UNIVERSITI SAINS MALAYSIA

First Semester Examination
2010/2011 Academic Session

November 2010

EKC 511 – Advanced Separation Processes
[Proses Pemisahan Lanjutan]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of TEN pages of printed material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEPULUH muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** (4) questions.

*[**Arahan:** Jawab **SEMUA** (4) soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.]

Answer ALL questions.
Jawab SEMUA soalan.

1. A mixture of Tetrahydrofuran (THF) and water containing 50 mol percent of THF is to be separated to give a product of 95 mol percent of THF and not more than 5 mol percent of THF in the waste. The designed flow rate of the final product containing 95% THF is 1000 kmol/h. As the THF-water mixture exhibits azeotropic characteristics, it is proposed that the separation processes employ pressure swing distillation (PSD) technique to take advantage of the distinct shift of azeotrope in its vapour liquid equilibria (VLE) at different pressures as shown in Figure Q.1.1. Table Q.1.3. gives the vapour liquid equilibrium data for liquid mole fractions (X_{THF}) of THF at 8 bar for the range 0.6 to 1.0. The first column is to operate at 1 bar while the second column is to operate at 8 bar. The respective mole fractions of THF are shown in the flow chart (Figure Q.1.2). The reflux ratios of the columns are twice the minimum. The feed F_1 entering the column 1 has a q value of 0.125. D_1 enters the column 2 as a boiling liquid. Estimate the flow rates D_1, D_2, F, F_1 and W_1 and the number of theoretical plates of the top and bottom sections of the distillation column 2.

   Satu campuran tetrahidrofuran (THF) dan air yang mengandungi 50 peratus mol THF akan dipisahkan untuk memberi satu produk dengan 95 peratus mol THF dan tidak lebih daripada 5 peratus mol THF terkandung dalam bahan buangan. Kadar aliran rekabentuk produk akhir yang mengandungi 95 % THF ialah 1000 kmol/j. Memandangkan campuran THF-air mempamerkan ciri-ciri azeotrop, penggunaan teknik penyulingan buaian tekanan (PSD) telah dicadangkan untuk proses pemisahan bagi menggunakan kelebihan peralihan ketara azeotrop semasa keseimbangan wap cecair (VLE) pada tekanan-tekanan yang berbeza seperti ditunjukkan dalam Rajah S.1.1. Jadual S.1.3 memberikan data keseimbangan wap cecair bagi pecahan mol cecair (X_{THF}) THF pada 8 bar untuk julat 0.6 ke 1.0. Turus pertama akan beroperasi pada 1 bar sementara turus kedua akan beroperasi pada 8 bar. Pecahan-pecahan mol THF, masing-masing ditunjukkan dalam carta aliran (Rajah S.1.2). Nisbah refluks bagi turus-turus ialah dua kali minimum. Suapan F_1 yang memasuki turus 1 mempunyai nilai q 0.125. D_1 memasuki turus 2 sebagai cecair mendidih. Anggarkan kadar aliran bagi D_1, D_2, F, F_1 dan W_1 serta bilangan plat teori bahagian atas dan bawah turus penyulingan 2.

[25 marks/markah]

