UNIVERSITY OF
KWAZULU-NATAL

INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: JUNE 2023

COURSE AND CODE: PROCESS DYNAMICS & CONTROL ENCH4DC

DURATION: 3 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINERS: PROF K MOODLEY
PROF R RAWATLAL

INTERNAL MODERATOR: DR S MOODLEY

EXTERNAL MODERATOR: MR A HIGGINSON

INSTRUCTIONS:

1. **ALL** questions should be attempted.
2. Two answer books are provided. Label them Book A and Book B respectively. Answer Section A in Book A and Section B in Book B.
3. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
4. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
5. **Two answer books are provided. Label them Book A and Book B. Answer Section A in Book A and Section B in Book B.**
6. Detach page 6 and hand in with answer booklet A.
7. This examination question paper, together with all associated diagrams **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

Student Number:

SECTION A

QUESTION 1 [12 marks]

In Figure 1 below, a constant volume (V in m^3) mixed, insulated vessel is initially charged with component A ($C_{A,0} = 1$ mol/m^3), which reacts endothermically when heated to form component B according to the second order reaction:

$$A \rightarrow B$$

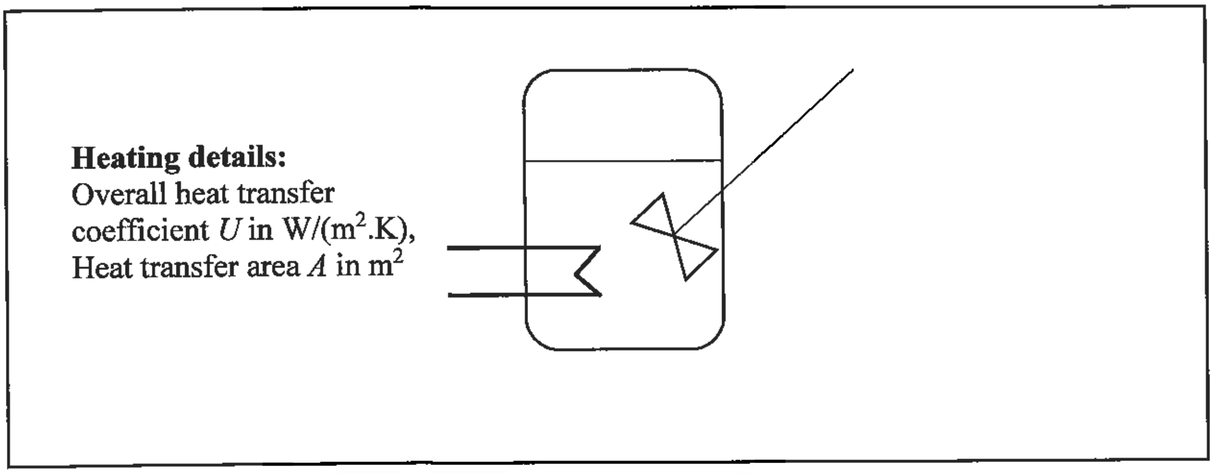

Figure 1. A constant volume mixed reactor.

(a) Determine the dynamic conversion and temperature behaviour of the vessel contents if the reaction rate constant is not temperature dependent.

(7)

(b) Linearize the result in (a) considering suitable input and output variables

(5)

TOTAL /12/

QUESTION 2 [14 marks]

A distillation column distillate composition (x_D) and tray temperature of tray 21 ($T_{tray\ 21}$) are controlled by the reflux rate (Rr) in dm^3/min and reboiler steam rate in dm^3/min (QSr) using a MIMO DMC controller. The following step responses were determined during testing, sampled at 1-minute intervals when the controller was commissioned:

