CHAPTER II

GLOBAL WARMING IN CHEMICAL ENGINEERING ASPECT

The serious trouble due to the global warming recognised recently is caused by the increase of greenhouse gases which are able to hold the thermal energy. The processes of temperature changes generally consist of heat conduction, heat convection, and heat radiation. The estimation of temperature increase can be done by using the law of energy conservation of a determined system.

2.1 A Control Volume

A control volume is defined as a region of space having a finite volume and having prescribed boundaries which unambiguously separate the region from the rest of the universe. The law of conservation of mass and energy may be applied to such a control volume. Here, we concern with nonnuclear processes so that the conservation laws for mass and energy can be considered separately.

In this work, a computer program is developed for predicting the climatic temperature change of the Earth, resulted from the more heat trapped by the carbon dioxide and other greenhouse gases in the troposphere. The Earth including the atmosphere is a control volume, while the space as well as the sun is the surrounding for this system. Energy is allowed to flow across the boundary, but matter is not, therefore the control volume of the Earth are specified as the closed system or a batch reactor, which has neither input nor output of mass. The amounts of individual components may change due to reactions but not due to flow into or out of the system.

Since the space is considered as vacuum, there is no heat transfer through it by conduction or convection. Energy may enter or leave the system, which is the Earth, by the mechanism of heat radiation only. The input of all the system is the solar radiation from the sun and the output from the control volume is the outgoing long-wavelength radiation. Inside the system, thermal energy may also transfer by virtue of the heat conduction and heat convection as Figure 2.1.

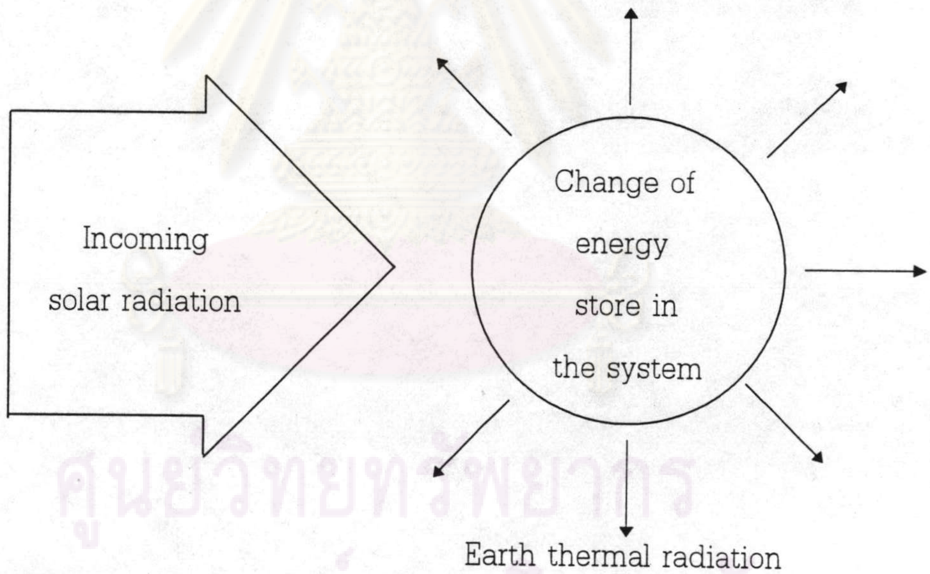

Figure 2.1 Control Volume of Conservation of Energy

For this system, energy transferring into the control volume is not equal to energy radiating out of the system, due to the alteration of chemical composition in the control volume. In this work, some of the long-wavelength radiated from the Earth is absorbed by the greenhouse gases while the incoming solar energy is still constant. A rapid increase in these gases concentration with the growth in human population and industrial activities, may alter atmospheric heating rates, resulting in the global warming phenomena. From the above details, we can conclude the description of control volume concerning this work as shown in Table 2.1.

Table 2.1 Description of the Control Volume of this Work

Description of general control volume	Control volume of this work
System	Earth+atmosphere
Surrounding	Space+sun
Input of mass	-
Output of mass	-
Input of energy	Solar radiation
Output of energy	Long-wavelength radiation
Heat transfer	Heat radiation
System	Closed system
Reactor	Batch reactor
Liquid Component	Ocean
Gas Component	Atmospheric gases
Solid component	Continent
Change	Thermal energy is more trapped.
Cause of change	The increase in greenhouse gases concentration
Unknown variables	Average global temperature

For the control volume (the Earth), the surface is dominated by existence of two fluids envelops: a gaseous one, the atmosphere, that covers the entire

Earth and a liquid one, the ocean, lying below the atmosphere and covering nearly three quarters of the surface and the land covering the rest of one quarter. To simulate the change in this control volume, it is necessary to consider both of ocean and atmosphere. Consequently the modified atmospheric-oceanic model is developed in this work. As we consider the globe as the control volume and simulate the change in this control volume by developing the model, therefore the simulation results acquired are equivalent to the results of temperature change of the globe.

2.2 Energy Input of a Control Volume

A control volume of the Earth consists of the energy supplied from the sun like a batch reactor in chemical engineering processes. The amount of energy received from the sun at the top of the atmosphere is called the solar constant. Details of energy input by heat radiation is described in the following information.

Unlike conduction and convection, radiation energy is transported in form of electromagnetic waves and does not require any medium. Any object can emit thermal radiation. The usual way to describe how much radiation a real object emits is to compare it to a theoretical object called a blackbody.

A blackbody is defined to be a perfect emitter as well as a perfect absorber. As a perfect emitter, it radiates more energy per unit of surface areas than any real object at the same temperature. As a perfect absorber, it absorbs all radiation that impinges upon it; that is, none is reflected.

