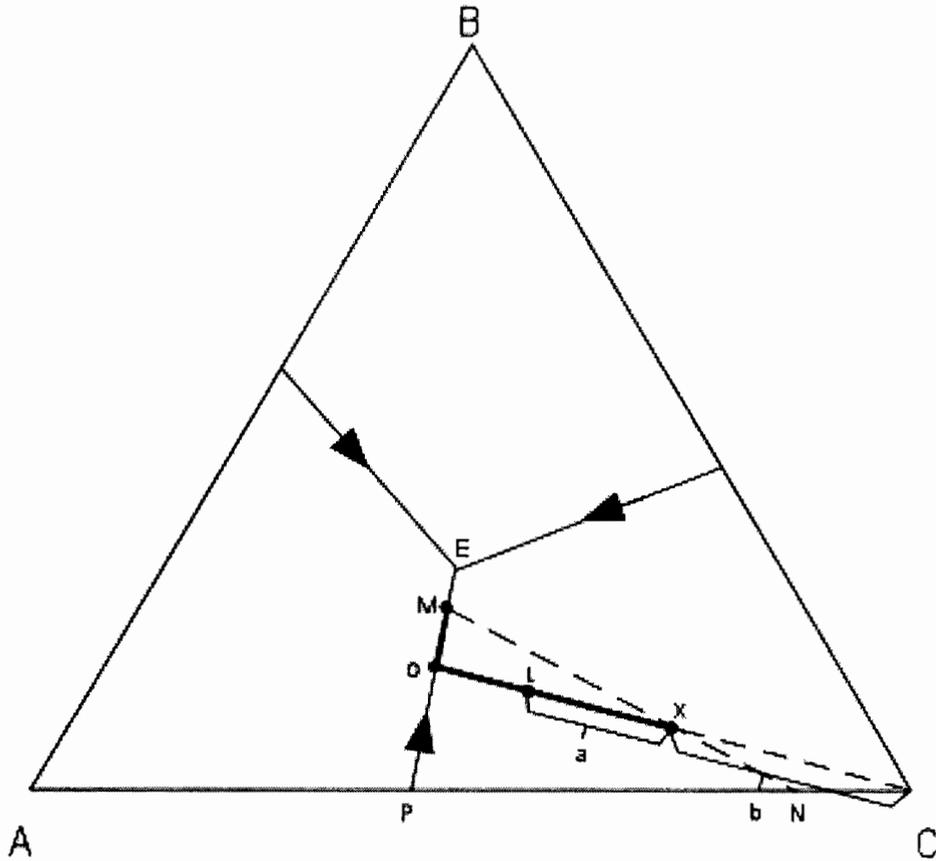# APPENDIX A
Estimation of the ash melt fraction

X_{melt} in Equation 4.14 was estimated according to well known "Lever rule" on the ternary phase of the given elemental system. For instance, a system composed of three compounds A-B-C has the composition of A, B and C at point X as illustrated in Figure A.1. Point E in this figure is the ternary eutectic.

Figure A.1 Thermal behaviors of compounds in ternary phase diagram

Temperature referred to point X is called "liquidus temperature", at which the composition at X would be completely in liquid phase. At this point it would begin to precipitate crystals of C. As temperature is lowered, crystals of C would continue to precipitate, and the composition of the liquid would move along a straight line away from C. This is because C is precipitating and the liquid is becoming less in C and enriched in the components A + B.

As temperature decreased to point L which some amount of C has been precipitated, the relative portion of liquid phase and solid phase can be determined;

$$X_{liquid.at.L} = \frac{b}{a+b} \qquad (A.1)$$

$$X_{soild.at.L} = \frac{a}{a+b} \qquad (A.2)$$

With further cooling, the path of the liquid composition will intersect the boundary curve at point O. At the boundary curve, crystals of A will then precipitate. The liquid path will then follow the boundary curve towards point M. The bulk composition of the solid phase precipitated during this interval will be a mixture of A + C in the proportion shown by point P.