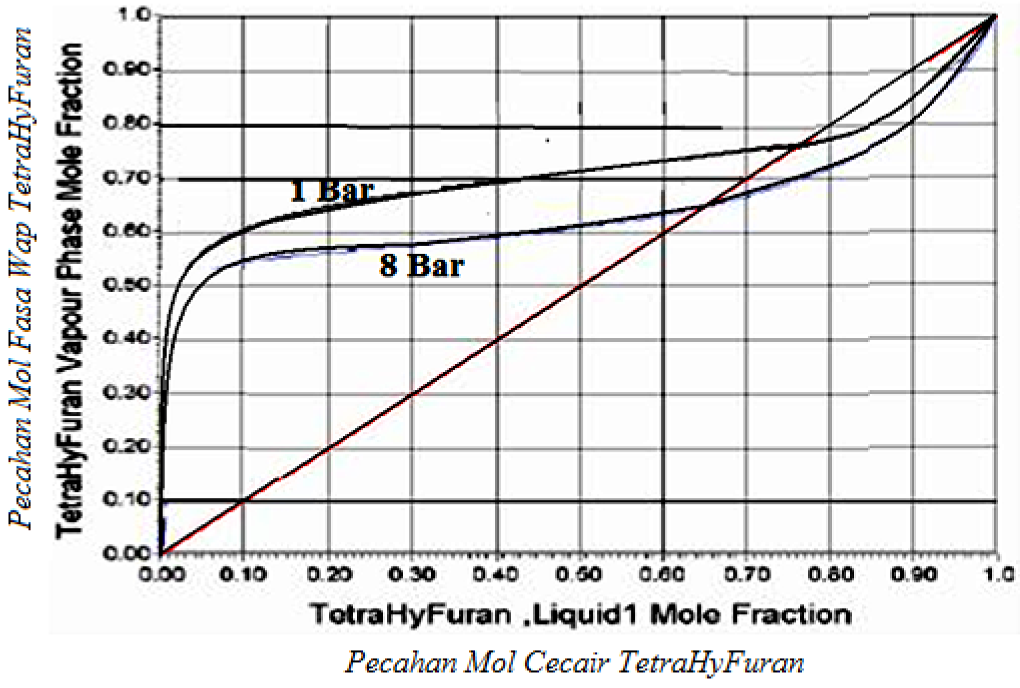

Figure Q.1.1. Equilibrium Diagrams
Rajah S.1.1. Gambarajah Keseimbangan

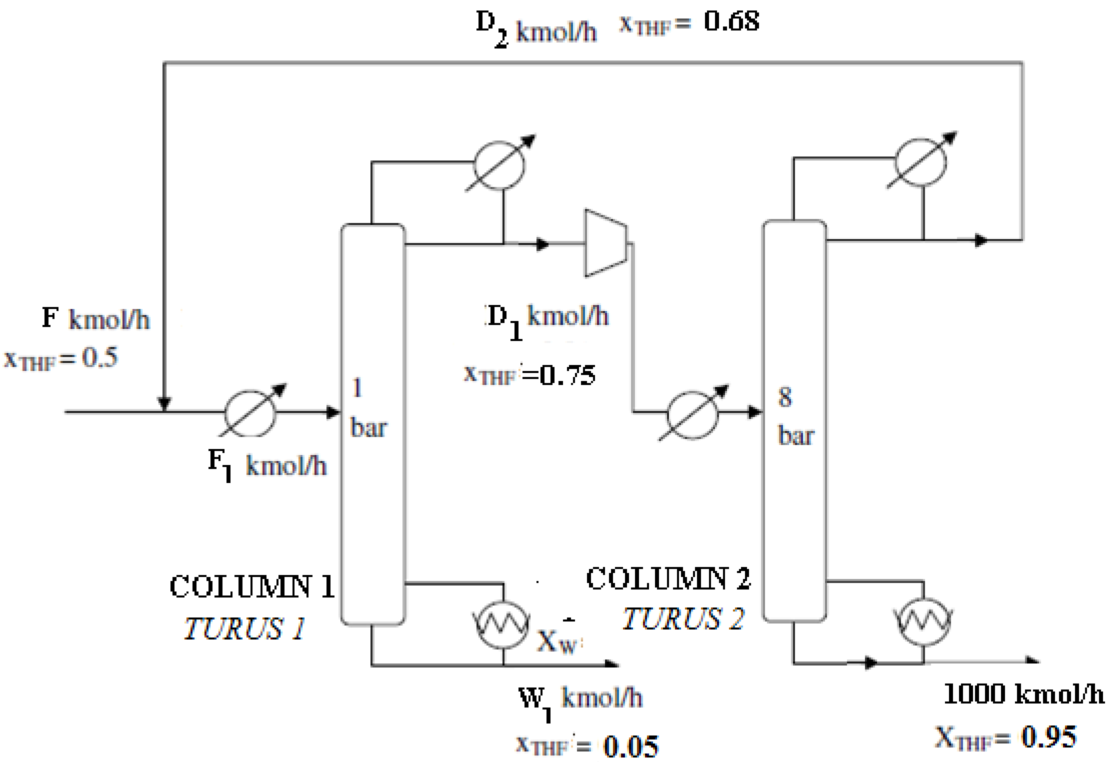

Figure Q.1.2.
Rajah S.1.2.