For a blackbody with surface area A and absolute temperature T, the total rate at which radiant energy emitted is given by the Stefan-Boltzmann law of radiation:

$$E = \sigma A T^4 \qquad (2\text{-}1)$$

where

E = total blackbody emission rate (W)

σ = the Stefan-Boltzmann constant = 5.67×10^{-8} W/m^2K^4

A = surface area of the object (m^2)

T = absolute temperature (K)

Actual objects do not emit as much radiation as the hypothetical blackbody. The ratio of the amount of radiation that an actual object would emit to the amount that a blackbody would emit at the same temperature is known as the emittance, ε. The emittance of most natural materials is relatively high and is not particularly related to colour.

The solar constant is the rate at which solar radiation falls on a surface located at the top of the atmosphere (1.496×10^8 kilometres height from the Earth's surface) and positioned perpendicular to the solar radiation. The "constant" designation is actually misleading, because solar energy input fluctuates by a few tenths of a percent over a year and exhibits some longer-term variations. Nevertheless, we can approximate the solar constant as 1372 W/m^2.

While the Stefan-Boltzmann's law gives the total rate at which energy is radiated from a blackbody, it does not tell us anything about the wavelengths emitted. A blackbody emits radiation with a range of wavelengths that can be described with a spectral distribution such as the one shown in Figure 2.2. The wavelength at which the spectrum reaches its maximum is, known as Wein's displacement rule:

$$\lambda_{max}(\mu\, m) = \frac{2898}{T(K)} \qquad (2\text{-}2)$$

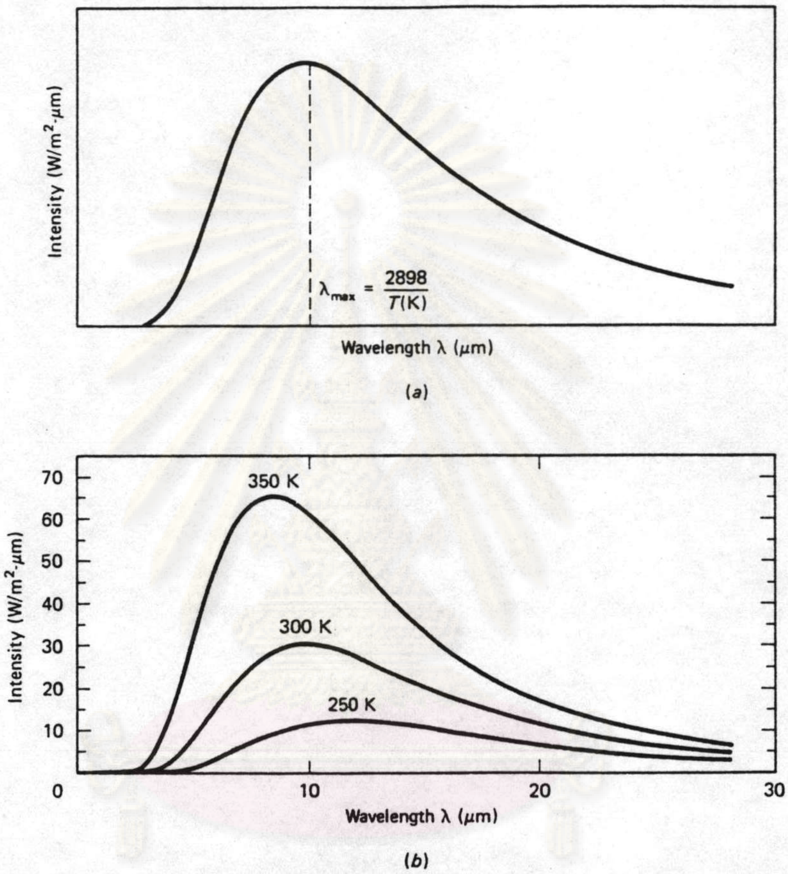

Figure 2.2 Spectral Emissive Power of a Blackbody
(a) Showing Wein's Rule for the Wavelength at which Power is a Maximum
(b) Showing the Effect of Temperature

The way to interpret a spectral diagram is to realise that the area under the curve between any two wavelengths is equal to the power radiated by the object within that band of wavelengths. Hence, the total area under the curve is equal to the total power radiated, given by the Stefan-Boltzmann law. Objects at higher temperatures have higher curves (greater area). In addition, Wein's rule indicates that objects with higher temperature reach their maximum emission intensity at shorter wavelengths, so their spectral curves are also shifted toward the left, as is shown in Figure 2.2b.

The effective radiating temperature of the sun is about 6000 K. The electromagnetic waves emitted by the sun are therefore relatively short. The most intense solar radiation, which is within the visible portion of the electromagnetic spectrum, is emitted by waves of about 0.50 μm in length. Figure 2.3 shows how the intensity of solar radiation varies by wavelength.

