Solid –Waste Management and Control:
A Case Study of Abu Wiledat Area, Omdurman Locality, Khartoum State, Sudan

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Date: July, 2015
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Date of examination: 14.7. 2015
الآية

بسم الله الرحمن الرحيم

قال تعالى:

«اقرأ باسم ربك الذي خلق (1) خلق الإنسان من علق (2) اقرأ و ربك الأكرم (3) الذي علم بالقلم (4) علم الإنسان ما لم يعلم»

صدق الله العظيم

سورة العلق، الآيات (1) – (5)»
DEDICATION

To My Parents…
To My brothers…
To My Family…
And to My friends
ACKNOWLEDGEMENT

Above all, I render my thanks to the merciful "Allah" how offered me health and patience to accomplish this study.

I would like to express my very grate appreciation to my research supervisor Prof. Gurashi A. Gasmelseed for this valuable and constructive suggestion during the planning and development of this research.

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Last but not least, thanks go to everyone, who contributed to this work.
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ABSTRACT

In Khartoum state the conditions are worst and threatening due to lack of fund to provide collection and of making treatment possible. In some areas, but not regularly, the collection of domestic and industrial wastes are made and transferred to a dumpster in west Omdurman. In west Omdurman at Abo wilaidat area, the waste is collected, sorted and directed to landfilling in cells. Part of the organic solid wastes was composted aerobically to fertilizer of 1.72% nitrogen, 2.6 phosphate and 1.75 potassium. A control design strategy was made for the release of natural gas (CH$_4$) as well as means for collection of the leachlate, these were $K_C$, $\tau_1$ and $\tau_D$ for loop 1, 2 and 3 respectively. There is always the danger to pollute the underground water and there should be at least two wells to check and make sure that the ground water is not contaminated. In this research work the aim is to design a proper dumpster for solid waste and to utilize the natural gas for electricity generation as well as production of fertilizer. A complete control system for the dumpster was designed and checked for stability, tuning and response upon disturbances, the tuning parameters for loop 1 were found to be 17.1, 2.9 and 0.725 for a PID controller. The same were calculated for loop 2 and loop 3 which were 6.7, 0.75, 0.19 and 1.32, 2.25, 0.56 respectively. It is recommended that dumpster should be far from agricultural, animal feeding and residential areas.
الإدارة و التحكم في النفايات الصلبة:
دراسة حالة منطقة أبو وليدات، محلية أمدرمان، ولاية الخرطوم، السودان
زينب عبدالرحمن العوض محمد على
درجة الماجستير في الهندسة الكيميائية
قسم الكيمياء التطبيقية و تكنولوجيا الكيمياء
كلية الهندسة و التكنولوجيا
جامعة الجزيرة

الملخص

في ولاية الخرطوم الوضع أسوأ و يشكل تهديد بسبب عدم وجود حاويات لتجمع ومعالجة النفايات.
في بعض المناطق يتم تجميع ونقل النفايات ومخلفات المصانع الى مكبات غرب أم درمان منطقة
أبو ولدات حيث تؤخذ النفايات الى مكباتها النهائية بعد أن تجمع وتصنف لكن بعض النفايات
العضوية الصلبة تتحول الى أملاح عضوية بصورة تلقائية تحتوي 1.72% نتروجين و 2.6% سفارات
و 1.75% بونتاسيوم . تم انشاء بعض التصاميم الاستراتيجية للتحكم في تحرير الغاز
الطبيعي (CH4). كما ان تجميع النفايات وتصنيفها يكون في حلقات هي
Kcτdτi على التوالي. هناك
دائما خطر تلوث المياه الجوفية لذلك يجب أن يكون هناك فحص لمياه الآبار على أقل تقدير
من الآبار للتأكد من صلاحية مياهها. يهدف هذا العمل البحثي إلى انشاء مكبات مثالية
الصلبة واستغلال الغاز الطبيعي في توليد الكهرباء بالإضافة الى انتاج السماد. قد أنشئ نظام تحكم
متكامل لمكبات النفايات و تم فحصه للتأكد من استقراره و مقاومته و استجابةه لكل طائرة 
العوامل المتغيرة للحلقة الأولى ضبطت لتكون 17.1 و 2.9 , 0.725 للPID للتحكم.
الحلقة الثانية والتي كانت 6.7 , 0.75, 0.19 و 1.32 , 2.25 , 0.56 على التوالي.
وتوصى أن تكون أماكن تجميع القمامه بعيدة من الأراضي الزراعية و المراعي و المناطق السكنية.

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## Nomenclature

<table>
<thead>
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<tr>
<td>A</td>
<td>The tank area ((m^2)).</td>
</tr>
<tr>
<td>a</td>
<td>Acceleration ((m^2)).</td>
</tr>
<tr>
<td>(B_{(S)})</td>
<td>Primary feedback signal.</td>
</tr>
<tr>
<td>(C_{(S)})</td>
<td>Laplace transform of controlled output.</td>
</tr>
<tr>
<td>C(dx/dt)</td>
<td>Frictional force exerted upward and resulting from the close contact of the stem with valve packing, (C) in the friction coefficient between stem and packing apply Newton.</td>
</tr>
<tr>
<td>(E_{(S)})</td>
<td>Actuating or error signal.</td>
</tr>
<tr>
<td>F</td>
<td>Force((Newton)).</td>
</tr>
<tr>
<td>H</td>
<td>The tank deep ((m)).</td>
</tr>
<tr>
<td>(H_{(S)})</td>
<td>Product of all transfer functions along the feedback path.</td>
</tr>
<tr>
<td>(g_c)</td>
<td>Conversion constant needed.</td>
</tr>
<tr>
<td>(G_c)</td>
<td>The controller transfer function.</td>
</tr>
<tr>
<td>(G_m)</td>
<td>The Sensor transfer function.</td>
</tr>
<tr>
<td>(G_{overall})</td>
<td>The overall transfer function.</td>
</tr>
<tr>
<td>(G_p)</td>
<td>Process transfer function.</td>
</tr>
<tr>
<td>(G_{(s)})</td>
<td>Product of all transfer function along the forward path.</td>
</tr>
<tr>
<td>(G_v)</td>
<td>The valve Transfer function.</td>
</tr>
<tr>
<td>(K_d)</td>
<td>The derivative controller gain.</td>
</tr>
<tr>
<td>(K_i)</td>
<td>The integral controller gain.</td>
</tr>
<tr>
<td>(K_m)</td>
<td>The Sensor gain.</td>
</tr>
<tr>
<td>(K_p)</td>
<td>The proportional controller gain.</td>
</tr>
<tr>
<td>(K_u)</td>
<td>Ultimate gain.</td>
</tr>
<tr>
<td>M</td>
<td>Mass ((kg)).</td>
</tr>
<tr>
<td>PA</td>
<td>PA force exerted be the compressed air at the top of the diaphragm, (P=) pressure is the signal that opens or closes the valve and (A) is the area of the diaphragm, this force acts downward.</td>
</tr>
</tbody>
</table>
\( p_u \)  
Ultimate period.

\( q_t \)  
Volumetric flow rate into a system at time \( t \).

\( q_0(t) \)  
Volumetric flow rate out of a system at time \( t \).

\( Q(s) \)  
Process output.

\( R \)  
Resistance of flow.

\( R(s) \)  
Laplace transform of reference input \( r(t) \).

\( \tau \)  
Time constant.

\( \tau_d \)  
The deviation time.

\( \tau_i \)  
The integration time.

\( U(s) \)  
Control action.

\( P \)  
Density assumed to constant (kg/m\(^3\)).

\( \otimes \)  
Summing point symbol.
### List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>P</td>
<td>The proportional controller</td>
</tr>
<tr>
<td>PI</td>
<td>The proportional Integral controller</td>
</tr>
<tr>
<td>PID</td>
<td>The proportional Integral derivative controller</td>
</tr>
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</table>
Chapter One

Introduction
Chapter One

Introduction

1.1 Preface

Improper solid waste disposal poses a major threat to the environment and high risks to human health. Most of these wastes are biodegradable and can be converted into valuable resources that reduce their otherwise negative impact. There are many ways to convert solid wastes into a valuable resource, such as organic fertilizer and its subsequent utilization as source of plant nutrients in intensive small-scale organic-based vegetable production and for sustaining soil health and productivity. Generally, the research aimed to promote proper waste management via organic fertilizer production. It aims to develop and apply technology on solid waste composting for the production of organic fertilizer.

Waste generation and subsequent accumulation generated by unabating increase in human populations is one of the major problems confronting future generations. This is aggravated by improper waste disposal that often causes greater problems in terms of environmental pollution and disease occurrence, not only to human beings but also to animals[1].

1.2 Solid Wastes

Waste (also known as rubbish, trash, refuse, garbage, junk and litter) is unwanted or useless materials.

Waste is directly linked to human development, both technological and social. The compositions of different wastes have varied over time and locations; will industrial development and innovation being directly linked to waste materials. Examples of this include plastic and unclear technology. Some waste components have economic value and can be recycled once correctly recovered. Waste is sometimes a subjective concept, because items that some people discard may have valuable resources, whilst there is debate as to how this value is best realized[1].

