
2002-03	21,805
2003-04	23,136
2004-05	24,718
2005-06	27,638
2006-07	30,924
2007-08	30,262

2.3.2 Wood

Wood is the most important carrier of solar energy. It can be processed into wood logs, wood chip and pellets as shown in Figure 2.7. The most convenient means of wood processing is the preparation of short logs and split logs for small volume, hand charged stoves. Fuelwood is widely available in Myanmar. Over 23 million metric tons of fuelwood were reported used for 1999 domestic consumption (A. Koopmans, 2005). The majority of fuelwood originated from forests. Any different between fuelwood demand and the amount forests could supply on a sustainable basis would lead to deforestation.

Myanmar is rich in forest resources. Forest area of the country has been estimated by forest types as shown in Table 2.2.

Table 2.2 Forest area by types of forests

(Ref: http://www.fao.org/docrep/x2613e/x2613e2p.htm)

No	Types of Forests	Area (Hectares)	%
1.	Tidal, beach and dune, and swamp forests	1,376,900	4
2.	Tropical evergreen forests	5,507,800	16
3.	Mixed deciduous forests	13,425,300	39
4.	Dry Forests	3,442,400	10
5.	Deciduous dipterocarp forest	1,721,200	5
6.	Hill and temperate evergreen forest	8,950,100	26
	Total	34,423,700	100

Figure 2.7 Wood

2.3.3 Bamboo

Bamboo is the common term applied to a broad group of woody grasses ranging from 10 cm to 40 m in height as shown in Figure 2.8. There are over 200 kinds of Myanmar Bamboo. Bamboo is distributed mostly in the tropics, comprising natural stands of native species. Myanmar is one of the nations with significant bamboo production and utilization.

Villagers rely on bamboo for house pole, cross beam, partition and floor. Some houses in villages are made of bamboo as a whole. It is also used to construct fences to protect property and hold livestock. Bamboo utensils such as flat wooden ladle, blow piper basket, hat, and tray are also common in Myanmar households. Some lacquer ware has bamboo for a base. It is the raw material for making paper, and bamboo plants decorate gardens. Bamboo has long been neglected, but it may have potential as a bioenergy crop. Bamboo productive forest area is 963,000 ha in Myanmar.

Figure 2.8 Bamboo

2.4 Economic Analysis

2.4.1 Net present value

Net present value (NPV) is defined as the total present value of a time series of cash flows. NPV is an indicator of how much value an investment or project adds to the value of the firm. It is a standard method for using the time value of money to appraise long-term projects. Used for capital budgeting, and widely throughout economics, it measures the excess or shortfall of cash flows, in present value terms, once financing charges are met.

Each cash inflow/outflow is discounted back to its present value. Then they are summed. Therefore NPV is the sum of all terms $\frac{C_t}{(1+r)^t}$,

$$C_t = C(1+r)^{-t} = \frac{C_t}{(1+r)^t} \tag{2.8}$$

$$NPV = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t} - C_0 \tag{2.9}$$

where t - the time of the cash flow

r - the discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.)

C_t - the net cash flow (the amount of cash, inflow minus outflow) at time t (for educational purposes,

C_0 is commonly placed to the left of the sum to emphasize its role as the initial investment.

2.4.2 Internal rate of return

The internal rate of return (IRR) is a capital budgeting metric used by firms to decide whether they should make investments. It is an indicator of the efficiency of an investment, as opposed to net present value (NPV), which indicates value or magnitude. The IRR is the annualized effective compounded return rate which can be earned on the invested capital, i.e., the yield on the investment.

Given a collection of pairs (time, cash flow) involved in a project, the internal rate of return follows from the net present value as a function of the rate of return. A rate of return for which this function is zero is an internal rate of return.

Thus, in the case of cash flows at whole numbers of years, to find the internal rate of return, find the value(s) of r that satisfies the following equation:

$$NPV = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t} = 0 \tag{2.10}$$

2.4.3 Payback period

The payback is another method to evaluate an investment project. The payback method focuses on the payback period. The payback period is the length of time that it takes for a project to recoup its initial cost out of the cash receipts that it generates. This period is some times referred to as" the time that it takes for an investment to pay for itself." The basic premise of the payback method is that the more quickly the cost of an investment can be recovered, the more desirable is the investment. The payback period is expressed in years. When the net annual cash inflow is the same every year, the following formula can be used to calculate the payback period.

$$\text{Payback period} = \text{Investment required} / \text{Net annual cash inflow}^{*} \qquad (2.11)$$

**If new equipment is replacing old equipment, this becomes incremental net annual cash inflow.*