Open University of Cyprus

Faculty of pure and applied sciences

Postgraduate Programme of *Sustainable Energy Systems*

Master's Dissertation

Steam Generation & Distribution System in Remedica Ltd

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Supervisor
Dr.-Ing. Paris A. Fokaides

May 2023

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This Master's Dissertation was submitted in partial fulfillment of the requirements
for the award of the postgraduate title
on Sustainable Energy Systems
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Summary

This project is describing the steam generation system in a pharmaceutical company in Limassol, Cyprus. The chosen company is Remedica Ltd. At this master thesis is present the basic operating principles of steam boilers as well as heat exchangers which are used to transfer heat to the corresponding equipment. Then the applications for which the production of steam is necessary are presented as well as the steam boilers that is used for the production of steam. During this thesis is presented also a study of the distribution loop of the steam at Remedica Ltd. At the end within the conclusions, proposals for increasing the energy efficiency of the system are analysed.

The method used for this master's thesis is the on-site inspection and application of the knowledge acquired through the courses of the master's program with the ultimate goal of the energy upgrade of the steam production and distribution system in Remedica Ltd.

Acknowledgements

I would like to thank Dr. Paris A. Fokaides, for the assignment of this Diplomatic thesis as well as for the support he offered me throughout my academic journey for the master's degree.

I would like to thank REMEDICA LTD for allow me to study their steam generation system and hear my proposals for energy investments of the system.

Also, I would like to thank my wife for her patience during my graduate studies.

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Chapter 1 - Introduction

Steam production for a company that needs large quantities requires a large part of a company's finances. Beyond the production cost, you also require space for fuel storage, space for the steam boilers as well as professional staff where you can work and maintain this sector. Large industries that use HVAC to have controlled air conditioning conditions in their production areas usually have steam boilers and chillers that work accordingly to achieve the necessary conditions in the operating areas. Steam generation is a subject that most companies in our days are looking to and they try to have efficient boilers that will generate he highest amount of steam with as less as possible fuels. The problem on this is that a big part of the companies didn't invest the same for the distribution loop of the steam and either the tubes are not insulated either are not maintained regularly. This affect direct to the efficiency of the system since the thermal energy loses from the distribution loop, special in companies that have long distances of distribution loop, are huge. In pharmaceutical industries the steam is used also for equipment's in production procedures.

1.1 Remedica – Pharmaceutical industry

Remedica is a leading pharmaceutical company located in Cyprus and its pharmaceutical products are distributed in more than 160+ countries worldwide. Originally founded in 1980, it went through various development stages and is now specialising in the development, production and sale of high-quality, safe and efficacious pharmaceutical products for human use. It also markets a number of other health and care products. Its pharmaceutical range consists of a product portfolio of more than 300 generic, branded generic and over-the-counter (OTC). It offers products from various therapeutic categories including antineoplastic agents, antivirals, cardiovascular, central nervous system agents, gastrointestinal agents, respiratory tract agents, dermatological agents and anti-infective products. Currently, Remedica has 5 state-of-the-art factories all of which have been inspected and approved by the health authorities of several European Union Member States including those of Cyprus, Germany and Denmark as well as those of United Kingdom, Russia, Australia (TGA), Brazil (ANVISA), Japan (PMDA), and many more.[1]

Figure 1: Remedica Logo

1.2 Steam needs in a pharmaceutical industry

All Pharmaceutical industries are working under very strict regulations and are very often inspected for the implementation of them since their operations are direct related with human's lives. One of the basic characteristics that pharmaceutical products production had is the environmental conditions of the production. Due to this the HVAC of the companies need to serve the areas with high accuracy on their values in order to achieve this they are using steam for heating the air and cold water for cooling the air. Steam is generated from steam generators and cold water from chillers.

Some of the production equipment are also use steam to heat air through heat exchangers to heat or dry raw materials, semi-finished or finished products. Also, as most of the companies need hot water for their operations a pharmaceutical industry is use hot water for cleaning procedures or other operations may needed.

1.3 Steam Generators in Remedica Ltd

In Remedica Ltd actual there is not a direct use of steam to the production procedure. The seam is uses to head air or water thought heat exchangers. Remedica premises is split into 3 block of buildings the 1st is the main premises that include factories offices, Laboratories and warehouses, the second are include one factory with it warehouse and the last is only offices areas. At this thesis it will present the study of steam generation and distribution loop of the main premises of the company. The main premises are served for their steam needs from 3 steam boilers that location is at central point and distribute the steam to all the buildings via steam distribution loop.

Chapter 2 - Steam Boilers

Steam boilers are equipment that generate steam from water through the use of heat. They are used in a wide range of applications, including power generation, industrial processes, and heating systems. The most times the steam is used to transfer heat through heat exchanger. The direct usage of steam is basically on power generation and secondary to specific processes.

There are different types of steam generators, including:

- Fire-tube steam generators
- Water-tube steam generators
- Heat recovery steam generators (HRSGs)
- Nuclear steam generators

Steam boiler generators is devises that have a critical role in many industries and their design and operation a lot of times are specialized. Steam boilers are generating steam by heating water using fuels. These fuels could be gas, oil or coal.

2.1 Steam boiler components and basic operation principles

The components of a steam boiler might have differences in design but the basic parts are the same. The main parts of steam boilers and their usage are:

- <u>The Combustion chamber:</u>

  Is the part hat is responsible for burning the fuel inside and generate heat and then this heat is transfer to the heat exchanger part of boiler. Temperatures into chamber can be increased several hundred degrees in a short time. [2]

- <u>The heat exchanger:</u>

  The heat that generated from combustion chamber is passes through water (without mixed) and heat the water. The boiling water gone under pressure and pumped through pipes into heaters or radiators and the heat energy produced in the boiler will be separated from the water.[2]

- The burner

  A thermostat will send electronic signals in case the system needs to generate heat and then the burner activate the reaction. The burner is the part that initiates the combustion reaction inside the boiler. An outside source with the help of a filter mechanism pumps fuel to the boiler. The source is often an adjacent fuel tank. The fuel then turns into a fine spray with the help of burner's nozzle and will be ignited which results in reaction in the combustion chamber.[2]

How a steam boiler work

Instead, there are different type of steam boilers the operation principles due to the fact that they are working to reach similar goals and the basic components are the same, are almost the same for all the designs. The boilers are heating water up to boiling level with a combustion process using fuels. The combustion is producing heat in a tube that include water. The heat is "rejected" from the system as a steam through pipelines that are used for the needed purpose. The steam that is generated is pressurized steam.[3]

The steam is transferring heat to the needed application and this have as a result the steam to condensing back into water again. This water is return to the feedwater tank in order to be used again. During the process of steam generation and the transaction of water to steam, dissolved solids are left behind in the process. The most of these solids are removed during blowdown for the concentrations in the boiler water to remain at the desired ranges. There are not all of them removed through the blowdown procedure and this is one important reason to perform a regular maintenance on the boilers. Also, in order to minimize the dissolved solids is better to pass the fresh water though filters, softener and demine razed the water. [3], [4]

2.2 Steam Boiler types

Fire-tube steam generators:

These are the simplest and oldest type of steam generators. A fire-tube boiler is a type of boiler in which hot gases pass from a fire through one or more tubes running through a sealed container of water. The heat of the gases is transferred through the walls of the tubes by thermal conduction, heating the water and ultimately creating steam. [5], [6]