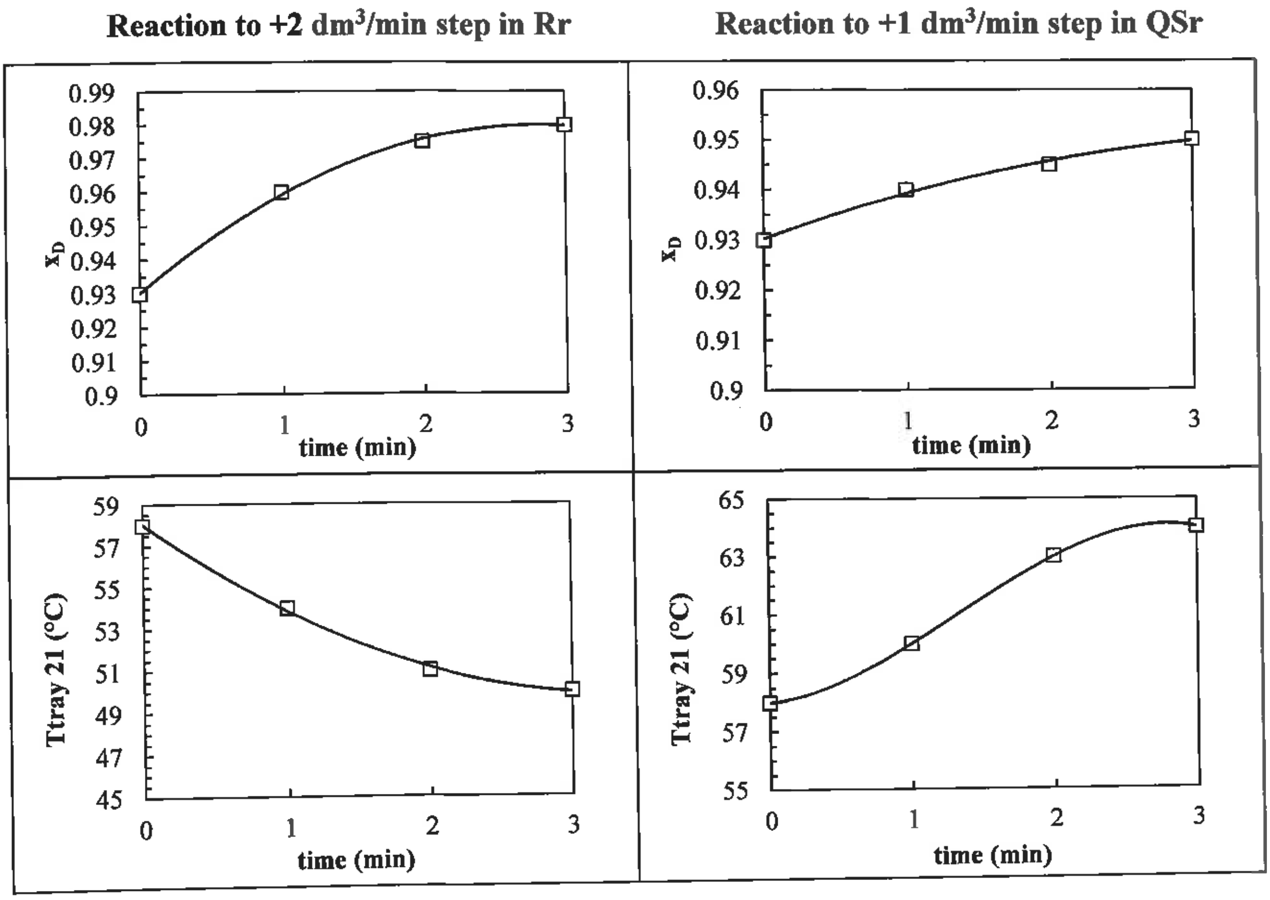

Figure 2. Step response curves for a distillation system.

Now the controller has been on for some time in the past but was then switched to manual. You are required to determine the openloop responses from a given set of historical control moves from 3 minutes ago to present, hence:

a) Determine a suitable matrix to determine the future **openloop response** of the system to the historical control moves. (7)

b) If Rr was changed by (+2, -2, +1→ (present)) and the QSr (+1, +1, -1→ (present)) determine the openloop response for distillate composition and tray 21 temperature. (7)

TOTAL/14/

QUESTION 3 [14 marks]

A hydrogenation reaction producing component B from A, along with by-product C occurs in the CSTR in Figure 3, where air is sparged from below.

