DESIGN OF A PLANT TO PRODUCE 20,000LITRES PER DAY OF NITRIC ACID FROM AMMONIA AND AIR (USING OSWALD PROCESS).

BY

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A PROJECT SUBMITTED TO THE DEPARTMENT OF CHEMICAL ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY,FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA,
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DECLARATION

I AFOLAYAN AYODELE S, (2001/11454EH) do hereby declare that the project work titled "Design of a Plant for Production of Nitric Acid from Ammonia and Air using (OSWALD Process)" was my personal work presented to the Department of Chemical Engineering for the award of Bachelor of Engineering (B.Eng) Degree and that this work has never been presented anywhere for the award of Degree.

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CERTIFICATION

This project has been read and approved to have met the requirement of the Department of Chemical Engineering, Federal University of Technology, Minna. For the award of Bachelor of Engineering, B.Eng (Hons) Degree in Chemical Engineering.

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ABSRTACT

This design plant was aimed at producing 20,000litres of Nitric Acid per day, using ammonia oxidation (ostwald process).The plant was designed to operate for 8hours per working day.100kgmole per hour of air was used as a basis and 15680.125litres of 97.5percent Nitric Acid was produced.

Hence,the scale up factor was calculated as 1.2755. Considerations on plant safety, quality control, cost control and general economic analysis, as well as plant site were carried out. Based on the design data and specification, equipment sizing was carried out on the following equipment: Separators, Compressors, Mixer, Heat exchanger and reactors.

The estimated capital investment is S 115,855,000, the rate of return is 46.02% and the pay-back period is 1.78 years. Hence the project is economically viable.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 DESIGN PROBLEM

The general term plant design includes all the engineering aspects involved in development of either a new, modified or expanded industrial plant. The economic evaluation and general economic analysis of the process is called engineering, while process design refers to the actual design of the equipment and facilities necessary for carrying out the process.

The design itself requires the use of engineering principles and theories combined with a practical realization of the limits imposed by industrial conditions. A plant design project moves to completion through a series of stages such as;

1. inception
2. preliminary evaluation of market
3. development of data necessary for final design
4. final economic evaluation
5. detailed engineering
6. procurement
7. construction, check-out and start-up

Plant design project involves a wide variety of skills, among these are; research, market analysis, design of individual pieces of equipment, cost estimation, computer programming and plant location surveys.

The general approach in any plant design involves a carefully balanced combination of theory, practice and common sense.

This Design work is concerned with the production of nitric acid via the oxidation of ammonia using atmospheric air. The plant for the production of nitric acid is currently based on the basic chemical operations:-

- Oxidation of ammonia with air to give nitric oxide
- Oxidation of the nitric oxide to nitrogen dioxide and
- absorption in water to give a solution of nitric acid

The efficiency of the first step is favoured by low pressure whereas that of the second is favoured by high pressure. These considerations, combined with economic reasons give rise to two types of nitric acid plant, single pressure plants and dual pressure plants.

In the single pressure plant, the oxidation and absorption steps take place at essentially the same pressure. In dual pressure plants absorption takes place at a higher pressure than the oxidation stage.

The oxidation and absorption steps can be classified as:-

- Low pressure (pressure below 1.7bar)
- Medium pressure (pressure between 1.7 and 6.5bar)
- High pressure (pressure between 6.5 and 13bar)

Except for some very old plants, single pressure plants operate at medium or high pressure and dual pressure plants operate at medium pressure for the oxidation stage and high pressure for the absorption.

The main unit operations involved in the nitric acid process are the same for all types of plant and in sequential order these are:-

- Air filtration
- Air compression
- Air/ammonia mixing

- Air/ammonia oxidation over catalytic gauzes
- Energy recovery by steam generation and/or gas re-heating
- Gas cooling
- Gas compression, energy recovery and cooling (dual pressure plants only)
- Absorption, with the production of nitric acid
- Waste gas (tail gas) heating
- Energy recovery by expansion of the waste gas to atmosphere, in a gas turbine

A typical plant of 1.83m^3 capacity has been selected for the design purpose after carrying out the necessary optimization of all the equipment through a rigorous simulation. The most common material and energy scheme has been adopted. That is: the use of nitrogen that is produced as a by-product in the first reactor to produce more nitrogen oxide that will be reacted with water to form nitric acid.

Raw materials (ammonia and dematerialized water) and cooling water facilities are required in addition to the nitric acid process unit itself, as well as an auxiliary preheater which is to preheat water that is used by absorption reactor start-up

1.2 HYSYS PLANT SIMULATOR

HYSYS provides an intuitive and interactive approach toward process modeling, simulation and optimization.

This software creates detailed high-fidelity plant simulations for analyzing and optimizing plant's operation. Through the completely interactive HYSYS interface, a fine level of equipment geometry, performance detail as well as the ability to completely customize simulation using its OLE extensibility capability.

1.3 NITRIC ACID

Nitric acid is made in three stages. The first step is the oxidation of ammonia gas with air to form nitric oxide. In order to achieve a high conversion efficiency, this is normally carried out at pressure over a platinum-rhodium catalyst. The nitric oxide is cooled and further oxidised to form nitrogen dioxide, which is then absorbed in water to nitric acid.

The principal end-use of nitric acid is in the production of nitrogen fertilizers, an important source of plant nutrients. Non-fertilizer uses include the production of: explosive-grade ammonium nitrate; adipic acid, for making nylon, and toluene diisocyanate, for manufacturing polyurethane.

1.4 DESIGN OBJECTIVES

The objective of this design work is to;

1. To design a plant with the capacity to produce 20,000 liters/day of nitric acid by oxidation of ammonia.
2. To determine the cost of equipment and materials in trying to set up a nitric acid plant.

1.5 LIMITATIONS/ PRODUCT SPECIFICATIONS

Services available are cooling water at 25°c and 130kPa. It was also specified that the ammonia gas must be free from water vapour and the air is not contaminated.

CHAPTER TWO

2.0 LITERATURE REVIEW

Nitric Acid is a colourless, corrosive liquid that has the chemical formula HNO_3. Medieval alchemists called it *aqua fortis* (strong water). Commercially, nitric acid is made by the action of sulfuric acid on sodium nitrate or the oxidation of ammonia by atmospheric air to form nitrogen oxide which is in turn absorbed in water. Nitric acid is a strong acid and a strong oxidizing agent. When dropped on the skin, the acid produces a yellow coloration because of the reaction of the acid with certain proteins to form yellow xanthoproteic acid.

The concentrated nitric acid used commercially contains about 71 percent HNO_3; the rest is water. Fuming nitric acid, which also is widely used commercially, consists of nitric acid with gaseous nitrogen oxide in solution. It is red or brown in color and more active than other forms of nitric acid. Ordinary and fuming nitric acid has many applications. They are used in chemical synthesis, in the nitration of organic materials to form nitro compounds (compounds that contain an NO_2 group), and in the manufacture of dyes and explosives. Nitric acid melts at -42° C (-44° F) and boils at 83° C (181° F).

The salts of nitric acid are called nitrates. Potassium nitrate, or saltpeter, and sodium nitrate are the nitrates of greatest commercial importance. Nearly all nitrates are soluble in water; one of the exceptions is bismuth subnitrate, $BiONO_3 \cdot H_2O$, which is used in medicine for treating intestinal disorders. Amitol, a powerful explosive, is a mixture of ammonium nitrate and trinitrotoluene (TNT). The reaction of nitric acid with organic compounds yields many important nitrates, such as nitroglycerin and nitrocellulose. Calcium, sodium, potassium, and ammonium nitrates are used in fertilizers to provide a source of nitrogen for plant growth.

Present day nitric acid production is almost entirely via the oxidation of ammonia and absorption of the oxidation product in water. the chemistry of this process was proven experimentally by Kuhlmann in 1839, but had to wait for the development of an economical route to ammonia before it could become commercially significant. Ostwald, working in Germany in about 1900, re-examined an extended Kuhlmann's data and established the proper condition required for the ammonia oxidation step. Very shortly after this, operating processes based on this principle were assembled both in Germany and United States and since then, production levels have gradually risen, so that in the United States since 1980, 7 to 8 million tonnes (100% basis) of nitric acid have been produced annually.

TABLE 2.1: Production of Nitric Acid (100% Basis) by Selected Countries (Chemical and Engineering News and Statistics, page 36)

Thousands of metric tonnes

Austalia	25	126	174	180		
Belgium	616	718	794	1167		
Canada	344	503	365	713	965	991
Finland	5	261	398	422		
France	2319	2575	3287	-		
W.Germany	2599	3254	3035	3173	1880	2354
Italy	946	1038	967	1011	1040	578
Japan	246	474	553	577		
Sweden	190	270	337	346		
UnitedKingdom		2550	2825			
United States	4444	6897	6418	8102	7033	7822
World	15,260	20,681	24,852			

2.1 PRODUCTION OF NITRIC ACID

Processes used by the European Fertilizer Industry

At the end of 1992 a tentative survey of the type of plants still in operation within the European Community gave the following results. Plants are classified by oxidation pressure and absorption pressure

Table 2.2 Type of Pressure

Dual pressure processes :	
-Low pressure/Medium pressure	9 (oldest plant)
-Medium pressure/High pressure	36 (newest plant)
Single pressure processes:	
-Medium pressure/Medium pressure	22
-High pressure/High pressure	11
Total number of plants	78

The typical capacity of the newest plants is $1000.d^{-1}$

These plant numbers are probably optimistic as the European industry is engaged in considerable rationalization. The various processes used in Europe are discussed below.

2.1.1 Process Basis (Ammonia oxidation)

Ammonia is reacted with air on platinum/rhodium alloy catalysts in the oxidation section of nitric acid plants. Nitric oxide and water are formed in this process according to the main equation:-

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O \qquad (1)$$

Simultaneously nitrous oxide, nitrogen and water are formed as well, in accordance with the following equations:-

$$4NH_3 + 3O_2 \longrightarrow 2N_2 + 6H_2O \qquad (2)$$

$$4NH_3 + 4O_2 \longrightarrow 2N_2O + 6H_2O \qquad (3)$$

The yield of nitric oxide depends on pressure and temperature as indicated in the table.

Table 2.3 Pressure effect on yield

Pressure (bar)	Temperature (°C)	NO yield (%)
below 1.7	810 – 850	97
1.7 to 6.5	850 – 900	96
above 6.5	900 – 940	95

The catalyst typically consists of several woven or knitted gauzes formed from wire containing about 90% platinum alloyed with rhodium for greater strength and sometimes containing palladium. Air pollution and contamination from the ammonia can poison the catalyst. This effect, as well as poor ammonia-air mixing and poor gas distribution across the catalyst, may reduce the yield by 10%. Some of the platinum and rhodium vaporizes during the reaction process and in most cases a platinum recovery system is installed below the catalyst. In this system a palladium alloy, known as a "getter" or catchment, allows a 60 to 80% recovery of the total catalyst losses.

The enthalpy of the hot reaction gases is used to produce steam and/or to preheat the waste gas (tail gas). The heated waste gas is discharged to the atmosphere through a gas turbine for energy recovery.

The combustion gas after this heat transfer for energy recovery has a temperature of 100 to 200°C, depending on the process and it is then further cooled with water. The water produced in reactions (1) to (3) is then condensed in a cooler-condenser and transferred to the absorption column.

Nitric oxide is oxidised to nitrogen dioxide as the combustion gases are cooled, according to the equation:-

$$2NO + O_2 \longleftrightarrow 2NO_2 \qquad (4)$$

For this purpose, secondary air is added to the gas mixture obtained from the ammonia oxidation to increase the oxygen content to such a level that the waste gas leaving the plant has normal oxygen content of between 2 and 4% by volume. The absorber is operated with a counter-current flow of water. The absorption of the nitrogen dioxide and its reaction to nitric acid and nitric oxide take place simultaneously in the gaseous and liquid phases according to equations (4) and (5). These reactions depend on pressure and temperature to a large extent and are favoured by higher pressure and lower temperature.

$$3NO_2 + H_2O \longleftrightarrow 2HNO_3 + NO \qquad (5)$$

Reaction (5) is exothermic and continuous cooling is therefore required within the absorber. As the conversion of NO to NO_2 is favoured by low temperature, this reaction will take place significantly until the gases leave the absorption column. The nitric acid produced in the absorber contains dissolved nitrogen oxides and is then bleached by the secondary air.

2.1.2 Medium pressure, single pressure plants

A typical plant is represented in the block diagram in Figure 1 and includes:-

Ammonia evaporation section

Liquid ammonia from storage is evaporated using water or condensates and superheated to prevent any liquid carry-over.

Ammonia filtration section

Gaseous ammonia is filtered to remove any rust from carbon steel equipment. Some plants also use a magnetic filter on the liquid ammonia.

Air filtration section

High purity air is obtained by using two or three stage filtration. In some plants there is additional filtration of the air/ammonia mixture.

Air compression section

An air compressor is driven by a tail gas expander and by a steam condensing turbine.

Mixing section

Modern plants use static mixers to give the high quality mixture which is essential to maintain good catalyst operation.

Catalytic Reactor Section

The catalytic reactor is designed to give a uniform distribution of the air/ammonia mixture over the catalyst gauzes. Maintenance of the catalyst operating temperature is very important for the NO yield. This is achieved by adjusting the air/ammonia ratio and ensuring that the lower explosive limit for ammonia in air is not exceeded.

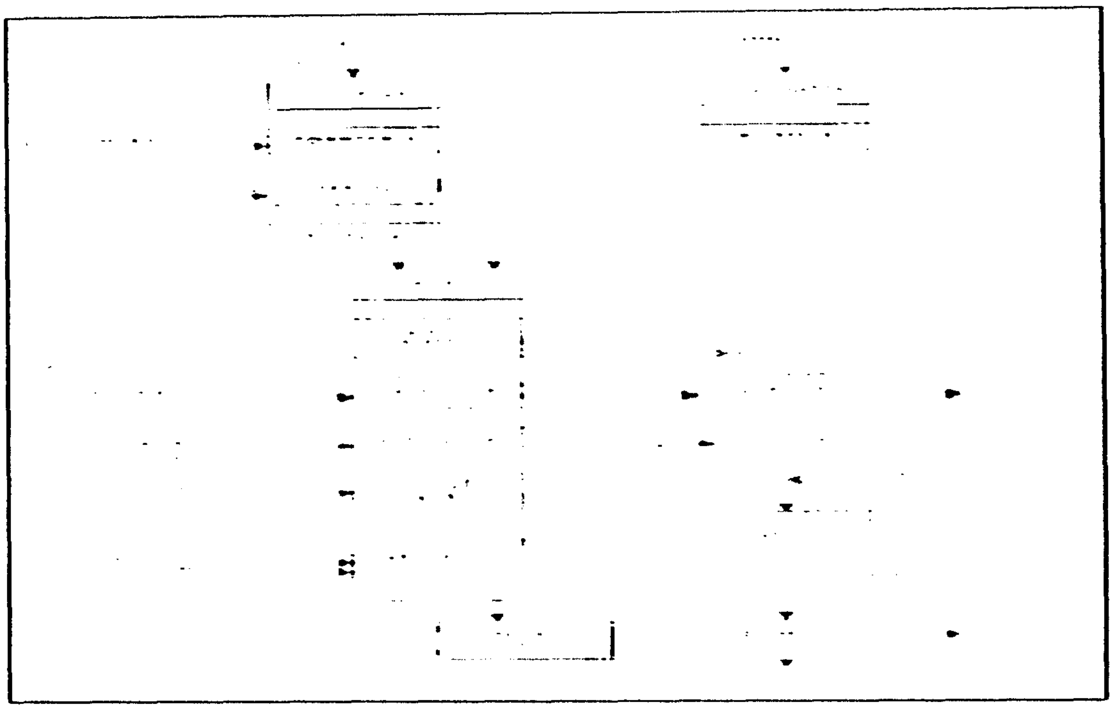
Heat recovery sections

The catalytic reactor is typically mounted as the upper part of a vessel which contains the first heat recovery section (steam superheater and steam generator). A set of gas/gas heat exchangers transfers the energy from the gas leaving the boiler set, to the tail gas.

Cooling section

A cooler condenser ensures final cooling down to 50°C after the final heat recovery. Weak acid solution is formed and is separated and pumped to the absorption tower.

Fig.1.



Absorption section

The modern absorber design uses counter-current flow circulation with high efficiency trays which are usually sieve trays or bubble cap trays. The tray spacing increases progressively from the bottom to the top of the absorber. Many of the trays are fitted with internal cooling coils to remove the heat of reaction. The absorption section consists of one or more columns in series.

Dematerialized water or steam condensate is added at the top of the tower as make-up. Process condensate from the manufacture of ammonium nitrate may be used after acidification. The acid solution leaving the absorption section is rich in dissolved nitrogen oxides and is passed to a bleaching tower where it is contacted with a counter-current flow of secondary air. The secondary air and the nitrogen oxides which have been stripped out are mixed with the gases leaving the cooling section and are recycled to the absorption section. The gas leaving the absorption section is commonly known as tail gas.

Expander section

The tail gas from the absorber is passed through the heat recovery and the expander sections for energy recovery and is then passed to the stack.

Steam turbine section

The expander generates insufficient energy to drive the air compressor. A steam turbine using part of the superheated steam generated in the plant makes up the deficiency. The steam turbine is also used for plant start-up. In some plants the energy make-up comes from an electric motor and the generated steam is exported.

2.1.3 Dual Pressure Plants

A typical plant is represented in the block diagram in Figure 2. It is similar to the single pressure plant as far as the cooling section. After the cooling section the plant layout is as follows: -

NO_x compression section

In dual pressure plants the gases leaving the cooling section are mixed with the air and nitrogen oxides from the bleaching of the acid solution and compressed to a higher pressure for the absorption stage. The heat of compression is removed from the compressed gases by heat recovery into the tail gas or the boiler feed water.

Cooling section

A second cooler condenser reduces the temperature of the gases to about 50°C and the acid solution formed is mixed with the product acid.

Absorption section

The acid solution from the absorption section is passed to a column working at the pressure of the air compressor discharge, where it is stripped of the nitrogen oxides by a flow of air from the air compressor. The air and the stripped nitrogen oxides return to the NO_x gas compressor.

2.1.4 High Pressure, Single Pressure Plants

A typical high pressure, single pressure plant is similar in layout to the medium pressure single pressure plant. The process parameters differ because of the higher operating pressure. The main differences are:-

- A higher operating catalyst temperature and pressure with a lower NO yield and a greater loss of catalyst
- A higher inlet pressure to the gas expander allowing a higher inlet temperature and thus more energy recovered in the expander and a smaller steam turbine
- A higher operating pressure in the absorber with a lower tail gas NO_x content.

2.1.5 Process gas filtration in Nitric Acid production using Bekaert's sintere metal fibre filter elements

Nitric acid manufacture is an important process based on catalytic ammonia combustion followed by nitric oxide absorption (flow sheet below). Every proprietary process has its own solution but all of them are very similar with the exception of the operating pressure. Many refinements have been made to optimize and improve the process operation such as the improvement of the process gas filtration.

Process gas filters are used for the air and ammonia feed streams that are ahead of the catalytic oxidizer to prevent the entrance of contaminant (e.g. iron-oxide) into the reaction chamber and to protect downstream equipment against fouling. Contaminant is harmful to the catalyst (poisoning and deactivation), reduces yields and increases ammonia production.

Another application of process gas filtration in some nitric acid processes (e.g. Chemico-process) is the recovery of the expensive Pt-Rh-catalyst. Volatile oxide vapours formed during the reaction and carried over with the gas stream will decompose in the cooler parts of the plant, partly forming deposits of Pt and Rh as fine particles, some leaving the plant with the tail gases. Several chemical plants make use of Bekaert's Bekiflow® HG filter elements to optimize their process gas filtration, which directly impacts the profitability of their nitric acid production facility.

Bekaert's gas filters consist of a rigid metal fibre fleece, a weld-on supporting core and a mounting flange. The metal fleece, Bekipor® is the heart of the filtration system. It is composed of several layers with its own specific fibre diameter, tailor made for the nitric acid industry. In the case of depth filtration, particles are trapped inside the medium structure. The metal fibre filter medium is graded using finer fibres as the gas flows through the medium. This provides a greater capacity to hold dirt (longer on-stream life-time) combined with small pressure drops because of high porosity and small wall thickness. The fibres are sintered in an inert gas atmosphere or under vacuum at temperatures above 1000°C to transform the loose web of fibres to a stable, not brittle matrix connected by inter-metallic bounds.

Finally, the fleece is compressed to the desired permeability and thickness. The superiority of Bekipor® is enhanced through its excellent mechanical characteristics.

In addition, the media may be pleated, a con-figuration that minimizes housing size and cost. Cleaning can be done off-line with solvents, ultrasonic vibration, pyrolysis or water back flushing to be reusable for a high number of campaigns.

At one plant two filter systems, each equipped with 25 pleated elements, were installed on two trains of 49,300 Nm³/h mixed gas stream of air and ammonia (F4 in flow sheet below), as replacement of brittle ceramic filters. Each filter, installed for the protection of the fixed bed Pt-catalyst, operates at a face velocity of 390 m^3/m^2h. The company has chosen for this solution because of the rigid, not brittle structure of the Bekiflow® HG metal fibre elements.

Another set of 25 pleated elements is installed on the air feed stream of 115,000 Nm^3/h as replacement of metal powder filter elements (F3 in flow sheet below). The filter is designed to work at a temperature of 245°C and a high operating pressure of 9 barg. It operates at a face velocity of $600m^3/m^2h$. The main benefits are the longer life time performance because of higher dirt holding capacity and lower pressure drop in comparison with metal powder filters.

Another plant selected Bekaert's metal fibre filter for the recovery of the precious and expensive Pt-catalyst at high operating pressure downstream the catalytic combustion reactor. The filter is designed for a gas stream of 18,500 m^3/h at high operation pressure of 9.5 bara and operates at a very high filter face velocity of 2,700 m^3/m^2h. The filter system consists of only one filter element with dimensions of 1,350 mm diameter and 1,675 mm length. The company has selected Bekaert's metal fibre filter as replacement of the former glass fibre filter because of the benefit of backflush cleaning instead of dissolving it in a solvent to recuperate the catalyst.

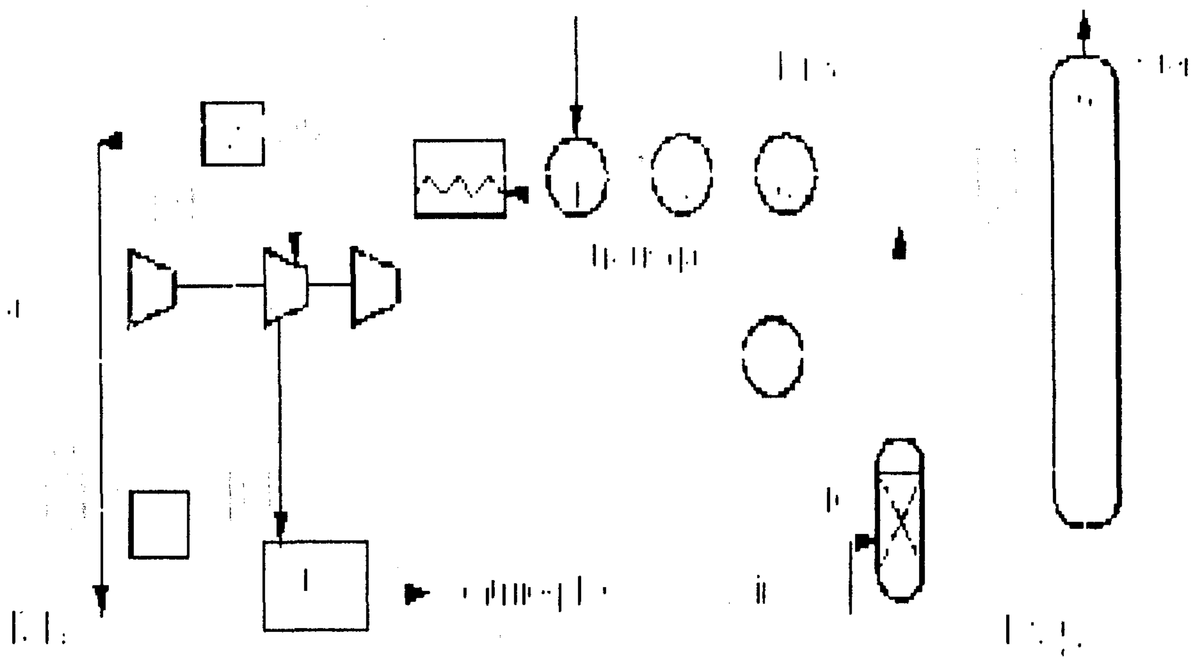


Fig 2 Schematic diagramof a nitric acid plant

Example flow sheet: dual pressure HNO_3 process with medium-pressure combustion: (1) vaporizer, (2) mixer,(3) ammonia combustion, (4) tail gas heater, (5)economiser, (6) cooler-condenser, (7) cooler-condenser,(8) weak acid separator, (9) absorber, (10) bleacher, (11)DeNOx, (F1) ammonia liquid filter, (F2) ammonia gas filter,(F3) hot air filter, (F4) mixed gas filter, (F5) weak acid Pt-recovery filter

2.2 USES OF NITRIC ACID

As shown in Fig. 3, about 80 % of the nitric acid production is used for fertilisers. The main product is ammonium nitrate (AN) and its various derivatives as calcium nitrate(CN), calcium ammonium nitrate (CAN), ammonium sulphate nitrate (ASN) and liquid Nfertilisers (UAN). The other main branch is nitrophosphate (NP) compounds. Non-fertilisers are dominated by explosive grade ammonium nitrate (LAN). Nitric acid is also required for chemicals, represented in this graph by caprolactam, adipic acid as an intermediate product for nylon and toluene diisocyanate as an intermediate product for polyurethane.

In the recent past, the world market has exhibited noticeable demand for so-called azeotropic acid with an elevated concentration of about 68 % by weight. Obviously some nitrations which only took place in the presence of high concentrated nitric acid in the past can be performed under less severe conditions nowadays. That means concentrated nitric acid can be partly or completely replaced by azeotropic acid. Consequently, Krupp Uhde has developed an enhanced process design for the reliable production of azeotropic acid.

