



FACULTY OF ENGINEERING AND THE ENVIRONMENT

DEPARTMENT OF METALLURGICAL ENGINEERING

FUELS, ENERGY AND ENVIRONMENT

EMG 2205

Final Examination Paper

June 2025

This examination paper consists of 4 printed pages

Time Allowed: 3 hours

Total Marks: 100

INSTRUCTIONS

1. Choose any **FOUR (4)** questions out of a total of **SIX** questions.
2. Each question carries **25 marks**.
3. Where a question contains subdivisions, the mark value of each subdivision is shown in brackets.
4. Illustrate your answer, where appropriate, with large clearly labeled diagrams.
5. Start each question on a new page.

Additional Requirements

1. Calculator

MARK ALLOCATION

Question 1 to 6	25 Marks
Part Questions	As shown in each part question
Total Attainable Marks	100

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QUESTION 1

- a) Define the following terms as used in metallurgical engineering:
- Power. [2]
 - Specific energy. [2]
 - Energy efficiency. [2]
- b) Differentiate between exothermic and endothermic reactions, giving one example of each from metallurgical operations. [4]
- c) A steel reheating furnace operates as follows:

Natural gas consumption: 500 m³/hr (calorific value: 38 MJ/m³)

Steel throughput: 25 tons/hr

Steel enters at 30°C and exits at 1250°C

Specific heat capacity of steel: 0.5 kJ/kg·°C

Stack gas losses: 1650MJ/hr

Wall losses: 2.2% of input energy

Opening losses: 3.5% of input energy

Cooling water absorbs 5.3% of input energy

- Calculate the total energy input to the furnace in MJ/hr. [3]
- Calculate the useful energy absorbed by the steel in MJ/hr. [4]
- Quantify all energy losses in MJ/hr and as percentages of total input. [5]
- Determine the thermal efficiency of the furnace. [3]

QUESTION 2

- a) Discuss three environmental advantages and three challenges of using nuclear energy in metallurgical processes. [6]
- b) Discuss the importance of environmental impact assessment (EIA) in metallurgical engineering projects. [6]
- c) A mineral processing plant has the following electrical equipment:

Equipment	Power Rating (W)
Induction Furnace	5000
Muffle Furnace	3000
Oven	2000
Lights	500
Jaw Crusher	8000
Ball Mill/Rod Mill	7000
Pulveriser	3500
Sieve Shaking Machine	1500

- i. Calculate the total power consumption in kW of the plant. [2]
- ii. Propose a suitable renewable energy system (solar/wind/hybrid) to supply 60% of this power requirement. Include system capacity and basic components. [6]
- iii. Estimate the annual energy cost savings if the plant reduces its energy consumption by 15%. Assume electricity costs \$0.12 per kWh and the plant operates 340 days per year, 24 hours per day. [4]

QUESTION 3

a) Define the following terms as used in the combustion of fuels:

- i. Excess air. [2]
- ii. Stoichiometric combustion. [2]
- iii. Waste heat recovery. [2]

b) A coal sample has the following composition (by mass): Carbon: 74%; Hydrogen: 5.2%; Oxygen: 8.4%; Nitrogen: 1.6%; Sulfur: 1.8% and Ash: 9.0%.

Standard conditions: 0°C, 1 atm; Standard molar volume of gas = 22.4 L/mol

Atomic masses: C=12, H=1, O=16, N=14, S=32

- i. Calculate the theoretical air required for complete combustion of this coal in kg air/kg coal. [4]
- ii. If the coal is burned with 25% excess air, calculate the actual air supplied per kg of coal. [3]
- iii. Calculate the volume of flue gas produced per kg of coal at standard conditions (0°C, 1 atm) when burning with 25% excess air. [6]
- iv. Determine the composition of the flue gas on a dry volumetric basis. [6]

QUESTION 4

a) Define the following terms as used in metallurgical engineering:

- i. Calorific value. [2]
- ii. Pyrometallurgy. [2]

b) Distinguish between coking coal and thermal coal, highlighting four key differences. [6]

c) A coal sample has the following elemental composition (by mass): Carbon 68%; Hydrogen 4.5%; Oxygen 9.2%; Sulfur 1.0%; Ash 8.0% and Moisture 8.0%.

Using Dulong's formula;

- i. Calculate the Gross Calorific Value (GCV) of this coal on an as-received basis. [4]
- ii. Calculate the Net Calorific Value (NCV) of this coal on an as-received basis. [3]
- iii. Calculate the Gross Calorific Value on a dry basis. [4]
- iv. Calculate the Gross Calorific Value on a dry ash-free basis. [4]

QUESTION 5

a) State two environmental concerns associated with burning fossil fuels and propose one mitigation measure for each concern. [6]

b) Define the term "air pollution cycle" and explain its three distinct stages. [7]

c) A lead smelter emits 250 m³/min of exhaust gas containing:

Lead (Pb): 15 mg/m³

Sulfur dioxide (SO₂): 500 ppm (1,310 mg/m³)

Particulate matter (PM): 100 mg/m³

Given:

Regulatory limits: Pb = 0.5 mg/m³, SO₂ = 50 ppm, PM = 30 mg/m³

Operating hours: 24 h/day, 330 days/year

SO₂ density at STP = 2.86 kg/m³

- i. Calculate the annual emissions (kg/year) of each pollutant. [6]
- ii. Determine the percentage reduction required for each pollutant to meet regulatory standards. [6]

QUESTION 6

a) List three advantages of biological methods over chemical methods for treating metallurgical effluents. [3]

b) Describe the principle of operation of electrostatic precipitators (ESPs) and list three factors that affect their collection efficiency. [5]

c) A metallurgical plant uses a fabric filter (baghouse) to control particulate emissions. Calculate the required filter area if the gas flow rate is 75,000 m³/hr and the recommended air-to-cloth ratio is 1.25 m/min. [3]

d) A zinc smelter plans to replace 20% of its fossil fuel energy with solar thermal energy. The plant currently consumes 50,000 MWh/year of coal (CV: 24 MJ/kg).

- i. Calculate the annual coal savings (in tonnes/year) if solar thermal energy replaces 20% of coal use. [4]
- ii. If the solar thermal system has an efficiency of 35%, determine the required solar collector area (in m²) assuming an average solar irradiance of 5 kWh/m²/day. [6]
- iii. Discuss two challenges of implementing solar thermal energy in metallurgical plants. [4]

END OF QUESTION PAPER