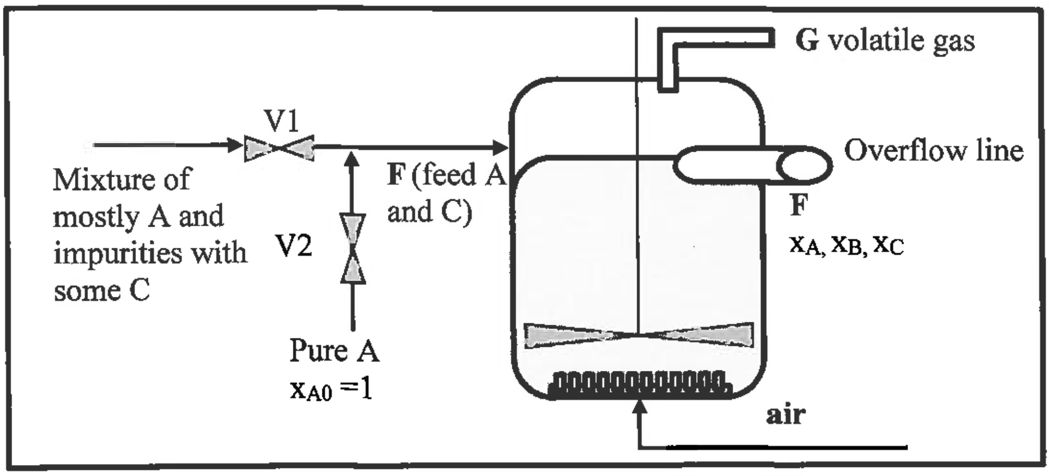

Figure 3. MIMO hydrogenation CSTR.

The following reactions occur in the reactor:

$$A \overset{k_1}{\rightarrow} B \overset{k_2}{\rightarrow} C$$

Where $r_1 = k_1 x_A$ and $r_2 = k_2 x_B$

The linearized model for the liquid composition variation with time in the reactor is given by:

$$\frac{d}{dt}\begin{pmatrix} x_A{}^* \\ x_B{}^* \end{pmatrix} = \begin{bmatrix} 1 & 1 \\ -1 & 0 \end{bmatrix}\begin{pmatrix} F^* \\ x_{A0}{}^* \end{pmatrix} + \begin{bmatrix} -2 & 0 \\ 1 & -3 \end{bmatrix}\begin{pmatrix} x_A{}^* \\ x_B{}^* \end{pmatrix}$$

The following proportional control action is proposed for this system: $\boldsymbol{K} = \begin{bmatrix} 1 & 0 \\ 0 & 20 \end{bmatrix}$

Perform calculations to determine if the system is closed loop stable. (14)

TOTAL/14/

QUESTION 4 [10 marks]

Methane derived from biogas can be used to produce power, heat and steam in a sustainable way. The process shown in Figure 4 proposes a design for power generation, and the production of heat and steam from biogas. First, a methane + CO_2 feed mixture is scrubbed in an absorber. Rich methane product is compressed and cooled and fed to a combustor, along with air from a three-stage compression-intercooling chain. The combustion gasses are passed through a turbine to generate power. The hot gas is then sent to a superheating exchanger to superheat saturated steam feed. This cooler combustion gas is exchanged with a boiler drum with liquid boiler feed water to produce the saturated steam that is fed to the superheater. The cooled combustion gas is sent through an auxiliary turbine to recover additional power. The superheated steam from the superheater is expanded to produce additional power, and the condensate is eventually recycled to the BFW.

Design a control scheme on the diagram provided on Page 9 to achieve the following control objectives:

1. Biogas feed is flow controlled by compressor power (1)
2. Air feed is flow controlled by compressor power to all air compressors (1.5)
3. Air flow setpoint is determined by ratio to feed flowrate and an additional multiplication factor from a temperature controller on the combustor. (2)
4. Air interstage temperatures controlled by intercooler coolant flowrates (1.5)
5. Lean solvent flowrate ratioed to feed flow rate (2)
6. Absorber pressure controlled by off gas compressor power (1)
7. Combustion pressure controlled by resistance in combustion gas turbine (1)

TOTAL/10

SECTION B

QUESTION 5 [25 marks]

We wish to develop the Bode diagrams for a process.

a) For a process described by $G = \frac{1}{\tau s+1}$, we may draw the log modulus for the Bode diagram from two asymptotes, viz.

$L = 0$, and, from $\omega = 1/\tau$, $\frac{dL}{d\log_{10}\omega} = -20$.