Table Q.1.3. Vapour liquid equilibrium data for liquid mole fractions (X_{THF}) of THF at 8 bar for the range 0.6 to 1.0.
Jadual S.1.3. Data keseimbangan wap cecair bagi pecahan mol cecair (X_{THF}) THF pada 8 bar untuk julat 0.6 ke 1.0.

Mole fraction of THF in Liquid *Pecahan mol THF dalam cecair*	1.0	0.95	0.9	0.85	0.8	0.75	0.7	0.65
Mole fraction of THF in vapour *Pecahan mol THF dalam wap*	1.0	0.9	0.8	0.75	0.72	0.7	0.68	0.65

2. [a] Explain the principles of the ion-exchange separation process.
Terangkan prinsip-prinsip proses pemisahan penukaran ion.

[3 marks/markah]

[b] An ion-exchange process in which a divalent ion *D* displaces a monovalent ion *B* from a resin is shown as follows:
Suatu proses penukaran ion di mana ion dwi-valensi D *menggantikan ion mono-valensi* B *dari resin seperti ditunjukkan:*

$$D + \overline{2B} \leftrightharpoons \overline{D} + 2B$$

Derive an expression for equilibrium constant (K_{DB}) for the process in term of:
Terbitkan ungkapan bagi pekali keseimbangan (K_{DB}) bagi proses tersebut dalam sebutan:

[i] Total ionic contents of the solution phase, *C*.
Kandungan keseluruhan ion bagi fasa larutan, C.

[ii] Total ionic contents of the resin phase, $\overline{C}$.
Kandungan keseluruhan ion bagi fasa resin, $\overline{C}$.

[iii] Equivalent fraction of *D* in the solution phase, X_D.
Nisbah setara bagi D *dalam fasa larutan,* X_D.

[iv] Equivalent fraction of *D* in the resin phase, $\overline{X}_D$.
Nisbah setara bagi D *dalam fasa resin,* $\overline{X}_D$.

[5 marks/markah]

[c] A research conducted by USM found out that the water supply to Kuala Gula's residence can be classified as hard water and not safe. To solve the problem, the research team suggested to built a new plant at that area to soften the drinking water containing 50 $meqL^{-1}$ (2500 ppm) Ca^{2+} by means of ion-exchange using a strongly ionized resin. The cheapest means of regenerating the resin is to use sea-water, which may be taken to have a composition of 0.2 eqL^{-1} Ca^{2+} and 0.6 eqL^{-1} Na^{+}.

Suatu penyelidikan yang dijalankan oleh USM mendapati bahawa bekalan air ke penempatan Kuala Gula sebagai air liat (air berion tinggi) dan tidak selamat untuk diminum. Untuk menyelesaikan masalah tersebut, kumpulan penyelidik tersebut mencadangkan untuk membina satu loji baru di kawasan tersebut untuk melembutkan air minuman berkenaan yang mengandungi 50 $meqL^{-1}$(2500 ppm) Ca^{2+}dengan menggunakan resin berion yang kuat. Cara termurah untuk pemulihan semula resin adalah dengan menggunakan air laut yang mempunyai kepekatan 0.2 eqL^{-1} Ca^{2+} dan 0.6 eqL^{-1} Na^{+}.

[i] Is this a reasonable suggestion if Malaysian Department of Environment enforcement has set a limit that the softened water is to have a hardness less that 100 ppm of Ca^{2+}. Justify your answer.

Adakah ini merupakan suatu proses yang munasabah sekiranya penguatkuasaan Jabatan Alam Sekitar Malaysia menetapkan air lembut mengandungi ion tidak melebihi had keliatan 100 ppm Ca^{2+}. Berikan justifikasi jawapan anda.

[ii] Suggest another alternative process which could be used to reduce the hardness of the drinking water.
Cadangkan suatu proses yang lain yang mungkin boleh digunakan untuk mengurangkan keliatan air minuman.

[Note: 50 $meqL^{-1}$ = 2500 ppm]
[Nota: 50 $meqL^{-1}$ = 2500 ppm]

[17 marks/markah]

3. [a] Explain five different types of commercially available adsorbent used in industry.
Terangkan lima jenis bahan penjerap komersial yang digunakan dalam industri.