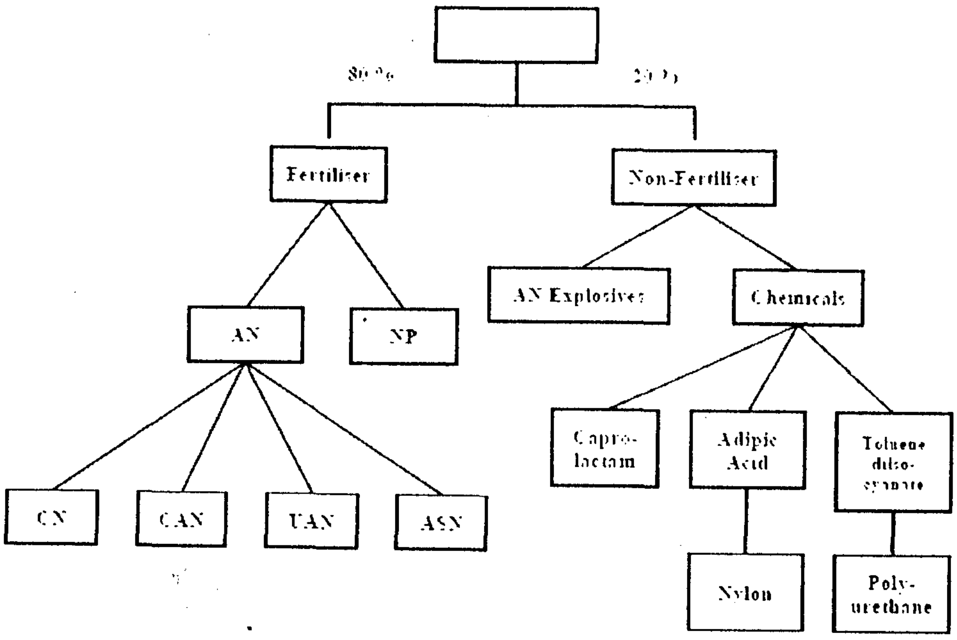


Figure 2 Nitric Acid Application

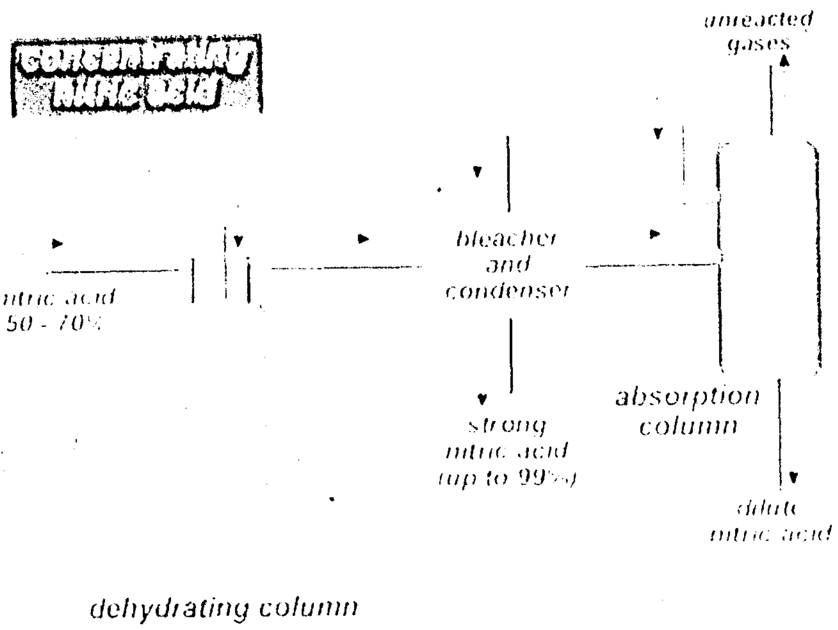


Figure 3 PROCESS OF CONCENTRATING NITRIC ACID

2.3 ENVIRONMENTAL DATA

2.3.1 Waste gas (Tail gas)

This is a continuous emission and depending on the process, the gas at the outlet of the absorber reactor may vary within the following limits during stable operation:-

No_x	100 to 3,500ppmv
N_2O	300 to 3,500ppmv
O_2	1 to 4% by volume
H_2O	0.3 to 2% by volume
N_2	Balance
Flow	3,100 to 3,400$Nm^3.t^{-1}$ 100% HNO_3

Table 2.4 Tail gas composition

Start-up and shut-down periods will normally increase the NO_x content of the tail gas at the stack during the few hours needed for the process to stabilise or for NO_x to be cleared from the plant. During ammonia oxidation some nitrous oxide (NO_2) is formed. The amount depends inter alia on combustion conditions (pressure, temperatures), catalyst composition and age, and burner design.

2.3.2 Fugitive emissions

Water present in the liquid ammonia (typically 0.5%) oncentrates in the ammonia vaporiser and periodic blow-down generates a small gaseous ammonia release.

2.3.3 Boiler blow-down

The dissolved salt content of the boiler water is controlled by a blow-down of the water in the steam drum.

2.3.4 Ammonia vaporiser blow-down

The build-up of water in the liquid ammonia in the vaporiser is controlled by a periodic blow-down.

2.3.5 Purging and sampling

Occasional emissions from the purging and sampling of nitric acid solutions.

2.3.6 Lubricating oil

Periodic replacement of the lubricating oil in rotating machines such as compressors, turbines and pumps.

2.4 WASTE MINIMISATION AND TREATMENT

2.4.1 Gaseous emissions

The main environmental factor affecting the process selection is the NO_x (acid forming oxides of nitrogen) level in the tail gas emission. The minimum emission levels currently achieved in a modern plant without added pollution abatement are:-

Table 2.5 Factors afecting the selection of process route selection

For medium pressure absorption	1000 to 2000ppmv
For high pressure absorption	100 to 200ppmv

The absorption is also influenced by other process parameters such as the cooling water temperature and by the absorber design technology, as well as the operating pressure.

Whereas a modern dual pressure plant or high pressure, single pressure plant (with high pressure absorption) may give acceptable emission levels, the medium pressure absorption used in the other types of plant must be followed by an abatement system.

The oxides of nitrogen in the tail gas consist of; Dinitrogen monoxide (N_2O, nitrous oxide); Nitrogen monoxide (NO, nitric oxide); and Nitrogen dioxide (NO_2 and its dimer, N_2O_4). The nitrous oxide is specifically excluded when NO_x is referred to.

The same techniques can be used on new and existing plants for NO_x abatement. All are based on chemical reactions.

2.4.2 Abatement action for NO_x in tail gas

Extended absorption with water, this is merely an extension of the absorption process developed for nitric acid production. A NO_x content of less than 100ppmv can be achieved with a high pressure absorption.

2.4.3 Non-selective catalytic reduction (NSCR)

In this process, hydrogen, natural gas or naphtha react with the NO_x and the free oxygen in the waste gas over a platinum, rhodium or palladium catalyst. The nitrogen dioxide is reduced first and if the reduction is not taken further, the process merely decolorises the gas according to the reactions:-

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$ (6)

$CH_4 + 4NO_2 \longrightarrow CO_2 + 2H_2O + 4NO$ (7)

when methane is used.

$2H_2 + O_2 \longrightarrow 2H_2O$ (8)

$H_2 + NO_2 \longrightarrow 2H_2O + NO$ (9)

when hydrogen is used.

An excess of the reducing agent is required to reduce nitrogen oxides to nitrogen. This may result in a high temperature gas containing methane and naphtha and also, when hydrocarbons are used, the release of carbon monoxide and hydrocarbons into the atmosphere:-

$CH_4 + 4NO \longrightarrow O_2 + 2H_2O + 2N_2$ (10)

$CH_4 + 4\,N_2O \longrightarrow CO_2 + 2H_2O + 4N_2$ (11)

when methane is used.

$2H_2 + 2NO \longrightarrow 2H_2O + N_2$ (12)

$H_2 + N_2O \longrightarrow H_2O + N_2$ (13)

when hydrogen is used.

The tail gas from the absorber has to be pre-heated to a minimum of 300°C with hydrogen or 550°C with methane for efficient operation of the NSCR catalyst. The reactant gas is mixed with the pre-heated tail gas and the mixture is passed into a reactor containing the catalytic bed.

The advantages of NSCR are:-

- Substantial N_2O reduction

The disadvantages are:-

- The release of ammonia and also carbon monoxide, carbon dioxide and unburned hydrocarbons if a hydrocarbon reducing agent is used
- The high pre-heat temperature of the tail gas unless hydrogen is used as the reducing agent
- The impossibility of starting the NSCR until the oxygen content has stabilised
- The system is not available as an add-on system because of the need for a high temperature gas expander and a complete restructuring of the heat recovery system

For these reasons, the NSCR process is not normally used in new plants.

2.4.4 Selective catalytic reduction (SCR)

In selective catalytic reduction ammonia reacts with nitric oxide and nitrogen dioxide but only to a lesser extent with oxygen. The reactions involved are:-

$6NO + 4NH_3 \longrightarrow 5N_2 + 6H_2O$ (14)

$6NO_2 + 8NH_3 \longrightarrow 7N_2 + 12H_2O$ (15)

$3O_2 + 4NH_3 \longrightarrow 2N_2 + 6H_2O$ (16)

Vanadium pentoxide, platinum, iron/chromium oxides and zeolites are among the catalysts that can be used. The operating temperature is generally above 200°C and operating pressure has only a minor effect on overall efficiency. The ammonia leakage through the catalyst beds depends on the catalyst efficiency and the gas temperature after the expander has to be kept high enough for safety reasons.

The tail gas from the absorber is pre-heated to a minimum temperature for good operation of the SCR catalyst. The reactant gas is mixed with the pre-heated tail gas and the mixture passed into a reactor containing the catalyst bed.

The advantages of the SCR system are:-

- Ammonia is readily available in a nitric acid plant
- A low NO_x content can be achieved
- There is a negligible increase in tail gas temperature because of the add-on units
- No oxygen consumption
- No added pollution when a high efficiency catalyst is used

The disadvantages of the SCR system are:-

- The tail gas temperature after the expander must be kept high enough to avoid any ammonium salt deposits
- A small ammonia slip cannot be excluded
- The system can only start when temperatures are high enough

The SCR system has a proven economic edge over other processes despite an increase in ammonia consumption.

2.4.5 Absorption in sodium hydroxide solution

Nitric oxide and nitrogen dioxide are absorbed in sodium hydroxide in equal volume with the formation of sodium nitrite. Excess nitrogen dioxide reacts slowly to form sodium nitrite and nitrate. A limited reduction can be achieved with suitable process conditions but this technique is only suitable when the resulting nitrite/nitrate solution can be further used or disposed of in a way which does not harm the environment.

2.5 BEST AVAILABLE TECHNOLOGIES

Extended absorption and selective catalytic reduction are recommended as BAT for NO_x reduction.

The main concern when designing a new nitric acid plant is the NO_x emission to the atmosphere and the energy recovery. The optimisation between capital costs and operating costs, taking into account a limit of 100ppmv NO_x, should be based on the following combinations: -

- High pressure single pressure process with an absorption efficiency high enough to avoid an additional abatement technique
- Dual pressure process with an absorption efficiency high enough to avoid the need for additional abatement
- Dual pressure process combined with an SCR technique
- Medium pressure, single pressure process combined with an SCR technique

Technical and economic considerations will dictate the choice between the extended absorption and the SCR techniques for an existing plant. At the present time the SCR technique has gained more references than the NSCR.

2.6. EMISSION MONITORING

The release of tail gas to the atmosphere must be monitored for oxides of nitrogen, principally NO, NO2 and N2O4. The content of these acid-forming oxides in the tail gas is usually expressed in terms of NOx. It may be expressed as:-

– Kg NOx. of nitric acid produced, with the NOx expressed as NO2
– or in ppmv

It will normally be sufficient to determine the tail gas flow by calculation to relate the emission concentrations to mass emissions.

Many monitoring techniques are available, with photometry and chemiluminescence as the most widely used. Chemiluminescence is emitted during the reaction between nitric oxide and ozone and thus nitrogen dioxide has to be converted catalytically into nitric oxide to be determined. A similar problem occurs with the photometric techniques where only nitric oxide or nitrogen dioxide is measured and the other component is catalytically converted.

Measurements are not always strictly continuous but because the speed of variation is slow, they can be considered as continuous. Particular attention must be paid to avoiding condensation of water in the sample lines.

2.7. OCCUPATIONAL HEALTH AND SAFETY

The chemicals to be considered in a nitric acid plant for occupational health and safety purposes are; ammonia ; nitric oxide; nitrogen dioxide; and nitric acid.

Nitric acid is corrosive to all parts of the body and contact may cause irritation, burns and necrosis.

Nitrogen dioxide (NO_2) is the most toxic of the oxides of nitrogen.

Occupational exposure limits for components associated with nitric acid production and storage are given in the table below. All the figures are in ppmv:-

Component	TLV-TWA (8hr)	TLV-STEL (15min)
NH_3	25	35
NO	25	35
NO_2	3	5
HNO_3	2	4

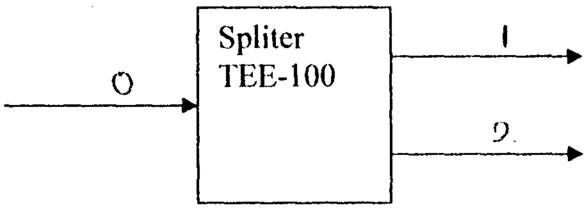
CHAPTER THREE

3.0 MATERIAL BALANCE

BASIS: 100 kgmoles / h of air.

Asumption;

- 50% of input Stream goes to the top



N_0=100kgmoles/h

$M_{wt,0}$=28.95kg/kgmole

$M_o=N_o*M_{wt,0}$=2895kg

N_1=50kgmole/h

$M_{wt,1}=M_{wt,0}$

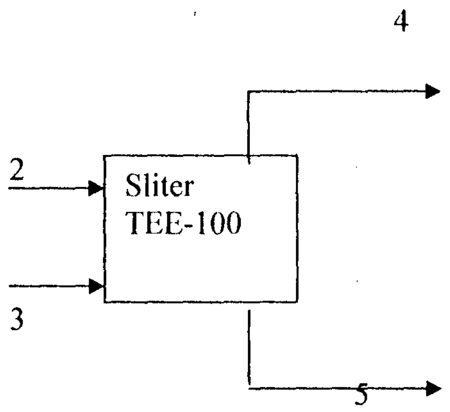
$M_{,1}=N_{,1}*M_{wt,1}$=1447.5kg

N_2=50kgmole/h

$M_{wt,2}=M_{wt,o}$

$M_{,2}=N_{,2}*M_{wt,2}$=1447.5kg

Material balance across Reactor 1



$4NH3 + 5AIR \rightarrow 4NO + 2H_2O + 2.028N_2$

50kgmole Air	4 kgmole NH_3
	5 kgmole Air

=40kgmole,h

For 99% conversion of NH_3

99% × 40=39.6kgmol/h consumed

Unreacted NH_3 = 0.4kgmol/h = 6.8kg/h

Reacted air 99% × 50 = 49.5kgmol/h

Unreacted Air = 0.5kgmol/h = 14.475kg/h

49.5kgmol/h Air	4 kgmole NO
	5 kgmol/h Air

= 39.6kgmol NO =1188kg/h NO

49.5kgmol/h Air	2 kgmole H_2O
	5 kgmol/h Air

= 19.8kgmol/h H_20 = 356.4kg/h H_20

49.5kgmol/h Air	2.028 kgmole N_2
	5 kgmol Air

= 20.0772kgmol/h N_2 = 562.1616kg N_2

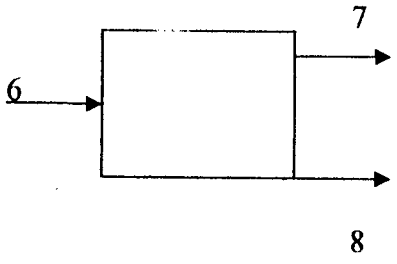
$N_{,4}$ = 80.38kgmol/h

$M_{,4}$ = 2127.8kg/h.

$M_{wtave} = M_{,4}/N_{,4}$.

= 26.5kg/kgmol.

UNIT 3



$N_{,6}$ = 664.8kgmol/hr

$M_{wt,6}$ = 18kg/kgmol.

$M_{,6} = N_{,6} \times M_{wt,6}$ = 11966.41kg.h

$N_{,7} = 640.4$kgmol/hr

$M_{wt,7} = M_{wt,6} = 18$kg/kgmol.

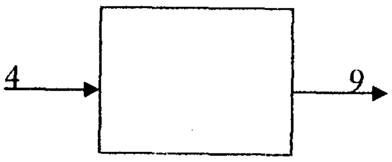
$M_{,7} = N_{,7} \times M_{wt,7} = 115207.21$kg

$N_{,8} = N_{,6} - N_{,7} = 24.4$kgmol/hr

$M_{wt,8} = M_{wt,7}$

$M_{,8} = N_{,8} \times M_{wt,8} = 439.2$kg/h

UNIT 4



$N_{,4} = 803.38$kgmol/h

$M_{,4} = 2127.8$kg/h

$M_{wt,Ave} = 26.5$kg/kgmol.

OUTPUT

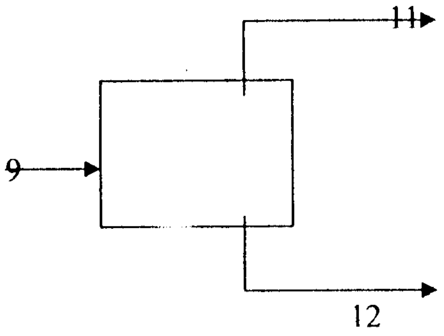
$N_{,9} = N_{,4} = 80.38$kgmol/h

$M_{,9} = M_{,4} = 2127.8$kg/h

$M_{wt,Ave} = 26.5$kg/kgmol.

Bottom stream is assumed to be 99.5% H_2O and 0.5% dissolved NH3.

UNIT 5



$N_{,9}$ = 80.38kgmol/h

$M_{,9}$ = 2127.8kg/h

OUTPUT

$N_{,12}$ = 17.50kgmol/h

$M_{,12}$, H_2O = (99.5/100) x 17.50 = 17.415kgmol/hr

M = 17.415 x 18

$M_{,12}$, NH_3 = (0.5/100) x 17.50 = 0.0875kgmol/hr

M = 17 x 0.0875

$N_{,11}$ = 80.38 – 17.50 = 62.88kgmol/hr

$N_{,11}$, NH_3 = 0.4 – 0.0875 = 0.3125kgmol/hr

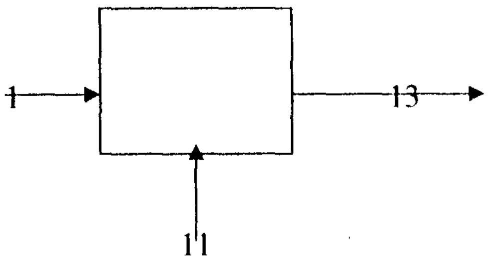
$N_{,11}$, Air = 0.5kgmol/hr,

$N_{,11}$, H_2O = 19.8 – 17.4125 = 2.3875 kgmol/hr

$N_{,11}$, N_2 = 20.0772kgmol/hr,

$N_{,11}$, N_0 = 39.6kgmol/hr

UNIT 6



Assume 100% conversion + No

$2No + Air \rightarrow 1.9No_2$ (i)

$No + 2Air \rightarrow 1.9No_2$ (ii)

$N_{,1} = 50.0$kgmol/hr

$N_{,11} = 62.88$kgmol/hr

$N_{,1air} = 50.0$kgmol/hr

$N_{,11air} = 0.5$kgmol/hr

Total inlet air

$N_{,1air}, + N_{,11air} = 50.5$kgmol/hr

$N_{,11}$ $NH_3 = 0.3125$kgmol/hr

$N_{,11}$ $H_2O = 2.3875$kgmol/hr

N,11 $N_2 = 20.0772$kgmol/hr

N,11 No = 39.6kgmol/hr

Reaction 1

Air consumed

39.6kgmol/h NO	1 kgmol Air
	2 kgmol NO

No_2 produced

39.6kgmol/h NO	1.9 kgmol Air
	2 kgmol NO

Reaction 2

Air left = 50.5 – 19.8 = 30.7kgmol Air

30.7kgmol/h Air	1 kgmol N_2
	2 kgmol Air

N2 left = 20.0772 – 15.23 = 4.7272kgmol N_2

NO2 formed.

30.7kgmol/h Air	1.9 kgmol NO_2
	2 kgmol Air

Total No_2 formed

37.62 + 29.165 = 66.285kgmol NO_2

$N_{13} = N_1 + N_{11}$ = 50 + 62.88 = 112.88kgmol/hr

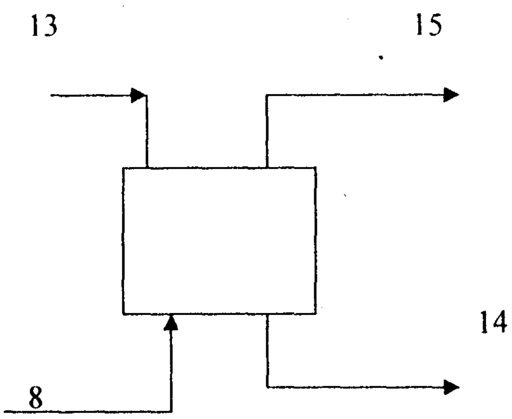
N_{13}, NH_3 = 0.3125kgmol/hr

N_{13}, Air = 0.0kgmol/hr

N_{13}, H_2O = 4.7272kgmol/hr

N_{13} NO_2 = 66.785kgmol/hr

UNIT 7



$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$

H_2O required

66.8 kgmol/h NO2	1 kgmol H2O
	3 kgmol Air

= 22.3kgmol

66.8kgmol/h NO2	1 kgmol NO
	3 kgmol NO2

= 22.3kgmol/hr

HNO3 formed

66.8kgmol/h NO2	1 kgmol HNO_2
	3 kgmol NO2

= 44.53kgmol HNO_3

Assume 27% of HNO_3 fornied pour out as vapour from the top

N_{15}, HNO_3 = 26% x 44.53 = 11.8kgmol/h

N_{14}, HNO_3 = 32.73kgmol/h

Assume 2.6kgmol H_2O is retained in the bottom stream and 1.9kgmol H_2O isretained in the top sream.

Thus

Total H_2O required.

22.3 + 2.6 + 1.9 = 26.8kgmol/h

H_2O from FFR = 2.3875kgmol/h

Thus required H_2O from water, 2 is 26.8 – 2.3875 = 24.4kgmol/h

Assume 4%NH_3 is dissolved in bottom stream

N_{14} HNO_3 = 32.73kgmol/h

$N_{,14}$ H_2O = 2.6kgmol/h

$N_{,14}$ NH_3 = 0.0125kgmol/h

Total = 35.34kgmol/h

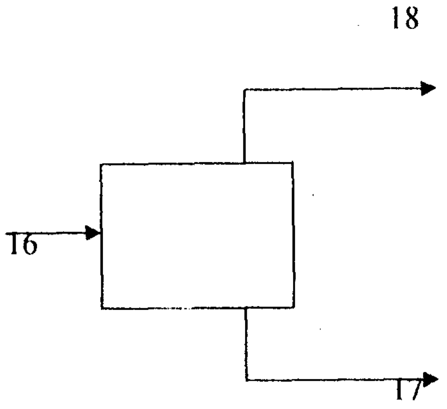
$N_{,15}$, NH_3 = 0.3kgmol/h

$N_{,15}$, H_2O = 1.9kgmol/h

$N_{,15}, N_2 = 4.7272$kgmol/h

$N_{,15}, HNO_3 = 11.84$kgmol/h

UNIT 8



$N_{,16}, NH_3 = N_{,15}\ NH_3$

$N_{,16}, HN = N_{,15}\ H_2O$

$N_{,16}, N_2 = N_{,15}\ N_2$

$N_{,16}, NO = N_{,15}\ NO$

$N_{,16NO2} = N_{,15no2}$

$N_{,16NO3} = N_{,15HNO3}$

- 16% of HNO_3 s removed at the top
- 31% of the water is removed at the top
- All the NO is remved at the top
- 7% of the ammonia is desoled in the bottom product
- All the N_2 isremoved at the top

N_{18,NH_3}=0.28kgmol/h

N_{18,H_2O} = 0.696 kgmol/h

N_{18,N_2} = 4.7272 kgmol/h

$N_{18,NO}$ = 22.34 kgmol/h

N_{18,HNO_3} = 1.888 kgmol/h

$N_{17} = N_{16} + N_{18}$

N_{17,N_2}= 0 kgmol/h

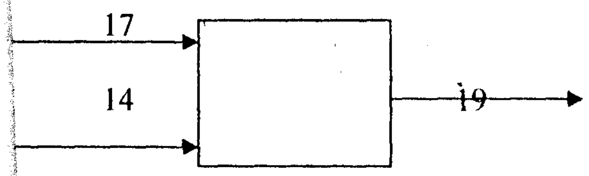
N_{17,N_2}= 0 kgmol/h

N_{17,H_2O} = 1.204 kgmol/h

N_{17,NH_3} = 0.02 kgmol/h

N_{17,HNO_3} = 9.912 kgmol/h

Unit 9



Stream 14

$N_{14,HNO3}$= 32.73 kgmol/h

$N_{14,H2O}$ = 2.61 kgmol/h

$N_{14,H2O}$ = 0.0125 kgmol/h

Stream 17

$N_{17,H2O}$ = 1.104 kgmol/h

$N_{17,NH3}$ = 0.016 kgmol/h

$N_{17,HNO3}$ = 10.08 kgmol/h

Stream 19

N19 = N14 + N17

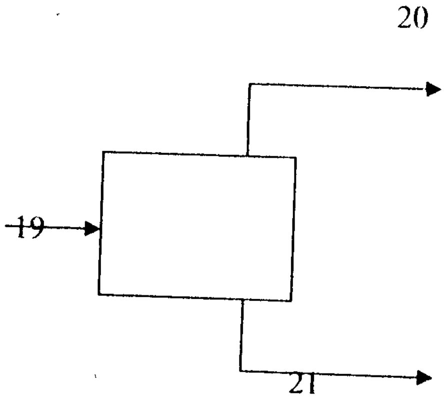
N19, HNO3 = 42.642kgmol/hr

N19, H2O = 3.804kgmol/hr

N19, NH_3 = 0.0325kgmol/hr

Total → 46.48kgmol/hr

UNIT 10



Assumption

(i) nothing escapes at top/vent.