Prove that this statement is true. How can this be used to graph more generally the following process:

$$G(s) = \Pi_i(\tau_i s + 1)^{n_i}$$

(10)

b) Sketch the Bode diagram for the process described by the following transfer function

$$G = \frac{(100s + 1)\left(\frac{s}{100} + 1\right)}{(10.s + 1)^2}$$

(10)

c) Comment on the stability of the process in b)

(5)

TOTAL/25

QUESTION 6 [25 marks]

We wish to implement a P-controller for a process for which there are no known governing laws or models. We therefore carry out three experimental programmes, where we apply a sine-wave for the input $u(t)$ and measure the output $y(t)$; the results are shown below in Figure 5. Using the 2Db optimality criterion, determine the value for the P-controller constant. A Nichols Chart is available in Figure 6. Detach and submit together with your answer book. (25)

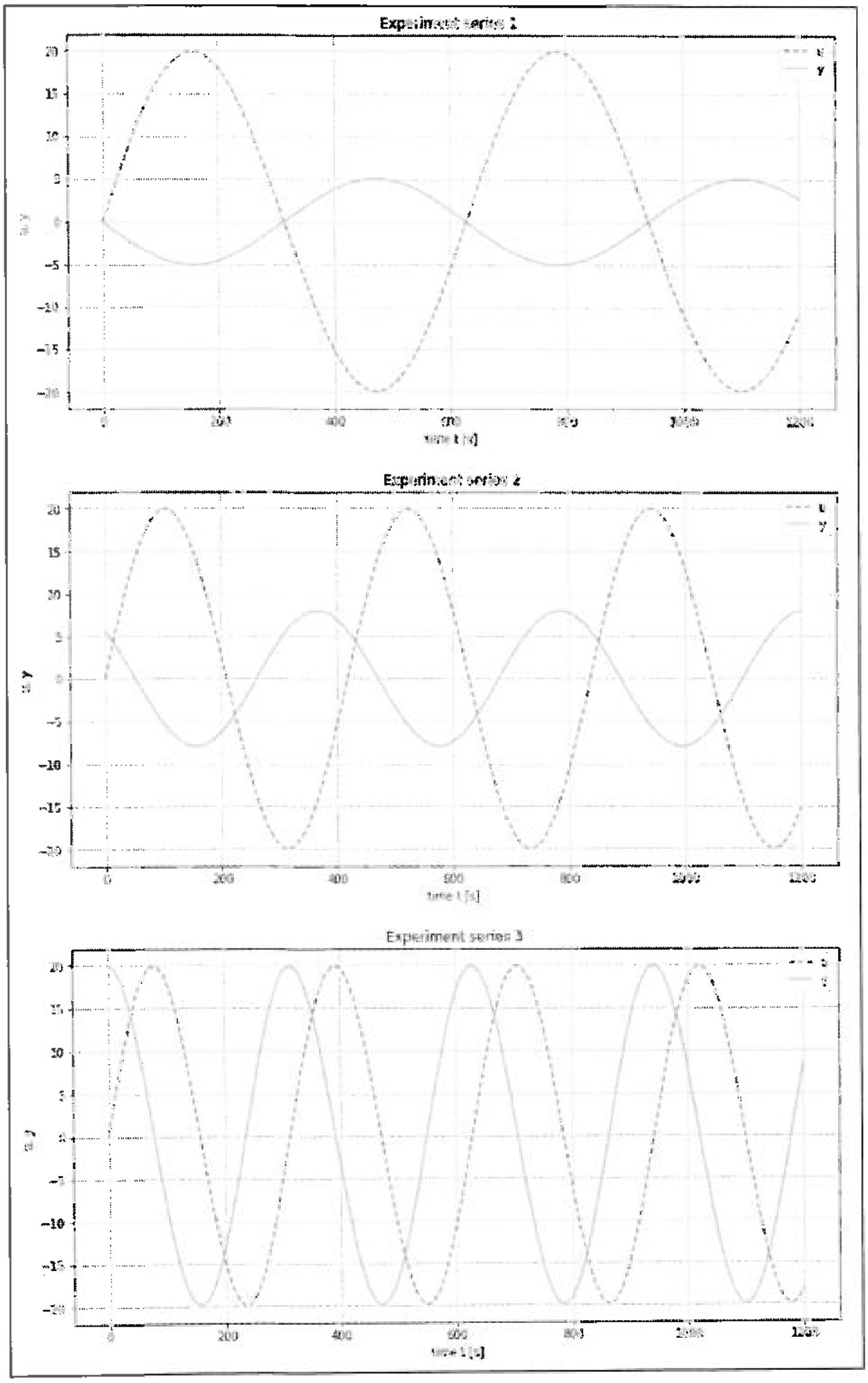

Figure 5. Results of sine-wave application.