Domestic and industrial solid wastes are generated and continue to generate significant amounts of solid wastes that require ultimate disposal' In fact the treatment of solid wastes produces residual wastes that require treatment as well.
Solid wastes landfills are ground units constructed to contain the solid wastes for indefinite periods while minimizing the release of contaminates to the environment.

Continuous increasing regulations and technological advances during the last two decades have resulted in improved land fill design and operation of solid waste[4]

1.3 Problem statement

- Large volume of solid waste generation.

- Environmental degradation, waste disposal, and need for biofuel.

1.4 Strategies

- Waste segregation and collection.

- Biocomposting of biodegradable wastes for the production of organic biogas and fertilizer.

- Control strategy and system analysis.

1.5 Expected Outputs

- Ecologically improved/better environment.

- Efficient biocomposting technology.

- Control system, control analysis of solid-waste treatment plant[3].

1.6 Objectives

• To develop an efficient method of solid waste collection

• To develop method of proper treatment of solid wastes.

• Production of biogas and fertilizer from solid wastes.

• To design an efficient unit for solid wastes treatment, management and control.
Chapter Two

Literature Review
Chapter Two
Literature Review

2.1 Waste management

Is the collection, processing or disposal, managing and monitoring of waste materials, the term usually relates to materials produced by human activity, and the process is generally undertaken to reduce their effect on health, the environment or aesthetics. Waste management is a distinct practice from resource recovery which focuses on delaying the rate of consumption of natural resources. The management of wastes treats all materials as a single class, whether solid, liquid, gaseous or radioactive substance, and tried to reduce the harmful environmental impacts of each through different methods.

Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial producers. Management for non-hazardous waste residential and institutional waste in metropolitan areas is usually the responsibility of local government authorities, while management for non-hazardous commercial and industrial waste is usually the responsibility of the generator[1].

2.2 Solid wastes

Intended household solid waste residues from homes, restaurants, hotels and other. These wastes are substances such as well–known food, paper, glass, plastic and etc...... In addition to the solid wastes house hold solid waste and industrial components are similar to household solid waste. Components can be collected, transported and processed with household solid waste without that pose a threat to public health and safety. The amount of household solid waste from one place to another depending on the population density and high standard of living and environmental awareness and season of the year, as often reach a maximum amount of waste in summer, when a lot of vegetables, fruits and etc. And generally do not constitute solid waste household practical problems as it can be collected and transported and processed very efficiently, and do not cause damage to public health and safety. This should get rid of household solid waste quickly and the presence of the organic materials decomposes quickly, and escalates bad smell, and cause the breeding of insects and rodents.

Most cities of the world bury most of household waste in special zones. Although a little part of them are burned incinerators suitable. The presence of contaminated plastic,
metals and other toxic substances in the waste buried happen environmental problem, but landfill sites and incinerators in most cities are tightly controlled by the health authorities, and are designed to how to make the degree of odors at an acceptable level. At present, due to increase in the cost of reclamation and the lack of spaces, should reduce waste through recycling treatment or incineration for energy[1].

Plans have been developed on a large scale to separate garbage and recycling or composting in most European cities, but in the future, half of garbage burned or converted to liquid fuel or gaseous fuel. The energy recovery from solid waste is an option fan of big cities, and that the lack of space for the bridge and the high cost of garbage, technology burning solid waste was tested and examined in both Europe and Japan, and also equipped wide networks for garbage collection and transfer in most large cities to ensure feed continuous incinerators waste as there in about 350 Holocaust constantly working at the present time in various parts of the world. In Switzerland and Japan, 8% of solid waste treated in this way. There are a number of industrialized countries burning waste burning waste is one of the important steps in the reheat. The heat produced by burning used in heating and electric power generation. The ash can be used in the construction and building. And dust emissions are monitored, and acids, minerals, and organic matter from ancient and modern incinerators good control in most of the world's big cities.

The burning of the solid waste in several areas British exploited for the purpose of production of thermal energy for multi-storey buildings and some public buildings, including stores owned by ordinary people[2].

present there are several plants recycling of solid waste in a manner the mechanical separation of materials of non-burning such as metal, glass, then forwards the remaining organic material to produce fuel systems. The process of extracting fuel from waste is easier than complex mechanical separation process, and is also used ash as a burned with coal for power generation. Have led strict laws and regulations set by some European countries regarding waste incinerators to reduce the use of this methods[18].

Waste generation and subsequent accumulation generated by unabating increase in human populations is one of the major problems confronting future generations. This is aggravated by improper waste disposal that often cause greater problems in terms of environmental pollution and disease occurrence not only to human beings but also to animals. The Central Luzon State University as a leading institution of higher learning is
not spared from this scenario particularly as it houses more than 8,000 people notwithstanding the huge area for agriculture production that produces large volumes of farm wastes. Results of our initial survey on waste generation in the campus indicated that an individual generates an average of 500-600 g of waste in one day. The volume of waste collected in one month is approximately 200 m³. The composition of waste, collected particularly in the dormitories, is about 40 to 60% biodegradable, the rest is non-biodegradable mostly plastic, foils, wrappers, Styrofoam, bottles and cans. Considering this huge volume, something has to be done to convert these wastes into a resource. Based on one of the guiding principles of solid waste management, Waste is a resource, waste recycling can alleviate the problem of solid waste management[18].

On the other hand, the agriculture sectors deemed unsustainable by various studies as the main focus of the current development agenda is feeding the ever-expanding population; it loses sight of the negative environmental consequences it creates, particularly on soil health. Land use is optimized through technologies and management practices that fall short of requirements for sustainability. This is because the current practice in agriculture is basically chemical-based farming that makes a considerable contribution to the degradation of our natural resources, particularly soils. Heavy application of fertilizers has polluted surface and groundwater resources. The high nutrient contents in water body surfaces generate algal blooms and red tide outbreaks as observed in Manila bay and other parts of the country. Intensive cropping to feed the ever-expanding population coupled with high erosion rates in the uplands has resulted in severe soil nutrient depletion. In fact about 13.5 million hectares or 45% of the total arable lands in the Philippines is affected by soil erosion and about 12 million hectares or 40.8% of the total land area is affected by severe low fertility. The most common deficient nutrients are nitrogen, phosphorus, potassium, sulphur and zinc. There is an urgent need to find ways and means to alleviate such problems. Nowadays, organic-based agriculture production is a rapidly emerging technology in the Philippines, which partly solves waste disposal problems through conversion of biodegradable wastes into organic compost; this ensures the availability of organic fertilizer for crop production. In addition, organic-based vegetables because of reduced chemical application at any given time of the year. It likewise contributes to rehabilitating and sustaining the fertility of our croplands that have been degraded or are in danger of degradation due to intensive crop production and improper soil management practices[4].
2.3 Characteristics of the organic fertilizer produced

The composted product was analyzed for N, P, K, Zn, Cu and Cd. The compost leachate was analyzed for nitrate and ammoniacal N, P, K, PH and microbial counts as . The organic fertilizer produced contain an average of 2.0% N, 2.60% P, 1.75% K and 196 ppm Zn while the leachate contained 100 ppmNO₃–N, 770 ppmNH₄-N, 60 ppm K and P was traces while the PH was 7.4. The microbial population was determined by counting the number of colony-forming units per ml of sample using the serial dilution technique; it shows that the leachate has 4.*10⁴ cfu/ml for bacteria and 1.0 *10² cfu/ml for fungi . It was noted that bacteria are more abundant than fungi..

Landfill and incineration have until now been the most widely used means of solid waste disposal throughout the world, the land filling of biodegradable waste is proven to contribute to environmental degradation, mainly through the production of highly polluting leachate and methane gas. Methane constitutes one of the six greenhouse gases responsible for the global warming, which needs to be reduced, in order to tackle climate change under the Kyoto Protocol (UN,1998). The methane emissions from landfills constitute about 30% of the globalanthropogenic emissions of methane to atmosphere. The problems are like hundreds of tones biodegradable organic waste are being generated in cities and towns in the countries and creating disposal problems. Such as every day, grocery stores discard perishable products such as fruits, vegetables, bread, pastries, milk products, fish, seafood and other frozen products. The concept of recycling waste nutrients and organic matter back to agricultural land is feasible and desirable. Land application represents a cost effective outlet for the producers of compostable wastes and a potential cheap source of organic matter and fertilizer elements for landowners. Composting is one of the most promising technologies to treat wastes in a more economical way, for many centuries composting has been used as a means of recycling organic matter back into the soil to improve soil structure and fertility[2].

Composting is a natural process that turns organic material into a dark rich substance, this substance called compost is a wonderful conditioner for soil, during composting microorganisms such as bacteria and fungi break down complex organic. Compounds into simpler substances and produce carbon dioxide, water, minerals and stabilized organic matter (compost). The process produces heat, which can destroy pathogens (disease causing microorganisms) and weed seeds[3].
2.4 Compost application to agricultural soil

Compost helps to optimize nutrient management and the land application of compost may contribute to compact soil organic matter decline and soil erosion. Compost land application completes a circle where by nutrients and organic matter which have been removed in the harvested produce are replaced. The recycling of compost to land is considered as way of maintaining or restoring the quality of soils, mainly because of the fertilizing or improving properties of the organic matter contained in them. Furthermore, it may contribute to the carbon sequestration and may partially replace peat and fertilizers. Compost application to agricultural land needs to be carried out in a manner that ensures sustainable development. Management systems have to be developed to enable to maximize agronomics benefit, whilst ensuring the protection of environmental quality. The main determinant for efficient agronomics use is nitrogen availability, high nitrogen utilization in agriculture from mineral fertilizers is well established and understood, where is increasing the nitrogen use efficiency of organic fertilizers requires further investigation[4].