Stream 21

$N_{21} = N_{19}$

$N_{21,\ HNO3} = 42.642$kgmol/hr

$N_{21,\ H2O} = 3.804$kgmol/hr

$N_{21,\ NH3} = 0.0325$kgmol/hr

SUMMARY OF MATERIAL BALANCE

SUMMARY OF MATERIAL BALANCE

TEE 100

					INPUT			OUTPUT	
		Stream0			Stream 1			Stream2	
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Air	100	2895	100						
Air 1				50	1447.5	50%			
Air 2							50	1447.5	50%
	100	2895	100	50	1447.5		50	1447.5	

Reactor1

				INPUT			OUTPUT					
		Stream2			Stream3			Stream4			Stream 5	
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
	50	1447.5	100				0.5	14.475	0.62			
NH_3				40	680	100	0.4	6.8	0.5			
NO							39.6	1188	49.27			
H_2O							19.8	356.4	24.63			
N_2							70.0772	562.1616	24.98			
			100	40	680	100	130.3772	2127.837	100			

TEE 101

(splitter)

	INPUT			OUTPUT					
		Stream 6			Stream 7			Stream 8	
Components	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Water	664.8	11966.4	100						
Water 1				640.4	11527.2	100			
Water 2							24.4	439.2	100
	664.8	11966.4	100	640.4	11527.2	100	24.4	439.2	100

HEAT EXCHANGER

		INPUT			OUTPUT	
		Stream 4			Stream 9	
Components	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Air 2	0.5	14.5	0.62	0.5	14.5	0.62
NH3	0.4	6.8	0.5	0.4	6.8	0.5
NO	39.6	1188	49.24	39.6	1188	49.24
H2O	19.8	356.4	24.63	19.8	356.4	24.63
N 2	20.1	562.2	25	20.1	562.2	25
	80.4	2127.9	100	80.4	2127.9	100

2 PHASE

SEPARATOR

		INPUT					OUTPUT		
		Stream9			Stream11			Stream12	
ponents	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Air 2	0.5	14.5	0.62	0.5	14.5				
NH3	0.4	6.8	0.5	0.31	5.3		0.0875	1.5	0.5
NO	39.6	1188	49.24	39.6	1188				
H2O	19.8	356.4	24.63	2.4	43		17.4	313.4	99.5
N 2	20.1	562.2	25	20.1	562.2				
	80.4	2127.9	100	62.91	1813		17.488	314.9	100

FR

	INPUT						OUTPUT		
	Stream 11			Stream 1			Stream 13		
mponent	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Air 1				50	1447.5	100			
Air 2	0.5	14.48	0.72						
NH3	0.32	5.31	0.44				0.32	5.31	0.43
NO	39.6	1188	56.64						
H2O	2.39	42.98	3.43				2.39	42.97	3.21
N 2	20.1	562.16	28.75				4.73	132.36	6.37
NO2							66.79	3072.11	89.98
	62.91	1812.93	100	50	1447.5	100	74.23	3252.75	100

CVR – 100

	INPUT						OUTPUT					
	Stream 13			Stream 8			Stream 14			Stream 15		
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
NH3	0.32	5.31	0.43				0.0125	0.21	0.04	0.3	5.1	0.73
NO										22.3	669	54.35
H2O	2.39	42.98	3.21	24.4	439.2	100	2.6	46.8	7.36	1.9	34.2	4.63
N 2	4.73	132.36	6.37							4.73	132.4	11.53
NO2	66.79	3072.11	89.98									
HNO3							32.73	2062	92.61	11.8	743.4	28.76
	74.23	3252.76	100	24.4	439.2	100	35.343	2109	100	41.03	1584	100

SEPARATOR_2

	INPUT			OUTPUT					
	Stream 16			Stream 17			Stream 18		
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
NH3	0.3	5.1	0.73	0.02	0.34	0.18	0.28	4.76	0.94
NO	22.3	669	54.35				22.3	669	74.59
H2O	1.9	34.2	4.63	1.21	21.67	10.86	0.696	12.53	2.33
N 2	4.73	132.36	11.53				4.73	132.36	15.82
HNO3	11.8	743.4	28.76	9.91	624.46	88.96	1.89	118.94	6.32
	41.03	1584.06	100	11.14	646.47	100	29.896	937.59	100

MIXER-100

	INPUT						OUTPUT		
	Stream14			Stream17			Stream 19		
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
HNO3	32.73	9747.44	92.61	9.91	624.56	89.04	42.62	2686.45	91.75
H2O	2.6	46.8	7.36	1.2	21.67	10.78	3.8	68.47	8.18
NH3	0.013	0.21	0.04	0.02	0.34	0.18	0.033	0.55	0.071
	35.343	9794.45	100	11.13	646.57	100	46.453	2755.47	100

V-100

	INPUT			OUTPUT					
	Stream19			Stream21			Stream 2o		
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
HNO3	42.64	2686.45	91.75	42.64	2686.45	91.75			
H2O	3.8	68.47	8.18	3.8	68.47	8.18			
NH3	0.033	0.55	0.071	0.033	0.55	0.071			
	46.473	2755.47	100	46.473	2755.47	100			

3.2 CORRECTED MATERIAL BALANCE (S.F =1.2755)

TEE 100

				INPUT				OUTPUT	
		Stream0			Stream 1			Stream2	
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Air	127.55	3692.57	100						
Air 1				63.775	81.345	50%	63.775		
Air 2								81.345	50%
	127.55	3692.57	100	63.775	81.345		63.775	81.345	

Reactor 1

		INPUT			OUTPUT					
Stream 2			Stream 3			Stream 4			Stream 5	
kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
81.345	100				0.64	18.46	0.62			
		51.02	867.34	100	0.51	8.67	0.5			
					50.51	1515.3	49.27			
					25.25	454.59	24.63			
					25.61	717.04	24.98			
	100	51.02	867.34	100	102.52	2714.1	100			

TEE

101

(splitter)

	INPUT			OUTPUT					
	Stream 6			Stream 7			Stream 8		
Components	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Water	847.95	15263.1	100						
Water 1				816.83	14702.9	100			
Water 2							31.12	560.2	100
	847.95	15263.1	100	816.83	14702.9	100	31.12	560.2	100

HEAT

EXCHANGER

	INPUT			OUTPUT		
	Stream 4			Stream 9		
Components	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Air 2	0.64	18.26	0.62	0.64	18.26	0.62
NH3	0.51	8.67	0.5	0.51	8.67	0.5
NO	50.51	1515.29	49.24	50.51	1515.29	49.24
H2O	25.25	454.59	24.63	25.25	454.59	24.63
N 2	25.61	717.04	25	25.61	717.04	25
	102.52	2713.85	100	102.52	2713.85	100

2 PHASE

SEPARATOR

	INPUT			OUTPUT					
	Stream 9			Stream 11			Stream 12		
Components	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Air 2	0.64	18.26	0.62	0.64	18.26				
NH3	0.51	8.67	0.5	0.4	6.78		0.11	1.9	0.5
NO	50.51	1515.3	49.24	50.51	1515.29				
H2O	25.25	454.59	24.63	3.05	54.81		22.21	399.77	99.5
N 2	25.61	717.04	25	25.61	717.04				
	102.52	2713.9	100	80.21	2312.18		22.32	401.67	100

PFR

	INPUT						OUTPUT		
	Stream 11			Stream 1			Stream 13		
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
Air 1				63.78	81.34	100			
Air 2	0.64	18.26	0.72						
NH3	0.4	6.78	0.44				0.4	6.78	0.43
NO	50.51	1515.29	56.64						
H2O	3.05	54.81	3.43				3.05	54.81	3.21
N 2	25.61	717.04	28.75				6.03	168.83	6.37
NO2							85.18	3918.47	89.98
	80.21	2312.18	100	63.78	81.34	100	94.66	4148.89	100

100

	INPUT						OUTPUT					
	Stream 13			Stream 8			Stream 14			Stream 15		
ponent	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
NH3	0.4	6.78	0.43				0.02	0.27	0.04	0.38	6.51	0.73
NO										28.44	853.3	54.35
H2O	3.05	54.81	3.21	31.12	560.2	100	3.32	59.69	7.36	2.42	43.62	4.63
N 2	6.03	168.83	6.37							6.03	168.8	11.53
NO2	85.18	3918.47	89.98									
HNO3							41.75	2630.07	100	52.32	948.2	28.76
	94.66	4148.89	100	31.12	560.2	100	45.09	2690.03			2020	100

SEPARATOR2

	INPUT			OUTPUT					
	Stream 16			Stream 17			Stream 18		
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%
NH3	0.38	6.51	0.73	0.03	0.43	0.18	0.36	6.07	0.94
NO	28.44	853.31	54.35				28.44	853.31	74.59
H2O	2.42	43.62	4.63	1.54	27.64	10.86	0.89	15.98	2.33
N 2	6.03	168.83	11.53				6.03	168.83	15.82
HNO3	15.05	948.21	28.76	12.64	796.49	88.96	2.41	151.71	6.32
	52.32	2020.48	100	14.21	824.56	100	38.13	1195.9	100

MIXER-100

				INPUT					OUTPUT	
		Stream			Stream			Stream	
		14			17			19	
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	Mole%
HNO3	41.75	12432.9	92.61	12.64	796.49	89.04	54.39	3426.56	91.75
H2O	3.32	59.69	7.36	1.54	27.64	10.78	4.85	87.34	8.18
NH3	0.02	0.27	0.04	0.03	0.43	0.18	0.04	0.7	0.071
	45.09	12492.8	100	14.21	824.56	100	59.28	3514.6	100

V-100

		INPUT				OUTPUT			
		Stream			Stream			Stream	
		19			21			2o	
Component	kgmol/h	kg/h	mole%	kgmol/h	kg/h	mole%	kgmol/h	kg/h	Mole%
HNO3	54.39	3426.56	91.75	54.39	3426.6	91.75			
H2O	4.85	87.34	8.18	4.85	87.34	8.18			
NH3	0.04	0.7	0.071	0.04	0.7	0.071			
	59.28	3514.6	100	59.28	3514.6	100			

CHAPTER FOUR

4.0 ENERGY BALANCE

4.1 The following assumptions were made in carrying out the energy balance;

1 A Steady state condition exits

2 There are no effect of mixing enthalpy

ΔH_2= N Air-2 CpAir-2 (T – Tref)

N Air-2=

N_{11} = 63.775 kgmol/hr

T = 383.9k

Tref = 298k

Tave = 340.95k

Cp Air-2 (340.95k) = 28.914 kJ/kg°c

ΔH_2 = 63.775 + 28.914 (383.9 – 298)

= 158398.7711 KJ/hr

H_f Air-2 = 0 KJ/hr.

$\Delta H_3 = N_3, NH_3. CpNH_3 (T - Tref) + N_3\Delta H_f NH_3$

$N_3NH_3 = N_3$ = 51.02 kgmol/hr

T = 341.84k Tref = 298k

Tave = 319.92k

P = 200kPa

$CpNH_3$ = 36.215kJ/kgmol°c

$\Delta T\ \Sigma NCp = 51.02 \times 36.215\ (341.84 - 298) = 81002.69891$

$\Delta H_f NH_3 = -45812.6656$ KJ/mol.hr

$N\Delta H_f\ NH_3 = -45812.6656 \times 51.02 - 2337362.199$ KJ/hr

$\Delta H_3 = 81002.69891 - 2337362.199$

$= 2256359.5$ KJ/hr

$= -2.26 \times 10^6$

$\Delta H_4 = \Sigma N_{4i} Cp_{4i} \Delta T + \Sigma N_{4i} \Delta H_{fi}$

N_4, Air-2 = 0.63775 kgmol/hr

N_4, NH_4 = 0.5102 kgmol/hr

N_4, NO = 50.5098 kgmol/hr

N_4, H_2O = 25.2549 kgmol/hr

N_4, N_2 = 25.6085 kgmol/hr

T = 393 k Tref = 298k

Tave = 345.5k P = 200 kPa

At 345.5 k;

Cp_4, Air-2 = 28.939kJ/kgmol°c

Cp_4, NH_4 = 36.867kJ/kgmol°c

Cp_4, NO = 30.027kJ/kgmol°c

Cp_4, H_2O =75.626kJ/kgmol°c

Cp_4, N_2 = 29.39 kJ/kgmol°c

ΔH_4, Air-2 = N_4, Air-2 X Cp4, Air-2

ΔT = 1753.3055 KJ/hr

ΔH_4, NO = N_4, NO X Cp_4, NOΔT = 144082.48764 KJ/hr

ΔH_4, H_2O = N_4, H_2O X Cp_4, $H_2O\Delta T$ = 181443.0714 KJ/hr

$\Delta H4$, N2 = N4, N2 X Cp4, = 71500.2124 KJ/hr

$\Sigma N_{4i}Cp_{4i}\Delta T$ = 3.29×10^5 KJ/hr

$\Sigma N4i\Delta H_{fi}$ =

Air, 63775 X 0 =0Kg/h

NH_3, 0.5102 X -45812.6656 = -23373.62kJ/h

NO_3, 50.5098 X 90374.0 =4564772.62KJ/h

H_2O, 25.2547 X 2416.5 =-6108213.251KJ/h

N_2, 25.6085 X 0 = KJ/h

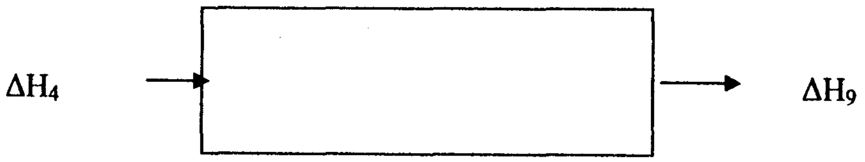
=-1566814.806KJ/h

$\Delta H_4 = 3.29 \times 10^5 - 1.566 \times 10^6 = 1.24 \times 10^6$ KJ/h

Heat load $= \Delta H_4 - (\Delta H_2 + \Delta H_3) = 1.24 \times 10^6 - (158398.7711 - 2.26 \times 10^6)$

$= 8.64 \times 10^5$ KJ/h

HEAT EXCHANGER



$\Delta H_9 = \Sigma N_9, iCp_{9,I}\,\Delta T + \Sigma N_{9,}i\Delta Hfi$

$\Sigma N_9 i\Delta Hfi = \Sigma N_4 i\Delta Hfi$

N_9, air = $N_{4,AIR}$

N_9, NH_3 = N_4, NH_3

N_9, NO = N_4, NO

$N_9, H_2O = N_4, H_2O$

$N_9, N_2 = N_{4,} N_2$

$T = 313K \qquad T_{REF} = 298K$

$C_{P,}$ air_2 =28.741kJ/kmol^{0}C

$C_{P,} NH_3$ =35.855kJ/kgmol^{0}C

$C_{P,}$ NO = 29.862kJ/kgmol^{0}C

$C_{P,} H_2O$ = 76.122kJ/kgmol^{0}C

$C_{P,} N_2$ = 29.175kJ/kgmol^{0}C

$N_9air2 \times Cp_9air_2$ = 18.31kJ/h^{0}C

$N_{9NH3} \times Cp_{9NH3}$ = 18.29kJ/h^{0}C

$N_{9NO} \times Cp_{9NO}$ = 1508.32kJ/h^{0}C

$N_{9H2O} \times Cp_{9H2O}$ = 1922.45kJ/h^{0}C

$N_{9N2} \times Cp_{9N2}$ = 747.13kJ/h^{0}C

Total 4214.5kJ/ h^{0}C

ΣN_9,i Cp_9,I ΔT=

4214.5 × 15 = 63217.5KJ/h

$\Delta H_9 = 63217.5 - 1.566\times10^6 = -1.5\times10^6$KJ/h

Heat load = $\Delta H_9 - \Delta H_4$

= -2.28×10^6kJ/h.

3 – PHASE SEPARATOR

Isothermal process $N\Sigma Cpdt = 0$

No reaction $N\Delta H_f = 0$

Thus; Heat load = 0.0KJ/h.

P F R

Stream 11.

$\Delta H_{11} = \Sigma N_{11}, i\ Cp_{11},i\ \Delta T + \Sigma N_{11}, i\ \Delta H_{f\,i}$

$N_{11,Air-2} = 0.63775$Kgmol/h

$N_{11,NH3} = 0.3986$Kgmol/h

$N_{11,NO} = 50.5098$Kgmol/h

$N_{11,H2O} = 3.0456$Kgmol/h

$N_{11,N2} = 25.6085$Kgmol/h

T = 313K Tref =298k Tave = 305

$Cp_{,11,Air-2} = Cp_9$,air-$_2$

$Cp_{11,NH3} = Cp_{9,NH3}$

$Cp_{11,NO} = Cp_{9,NO}$

$Cp_{11,H2O} = Cp_{9,H2O}$

$Cp_{11,N2} = Cp_{9,N2}$

$N_{11,\ Air-2}\ Cp_{11,\ Air-2} = 18.31$KJ/h°C.

$N_{11,\ NH3}\ Cp_{11,\ NH3} = 18.29$KJ/h°C.

$N_{11,\ NO}\ Cp_{11,\ NO} = 1508.32$KJ/h°C.

$N_{11,\ H2O}\ Cp_{11,\ H2O} = 231.84$KJ/h°C.

$N_{11,\ N2}\ Cp_{11,\ N2} = 747.13$KJ/h°C.

$\Sigma N_{11}, Cp_{11},i = 2523.89$KJ/h°C

$\Sigma N_{11}, Cp_{11},i\ \Delta T = 37858.35$KJ/h.

$\Delta H_{f,\ Air-2} = 0$

$\Delta H_{f,\ NH3} = -46191$KJ/kgmol

$\Delta H_{f,\ NO} = 90374 kJ/kgmol$

$\Delta H_{f,\ H2O} = -\ 241826 kJ/kgmol$

$\Delta H_{f,\ N2} = 0$

$N_{11,\ Air\text{-}2}\ X\ \Delta H_{f11,\ Air\text{-}2} = 0$

$N_{11,\ NH3}\ X\ \Delta H_{f11,\ NH3} = -\ 18411.73$ kJ/h

$N_{11,\ NO}\ X\ \Delta H_{f11,\ NO} = 4564772.7$ kJ/h

$N_{11,\ H2O}\ X\ \Delta H_{f11,\ H2O} = -\ 736505.27$ kJ/h

$N_{11,\ N2}\ X\ \Delta H_{f11,\ N2} = 0$

$\Sigma N_{11},i\Delta H_{11},i = 3809855.704$ kJ/h

$\Delta H_{11} = 37858.35 + 3809855.704$

$= 3847714.054$ kJ/kg

Stream 1

$\Delta H_1 = \Sigma N_1,iCp_1,i\Delta T + \Sigma N_1,i\Delta H_f,i$

$N_{1,\ Air\text{-}1} = 63.775$ kgmol/h

$Cp_{1,\ Air\text{-}1} = 29.217$ kJ/mol°C

T = 383.93k Tref =298k

$\Sigma N_1,\ iCp_1,\ i\Delta T = 160114.59$ kJ/h

$\Delta H_{f1,\ Air\text{-}1} = 0$

$\Delta H_1 = 160114.59$ kJ/h

Stream 13

$\Delta H_{13} = \Sigma N_{13},\ iCp_{13},\ i\Delta T + \Sigma N_{13},\ i\Delta H_{f13},\ i$

$N_{13,\ NH3} = 0.3986$ kgmol

$N_{13,\ H2O} = 3.0456$ kgmol

$N_{13,\ NO2}$ = 6.0295 kgmol

$N_{13,\ NO2}$ = 85.1843 kgmol

T = 759.7 k Tref = 298k

$Cp_{13,\ NH3}$ = 49.641 kJ/kgmol°C

$Cp_{13,\ NO2}$ = 49.105 kJ/kgmol°C

$Cp_{13,\ H2O}$ = 38.381 kJ/kgmol°C

$Cp_{13,\ N2}$ = 31.484 kJ/kgmol°C

ΣN_{13}, iCp_{13}, i = 4509.49 kJ/h°C

ΣN_{13}, iCp_{13}, i – ΔT = 20hJ/82030.566 kJ/h

$\Delta H_{f13,\ NH3}$ = - 46191kJ/h

$\Delta H_{f13,\ H2O}$ = - 241826kJ/h

$\Delta H_{f13,\ N2}$ = 0

$\Delta H_{f13,\ NO2}$ = 33850

$\Sigma N13,i\Delta H_{f13,i}$=2128571.557kJ/h

ΔH_{13}-(ΔH_1+ΔH_{11})

= 202773.48 kJ/h

CRV-100

Stream 13

ΔH_{13}= 4210602.123 kJ/h

Stream 8

ΔH_8=$\Sigma N_{8,i}Cp_{8,i}\Delta T$+$\Sigma N_{8,i}\Sigma\Delta H_{f8,i}$

N8,H_2O=31.1222kgmol/h

Cp_8,H_2O=36.143kJ/kgmol.^{O}C

ΔT=0

$\Sigma N8,iCp8,i\Delta T$=0

ΔH_{f8}=-285840kJ/h

$\Sigma N_{8i}\Delta H_{f8,i}$=-8895969.648kJ/h ΔH_8=-8895969.648kJ/h

Stream 14

$\Delta H_{14}=\Sigma N_{14,i}Cp_{14,i}\Delta T+\Sigma N_{14,i}\Delta H_{f14,i}$

$N_{14,NH3}$=0.0159kgmol/h

$N_{14,H2O}$=3.3163kgmol/h

$N_{14,HNO3}$=41.7471kgmol/h

Cp_{14NH3}=36.547kJ/kgmol^{O}C

Cp_{14H2O}=75.845kJ/kgmol^{O}C

Cp_{14HNO3}=156.95kJ/kgmol^{O}C

T=333k Tref=298k P=130kPa

$\Sigma N_{14},Cp_{14,i}\Delta T$=238150.9626kJ/h

$\Delta H_{f14,NH3}$=-46191kJ/kgmol.

ΔH_{f14H2O}=-285840kJ/kgmol

$\Delta H_{f14HNO3}$=-206570kJ/kgmol

$\Sigma N_{14,i}\Delta H_{f14,i}$=-9572364.076kJ/h

ΔH14=238150.9626-9572364.076

=-9334213.113kJ/h

Stream 15

$\Delta H_{15}=\Sigma N_{15,i}Cp_{15,i}\Delta T+\Sigma N_{15,i}\Delta H_{f15,i}$

$N_{15,NH3}$=0.38265kgmol

$N_{15,NO}$=28.4437kgmol

$N_{15,H2O}$=2.4235kgmol

N15,N2=6.0295kgmol

$N_{15,HNO3}$=15.0509kgmol

$T=333k$ $\quad$ $T_{ref}=298k$ $\quad$ $P=130kPa$

$Cp_{15NH_3}=36.547kJ/kgmol^{O}C$

$Cp_{15NO}=29.974kJ/kgmol^{O}C$

$Cp_{15H_2O}=75.845kJ/kgmol^{O}C$

$Cp_{15N_2}=29.325kJ/kgmol^{O}C$

$Cp_{15HNO_3}=156.95kJ/kgmol^{O}C$

$\Sigma N_{15,i}Cp_{15,i}\Delta T=125471.6786kJ/h$

$\Delta H_{f15,NH_3}=-46191kJ/kgmol$

$\Delta H_{f15,NO}=90374kJ/kgmol$

$\Delta H_{15,H_2O}=-241826kJ/kgmol$

$\Delta H_{f15,N_2}=0$

$\Delta H_{f15,HNO_3}=-206570kJ/kgmol.$

$\Sigma N_{15,i}\Delta H_{f15,i}=-1142433.766kJ/h$

$\Delta H_{15}=125471.6786-1142233.766$

$=-1016762.088kJ/h$

Heat Load$=(\Delta H_{15}+\Delta H_{14})-(\Delta H_{13}+\Delta H_{8})$

$=5665607.676kJ/h$

E-- 101

Stream 15

$\Delta H_{15}=-1016762.088kJ/h$

Stream 16

$\Delta H_{16}=\Sigma N_{16,i}Cp_{16,i}\Delta T+\Sigma N_{16,i}\Delta H_{f16,i}$

$N_{16,NH_3}=N_{15,NH_3}$

$N_{16,NO}=N_{15,NO}$

$N_{16,H_2O}=N_{15,H_2O}$

$N_{16,N2}=N_{15,N2}$

$N_{16,HNO3}=N_{16,HNO3}$

T=303k, Tref=298k P=125kPa

$Cp_{16,NH3}$=35.811kJ/kgmol^{O}C

$Cp_{16,NO}$=29.854kJ/kgmol^{O}C

Cp1ΔCp16,N2=29.165kJ/kgmolOC

$Cp_{16,HNO3}$=152.61kJ/kgmol^{O}C

$\Sigma N_{16,i}Cp_{16,i}\Delta T$=17606.41kJ/h

$\Sigma N_{16,i}\Delta H_{16fi}=\Sigma N_{15,i}\Delta H_{f15,i}$

=-1142233.766kJ/h

ΔH_{16}=-1424627.357kJ/h

Heat Load

$\Delta H_{16}-\Delta H_{15}$=(-1424627.357)-(-1016762.088)

=-407865.269kJ/h

MIX-100

$\Delta H_{17}=\Sigma N_{17,i}Cp_{17,i}\Delta T+\Sigma N_{17,i}\Delta H_{f17,i}$

N_{17HNO3}=12.6428kgmol

N_{17H2O}=1.5357kgmol

N_{17NH3}=0.0255kgmol

T=303k Tref=298k

Cp_{17HNO3}=152.61kJ/kmol^{O}C

Cp_{17H2O}=76.095kJ/kmol^{O}C

Cp_{17NH3}=35.811kJ/kmol^{O}C

$\Sigma N_{17,i}Cp_{17,i}\Delta T$=10235.9499kJ/h

$\Delta H_{f17,HNO3}$=-206570kJ/kgmol^{O}C

ΔH_{fH2O}=-241826kJ/kgmol^{O}C

ΔH_{fNH3}=-46191kJ/kgmol^{O}C

$\Sigma N_{17}\Delta H_{f17,i}$=-2984173.255kJ/h

ΔH_{17}=-2973937.305kJ/h

Stream 14

ΔH_{14}=-9334213.113kJ/h

Stream 19

$\Delta H_{19}=\Sigma N_{19,i}Cp_{19,i}\Delta T+\Delta N_{17,i}\Delta H_{f19,i}$

$N_{19,HNO3}$=54.3899kgmol

$N_{19,H2O}$=4.8520kgmol

$N_{19,NH3}$=0.04145kgmol

T=325.96k Tref=298k P=125kPa

Cp_{19HNO3}=155.79kJkmol^{O}C

Cp19H2O=75.982kJ/kmolOC

Cp_{19NH3}=36.360kJ/kmol^{O}C

$\Sigma N_{19,}Cp_{19}\Delta T$=247266.33kJ/h

$\Delta H_{f,19HNO3}$=-206570kJ/kgmol^{O}C

$\Delta H_{f,19H2O}$=-241826kJ/kgmol^{O}C

$\Delta H_{f,19NH3}$=-46191kJ/kgmol^{O}C

$\Sigma N_{19}\Delta H_{f19,i}$=-12410576.01kJ/h

ΔH_{19}=-12163309.67kJ/h

Heat Load =$\Delta H_{19}-(\Delta H_{14}+\Delta H_{17})$

=144840.74kJ/h=Heat of mixing

Reactor 1

	INPUT		OUTPUT	
	NΔHf	NCpΔT	NΔHf	NCpΔT
Component	Kj/h	kJ/h	kJ/h	kJ/h
Air 2				1.753×10^3
NH3	-2.337×10^6	1.58×10^5	-2.34×10^4	1.786×10^3
NO		8.1×10^4	4.56×10^6	1.44×10^5
H2O		9.68	-6.1×10^6	1.81×10^5
N 2				7.15×10^4
	-2.337×10^5	9.68	-1.57×10^6	3.29×10^5

Heat Load =

8.46×10^5 kJ/h

Heat Exchanger

	INPUT		OUTPUT	
	NΔHf	NCpΔT	NΔHf	NCpΔT
Component	kJ/h	kJ/h	kJ/h	kJ/h
Air 2		1.75×10^3		274.5
NH3	-2.34×10^4	1.79×10^3	-2.34×10^4	274.35
NO	4.56×10^6	1.44×10^5	4.56×10^6	22624.8
H2O	-6.1×10^6	1.81×10^5	-6.1×10^6	28836.75
N 2		7.15×10^4		11206.95
	-1.57×10^6	3.29×10^5	1.87×10^6	63217.35

Heat Load =

-2.28×10^6 kJ/h

E-101

	INPUT		OUTPUT	
	NΔHf	NCpΔT	NΔHf	NCpΔT
Component	kJ/h	kJ/h	kJ/h	kJ/h
NH3	-17674.99	509.8	-17674.99	68.51
NO	2570236.56	2780	2570236.56	4245.19
H2O	-586053.22	15236.73	-586053.22	922.08
N2		6188.53		879.25
NO2				
HNO3	-3109064.4	312000	-3109064.4	11483.84
	-1142233.77	363622.64	-1142233.77	17606.41