At point M, the bulk composition of the solid phases so far precipitated through the cooling history lies at point N (the extension of the straight line from M through the initial composition X). At this time the liquid and solid fraction will be given by the distances:

$$X_{liquid.at.M} = \frac{\overline{XN}}{\overline{MN}} \qquad (A.3)$$

$$X_{solid.at.M} = \frac{\overline{XM}}{\overline{MN}} \qquad (A.4)$$

With further cooling, the liquid composition will move to the ternary eutectic, Point E, at which crystals of B will precipitate. The temperature will remain constant until all of the liquid is used up. The final crystalline product will consist of crystals of A+B+C in the proportions given by the initial composition X.

APPENDIX B
Calculation of char surface temperature

The char surface temperature (T_{char}), an important parameter to estimate X_{melt}, is described by the energy balance at char surface between the heat generated by the combustion and the surface heat loss of char by fluidized bed. The main equations reported in a previous literature [180] are

$$T_{char} - T_b = \frac{\beta}{(1+\alpha)}(C_b q)\frac{D_{AB}}{k_g}\frac{Sh}{Nu} \tag{B.1}$$

where

$$\beta = \frac{1}{1 + k_m/k_c} \tag{B.2}$$

$$\alpha = \sigma\varepsilon(T_{char}^4 - T_b^4)\big/h(T_{char} - T_b) \tag{B.3}$$

where C_b is the oxygen concentration, 21 %Vol. can be assumable. q is the heat of combustion associated to the complete combustion of carbon content in biomass. Gas diffusivity (D_{AB}) and combustion rate constant (k_c) are determined by equation B.4 and B.5, respectively [180].

$$D_{AB} = 5.2x10^{-4}T_b^{1.5}/P \tag{B.4}$$

$$k_c = 595 T_{char}\exp(-149200/RT_{char}) \tag{B.5}$$

Heat transfer coefficient (h) and mass transfer coefficient (k_m) included in Nusselt number (Nu) and Sherwood number (Sh), respectively, can be determined by the correlations [181].