2.5 The composting process

Composting of agricultural waste and municipal solid waste has a long history and is commonly employed to recycle organic matter back into the soil to maintain soil fertility. The recent increased interest in composting however has arisen because of the need for environmentally sound waste treatment technologies. Composting is seen as an environmentally acceptable method of waste treatment. It is an aerobic biological process which uses naturally occurring microorganisms to convert biodegradable organic matter into a humus like product. The process destroys pathogens, converts N from unstable ammonia to stable organic forms, reduces the volume of waste and improves the nature of the waste. It also makes waste easier to handle and transport and often allows for higher application rates because of the more stable, slow release, nature of the N in compost. The effectiveness of the composting process is influenced by factors such as temperature, oxygen supply (aeration) and moisture content. There are two fundamental types of composting aerobic and anaerobic[18]
2.5.1 Aerobic

Composting is the decomposition of organic wastes in the presence of oxygen (air); products from this process include CO₂, NH₃, water and heat. This can be used to treat any type of organic waste but, effective composting requires the right blend of ingredients and conditions. These include moisture contents of around 60-70% and carbon to nitrogen ratios (C/N) of 30/1. Any significant variation inhibits the degradation process. Generally wood and paper provide a significant source of carbon while sewage sludge and food waste provide nitrogen. To ensure an adequate supply of oxygen throughout, ventilation of the waste, either forced or passive is essential[18].

2.5.2 Anaerobic

Composting is the decomposition of organic wastes in the absence of O₂, the products being methane (CH₄), CO₂, NH₃ and trace amounts of other gases and organic acids. Anaerobic composting was traditionally used to compost animal manure and human sewage sludge, but recently is has become more common for some municipal solid waste (MSW) and green waste to be treated in this way[18].

2.6 Process description

- Collection of raw materials (leaf litter, farm waste, household and market waste, buffalo or goat manure, carbonized rice hull).
- Mixing of the materials at a ratio of 2:1:1 (2 solid waste [household, farm, market]: 1 buffalo, chicken or goat manure:1 carbonized rice hull).
- The materials have to be moisten and shred to reduce the size and to enhance the decomposition process.
- The materials have to be piled at the height of 100-150 cm under shed and cover with plastic to increase the temperature, maintain moisture and minimized escape of gases to the atmosphere.
- The moisten of the material is to be maintain of 60% moisture in the pile. If the compost pile becomes dry, It is moistened using compost leachate or manure tea.
- After two weeks, It has to be open and turn thoroughly to facilitate uniform decomposition.
- The material is to be of another two weeks or more depending on the type of compost material. If most of the compost material is composed of leaf litter and/or rice straw, decomposition is prolonged from 30 days to 60 to 75 days.
- After another two weeks, the compost is already mature. Matured compost material that does not generating heat, has no smell of decomposing material and looks like soil. Harvest the composted material and spread on a flat floor in the drying area for at least a week or to a moisture level of 30%. Avoid sun drying the harvested composted material.
- The material is shredded and sieved using a 2 cm mesh prior to bagging.
- The composted material is packed using polyethylene plastic bags in a sack (50 kg/bag) and store in a cool dry place[2].

Fig (2.1) Solid-wastes treatment
Through reuse, recycling, and composting or managed by burying them in landfill or incinerating them most countries rely primarily on burial and incineration[1].

2.7 Sequence of priorities

2.7.1 Pollution preparation and waste reduction

As with solid waste, the top priority should be pollution prevention and waste reduction. With this approach, industries try to find substitutes for toxic or hazardous materials, reuse or recycle them within industrial processes, or use them as raw materials for making other products[8].

2.7.2 Produce less hazardous waste

- Change industrial processes to reduce or eliminate hazardous waste production.
- Recycle and reuse hazardous waste.

2.7.3 Convert less hazardous wastes

- Natural decomposition
- Incineration
- Thermal treatment

2.7.4 Perpetual storage

- Landfill
- Underground injection wells
- Surface impoundments
- Underground sail formations

2.8 Recycling

Tanneries produce a lot of solid wastes from spits, trims and sharings. These can be collected, ground and recycled into leather board.

2.8.1 Advantages of recycling

- Saves energy
- Reduces greenhouse gas emissions
- Reduces air and water pollution
• solid waste production and disposal
• Helps protect biodiversity
• Can save landfill space
• Important part of economy

2.8.2 Disadvantages of recycling

• Can cost more than burying in areas with ample landfill space
• May lose money for items such as glass and some plastics.
• Reduces profits for landfill and incinerator owners.
• Sources separation is inconvenient for some people[3].

2.9 Reuse

• Restaurants give take a way mails in disposal containers, while give it in no disposal containers that can reused again and a gain, this reducing the solid waste.
• Buy beverages in refillable glass containers instead of cans or throwaway bottles.
• Use reusable plastic or metal lunchbox.
• Carry sandwiches and store food in the refrigerator in reusable containers instead of wrapping them in aluminum foil or plastic wrap.
• Reuse involves cleaning and using materials over and over and thus increasing the typical life span of a product. This form of waste reduction decreases the use of matter and energy resources, cut pollution and waste, creates local jobs, and saves money.
• Reuse is alive and well in most developing countries, but it has a downside for some people. The poor who scavenge in open dumps for food scrap and items they can reuse or sell are often exposed to toxins and infectious diseases[2].

2.10 Incineration

Shows of the schematic diagram of incineration
2.10 Advantages of incineration

- Reduces trash volume
- Less need for landfills
- Low water pollution
- Concentrates hazardous substances into ash for burial
- Sale of energy reduces cost
- Modern controls reduce air pollution
- Some facilities recover and sell metals

2.10.2 Disadvantages of incineration

- Expensive to build
- Costs more than short–distance hauling to landfills
- Difficult to site because of citizen opposition
- Some air pollution and CO₂ CO₂ emissions
- Older or poorly managed facilities can release large amounts of air pollution
- Output approach that encourages waste production
- Can compete with recycling for burnable materials such as newspaper[7].
2.11 Cells construction

Excavation of cells of 5 to 6 meters in depth is to be made and divided into smaller cells to accommodate a compacted solid waste. Waste buried is typically covered with a 0.3m layer of clean compacted soil is placed over the waste layer. Leachate of liquids may be generated within the cells and diffuses by infiltration through the compacted solid which should have an appropriate permeability to prevent water accumulation within the cell. Perforated pipe below the cell liners are used to collect the biogas generated. The biogas has to be collected, pressure controlled, packed and sold[2].

2.12 Leachate collection system

Leachate collection system should be installed during the construction of the cells after compaction and before waste dumping.

2.13 Biogas collection

Biogas generated from the biodegrading of the waste inside the land fill, the daily compaction of the waste will enforce the waste to be diverted to the perforated pipe below the cell liners, then through these pipes will be collected outside the cell for flaring or electricity generation the gas collection system should be installed initially on the ground of the cells[19].
Chapter Three

Material and Methods
Chapter Three
Material and Methods

3.1 Introduction

This chapter contain brief information about the type of materials used in this research such as: sensors, controllers, valves, types of control, and a brief history about MATLAB software. Also the methods for determining the overall transfer function of the system and the stability tests, tuning the controllers and the overall system response.

3.2 Integrated waste management

The following processing sheet presented in fig. (3.1) shows how the solid wastes have to be managed.

![Integrated waste management diagram]

Fig (3.1) Integrated waste management
Wastes are reduced through reuse, recycling, and composting or managed by burying them in landfill or incinerating them most countries rely primarily on burial and incineration[1].

3.3 Sensors and measuring devices

The successful operation of any feedback control system depends in a very critical manner. There are different commercial measuring devices which differ either in the basic measuring principle or in their construction characteristics [8].

A sensor is a device that measures and converts a physical quantity into a signal which can be observed and recorded by a property instrument[13].

3.4 Definition of control error

Steady-state control error is defined as the difference between the input and output of the system as time goes to infinity (i.e when the response has reached the steady state). Generally, the steady-state control error depends on the type of input (step, ramp, etc) as well as on the system type (0, I or II) [10].