Heat Load =

-407865.27kJ/h

CHAPTER FIVE

5.0 PROCESS FLOW SHEET

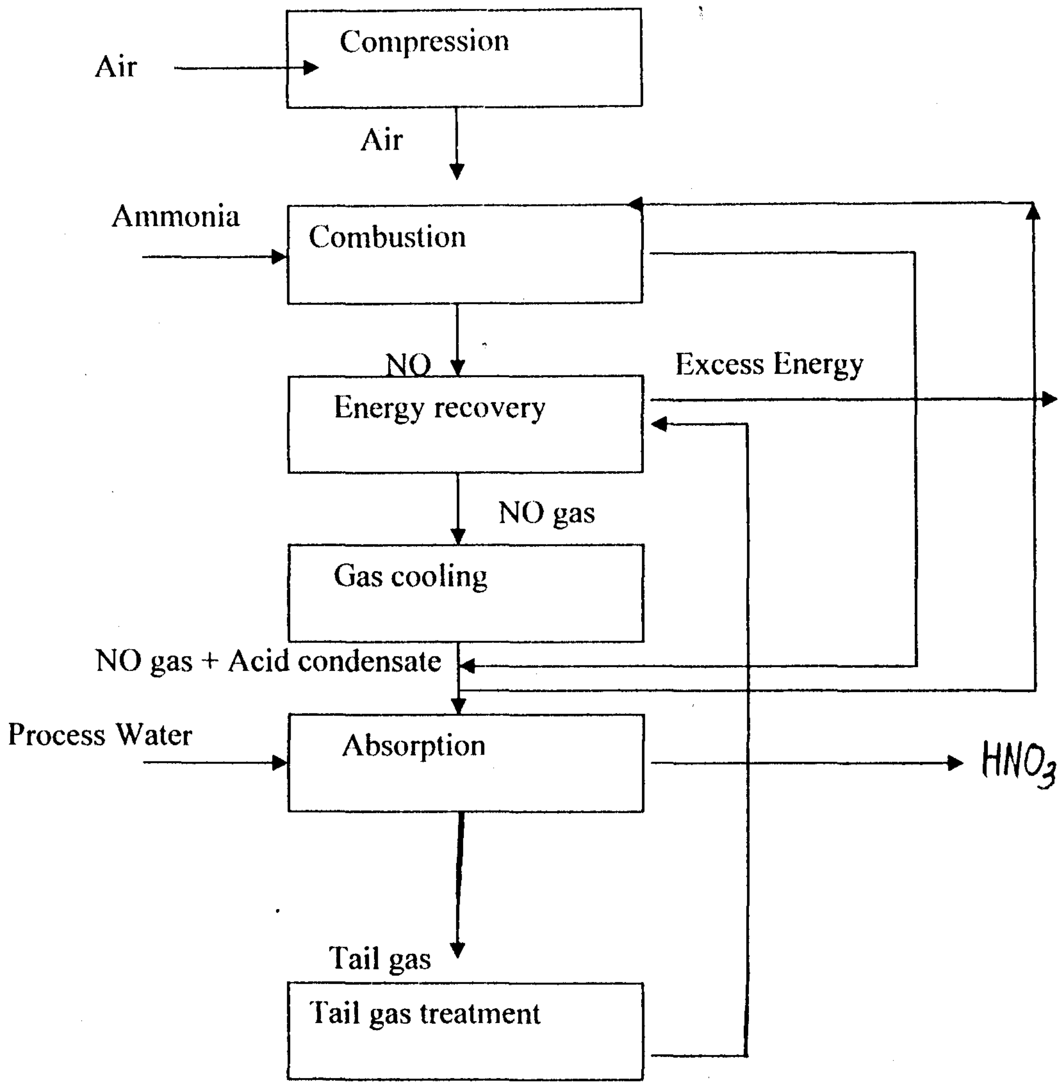
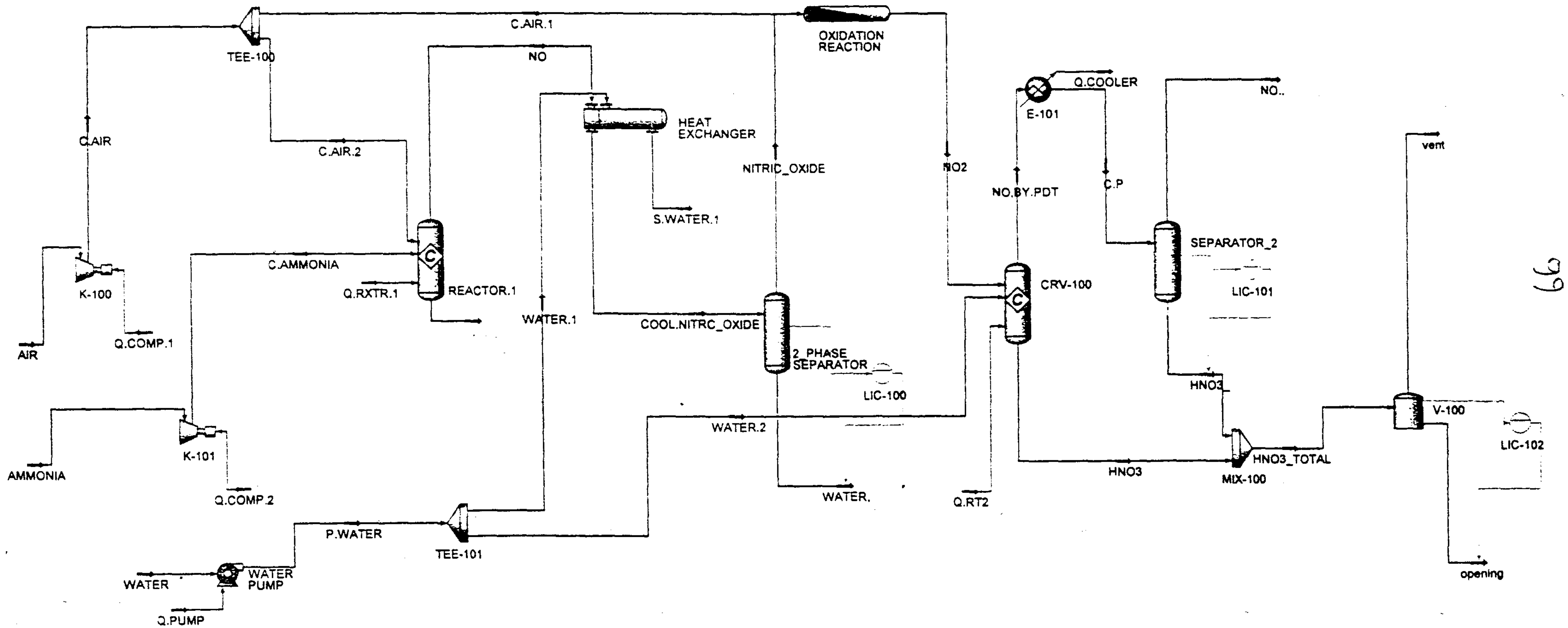


Fig 5.1: Block diagram of nitric acid process



C.AIR.1
OXIDATION REACTION
TEE-100
NO
HEAT EXCHANGER
Q.COOLER
NO..
E-101
C.AIR
C.AIR.2
NITRIC_OXIDE
NO2
NO.BY.PDT
C.P
vent
S.WATER.1
SEPARATOR_2
C.AMMONIA
C
LIC-101
K-100
Q.RXTR.1
REACTOR.1
CRV-100
AIR
Q.COMP.1
WATER.1
COOL.NITRC_OXIDE
2_PHASE SEPARATOR
LIC-100
HNO3_
V-100
WATER.2
LIC-102
K-101
HNO3_TOTAL
AMMONIA
HNO3
MIX-100
Q.COMP.2
WATER.
Q.RT2
P.WATER
TEE-101
opening
WATER
WATER PUMP
Q.PUMP

CHAPTER SIX

6.0 EQUIPMENT DESIGN

HYPROTECH	TEAM LND Calgary, Alberta CANADA	Case Name:	E:\HNO3\nitric plant.hsc
		Unit Set:	SI
		Date/Time:	Mon Dec 10 16:12:14 2007

Conversion Reactor: REACTOR.1

RATING

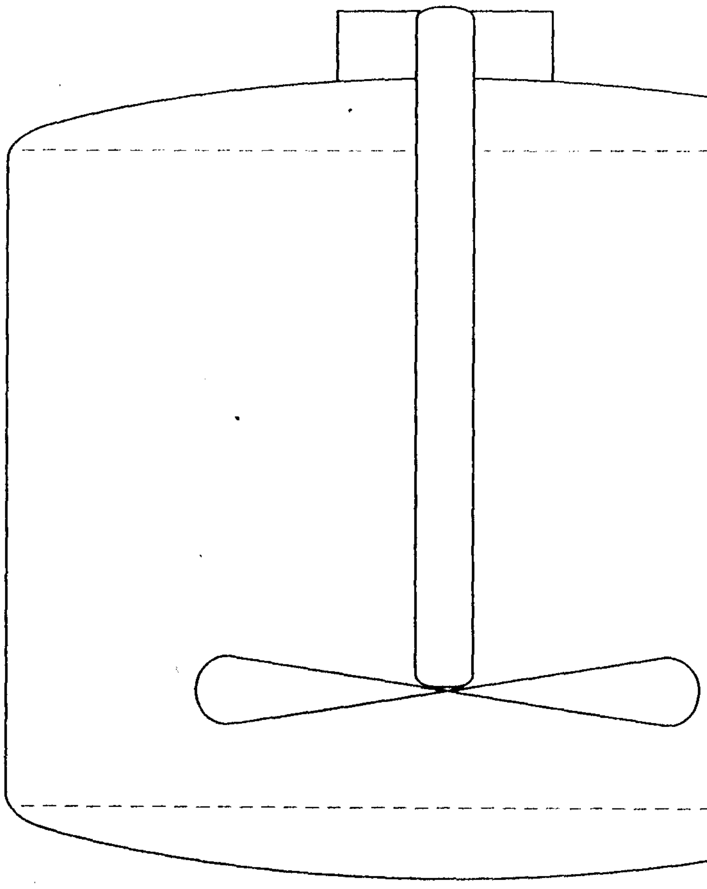
Sizing

Cylinder		Vertical		Reactor has a Boot: No	
Volume	1.920 m3 *	Diameter	1.177 m	Height	1.765

Nozzles

Base Elevation Relative to Ground Level	0.0000 m *	Diameter	1.177 m	Height	1.765

		C.AMMONIA	C.AIR.2	NO
Diameter	(m)	8.826e-002	8.826e-002	8.826e-002
Elevation (Base)	(m)	0.8826	0.8826	1.765
Elevation (Ground)	(m)	0.8826	0.8826	1.765
Elevation (% of Height)	(%)	50.00	50.00	100.00
Diameter	(m)	8.826e-002		
Elevation (Base)	(m)	0.0000		
Elevation (Ground)	(m)	0.0000		
Elevation (% of Height)	(%)	0.00		



REACTOR 1

Conversion Reactor: REACTOR.1

DYNAMICS

Vessel Parameters: Initialize from Product

Vessel Volume	(m3)	1.920 *	Level Calculator		Vertical cylinder
Vessel Diameter	(m)	1.177	Fraction Calculator		Use levels and nozzles
Vessel Height	(m)	1.765	Feed Delta P	(kPa)	0.0000 *
Liquid Level Percent	(%)	50.00	Vessel Pressure	(kPa)	200.0

Holdup: Vessel Levels

Phase	Level (m)	Percent (%)	Volume (m3)
Vapour	---	---	0.0000
Liquid	---	---	0.0000
Aqueous	---	---	0.0000

Holdup: Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000 *	0.0000
Liquid	0.0000	0.0000 *	0.0000
Aqueous	0.0000	0.0000 *	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

Duty Valve Source : Direct_Q

SP (kJ/h)	Min. Available (kJ/h)	Max. Available (kJ/h)
6.690e+005	---	---

Liquid Heater Height as % of Vessel Volume

Top of Heater : 5.00 % *	Bottom of Heater : 0.00 % *

Heat Flow into the PFR: Heating

Heat Exchanger: HEAT EXCHANGER

RATING

Sizing

Overall Data

Configuration

# of Shells in Series	1 *	Tube Passes per Shell	2 *	Elevation (Base)	0.0000 m *
# of Shells in Parallel	1 *	Exchange Orientation	Horizontal	First Tube Pass Flow Direction	Counter

TEMA Type:	A	E	L

Calculated Information

Shell HT Coeff ---	Overall U 5 kJ/h-m2-C	Shell DP 0.0000 kPa *	Shell Vol per Shell 2.272 m3	HT Area per Shell 60.32 m2
Tube HT Coeff ---	Overall UA +004 kJ/C-h	Tube DP 0.0000 kPa *	Tube Vol per Shell 0.1930 m3	

Shell Data

Shell and Tube Bundle

Shell Diameter	739.0 mm *	Tube Pitch	50.00 mm *	Shell Fouling	0.0000 C-h-m2/kJ *
# of Tubes per Shell	160 *	Tube Layout Angle			Triangular (30 degrees)

Shell Baffles

Shell Baffle Type	Single	Shell Baffle Orientation	Horizontal	Baffle Cut (%Area)	20.00 *	Baffle Spacing	800.0 mm *

Tube Data

Dimensions

OD	20.00 mm *	ID	16.00 mm *	Tube Thickness	2.000 mm	Tube Length	6.000 m *

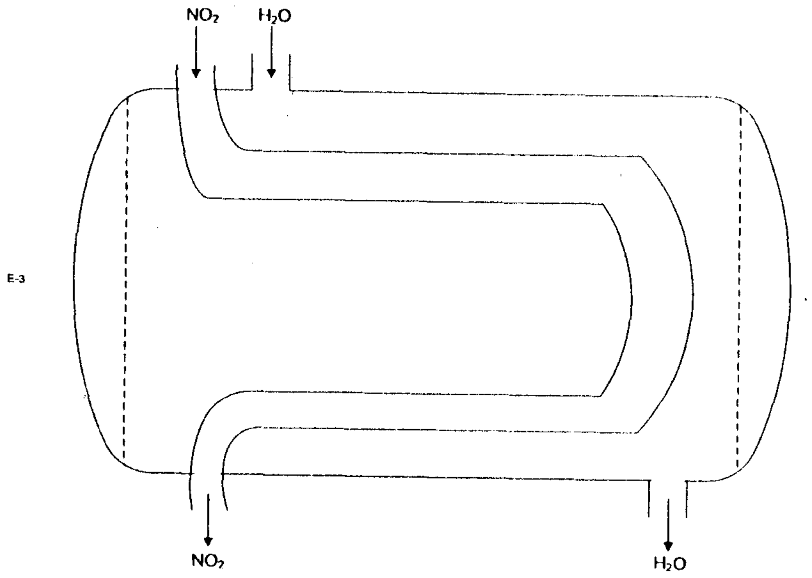
Tube Properties

Tube Fouling	0.0000 C-h-m2/kJ *	Thermal Cond.	45.00 W/m-K *	Wall Cp	---	Wall Density	---

Nozzle Parameters

Base Elevation Relative to Ground Level 0.0000 m *

		NO	WATER.1	COOL.NITRC_OXIDE
Diameter	(m)	5.000e-002	5.000e-002	5.000e-002
Elevation (Base)	(m)	0.0000	0.0000	0.0000
Elevation (Ground)	(m)	0.0000	0.0000	0.0000
Elevation (% of Height)	(%)	0.00	0.00	0.00
		S.WATER.1		
Diameter	(m)	5.000e-002		
Elevation (Base)	(m)	0.0000		
Elevation (Ground)	(m)	0.0000		
Elevation (% of Height)	(%)	0.00		



Heat Exchanger: HEAT EXCHANGER (continued)

DYNAMICS

Basic Model

Model Parameters

Tube Volume	(m3)	0.1000	Shell UA	(kg/h)	---
Shell Volume	(m3)	0.1000	Tube UA	(kg/h)	---
Elevation	(m)	0.0000 *	Minimum Flow Scale Factor		0.0000 *
Overall UA	(kJ/C-h)	3.001e+004			

Summary

Shell Duty: ---	Tube Duty: ---

Pressure Flow Specifications

Shell Side Specification

Delta P	(kPa)	0.0000 *	Active	k	kg/hr/sqrt(kPa-kg/m3)	---	Not Active

Tube Side Specifications

Delta P	(kPa)	0.0000 *	Active	k	kg/hr/sqrt(kPa-kg/m3)	---	Not Active

Holdup

Shell Holdup

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000 *	0.0000
Liquid	0.0000	0.0000 *	0.0000
Aqueous	0.0000	0.0000 *	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

Tube Holdup

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000 *	0.0000
Liquid	0.0000	0.0000 *	0.0000
Aqueous	0.0000	0.0000 *	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

NOTES

HTFS

Case Name:	E:\HNO3\nitric plant.hsc
Unit Set:	SI
Date/Time:	Mon Dec 10 16:14:34 2007

Separator: 2_PHASE SEPARATOR

RATING

Sizing

Cylinder		Vertical		Separator has a Boot: No	
Volume	0.6227 m3	Diameter	0.6096 m *	Height	2.134 *

Nozzles

Base Elevation Relative to Ground Level	0.0000 m *	Diameter	0.6096 m *	Height	2.134 *

		COOL.NITRC_OXIDE	NITRIC_OXIDE	WATER,
Diameter	(m)	0.1067	0.1067	0.1067
Elevation (Base)	(m)	1.067	2.134	0.0000
Elevation (Ground)	(m)	1.067	2.134	0.0000
Elevation (% of Height)	(%)	50.00	100.00	0.00

Detailed Heat Loss Parameters

Overall Heat Loss (kJ/h)	0.0000	Area (m2)	4.086

Temperature Profile

Fluid (C)	0.0000 *	Inner Wall (C)	25.00	Outer Vessel (C)	25.00	Outer Insulation (C)	25.00	Ambient (C)	25.00

Conduction

		Metal	Insulation
Thickness	(m)	1.000e-002	3.000e-002
Cp	(kJ/kg-C)	0.4730	0.8200
Density	(kg/m3)	7801	520.0
Conductivity	(W/m-K)	45.00	0.1500

Convection

Inside Vap Phase U (kJ/h-m2-C)	7200	Inside Liq Phase U (kJ/h-m2-C)	---	Outside U (kJ/h-m2-C)	54.00

Level Taps: Level Tap Specification

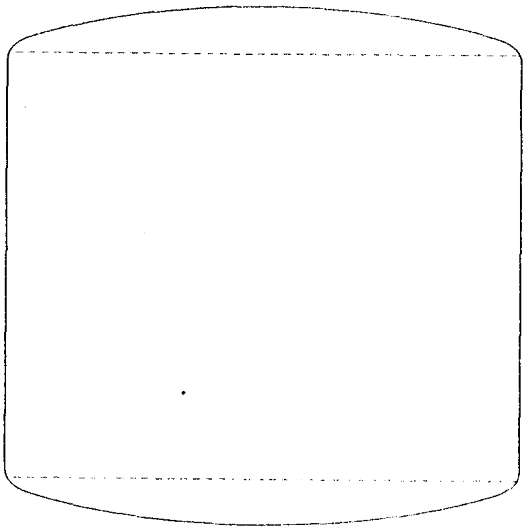
Level Tap	PV High	PV Low	OP High	OP Low

Level Taps: Calculated Level Tap Values

Level Tap	Liquid Level	Aqueous Level

Options

PV Work Term Contribution	(%)	100.00 *	



Separator: 2_PHASE SEPARATOR (continued)

		WATER,	NITRIC_OXIDE		
Temperature	(C)	40.00	40.00		
Pressure	(kPa)	200.0	200.0		
Molar Flow	(kgmole/h)	17.50	62.88		
MassFlow	(kg/h)	315.2	1814		
Std Ideal Liq Vol Flow	(m3/h)	0.3167	17.43		
HeatFlow	(kJ/h)	-4.946e+006	3.018e+006		

DYNAMICS

Vessel Parameters: Initialize from Product

Vessel Volume	(m3)	0.6227	Level Calculator		Vertical cylinder
Vessel Diameter.	(m)	0.6096 *	Fraction Calculator		Use levels and nozzles
Vessel Height	(m)	2.134 *	Feed Delta P	(kPa)	0.0000 *
Liquid Level Percent	(%)	85.00 *	Vessel Pressure	(kPa)	200.0

Holdup: Vessel Levels

Phase	Level (m)	Percent (%)	Volume (m3)
Vapour	---	---	0.0000
Liquid	---	---	0.0000

HYPROTECH

TEAM LND
Calgary, Alberta
CANADA

Case Name:	E:\HNO3\nitric plant.hsc
Unit Set:	SI
Date/Time:	Mon Dec 10 16:15:16 2007

Separator: SEPARATOR_2

RATING

Sizing

Cylinder	Vertical	Separator has a Boot: No
Volume 0.9786 m3	Diameter 0.6096 m *	Height 3.353 *

Nozzles

Base Elevation Relative to Ground Level 0.0000 m *	Diameter 0.6096 m *	Height 3.353 *

		C.P	NO..	HNO3
Diameter	(m)	0.1676	0.1676	0.1676
Elevation (Base)	(m)	1.676	3.353	0.0000
Elevation (Ground)	(m)	1.676	3.353	0.0000
Elevation (% of Height)	(%)	50.00	100.00	0.00

Detailed Heat Loss Parameters

Overall Heat Loss (kJ/h)	0.0000	Area (m2)	6.421

Temperature Profile

Fluid (C)	0.0000 *	Inner Wall (C)	25.00	Outer Vessel (C)	25.00	Outer Insulation (C) 25.00	Ambient (C) 25.00

Conduction

		Metal	Insulation
Thickness	(m)	1.000e-002	3.000e-002
Cp	(kJ/kg-C)	0.4730	0.8200
Density	(kg/m3)	7801	520.0
Conductivity	(W/m-K)	45.00	0.1500

Convection

Inside Vap Phase U (kJ/h-m2-C)	7200	Inside Liq Phase U (kJ/h-m2-C)	---	Outside U (kJ/h-m2-C)	54.00

Level Taps: Level Tap Specification

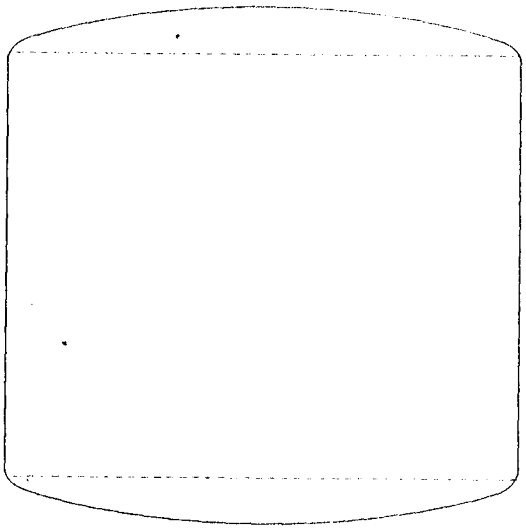
Level Tap	PV High	PV Low	OP High	OP Low

Level Taps: Calculated Level Tap Values

Level Tap	Liquid Level	Aqueous Level

Options

PV Work Term Contribution	(%)	100.00 *	



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Separator: SEPARATOR_2

DYNAMICS

Vessel Parameters: Initialize from Product

Vessel Volume	(m3)	0.9786	Level Calculator		Vertical cylinder
Vessel Diameter	(m)	0.6096 *	Fraction Calculator		Use levels and nozzles
Vessel Height	(m)	3.353 *	Feed Delta P	(kPa)	0.0000 *
Liquid Level Percent	(%)	85.00 *	Vessel Pressure	(kPa)	125.0

Holdup: Vessel Levels

Phase	Level (m)	Percent (%)	Volume (m3)
Vapour	---	---	0.0000
Liquid	---	---	0.0000
Aqueous	---	---	0.0000

Holdup: Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000 *	0.0000
Liquid	0.0000	0.0000 *	0.0000
Aqueous	0.0000	0.0000 *	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

HYPROTECH	TEAM LND Calgary, Alberta CANADA	Case Name: E:\HNO3\nitric plant.hsc Unit Set: SI Date/Time: Mon Dec 10 16:14:50 2007

Conversion Reactor: CRV-100

RATING

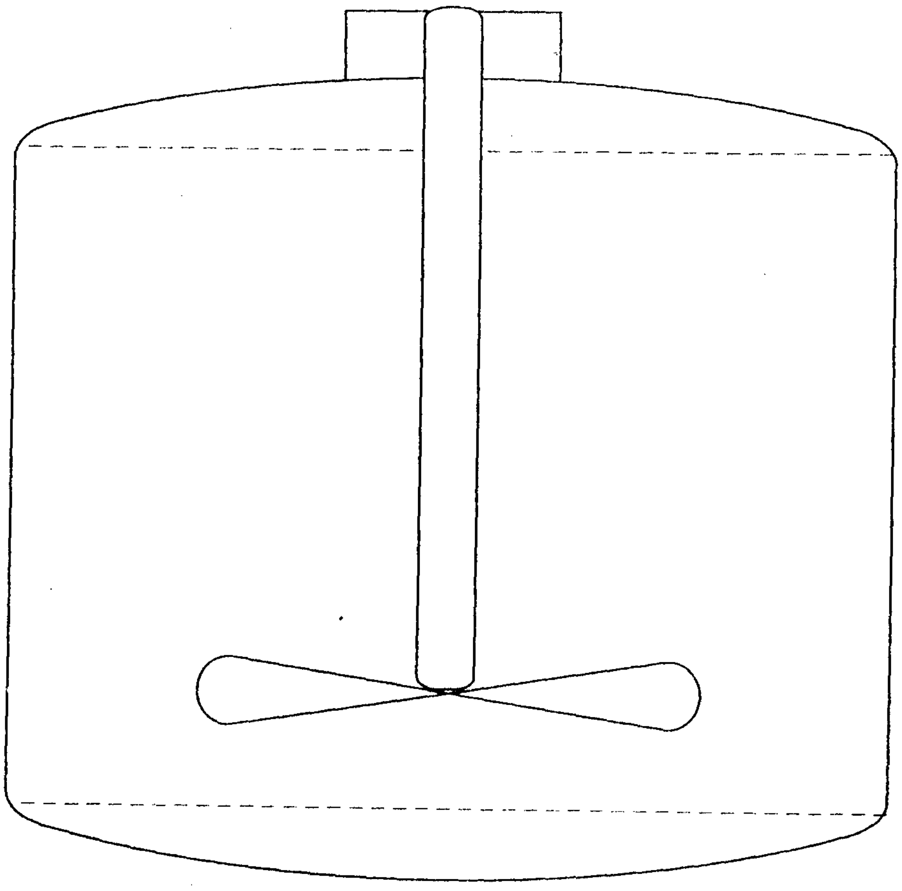
Sizing

Cylinder		Vertical		Reactor has a Boot: No	
Volume	1.200 m3 *	Diameter	1.006 m	Height	1.509

Nozzles

Base Elevation Relative to Ground Level	0.0000 m *	Diameter	1.006 m	Height	1.509

		WATER.2	NO2	NO,BY.PDT
Diameter	(m)	7.546e-002	7.546e-002	7.546e-002
Elevation (Base)	(m)	0.7546	0.7546	1.509
Elevation (Ground)	(m)	0.7546	0.7546	1.509
Elevation (% of Height)	(%)	50.00	50.00	100.00
		HNO3		
Diameter	(m)	7.546e-002		
Elevation (Base)	(m)	0.0000		
Elevation (Ground)	(m)	0.0000		
Elevation (% of Height)	(%)	0.00		



REACTOR 1

HYPROTECH	TEAM LND Calgary, Alberta CANADA	**Case Name:** E:\HNO3\nitric plant.hsc **Unit Set:** SI **Date/Time:** Mon Dec 10 16:13:53 2007

Plug Flow Reactor: OXIDATION REACTION

RATING

Sizing

Tube Dimensions

Total Volume	.540e-003 m3	Length	6.000 m *	Diameter	.000e-002 m *	Number of Tubes	1 *	Wall Thickness	5.000e-003 m *

Tube Packing

Void Fraction	1.0000 *	Void Volume	7.540e-003 m3

Nozzle Parameters

Base Elevation Relative to Ground Level	0.0000 m *	Diameter	4.000e-002 m *	Length	6.000 *

		NO2	C.AIR.1	NITRIC_OXIDE	
Diameter	(m)	5.000e-002	5.000e-002	5.000e-002	
Elevation (Base)	(m)	0.0000	0.0000	0.0000	
Elevation (Ground)	(m)	0.0000	0.0000	0.0000	

CHAPTER SEVEN

7.0 MATERIAL FOR CONSTRUCTION

costuction purposes. For chemical proces plant the most important cnsideration is usually the ability to resist corrosion.

Based on these, the materials selected for the construction of various equipments involved in this plant are as outlined below.

EQUIPMENT	MATERIAL OF CONSTUCTION
Reactor	Stainless Steel
Heat Exchanger	Stainless Steel
2_Phase Separator	Stainless Steel
PFR	Stainless Steel
CRV_100	Stainless Steel
Separator_2	Stainless Steel
Mixer	Stainless Steel
Storage Tank	Stainless Steel

CHAPTER EIGHT

8.0 SAFETY MEASURE AND QUALITY CONTROL

8.1 EMISSION CONTROL FEATURES

The chief environmental problem associated with the operation of a nitric acid plant is the discharge of residual nitric oxide and nitrogen dioxide from the vent stack of the absorber .For high pressure process, total concentration of nitrogen oxide discharged, typically amounted to about 0.3% by volume through nitric acid plants are not the only sources of nitrogen oxides (NO_X) but they do correspond to a relatively large point sources emissions unlike the more diffuse discharge resulting from automobiles. The need to regulate NO_X discharge arise from the implication of nitrogen oxides photochemical air pollution problems toxic effects felt during photochemical smog episodes, nitric acid is a component of acid rain ,it is a powerful oxidizing agent, reacts with compound such as cyanide, carbides and metallic powder which can be explosive. It also reacts with many organic compounds such as turpentine, are violent and hypergolic (i.e. self igniting) and the concentration of nitric acid dyes human skin yellow.

Nitric oxide is dangerous to human, at concentration above 50ppm at ambient condition. An industrial an hygiene standard of 5 ppm for a 8-hr workday has been set. Colourless Nitric Oxide is not itself an irritant, but at high concentration(1000 – 2000 ppm) in air can cause loss of consciousness and convulsions.

8.2 CONTROL MEASURES

Emission control measure centered on catalytic reduction of Nitrogen Oxide using methane gas (natural gas) or hydrogen for methane reduction, tail gases from the absorber vent are pre-heater to about 400c and then blended with the appropriate proportion of methane before passage over platinum or palladium catalytic surface s for reduction. The concentration of nitrogen oxide is decreased by about 90% from 0.3% to 0.01% -0.2% by volume depending on conditions from the reaction e.g

$CH_4 + 2O_2$ -----$CO_2 + 2H_2O$

$CH_4 + 4NO_2$-----$4NO + CO_2 + 2H_2O$

Brown colourless

$CH_4 + 4NO$-----$2N_2 + CO_2 + 2H_2O$

Methane is first rapidly oxidized by the excess oxygen nomally pressure in the vent gases (for reoxidation of nitric oxide to nitrogen dioxde in the absorbers)

Nitric oxide and nitrogen dioxde may also be reduced by ammonia using alumina supported platinum catalysts without requiring sufficient ammonia to consume the residual oxygen

$6NO + 4NH_3$------$5N_2 + 6H_2O$

$6NO_2 + 8NH_3$-----$7N_2 + 12H_20$

This has be shown to be a feasible option to confer fuel and capital cost saving while meeting stringent regulatory requirements.The processing train used is very similar to that given for methane reduction.Physical absorption in scrubbers which employ water or nitric acid has also been employed ,as has chemical absorption by alkaline solutions or solution of urea in water . All can reduce tail gas NO concentrations to below 200ppm.

