Application of Raoult's law to a fermentation broth in equilibrium to its vapor phase

【Associated Sections in Selected Textbooks】

- Introduction to Chemical Engineering Thermodynamics [1] Sec. 10.4

【Module Learning Objectives】

- VLE calculation using Raoult's law.

【Problem】

The production of renewable biofuels has been receiving increased attention due to the effect of non-renewable fossil fuel combustion on the earth's climate. Currently, the conversion of corn to ethanol accounts for the vast majority of liquid biofuels produced in the United States. While corn and other agricultural crops, such as sweet sorghum, sugar cane, sugar beet, etc, will remain a sizeable fraction of the starting material for liquid biofuels, other carbon sources will be required if renewable biofuels are to make more significant inroads into the world's energy portfolio. A variety of biomass materials are available for production of liquid biofuels, both intentionally grown for this purpose and that which is a side product or waste material from another process. The latter category includes agricultural residues, such as corn stover, fruit and vegetable processing wastes, plant trimmings; pulp and paper sludge; wood chips; cheese whey; and waste paper, to name just a few [2]. The amount of this distributed biomass waste is significant, although often overlooked. For example, Kim and Dale estimated ethanol produced from the world's waste crops and crop residues could replace 32% of global gasoline consumption [3]. More information on fermentation process in general can be found on the following page:

http://biofuelsacademy.org/web-modules/process/fermentation/general-overview-of-fermentation/

Different fermentation processes based on feedstock and technology and links to video clips can be found on the following page:

http://biofuelsacademy.org/web-modules/process/fermentation/

In the biomass fermentation process, lignocellulosic biomass is converted into sugars which are then fermented to ethanol. Cellulose, hemicellulose, and lignin are the most prevalent components in lignocellulosic biomass. The most common sugars produced from these materials are glucose ($C_6H_{12}O_6$) and xylose ($C_5H_{10}O_5$) which can be converted fermentatively to ethanol, carbon dioxide, and a range of co-products. Ideally, each unit mass of sugar yields about 0.5 unit mass of ethanol. Standard baker's yeast strains are capable of fermenting glucose, but not xylose. Other yeast

strains, genetically engineered species, and other microorganisms can be employed to ferment xylose to ethanol [2].

In one particular fermentation broth after removing/recycling cells, sugars etc., the main components left are ethanol (1) and water (2). If we assume that the binary system is at vapor liquid equilibrium in a container and it conforms closely to Rault's law, do the following calculations for the ethanol (1)/ water (2) system:

(a) Given x_1=0.1 and T=25^{o}C, find y_1 and P
(b) Given y_1=0.5 and T=25^{o}C, find x_1 and P
(c) Given x_1=0.1 and P=5kPa, find y_1 and T
(d) Given y_1=0.5 and P=5kPa, find x_1 and T
(e) Given T=25^{o}C and P=5kPa, find x_1 and y_1

1 Bibliography

[1] J. Smith, H. Van Ness and M. Abbott, Introduction to Chemical Engineering Thermodynamics, 7th Ed. ed., New York: McGraw Hill, 2005.

[2] L. M. Vane, "A review of pervaporation for product recovery from biomass fermentation processes," *Journal of Chemical Technology and Biotechnology*, vol. 80, pp. 603--629, 2005.

[3] S. Kim and B. E. Dale, "Global potential bioethanol production from wasted crops and crop residues," *Biomass and Bioenergy*, vol. 26, pp. 361 - 375, 2004.