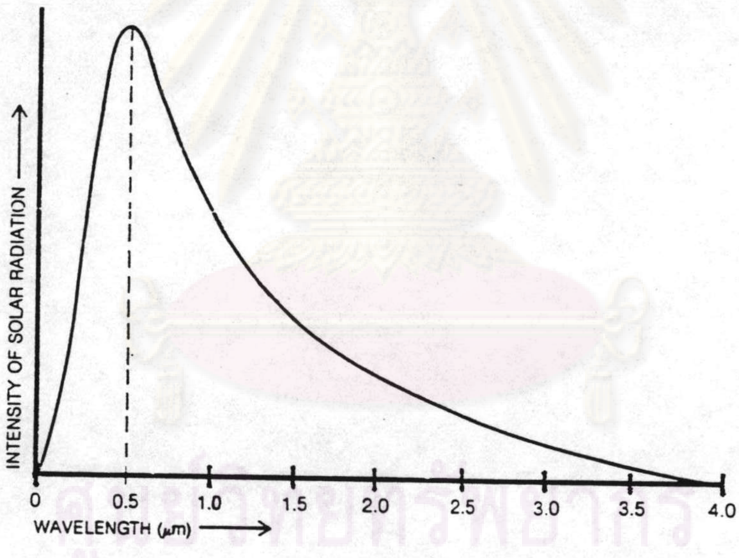

Figure 2.3 Intensity of the Solar Radiation

2.3 Energy Output of a Control Volume

If the solar radiation were continually absorbed by the Earth-atmosphere system without any compensating flow of heat out of the system, the air temperature would rise steadily. In reality, the average global air temperature changes little from year to year, because an equal amount of heat leaves the Earth-atmosphere system, mainly in the form of infrared radiation. It emitted ceaselessly, both day and night, by the entire Earth-atmosphere system.

The cooler the surface of the Earth, emitting radiation at an average temperature of about 288 K, the longer waves are emitted, as shown in Figure 2.4. In fact, the Earth-atmosphere system emits infrared radiation of maximum intensity at a wavelength of about 10.1 μm. The Earth-atmosphere system thus responds to solar radiant heating by emitting comparatively long-wave radiation.

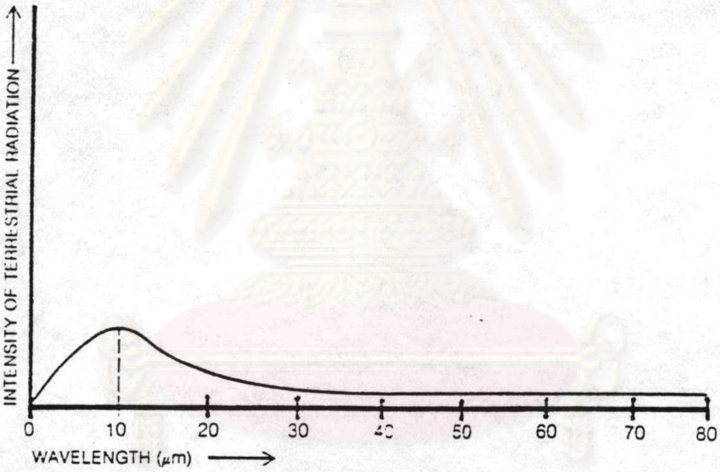

Figure 2.4 Intensity of the Terrestrial Radiation

If we assume that the Earth is uniform, with temperature T(K) everywhere, the energy, E_r, radiated from the Earth with surface area of $4\pi R^2$ is given by the Stefan-Boltzmann equation as

$$E_r = \sigma 4\pi R^2 T^4 \qquad (2\text{-}3)$$

Actually, the energy transferring from the Earth is not the thermal radiation from the surface only, but the latent heat, and the sensible heat are also. Nevertheless, in this work, we consider only the energy escaping in radiation form because it considerably higher than the energy from the others as shown in Table 2.2.

Table 2.2 Energy Output of the Earth's Surface (Harte, J., 1985)

Form	Energy (W/m^2)
Surface radiation	401
Latent heat	80
Sensible heat	17

2.4 A Change in the Control Volume

Reactant can changes to product because there are chemical reactions taking place in a reactor. At the present, as the human activities increase more, the amounts of greenhouse gases in the control volume will also become higher. These will cause more thermal energy to be trapped in the globe control volume.

In this work, we consider carbon dioxide, methane, nitrous oxide, and chlorofluorocarbon greenhouse gases. Each gas has different potency to global warming, carbon dioxide contribute 55 percent, methane contribute 15 percent, nitrous oxide contribute 6 percent, and chlorofluorocarbon contribute 24 percent of the greenhouse impact (วิศวกรรมสาร, 2534).

Greenhouse gases are emitted to the atmosphere by natural and anthropogenic processes. Carbon dioxide is emitted from natural sources as volcanic emissions and decaying organic matter, and anthropogenic sources as fossil fuel combustion, natural gas flaring, cement production, and clearing land. Methane is emitted by a variety of sources, both natural and anthropogenic. Natural sources include wetlands and wild ruminants. Human-influenced sources include extensive rice cultivation, livestock management, natural gas venting, and biomass combustion. Nitrous oxide is emitted by the decomposition of organic matter and the combustion of fossil fuels and biomass. Chlorofluorocarbon are a group of synthetic industrial chemicals used as aerosol propellants, refrigerant working fluids, solvents, and foam blowing agents. In the developed program, we consider the overall concentration of each greenhouse gases from all of sources mentioned above.

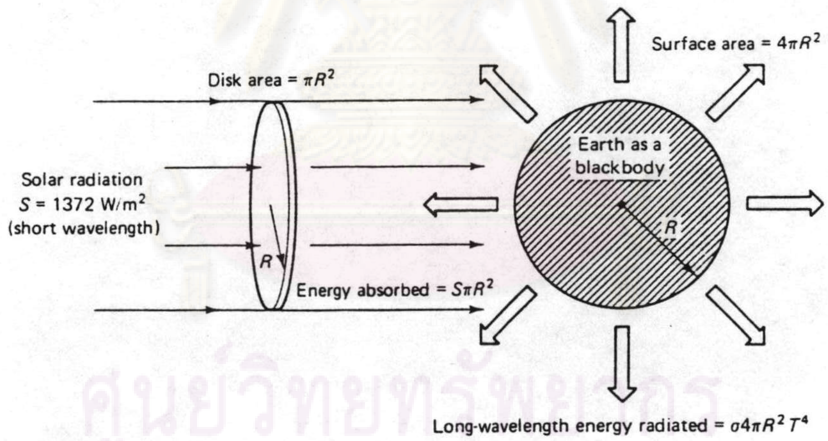

Figure 2.5 Simple Global Temperature Model

Figure 2.5 shows a simple model that treats the Earth as a blackbody. Radiation from the sun arrives just outside the Earth's atmosphere with an average annual intensity, called the solar constant, S, equal to 1372 W/m^2. A simple way to calculate the total rate at which energy is absorbed by the Earth is to note that all of the flux passing through a disk having radius equal to radius of the Earth, and placed normal to the incoming radiation, strikes the Earth's surface. Since we are considering the Earth to be a blackbody, all of that incoming radiation is absorbed, so we can write

$$E_a = S\pi R^2 \tag{2-4}$$

where E_a is the rate of energy absorption (watts, averaged over all latitudes for a year's time) and R is the radius of the Earth (and disk) in meters.