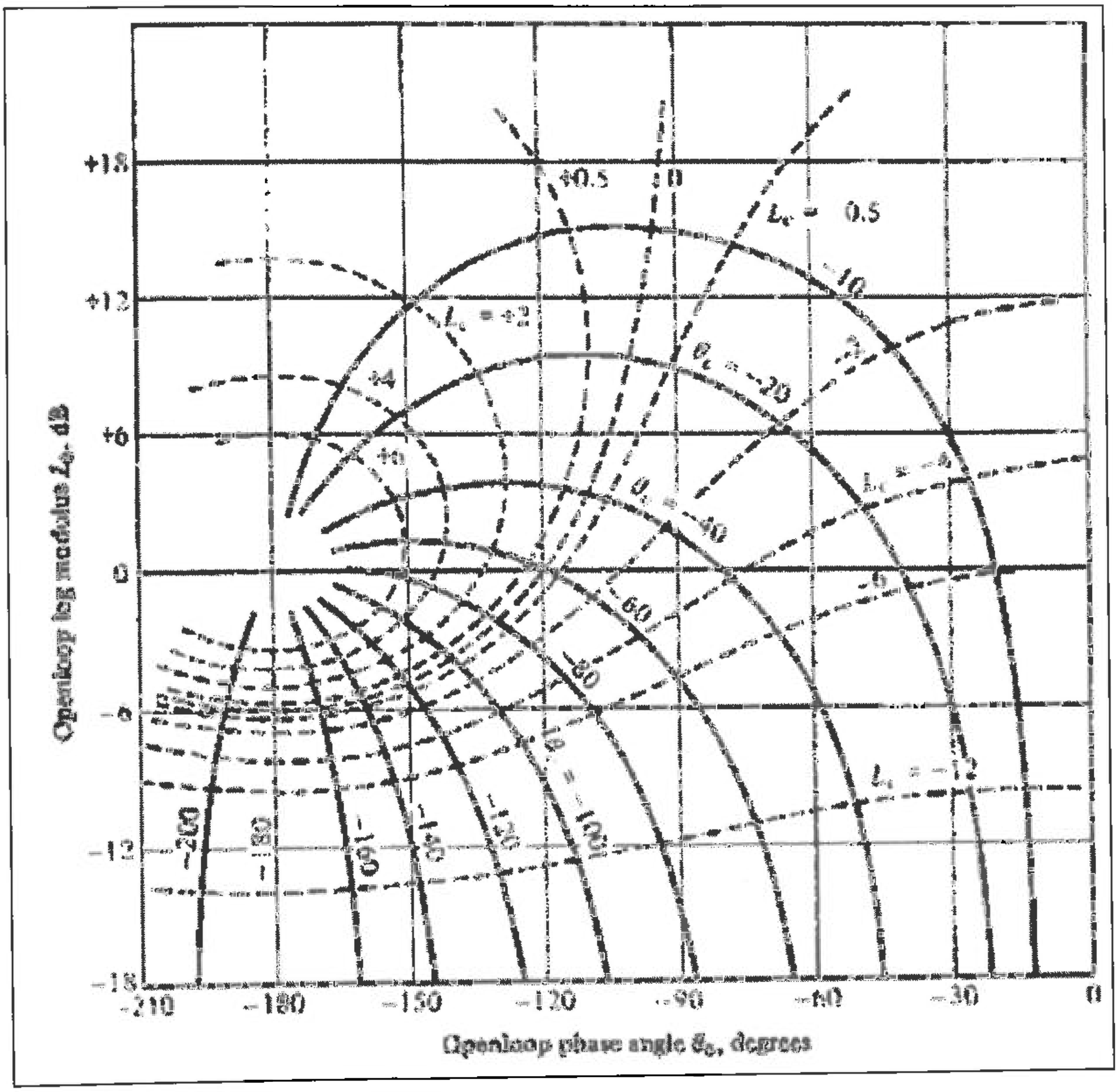

Figure 6. Closed loop characteristic mappings.