8.3 REGULATOR REQUIREMENT FOR NITRIC ACID DISCHARGE

Nitric acid plant discharges in united states now stand at 1.5kg of NOX (asNO2 equivalent) per tonne of acid equating to about 230ppm NOX and the discharge must be colourless (opacity of 10% or less) for new plant. Older plant a maximum of 400ppm by volume NOX

For European jurisdications the requirements vary but generally lie near the proposed requirements U.S, where U.S.S.R requires 0.55kg NOX (calculated asNO2) discharge rate per tonne of acid.

CHAPTER NINE

9.0 PROCESS CONTROL AND INSTRUMENTATION

It is intended that most of the equipment in the Nitric acid plant should be operated automatically, that is, with automatic control, with the indicating instruments located in a central control room. Actually, this is the general practice of this kind that is proposed not to be labour intensive. The instrumentation and control will be based upon temperature, flow and level measurements. Measurements of these parameters will be made using, for instance, thermocouples for the temperatures, orifice plates for the flow and float type indicators for the level measurements. Regulation by pneumatic control is recommended due to the flammability of the process fluids. The description of typical instrumentation and control systems of the plant equipments are as given below.

9.1 PROCESS CONTROL OF EQUIPMENTS

9.1.1 PROCESS CONTROL OF CONVERTER (REACTOR) CONTROL

The temperature of the converter (reactor) is controlled by heat transfer. Even though the reaction is autothermal, it is still necessary to check that the temperature range within the reactor is correct. As such, a temperature controller is used. In addition, a pressure controller is also used to maintain the pressure at the design value of between 195 to 205 kPa absolute. Finally, a flow controller is used to maintain the flow around the converter. See the figure 9.1 below.

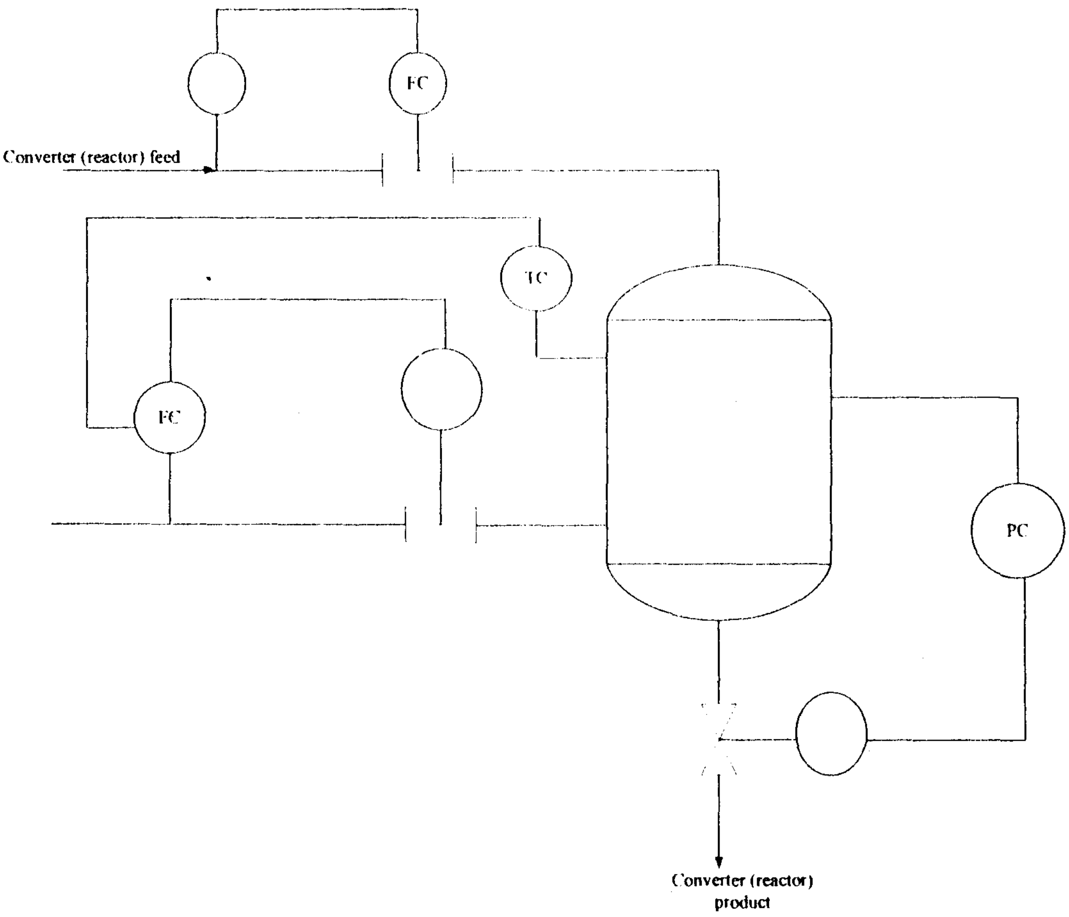


Fig. 9.1a: Converter (reactor) controller

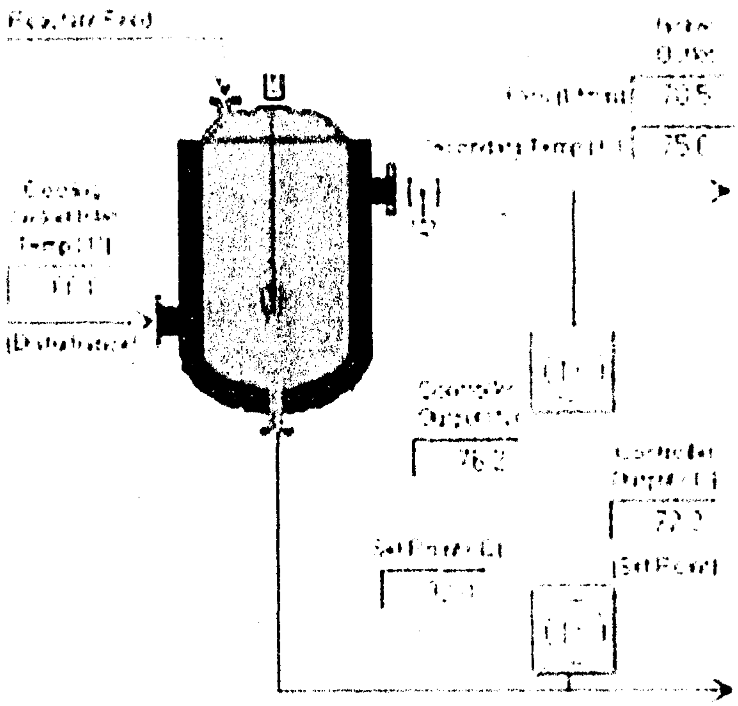


Fig. 9.1b: Cascade control of the converter

9.1.2 ABSORBER (REACTOR) CONTROL

Since the flow to the absorber is fixed, control of the absorber process will be accomplished by maintenance of the specified liquid/vapour flow ratio. Control of this parameter is very desired because it is this ratio that is used to determine the exit composition. At the start-up period, maximum capacity of the absorber is required when all the reaction products are transferred directly to the column from the reactor.

The temperature of the entering reactor product also affects the efficiency of the absorption process, so a temperature controller is also used in the control of the absorber.

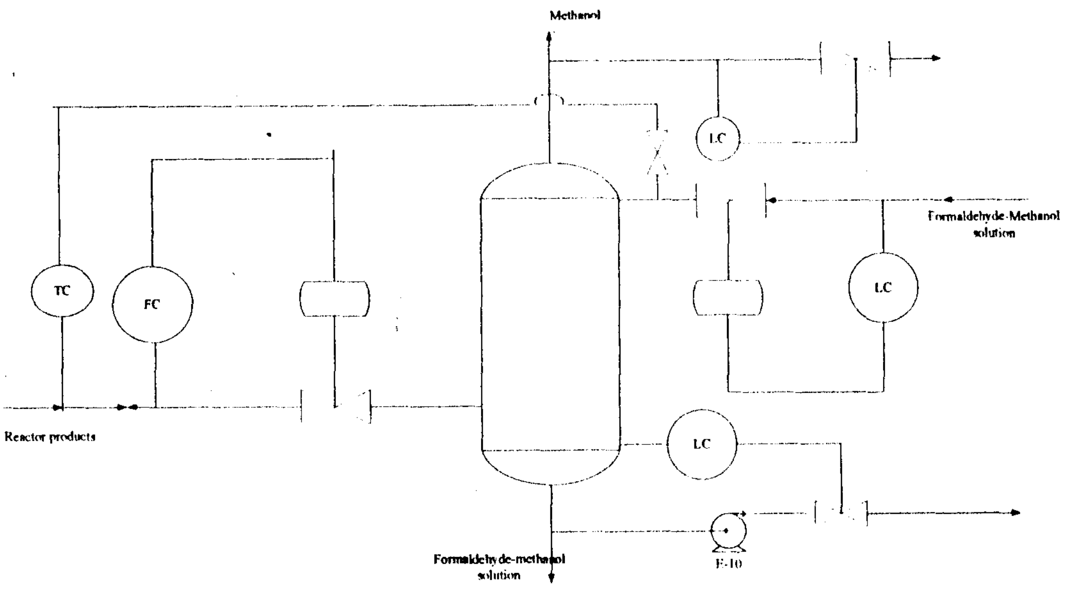


Fig. 9.2: Absorber control

9.1.3 COMPRESSOR CONTROL

A compressor is normally provided with a flow controller in order to control the rate of flow of gas leaving the compressor. A pressure controller is also attached to maintain the desired pressure of the air and ammonia respectively. In order to provide flow control on a compressor running at a fixed speed and supplying a near constant volume output, a by-pass control would be employed. See the figure 9.3 below.

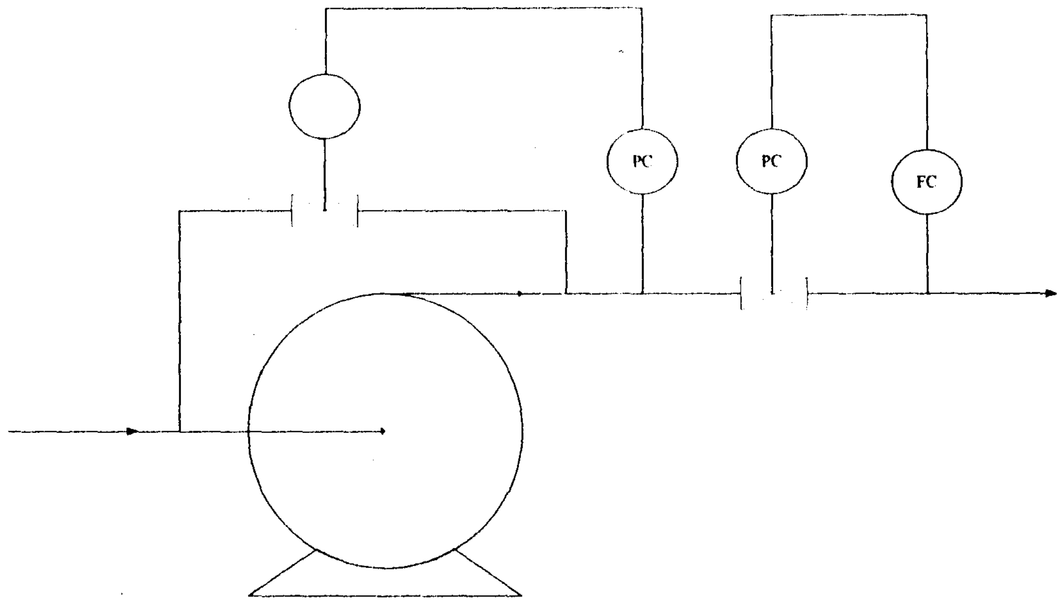


Fig. 9.3: Flow and pressure control of a centrifugal compressor

9.1.4 PROCESS CONTROL OF HEAT EXCHANGER

The heat exchanger has its temperature being controlled by varying the flow of the cooling or heating medium. In this case where the process is dealing with preheaters and superheater, the medium is a hot one. For the heat exchange between streams whose flows are fixed, by-pass control would be used. The diagram is shown in the figure below.

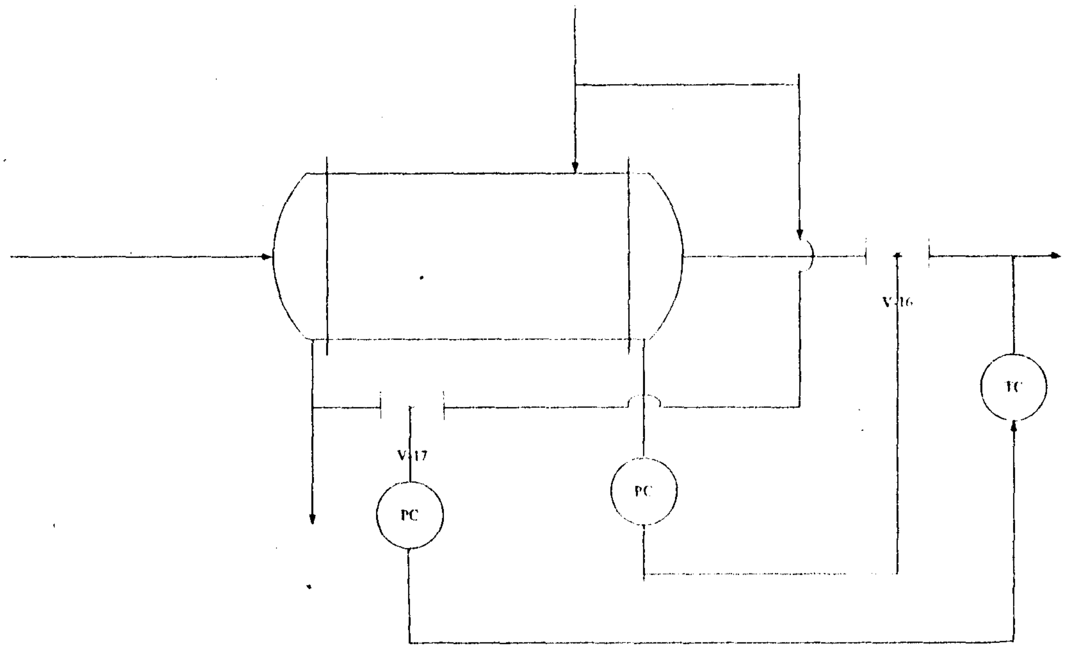


Fig. 9.4: Heat exchanger control (temperature and pressure control)

9.2 SPECIFICATION OF CONTROLLER/INSTRUMENT TYPE

From the control diagrams shown above, the different controllers and instruments used are as follows.

TI	Temperature Indicator [thermocouples (Chromel-alumel)]
TC	Temperature Controller (PID–Proportional-Integral-Derivative controller)
PC	Pressure Controller (P – Proportional controller)
PI	Pressure Indicator (Differential Pressure Gauge - diaphragm)
LC	Level Controller (PI – Proportional-Integral controller)
LI	Level Indicator (Float-type indicator)
FC	Flow Controller (PI – Proportional-Integral controller)
FI	Flow Indicator (orifice plate)
-----	Pneumatic control due to high flammability of the process fluid

CHAPTER TEN

10.0 START UP AND SHUT DOWN PROCEDURE

The plant startup and shutdown procedure must be made to procedure safely and easily flexible to carried out in numerous ways. This is so important that it should be remembered that the operating limit of the plant must not be exceeded,this may lead to an undesirable event if allowed to occur.

10.1NORMAL PLANT STARTUP PROCEDURE

For normal plant operations, the following steps should be embrassed when starting up a plant:

1) The boiler should be turned on to start up the steam production process.
2) All reactor must be heated and maintained at their operating temperatures and pressures.
3) To enable maximum conversion of the feed in the reactor, once it is charged in,the outlet and inlet valves must be shut. A vent system should be installed and should be connected to the controllers to checkmate against excessive pressure build up.
4) The reactor must be clean from any product before any new feed is charge in.

10.2 NORMAL PLANT SHUT DOWN PROCEDURE

While shutting down the plant operation, the following should be considered:

1) cut off the pumping of air into the compressor.
2) Water supply into the heat exchanger should be shut.

3) Utilites to other units should be cut off and the operating temperature of all units be main tain and allow conversion of the feeds within such reactor.

4) All reminant should be flushed out from pipes,reactors and other units.this is to prevent contermination of the next production.

10.3 START UP AFTER EMERGENCY SHUT DOWN

1 undesirable or toxic materials should be removed during startup. This includes all materials that may be residual as a result of the emergency shutdown procedure.

2 Recycling disposal of non conforming specification process should be carried out.

3 Ensure that the material used in cleaning the unit be removed with appropriate equipment using the right procedure,this include chemical,air e.t.c.

4 Check the control and adjust the set point values prior to emergency shutdown.

CHAPTER ELEVEN

11.0 SITE FOR PLANT LOCATION

11.1 INTRODUCTION

The geographical location of the final plant can have a strong influence on the success of an industrial venture and profitability of a project. Much care must be exercised in choosing the plant site and many different factors must be considered. The plant should be located where the minimum cost of production and distribution can be obtained, but other factors, such as room for expansion and general living condition are also important.

11.2 CONSIDERATIONS IN LOCATION OF PLANT

In selecting a suitable site for nitric acid plant, the following factors should be considered.

11.2.1 RAW MATERIALS

The source of raw materials is one of the most important factors influencing the selection of a plant site. The availability, proximity to proposed site, and price of the raw materials must be put into consideration. This is particularly true for nitric acid process, which involves large tonnage of raw material consumption.

The major raw material for this process is ammonia which can be obtained in relatively large quantity from the gasification of coal or as a bye product from petroleum processing. The plant could be sited in areas around the south-east or south-south part of Nigeria e.g. Enugu, Port-Harcourt, Warri etc. Therefore the sitting of the plant in these regions permit considerable reduction in transportation and storage costs.

11.2.2 MARKETS

The nearness of markets and/or intermediate distribution outlets to the proposed plant site influences the cost of product, distribution and time required for transportation. Since the nitric acid is processed in bulk, sitting the plant in the regions above, reduces the cost of transporting the final product to the primary market.

11.2.3 SITE CHARACTERISTICS

The characteristics of the land for the proposed plant site should be examined carefully. The topography of the tract of land and the soil structure must be considered, both of them have pronounced effect on the cost of constructing the plant. Other site characteristics to be put into consideration are land cost, local building cost, living conditions, and availability of land for future expansion.

11.2.4 LABOUR SUPPLY

The type and supply of labour available in the vicinity of a proposed plant site must be examined. Considerations must be given to the prevailing pay rates, restrictions on number of hours worked per week, competing industries that can cause dissatisfaction or high turn over rates among the workers, tribalism and variation in the skill and intelligence of workers. In the light of the above considerations, the proposed plant site seems to be the right choice.

11.2.5 TRANSPORTATION FACILITIES

Water, railroad, and highways are the common means of transportation used by major industrial sectors.

The good road network, railroad facility, and the proximity of the regions listed above to the primary market, make it suitable for the citing of the plant in any of these places.

11.2.6 ENERGY AVAILABILITY

Power and steam requirements are high in most industrial plants, and fuel is ordinarily required to supply these utilities. Consequently, power and fuel can be combined as one major factor in the choice of a plant site. The local cost of power can help determine whether power should be purchased or self- generated.

11.2.7 WATER SUPPLY

The process industries use large quantities of water for cooling, washing, steam generation, and as a raw material. The plant, therefore, must be located where a dependable supply of water is available. The level of the existing water table should be checked by consulting the state geological survey, and information on the constancy of the water table and the year-round capacity of local rivers or lakes should be obtained. If the water supply shows seasonal fluctuations, it may be desirable to construct a reservoir or to drill several standby boreholes. The temperature, mineral content, silt or sand content, bacteriological content, and cost of supply and treatment must also be considered when choosing a water supply.

11.2.8 TAXATION AND LEGAL RESTRICTIONS

State and local tax rates on property income, unemployment insurance and similar items vary from one location to another.

Similar, local regulations on zoning, building codes, nuisance aspects, and transportation facilities can have a major influence on the final choice of a plant site.

11.2.9 COMMUNITY FACTORS

The hospitality or otherwise, and facilities of a community can have quite a significant effect on the location of the plant. If a plant is located in a place where certain basic infrastructures for satisfactory living of plant personnel do not exist, it often becomes a burden to subsidize, or worse still, try to provide such facilities. Churches, libraries, schools, civic theatres, concert associations, and other similar groups, if active and dynamic, do much to make a community progressive. The efficiency, disposition, and history of both the state and local governments should be evaluated.

11.3 JUSTIFICATION OF PLANT LOCATION

Having considered the factors discussed above, the citing of the plant in the south-south or south-eastern part of the nation, is definitely not far from justifiable. The nearness and availability of the raw material (ammonia), cheap labour supply, dependable water supply, proximity to the primary market , the good road network and availability of rail lines and so on, makes these regions suitable places for the citing the nitric acid plant.

CHAPTER TWELVE

```
EXECUTIVE SUMMARY (2006 prices)
****************************************************************************
TOTAL CAPITAL INVESTMENT                    115855000   $
CAPITAL INV. CHARGED TO THIS
PROJECT                                     115855000   $
OPERATING COST                              173353000   $/year

PRODUCTION RATE                                  1.83   m^3 per hour

UNIT PRODUCTION COST                            44.16   $/m^3 HNO3

TOTAL REVENUES                              266443000   $/year

GROSS MARGIN                                    34.94   %
RETURN ON INVESTMENT                            56.18   %
PAYBACK TIME                                     1.78   years
IRR AFTER TAXES                                46.02%

NPV (at 7.0 % interest)                     358258000   $
****************************************************************************
```

COSTING

```
MAJOR EQUIPMENT SPECIFICATION AND FOB COST (2006 prices)
************************************************************************************************
                                                                        Unit
Quantity/                                           Description         Cost        Cost
Stand-by                                                                 ($)         ($)
************************************************************************************************

 1/0                                                water Pump           8000        8000


 1/0                                                Mixer               12000       12000


 1/0


 3/0                                                Compressor 1       235500      235500


 1/0                                                Separators 1        64000       64000
```

1/0	Separator 2	65000	65000
1/0			
1/0	Cooler	44000	44000
1/0			
1/0	Reactor 2	90000	90000
3/0	Reactor 1	82000	82000
3/0	Plug Flow Reactor	41000	41000
1/0	Heat Exchanger	10000	10000
1/0	Water Splitter	7000	7000
3/0	Piping	141/m	141000
	Compressor 2	2355500	235500
1/0			
43/0			
1/0	Storage Tank	23000	23000

1/0	Level Controller 1	68000	68000
1/0	Level Controller 2	45000	45000
1/0	Level Controller 3	54000	54000
1/0			
11/0			
8/0			
2/0			
1/0			
3/0			
1/0			

Cost of Unlisted Equipment and other accesories	3058000

****

TOTAL EQUIPMENT PURCHASE COST	4260000

****

FIXED CAPITAL ESTIMATE SUMMARY (2006 prices)

****

A. TOTAL PLANT DIRECT COST (TPDC) (physical cost)

1. Equipment Purchase Cost	#	4260000
2. Installation		8764000
3. Process Piping		5351000
4. Instrumentation		6116000
5. Insulation		459000
6. Electricals		1529000
7. Buildings		6880000
8. Yard Improvement		13323000
9. Auxiliary Facilities		6116000
		******************
	TPDC =	52798000

B. TOTAL PLANT INDIRECT COST (TPIC)

10. Engineering		13200000
11. Construction		18479000
		******************
	TPIC =	31679000

Cost of Unlisted Equipment and other accesories	5462000

****

TOTAL EQUIPMENT PURCHASE COST	6664000

****

FIXED CAPITAL ESTIMATE SUMMARY (2006 prices)

****

A. TOTAL PLANT DIRECT COST (TPDC) (physical cost)

1. Equipment Purchase Cost	#	7497444.444
2. Installation		7823644.444
3. Process Piping		8149844.444
4. Instrumentation		8476044.444
5. Insulation		8802244.444
6. Electricals		9128444.444
7. Buildings		9454644.444
8. Yard Improvement		9780844.444
9. Auxiliary Facilities		10107044.44
		******************
	TPDC =	4965571.429
		-2765571.429
B. TOTAL PLANT INDIRECT COST (TPIC)		-10496714.29
		-18227857.14
10. Engineering		-25959000
11. Construction		-33690142.86

```
                                                  ******************
                                 TPIC =              31679001

Cost of Unlisted Equipment and other accesories                                  7866000

******************************************************************************
TOTAL EQUIPMENT PURCHASE COST                                                    9068000
******************************************************************************


FIXED CAPITAL ESTIMATE SUMMARY (2006 prices)
******************************************************************

A. TOTAL PLANT DIRECT COST (TPDC)  (physical cost)

 1. Equipment Purchase Cost          #            10433244.44
 2. Installation                                  10759444.44
 3. Process Piping                                11085644.44
 4. Instrumentation                               11411844.44
 5. Insulation                                    11738044.44
 6. Electricals                                   12064244.44
 7. Buildings                                     12390444.44
 8. Yard Improvement                              12716644.44
 9. Auxiliary Facilities                          13042844.44

                                                  ******************
                                 TPDC =           -41421285.71
                                                  -49152428.57
B. TOTAL PLANT INDIRECT COST (TPIC)               -56883571.43
                                                  -64614714.29
 10. Engineering                                  -72345857.14
 11. Construction                                    -80077000

                                                  ******************
                                 TPIC =              31679002

Cost of Unlisted Equipment and other accesories                                 10270000

******************************************************************************
TOTAL EQUIPMENT PURCHASE COST                                                   11472000
******************************************************************************


FIXED CAPITAL ESTIMATE SUMMARY (2006 prices)
******************************************************************

A. TOTAL PLANT DIRECT COST (TPDC)  (physical cost)

 1. Equipment Purchase Cost          #            13369044.44
 2. Installation                                  13695244.44
```

3. Process Piping		14021444.44
4. Instrumentation		14347644.44
5. Insulation		14673844.44
6. Electricals		15000044.44
7. Buildings		15326244.44
8. Yard Improvement		15652444.44
9. Auxiliary Facilities		15978644.44
		******************
	TPDC =	-87808142.86
		-95539285.71
B. TOTAL PLANT INDIRECT COST (TPIC)		-103270428.6
		-111001571.4
10. Engineering		-118732714.3
11. Construction		-126463857.1
		******************
	TPIC =	31679003

Cost of Unlisted Equipment and other accesories	12674000
**	
TOTAL EQUIPMENT PURCHASE COST	13876000
**	

FIXED CAPITAL ESTIMATE SUMMARY (2006 prices)

****

A. TOTAL PLANT DIRECT COST (TPDC) (physical cost)

1. Equipment Purchase Cost	#	16304844.44
2. Installation		16631044.44
3. Process Piping		16957244.44
4. Instrumentation		17283444.44
5. Insulation		17609644.44
6. Electricals		17935844.44
7. Buildings		18262044.44
8. Yard Improvement		18588244.44
9. Auxiliary Facilities		18914444.44
		******************
	TPDC =	-134195000
		-141926142.9
B. TOTAL PLANT INDIRECT COST (TPIC)		-149657285.7
		-157388428.6
10. Engineering		-165119571.4
11. Construction		-172850714.3
		******************
	TPIC =	31679004

```
Cost of Unlisted Equipment and other accesories                                   15078000

*****************************************************************************
TOTAL EQUIPMENT PURCHASE COST                                                      16280000
*****************************************************************************


FIXED CAPITAL ESTIMATE SUMMARY (2006 prices)
*****************************************************************

A. TOTAL PLANT DIRECT COST (TPDC)  (physical cost)

 1. Equipment Purchase Cost          #              19240644.44
 2. Installation                                    19566844.44
 3. Process Piping                                  19893044.44



?
 LOAN INFORMATION (thousand US
$)
*****************************************************************************
                                  Direct Fixed   Working       Up Front     Up Front
                                    Capital      Capital       R&D          Royalties

 Amount                                 97149         13848          0            0
 Equity   (%)                             100           100        100          100
 Debt     (%)                               0             0          0            0
 Interest (%)                               9            12         12           12
 Loan Time (yrs)                           10             6          6            6

*****************************************************************************
```

CHAPTER THIRTEEN

CONCLUSION

The objectives of the design, which is to produce 20,000 Litres per day of nitric acid was met. The plant is to be operated for 8hours per working day. The conditions necessary for optimum production were clearly stated.