The first law of thermodynamics says simply that energy can neither be created nor destroyed. Energy may changes forms in any given process, as when chemical energy in a fuel is converted to heat and electricity in a power plant, or when potential energy of water behind a dam is converted to mechanical energy that spins a turbine in a hydroelectric plant. No matter what is happening, the first law says we should be able to account for every bit of energy as it takes part in the process under study, so that in the end we have just as much as we had in the beginning. With proper accounting, even nuclear reactions involving conversion of mass to energy can be treated.

In this work, there is no change in volume of the system, so internal energy is considered to be equal to enthalpy as explained from the first law of thermodynamics.

$$\Delta U = \Delta Q + \Delta W = T\Delta S - P\Delta V \tag{2-5}$$

where

ΔU = change of internal energy

ΔQ = change of heat

ΔW = change of work

T = temperature

ΔS = change of entropy

P = pressure

ΔV = change of volume

Since energy is conserved, we can write the following equation for any systems.

Rate of energy in = Rate of energy out

+ Rate of change in the internal energy of the system (2-6)

where the internal energy is the energy stored in the system. Because there is no change in the volume of the Earth, we can estimate that there is no work done by the system. Therefore the change in the internal energy is equal to the change in the enthalpy, which can be calculated by the following equation.

$$\text{Change in internal energy} = mC\Delta T \quad (2\text{-}7)$$

where C is specific heat of substances. Specific heat is defined as the amount of energy required to raise the temperature of a unit of mass of a substance by one degree. In the definition just mentioned, the assumed temperature of the water is 15 ^{o}C (59 ^{o}F). Value of specific heat in the SI system is given in J/kg ^{o}C, where 1 cal/g ^{o}C = 1 Btu/lb ^{o}F = 4184 J/kg ^{o}C.

If we go on assumption of steady-state condition, which the Earth's temperature is not change with time, we can equate the rate at which thermal energy from the sun is absorbed with the rate at which energy is radiated back to space. And, since the Earth's temperature is assumed constant, we assume that there is no change in the internal energy therefore the energy absorbed is equal to the energy radiated.

$$S\pi R^2 = \sigma 4\pi R^2 T^4 \qquad (2\text{-}8)$$

Then we will be able to solve for the Earth's temperature from the above equality. Notice that the radius of the Earth is conveniently dropped out of the equation:

$$T = \left(\frac{S}{4\sigma}\right)^{1/4}$$

$$T = \left(\frac{1372 W/m^2}{4x5.67x10^{-8} W/m^2 K^4}\right) = 279K \qquad (2\text{-}9)$$

As we consider the simple global temperature model, the calculated global temperature after applying the conservation of energy is lower than the observed average temperature. According to the fact that the Earth cannot absorb the whole input solar energy, some of the solar energy are reflected from the control volume itself. Moreover, this model does not consider the change of internal energy varied with time.

2.4.1 A Simple Radiation Balance Model that includes the Earth's Reflectivity

One simple modification of the blackbody model includes the reflection of the incoming solar energy of the atmosphere and the Earth s surface back into the space. Such reflected energy is not absorbed by the Earth or its atmosphere and does not contribute to their heating. Then the control volume in this model can be considered as gray body rather than black body.

The emittance and the absorptance of gray body are independent of wavelength. The term gray is employed to indicate that the surface is completely unselective in its spectral characteristics. Due to the fact that our system cannot absorb and emit whole radiation, then the concept of gray body is applied in this model as well as the developed modified atmospheric-oceanic model which will be described in the next section.

Fraction of the incoming solar radiation that is reflected is known as the albedo. Albedo then represents the reflectivity of the surface. We have seen that clean, white snow can reflect up to 95 percent of the solar radiation that reaches it. Such snow, therefore, can have an albedo as high as 95 percent. The albedo of a water surface depends upon the angle at which the sunlight strikes it and whether the surface is smooth or rough.

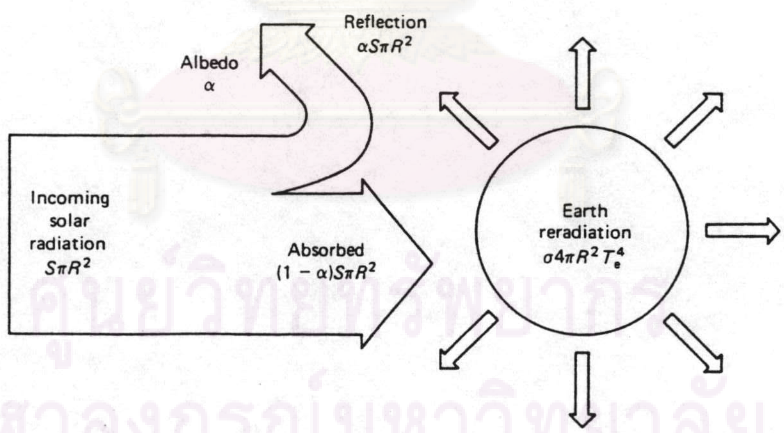

Figure 2.6 More Realistic Model that includes the Earth's Reflectivity

The global annual mean value of reflectivity is usually estimated to be about 30 percent. Figure 2.6 shows that revised model, again under the assumption that the Earth is a blackbody absorbing all of the nonreflected, incoming solar radiation. Setting the absorbed energy equal to the reradiated energy, assuming equilibrium conditions and a uniform temperature for the Earth, yields