[5 marks/markah]

[b] Derive and show that the solute flux across a membrane is given by the following expression:
Terbit dan tunjukkan bahawa fluks bahan larut merentasi lapisan membran adalah seperti persamaan berikut:

$$N_A = \frac{C_1 - C_2}{1/k_{C1} + 1/P_m + 1/k_{C2}}$$

where,

N_A	=	solute flux across the membrane
C_1	=	bulk liquid-phase concentration of diffusing solute at feed (kgmol/m^3)
C_2	=	bulk liquid-phase concentration of diffusing solute at permeate (kgmol/m^3)
K_{C1}	=	mass transfer coefficient at feed side (m/s)
K_{C2}	=	mass transfer coefficient at permeate side (m/s)
P_M	=	permeability in the membrane (m/s)

di mana,

N_A	=	*fluks bahan larut merentasi membran*
C_1	=	*kepekatan pukal fasa cecair bagi bahan larut yang meresap di bahagian suapan (kgmol/m^3)*
C_2	=	*kepekatan pukal fasa cecair bagi bahan larut yang meresap di bahagian telapan (kgmol/m^3)*
K_{C1}	=	*pekali pemindahan jisim di bahagian suapan (m/s)*
K_{C2}	=	*pekali pemindahan jisim di bahagian telapan (m/s)*
P_M	=	*kebolehtelapan dalam membran (m/s)*

[10 marks/markah]

[c] Pak Abu is already 60 years old and has some chronic illnesses such as cardiovascular, high blood pressure and diabetes. Recently, Pantai Medical Centre confirmed that his kidney is not functioning well. His son decided to install an artificial kidney to remove urea and toxics from his father's blood in a cuprophane membrane dialyzer at 37°C. The membrane is 0.025 mm thick and has an area of $2.5 m^2$. The mass transfer coefficient on the blood side is 1.25×10^{-5} m/s and that on the aqueous side is 3.50×10^{-5} m/s. The permeability of the membrane is 8.70×10^{-6} m/s. The concentration of urea in the blood is 0.05 g urea/100 mL and that in the dialyzing fluid can be assumed as zero. Calculate the flux and how much urea can be removed per day.

Usia Pak Abu telah menjangkau 60 tahun dan mempunyai pelbagai sakit kronik antaranya sakit jantung, tekanan darah tinggi dan kencing manis. Baru-baru ini, Pusat Perubatan Pantai telah mengesahkan bahawa buah pinggang beliau tidak berfungsi dengan baik. Anak lelaki beliau mengambil keputusan untuk memasang buah pinggang palsu untuk membuang urea dan bahan-bahan toksik terlarut yang terkandung dalam darah bapanya menggunakan pendialisis membran 'cuprophane' pada suhu 37 °C. Membran tersebut mempunyai ketebalan 0.025 mm dan keluasan $2.5 m^2$. Pekali pemindahan jisim di bahagian darah ialah 1.25×10^{-5} m/s dan di bahagian akues ialah 3.50×10^{-5} m/s. Kebolehtelapan membran ialah 8.70×10^{-6} m/s. Kepekatan urea dalam darah ialah 0.05 g /100 mL dan dalam bendalir dialisis boleh dianggapkan sifar. Kirakan fluks dan berapa banyakkah urea yang boleh dikeluarkan dalam satu hari.

[10 marks/markah]

4. [a] A room temperature ionic liquid(RTIL) is used to absorb CO_2. Show that the fugacities of CO_2 can be expressed as $f_{(CO_2)} = X_{CO_2} (0.5\, f_{CO_{2L}})$ for low values of X_{CO_2}.

Suatu cecair ion pada suhu bilik (RTIL) digunakan untuk menyerap CO_2. Tunjukkan bahawa fugasiti CO_2 boleh diungkapkan sebagai $f_{(CO_2)} = X_{CO_2}$ $(0.5\, f_{CO_{2L}})$ bagi nilai X_{CO_2} yang rendah.

where
di mana

f_{CO_2} is the fugacity of the CO_2 in equilibrium with the RTIL,
ialah fugasiti CO_2 dalam keseimbangan dengan RTIL,

$f_{CO_{2L}}$ is the fugacity of liquid CO_2 at the solution temperature and
ialah cecair CO_2 pada suhu larutan dan

X_{CO_2} is the CO_2 solubility in mole fraction.
ialah kebolehan larutan CO_2 dalam pecahan mol.