3.5 Definition of controller

A controller is a device possibly in the form of a chip, analogue electronics, or computer which monitors and physically alters the operating conditions of a given dynamical system[14].
### Table (3.1) Typical Measuring Devices for process control

<table>
<thead>
<tr>
<th>Process variable</th>
<th>Measuring devices</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Manometers</td>
<td>With floats or displaces</td>
</tr>
<tr>
<td></td>
<td>Bourdon-tube elements</td>
<td>Based on the elastic deformation of materials</td>
</tr>
<tr>
<td></td>
<td>Bellows elements</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diaphragm elements</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strain gases</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Piezoresistivity elements</td>
<td>Used to convert pressure to electrical</td>
</tr>
<tr>
<td></td>
<td>Piezoelectric elements</td>
<td></td>
</tr>
<tr>
<td>Liquid level</td>
<td>Float-actnated devices</td>
<td>Couple with various types of indicators and signal converters</td>
</tr>
<tr>
<td></td>
<td>Displacer devices</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liquid head pressure devices</td>
<td>Good for systems with two phases</td>
</tr>
<tr>
<td></td>
<td>Conductivity measurement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dielectric measurement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sonic resonance</td>
<td></td>
</tr>
<tr>
<td>Composition</td>
<td>Infrared analyzers</td>
<td>Long times required for analyzers</td>
</tr>
<tr>
<td></td>
<td>Ultraviolet analyzers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visible-radiation analyzers</td>
<td>Convenient for one or two chemicals</td>
</tr>
<tr>
<td></td>
<td>Turbidimetry analyzers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paramagnetism analyzers</td>
<td>Not very convenient for process control</td>
</tr>
<tr>
<td></td>
<td>Nephelometry analyzers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potentiometry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conductimetry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oscillometry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PH meters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polarographic analyzers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coulometers spectorometers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(x-ray, electron, ion, Mossbaner, Raman)</td>
<td>Expensive for low-cost control loops</td>
</tr>
<tr>
<td></td>
<td>Differential thermal analyzers</td>
<td></td>
</tr>
</tbody>
</table>

(Source: D. Grimes; 2006[9])

#### 3.6 Type of controllers

Process control is the measurement of a process variable, the comparison of that variables with its respective set point, and the manipulation of the process in a way that will hold the variable at its set point when the set point changes or when a disturbance changes the process[15].
One way to improve the step response of a control system is to add a controller to the feedback control system, the closed-loop systems can be controlled by Proportional (P) control, Proportional Integral (PI) control and Proportional plus Integral plus Derivative (PID) control.

3.6.1 Proportional control

The proportional action is responds quickly to changes in error deviation. However the proportion controller does not guarantee a zero steady-state control error. The proportional controller is consider to be simple controller which is the best and can be used when nonzero steady-state error is acceptable or if the controlled system contains pure integrator generally, it used in pressure control or level control[2].

3.6.2 Proportional integral (PI) control

The reset (or integral) contribution from a more mathematical point of view, at any time the rate of change of the output is the gain time the reset rate times the error. If the error is zero the output does not change; if the error is the positive the output increases[16].

3.6.3 Proportional plus integral plus derivative (PID) control

The PID control algorithm is the made of three basic response, Proportional (or gain), integral (or reset), and derivative[16].

Derivative is the third and final element of PID control. Derivative responds to the rate of change of the process (or error). Derivative is the normally applied to the process only.

Analog PID controllers are common in many applications. They can be easily constructed using analog devices such as operational amplifiers, capacitors and resistors. They are reliable in mechanical feedback systems, and able to satisfy many control problems.

3.6.4 Selection of the controller transfer function

In this work P, PI and PID will selected and install in the control loop, encl at a time. The controller will be tuned, the will be analized and the process will be simulated.
3.6.5 Final control elements

Each process control loop contains a final control element(s) which is a hardware component to implement the control action and enables the process variables to be manipulated[11].

For most chemical and petroleum process, the final control elements which are usually control valves used to directly adjust the flow rate. The control valves are also used to indirectly control of the rates of energy transfer to and from the process.

3.7 Control system block diagram and system identification

3.7.1 Flow sheet of the procedure

This chart describes the overall methodology

![Flow diagram of research methodology](image-url)

Figure (3.2) Flow diagram of research methodology
3.7.2 Transfer function representation

System has extremely important property that if the input to the system is sinusoidal, then the output will also be sinusoidal at the same frequency but in general with different magnitude and phase. These magnitude and phase differences as a function of frequency are known as the frequency response of the system.

3.7.3 The recycling System

In the recycling system each process liquid waste will be treated separately. The recycling system for every process will be level controlled.

3.8 Closed loop overall transfer function the recycling system

![Diagram](image)

Figure(3.3) Overall transfer function of the recycling system

3.8.1 Process transfer function \((G_P)\)

The law of conservation of mass:

[Mass flow in to s system]-[mass flow out of a system]=[mass accumulation within the system]

\[q_{t}p - q_{o}(t)p = v*p \] \[\text{………………………………………………..(3.1)}\]

\[V = A*h\]

\[q_{t} - q_{(0t)} = A * \frac{dh}{dt} \] \[\text{………………………………………………..(3.2)}\]

\[q_{(0)} = \frac{h}{R} \] \[\text{………………………………………………..(3.3)}\]
For laminar flow

\[ q_t = A \ast \frac{\delta h}{\delta t} + \frac{h}{R} \]  

(3.4)

\( A \): The tank area

\( q_t \): Volumetric flow rate into a system at time \( t \).

\[ R \ast A = \tau \]  

(3.5)

\[ \tau \ast \delta h/\delta t + h = q_t \]  

(3.6)

\( \tau \): volume hold up/volumetric flow rate.

Laplace transformation

\[ S \ast H(S) + H(S) = R \ast Q(S) \]  

(3.7)

The process transfer function is developed:

Transfer function = input/output = \( H(S)/Q(S) = R/\tau \)  

(3.8)

3.8.2 The Sensor transfer function (\( G_m \))

The sensor transfer function can take as first or second order

First order

\[ G_m = \frac{km}{\tau s + 1} \]  

(3.9)

The sensor is too fast and the time constant is small but it has a dead time of transfer function \( e^{-Ds} \) and can be neglected.

\[ G_m = \frac{km}{\tau s + 1} = \frac{1}{\tau s + 1} \]  

(3.10)

Second order

\[ G_m = \frac{km}{\tau s + 1 + 2\epsilon \tau s + 1} \]  

(3.11)

3.8.3 The controller transfer function (\( G_c \))

P, PI, PD and PID will selected and install in the control loop, encl at a time. The controller will be tuned, the stability will be analyzed and the process will be simulated.
The proportional controller transfer function is

\[ G_{m} \left( \frac{U_{S}}{E_{S}} \right) = K_{p} \]  \hspace{3cm} (3.12)

The proportional integral controller transfer function is

\[ G_{m} \left( \frac{U_{S}}{E_{S}} \right) = Ki/\tau \]  \hspace{3cm} (3.13)

The proportional integral derivative controller transfer function is

\[ G_{s} = K_{p} + \frac{Ki}{\tau_{s}} + K_{d} \tau_{d}s \]  \hspace{3cm} (3.14)

3.8.4 The valve transfer function \((G_v)\)

Newton's second law of motion says that force is equal to mass times acceleration for a system with constant mass \(M\).

\[ F = \frac{M \times a}{g_{c}} \]  \hspace{3cm} (3.15)

The valve motion was calculated by:

\[ PA - KX - C \frac{dx}{dt} = \left( \frac{M}{g_{c}} \right) \frac{d^{2}x}{dt^{2}} \]  \hspace{3cm} (3.16)

\[ \frac{A}{K} = \left( \frac{M}{K \times g_{c}} \right) \frac{d^{2}x}{dt^{2}} + \frac{C}{K} \frac{dx}{dt} + X \]  \hspace{3cm} (3.17)

\[ K_{p}P = \tau^{2} \frac{d^{2}x}{dt^{2}} + 2\varepsilon \tau \frac{dx}{dt} + X \]  \hspace{3cm} (3.18)

\[ \tau^{2}s^{2} + 2\varepsilon \tau s + 1 = p_{s} \]  \hspace{3cm} (3.19)

\[ X_{S} = \frac{A}{K} = K_{v} = 1 \]  \hspace{3cm} (3.20)

\[ 2\varepsilon \tau = \frac{C}{K} \]  \hspace{3cm} (3.21)

\[ \tau = \frac{M}{K \times g_{c}} = \frac{A_{p} \times l \times \rho}{K \times g_{c}} \]  \hspace{3cm} (3.22)
\[
\frac{X_S}{P_S} = \frac{K_V}{\tau^2 s^2 + 2\varepsilon \tau s + 1}
\]  \hspace{1cm} \text{(3.23)}

\[
G_V = \frac{1}{\tau^2 s^2 + 2\varepsilon \tau s + 1}
\]  \hspace{1cm} \text{(3.24)}

### 3.9 MATLAB

MATLAB (matrix laboratory) is a high-level scientific and engineering computing programming language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. This has an extensive library of built-in functions for data manipulation. It is widely used in universities and research labs around the world. By using the MATLAB product, solving of technical computing problems is faster than with traditional programming languages, such as c, c++, and Fortran.

MATLAB is used in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas. MATLAB provides a number of features for documenting and sharing person work[12].

### 3.10 System Stability and tuning

Mathematical models of a system have been obtained in transfer function form, and then these models can be analyzed to predict how the system will respond in both the time and frequency domains.

#### 3.10.1 Stability test

System is stable if the output remains bounded for all bounded (finite) inputs. Practically, this means that the system will not "blow up" while in operation. The transfer function representation is especially useful when analyzing system stability.