$$S(1-\alpha)\pi R^2 = \sigma 4\pi R^2 T_e^4 \qquad (2\text{-}10)$$

where α is the albedo (reflectivity) and T_e is usually called the effective temperature, or the equivalent (blackbody) temperature of the Earth. Solving for T_e yields

$$T_e = \left[\frac{S(1-\alpha)}{4\sigma}\right]^{1/4} \qquad (2\text{-}11)$$

Substitute appropriate values into (2-11) yields

$$T_e = \left[\frac{1372 W/m^2(1-0.3)}{4x5.67x10^{-8} W/m^2K^4}\right]^{1/4} = 255K$$

The correction that we have applied to account for the albedo has unfortunately made our estimate worse. While we are only 11 percent off of the correct data, which might seem a modest error, in term of life on the Earth, the 255 K (-18 ^{o}C) estimated as T_e is extreme. We need to find an explanation for why the Earth is (fortunately) not that cold. The key factor that makes our model differ so much from the reality is that it does not take interactions between the atmosphere and radiation that is emitted from the Earth's surface into account. That is, it does not include the change of internal energy in the control volume by assuming the change of temperature varied by the time is constant or, it does not contain the greenhouse effect.

2.4.2 The Greenhouse Effect

The surface of the Earth is 33 $^{\circ}$C higher than what is predicted by (2-11). To understand the reason for the higher temperature, it is concerning the spectrum of wavelengths radiated by an object and its temperature. Wein's displacement rule gives the wavelength at which a blackbody spectrum peaks, as a function of absolute temperature as Equation (2-2).

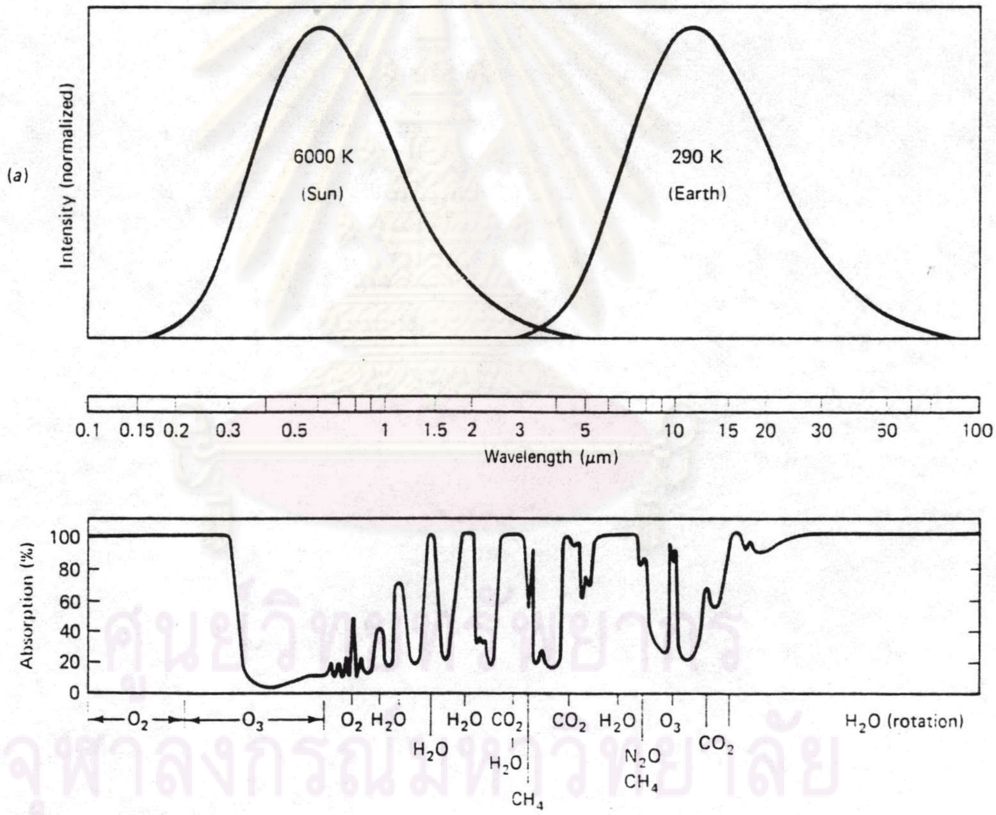

Figure 2.7 (a) Normalised Radiation Curves of the Sun and the Earth

(b) Characteristic Absorption Curve of Greenhouse Gases

(Wallace, J. M., and Hobbs, P. V., 1977)

The sun can be represented as a blackbody with temperature around 6000 K, so its spectrum peaks at around 0.5 μm. The Earth, at 288 K, has a peak wavelength of about 10.1 μm. Figure 2.7a shows the two spectra normalised to have the same areas. Notice that nearly all the incoming solar energy arrives extraterrestrially, with wavelengths less than 4 μm, while the outgoing energy radiated by the Earth has essentially all of its energy in wavelengths greater than 4 μm. With so little overlap, we can conclude that the solar energy is the short-wavelength radiation, while the energy radiated from the Earth's surface is long-wavelength radiation, or thermal radiation.