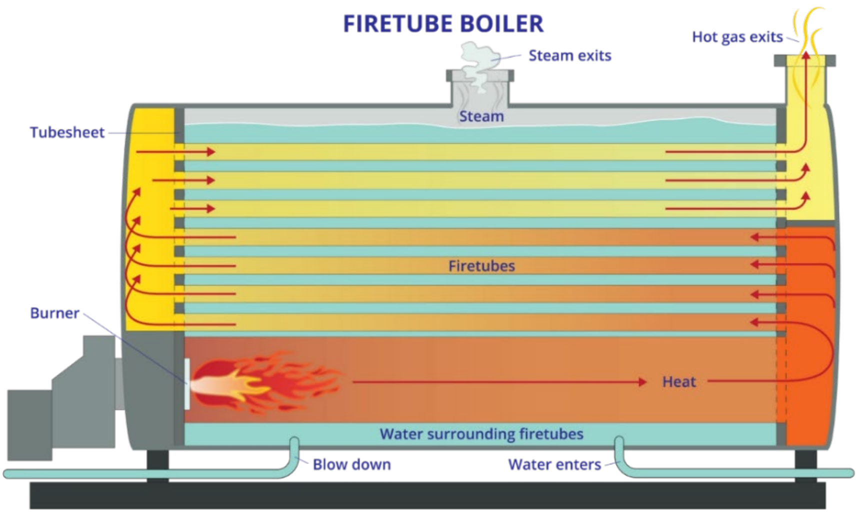


Figure 2: Fire tube boiler schematic[6]

<u>Water-tube steam generators:</u>

In these steam generators, water flows through tubes that are heated by the hot gases produced by the combustion process. The resulting steam is collected in a chamber above the tubes. Water tube boilers are also much more efficient, making them a preferred choice for intensive industrial processes.[6]

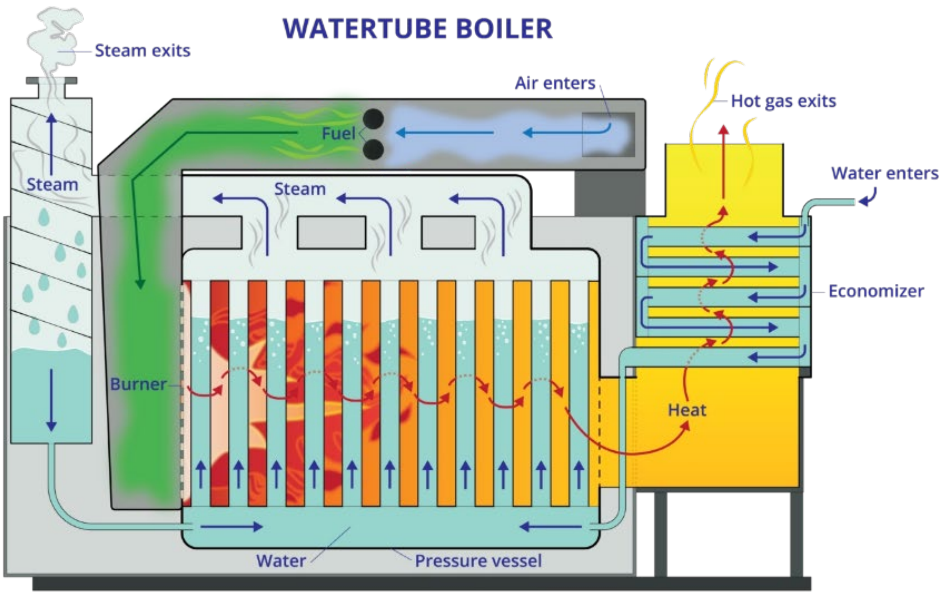


Figure 3: Water-tube steam boiler schematic[6]

Heat recovery steam generators (HRSGs):

These steam generators are working actual as a heat exchanger and are used in power generation applications to recover waste heat from the exhaust gases of gas turbines or diesel engines. The recovered heat is used to produce steam that can be used to generate additional power.[7]

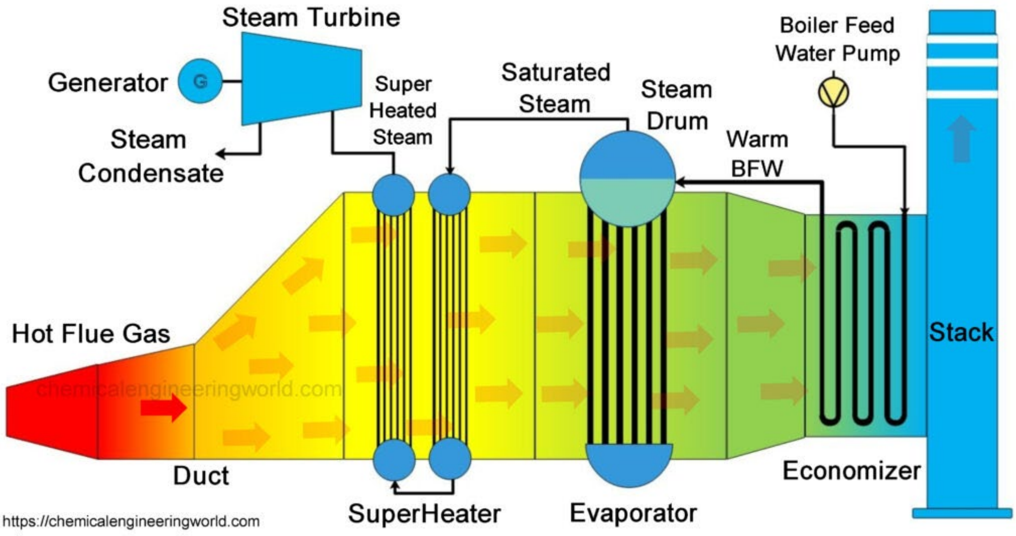


Figure 4: Heat Recovery Steam generator[8]

Nuclear steam generators:

These steam generators are used in nuclear power plants to produce steam that drives turbines to generate electricity. They are designed to handle the high pressures and temperatures associated with nuclear power generation. This type of generators is used by countries and are used for power generation.

2.3 Boiler maintenance

Boilers as any other machine need regularly maintenance. Effectively monitoring and maintaining boilers before any problems arise will help ensure your facility stays safe and productive. The maintenance contains the cleaning of the internal space of the conduction chamber from solids and check to all the other components of the boiler. Its is a good for the boilers during this maintenance to check also the steam counters (temperature and pressure) that they measure correct in order to be sure that they export the requested quantity and quality of steam.

As it was referred before in this Chapter it is verry important the feet water the added to the system to be in high quality. For this reason, it is installed to the feed water a chemical treatment and softener.

Chemical Water Treatment

Chemical water treatments are used to reduce dissolved oxygen within the water or treat metal surfaces to prevent degradation. Using these treatments allows facilities to control pH, prevent scale, reduce corrosive ions, and ensure the boiler's reliable function[7].

Water Softeners

Water softeners remove hard metals (notably calcium and magnesium) from the water used in the boiler. Hard water can cause scale build-up and can damage boiler components over time.

Controllers and Monitoring Systems[7]

Chapter 3 - Heat Exchangers

Heat exchangers are an essential principle in the modern power plant. Is a mechanical device which is used for the purpose of exchange of heats between two or more fluids. Heat exchangers are used in both cooling and heating processes at different temperatures. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. [9] [10]