[8 marks/markah]

...8/-

[b] Extraction of caffeine from coffee beans is to be carried out using a supercritical fluid. For this purpose supercritical carbon dioxide has been used in preference to other fluids. Describe the considerations that you would employ for the selection of operating conditions of the extraction process. Your answer should include criteria in the selection of

Penyarian kafein dari biji-biji kopi akan dijalankan melalui penggunaan bendalir genting lampau. Karbon dioksida genting lampau telah digunakan bagi tujuan ini berbanding bendalir-bendalir lain. Huraikan pertimbangan yang anda akan gunakan bagi pemilihan keadaan-keadaan proses penyarian. Jawapan anda harus merangkumi kriteria bagi pemilihan

[i] the solvent (preference of carbon dioxide over other solvents),
pelarut (pemilihan karbon dioksida berbanding pelarut-pelarut lain)

[6 marks/markah]

[ii] operating conditions, and
keadaan-keadaan operasi, dan

[5 marks/markah]

[iii] the process flow sheet.
helaian aliran proses.

[6 marks/markah]

You may base your answer on the following data provided
Anda boleh menggunakan data-data yang berikut sebagai asas jawapan anda.

Table Q.4.1.
Jadual S.4.1

TYPICAL DENSITIES ,VISCOSITIES AND DIFFUSION COEFFICIENTS OF GASES, SUPERCRITICAL FLUIDS AND LIQUIDS

KETUMPATAN, KELIKATAN DAN PEKALI RESAPAN BAGI GAS, BENDALIR GENTING LAMPAU DAN CECAIR

		Density ρ [kg/m^3] *Ketumpatan*	Dyn. Viscosity η [g/(cm s)] *Kelikatan Dir.*	Diffusion coefficient D [cm^2/s] *Pekali Resapan*
Gas	0.1 MPa, 298 K	0.6 to 2	(1 to 3) x 10^{-4}	0.1 to 0.4
Supercritical Fluid *Genting lampau*	p_c, T_c 4 x p_c, T_c	200 to 500 400 to 900	(1 to 3) x 10^{-4} (3 to 9) x 10^{-4}	0.7 x 10^{-3} 0.2 x 10^{-3}
Liquid *Cecair*	0.1 MPa, 298 K	600 to 1600	(0.2 to 3) x 10^{-2}	(0.2 to 2) x 10^{-5}

Table Q.4.2. Critical Data of Some Supercritical Solvents
Jadual S.4.2. Data Genting Bagi Beberapa Pelarut Genting Lampau

Fluid *Bendalir*	Critical Temperature (K) *Suhu Genting (K)*	Critical Pressure (bar) *Tekanan Genting (bar)*
Carbon dioxide *Karbon Dioksida*	304.1	73.8
Ethane *Etana*	305.4	48.8
Ethylene *Etilena*	282.4	50.4
Propane *Propana*	369.8	42.5
Propylene *Propilena*	364.9	46.0
Trifluoromethane (Fluoroform) *Trifluorometana (Fluoroform)*	299.3	48.6
Chlorotrifluoromethane *Klorotrifluorometana*	302.0	38.7
Trichlorofluoromethane *Triklorofluorometana*	471.2	44.1
Ammonia *Amonia*	405.5	113.5
Water *Air*	647.3	221.2
Cyclohexane *Sikloheksana*	553.5	40.7
n-Pentane *n-Pentana*	469.7	33.7
Toluene *Toluena*	591.8	41.0