In Figure 2.7b the ability of various gases in the atmosphere to absorb radiation is shown as a function of wavelength. Notice that all of the incoming solar radiation with wavelengths less than 0.3 μm (ultraviolet) is absorbed by oxygen and ozone. This absorption of ultraviolet occurs in the stratosphere, shielding the Earth's surface from harmful ultraviolet radiation.

Figure 2.7b shows that most of the long-wavelength energy radiated by the Earth is affected by a combination of radiatively active gases, most importantly water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Water vapour strongly absorbs the thermal radiation with wavelengths less than 8 μm and greater than 18 μm. Carbon dioxide shows a strong absorption band centred at 15 μm and extending from 13 to 18 μm, as well as bands centred at 2.7 and 4.3 μm. Between 7 and 12 μm there is a relatively clear sky for the outgoing thermal radiation, referred to as the atmospheric radiative window. The radiation in those wavelengths easily passes through the atmosphere, except for a small, but important, absorption band between 9.5 and 10.6 μm associated with ozone (O_3).

Radiatively active gases absorbing wavelengths longer than 4 μm are called greenhouse gases. As Figure 2.7 suggests, these gases trap most of the outgoing thermal radiation attempting to leave the Earth's surface. This absorption cause the atmosphere to become warmer, which, in turn, radiates energy back to the Earth as well as out to the space, as shown in Figure 2.8. These greenhouse gases act as a thermal blanket around the globe, raising the Earth's surface temperature beyond the equivalent temperature calculated earlier. It is interesting to note that the term greenhouse effect is based on the concept of a conventional greenhouse with glass acting much like these kinds of gases. This radiation trapping is partly responsible for the elevated temperatures inside the globe.

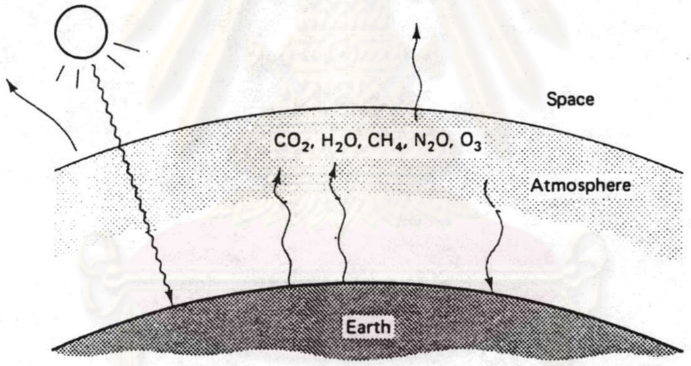

Figure 2.8 The Greenhouse Effect

If the Earth did not already have a greenhouse effect, its temperature would be 255 K as predicted by (2-11). That is, the planet would have an average temperature of -18 °C, or about 0 °F. In fact, one way to quantify the magnitude of the greenhouse effect is to compare the effective temperature T_e, given in (2-11) with the actual surface temperature T_s:

$$\text{Greenhouse effect } (^{\circ}C) = T_s - T_e \qquad (2\text{-}13)$$

Thus, since the actual temperature of the Earth is 288 K and its effective temperature is 255 K, we can say that the greenhouse effect adds 33 $^{\circ}C$ of warming to the Earth's surface.

Let us add some quantitative information to the simple greenhouse diagram presented in Figure 2.8. As suggested there, it is convenient to consider the Earth, its atmosphere, and the outer space as three separate regions. We will normalise energy flows between these regions by expressing them in terms of rates per unit of surface area of the Earth. For example, (2-4) indicates that the total amount of solar radiation striking is $S\pi R^2$. Distributed over the entire surface of the Earth, the incoming solar radiation is equal to

$$\frac{\text{Incoming solar energy}}{\text{Surface area of the Earth}} = \frac{S\pi R^2}{4\pi R^2} = \frac{S}{4} = \frac{1372 \text{ W/m}^2}{4} = 343 \text{ W/m}^2 \qquad (2\text{-}14)$$

Since the albedo (reflectivity) is 30 percent, the amount of incoming radiation reflected back into space is

$$\text{Incoming radiation reflected} = 0.30 \times 343 \text{ W/m}^2 = 103 \text{ W/m}^2$$

Of this 103 W/m^2, 89 W/m^2 is reflected off of the atmosphere itself while the remaining 14 W/m^2 is reflected off of the Earth's surface (Harte, J., 1985).

Amount of the incoming radiation absorbed by the atmosphere and the Earth is

$$\text{Incoming radiation absorbed} = 0.70 \times 343 \text{ W/m}^2 = 240 \text{ W/m}^2$$

From all of 240 W/m^2, 86 W/m^2 is absorbed by the atmosphere and the remaining 154 W/m^2 is absorbed by the Earth's surface (Harte, J., 1985).

If we assume that the global temperature are unchanging with time, then the rate at which the Earth and its atmosphere absorb energy from the space must equal the rate at which energy is being returned to the space. That is, the Earth and its atmosphere must radiate 240 W/m^2 back into space. If the temperature of the Earth's surface were at 255 K, it would radiate 240 W/m^2, which is just enough to balance the incoming energy. We know, however, that the greenhouse gases would not be realised. Therefore, to force enough energy through the atmosphere to create the necessary balance, the temperature of the Earth's must be higher than 255 K.

If we treat the Earth as a blackbody, we can use (2-3) to estimate the rate at which energy is radiated from the Earth's surface toward the atmosphere. We could use temperature of 288 K as the global average temperature, but this is the temperature of the air just above the surface. The actual temperature of the solid and liquid surface of the Earth itself is considered to be about 2 $^{\circ}C$ higher. Using 290 K in (2-3) gives

$$\frac{\text{Energy radiated surface}}{\text{Surface area}} = \frac{\sigma 4\pi R^2 T_s^4}{4\pi R^2} = \sigma T_s^4$$

$$= 5.67 \times 10^{-8}\ W/m^2K^4 \times (290\ K)^4 = 401\ W/m^2 \qquad (2\text{-}15)$$

Of that 401 W/m^2 , only 20 W/m^2 passes directly through the atmosphere, mostly through the atmospheric window. The remaining 381 W/m^2 is absorbed by the greenhouse gases in the atmosphere. The atmosphere then radiates 344 W/m^2 back to the surface.