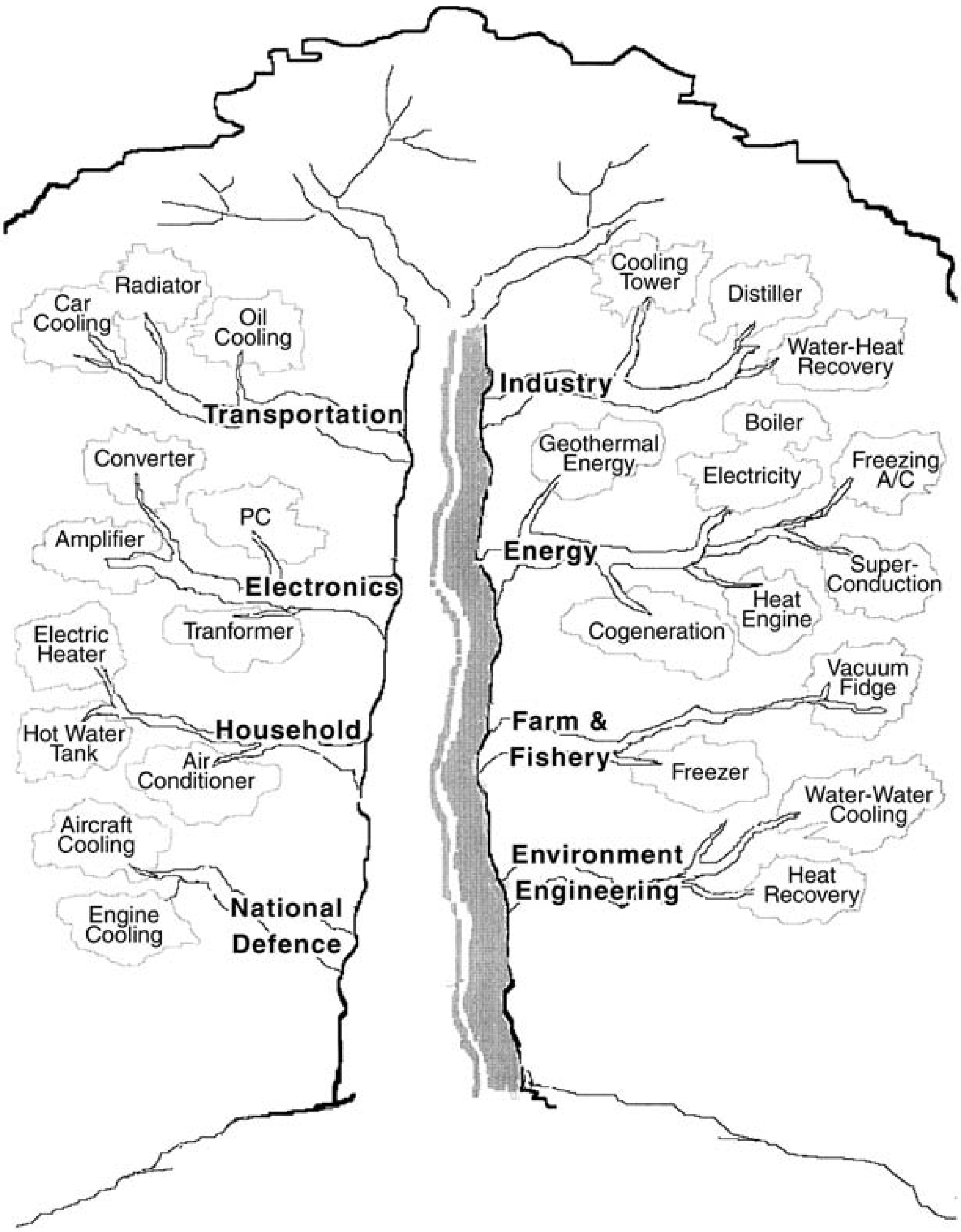


Figure 5: Applications of heat exchangers [2]

3.1 Classification of Heat Exchangers

All heat exchangers operate under the same basic principles. However, these devices can be classified and categorized in several different ways based on their design characteristics. The main characteristics by which heat exchangers can be categorized include:

- Flow configuration
- Construction method
- Heat transfer mechanism

Heat exchangers may be classified according to the following main criteria:

1. Recuperators/regenerators
2. Transfer processes: direct contact and indirect contact
3. Geometry of construction: tubes, plates, and extended surfaces
4. Heat transfer mechanisms: single-phase and two-phase
5. Flow arrangements: parallel-, counter-, and crossflows[10]

3.1.1 Recuperation and Regeneration

The conventional heat exchanger is called a recuperate because the hot stream A recovers (recuperates) some of the heat from stream B. The heat transfer occurs through a separating wall or through the interface between the streams as in the case of the direct contact type of heat exchangers. [10]

3.1.2 Classification According to Transfer Processes

Heat exchangers are classified according to transfer processes into indirect and direct contact types.[11]

3.1.2.1 Indirect Contact Type Heat Exchangers

In an indirect-contact heat exchanger, the fluid streams remain separate and the heat transfers continuously through an impervious dividing wall or into and out of a wall in a transient manner. Thus, ideally, there is no direct contact between thermally interacting fluids. This type of heat exchanger, also referred to as a surface heat exchanger, can be further classified into direct-transfer type, storage type, and fluidized-bed exchangers.[11]

3.1.2.2 Direct Contact Type Heat Exchangers

In this type, heat transfers continuously from the hot fluid to the cold fluid through a dividing wall. Although a simultaneous flow of two (or more) fluids is required in the exchanger, there is no direct mixing of the two (or more) fluids because each fluid flows in separate fluid passages. In general, there are no moving parts in most such heat exchangers. This type of exchanger is designated as a recuperative heat exchanger or simply as a recuperator. The term recuperator is not commonly used in the process industry for shell-and-tube and plate heat exchangers, although they are also considered recuperators. Recuperators are further sub-classified as prime surface exchangers and extended-surface exchangers. Prime surface exchangers do not employ fins or extended surfaces on any fluid side. Plain tubular exchangers, shell-and-tube exchangers with plain tubes, and plate exchangers are good examples of prime surface exchangers.[11][12]

3.1.3 Classification According to construction

Heat exchangers also can be classified according to their construction features. An important performance factor for all heat exchangers is the amount of heat transfer surface area within the volume of the heat exchanger. This is called its compactness factor and is measured in square meters per cubic meter.[11]

Heat exchangers are therefore also classified as:

1. Shell and Tube type
2. Plate Heat Exchangers
3. Tubular Heat Exchangers
4. Plate Fin Heat Exchangers
5. Tube Fin Heat Exchangers

3.1.3.1 Shell and Tube type

It is the most common type of heat exchanger in oil refineries and other large chemical processes. As its name implies, this type of heat exchanger consists of a shell (a large vessel) with a bundle of tubes inside it. This type of heat exchangers exhibits more than 65% of the market share with a variety of design experiences of about 100 years.[13] Shell-and tube heat exchangers provide typically the surface area density ranging from 50 to 500 m2/m3 and are easily cleaned.[9] Shell-and-tube heat exchangers are built of round tubes mounted in large cylindrical shells with the tube axis parallel to that of the shell. They are widely used as oil coolers, power condensers, preheaters in power plants, steam generators in nuclear power plants, in process applications, and in chemical industry. One fluid stream flow through the tubes while the other flows on the shell side, across or along the tubes. In a baffled shell-and-tube heat exchanger, the shell-side stream flows across between pairs of baffles and then flows parallel to the tubes as it flows from one baffle compartment to the next. There are wide differences between shell-and-tube heat exchangers depending on the application.[11]

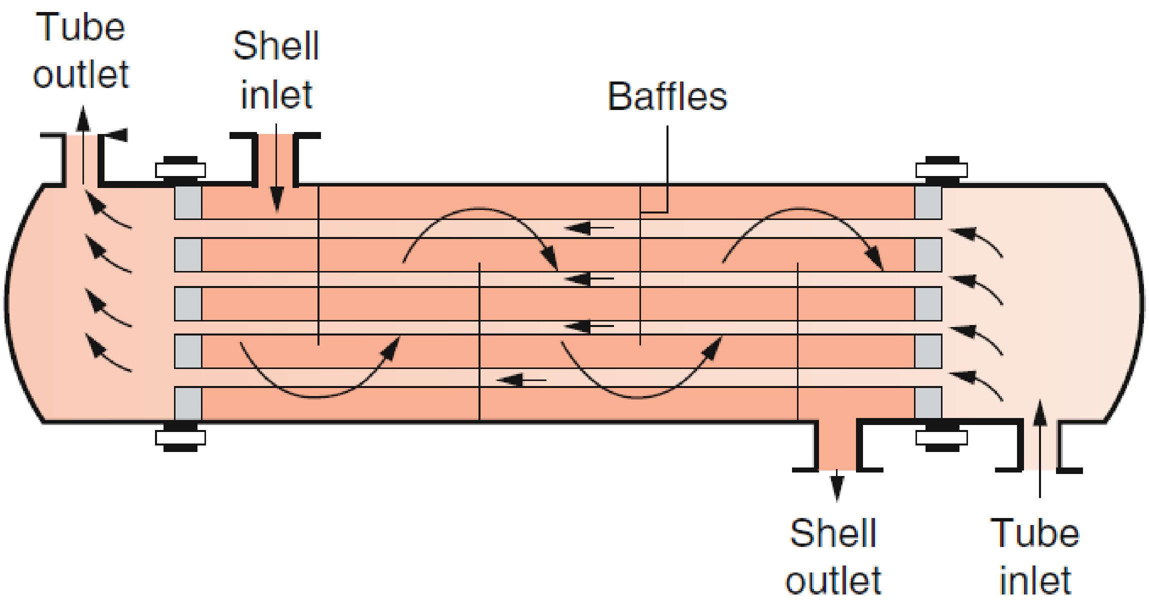


Figure 6:A shell-and-tube heat exchanger; one shell pass and one tube pass [3]

Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C).[14] This is because the shell and tube heat exchangers are robust due to their shape. Several thermal design features must be considered when designing the tubes in the shell and tube heat exchangers: There can be many variations on the shell and tube design. Typically, the ends of each tube are connected to plenums (sometimes called water boxes) through holes in tube sheets. The tubes may be straight or bent in the shape of a U, called U-tubes.[15]

<u>Tube diameter:</u> Using a small tube diameter makes the heat exchanger both economical and compact. However, it is more likely for the heat exchanger to foul up faster and the small size makes mechanical cleaning of the fouling difficult. To prevail over the fouling and cleaning problems, larger tube diameters can be used. Thus, to determine the tube diameter, the available space, cost and fouling nature of the fluids must be considered.

Tube thickness: The thickness of the wall of the tubes is usually determined to ensure:[15]

- There is enough room for corrosion
- That flow-induced vibration has resistance
- Axial strength
- Hoop strength (to withstand internal tube pressure)
- Buckling strength (to withstand overpressure in the shell)

Tube length: heat exchangers are usually cheaper when they have a smaller shell diameter and a long tube length. Thus, typically there is an aim to make the heat exchanger as long as physically possible whilst not exceeding production capabilities. However, there are many limitations for this, including space available at the installation site and the need to ensure tubes are available in lengths that are twice the required length (so they can be withdrawn and replaced). Also, long, thin tubes are difficult to take out and replace.[15]

Tube pitch: when designing the tubes, it is practical to ensure that the tube pitch (i.e., the centre-centre distance of adjoining tubes) is not less than 1.25 times the tubes' outside diameter. A larger tube pitch leads to a larger overall shell diameter, which leads to a more expensive heat exchanger.[15]

Tube corrugation: this type of tubes, mainly used for the inner tubes, increases the turbulence of the fluids and the effect is very important in the heat transfer giving a better performance.[15]

Tube Layout: refers to how tubes are positioned within the shell. There are four main types of tube layout, which are, triangular (30°), rotated triangular (60°), square (90°) and rotated square (45°). The triangular patterns are employed to give greater heat transfer as they force the fluid to flow in a more turbulent fashion around the piping. Square patterns are employed where high fouling is experienced and cleaning is more regular.[15]

Baffle Design: baffles are used in shell and tube heat exchangers to direct fluid across the tube bundle. They run perpendicularly to the shell and hold the bundle, preventing the tubes from sagging over a long length. They can also prevent the tubes from vibrating. The most common type of baffle is the segmental baffle. The semi-circular segmental baffles are oriented at 180 degrees to the adjacent baffles forcing the fluid to flow upward and downwards between the tube bundle. Baffle spacing is of large thermodynamic concern when designing shell and tube heat exchangers. Baffles must be spaced with consideration for the conversion of pressure drop and heat transfer. For thermo economic optimization it is suggested that the baffles be spaced no closer than 20% of the shell's inner diameter. Having baffles spaced too closely causes a greater pressure drop because of flow redirection. Consequently, having the baffles spaced too far apart means that there may be cooler spots in the corners between baffles. It is also important to ensure the baffles are spaced close enough that the tubes do not sag. The other main type of baffle is the disc and doughnut baffle, which consists of two concentric baffles. An outer, wider baffle looks like a doughnut, whilst the inner baffle is shaped like a disk. This type of baffle forces the fluid to pass around each side of the disk then through the doughnut baffle generating a different type of fluid flow.[15]

3.1.2.2 Plate type

Plate heat exchangers are built of thin plates forming flow channels plates to transfer heat between two fluids. The fluid streams are separated by flat plates which are smooth or between which lie corrugated fins. Plate heat exchangers are used for transferring heat for any combination of gas, liquid, and two-phase streams. The classic example of a heat exchanger is found in an internal combustion engine in which an engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. When compared to shell and tube exchangers, the stacked-plate arrangement typically has lower volume and cost. Another difference between the two is that plate exchangers typically serve low to medium pressure fluids, compared to medium and high pressures of shell and tube.[10] [16]

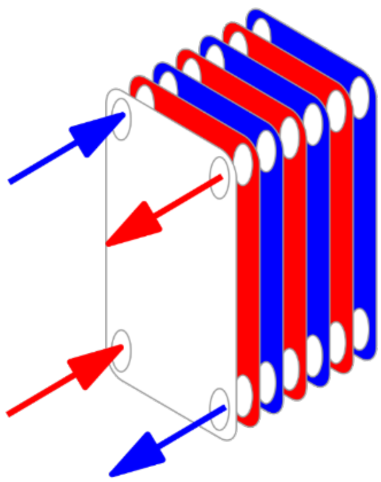


Figure 7:: Plate heat exchanger [7]

3.1.2.3 Tubular Heat exchangers

Tubular exchangers are widely used, and they are manufactured in many sizes, flow arrangements, and types. They can accommodate a wide range of operating pressures and temperatures. The ease of manufacturing and their relatively low cost have been the principal reason for their widespread use in engineering applications. A commonly used design, called the shell-and-tube exchanger, consists of round tubes mounted on a cylindrical shell with their axes parallel to that of the shell.[11]

3.2.2.4 Plate Fin Heat Exchangers

Corrugated metal fins are placed between flat plates. The structure is joined together by brazing (see later). The fins have the dual purpose of holding the plates together, thus containing pressure, and of forming a secondary (fin) surface for heat transfer. At the edges of the plates are bars, which contain each fluid within the space between adjacent plates.

The heights of corrugations and bars may vary between plates, as shown. For a liquid stream we can use a low height corrugation, matching high heat transfer coefficient with lesser surface area while for a low pressure stream we can use a high corrugation height, matching low coefficient with higher surface area but also giving larger through area to achieve lower pressure drop. An industrial unit contains about 1000 m2 of surface per cubic meter.[17]

3.1.2.5 Tube Fin Heat Exchangers

When a high operating pressure or an extended surface is needed on one side, tube in exchangers are used. Tube-fin exchangers can be used for a wide range of tube fluid operating pressures not exceeding about 30 atm and operating temperatures from low cryogenic applications to about 870 _C. The maximum compactness ratio is somewhat less than that obtainable with plate-fin exchangers.

The tube-fin heat exchangers are used in gas turbine, nuclear, fuel cell, automobile,
airplane, heat pump, refrigeration, electronics, cryogenics, air conditioning,
and many other applications.[11]

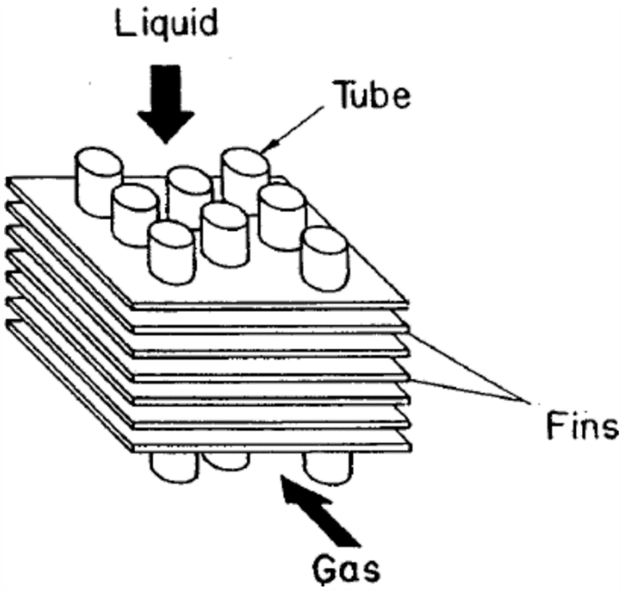


Figure 8: Tube Fin Heat Exchanger[18]

3.2 Applications of Heat Exchangers in Remedica

Heat exchangers had applications at Various types of industries, the aim of them are Air conditioning systems, Power Production, Central Heating System, Automobile Radiator, Electronic Parts and Chemical Industries.