$$(Nu - Nu_{i,large})/(Nu_l - Nu_{i,large}) = (d_{p,char}/d_p)^{2/3} \tag{B.6}$$

$$(Sh - Sh_{i,large})/(Sh_l - Sh_{i,large}) = (d_{p,char}/d_p)^{2/3} \tag{B.7}$$

where

$$Nu_{i,large} = 0.85Ar^{0.19} + 0.006Ar^{0.5}\Pr^{0.33} \tag{B.8}$$

$$Sh_{i,large} = 0.009Ar^{0.5}Sc^{0.33} \tag{B.9}$$

$$Nu_l = 6 + 0.117Ar^{0.39}\Pr^{0.33} \tag{B.10}$$

$$Sh_l = 2\varepsilon_{mf} + 0.117Ar^{0.39}Sc^{0.33} \tag{B.11}$$

T_{char} at specific experimental conditions is calculated according to a diagram illustrated in Figure B.1 based on the **trial and error** methods.
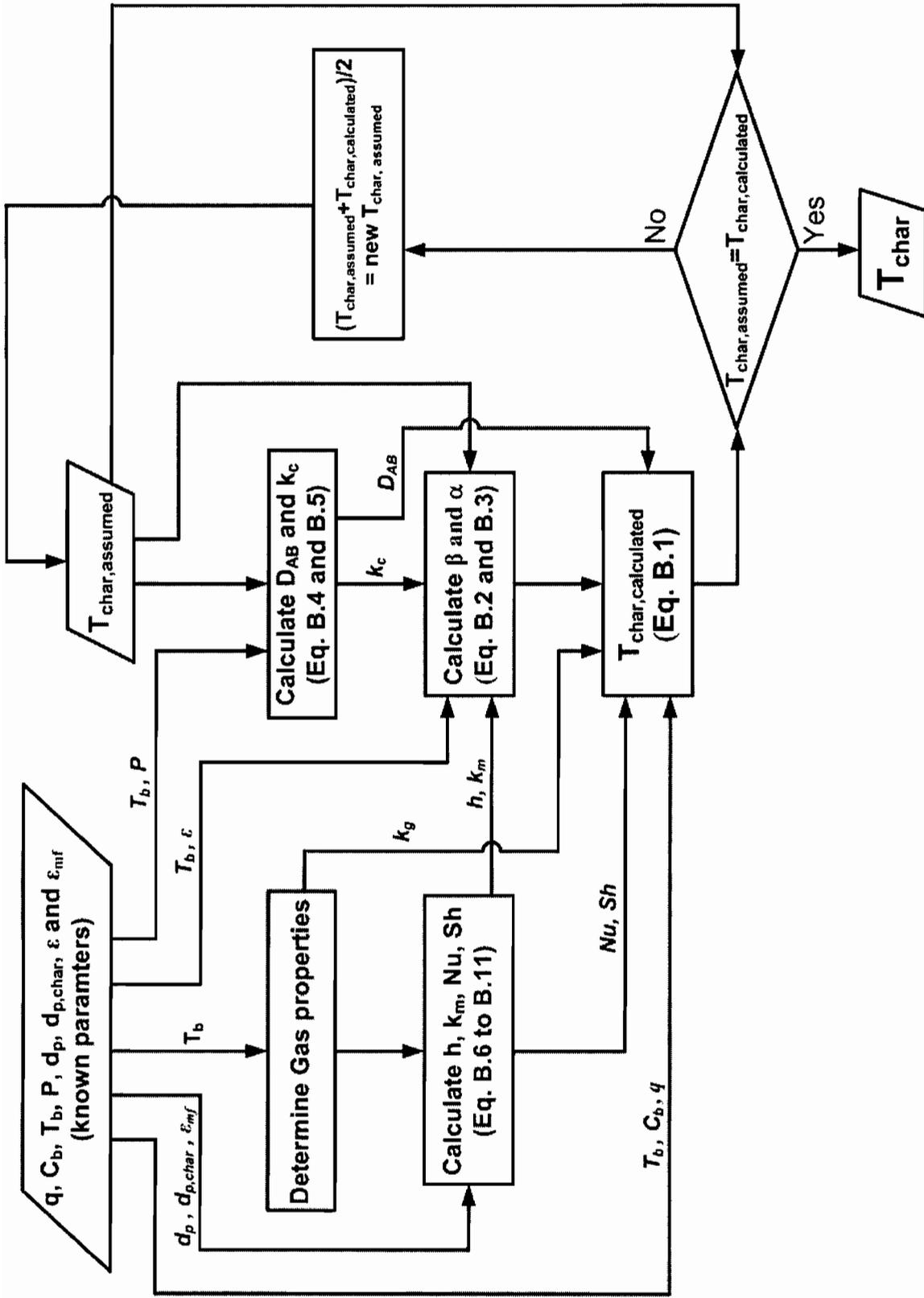
Figure B.1 Calculation diagram of char surface temperature

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- Technical Engineer, Perform the tapioca industrial waste water survey under Thai-Belgium Project.

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1997 – 1999
(Researcher, Research assistant and Teaching assistant)
- Study on heat transfer mechanisms in Crater bed.
- Combustion of plastic waste in a fluidized-bed furnace.
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- Technical Consultant, Perform in Fluidized Bed Furnace Design for Retrofitting a 20 ton/hr Biomass-fired Stroker-type Steam Boiler, Thai Power Supply Co. Ltd., Chachoengsao, Thailand.

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- Hydrodynamics and Heat Transfer Characteristics of Crater Bed
- Development of Crater Bed Combustor for Solid Fuel Powder
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- Catalytic Combustion of Soot from Diesel Engine
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3. Chaivatamaset, P. and Tia, S., "Heat Transfer in a Crater Bed", **Applied Thermal Engineering**, Vol. 27, No. 17-18, 2007, pp. 2767-2778.
4. Chaivatamaset, P., Sricharoon, P. and Tia, S., 2011, "Bed agglomeration characteristics of palm shell and corncob combustion in fluidized bed", **Applied Thermal Engineering**, Vol. 31, 2916-2927.

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