All of these energy flows are shown in Figure 2.9. If this model is internally self-consistent, the rate of energy gain should equal the rate of energy loss in each of the three regions: the atmosphere, and the Earth's surface. Consider the following checks:

	Rate of energy gain = Rate of energy loss?
The Earth's surface:	154 + 344 = 80 + 17 + 20 + 381
The atmosphere:	80 + 86 + 17 + 381 = 220 + 344
The space:	103 + 20 + 220 = 343

So, the model shows the necessary balances.

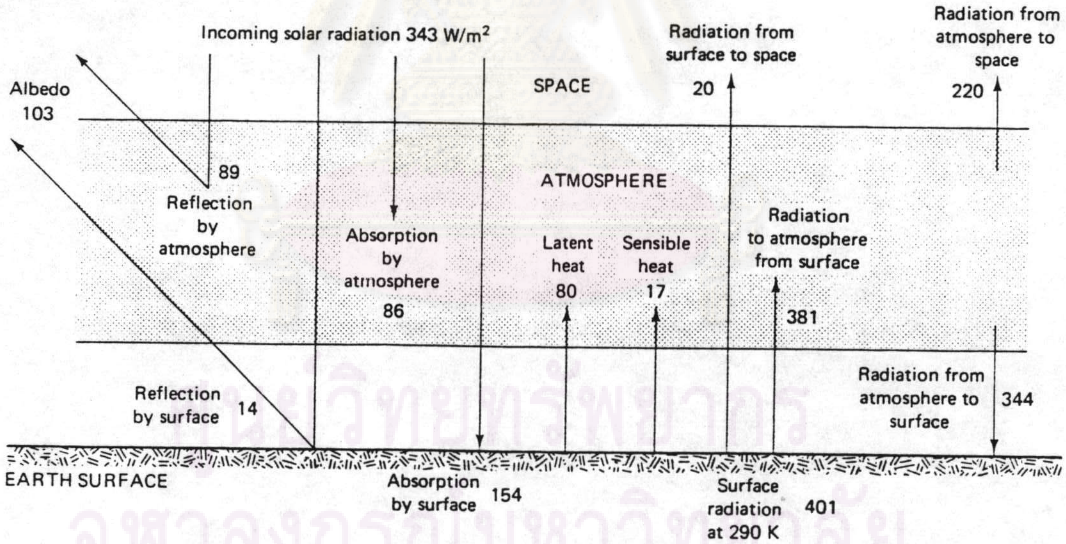

Figure 2.9 Global Average Energy Flows between Space, the Atmosphere, and the Earth's Surface (W/m^2) (Harte, J., 1985)

2.4.3 The Modified Atmospheric-Oceanic Model

The program developed in this work takes more consideration on other greenhouse gases including methane, nitrous oxide, and chlorofluorocarbon for the accuracy purpose. As discussed, the ocean has a strong relation to climate system, therefore we consider both of the atmospheric and oceanic model.

Oceanic Model

The ocean, which covers about three fourths of the planet, is the greatest climate-feedback system. The top three meters of the ocean have as much thermal capacity as the entire atmosphere thus the ocean is able to absorb and to provide great quantities of heat. The ocean's layer and characterisation is defined as a mixed layer, lower layer and a rectangular system, respectively. At mixed layer, heat transfer can occur quite well so that there is no spatial variation in the temperature. At the lower level of more than 70-meter depth, ocean's temperature change depends on time, t and ocean depth, z.

We can determine the temperature profile in a system by generalising the shell energy balances to obtain the equations of energy. To do this, we start with a stationary volume element through which a fluid is flowing; we then write the law of conservation of energy for the fluid contained within this volume element at any time:

Rate of accumulation of internal energy

= Net rate of internal energy in by convection

+ Net rate of heat addition by conduction (2-16)

The rate of accumulation of internal energy within $\Delta x \Delta y \Delta z$ is

$$\Delta x \Delta y \Delta z \frac{\partial(\rho \hat{U})}{\partial t} \tag{2-17}$$

Here $\hat{U}$ is the internal energy per unit mass of the fluid in the element, and is the magnitude of the local fluid velocity.

The net rate of energy input by conduction is

$$\Delta x \Delta y \left\{ q_z \Big|_z - q_z \Big|_{z+\Delta z} \right\} \tag{2-18}$$

The net rate of internal energy change due to convection into the element is

$$\Delta x \Delta y \left\{ \upsilon_z (\rho \hat{U}) \Big|_z - \upsilon_z (\rho \hat{U}) \Big|_{(z+\Delta z)} \right\} \tag{2-19}$$

Here q_z is the z-component of the heat flux vector q.