If all poles of the transfer function (value of s at which the denominator equals zero) have negative real parts, then the system is stable. If any pole has a positive real part, then the system is unstable. On the complex s-plane, all poles must be in the left half plane.
to ensure stability. If any pair of poles is on the imaginary axis, then the system is
marginally stable and the system is will oscillate[6].

To ensure a good performance of the system, each of the control loops
Mentioned earlier should be analyzed for the stability. For the present work, four
methods have boon used to check the stability of the system. Such methods are:

- Routh Hurwitz
- Root-locus Plot
- Bode plot

3.10 .1.1 Routh-Hurwitz method

It used to determine the positions of the poles of the transfer function of the system
which effect the system's stability and play.

Taking the closed-loop system transfer function:

\[ H(s) = \frac{G(S)}{[1+G(S)C(S)]} \] .................................................................(3.25)

Characteristic equation =\[ 1 + G(S)C(S) \] ..........................................................(3.26)

\[ [1 + G(S)C(S)] = s^n a_n + s^{n-1} a_{n-1} + s^{n-2} a_{n-2} + \ldots + s a_1 + a_0. \] (3.27)

By using the Routh array, as follows:

\[ b_1 = \begin{bmatrix} a_n & a_{n-2} \\ a_{n-1} & a_{n-3} \end{bmatrix} \] .................................(3.28)

\[ b_2 = \begin{bmatrix} a_n & a_{n-4} \\ a_{n-1} & a_{n-5} \end{bmatrix} \] .................................(3.29)

\[ b_1 = \begin{bmatrix} a_{n-1} & a_{n-3} \\ b_1 & b_2 \end{bmatrix} \] .................................(3.30)

\[ b_1 = \begin{bmatrix} a_{n-1} & a_{n-5} \\ b_1 & b_3 \end{bmatrix} \] .................................(3.31)
Table (3.2) construction of Routh Array

<table>
<thead>
<tr>
<th>Row</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$S^n$</td>
</tr>
<tr>
<td></td>
<td>$a_n$</td>
</tr>
<tr>
<td></td>
<td>$a_{n-2}$</td>
</tr>
<tr>
<td></td>
<td>$a_{n-4}$</td>
</tr>
<tr>
<td></td>
<td>$a_{n-6}$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
<tr>
<td>2</td>
<td>$S^{n-1}$</td>
</tr>
<tr>
<td></td>
<td>$a_{n-1}$</td>
</tr>
<tr>
<td></td>
<td>$a_{n-3}$</td>
</tr>
<tr>
<td></td>
<td>$a_{n-5}$</td>
</tr>
<tr>
<td></td>
<td>$a_{n-7}$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
<tr>
<td>3</td>
<td>$S^{n-2}$</td>
</tr>
<tr>
<td></td>
<td>$b_1$</td>
</tr>
<tr>
<td></td>
<td>$b_2$</td>
</tr>
<tr>
<td></td>
<td>$b_3$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
<tr>
<td>4</td>
<td>$S^{n-3}$</td>
</tr>
<tr>
<td></td>
<td>$c_1$</td>
</tr>
<tr>
<td></td>
<td>$c_2$</td>
</tr>
<tr>
<td></td>
<td>$c_3$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
<tr>
<td>n-1</td>
<td>$S^2$</td>
</tr>
<tr>
<td></td>
<td>$h_1$</td>
</tr>
<tr>
<td></td>
<td>$h_2$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
<tr>
<td>N</td>
<td>$S^1$</td>
</tr>
<tr>
<td></td>
<td>$j_1$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
<tr>
<td>N+1</td>
<td>$S^1$</td>
</tr>
<tr>
<td></td>
<td>$K$</td>
</tr>
<tr>
<td></td>
<td>$\ldots$</td>
</tr>
</tbody>
</table>

(Source: Ogata, K. and Y. Yang; 1970[5])

Taking the first column of the Routh array if there is no sign changes then the system stable else the system is unstable. The number of roots of $p(s)$ with positive real part is equal to the number of sign changes.

3.10.1.2 The root locus plot

The root locus of an (open-loop) transfer function OLTF is a plot of the locations (locus) of all possible closed-loop poles with proportional gain $K$ and unity feedback therefore the root-locus is the locus of points where roots of characteristic equation can be found as a single gain is varied from zero to infinity.
Closed loop transfer function (CLTF) characteristic equation is equal to zero.

\[ \text{CLTF} = 1 + \text{OLTF} \] \hspace{1cm} (3.32)

\[ S = \omega i \] \hspace{1cm} (3.33)

But since:

\[ I = \sqrt{-1} \] \hspace{1cm} (3.33)

Then

\[ i^2 = -1 \] \hspace{1cm} (3.33)

\[ K_u = K_c \text{ at } AR = 1 \text{ and } \omega_{co} \] \hspace{1cm} (3.36)

\[ AR = \sqrt{\text{Re}^2 + \text{Im}^2} \] \hspace{1cm} (3.37)

The value of the frequency \( \omega_{co} \) which is taken from the Root locus plot used to calculate the limit gain and ultimate period \( (k_u \text{ and } p_u) \)

\[ p_u = \frac{2 \pi}{\omega_{co}} \] \hspace{1cm} (3.38)
3.10.1.3 Bode Plot

Bode plots two curves to be plotted instead of one. The two curves show how magnitude ratio and phase angle (argument) vary with frequency.

To find the Amplitude Ratio (AR)

\[
AR = \frac{K_1K_2 \cdots K_N}{\sqrt{1+(\omega_1)^2} \cdot \sqrt{1+(\omega_2)^2} \cdot \sqrt{1+(\omega_3)^2} \cdot \sqrt{1+(\omega_4)^2}} \tag{3.39}
\]

The value of the frequency \(\omega_{co}\) which take from the Bode plot used to calculate the limit gain and ultimate period (\(k_c\) and \(p_u\))

\[
p_u = \frac{2\pi}{\omega_{co}} \tag{3.40}
\]

3.10.2 Tuning of controllers

Tuning a control loop is the adjustment of its control parameters (proportional land/gain, integral gain/reset, derivative gain/rate) to the optimum values for the desired
control response [18]. According there are several methods for loop tuning these are: Manual tuning, Cohen-Coon and Ziegler-Nichols. The Ziegler-Nichols method is used in this work.

### 3.10.2.1 Zeigler-Nichols Tuning Method

The Zeigler-Nichols Tuning Method is based on both open and closed loop testing.

#### Table (3.3) Ziegler-Nichols adjustable parameters

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>$K_C$</th>
<th>$\tau_i$(min)</th>
<th>$\tau_d$(min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>$0.5k_u$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>$0.45k_u$</td>
<td>$\frac{p_u}{1.2}$</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>$0.6k_u$</td>
<td>$\frac{p_u}{2}$</td>
<td>$\frac{p_u}{8}$</td>
</tr>
</tbody>
</table>

### 3.10.3 Time Response

The time response represents how the state of a dynamic system changes in time when subjected to a particular input.

Since the models has been derived consist of differential equation, some integration must be performed in order to determine the time response of the system. Fortunately, MATLAB provides many useful resources for calculating time responses for many types of inputs.
Figure (3.6) Response plot
Chapter Four

Results and Discussion
Chapter Four

Results and Discussion

4.1 Introduction

In this chapter the result of chemical properties, constituents, control system of a solid waste treatment plant have been discussed and tested for stability, tuning and response.

4.2 Production of fertilizer

This is obtained by taking 30% of the organic waste, composted, ground, sieved and packed in bags.

Table (4.1) Analysis of the organic produced fertilizer

<table>
<thead>
<tr>
<th>Chemical properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO (%)</td>
<td>32.00</td>
</tr>
<tr>
<td>N(%)</td>
<td>1.72</td>
</tr>
<tr>
<td>P(%)</td>
<td>2.60</td>
</tr>
<tr>
<td>K(%)</td>
<td>1.75</td>
</tr>
<tr>
<td>Zn(ppm)</td>
<td>196</td>
</tr>
<tr>
<td>Cu(ppm)</td>
<td>45.50</td>
</tr>
<tr>
<td>Cd(ppm)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table (4.2) Analysis of compost leachate

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate N (NO$_3$ – N) (PPM)</td>
<td>100</td>
</tr>
<tr>
<td>Ammoniacal N(NH$_4$ – N) (ppm)</td>
<td>70</td>
</tr>
<tr>
<td>P(ppm)</td>
<td>Trace</td>
</tr>
<tr>
<td>K(ppm)</td>
<td>60</td>
</tr>
<tr>
<td>Ph</td>
<td>7.4</td>
</tr>
</tbody>
</table>

4.3 Control strategy

Fig (4.1) showed the physical diagram and control strategy
4.3 Control strategy

Fig (4.1) showed the physical diagram and control strategy
4.4 Control Loops

Three loops are proposed

4.5 loop 1

\[ G_c = K_c \]

Process T.F, \( G_p = \frac{1}{(s+1)(0.5s+1)} \)

Valve T. F, \( G_v = \frac{1}{15s+1} \)

Sensor T.F, \( G_m = \frac{1}{0.3s+1} \)

4.5.1 Block diagram for loop 1

[Diagram showing the block diagram for loop 1]