In the pharmaceutical industry as Remedica, fossil fuel boilers are used to generate steam that is distribute to the HVACs and Production equipment and then through Heat exchangers is transfer the heat, to the required equipment. Heat exchangers are used also to heat water for operation procedures.

At steam distribution loo of the company the return steam (is water at ≈60°C) return to a tank that is preheated with steam to 90°C. this is also work as a heat exchanger.

Chapter 4 - Steam usage in Remedica Ltd

Remedica company, doesn't need direct steam for it's needs but it needs it indirect in order to transform the high temperature in high pressure through heat exchangers for water heating, production equipment needs and Production rooms/warehouses ventilation.

4.1 Production equipment

Pharmaceutical procedures in many steps of the procedure are required hot air. The air is heated through heat exchangers. Steam pass though heat exchanger in high pressure and heats the purified air that pass from there in order to dry the pharmaceutical powder or tablets after coating procedure. In total there are 25 Production Machines in that complex that served by this steam loop.

There are 2 main machines in pharmaceutical companies that need steam for their processes. The 1st is the Film Coating machines and the 2nd is the Fluid Bed Dryer (FBD), both of them are using steam to heat air in order to dry the product.

Fluid Bed Dryer (FBD):

The Fluid Bed Dryer is the equipment is used in order to dry the wet product in specific temperature. The product is placed in the drying bed as shown on the Figure 9: Fluid Bed Dryer schematic then hot air the preset temperature is pass from the product and dry it. It is important to note that the air that pass from the product is pass through filters and is clean before contact product and then there is again filters before release to the environment.

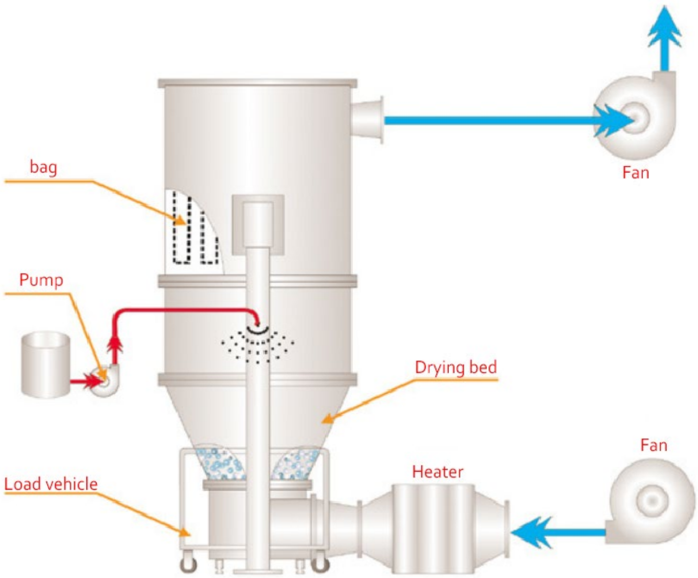


Figure 9: Fluid Bed Dryer schematic[19]

.

<u>Film Coating machines:</u>

The film coating machine is the equipment is used to apply coating to the tablets (is the time that tablet take the outline color). During this prosses steam is used to heat air through a heat exchanger. The air is clean air that pass from filters before contact with product and before the release to the environment.

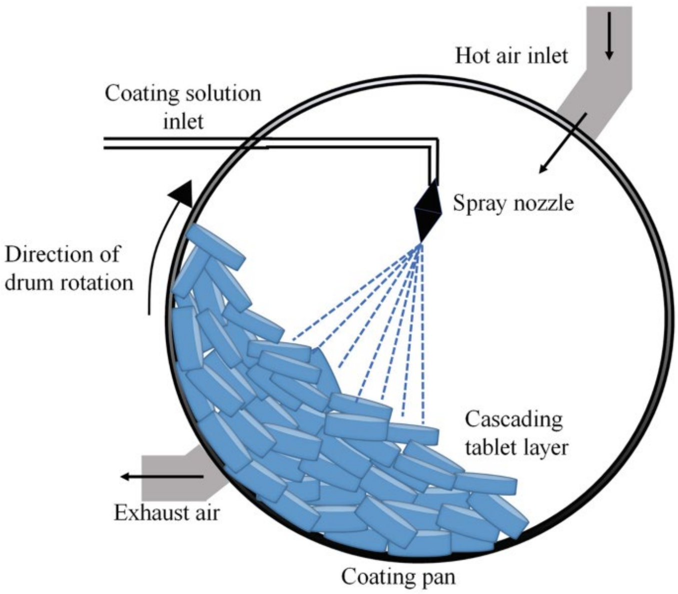


Figure 10: Tablet Film Coating Machine [20]

4.2 Ventilation Systems

For production areas and for storage rooms are used HVAC to control the environmental conditions. HVAC is for **H**eating, **V**entilation, and **A**ir **C**onditioning. HVAC systems are designed to control temperature, humidity, and air quality to maintain a specific environmental condition depends on the user needs.

In Remedica Ltd there are in total there are 25 HVAC units in the block that is performed this study that served production areas and warehouses.

On the Figure 11: simple HVAC flow schematic[21] below there is a typical Air Handling System. During winter there is bigger need for steam on HVACs although during summer there is bigger need on chillers.