Also, the economic analysis of the plant indicates that the plant is viable. The estimated capital investment is, S 115855000

The rate of return is, 46.02%

The expected pay-back period is 1.78 years

CHAPTER FOURTEEN

RECOMMENDATIONS

In order to improve on the design of a nitric acid plant, the designer should have all the facts and data, and the project should be carried out under meticulous supervision.

Predictive and routine maintenance of the units involved must be adopted to ensure performance excellence and to extend the life span of the plant.

The plant should be sited reasonably far from the residential area in order to reduce communal risks.

REFERENCES

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TEAM LND
Calgary, Alberta
CANADA

Case Name:	E:\HNO3\nitric plant.hsc
Unit Set:	SI
Date/Time:	Sat Dec 08 21:49:36 2007

Tee: TEE-100

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION	
C.AIR	Compressor	K-100

Outlet Stream

STREAM NAME	TO UNIT OPERATION	
C.AIR.1	Plug Flow Reactor	OXIDATION REACTION
C.AIR.2	Conversion Reactor	REACTOR.1

PARAMETERS

	Flow Ratios	Dynamic Valve Openings
C.AIR.1	0.5000	50.00
C.AIR.2	0.5000	50.00

Valve Control: Multiple Stream

User Variables

RATING

Nozzle Parameters

Base Elevation Relative to Ground Level 0.0000 m *

		C.AIR	C.AIR.1	C.AIR.2
Diameter	(m)	5.000e-002	5.000e-002	5.000e-002
Elevation (Base)	(m)	0.0000	0.0000	0.0000
Elevation (Ground)	(m)	0.0000	0.0000	0.0000

PROPERTIES

C.AIR

		Overall	Vapour Phase
Vapour/Phase Fraction		1.0000	1.0000
Temperature:	(C)	110.9	110.9
Pressure:	(kPa)	200.0 *	200.0
Molar Flow	(kgmole/h)	100.0	100.0
Mass Flow	(kg/h)	2895	2895
Std Ideal Liq Vol Flow	(m3/h)	3.291	3.291
Molar Enthalpy	(kJ/kgmole)	2475	2475
Mass Enthalpy	(kJ/kg)	85.49	85.49
Molar Entropy	(kJ/kgmole-C)	119.8	119.8
Mass Entropy	(kJ/kg-C)	4.140	4.140
Heat Flow	(kJ/h)	2.475e+005	2.475e+005
Molar Density	(kgmole/m3)	6.264e-002	6.264e-002
Mass Density	(kg/m3)	1.813	1.813
Std Ideal Liq Mass Density	(kg/m3)	879.6	879.6
Liq Mass Density @Std Cond	(kg/m3)	—	—
Molar Heat Capacity	(kJ/kgmole-C)	29.22	29.22
Mass Heat Capacity	(kJ/kg-C)	1.009	1.009
Thermal Conductivity	(W/m-K)	3.035e-002	3.035e-002
Viscosity	(cP)	2.269e-002	2.269e-002
Surface Tension	(dyne/cm)	—	—
Molecular Weight		28.95	28.95
Z Factor		0.9999	0.9999

C.AIR.1

		Overall	Vapour Phase
Vapour/Phase Fraction		1.0000	1.0000
Temperature:	(C)	110.9	110.9
Pressure:	(kPa)	200.0	200.0
Molar Flow	(kgmole/h)	50.00 *	50.00
Mass Flow	(kg/h)	1448	1448

Tee: TEE-100 (continued)

PROPERTIES

C.AIR.1

		Overall	Vapour Phase			
Std Ideal Liq Vol Flow	(m3/h)	1.646	1.646			
Molar Enthalpy	(kJ/kgmole)	2475	2475			
Mass Enthalpy	(kJ/kg)	85.49	85.49			
Molar Entropy	(kJ/kgmole-C)	119.8	119.8			
Mass Entropy	(kJ/kg-C)	4.140	4.140			
Heat Flow	(kJ/h)	1.237e+005	1.237e+005			
Molar Density	(kgmole/m3)	6.264e-002	6.264e-002			
Mass Density	(kg/m3)	1.813	1.813			
Std Ideal Liq Mass Density	(kg/m3)	879.6	879.6			
Liq Mass Density @Std Cond	(kg/m3)	---	---			
Molar Heat Capacity	(kJ/kgmole-C)	29.22	29.22			
Mass Heat Capacity	(kJ/kg-C)	1.009	1.009			
Thermal Conductivity	(W/m-K)	3.035e-002	3.035e-002			
Viscosity	(cP)	2.269e-002	2.269e-002			
Surface Tension	(dyne/cm)	---	---			
Molecular Weight		28.95	28.95			
Z Factor		0.9999	0.9999			

C.AIR.2

		Overall	Vapour Phase			
Vapour/Phase Fraction		1.0000	1.0000			
Temperature:	(C)	110.9	110.9			
Pressure:	(kPa)	200.0	200.0			
Molar Flow	(kgmole/h)	50.00	50.00			
Mass Flow	(kg/h)	1448	1448			
Std Ideal Liq Vol Flow	(m3/h)	1.646	1.646			
Molar Enthalpy	(kJ/kgmole)	2475	2475			
Mass Enthalpy	(kJ/kg)	85.49	85.49			
Molar Entropy	(kJ/kgmole-C)	119.8	119.8			
Mass Entropy	(kJ/kg-C)	4.140	4.140			
Heat Flow	(kJ/h)	1.237e+005	1.237e+005			
Molar Density	(kgmole/m3)	6.264e-002	6.264e-002			
Mass Density	(kg/m3)	1.813	1.813			
Std Ideal Liq Mass Density	(kg/m3)	879.6	879.6			
Liq Mass Density @Std Cond	(kg/m3)	---	---			
Molar Heat Capacity	(kJ/kgmole-C)	29.22	29.22			
Mass Heat Capacity	(kJ/kg-C)	1.009	1.009			
Thermal Conductivity	(W/m-K)	3.035e-002	3.035e-002			
Viscosity	(cP)	2.269e-002	2.269e-002			
Surface Tension	(dyne/cm)	---	---			
Molecular Weight		28.95	28.95			
Z Factor		0.9999	0.9999			

DYNAMICS

Dynamic Splits

Outlet Streams	Fractions	VlvOpening
C.AIR.1	0.5000	50.00
C.AIR.2	0.5000	50.00

Holdup Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000	0.0000
Liquid	0.0000	0.0000	0.0000
Aqueous	0.0000	0.0000	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

TEAM LND
Calgary, Alberta
CANADA

Case Name:	E:\HNO3\nitric plant.hsc
Unit Set:	SI
Date/Time:	Sat Dec 08 21:51:01 2007

Conversion Reactor: REACTOR.1

CONNECTIONS

Inlet Stream Connections

Stream Name	From Unit Operation	
C.AMMONIA	Compressor	K-101
C.AIR.2	Tee	TEE-100

Outlet Stream Connections

Stream Name	To Unit Operation	
NO	Heat Exchanger:	HEAT EXCHANGER

Energy Stream Connections

Stream Name	From Unit Operation
Q.RXTR.1	

PARAMETERS

Physical Parameters		Optional Heat Transfer:	Heating
Delta P	**Vessel Volume**	**Duty**	**Energy Stream**
0.0000 kPa *	1.920 m3 *	6.690e+005 kJ/h	Q.RXTR.1

User Variables

REACTION DETAILS

Reaction: main rxn

Component	Mole Weight	Stoichiometric Coeff.
Ammonia	17.03	-4 *
Air	28.95	-5 *
NO	30.01	4 *
H2O	18.02	2 *
Nitrogen	28.01	2 *

REACTION RESULTS FOR : Set-1

Extents

Name	Rank	Specified % Conversion	Use Default	Actual % Conversion	Base Component	Reaction Extent (kgmole/h)
main rxn	0 *	99.00	Yes	99.00	Ammonia	9.900

Balance

Components	Total Inflow (kgmole/h)	Total Reaction (kgmole/h)	Total Outflow (kgmole/h)
Ammonia	40.00	-39.60	0.4000
H2O	0.0000	19.80	19.80
NO2	0.0000	0.0000	0.0000
Nitrogen	0.0000	20.08	20.08
HNO3	0.0000	0.0000	0.0000
NO	0.0000	39.60	39.60
Air	50.00	-49.50	0.5000
Oxygen	0.0000	0.0000	0.0000

RATING

Sizing

Cylinder		Vertical		Reactor has a Boot: No	
Volume	1.920 m3 *	Diameter	1.177 m	Height	1.765

Nozzles

Base Elevation Relative to Ground Level	0.0000 m *	Diameter	1.177 m	Height	1.765

		C.AMMONIA	C.AIR.2	NO
Diameter	(m)	8.826e-002	8.826e-002	8.826e-002
Elevation (Base)	(m)	0.8826	0.8826	1.765

Conversion Reactor: REACTOR.1 (continued)

Elevation (Ground)	(m)	0.8826	0.8826	1.765
Elevation (% of Height)	(%)	50.00	50.00	100.00
Diameter	(m)	8.826e-002		
Elevation (Base)	(m)	0.0000		
Elevation (Ground)	(m)	0.0000		
Elevation (% of Height)	(%)	0.00		

PROPERTIES

C.AMMONIA

		Overall	Vapour Phase			
Vapour/Phase Fraction		1.0000	1.0000			
Temperature:	(C)	68.84	68.84			
Pressure:	(kPa)	200.0 *	200.0			
Molar Flow	(kgmole/h)	40.00	40.00			
Mass Flow	(kg/h)	681.2	681.2			
Std Ideal Liq Vol Flow	(m3/h)	1.106	1.106			
Molar Enthalpy	(kJ/kgmole)	-4.421e+004	-4.421e+004			
Mass Enthalpy	(kJ/kg)	-2596	-2596			
Molar Entropy	(kJ/kgmole-C)	169.7	169.7			
Mass Entropy	(kJ/kg-C)	9.967	9.967			
Heat Flow	(kJ/h)	-1.769e+006	-1.769e+006			
Molar Density	(kgmole/m3)	7.114e-002	7.114e-002			
Mass Density	(kg/m3)	1.212	1.212			
Std Ideal Liq Mass Density	(kg/m3)	616.1	616.1			
Liq Mass Density @Std Cond	(kg/m3)	612.3	612.3			
Molar Heat Capacity	(kJ/kgmole-C)	37.19	37.19			
Mass Heat Capacity	(kJ/kg-C)	2.184	2.184			
Thermal Conductivity	(W/m-K)	3.198e-002	3.198e-002			
Viscosity	(cP)	9.719e-003	9.719e-003			
Surface Tension	(dyne/cm)	---	---			
Molecular Weight		17.03	17.03			
Z Factor		0.9887	0.9887			

C.AIR.2

		Overall	Vapour Phase			
Vapour/Phase Fraction		1.0000	1.0000			
Temperature:	(C)	110.9	110.9			
Pressure:	(kPa)	200.0	200.0			
Molar Flow	(kgmole/h)	50.00	50.00			
Mass Flow	(kg/h)	1448	1448			
Std Ideal Liq Vol Flow	(m3/h)	1.646	1.646			
Molar Enthalpy	(kJ/kgmole)	2475	2475			
Mass Enthalpy	(kJ/kg)	85.49	85.49			
Molar Entropy	(kJ/kgmole-C)	119.8	119.8			
Mass Entropy	(kJ/kg-C)	4.140	4.140			
Heat Flow	(kJ/h)	1.237e+005	1.237e+005			
Molar Density	(kgmole/m3)	6.264e-002	6.264e-002			
Mass Density	(kg/m3)	1.813	1.813			
Std Ideal Liq Mass Density	(kg/m3)	879.6	879.6			
Liq Mass Density @Std Cond	(kg/m3)	---	---			
Molar Heat Capacity	(kJ/kgmole-C)	29.22	29.22			
Mass Heat Capacity	(kJ/kg-C)	1.009	1.009			
Thermal Conductivity	(W/m-K)	3.035e-002	3.035e-002			
Viscosity	(cP)	2.269e-002	2.269e-002			
Surface Tension	(dyne/cm)	---	---			
Molecular Weight		28.95	28.95			
Z Factor		0.9999	0.9999			

		Overall	Vapour Phase	Liquid Phase		
Vapour/Phase Fraction		0.0000	0.0000	1.0000		
Temperature:	(C)	120.0 *	120.0	120.0		

Conversion Reactor: REACTOR.1 (continued)

PROPERTIES

	Overall	Vapour Phase	Liquid Phase		
Pressure: (kPa)	200.0	200.0	200.0		
Molar Flow (kgmole/h)	0.0000	0.0000	0.0000		
Mass Flow (kg/h)	0.0000	0.0000	0.0000		
Std Ideal Liq Vol Flow (m3/h)	0.0000	0.0000	0.0000		
Molar Enthalpy (kJ/kgmole)	-2.774e+005	-1.214e+004	-2.774e+005		
Mass Enthalpy (kJ/kg)	-1.540e+004	-458.4	-1.540e+004		
Molar Entropy (kJ/kgmole-C)	75.85	171.6	75.85		
Mass Entropy (kJ/kg-C)	4.211	6.481	4.211		
Heat Flow (kJ/h)	0.0000	0.0000	0.0000		
Molar Density (kgmole/m3)	43.61	6.129e-002	43.61		
Mass Density (kg/m3)	785.5	1.623	785.5		
Std Ideal Liq Mass Density (kg/m3)	996.5	120.0	996.5		
Liq Mass Density @Std Cond (kg/m3)	1014	—	1014		
Molar Heat Capacity (kJ/kgmole-C)	75.11	31.27	75.11		
Mass Heat Capacity (kJ/kg-C)	4.170	1.181	4.170		
Thermal Conductivity (W/m-K)	0.6886	3.153e-002	0.6886		
Viscosity (cP)	0.1826	2.057e-002	0.1826		
Surface Tension (dyne/cm)	54.65	—	54.65		
Molecular Weight	18.01	26.48	18.01		
Z Factor	1.403e-003	0.9983	1.403e-003		

NO

	Overall	Vapour Phase	Liquid Phase		
Vapour/Phase Fraction	1.0000	1.0000	0.0000		
Temperature: (C)	120.0	120.0	120.0		
Pressure: (kPa)	200.0	200.0	200.0		
Molar Flow (kgmole/h)	80.38	80.38	0.0000		
Mass Flow (kg/h)	2129	2129	0.0000		
Std Ideal Liq Vol Flow (m3/h)	17.74	17.74	0.0000		
Molar Enthalpy (kJ/kgmole)	-1.214e+004	-1.214e+004	-2.774e+005		
Mass Enthalpy (kJ/kg)	-458.4	-458.4	-1.540e+004		
Molar Entropy (kJ/kgmole-C)	171.6	171.6	75.85		
Mass Entropy (kJ/kg-C)	6.481	6.481	4.211		
Heat Flow (kJ/h)	-9.759e+005	-9.759e+005	0.0000		
Molar Density (kgmole/m3)	6.129e-002	6.129e-002	43.61		
Mass Density (kg/m3)	1.623	1.623	785.5		
Std Ideal Liq Mass Density (kg/m3)	120.0	120.0	996.5		
Liq Mass Density @Std Cond (kg/m3)	—	—	1014		
Molar Heat Capacity (kJ/kgmole-C)	31.27	31.27	75.11		
Mass Heat Capacity (kJ/kg-C)	1.181	1.181	4.170		
Thermal Conductivity (W/m-K)	3.153e-002	3.153e-002	0.6886		
Viscosity (cP)	2.057e-002	2.057e-002	0.1826		
Surface Tension (dyne/cm)	—	—	54.65		
Molecular Weight	26.48	26.48	18.01		
Z Factor	0.9983	0.9983	1.403e-003		

DYNAMICS

Vessel Parameters: Initialize from Product

Vessel Volume (m3)	1.920 *	Level Calculator	Vertical cylinder
Vessel Diameter (m)	1.177	Fraction Calculator	Use levels and nozzles
Vessel Height (m)	1.765	Feed Delta P (kPa)	0.0000 *
Liquid Level Percent (%)	50.00	Vessel Pressure (kPa)	200.0

Holdup: Vessel Levels

Phase	Level (m)	Percent (%)	Volume (m3)
Vapour	—	—	0.0000
Liquid	—	—	0.0000

Conversion Reactor: REACTOR.1 (continued)

Phase	Level (m)	Percent (%)	Volume (m3)
Aqueous	---	---	0.0000

Holdup: Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000	0.0000
Liquid	0.0000	0.0000	0.0000
Aqueous	0.0000	0.0000	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

Duty Valve Source : Direct_Q

SP (kJ/h)	Min. Available (kJ/h)	Max. Available (kJ/h)
6.690e+005	---	---

Liquid Heater Height as % of Vessel Volume

Top of Heater : 5.00 %	Bottom of Heater : 0.00 %

Heat Flow Into the PFR: Heating

NOTES

Heat Exchanger: HEAT EXCHANGER

RATING

Sizing

Overall Data

Configuration

# of Shells in Series	1 *	Tube Passes per Shell	2 *	Elevation (Base)	0.0000 m *
# of Shells in Parallel	1 *	Exchange Orientation	Horizontal	First Tube Pass Flow Direction	Counter

TEMA Type:	A	E	L

Calculated Information

Shell HT Coeff	---	Overall U	.5 kJ/h-m2-C	Shell DP	0.0000 kPa *	Shell Vol per Shell	2.272 m3	HT Area per Shell 60.32 m2
Tube HT Coeff	---	Overall UA	+004 kJ/C-h	Tube DP	0.0000 kPa *	Tube Vol per Shell	0.1930 m3	

Shell Data

Shell and Tube Bundle

Shell Diameter	739.0 mm *	Tube Pitch	50.00 mm *	Shell Fouling	0.0000 C-h-m2/kJ *
# of Tubes per Shell	160 *	Tube Layout Angle			Triangular (30 degrees)

Shell Baffles

Shell Baffle Type	Single	Shell Baffle Orientation	Horizontal	Baffle Cut (%Area)	20.00 *	Baffle Spacing	800.0 mm *

Tube Data

Dimensions

OD	20.00 mm *	ID	16.00 mm *	Tube Thickness	2.000 mm	Tube Length	6.000 m *

Tube Properties

Tube Fouling	0.0000 C-h-m2/kJ *	Thermal Cond.	45.00 W/m-K *	Wall Cp	---	Wall Density	---

Nozzle Parameters

Base Elevation Relative to Ground Level 0.0000 m *

		NO	WATER.1	COOL.NITRC_OXIDE
Diameter	(m)	5.000e-002	5.000e-002	5.000e-002
Elevation (Base)	(m)	0.0000	0.0000	0.0000
Elevation (Ground)	(m)	0.0000	0.0000	0.0000
Elevation (% of Height)	(%)	0.00	0.00	0.00
		S.WATER.1		
Diameter	(m)	5.000e-002		
Elevation (Base)	(m)	0.0000		
Elevation (Ground)	(m)	0.0000		
Elevation (% of Height)	(%)	0.00		

PROPERTIES

NO

		Overall	Vapour Phase	Liquid Phase		
Vapour/Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	120.0	120.0	120.0		
Pressure:	(kPa)	200.0	200.0	200.0		
Molar Flow	(kgmole/h)	80.38	80.38	0.0000		
Mass Flow	(kg/h)	2129	2129	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	17.74	17.74	0.0000		
Molar Enthalpy	(kJ/kgmole)	-1.214e+004	-1.214e+004	-2.774e+005		
Mass Enthalpy	(kJ/kg)	-458.4	-458.4	-1.540e+004		
Molar Entropy	(kJ/kgmole-C)	171.6	171.6	75.85		
Mass Entropy	(kJ/kg-C)	6.481	6.481	4.211		
Heat Flow	(kJ/h)	-9.759e+005	-9.759e+005	0.0000		
Molar Density	(kgmole/m3)	6.129e-002	6.129e-002	43.61		
Mass Density	(kg/m3)	1.623	1.623	785.5		
Std Ideal Liq Mass Density	(kg/m3)	120.0	120.0	996.5		
Liq Mass Density @Std Cond	(kg/m3)	---	---	1014		
Molar Heat Capacity	(kJ/kgmole-C)	31.27	31.27	75.11		
Mass Heat Capacity	(kJ/kg-C)	1.181	1.181	4.170		
Thermal Conductivity	(W/m-K)	3.153e-002	3.153e-002	0.6886		
Viscosity	(cP)	2.057e-002	2.057e-002	0.1826		
Surface Tension	(dyne/cm)	---	---	54.65		
Molecular Weight		26.48	26.48	18.01		
Z Factor		0.9983	0.9983	1.403e-003		

Heat Exchanger: HEAT EXCHANGER (continued)

COOL.NITRC_OXIDE

	Overall	Vapour Phase	Aqueous Phase
Vapour/Phase Fraction	0.7823	0.7823	0.2177
Temperature: (C)	40.00	40.00	40.00
Pressure: (kPa)	200.0	200.0	200.0
Molar Flow (kgmole/h)	80.38	62.88	17.50
Mass Flow (kg/h)	2129	1814	315.2
Std Ideal Liq Vol Flow (m3/h)	17.74	17.43	0.3167
Molar Enthalpy (kJ/kgmole)	-2.399e+004	4.799e+004	-2.827e+005
Mass Enthalpy (kJ/kg)	-905.9	1664	-1.569e+004
Molar Entropy (kJ/kgmole-C)	137.0	158.6	59.28
Mass Entropy (kJ/kg-C)	5.172	5.498	3.292
Heat Flow (kJ/h)	-1.928e+006	3.018e+006	-4.946e+006
Molar Density (kgmole/m3)	9.825e-002	7.689e-002	55.15
Mass Density (kg/m3)	2.602	2.218	993.2
Std Ideal Liq Mass Density (kg/m3)	120.0	104.1	995.0
Liq Mass Density @Std Cond (kg/m3)	---	---	1012
Molar Heat Capacity (kJ/kgmole-C)	39.33	30.01	72.82
Mass Heat Capacity (kJ/kg-C)	1.485	1.040	4.043
Thermal Conductivity (W/m-K)	---	2.717e-002	0.6304
Viscosity (cP)	---	2.171e-002	0.6847
Surface Tension (dyne/cm)	---	---	69.26
Molecular Weight	26.48	28.84	18.01
Z Factor	---	0.9990	1.393e-003

WATER.1

	Overall	Aqueous Phase
Vapour/Phase Fraction	0.0000	1.0000
Temperature: (C)	25.00	25.00
Pressure: (kPa)	130.0	130.0
Molar Flow (kgmole/h)	640.4	640.4
Mass Flow (kg/h)	1.154e+004	1.154e+004
Std Ideal Liq Vol Flow (m3/h)	11.56	11.56
Molar Enthalpy (kJ/kgmole)	-2.848e+005	-2.848e+005
Mass Enthalpy (kJ/kg)	-1.581e+004	-1.581e+004
Molar Entropy (kJ/kgmole-C)	55.43	55.43
Mass Entropy (kJ/kg-C)	3.077	3.077
Heat Flow (kJ/h)	-1.824e+008	-1.824e+008
Molar Density (kgmole/m3)	55.92	55.92
Mass Density (kg/m3)	1007	1007
Std Ideal Liq Mass Density (kg/m3)	998.0	998.0
Liq Mass Density @Std Cond (kg/m3)	1015	1015
Molar Heat Capacity (kJ/kgmole-C)	72.84	72.84
Mass Heat Capacity (kJ/kg-C)	4.043	4.043
Thermal Conductivity (W/m-K)	0.6110	0.6110
Viscosity (cP)	0.8904	0.8904
Surface Tension (dyne/cm)	72.10	72.10
Molecular Weight	18.02	18.02
Z Factor	9.379e-004	9.379e-004

S.WATER.1

	Overall	Aqueous Phase
Vapour/Phase Fraction	0.0000	1.0000
Temperature: (C)	45.44	45.44
Pressure: (kPa)	130.0	130.0
Molar Flow (kgmole/h)	640.4	640.4
Mass Flow (kg/h)	1.154e+004	1.154e+004
Std Ideal Liq Vol Flow (m3/h)	11.56	11.56
Molar Enthalpy (kJ/kgmole)	-2.833e+005	-2.833e+005
Mass Enthalpy (kJ/kg)	-1.573e+004	-1.573e+004
Molar Entropy (kJ/kgmole-C)	60.26	60.26
Mass Entropy (kJ/kg-C)	3.345	3.345
Heat Flow (kJ/h)	-1.814e+008	-1.814e+008

Heat Exchanger: HEAT EXCHANGER (continued)

S.WATER.1

	Overall	Aqueous Phase			
Molar Density (kgmole/m3)	55.05	55.05			
Mass Density (kg/m3)	991.8	991.8			
Std Ideal Liq Mass Density (kg/m3)	998.0	998.0			
Liq Mass Density @Std Cond (kg/m3)	1015	1015			
Molar Heat Capacity (kJ/kgmole-C)	72.78	72.78			
Mass Heat Capacity (kJ/kg-C)	4.040	4.040			
Thermal Conductivity (W/m-K)	0.6381	0.6381			
Viscosity (cP)	0.5892	0.5892			
Surface Tension (dyne/cm)	68.54	68.54			
Molecular Weight	18.02	18.02			
Z Factor	8.915e-004	8.915e-004			

Stream Properties

	NO	COOL.NITRC_OXIDE	WATER.1	S.WATER.1
Vapour Fraction	1.0000	0.7823	0.0000	0.0000
Temperature	120.0	40.00 *	25.00	45.44
Pressure	200.0	200.0	130.0	130.0
Enthalpy	-1.214e+004	-2.399e+004	-2.848e+005	-2.833e+005
Molar Flow	80.38	80.38	640.4	640.4
MassFlow	2129	2129	1.154e+004	1.154e+004
Std Ideal Liq Vol Flow	17.74	17.74	11.56	11.56
HeatFlow	-9.759e+005	-1.928e+006	-1.824e+008	-1.814e+008

DETAILS

Overall/Detailed Performance

Duty:	9.526e+05 kJ/h	UA:	3.001e+04 kJ/C-h	UA Curv. Error:	1.18e+02 kJ/C-h	Ft Factor:	---
Heat Leak:	0.000e-01 kJ/h	Min. Approach:	15.00 C	Hot Pinch Temp:	40.00 C	Uncorrected Lmtd:	---
Heat Loss:	0.000e-01 kJ/h	Lmtd:	31.75 C	Cold Pinch Temp:	25.00 C		