Figure (4.2) Block diagram for loop 1

4.5.2 System stability and tuning using direct substitution method

4.5.2.1 The overall TF

\[ G(S) = \frac{\pi F}{1 + \pi L} \] \hspace{1cm} \text{(4.1)}

\[ \pi_f = \frac{k_c}{(15s+1)(s+1)(0.5s+1)} \] \hspace{1cm} \text{(4.2)}
\[ l + p_l = \frac{k_c + (15s+1)(s+1)(0.5s+1)(0.3s+1)}{(15s+1)(s+1)(0.5s+1)(0.3s+1)} \] .................................(4.3)

\[ G(s) = \frac{k_c(0.3s+1)}{(15s+1)(s+1)(0.5s+1)(0.3s+1)+k_c} \] .................................(4.4)

The characteristic equation is:

\[ (15S+1)(S+1)(0.5S+2)(0.3S+1)+k_c=0 \] .................................(4.5)

\[ 2.25s^4 + 14.4s^3 + 27.95s^2 + 16.8s + (1 + k_c) = 0 \] .................................(4.6)

Set \( s=i\omega \)

\[ 2.25\omega^4 - 14.4i\omega^3 - 27.95\omega^2 + 16.8i\omega + (1 + k_c) = 0 \] .................................(4.7)

Taking the imaginary part

\[ 14.4\omega^3 = 16.8\omega \]

\[ \omega_{co} = 1.08 \text{ rad/sec} \] .................................(4.8)

Taking the real part

\[ 2.25\omega^4 - 27.95\omega^2 + (1 + k_c) = 0 \] .................................(4.9)

\[ 2.25(1.08)^4 - 27.95(1.08)^2 + (1 + k_c) = 0 \] .................................(4.10)

\[ k_c = 28.54 \]

\[ k_u = 28.54 \]

\[ p_u = \frac{2\pi}{\omega_{co}} = \frac{2\pi}{1.08} = 5.8 \text{ sec} \]

4.5.2.2 Determination of adjustable parameters

Table (4.3) Z–N tuning parameters of loop 1, direct substitution method

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>( K_c )</th>
<th>( \tau_i )</th>
<th>( \tau_D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>14.27</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>12.8</td>
<td>4.8</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>17.1</td>
<td>2.9</td>
<td>0.725</td>
</tr>
</tbody>
</table>
k_c = 14.27 substituting for the valve of k_c = 14.27 for P-action:

\[ 2.25s^4 + 14.4s^3 + 27.95s^2 + 16.8s + 15.27 = 0 \] .................................(4.11)

Checking stability using Routh:

\[
\begin{bmatrix}
2.25 & 27.95 & 15.27 \\
14.4  & 16.8 & 0 \\
25.3  & 15.27 & 0 \\
8.1   & 0 & 0 \\
-15.27 & 0 & 0 \\
\end{bmatrix}
\]

Data of the first column in Routh array:

\[
\begin{bmatrix}
2.25 \\
14.4 \\
25.3 \\
8.1 \\
-15.27 \\
\end{bmatrix}
\]

The system is stable, all elements of the first column were positive and there is no changes of sign

4.5.2.3 Impulse response of the system, direct substitution method

\[ G(S) = \frac{14.27}{(15s+1)(s+1)(0.5s+1)(0.3s+1)} \] .................................(4.12)
4.5.3 System stability and tuning using root-locus method

Open loop transfer function:

\[ G(s) = \frac{k_c}{(15s + 1)(s+1)(0.5s+1)(0.3s+1)} \]  \hspace{1cm} (4.13)
Figure (4.4) root-locus plot, for loop 1

\[ k_u = 29.4 \]

\[ \omega_{co} = 1.09 \text{ rad/sec} \]

\[ p_u = \frac{2\pi}{\omega_{co}} = \frac{2\pi}{1.09} = 5.76 \]

4.5.3.1 Determination of adjustable parameters

Table (4.4) Z – N tuning parameters of loop 1, root-locus method

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>( K_C )</th>
<th>( \tau_i )</th>
<th>( \tau_D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>14.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>13.23</td>
<td>4.8</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>17.64</td>
<td>2.88</td>
<td>0.72</td>
</tr>
</tbody>
</table>

\( k_c = 14.7 \) substituting for the valve of \( k_c = 14.7 \) for P-action:

\[ 2.25s^4 + 14.4s^3 + 27.95s^2 + 16.8s + 15.7 = 0 \] \hspace{1cm} \text{equation (4.14)}
Checking stability using Routh:
\[
\begin{bmatrix}
2.25 & 27.95 & 15.7 \\
14.4 & 16.8 & 0 \\
25.3 & 15.7 & 0 \\
7.86 & 0 & 0 \\
15.7 & 0 & 0
\end{bmatrix}
\]

Data of the first column in Routh array:
\[
\begin{bmatrix}
2.25 \\
14.4 \\
25.3 \\
7.86 \\
15.7
\end{bmatrix}
\]

The system is stable, all elements of the first column were positive and there is no changes of sign

4.5.3.2 Impulse response of the system, root- locus method

\[G(S) = \frac{14.7}{(15s+1)(s+1)(0.5s+1)(0.3s+1)}\] .................................(4.15)

![Impulse Response](image)

Figure (4.5) impulse response for loop1, root- locus method
4.5.4 System stability and tuning using Bode method

Open loop transfer function:

\[ G(s) = \frac{k_c}{(15s+1)(s+1)(0.5s+1)(0.3s+1)} \]  \hspace{1cm} (4.16)

\[ \omega_{co} = 1.09 \, \text{rad/sec} \]

AR = 1

\[ AR = \frac{K_1 K_2 \ldots \cdots K_N}{\sqrt{1 + (\omega_1)^2} \cdot \sqrt{1 + (\omega_2)^2} \cdot \sqrt{1 + (\omega_3)^2} \cdot \sqrt{1 + (\omega_4)^2}} \]  \hspace{1cm} (4.17)

\[ G(s) = \frac{k_c}{(15s+1)(s+1)(0.5s+1)(0.3s+1)} \]  \hspace{1cm} (4.18)

\[ AR = \frac{1}{\sqrt{1 + (15 \times 1.09)^2} \cdot \sqrt{1 + (1.09)^2} \cdot \sqrt{1 + (0.5 \times 1.09)^2} \cdot \sqrt{1 + (0.3 \times 1.09)^2}} \]

Figure (4.6) Bode plot for loop 1
\[ 1 = \frac{k_c}{29.4} \]

\[ k_c = 29.4 \]

\[ k_u = 29.4 \]

\[ p_u = \frac{2\pi}{\omega_{co}} = \frac{2\pi}{1.09} = 5.76 \]

4.5.4.1 Determination of adjustable parameters

Table (4.5) Z – N tuning parameters of loop 1, Bode method

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>( K_C )</th>
<th>( \tau_i(\text{min}) )</th>
<th>( \tau_D(\text{min}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>14.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>13.23</td>
<td>4.8</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>17.67</td>
<td>2.88</td>
<td>0.72</td>
</tr>
</tbody>
</table>

\( k_c = 14.7 \) substituting for the value of \( k_c = 14.7 \) for P-action

\[ 2.25s^4 + 14.4s^3 + 27.95s^2 + 16.8s + 15.7 = 0 \] .........................................................(4.19)

Checking stability using Routh:

\[
\begin{bmatrix}
2.25 & 27.95 & 15.7 \\
14.4 & 16.8 & 0 \\
25.3 & 15.7 & 0 \\
7.86 & 0 & 0 \\
15.57 & 0 & 0 \\
\end{bmatrix}
\]

Data of the first column in Routh array:

\[
\begin{bmatrix}
2.25 \\
14.4 \\
25.3 \\
7.86 \\
15.57 \\
\end{bmatrix}
\]

The system is stable, all elements of the first column were positive and there is no changes of sign
4.5.4.2 Impulse response of the system, Bode method

\[ G(s) = \frac{14.7}{(15s+1)(s+1)(0.5s+1)(0.3s+1)} \] ... (4.20)

4.6 loop 2

\[ G_c = K_c \]

Process T.F. \( G_p = \frac{1}{(0.3s+1)} \)

Valve T. F. \( G_v = \frac{1}{s+1} \)

Sensor T.F. \( G_m = \frac{1}{0.3s+1} \)
4.6.1 Block diagram for loop2

![Block diagram for loop2](image)

4.6.2 System stability and tuning using direct substitution method

4.6.2.1 The overall TF

\[ G(S) = \frac{\pi F}{1+\pi L} \] .............................(4.21)

\[ \pi F = \frac{k_c}{(s+1)(0.3s+1)} \] .............................(4.22)

\[ \pi l = \frac{k_c}{(s+1)(0.3s+1)(0.3s+1)} \] .............................(4.23)

\[ 1+\pi l = \frac{k_c+(s+1)(0.3s+1)(0.3s+1)}{(s+1)(0.3s+1)(0.3s+1)} \] .............................(4.24)

\[ G(s) = \frac{k_c(0.3s+1)}{(s+1)(0.3s+1)(0.3s+1)+k_c} \] .............................(4.25)