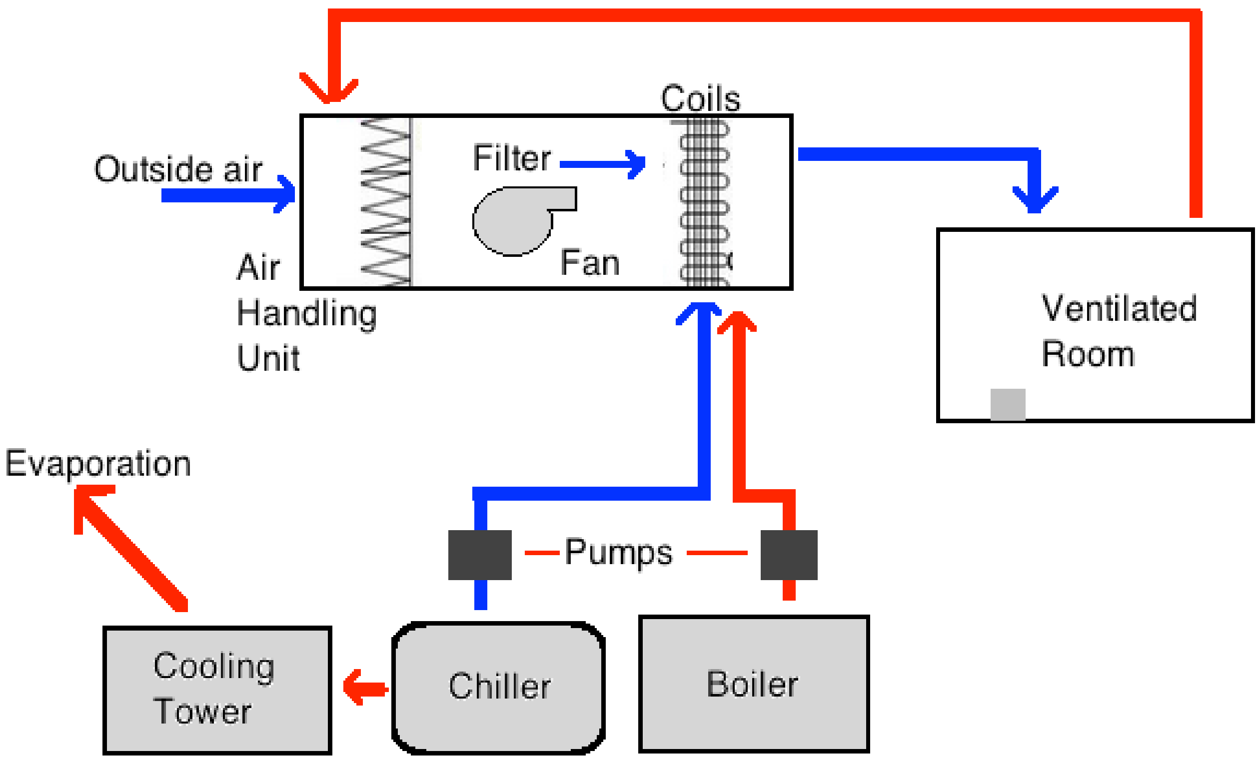


Figure 11: simple HVAC flow schematic[21]

4.3 Water heating

All big industries need hot water either for their operations in production procedure either for their facilities operation. In Remedica hot water is used for operation purposes and not in production procedure since for the medicines is used only purified water. The hot water is used for cleaning procedures and for other operations. In Remedica's facilities water is heated by steam loop through heat exchangers.

Steam is pass direct into the water tank (without mixing between them) until the water achieve the needed temperature. When the thermometer inside the tank read the requested temperature, then a controller is close a check valve and the steam flow stop passing until there is a need again.

Chapter 5 - Steam Boilers of Remedica Ltd

Remedica is using 3 steam boilers in order to generate the needed quantity of steam (at main block of premisses). These 3 steam boilers are connected to the same loop and serve all the need for production machines or facilities ventilation.

The capacity and the type of steam boilers are present on the Table 1: Boilers used in Remedica for steam Generation below.

A/A	Boiler ID	Type of boiler	Capacity	Area Served
1	Boiler 1	Water tube steam boiler	2000kg/h	All Remedica Facilities at main block of the company
2	Boiler 2	Water tube steam boiler	2000kg/h	
3	Boiler 3	Water tube steam boiler	10000kg/h	

Table 1: Boilers used in Remedica for steam Generation

All the above 3 boilers are used fuel oil in order to heat the water and generate steam and there are all water tube steam boilers. At the Appendix B is present photographs of the steam generation system of the company.

Chapter 6 - Steam Pipeline Loop

Steam is generated by boilers located in a central point in Remedica premises and distribute to all main premises of the company. All the boilers are connected to the main distribution manifold and from this manifold the steam is distributed to all buildings of the company. For this project purposes the steam distribution loop was scanned with thermometry in order to detect any energy loses or malfunctions of the steam distribution loop. For the purpose of this project the conditions of the steam tubes were also checked in order to check their condition and if there are any leaks.

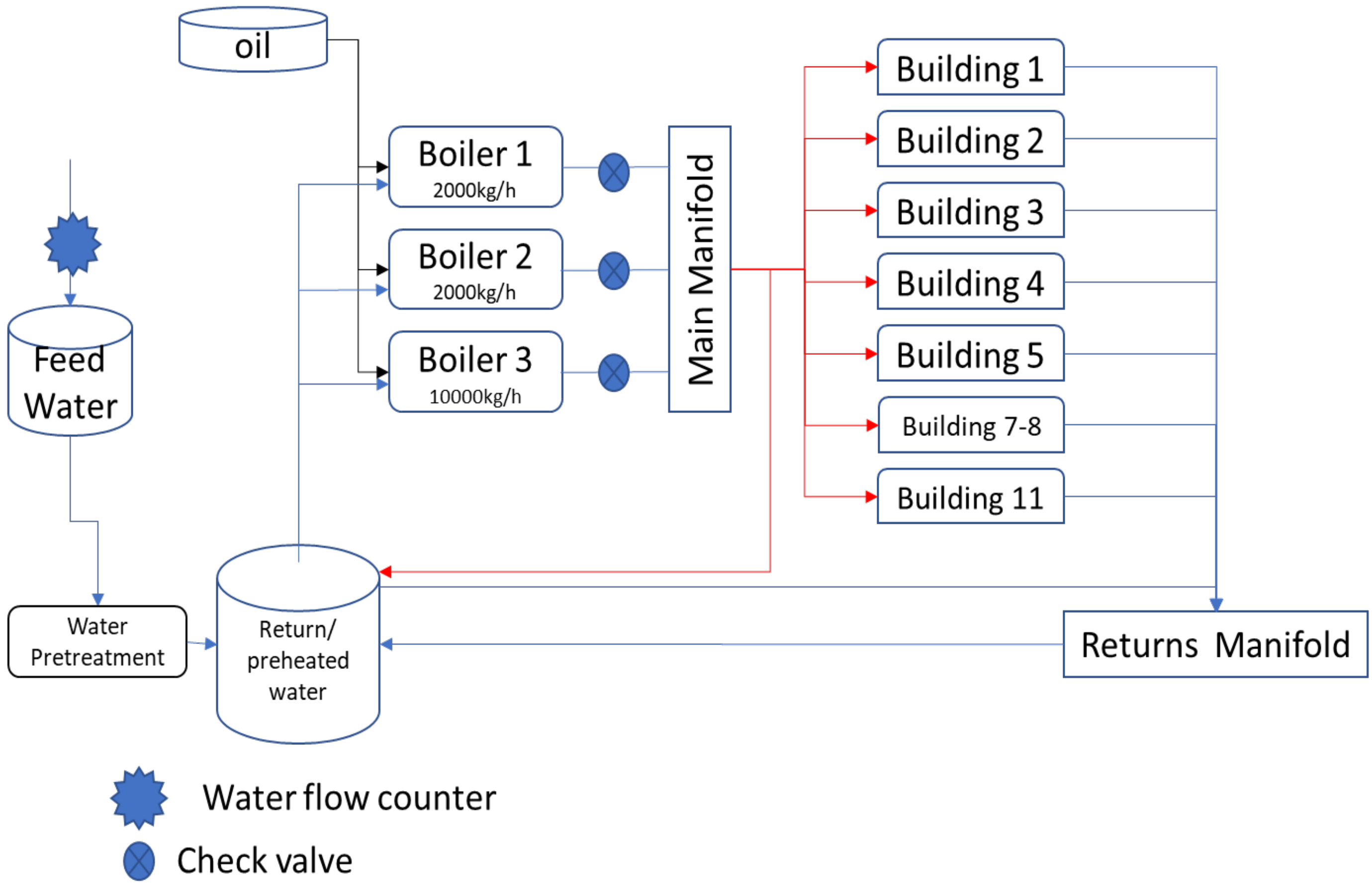


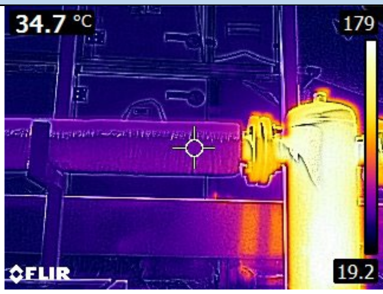
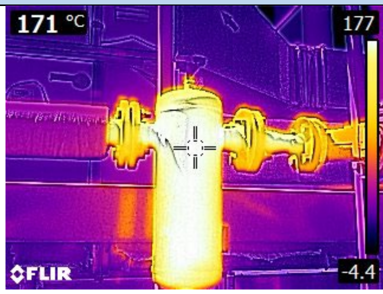
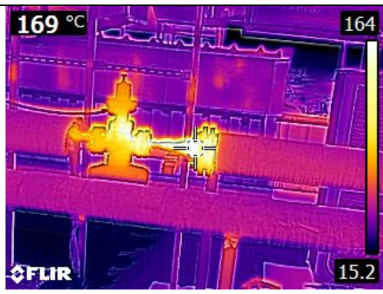
Figure 12: Steam Loop in Remedica Ltd