TABLES

Shell Side

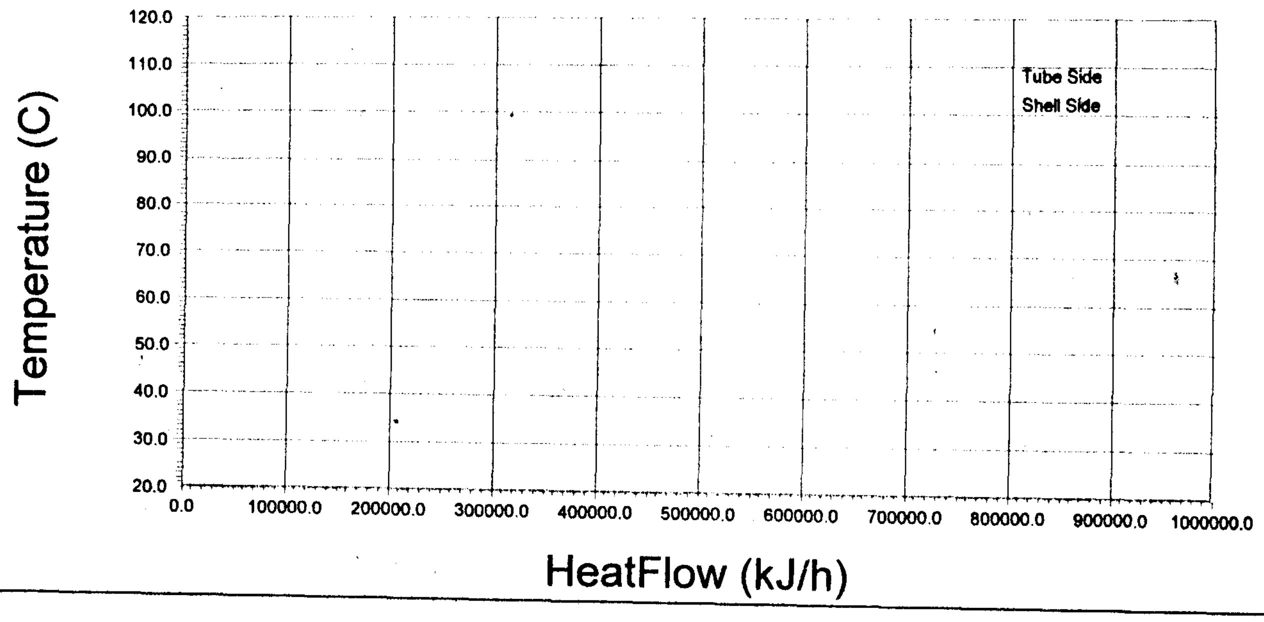
Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)	Molar Vap Frac	Mass Vap Frac
25.00	130.00	0.00	-284784.85	0.0000	0.0000
29.09	130.00	190527.04	-284487.32	0.0000	0.0000
33.17	130.00	380974.36	-284189.92	0.0000	0.0000
37.26	130.00	571477.75	-283892.44	0.0000	0.0000
41.35	130.00	762035.81	-283594.87	0.0000	0.0000
45.44	130.00	952635.19	-283297.23	0.0000	0.0000

Tube Side

Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)	Molar Vap Frac	Mass Vap Frac
40.00	200.00	0.00	-23992.45	0.7823	0.8519
56.13	200.00	190527.04	-21622.09	0.8233	0.8798
66.16	200.00	381054.08	-19251.74	0.8707	0.9121
73.16	200.00	571581.11	-16881.38	0.9214	0.9466
78.40	200.00	762108.15	-14511.03	0.9742	0.9824
120.00	200.00	952635.19	-12140.67	1.0000	1.0000

Heat Flow vs Temp

Heat Exchanger: HEAT EXCHANGER (continued)



Separator: 2_PHASE SEPARATOR

RATING

Sizing

Cylinder		Vertical		Separator has a Boot: No	
Volume	0.6227 m3	Diameter	0.6096 m *	Height	2.134 *

Nozzles

Base Elevation Relative to Ground Level	0.0000 m *	Diameter	0.6096 m *	Height	2.134 *

		COOL.NITRC_OXIDE	NITRIC_OXIDE	WATER,
Diameter	(m)	0.1067	0.1067	0.1067
Elevation (Base)	(m)	1.067	2.134	0.0000
Elevation (Ground)	(m)	1.067	2.134	0.0000
Elevation (% of Height)	(%)	50.00	100.00	0.00

Detailed Heat Loss Parameters

Overall Heat Loss (kJ/h)	0.0000	Area (m2)	4.086

Temperature Profile

Fluid (C)	0.0000 *	Inner Wall (C)	25.00	Outer Vessel (C)	25.00	Outer Insulation (C)	25.00	Ambient (C)	25.00

Conduction

		Metal	Insulation
Thickness	(m)	1.000e-002	3.000e-002
Cp	(kJ/kg-C)	0.4730	0.8200
Density	(kg/m3)	7801	520.0
Conductivity	(W/m-K)	45.00	0.1500

Convection

Inside Vap Phase U (kJ/h-m2-C)	7200	Inside Liq Phase U (kJ/h-m2-C)	---	Outside U (kJ/h-m2-C)	54.00

Level Taps: Level Tap Specification

Level Tap	PV High	PV Low	OP High	OP Low

Level Taps: Calculated Level Tap Values

Level Tap	Liquid Level	Aqueous Level

Options

PV Work Term Contribution	(%)	100.00 *	

PROPERTIES

COOL.NITRC_OXIDE

		Overall	Vapour Phase	Aqueous Phase		
Vapour/Phase Fraction		0.7823	0.7823	0.2177		
Temperature:	(C)	40.00 *	40.00	40.00		
Pressure:	(kPa)	200.0	200.0	200.0		
Molar Flow	(kgmole/h)	80.38	62.88	17.50		
Mass Flow	(kg/h)	2129	1814	315.2		
Std Ideal Liq Vol Flow	(m3/h)	17.74	17.43	0.3167		
Molar Enthalpy	(kJ/kgmole)	-2.399e+004	4.799e+004	-2.827e+005		
Mass Enthalpy	(kJ/kg)	-905.9	1664	-1.569e+004		
Molar Entropy	(kJ/kgmole-C)	137.0	158.6	59.28		
Mass Entropy	(kJ/kg-C)	5.172	5.498	3.292		
Heat Flow	(kJ/h)	-1.928e+006	3.018e+006	-4.946e+006		
Molar Density	(kgmole/m3)	9.825e-002	7.689e-002	55.15		
Mass Density	(kg/m3)	2.602	2.218	993.2		
Std Ideal Liq Mass Density	(kg/m3)	120.0	104.1	995.0		
Liq Mass Density @Std Cond	(kg/m3)	---	---	1012		
Molar Heat Capacity	(kJ/kgmole-C)	39.33	30.01	72.82		
Mass Heat Capacity	(kJ/kg-C)	1.485	1.040	4.043		
Thermal Conductivity	(W/m-K)	---	2.717e-002	0.6304		
Viscosity	(cP)	---	2.171e-002	0.6847		
Surface Tension	(dyne/cm)	---	---	69.26		
Molecular Weight		26.48	28.84	18.01		
Z Factor		---	0.9990	1.393e-003		

Separator: 2_PHASE SEPARATOR (continued)

NITRIC_OXIDE

	Overall	Vapour Phase	Aqueous Phase		
Vapour/Phase Fraction	1.0000	1.0000	0.0000		
Temperature: (C)	40.00	40.00	40.00		
Pressure: (kPa)	200.0	200.0	200.0		
Molar Flow (kgmole/h)	62.88	62.88	0.0000		
Mass Flow (kg/h)	1814	1814	0.0000		
Std Ideal Liq Vol Flow (m3/h)	17.43	17.43	0.0000		
Molar Enthalpy (kJ/kgmole)	4.799e+004	4.799e+004	-2.827e+005		
Mass Enthalpy (kJ/kg)	1664	1664	-1.569e+004		
Molar Entropy (kJ/kgmole-C)	158.6	158.6	59.28		
Mass Entropy (kJ/kg-C)	5.498	5.498	3.292		
Heat Flow (kJ/h)	3.018e+006	3.018e+006	0.0000		
Molar Density (kgmole/m3)	7.689e-002	7.689e-002	55.15		
Mass Density (kg/m3)	2.218	2.218	993.2		
Std Ideal Liq Mass Density (kg/m3)	104.1	104.1	995.0		
Liq Mass Density @Std Cond (kg/m3)	---	---	1012		
Molar Heat Capacity (kJ/kgmole-C)	30.01	30.01	72.82		
Mass Heat Capacity (kJ/kg-C)	1.040	1.040	4.043		
Thermal Conductivity (W/m-K)	2.717e-002	2.717e-002	0.6304		
Viscosity (cP)	2.171e-002	2.171e-002	0.6847		
Surface Tension (dyne/cm)	---	---	69.26		
Molecular Weight	28.84	28.84	18.01		
Z Factor	0.9990	0.9990	1.393e-003		

WATER,

	Overall	Vapour Phase	Aqueous Phase		
Vapour/Phase Fraction	0.0000	0.0000	1.0000		
Temperature: (C)	40.00	40.00	40.00		
Pressure: (kPa)	200.0	200.0	200.0		
Molar Flow (kgmole/h)	17.50	0.0000	17.50		
Mass Flow (kg/h)	315.2	0.0000	315.2		
Std Ideal Liq Vol Flow (m3/h)	0.3167	0.0000	0.3167		
Molar Enthalpy (kJ/kgmole)	-2.827e+005	4.799e+004	-2.827e+005		
Mass Enthalpy (kJ/kg)	-1.569e+004	1664	-1.569e+004		
Molar Entropy (kJ/kgmole-C)	59.28	158.6	59.28		
Mass Entropy (kJ/kg-C)	3.292	5.498	3.292		
Heat Flow (kJ/h)	-4.946e+006	0.0000	-4.946e+006		
Molar Density (kgmole/m3)	55.15	7.689e-002	55.15		
Mass Density (kg/m3)	993.2	2.218	993.2		
Std Ideal Liq Mass Density (kg/m3)	995.0	104.1	995.0		
Liq Mass Density @Std Cond (kg/m3)	1012	---	1012		
Molar Heat Capacity (kJ/kgmole-C)	72.82	30.01	72.82		
Mass Heat Capacity (kJ/kg-C)	4.043	1.040	4.043		
Thermal Conductivity (W/m-K)	0.6304	2.717e-002	0.6304		
Viscosity (cP)	0.6847	2.171e-002	0.6847		
Surface Tension (dyne/cm)	69.26	---	69.26		
Molecular Weight	18.01	28.84	18.01		
Z Factor	1.393e-003	0.9990	1.393e-003		

Inlet Stream

		COOL.NITRC_OXIDE		
Vapour Fraction		0.7823		
Temperature	(C)	40.00 *		
Pressure	(kPa)	200.0		
Molar Flow	(kgmole/h)	80.38		
MassFlow	(kg/h)	2129		
Std Ideal Liq Vol Flow	(m3/h)	17.74		
HeatFlow	(kJ/h)	-1.928e+006		

Outlet Stream

	WATER,	NITRIC_OXIDE		
Vapour Fraction	0.0000	1.0000		

Separator: 2_PHASE SEPARATOR (continued)

		WATER,	NITRIC_OXIDE		
Temperature	(C)	40.00	40.00		
Pressure	(kPa)	200.0	200.0		
Molar Flow	(kgmole/h)	17.50	62.88		
MassFlow	(kg/h)	315.2	1814		
Std Ideal Liq Vol Flow	(m3/h)	0.3167	17.43		
HeatFlow	(kJ/h)	-4.946e+006	3.018e+006		

DYNAMICS

Vessel Parameters: Initialize from Product

Vessel Volume	(m3)	0.6227	Level Calculator		Vertical cylinder
Vessel Diameter	(m)	0.6096 *	Fraction Calculator		Use levels and nozzles
Vessel Height	(m)	2.134 *	Feed Delta P	(kPa)	0.0000 *
Liquid Level Percent	(%)	85.00 *	Vessel Pressure	(kPa)	200.0

Holdup: Vessel Levels

Phase	Level (m)	Percent (%)	Volume (m3)
Vapour	---	---	0.0000
Liquid	---	---	0.0000
Aqueous	---	---	0.0000

Holdup: Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000 *	0.0000
Liquid	0.0000	0.0000 *	0.0000
Aqueous	0.0000	0.0000 *	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

HYPROTECH LIFECYCLE INNOVATION	TEAM LND Calgary, Alberta CANADA	Case Name:	E:\HNO3\nitric plant.hsc
		Unit Set:	SI
		Date/Time:	Mon Dec 10 15:00:40 2007

Plug Flow Reactor: OXIDATION REACTION

RATING

Sizing

Tube Dimensions

Total Volume .540e-003 m3	Length 6.000 m *	Diameter .000e-002 m *	Number of Tubes 1 *	Wall Thickness 5.000e-003 m *

Tube Packing

Void Fraction 1.0000 *	Void Volume 7.540e-003 m3

Nozzle Parameters

Base Elevation Relative to Ground Level 0.0000 m *	Diameter 4.000e-002 m *	Length 6.000 *

		NO2	C.AIR.1	NITRIC_OXIDE	
Diameter	(m)	5.000e-002	5.000e-002	5.000e-002	
Elevation (Base)	(m)	0.0000	0.0000	0.0000	
Elevation (Ground)	(m)	0.0000	0.0000	0.0000	

Conditions

Length (m)	Temperature (C)	Pressure (kPa)	Vapour Fraction	Duty (kJ/h)
0.150	485.9	200.00	1.0000	0
0.450	486.4	200.00	1.0000	0
0.750	486.4	200.00	1.0000	0
1.050	486.5	200.00	1.0000	0
1.350	486.6	200.00	1.0000	0
1.650	486.6	200.00	1.0000	0
1.950	486.6	200.00	1.0000	0
2.250	486.7	200.00	1.0000	0
2.550	486.7	200.00	1.0000	0
2.850	486.7	200.00	1.0000	0
3.150	486.7	200.00	1.0000	0
3.450	486.7	200.00	1.0000	0
3.750	486.7	200.00	1.0000	0
4.050	486.7	200.00	1.0000	0
4.350	486.7	200.00	1.0000	0
4.650	486.7	200.00	1.0000	0
4.950	486.7	200.00	1.0000	0
5.250	486.7	200.00	1.0000	0
5.550	486.7	200.00	1.0000	0
5.850	486.7	200.00	1.0000	0

Length (m)	Enthalpy (kJ/kgmole)	Entropy (kJ/kgmole-C)	Inside HTC (kJ/h-m2-C)	Overall HTC (kJ/h-m2-C)
0.150	41754	195.66	---	---
0.450	42145	195.72	---	---
0.750	42197	195.69	---	---
1.050	42211	195.69	---	---
1.350	42217	195.68	---	---
1.650	42221	195.68	---	---
1.950	42223	195.68	---	---
2.250	42224	195.68	---	---
2.550	42225	195.68	---	---
2.850	42226	195.68	---	---
3.150	42226	195.68	---	---
3.450	42227	195.68	---	---
3.750	42227	195.68	---	---
4.050	42227	195.68	---	---
4.350	42227	195.68	---	---
4.650	42226	195.68	---	---
4.950	42226	195.68	---	---
5.250	42226	195.68	---	---
5.550	42226	195.68	---	---
5.850	42226	195.68	---	---

Plug Flow Reactor: OXIDATION REACTION (continued)

Flows

Length (m)	Molar Flow (kgmole/h)	Mass Flow (kg/h)	Volumetric Flow (m3/h)	Heat Flow (kJ/h)
0.150	75.237	3261.04	2374.547	3.141e+006
0.450	74.540	3261.04	2353.867	3.141e+006
0.750	74.449	3261.04	2351.203	3.141e+006
1.050	74.423	3261.04	2350.616	3.141e+006
1.350	74.412	3261.04	2350.450	3.141e+006
1.650	74.406	3261.04	2350.404	3.141e+006
1.950	74.403	3261.04	2350.398	3.141e+006
2.250	74.401	3261.04	2350.407	3.141e+006
2.550	74.399	3261.04	2350.422	3.141e+006
2.850	74.398	3261.04	2350.464	3.142e+006
3.150	74.397	3261.04	2350.480	3.142e+006
3.450	74.396	3261.04	2350.495	3.142e+006
3.750	74.396	3261.04	2350.509	3.142e+006
4.050	74.395	3261.04	2350.495	3.141e+006
4.350	74.395	3261.04	2350.483	3.141e+006
4.650	74.395	3261.04	2350.473	3.141e+006
4.950	74.395	3261.04	2350.465	3.141e+006
5.250	74.394	3261.04	2350.458	3.141e+006
5.550	74.394	3261.04	2350.451	3.141e+006
5.850	74.394	3261.04	2350.446	3.141e+006

Segment Overall Reaction Rates (kgmole/m3-s)

Length (m)	OXIDATION RXN 1	OXIDATION RXN.2		
0.1500	14.38	10.96		
0.4500	0.1599	0.3028		
0.7500	2.126e-002	3.951e-002		
1.050	6.828e-003	1.043e-002		
1.350	3.227e-003	3.985e-003		
1.650	1.868e-003	1.889e-003		
1.950	1.219e-003	1.027e-003		
2.250	8.607e-004	6.140e-004		
2.550	6.413e-004	3.924e-004		
2.850	4.969e-004	2.638e-004		
3.150	3.966e-004	1.843e-004		
3.450	3.239e-004	1.327e-004		
3.750	2.693e-004	9.801e-005		
4.050	2.273e-004	7.384e-005		
4.350	1.942e-004	5.657e-005		
4.650	1.676e-004	4.396e-005		
4.950	1.459e-004	3.458e-005		
5.250	1.280e-004	2.749e-005		
5.550	1.130e-004	2.205e-005		
5.850	1.002e-004	1.782e-005		

Component Production Rates (kgmole/m3-s)

Length (m)	Ammonia	H2O	NO2	Nitrogen
0.1500	0.0000	0.0000	48.26	-10.96
0.4500	0.0000	0.0000	0.8746	-0.3028
0.7500	0.0000	0.0000	0.1149	-3.951e-002
1.050	0.0000	0.0000	3.269e-002	-1.043e-002
1.350	0.0000	0.0000	1.368e-002	-3.985e-003
1.650	0.0000	0.0000	7.139e-003	-1.889e-003
1.950	0.0000	0.0000	4.277e-003	-1.027e-003
2.250	0.0000	0.0000	2.811e-003	-6.140e-004
2.550	0.0000	0.0000	1.973e-003	-3.924e-004
2.850	0.0000	0.0000	1.453e-003	-2.638e-004
3.150	0.0000	0.0000	1.111e-003	-1.843e-004
3.450	0.0000	0.0000	8.742e-004	-1.327e-004
3.750	0.0000	0.0000	7.039e-004	-9.801e-005
4.050	0.0000	0.0000	5.775e-004	-7.384e-005

Plug Flow Reactor: OXIDATION REACTION (continued)

Component Production Rates (kgmole/m3-s)

Length (m)	Ammonia	H2O	NO2	Nitrogen
4.350	0.0000	0.0000	4.812e-004	-5.657e-005
4.650	0.0000	0.0000	4.063e-004	-4.396e-005
4.950	0.0000	0.0000	3.468e-004	-3.458e-005
5.250	0.0000	0.0000	2.988e-004	-2.749e-005
5.550	0.0000	0.0000	2.596e-004	-2.205e-005
5.850	0.0000	0.0000	2.271e-004	-1.782e-005

Length (m)	HNO3	NO	Air	Oxygen
0.1500	0.0000	-28.75	-36.29	0.0000
0.4500	0.0000	-0.3197	-0.7654	0.0000
0.7500	0.0000	-4.251e-002	-0.1003	0.0000
1.050	0.0000	-1.366e-002	-2.770e-002	0.0000
1.350	0.0000	-6.455e-003	-1.120e-002	0.0000
1.650	0.0000	-3.736e-003	-5.646e-003	0.0000
1.950	0.0000	-2.439e-003	-3.274e-003	0.0000
2.250	0.0000	-1.721e-003	-2.089e-003	0.0000
2.550	0.0000	-1.283e-003	-1.426e-003	0.0000
2.850	0.0000	-9.938e-004	-1.024e-003	0.0000
3.150	0.0000	-7.932e-004	-7.652e-004	0.0000
3.450	0.0000	-6.477e-004	-5.894e-004	0.0000
3.750	0.0000	-5.387e-004	-4.654e-004	0.0000
4.050	0.0000	-4.547e-004	-3.750e-004	0.0000
4.350	0.0000	-3.884e-004	-3.074e-004	0.0000
4.650	0.0000	-3.353e-004	-2.556e-004	0.0000
4.950	0.0000	-2.919e-004	-2.151e-004	0.0000
5.250	0.0000	-2.560e-004	-1.830e-004	0.0000
5.550	0.0000	-2.259e-004	-1.571e-004	0.0000
5.850	0.0000	-2.005e-004	-1.359e-004	0.0000

Transport

Length (m)	Viscosity (cP)	Moleular Weight	Mass Density (kg/m3)	Heat Capacity (kJ/kgmole-C)	Surface Tension (dyne/cm)	Z Factor
0.1500	4.044e-002	43.34	1.373	47.221	---	1.000
0.4500	3.996e-002	43.75	1.385	47.654	---	1.000
0.7500	3.990e-002	43.80	1.387	47.712	---	1.000
1.050	3.989e-002	43.82	1.387	47.730	---	1.000
1.350	3.988e-002	43.82	1.387	47.737	---	1.000
1.650	3.988e-002	43.83	1.387	47.741	---	1.000
1.950	3.988e-002	43.83	1.387	47.744	---	1.000
2.250	3.988e-002	43.83	1.387	47.746	---	1.000
2.550	3.988e-002	43.83	1.387	47.747	---	1.000
2.850	3.988e-002	43.83	1.387	47.748	---	1.000
3.150	3.988e-002	43.83	1.387	47.749	---	1.000
3.450	3.988e-002	43.83	1.387	47.749	---	1.000
3.750	3.988e-002	43.83	1.387	47.750	---	1.000
4.050	3.988e-002	43.83	1.387	47.750	---	1.000
4.350	3.988e-002	43.83	1.387	47.750	---	1.000
4.650	3.988e-002	43.83	1.387	47.751	---	1.000
4.950	3.988e-002	43.83	1.387	47.751	---	1.000
5.250	3.988e-002	43.83	1.387	47.751	---	1.000
5.550	3.988e-002	43.83	1.387	47.751	---	1.000
5.850	3.988e-002	43.83	1.387	47.751	---	1.000

Component Molar Flowrates (kgmole/h)

Length (m)	Ammonia	H2O	NO2	Nitrogen
0.1500	0.3122	2.3890	65.4932	5.2103
0.4500	0.3122	2.3890	66.6801	4.7994
0.7500	0.3122	2.3890	66.8360	4.7457
1.050	0.3122	2.3890	66.8804	4.7316
1.350	0.3122	2.3890	66.8990	4.7262
1.650	0.3122	2.3890	66.9087	4.7236
1.950	0.3122	2.3890	66.9145	4.7222

Plug Flow Reactor: OXIDATION REACTION (continued)

Component Molar Flowrates (kgmole/h)

Length (m)	Ammonia	H2O	NO2	Nitrogen
2.250	0.3122	2.3890	66.9183	4.7214
2.550	0.3122	2.3890	66.9210	4.7208
2.850	0.3122	2.3890	66.9229	4.7205
3.150	0.3122	2.3890	66.9244	4.7202
3.450	0.3122	2.3890	66.9256	4.7201
3.750	0.3122	2.3890	66.9266	4.7199
4.050	0.3122	2.3890	66.9274	4.7198
4.350	0.3122	2.3890	66.9280	4.7197
4.650	0.3122	2.3890	66.9286	4.7197
4.950	0.3122	2.3890	66.9290	4.7196
5.250	0.3122	2.3890	66.9295	4.7196
5.550	0.3122	2.3890	66.9298	4.7196
5.850	0.3122	2.3890	66.9301	4.7195

Length (m)	HNO3	NO	Air	Oxygen
0.1500	0.0000	0.5798	1.2523	0.0000
0.4500	0.0000	0.1459	0.2135	0.0000
0.7500	0.0000	0.0882	0.0774	0.0000
1.050	0.0000	0.0696	0.0398	0.0000
1.350	0.0000	0.0609	0.0246	0.0000
1.650	0.0000	0.0558	0.0169	0.0000
1.950	0.0000	0.0525	0.0125	0.0000
2.250	0.0000	0.0502	0.0097	0.0000
2.550	0.0000	0.0484	0.0077	0.0000
2.850	0.0000	0.0471	0.0063	0.0000
3.150	0.0000	0.0460	0.0053	0.0000
3.450	0.0000	0.0451	0.0045	0.0000
3.750	0.0000	0.0444	0.0039	0.0000
4.050	0.0000	0.0438	0.0033	0.0000
4.350	0.0000	0.0432	0.0029	0.0000
4.650	0.0000	0.0428	0.0026	0.0000
4.950	0.0000	0.0424	0.0023	0.0000
5.250	0.0000	0.0420	0.0020	0.0000
5.550	0.0000	0.0417	0.0018	0.0000
5.850	0.0000	0.0415	0.0016	0.0000

Component Mole Fractions

Length (m)	Ammonia	H2O	NO2	Nitrogen
0.1500	0.0041	0.0318	0.8705	0.0693
0.4500	0.0042	0.0321	0.8946	0.0644
0.7500	0.0042	0.0321	0.8977	0.0637
1.050	0.0042	0.0321	0.8987	0.0636
1.350	0.0042	0.0321	0.8990	0.0635
1.650	0.0042	0.0321	0.8992	0.0635
1.950	0.0042	0.0321	0.8994	0.0635
2.250	0.0042	0.0321	0.8994	0.0635
2.550	0.0042	0.0321	0.8995	0.0635
2.850	0.0042	0.0321	0.8995	0.0634
3.150	0.0042	0.0321	0.8996	0.0634
3.450	0.0042	0.0321	0.8996	0.0634
3.750	0.0042	0.0321	0.8996	0.0634
4.050	0.0042	0.0321	0.8996	0.0634
4.350	0.0042	0.0321	0.8996	0.0634
4.650	0.0042	0.0321	0.8996	0.0634
4.950	0.0042	0.0321	0.8996	0.0634
5.250	0.0042	0.0321	0.8997	0.0634
5.550	0.0042	0.0321	0.8997	0.0634
5.850	0.0042	0.0321	0.8997	0.0634

Length (m)	HNO3	NO	Air	Oxygen
0.1500	0.0000	0.0077	0.0166	0.0000
0.4500	0.0000	0.0020	0.0029	0.0000
0.7500	0.0000	0.0012	0.0010	0.0000

Plug Flow Reactor: OXIDATION REACTION (continued)

Component Mole Fractions

Length (m)	HNO3	NO	Air	Oxygen
1.050	0.0000	0.0009	0.0005	0.0000
1.350	0.0000	0.0008	0.0003	0.0000
1.650	0.0000	0.0008	0.0002	0.0000
1.950	0.0000	0.0007	0.0002	0.0000
2.250	0.0000	0.0007	0.0001	0.0000
2.550	0.0000	0.0007	0.0001	0.0000
2.850	0.0000	0.0006	0.0001	0.0000
3.150	0.0000	0.0006	0.0001	0.0000
3.450	0.0000	0.0006	0.0001	0.0000
3.750	0.0000	0.0006	0.0001	0.0000
4.050	0.0000	0.0006	0.0000	0.0000
4.350	0.0000	0.0006	0.0000	0.0000
4.650	0.0000	0.0006	0.0000	0.0000
4.950	0.0000	0.0006	0.0000	0.0000
5.250	0.0000	0.0006	0.0000	0.0000
5.550	0.0000	0.0006	0.0000	0.0000
5.850	0.0000	0.0006	0.0000	0.0000

PROPERTIES

C.AIR.1

	Overall	Vapour Phase			
Vapour/Phase Fraction	1.0000	1.0000			
Temperature: (C)	110.9	110.9			
Pressure: (kPa)	200.0	200.0			
Molar Flow (kgmole/h)	50.00 *	50.00			
Mass Flow (kg/h)	1448	1448			
Std Ideal Liq Vol Flow (m3/h)	1.646	1.646			
Molar Enthalpy (kJ/kgmole)	2475	2475			
Mass Enthalpy (kJ/kg)	85.49	85.49			
Molar Entropy (kJ/kgmole-C)	119.8	119.8			
Mass Entropy (kJ/kg-C)	4.140	4.140			
Heat Flow (kJ/h)	1.237e+005	1.237e+005			
Molar Density (kgmole/m3)	6.264e-002	6.264e-002			
Mass Density (kg/m3)	1.813	1.813			
Std Ideal Liq Mass Density (kg/m3)	879.6	879.6			
Liq Mass Density @Std Cond (kg/m3)	---	---			
Molar Heat Capacity (kJ/kgmole-C)	29.22	29.22			
Mass Heat Capacity (kJ/kg-C)	1.009	1.009			
Thermal Conductivity (W/m-K)	3.035e-002	3.035e-002			
Viscosity (cP)	2.269e-002	2.269e-002			
Surface Tension (dyne/cm)	---	---			
Molecular Weight	28.95	28.95			
Z Factor	0.9999	0.9999			