The characteristic equation is:

\[ (s+1)(0.3s+1)+k_c = 0 \] .............................(4.26)

\[ 0.09s^2+0.69s^2+1.6s+(1+k_c) = 0 \] .............................(4.27)
Set $s = i\omega$

$$-0.09i\omega^3 - 0.69\omega^2 + 1.6i\omega + (1 + k_c) = 0$$

(4.28)

Tacking the imaginary part:

$$0.09\omega^3 = 1.6\omega$$

$$\omega_{co} = 4.2 \frac{rad}{sec}$$

$$p_u = \frac{2\pi}{\omega_{co}}$$

(4.29)

$$p_u = \frac{2\pi}{4.2} = 1.5 \text{ sec}$$

Tacking the real part:

$$-0.69\omega^2 + (1 + k_c) = 0$$

(4.30)

$$1 + k_c = 0.69(4.2)^2$$

(4.31)

$$k_c = 11.17$$

4.6.2.2 Determination of adjustable parameters

Table (4.6) Z–N tuning parameters of loop 2, direct substitution method

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>$K_C$</th>
<th>$\tau_i$</th>
<th>$\tau_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>5.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>5</td>
<td>1.25</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>6.7</td>
<td>0.75</td>
<td>0.19</td>
</tr>
</tbody>
</table>

$k_c = 5.6$ substituting for the value of $k_c = 5.6$ for P-action:

$$0.09s^3 + 0.69s^2 + 1.6s + (1 + k_c) = 0$$

(4.32)

Checking stability using Routh:

$$\begin{bmatrix}
0.09 & 1.6 \\
0.69 & 6.6 \\
0.74 & 0 \\
6.6 & 0
\end{bmatrix}$$

Data of the first column in Routh array:
The system is stable, all elements of the first column were positive and there is no changes of sign.

4.6.2.3 Impulse response of the system, direct substitution method

\[ G(S) = \frac{5.6}{(s+1)(0.3s+1)(0.3s+1)} \] ………………………………………………………………(4.33)

Figure(4.9) Impulse response of loop2, direct substitution method

4.6.3 System stability and tuning using root-locus method

Open loop transfer function:

\[ G(s) = \frac{k_c}{(s+1)(0.3s+1)(0.3s+1)} \] ………………………………………………………………(4.34)
Figure (4.10) root-locus plot, for loop 2

$k_u = 11.1$

$\omega_{co} = 4.2$ rad/sec

$p_u = \frac{2\pi}{\omega_{co}} = \frac{2\pi}{1.09} = 1.5$

4.6.3.1 Determination of adjustable parameters

Table (4.7) Z – N tuning parameters of loop 2, root-locus method

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>$K_c$</th>
<th>$\tau_i$</th>
<th>$\tau_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>5.55</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>4.995</td>
<td>1.25</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>6.66</td>
<td>0.75</td>
<td>0.1875</td>
</tr>
</tbody>
</table>

$k_c = 5.55$ substituting for the value of $k_c = 5.55$ for P-action:

$0.09s^3 + 0.69s^2 + 1.6s + 6.55 = 0$ ................................................................. (4.35)
Checking stability using Routh:

\[
\begin{bmatrix}
0.09 & 1.6 \\
0.69 & 6.55 \\
0.51 & 0 \\
6.55 & 0 \\
\end{bmatrix}
\]

Data of the first column in Routh array:

\[
\begin{bmatrix}
0.09 \\
0.69 \\
0.51 \\
6.55 \\
\end{bmatrix}
\]

The system is stable, all elements of the first column were positive and there is no changes of sign

4.6.3.2 Impulse response of the system, root-locus method

\[
G(S) = \frac{6.55}{(s+1)(0.3s+1)(0.3s+1)}
\]

Figure (4.11) impulse response for loop2, root-locus method
4.6.4 System stability and tuning using Bode method

Open loop transfer function

\[ G(s) = \frac{k_c}{(s+1)(0.3s+1)(0.3s+1)} \] ...........................................(4.36)

\[ \omega_{co} = 4.27 \]

\[ \text{AR} = 1 \]

\[ \text{AR} = \frac{K_1 K_2 \ldots K_N}{\sqrt{1+(\omega_1)^2}\sqrt{1+(\omega_2)^2}\sqrt{1+(\omega_3)^2}}. \] ...........................................(4.37)

\[ G(s) = \frac{k_c}{(s+1)(0.3s+1)(0.3s+1)} \] ...........................................(4.38)

\[ \text{AR} = \frac{1}{\sqrt{1+(4.27)^2}} \cdot \frac{1}{\sqrt{1+(0.3+4.27)^2}} \cdot \frac{1}{\sqrt{1+(0.3+4.27)^2}} \] ...........................................(4.39)
\[ l = \frac{k_c}{11.23} \]

\[ k_c = 11.23 \]

\[ k_u = 11.23 \]

\[ p_u = \frac{2\pi}{\omega_c} = \frac{2\pi}{4.27} = 1.47 \]

### 4.6.4.1 Determination of adjustable parameters

**Table (4.8) Z – N tuning parameters of loop 2, Bode method**

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>K&lt;sub&gt;c&lt;/sub&gt;</th>
<th>τ&lt;sub&gt;i&lt;/sub&gt;</th>
<th>τ&lt;sub&gt;D&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>5.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>5.22</td>
<td>1.2</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>6.96</td>
<td>0.73</td>
<td>0.183</td>
</tr>
</tbody>
</table>

\[ k_c = 5.8 \] substituting for the valve of \( k_c = 5.8 \) for P-action:

\[ 0.09s^3 + 0.69s^2 + 1.6s + 6.8 = 0 \]………………………………………………………………………………(4.40)

Checking stability using Routh:

\[
\begin{bmatrix}
0.09 & 1.6 \\
0.69 & 6.8 \\
0.7 & 0 \\
6.8 & 0
\end{bmatrix}
\]

Data of the first column in Routh array:

\[
\begin{bmatrix}
0.09 \\
0.69 \\
0.7 \\
6.8
\end{bmatrix}
\]

The system is stable, all elements of the first column were positive and there is no changes of sign

### 4.6.4.2 Impulse response of the system, Bode method

\[
G(S) = \frac{5.8}{(s+1)(0.3s+1)(0.3s+1)}
\]
Figure (4.13) Impulse response of Bode

4.7 loop3

\[ G_c = K_c \]

Process T.F , \[ G_p = \frac{2}{(s+1)(0.5s+1)} \]

Valve T. F , \[ G_v = \frac{1}{0.5s+1} \]

Sensor T.F , \[ G_m = \frac{1}{s+1} \]
4.7.1 Block diagram for loop 3

![Block diagram for loop 3](image)

Figure (4.14) Block diagram for loop 3

4.7.2 System stability and tuning using direct substitution method

4.7.2.1 The overall TF

\[ G(S) = \frac{\pi F}{1 + \pi L} \]  
\[ (4.41) \]

\[ \pi_t = \frac{2k_c}{(0.5s+1)(s+1)(0.5+1)} \]  
\[ (4.42) \]

\[ 1 + \pi_l = \frac{2k_c+(0.5s+1)(s+1)(0.5s+1)(s+1)}{(0.5s+1)(s+1)(0.5s+1)(s+1)} \]  
\[ (4.43) \]

\[ G(s) = \frac{2k_c(s+1)}{(0.5s+1)(s+1)(0.5s+1)(s+1)+2k_c} \]  
\[ (4.44) \]

The characteristic equation is:

\[ (0.5S+1)(S+1)(0.5S+1)(S+1)+2k_c=0 \]  
\[ (4.45) \]

\[ 0.25s^4 + 1.5s^3 + 3.25s^2 + 3s + (1 + 2k_c) = 0 \]  
\[ (4.46) \]

Set \( s = i\omega \)

\[ 0.25s^4 + 1.5s^3 + 3.25s^2 + 3s + (1 + 2k_c) = 0 \]  
\[ (4.47) \]

\[ 0.25\omega^4 - 1.5i\omega^3 - 3.25\omega^2 + 3i\omega + (1 + 2k_c) = 0 \]  
\[ (4.48) \]

\[ \text{Re} = 0.25\omega^4 - 3.2\omega^2 + (1 + 2k_c) \]  
\[ (4.49) \]
Taking the imaginary part

\[ 1.5 \omega^3 = 3 \omega \]

\[ \omega_{co} = 1.4 \frac{rad}{sec} \] .................................................................(4.50)

Taking the real part

\[ 0.25 \omega^4 - 3.25 \omega^2 + (1 + 2 k_c) \] .................................................................(4.51)

\[ 0.25(1.4)^4 - 3.25(1.4)^2 + (1 + 2 k_c) \] .................................................................(4.52)

\[ k_c = 2.2 \]

\[ p_u = \frac{2\pi}{\omega_{co}} = \frac{2\pi}{1.4} = 4.5 \text{ sec} \]

4.7.2.2 Determination of adjustable parameters

Table (4.9) Z–N tuning parameters of loop 3, direct substitution method

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>( K_c )</th>
<th>( \tau_i )</th>
<th>( \tau_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>1.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>0.99</td>
<td>3.75</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>1.32</td>
<td>2.25</td>
<td>0.56</td>
</tr>
</tbody>
</table>

\( k_c = 1.1 \) substituting for the valve of \( k_c = 1.1 \) for P-action:

\[ 0.25 s^4 + 1.5 s^3 + 3.25 s^2 + 3s + 3.2 = 0 \] ........(4.53)

Checking stability using Routh:

\[
\begin{bmatrix}
0.25 & 3.25 & 3.2 \\
1.5 & 3 & 0 \\
2.75 & 3.2 & 0 \\
1.25 & 0 & 0 \\
3.2 & 0 & 0
\end{bmatrix}
\]

Data of the first column in Routh array:
The system is stable, all elements of the first column were positive and there is no changes of sign.