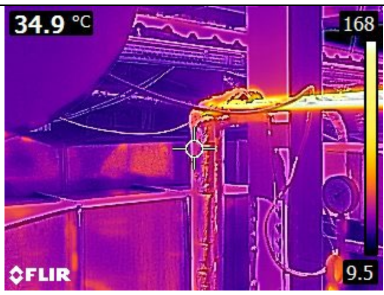
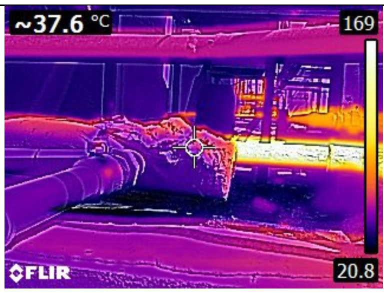
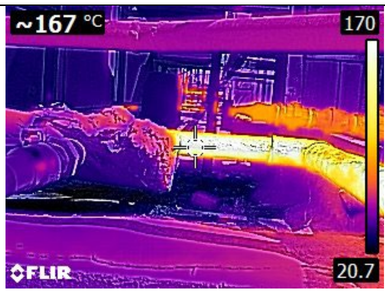
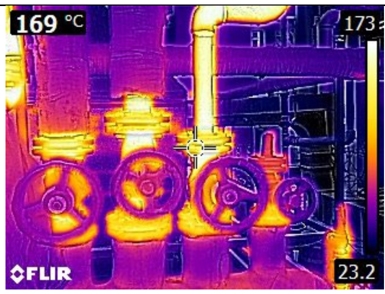
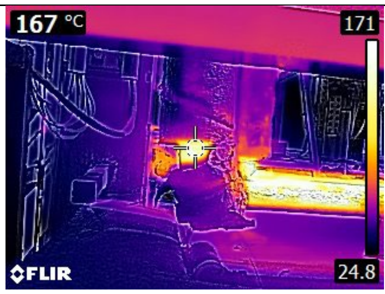
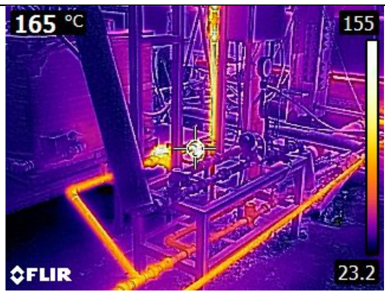
6.1 Steam distribution pipeline thermal insulation

Steam is generated at 180°C from the boilers and through the steam distribution loop of Remedica is distributed to all the needed equipment of the company. The main manifold is connecting the 3 boilers with all the buildings of the company.

The steam loop of the company is very long and with tubes with different dimensions and was very difficult to measured.

Although a check to the tubes was performed in order to check their conditions and there is anything that we could do in order to increase their efficiency. During this check I was notice that A lot of the pipelines are not insulated or their insulation it was damaged by the time it is exposed to the weather conditions and as a result we have temperature losses. In order to point out the losses of energy for every not insulated tube I measure the losses with a thermal camera.

Steam Pipes without thermal Insulation				
A/A	**Photograph**	**Insulated part of pipe**	**Non- Insulated part of pipe**	**Temperature different (°C)**
1				136.3°C
2				129.3°C

3				132.1°C
4				129.4°C
5				126.5°C
6				134.3°C
7				134°C
8				116.4°C

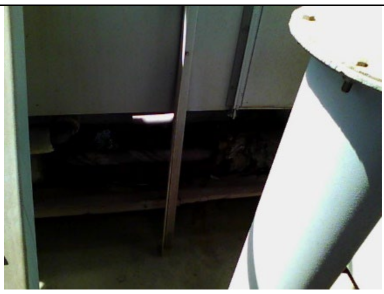
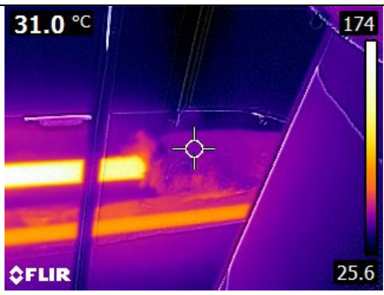
9				137°C
10				115.4
			Average different (°C)	129.07°C

Table 2:Non-Insulated Steam Pipes

From the results of the thermographs, we noticed that in general the thermal insulation of the hot was not at a good level since a big part of the tubes are not insulated or the insulation was destroyed. Nevertheless, during the thermal insulation process, points have been detected that need improvement due to wear or lack of thermal insulation. The results of this point were shared with Engineering and Works Department Manager of the company which is the responsible department. In collaboration with Works and Maintenance Supervisor of the company we initiate a schedule of maintain the insulation of all the steam tubes. At schedule we start from the main tubes that distributed steam from main manifold to the building's manifolds. The reason for this was because these tubes have bigger diameter from the others and this have a result bigger thermal (→energy) losses due to bigger surface area.

It is necessary to present also some points of the steam loop that they are properly thermally insulated and as a result we have minimised the energy losses. Some of these points are present on the Table 3:Steam pipes with thermal insulation below

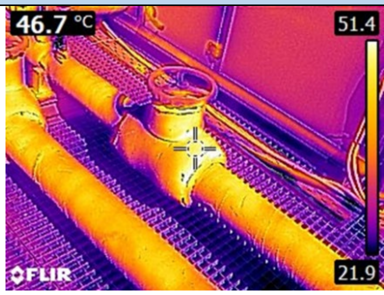
Insulated steam pipes		
A/A	**Photograph**	**Insulated part of pipe**
1		
2		

Table 3:Steam pipes with thermal insulation

6.2 Condition of loop pipelines

The steam distribution loop was checked by the thermal insulations we saw in the previous chapter and for any steam leaks. During the inspection it was found that there were leaks in many places. The leaks had been mainly detected in points that employees didn't present often for any maintenance. At places with employees present often for maintenances the steam leaks were not so great in quantity and intensity.

The main reason for the leaks was that the loop was old and this have a result in function with the high pressure steam the corrosion of the pipes and then the leak. With the aim of controlling steam leaks in the distribution loop, 2 proposals were made to the engineering and works department of the company

<u>Proposal 1:</u>

Periodically check of the steam distribution loop (and not only – since during the checks some more problems detect that belongs to Engineering & Works department). The frequency of this checks for steam leak purposes could be 2 times per week but since was including more subjects such as water leaks, compressed air leaks was proposed to performed at daily basis from a technician of the company that could perform direct the repairs or inform his supervisor for support.

Proposal 2:

Installation of online counter of feed water refill that can connected and monitored by Remedica BMS system. From this sensor we could see if the quantity of feed water increased and then immediately, we will know that somewhere in the loop was a leak.

Alternative we could installed steam counter (flow meter) on the steam pipelines and on the return pipeline (of steam – return as water) and then find the different that could show as if there is any leak. This could be installed from the main manifold to each factory and vice versa. With this way we could direct determine at which factory/building is the leak.

Engineering Department of Remedica Ltd has approved the 1st Proposal and direct start the daily checks on the distribution loop and this had as affect the reducing of losses and this is present on the fresh water that added on the system and described on

Chapter 8 - Feed water at steam . Regard the 2nd proposal it will evaluate within the next year since is priority the insulation of the steam pipelines due to high cost that described in Chapter 7 Energy losses and investments. In order t control the leakages is installed also a water counter that count the fresh water get into the system an from this point can confirmed that the leakages was reduced. From the counter if there is a bigger difference (big difference between current and the last count) from what is expected then there is a leak somewhere and we have to detect it.