NITRIC_OXIDE

	Overall	Vapour Phase	Aqueous Phase		
Vapour/Phase Fraction	1.0000	1.0000	0.0000		
Temperature: (C)	40.00	40.00	40.00		
Pressure: (kPa)	200.0	200.0	200.0		
Molar Flow (kgmole/h)	62.88	62.88	0.0000		
Mass Flow (kg/h)	1814	1814	0.0000		
Std Ideal Liq Vol Flow (m3/h)	17.43	17.43	0.0000		
Molar Enthalpy (kJ/kgmole)	4.799e+004	4.799e+004	-2.827e+005		
Mass Enthalpy (kJ/kg)	1664	1664	-1.569e+004		
Molar Entropy (kJ/kgmole-C)	158.6	158.6	59.28		
Mass Entropy (kJ/kg-C)	5.498	5.498	3.292		
Heat Flow (kJ/h)	3.018e+006	3.018e+006	0.0000		
Molar Density (kgmole/m3)	7.689e-002	7.689e-002	55.15		
Mass Density (kg/m3)	2.218	2.218	993.2		
Std Ideal Liq Mass Density (kg/m3)	104.1	104.1	995.0		

Plug Flow Reactor: OXIDATION REACTION (continued)

PROPERTIES

NITRIC_OXIDE

	Overall	Vapour Phase	Aqueous Phase		
Liq Mass Density @Std Cond (kg/m3)	—	—	1012		
Molar Heat Capacity (kJ/kgmole-C)	30.01	30.01	72.82		
Mass Heat Capacity (kJ/kg-C)	1.040	1.040	4.043		
Thermal Conductivity (W/m-K)	2.717e-002	2.717e-002	0.6304		
Viscosity (cP)	2.171e-002	2.171e-002	0.6847		
Surface Tension (dyne/cm)	—	—	69.26		
Molecular Weight	28.84	28.84	18.01		
Z Factor	0.9990	0.9990	1.393e-003		

NO2

	Overall	Vapour Phase	Liquid Phase		
Vapour/Phase Fraction	1.0000	1.0000	0.0000		
Temperature: (C)	486.7	486.7	486.7		
Pressure: (kPa)	200.0	200.0	200.0		
Molar Flow (kgmole/h)	74.39	74.39	0.0000		
Mass Flow (kg/h)	3261	3261	0.0000		
Std Ideal Liq Vol Flow (m3/h)	2.328	2.328	0.0000		
Molar Enthalpy (kJ/kgmole)	4.223e+004	4.223e+004	4.223e+004		
Mass Enthalpy (kJ/kg)	963.3	963.3	963.3		
Molar Entropy (kJ/kgmole-C)	195.7	195.7	195.7		
Mass Entropy (kJ/kg-C)	4.464	4.464	4.464		
Heat Flow (kJ/h)	3.141e+006	3.141e+006	0.0000		
Molar Density (kgmole/m3)	3.165e-002	3.165e-002	3.165e-002		
Mass Density (kg/m3)	1.387	1.387	1.387		
Std Ideal Liq Mass Density (kg/m3)	1401	1401	1401		
Liq Mass Density @Std Cond (kg/m3)	1353	1353	1353		
Molar Heat Capacity (kJ/kgmole-C)	47.75	47.75	47.75		
Mass Heat Capacity (kJ/kg-C)	1.089	1.089	1.089		
Thermal Conductivity (W/m-K)	4.107e-002	4.107e-002	4.478e-002		
Viscosity (cP)	3.988e-002	3.988e-002	1.170e-003		
Surface Tension (dyne/cm)	—	—	0.0000		
Molecular Weight	43.83	43.83	43.83		
Z Factor	1.000	1.000	1.000		

DYNAMICS

Vessel Parameters: Initialize from Product

Single Phase: Not Activated		Lag Rxn Temperature: Not Activated	
Laminar Flow	Activated	Fixed Delta P	Not Activated
Flow Equation	Activated	PFR Elevation (m)	0

Pressure Flow Relation / Segmented Holdup Details

Segment	Pressure-Flow K (kg/hr/sqrt(kPa-kg/m3))	View Holdup
1.000	—	OXIDATION REACTION:Seg-1:EnHoldup
2.000	—	OXIDATION REACTION:Seg-2:EnHoldup
3.000	—	OXIDATION REACTION:Seg-3:EnHoldup
4.000	—	OXIDATION REACTION:Seg-4:EnHoldup
5.000	—	OXIDATION REACTION:Seg-5:EnHoldup
6.000	—	OXIDATION REACTION:Seg-6:EnHoldup
7.000	—	OXIDATION REACTION:Seg-7:EnHoldup
8.000	—	OXIDATION REACTION:Seg-8:EnHoldup
9.000	—	OXIDATION REACTION:Seg-9:EnHoldup
10.00	—	OXIDATION REACTION:Seg-10:EnHoldup
11.00	—	OXIDATION REACTION:Seg-11:EnHoldup
12.00	—	OXIDATION REACTION:Seg-12:EnHoldup
13.00	—	OXIDATION REACTION:Seg-13:EnHoldup
14.00	—	OXIDATION REACTION:Seg-14:EnHoldup
15.00	—	OXIDATION REACTION:Seg-15:EnHoldup
16.00	—	OXIDATION REACTION:Seg-16:EnHoldup

Plug Flow Reactor: OXIDATION REACTION (continued)

Segment	Pressure-Flow K (kg/hr/sqrt(kPa-kg/m3))	View Holdup
17.00	---	OXIDATION REACTION:Seg-17:EnHoldup
18.00	---	OXIDATION REACTION:Seg-18:EnHoldup
19.00	---	OXIDATION REACTION:Seg-19:EnHoldup
20.00	---	OXIDATION REACTION:Seg-20:EnHoldup

Overall Holdup Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000	0.0000
Liquid	0.0000	0.0000	0.0000
Aqueous	0.0000	0.0000	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

Heat Flow into the PFR: **Heating**

NOTES

TEAM LND Calgary, Alberta CANADA	Case Name:	E:\HNO3\nitric plant.hsc
	Unit Set:	SI
	Date/Time:	Sat Dec 08 21:39:05 2007

Conversion Reactor: CRV-100

CONNECTIONS

Inlet Stream Connections

Stream Name	From Unit Operation	
WATER.2	Tee	TEE-101
NO2	Plug Flow Reactor	OXIDATION REACTION

Outlet Stream Connections

Stream Name	To Unit Operation	
NO,BY.PDT	Cooler:	E-101
HNO3	Mixer:	MIX-100

Energy Stream Connections

Stream Name	From Unit Operation
Q.RT2	

PARAMETERS

Physical Parameters		Optional Heat Transfer:	Heating
Delta P	**Vessel Volume**	**Duty**	**Energy Stream**
0.0000 kPa *	1.200 m3 *	-2.498e+006 kJ/h	Q.RT2

User Variables

REACTION DETAILS

Reaction: ABSORPTION REAXTION

Component	Mole Weight	Stoichiometric Coeff.
NO2	46.01	-3 *
H2O	18.02	-1 *
HNO3	63.01	2 *
NO	30.01	1 *

REACTION RESULTS FOR : Set-3

Extents

Name	Rank	Specified % Conversion	Use Default	Actual % Conversion	Base Component	Reaction Extent (kgmole/h)
ABSORPTION REAXTI	0 *	100.00	Yes	100.0	NO2	22.31

Balance

Components	Total Inflow (kgmole/h)	Total Reaction (kgmole/h)	Total Outflow (kgmole/h)
Ammonia	0.3122	0.0000	0.3122
H2O	26.78	-22.31	4.469
NO2	66.93	-66.93	0.0000
Nitrogen	4.720	0.0000	4.720
HNO3	0.0000	44.62	44.62
NO	4.147e-002	22.31	22.35
Air	1.644e-003	-1.906e-019	1.644e-003
Oxygen	0.0000	0.0000	0.0000

RATING

Sizing

Cylinder		Vertical		Reactor has a Boot: No	
Volume	1.200 m3 *	Diameter	1.006 m	Height	1.509

Nozzles

Base Elevation Relative to Ground Level		0.0000 m * Diameter 1.006 m	Height	1.509
		WATER.2	NO2	NO,BY.PDT
Diameter	(m)	7.546e-002	7.546e-002	7.546e-002
Elevation (Base)	(m)	0.7546	0.7546	1.509
Elevation (Ground)	(m)	0.7546	0.7546	1.509

Conversion Reactor: CRV-100 (continued)

Elevation (% of Height)	(%)	50.00	50.00	100.00
		HNO3		
Diameter	(m)	7.546e-002		
Elevation (Base)	(m)	0.0000		
Elevation (Ground)	(m)	0.0000		
Elevation (% of Height)	(%)	0.00		

PROPERTIES

WATER.2

		Overall	Aqueous Phase			
Vapour/Phase Fraction		0.0000	1.0000			
Temperature:	(C)	25.00	25.00			
Pressure:	(kPa)	130.0	130.0			
Molar Flow	(kgmole/h)	24.39 *	24.39			
Mass Flow	(kg/h)	439.4	439.4			
Std Ideal Liq Vol Flow	(m3/h)	0.4403	0.4403			
Molar Enthalpy	(kJ/kgmole)	-2.848e+005	-2.848e+005			
Mass Enthalpy	(kJ/kg)	-1.581e+004	-1.581e+004			
Molar Entropy	(kJ/kgmole-C)	55.43	55.43			
Mass Entropy	(kJ/kg-C)	3.077	3.077			
Heat Flow	(kJ/h)	-6.946e+006	-6.946e+006			
Molar Density	(kgmole/m3)	55.92	55.92			
Mass Density	(kg/m3)	1007	1007			
Std Ideal Liq Mass Density	(kg/m3)	998.0	998.0			
Liq Mass Density @Std Cond	(kg/m3)	1015	1015			
Molar Heat Capacity	(kJ/kgmole-C)	72.84	72.84			
Mass Heat Capacity	(kJ/kg-C)	4.043	4.043			
Thermal Conductivity	(W/m-K)	0.6110	0.6110			
Viscosity	(cP)	0.8904	0.8904			
Surface Tension	(dyne/cm)	72.10	72.10			
Molecular Weight		18.02	18.02			
Z Factor		9.379e-004	9.379e-004			

NO2

		Overall	Vapour Phase	Liquid Phase		
Vapour/Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	486.7	486.7	486.7		
Pressure:	(kPa)	200.0	200.0	200.0		
Molar Flow	(kgmole/h)	74.39	74.39	0.0000		
Mass Flow	(kg/h)	3261	3261	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	2.328	2.328	0.0000		
Molar Enthalpy	(kJ/kgmole)	4.223e+004	4.223e+004	4.223e+004		
Mass Enthalpy	(kJ/kg)	963.3	963.3	963.3		
Molar Entropy	(kJ/kgmole-C)	195.7	195.7	195.7		
Mass Entropy	(kJ/kg-C)	4.464	4.464	4.464		
Heat Flow	(kJ/h)	3.141e+006	3.141e+006	0.0000		
Molar Density	(kgmole/m3)	3.165e-002	3.165e-002	3.165e-002		
Mass Density	(kg/m3)	1.387	1.387	1.387		
Std Ideal Liq Mass Density	(kg/m3)	1401	1401	1401		
Liq Mass Density @Std Cond	(kg/m3)	1353	1353	1353		
Molar Heat Capacity	(kJ/kgmole-C)	47.75	47.75	47.75		
Mass Heat Capacity	(kJ/kg-C)	1.089	1.089	1.089		
Thermal Conductivity	(W/m-K)	4.107e-002	4.107e-002	4.478e-002		
Viscosity	(cP)	3.988e-002	3.988e-002	1.170e-003		
Surface Tension	(dyne/cm)	—	—	0.0000		
Molecular Weight		43.83	43.83	43.83		
Z Factor		1.000	1.000	1.000		

HNO3

		Overall	Vapour Phase	Liquid Phase		
Vapour/Phase Fraction		0.0000	0.0000	1.0000		
Temperature:	(C)	60.00 *	60.00	60.00		
Pressure:	(kPa)	130.0	130.0	130.0		

Conversion Reactor: CRV-100 (continued)

PROPERTIES

HNO3

		Overall	Vapour Phase	Liquid Phase		
Molar Flow	(kgmole/h)	35.20	0.0000	35.20		
Mass Flow	(kg/h)	2101	0.0000	2101		
Std Ideal Liq Vol Flow	(m3/h)	1.399	0.0000	1.399		
Molar Enthalpy	(kJ/kgmole)	-1.787e+005	-305.0	-1.787e+005		
Mass Enthalpy	(kJ/kg)	-2993	-7.872	-2993		
Molar Entropy	(kJ/kgmole-C)	51.09	167.1	51.09		
Mass Entropy	(kJ/kg-C)	0.8558	4.313	0.8558		
Heat Flow	(kJ/h)	-6.290e+006	0.0000	-6.290e+006		
Molar Density	(kgmole/m3)	23.41	4.717e-002	23.41		
Mass Density	(kg/m3)	1398	1.827	1398		
Std Ideal Liq Mass Density	(kg/m3)	1503	158.3	1503		
Liq Mass Density @Std Cond	(kg/m3)	1495	—	1495		
Molar Heat Capacity	(kJ/kgmole-C)	79.14	38.43	79.14		
Mass Heat Capacity	(kJ/kg-C)	1.326	0.9921	1.326		
Thermal Conductivity	(W/m-K)	0.1707	2.269e-002	0.1707		
Viscosity	(cP)	0.5466	1.587e-002	0.5466		
Surface Tension	(dyne/cm)	1984	—	1984		
Molecular Weight		59.70	38.74	59.70		
Z Factor		2.004e-003	0.9949	2.004e-003		

NO,BY.PDT

		Overall	Vapour Phase	Liquid Phase		
Vapour/Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	60.00	60.00	60.00		
Pressure:	(kPa)	130.0	130.0	130.0		
Molar Flow	(kgmole/h)	41.28	41.28	0.0000		
Mass Flow	(kg/h)	1599	1599	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	10.10	10.10	0.0000		
Molar Enthalpy	(kJ/kgmole)	-305.0	-305.0	-1.787e+005		
Mass Enthalpy	(kJ/kg)	-7.872	-7.872	-2993		
Molar Entropy	(kJ/kgmole-C)	167.1	167.1	51.09		
Mass Entropy	(kJ/kg-C)	4.313	4.313	0.8558		
Heat Flow	(kJ/h)	-1.259e+004	-1.259e+004	0.0000		
Molar Density	(kgmole/m3)	4.717e-002	4.717e-002	23.41		
Mass Density	(kg/m3)	1.827	1.827	1398		
Std Ideal Liq Mass Density	(kg/m3)	158.3	158.3	1503		
Liq Mass Density @Std Cond	(kg/m3)	—	—	1495		
Molar Heat Capacity	(kJ/kgmole-C)	38.43	38.43	79.14		
Mass Heat Capacity	(kJ/kg-C)	0.9921	0.9921	1.326		
Thermal Conductivity	(W/m-K)	2.269e-002	2.269e-002	0.1707		
Viscosity	(cP)	1.587e-002	1.587e-002	0.5466		
Surface Tension	(dyne/cm)	—	—	1984		
Molecular Weight		38.74	38.74	59.70		
Z Factor		0.9949	0.9949	2.004e-003		

DYNAMICS

Vessel Parameters: Initialize from Product

Vessel Volume	(m3)	1.200 *	Level Calculator		Vertical cylinder
Vessel Diameter	(m)	1.006	Fraction Calculator		Use levels and nozzles
Vessel Height	(m)	1.509	Feed Delta P	(kPa)	0.0000 *
Liquid Level Percent	(%)	50.00	Vessel Pressure	(kPa)	130.0

Holdup: Vessel Levels

Phase	Level (m)	Percent (%)	Volume (m3)
Vapour	—	—	0.0000
Liquid	—	—	0.0000
Aqueous	—	—	0.0000

Conversion Reactor: CRV-100 (continued)

Holdup: Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000	0.0000
Liquid	0.0000	0.0000	0.0000
Aqueous	0.0000	0.0000	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

Duty Valve Source : Direct_Q

SP (kJ/h)	Min. Available (kJ/h)	Max. Available (kJ/h)
-2.498e+006	---	---

Liquid Heater Height as % of Vessel Volume

Top of Heater : 5.00 %

Bottom of Heater : 0.00 %

Heat Flow into the PFR: Heating

NOTES

Case Name:	E:\HNO3\nitric plant.hsc
Unit Set:	SI
Date/Time:	Mon Dec 10 15:35:26 2007

Separator: SEPARATOR_2

RATING

Sizing

Cylinder		Vertical		Separator has a Boot: No	
Volume	0.9786 m3	Diameter	0.6096 m *	Height	3.353 *

Nozzles

Base Elevation Relative to Ground Level	0.0000 m *	Diameter	0.6096 m *	Height	3.353 *

		C.P	NO..	HNO3_
Diameter	(m)	0.1676	0.1676	0.1676
Elevation (Base)	(m)	1.676	3.353	0.0000
Elevation (Ground)	(m)	1.676	3.353	0.0000
Elevation (% of Height)	(%)	50.00	100.00	0.00

Detailed Heat Loss Parameters

Overall Heat Loss (kJ/h)	0.0000	Area (m2)	6.421

Temperature Profile

Fluid (C)	0.0000 *	Inner Wall (C)	25.00	Outer Vessel (C)	25.00	Outer Insulation (C)	25.00	Ambient (C)	25.00

Conduction

		Metal	Insulation
Thickness	(m)	1.000e-002	3.000e-002
Cp	(kJ/kg-C)	0.4730	0.8200
Density	(kg/m3)	7801	520.0
Conductivity	(W/m-K)	45.00	0.1500

Convection

Inside Vap Phase U (kJ/h-m2-C)	7200	Inside Liq Phase U (kJ/h-m2-C)	---	Outside U (kJ/h-m2-C)	54.00

Level Taps: Level Tap Specification

Level Tap	PV High	PV Low	OP High	OP Low

Level Taps: Calculated Level Tap Values

Level Tap	Liquid Level	Aqueous Level

Options

PV Work Term Contribution	(%)	100.00 *	

PROPERTIES

C.P

		Overall	Vapour Phase	Liquid Phase		
Vapour/Phase Fraction		0.7287	0.7287	0.2713		
Temperature:	(C)	30.00 *	30.00	30.00		
Pressure:	(kPa)	125.0	125.0	125.0		
Molar Flow	(kgmole/h)	41.28	30.08	11.20		
Mass Flow	(kg/h)	1599	952.9	646.1		
Std Ideal Liq Vol Flow	(m3/h)	10.10	9.670	0.4338		
Molar Enthalpy	(kJ/kgmole)	-1.202e+004	5.255e+004	-1.854e+005		
Mass Enthalpy	(kJ/kg)	-310.2	1659	-3214		
Molar Entropy	(kJ/kgmole-C)	130.9	162.6	45.94		
Mass Entropy	(kJ/kg-C)	3.380	5.132	0.7963		
Heat Flow	(kJ/h)	-4.960e+005	1.580e+006	-2.076e+006		
Molar Density	(kgmole/m3)	6.812e-002	4.967e-002	25.07		
Mass Density	(kg/m3)	2.639	1.574	1447		
Std Ideal Liq Mass Density	(kg/m3)	158.3	98.54	1490		
Liq Mass Density @Std Cond	(kg/m3)	---	---	1477		
Molar Heat Capacity	(kJ/kgmole-C)	43.23	31.79	73.94		
Mass Heat Capacity	(kJ/kg-C)	1.116	1.004	1.282		
Thermal Conductivity	(W/m-K)	---	2.513e-002	0.1951		
Viscosity	(cP)	---	1.984e-002	0.7794		
Surface Tension	(dyne/cm)	---	---	2187		
Molecular Weight		38.74	31.68	57.70		
Z Factor		---	0.9984	1.978e-003		

Separator: SEPARATOR_2 (continued)

NO..

	Overall	Vapour Phase	Liquid Phase
Vapour/Phase Fraction	1.0000	1.0000	0.0000
Temperature: (C)	30.00	30.00	30.00
Pressure: (kPa)	125.0	125.0	125.0
Molar Flow (kgmole/h)	30.08	30.08	0.0000
Mass Flow (kg/h)	952.9	952.9	0.0000
Std Ideal Liq Vol Flow (m3/h)	9.670	9.670	0.0000
Molar Enthalpy (kJ/kgmole)	5.255e+004	5.255e+004	-1.854e+005
Mass Enthalpy (kJ/kg)	1659	1659	-3214
Molar Entropy (kJ/kgmole-C)	162.6	162.6	45.94
Mass Entropy (kJ/kg-C)	5.132	5.132	0.7963
Heat Flow (kJ/h)	1.580e+006	1.580e+006	0.0000
Molar Density (kgmole/m3)	4.967e-002	4.967e-002	25.07
Mass Density (kg/m3)	1.574	1.574	1447
Std Ideal Liq Mass Density (kg/m3)	98.54	98.54	1490
Liq Mass Density @Std Cond (kg/m3)	---	---	1477
Molar Heat Capacity (kJ/kgmole-C)	31.79	31.79	73.94
Mass Heat Capacity (kJ/kg-C)	1.004	1.004	1.282
Thermal Conductivity (W/m-K)	2.513e-002	2.513e-002	0.1951
Viscosity (cP)	1.984e-002	1.984e-002	0.7794
Surface Tension (dyne/cm)	---	---	2187
Molecular Weight	31.68	31.68	57.70
Z Factor	0.9984	0.9984	1.978e-003

HNO3_

	Overall	Vapour Phase	Liquid Phase
Vapour/Phase Fraction	0.0000	0.0000	1.0000
Temperature: (C)	30.00	30.00	30.00
Pressure: (kPa)	125.0	125.0	125.0
Molar Flow (kgmole/h)	11.20	0.0000	11.20
Mass Flow (kg/h)	646.1	0.0000	646.1
Std Ideal Liq Vol Flow (m3/h)	0.4338	0.0000	0.4338
Molar Enthalpy (kJ/kgmole)	-1.854e+005	5.255e+004	-1.854e+005
Mass Enthalpy (kJ/kg)	-3214	1659	-3214
Molar Entropy (kJ/kgmole-C)	45.94	162.6	45.94
Mass Entropy (kJ/kg-C)	0.7963	5.132	0.7963
Heat Flow (kJ/h)	-2.076e+006	0.0000	-2.076e+006
Molar Density (kgmole/m3)	25.07	4.967e-002	25.07
Mass Density (kg/m3)	1447	1.574	1447
Std Ideal Liq Mass Density (kg/m3)	1490	98.54	1490
Liq Mass Density @Std Cond (kg/m3)	1477	---	1477
Molar Heat Capacity (kJ/kgmole-C)	73.94	31.79	73.94
Mass Heat Capacity (kJ/kg-C)	1.282	1.004	1.282
Thermal Conductivity (W/m-K)	0.1951	2.513e-002	0.1951
Viscosity (cP)	0.7794	1.984e-002	0.7794
Surface Tension (dyne/cm)	2187	---	2187
Molecular Weight	57.70	31.68	57.70
Z Factor	1.978e-003	0.9984	1.978e-003

Inlet Stream

		C.P
Vapour Fraction		0.7287
Temperature	(C)	30.00 *
Pressure	(kPa)	125.0
Molar Flow	(kgmole/h)	41.28
MassFlow	(kg/h)	1599
Std Ideal Liq Vol Flow	(m3/h)	10.10
HeatFlow	(kJ/h)	-4.960e+005

Outlet Stream

	HNO3_	NO..
Vapour Fraction	0.0000	1.0000

Separator: SEPARATOR_2 (continued)

		HNO3_	NO..		
Temperature	(C)	30.00	30.00		
Pressure	(kPa)	125.0	125.0		
Molar Flow	(kgmole/h)	11.20	30.08		
MassFlow	(kg/h)	646.1	952.9		
Std Ideal Liq Vol Flow	(m3/h)	0.4338	9.670		
HeatFlow	(kJ/h)	-2.076e+006	1.580e+006		

DYNAMICS

Vessel Parameters: Initialize from Product

Vessel Volume	(m3)	0.9786	Level Calculator		Vertical cylinder
Vessel Diameter	(m)	0.6096 *	Fraction Calculator		Use levels and nozzles
Vessel Height	(m)	3.353 *	Feed Delta P	(kPa)	0.0000 *
Liquid Level Percent	(%)	85.00 *	Vessel Pressure	(kPa)	125.0

Holdup: Vessel Levels

Phase	Level (m)	Percent (%)	Volume (m3)
Vapour	---	---	0.0000
Liquid	---	---	0.0000
Aqueous	---	---	0.0000

Holdup: Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000 *	0.0000
Liquid	0.0000	0.0000 *	0.0000
Aqueous	0.0000	0.0000 *	0.0000
Total	**0.0000**	**0.0000**	**0.0000**

HYPROTECH	TEAM LND Calgary, Alberta CANADA	Case Name:	E:\HNO3\nitric plant.hsc
		Unit Set:	SI
		Date/Time:	Mon Dec 10 15:49:05 2007

Mixer: MIX-100

NOZZLE PARAMETERS

Base Elevation Relative to Ground Level 0.0000 m *

		HNO3	HNO3_	HNO3_TOTAL
Diameter	(m)	5.000e-002	5.000e-002	5.000e-002
Elevation (Base)	(m)	0.0000	0.0000	0.0000
Elevation (Ground)	(m)	0.0000	0.0000	0.0000

PROPERTIES

Outlet Stream Properties

		HNO3_TOTAL				
Vapour Fraction		0.0000				
Temperature	(C)	52.96				
Pressure	(kPa)	125.0				
Molar Flow	(kgmole/h)	46.40				
MassFlow	(kg/h)	2748				
Std Ideal Liq Vol Flow	(m3/h)	1.832				
Enthalpy	(kJ/kgmole)	-1.803e+005				
Mass Enthalpy	(kJ/kg)	-3045				
Entropy	(kJ/kgmole-C)	49.93				
Mass Entropy	(kJ/kg-C)	0.8431				
HeatFlow	(kJ/h)	-8.366e+006				
Molar Density	(kgmole/m3)	23.74				
Std Ideal Liq Mass Density	(kg/m3)	1500				
Liq Mass Density @Std Cond	(kg/m3)	1491				
Molar Heat Capacity	(kJ/kgmole-C)	77.66				
Mass Heat Capacity	(kJ/kg-C)	1.311				
Thermal Conductivity	(W/m-K)	0.1767				
Viscosity	(cP)	0.5910				
Surface Tension	(dyne/cm)	2034				
Molecular Weight		59.22				
Z Factor		---				

Inlet Stream Properties

		HNO3	HNO3_			
Vapour Fraction		0.0000	0.0000			
Temperature	(C)	60.00 *	30.00			
Pressure	(kPa)	130.0	125.0			
Molar Flow	(kgmole/h)	35.20	11.20			
MassFlow	(kg/h)	2101	646.1			
Std Ideal Liq Vol Flow	(m3/h)	1.399	0.4338			
Enthalpy	(kJ/kgmole)	-1.787e+005	-1.854e+005			
Mass Enthalpy	(kJ/kg)	-2993	-3214			
Entropy	(kJ/kgmole-C)	51.09	45.94			
Mass Entropy	(kJ/kg-C)	0.8558	0.7963			
HeatFlow	(kJ/h)	-6.290e+006	-2.076e+006			
Molar Density	(kgmole/m3)	23.41	25.07			
Std Ideal Liq Mass Density	(kg/m3)	1503	1490			
Liq Mass Density @Std Cond	(kg/m3)	1495	1477			
Molar Heat Capacity	(kJ/kgmole-C)	79.14	73.94			
Mass Heat Capacity	(kJ/kg-C)	1.326	1.282			
Thermal Conductivity	(W/m-K)	0.1707	0.1951			
Viscosity	(cP)	0.5466	0.7794			
Surface Tension	(dyne/cm)	1984	2187			
Molecular Weight		59.70	57.70			
Z Factor		2.004e-003	1.978e-003			

DYNAMICS

Pressure Specification: Set Outlet to Lowest Inlet

Holdup Details

Mixer: MIX-100 (continued)

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000 *	0.0000
Liquid	0.0000	0.0000 *	0.0000
Aqueous	0.0000	0.0000 *	0.0000
Total	**0.0000**	**0.0000**	**0.0000**