### 4.7.2.3 Impulse response of the system, direct substitution method

\[
G(S) = \frac{2.2}{(0.5S+1)(S+1)(0.5S+1)(S+1)} \tag{4.54}
\]

**Figure(4.15) Impulse response of loop3, direct substitution method**

**4.7.3 System stability and tuning using root-locus method**

Open loop transfer function

\[
G(S) = \frac{2k_c}{(0.5s+1)(s+1)(0.5+1)} \tag{4.55}
\]
\[ \omega_{co} = 1.41 \frac{rad}{sec} \]

\[ k_u = 2.21 \]

\[ p_u = \frac{2\pi}{\omega_{co}} = \frac{2\pi}{1.41} = 4.456 \]

4.7.3.1 Determination of adjustable parameters

Table (4.10) Z – N tuning parameters of loop 3, root-locus method

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>( K_C )</th>
<th>( \tau_i )</th>
<th>( \tau_D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>1.105</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>0.99</td>
<td>3.7</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>1.326</td>
<td>2.22</td>
<td>0.557</td>
</tr>
</tbody>
</table>
\[ k_c = 1.105 \text{ substituting for the value of } k_c = 1.105 \text{ for P-action:} \]

\[ 0.25s^4 + 1.5s^3 + 3.25s^2 + 3s + 3.21 = 0 \] ……………………………………(4.56)

Checking stability using Routh:

\[
\begin{bmatrix}
0.25 & 3.25 & 3.21 \\
1.5 & 3 & 0 \\
2.75 & 3.21 & 0 \\
1.25 & 0 & 0 \\
3.21 & 0 & 0
\end{bmatrix}
\]

Data of the first column in Routh array:

\[
\begin{bmatrix}
0.25 \\
1.5 \\
2.75 \\
1.25 \\
3.21
\end{bmatrix}
\]

The system is stable, all elements of the first column were positive and there is no changes of sign

4.7.3.2 Impulse response of the system, root-locus method

\[
G(S) = \frac{2.21}{(0.5S+1)(S+1)(0.5S+1)(S+1)} \] ………………………………………………………………..(4.57)
Figure (4.17) impulse response for loop3, root-locus method

4.7.4 System stability and tuning using Bode method

Open loop transfer function

\[ G(s) = \frac{2k_c}{(0.5s+1)(s+1)(0.5s+1)(s+1)} \]  \hspace{1cm} (4.58)
Figure (4.18) Bode plot for loop 3

\[ \omega_{co} = 1.41 \frac{rad}{sec} \]

\[ AR = 1 \]

\[ AR = \frac{K_1 K_2 \ldots K_N}{\sqrt{1+\left(\omega_1\right)^2} \cdot \sqrt{1+\left(\omega_2\right)^2} \cdot \sqrt{1+\left(\omega_3\right)^2} \cdot \sqrt{1+\left(\omega_4\right)^2}} \] \hspace{1cm} (4.59)

\[ G(s) = \frac{2k_c(s+1)}{(0.5s+1)(s+1)(0.5s+1)(s+1)+2k_c} \] \hspace{1cm} (4.60)

\[ AR = \frac{1}{\sqrt{1+(0.5\cdot1.41)^2}} \cdot \frac{1}{\sqrt{1+(1.41)^2}} \cdot \frac{1}{\sqrt{1+(0.5\cdot1.41)^2}} \cdot \frac{1}{\sqrt{1+(1.41)^2}} \] \hspace{1cm} (4.61)

\[ l = \frac{2k_c}{4.16} \]

\[ k_c = 2.08 \]

\[ k_u = 2.08 \]
\[ p_u = \frac{2\pi}{\omega_c} = \frac{2\pi}{1.41} = 4.456 \]

### 4.7.4.1 Determination of adjustable parameters

Table (4.11) Z – N tuning parameters of loop 3, Bode method

<table>
<thead>
<tr>
<th>Type of controller</th>
<th>( K_C )</th>
<th>( \tau_i )</th>
<th>( \tau_D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>1.04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>0.936</td>
<td>3.7</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>1.248</td>
<td>2.2</td>
<td>0.557</td>
</tr>
</tbody>
</table>

\( k_c = 1.04 \) substituting for the value of \( k_c = 1.04 \) for P-action:

\[ 0.25s^4 + 1.5s^3 + 3.25s^2 + 3s + 3.08 = 0 \] \hspace{1cm} \text{(4.62)}

Checking stability using Routh:

\[
\begin{bmatrix}
0.25 & 3.25 & 3.08 \\
1.5  & 3    & 0 \\
2.75 & 3.08 & 0 \\
1.32 & 0    & 0 \\
3.05 & 0    & 0
\end{bmatrix}
\]

Data of the first column in Routh array:

\[
\begin{bmatrix}
0.25 \\
1.5 \\
2.75 \\
1.32 \\
3.05
\end{bmatrix}
\]

The system is stable, all elements of the first column were positive and there is no changes of sign.

### 4.7.4.2 Impulse response of the system, Bode method

\[ G(S) = \frac{2.08}{(0.5S+1)(S+1)(0.5S+1)(S+1)} \] \hspace{1cm} \text{(4.63)}
Figure (4.19) impulse response for loop3, Bode method

4.8 Comparison of tuning methods

Table (4.12) Comparison between the adjustable parameter using different method for loop1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Direct substitution method</th>
<th>Root locus method</th>
<th>Bode plot method</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_u$</td>
<td>28.54</td>
<td>29.4</td>
<td>29.4</td>
</tr>
<tr>
<td>$P_u$</td>
<td>5.8</td>
<td>5.76</td>
<td>5.76</td>
</tr>
</tbody>
</table>

Table (4.13) comparison between the adjustable parameter using different method for loop2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Direct substitution method</th>
<th>Root locus method</th>
<th>Bode plot method</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_u$</td>
<td>11.17</td>
<td>11.1</td>
<td>11.23</td>
</tr>
<tr>
<td>$P_u$</td>
<td>1.5</td>
<td>1.5</td>
<td>1.47</td>
</tr>
</tbody>
</table>

Table (4.14) comparison between the adjustable parameter using different method for loop3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Direct substitution method</th>
<th>Root locus method</th>
<th>Bode plot method</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_u$</td>
<td>2.2</td>
<td>2.21</td>
<td>2.08</td>
</tr>
<tr>
<td>$P_u$</td>
<td>4.5</td>
<td>4.456</td>
<td>4.456</td>
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</table>
4.9 Discussion

Solid waste of Khartoum state was investigated with regard to methods of collection from residential and industrial areas, where it is sorted to plastic, organic and inorganic materials, the plastic materials are cleaned and recycled while the organic material is composted for biogas and fertilizer.

A control strategy was developed as show in fig (4.1). The transfer functions were identified and the characteristic equation is used for stability and tuning using Routh and direct substitution. The open loop transfer functions were also derived for stability and tuning using Root-locus and Bode plots, the tuning parameters (Kc, τi, τd) for each loop were compared with each other and found to be within good agreement. The adjustable parameters were calculated and inserted into the overall transfer function and then the response of each loop was drawn and found to be stable.

A setup system for a dumper for solid waste should be made to cover a collection sorting and landfilling. From the result of tuning it is proved that Routh, direct substitution, root-locus and Bode plots, give similar result and that each one of them can be used for tuning.
Chapter Five

Conclusion and Recommendations
Chapter Five

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5.1 Conclusion

In conclusion, the method of collection of domestic and industrial wastes were investigated the method in practice for data collection is primitive, irregular and not efficient. The residential areas are not provided with collection pins, the wastes are left in open places inviting wild dogs, cats and animals. These waste are left for long period, get rotten giving nasty smells. The wastes which are collected irregularly an transferred to a dumpster in west of Omdorman, sorted and put in landfill. The cells in the landfill are not properly designed without collection, pipe line and control of the produced methane gas. The leachlate is not collected and may pollute the ground water. The fertilizer produced 15g low quality with nitrogen content of 7%.

A control system was designed to collect and control the natural gas produced this is to be used for thermal operations.

5.2 Recommendations

The following and recommended

• Collection of solid wastes has to be regular and more efficient.
• Residential areas should be provided with collection pins.
• The dumpster should properly be designed for gas collection, leachate drainage and regular analysis of ground water.
• Dumpster should be far from agricultural, animal feeding and residential areas, the natural gas produced should allocated to generate electricity for the nearby residential areas.
Reference


15. Chin, H.H., All digital design and implementation of proportional-integral-derivative (pid) controller 2006.