We now substitute the foregoing expression into Equation (2-16) and divide the entire equation by $\Delta x \Delta y \Delta z$. Taking the limit of the resulting expression as Δz approach zero, we obtain an equation of energy balance:

$$\frac{\partial(\rho \hat{U})}{\partial t} = -\frac{\partial q_z}{\partial z} - \frac{\partial \upsilon_z (\rho \hat{U})}{\partial z} \tag{2-20}$$

Internal energy $\hat{U}$ may be considered as a function of temperature T (for an ideal fluid at constant pressure and volume), so that

$$\partial \hat{U} = C_p \partial T \tag{2-21}$$

here C_p is the heat capacity of the fluid at constant pressure, per unit mass. Because ρ in the above equation can be assumed constant, therefore

$$\rho \frac{\partial \hat{U}}{\partial t} = \rho C_p \frac{\partial T}{\partial t} \qquad (2\text{-}22)$$

By substitute Equation (2-21), Equation (2-22) into Equation (2-20) and consider the fluid velocity along z-axis is constant, we obtain

$$\rho C_p \frac{\partial T}{\partial t} = -\frac{\partial q_z}{\partial z} - \rho C_p \upsilon_z \frac{\partial T}{\partial Z} \qquad (2\text{-}23)$$

The simplification of Equation (2-23) is obtained by expressing q_z in terms of temperature gradients. Then, for a Newtonian fluid with constant thermal conductivity (k), Equation (2-23) becomes

$$\rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial z^2} - \rho C_p \upsilon_z \frac{\partial T}{\partial Z} \qquad (2\text{-}24)$$

In this case, the estimated global average temperature is compered with the steady state temperature at the year before the industrial revolution (1860) as follows;

$$\theta_o(z,t) = T_o(z,t) - T_o(z,1860) \qquad (2\text{-}25)$$

By defining thermal conductivity k and fluid velocity υ_z in term of thermal diffusivity κ, and velocity along z-axis w, respectively, Equation (2-24), and (2-25) can be written as follows:

$$\frac{\partial \theta_o(z,t)}{\partial t} = \kappa \frac{\partial^2 \theta_o(z,t)}{\partial z^2} - w \frac{\partial \theta_o(z,t)}{\partial z} \quad (2\text{-}26)$$

The lower oceanic temperature at any depth or $\theta_o(z,t)$ depend on the heat flux from the atmosphere and mixed layer system to the lower ocean layer, $F_o(t)$. After applying the Fourier's law of heat conduction in z-axis, the correlation between the heat flux at interface with the temperature gradient is obtained.

$$F_o(t) = -k\left(\frac{\partial \theta_o(z,t)}{\partial z}\right)_{z=0} \quad (2\text{-}27)$$

where

k = Thermal conductivity (W/mK)

Replace thermal conductivity (k) in term of thermal diffusivity (κ), density (ρ), and specific heat (C_p), it readily follows that

$$F_o(t) = -\kappa \rho C_p \left(\frac{\partial \theta_o(z,t)}{\partial z}\right)_{z=0} \quad (2\text{-}28)$$

or

$$\left(\frac{\partial \theta_o(z,t)}{\partial z}\right)_{z=0} = -\frac{F_o(t)}{\kappa \rho C_p} \quad (2\text{-}29)$$

Equation (2-29) can be considered as the boundary condition of Equation (2-26). If we differentiate the lower oceanic temperature with depth (z) and rearrange those equations, the average global temperature change at sea-surface, $\theta_o(t)$, is acquired. This sea-surface temperature still up to the heat flux transferring to the lower layer, we may derived from the conservation law of energy in the mixed layer.

Heat flux absorbed by greenhouse gases at the troposphere together with heat transfer from the land to the ocean and heat flux from solar radiation absorbed by surface could change to the heat flux in the atmosphere and the mixed layer that transfer to the lower layer. Some parts of the heat flux is emitted by the Earth surface as longwave radiation. The remaining heat is trapped in the mixed layer. In this work, we considered only the albedo effect of ice. Then the heat flux transfers into the lower layer may thus be expressed as

$$F_o(t) = \Delta F(t) - B\theta_o(t) + \frac{\upsilon}{f_o}\left[\theta_{LS} - \theta_o(t)\right] - R_m\left\{\frac{d\theta_o(t)}{dt}\right\} \qquad (2\text{-}30)$$

where

$\Delta F(t)$ = Heat flux of the surface-troposphere system due to increasing atmospheric greenhouse gas (W/m^2)

B = Feedback parameter (1.26 W/m^2K)

υ = The overall heat transfer coefficient $(0,\infty)$

υ/f_o = The heat transfer coefficient based on ocean

f_o = The global ocean fraction (0.71)

R_m = The heat capacity of mixed layer (3×10^8 Ws/m^2K)

θ_{LS} = Land-surface temperature change relates to the 1860's (K)

$\theta_o(t)$ = Sea-surface temperature change relates to the 1860's (K)

Atmospheric Model

In the atmospheric model, the heat fluxes accumulated in the troposphere resulting from the increase of the greenhouse gases, especially carbon dioxide, methane, nitrous oxide and chlorofluorocarbon, were calculated. The higher the amount of these greenhouse gases, the higher the heat radiation from global surface can be absorbed by these gases in the atmosphere. These cause the global temperature elevation.

Heat fluxes occurred from the carbon dioxide gases at various periods of time can be estimated using Equation (2-31). This correlation is the net amount of the solar energy that affects the Earth and the thermal energy radiating from the global surface of 2 levels; at the global surface and the upper level of the troposphere. The difference of the net heat from these two levels is the amount of the heat accumulated in the lower part of the atmosphere. This estimating is considered in various scenarios. Finally, we have the relation between the heat fluxes and the concentrations of carbon dioxide. Then the relation with time is also acquired. The heat fluxes of other greenhouse gases can be estimated by using an index of which comparing the absorptivity of various greenhouse gases with that of carbon dioxide gas (Global Warming Potential).

$$\Delta F(t) = 0.0277\left(e^{\frac{t}{\tau_c}} - 1\right) \qquad (2\text{-}31)$$

where τ_c = 33 years.

The modified atmospheric-oceanic model equation is employed for predicting the global temperature change under the certain conditions mentioned in the above assumption. Chapter 3 will explained about the calculation methodology in details.