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TOTAL/25

DIAGRAM FOR QUESTION 4. DETACH THIS PAGE AND SUBMIT WITH ANSWER BOOKLET A.

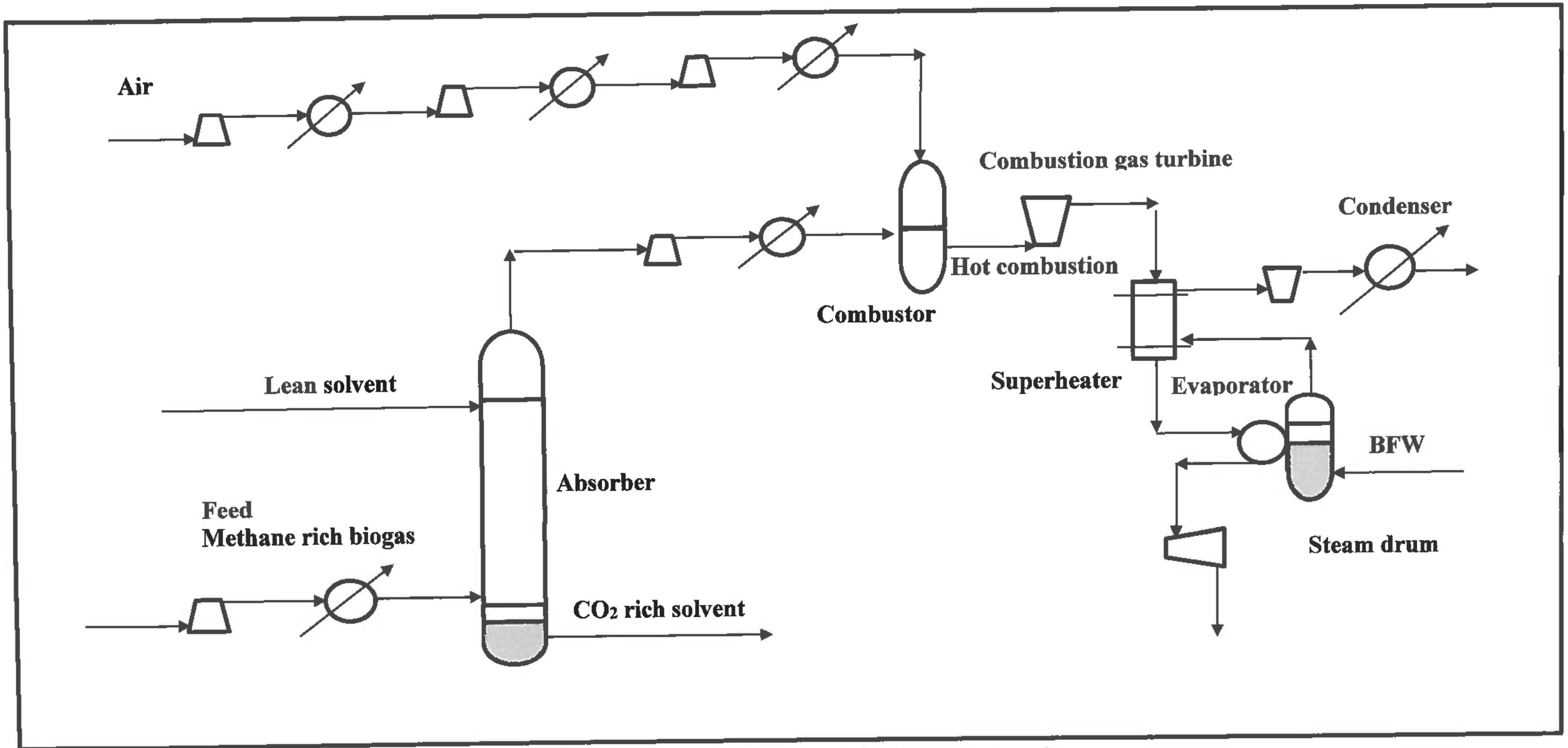

Figure 4. Biogas combustion process for power generation.