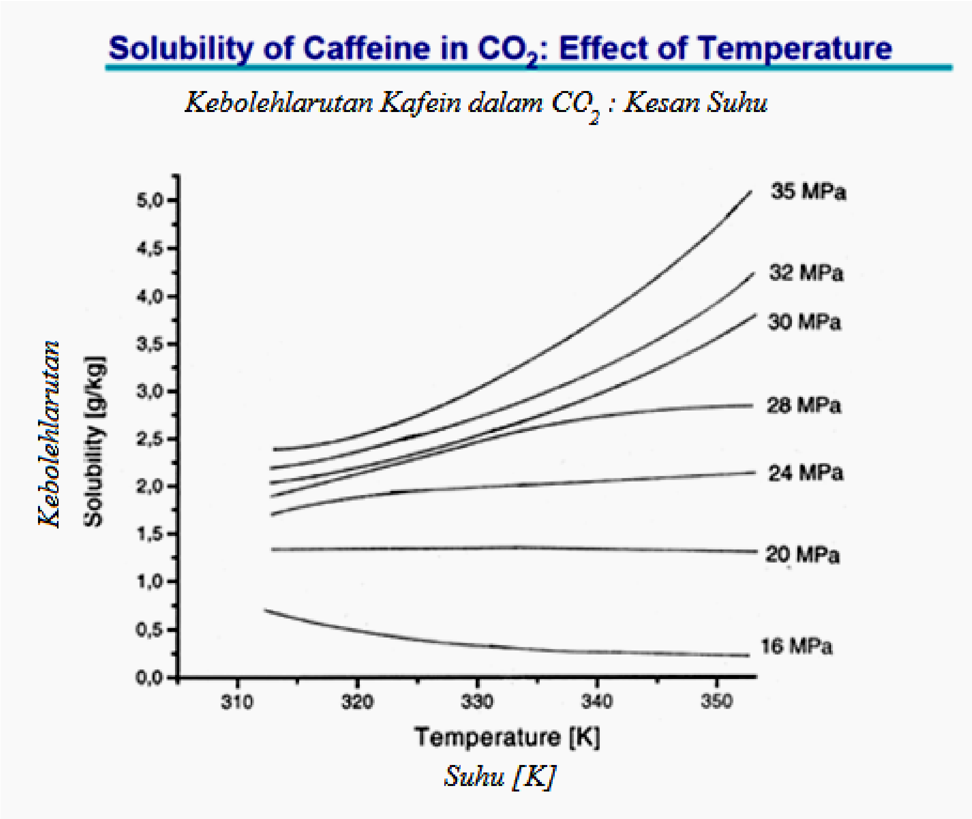

Figure Q.4.3. Solubility of caffeine in CO_2
Rajah S.4.3. Kebolehlarutan kafein dalam CO_2

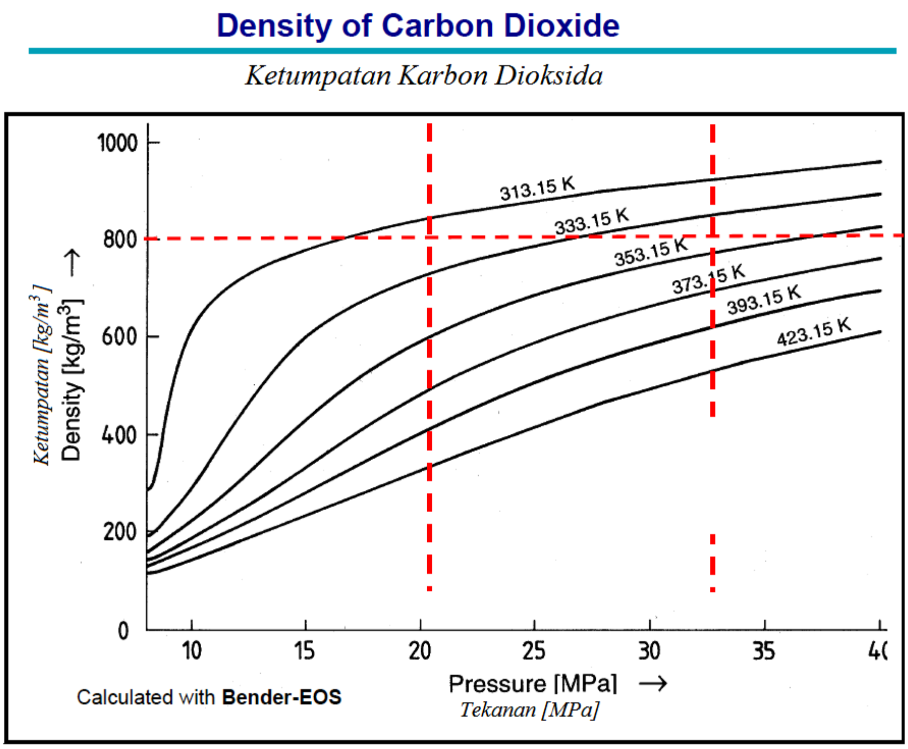

Figure Q.4.2. Density of Carbon Dioxide
Rajah S.4.2. Ketumpatan Karbon Dioksida

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