Chapter 7 - Energy loses and Investments

As it was described ate the chapter 6 section 6.1 Steam distribution pipeline thermal insulation there are energy losses due to the fact that great amount of the tubes are not insulated or the insulation was destroyed. At this chapter it present the amount of energy losses from each not insulated steam tube. Since all the length of the loop was not measured the calculations was for all the types of tubes (different diameter and thickness) are used. Remedica Ltd start to insulate this tubes and at the end of this chapter a short overview of energy savings was earned until now this year (2023).

7.1 Energy losses from steam loop

At this section the Energy loss of steam tubes that was not insulated was calculated. For the purpose of calculating the energy loss, the energy that is lost and would not be lost if the pipe was insulated was taken into account. For this purpose, the temperature of the environment was not used as a comparison measure, but the temperature in the directly adjacent isolated part of the pipe.

Since not all of the company's steam pipelines were temperature measured, we consider as representative measurements the measurements presented in the photographs in Table 2:Non-Insulated Steam Pipes and as the temperature difference the average of the differences of the above measurement.

The energy loss is given by the below equation of heat transfer and is assumed that the measured temperature is the inside temperature of the tube and is stable.

$$\boldsymbol{Q = kA\,\frac{\Delta T}{\Delta X} \quad (W)}$$

Which,

Q is Energy in Watts

K= thermal Conductivity in W/m°C

A is the Area in m²

Δχ is the thickness of the tube in meters

ΔT is the difference of temperature in °C

The material that the steam tubes is used in Remedica is Cast Iron and the thermal conductivity of Cast Iron is 50 W/m/°C

In Remedica the tubes are used is present on the table below Table 4: Steam Tubes are used in Remedica.

A/A	External Diameter (mm)	Thickness (mm)
1	27.32	3.27
2	33.9	3.75
3	48.57	3.75
4	60.24	3.75
5	88.75	4.73
6	115.2	5.2

Table 4: Steam Tubes are used in Remedica

The external Diameter of each tube was used in order to calculate the surface area. All the calculations was performed for 1 meter length tube.

The Energy lost per tube Diameter according with the equation of heat transfer is given from the Table 5: Energy losses per tube Diameter and present the Energy losses per tube size(diameter) fr the tubes that are not insulated in comparison with the insulated tubes.

A/A	Tube Diameter	Energy loss per meter of tube per Hour
1	27.32	169.39 kWh/m
2	33.90	183.28 kWh/m
3	48.57	262.59 kWh/m
4	60.24	325.69 kWh/m
5	88.75	314.02 kWh/m
6	115.2	376.71 kWh/m

Table 5: Energy losses per tube Diameter (without insulation)

In order to make the loss of energy more understandable and in economic terms, the cost has also been calculated if this energy had been purchased from the Cyprus Electricity Authority based on the average purchase cost in accordance with the company's electricity bills.
The average cost of purchasing electricity for Remedica Ltd was 0.24 euros per kilowatt hour. The bills are not present on this project since are contained sensitive data of the company.

A/A	Tube Diameter	Energy loss per meter of tube per Hour	Cost per meter in euro
1	27.32	169.39 kWh/m	€ 40,66
2	33.90	183.28 kWh/m	€ 44,00
3	48.57	262.59 kWh/m	€ 63.04
4	60.24	325.69 kWh/m	€ 78.18
5	88.75	314.02 kWh/m	€ 91.32
6	115.2	376.71 kWh/m	€ 107.82

Table 6: Energy losses from tubes compare with cost if was purchase from Electricity Authorities of Cyprus

Due to the high different of temperature the energy lost for the not insulated steam tubes is very high and the cost of thermal energy losses is too high for the company without thermal insulation. Although the company's management was informed through the thermographs that there are large losses, it has realized and is taking more active actions after calculating the energy losses related to the thermally insulated piping of the steam production network. The same happens with the piping of the refrigerants, but you do not analyze it in this work as it is not part of the subject.

7.2 Corrective Actions During to Steam loop

During the first 4 Months of 2023 engineering department and after the results presented in section 7.1 of this chapter of the company start to install insulation to the steam pipelines in order to decrease the thermal losses to the environment and mainly to decrease the energy cost of this losses.

During the period of first 4 Months of 2023, it was measured the length of the pipelines was repaired and the length for each tube diameter is present on the table below.

A/A	Tube Diameter	Length in meters of insulation installed	Energy loss per meter of tube per Hour	Total energy saving (kWh)
1	27.32	13	169.39 kWh/m	2202,07
2	33.90	9	183.28 kWh/m	1649,52
3	48.57	18	262.59 kWh/m	4726,62
4	60.24	5	325.69 kWh/m	1628,45
5	88.75	11	314.02 kWh/m	3454,22
6	115.2	16	376.71 kWh/m	6027,36
			Total energy	19688,24

Table 7: Insulated steam tubes during January-April 2023

On the Table 7: Insulated steam tubes during January-April 2023 is present also the energy savings was achieved during the las months due to the insulation of the steam tubes. The above measurement's is per hour and if taken into account that boilers are working from 06:00 until 21:00 every working day then the daily savings in energy is 15 hours x 19688.24 kW/h = 29.532 MW per Working Day.

7.3 Energy losses from heating water

One of the usages of steam is heating water for general operations of the company. During steam distribution loop with thermocamera was also checked the tanks that is used for water heating.

The way the water is heated inside water tanks is using steam. The steam pass though pipe inside the water tank and heat the water. With a controller that receive temperature measurements from the tank we control the temperature of the tank. The way that temperature is controlled is by one check valve that open and close the steam pipeline and stop or leave the steam pass to heat the water. In Remedica we have 7 of these tanks and their dimensions are 1 cubic meter each.

One of these tanks is no insulated and have high energy losses to the environment. It was checked with thermocamera and compare with one of the other tanks that they had the same set point for temperature and the results are present on the Table 8: Water tanks for heating water with insulation and without

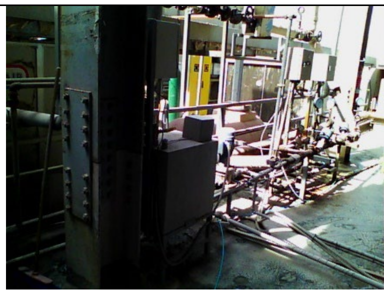
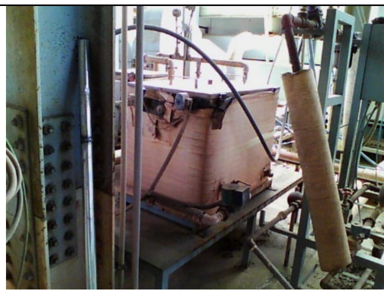
A/A	Real Photograph	Photograph with Thermocamera
1		
2		

Table 8: Water tanks for heating water with insulation and without

From the 1st tank, as we can see from the photo, temperature of 88.9°C are channeled to the environment, while in the 2nd tank, only 25.5°C. Thermal insulation of the tank offers a reduction of 63.4°C in the loss of energy to the environment. This means that it needs more steam to be used in order to heat the water and keep it at the required temperature.

If the above tank is thermal insulated with glass wool with thickness 4 cm, then we will have the below results

Thermal conductivity of glass wool = 0.03 W/m

Thickness= 0.04m

Area of Tank = 6m²

Assuming that the mean environment temperature is 24°C

Temperature of the tank is assumed that is stable at 88.9°C to all the area of tank

$$Q = kA\,\frac{\Delta T}{\Delta X} \quad (W)$$

$$Q = \frac{0.03\mathrm{W}}{\mathrm{m}} * \ 6\mathrm{m}^2 * \frac{(88.9-24)}{0.04m} = 292.05\ W$$

Chapter 8 - Feed water at steam generation procedure

There is a need to add fresh water to the steam loop for 2 reasons. The first reason is to replace the water you extract from the blow down procedure for system maintenance purposes from the impurities that may be present in the system due to natural wear and tear of the piping and the second reason is to replace the water it lost due to leaks in the distribution system.

A counter was installed at the feeding tube of fresh water tank in order to count the quantity of fresh water added to the boilers. The counter was installed at 15/03/2022 and in one year at 15/03/2023 the counter counts 4097 tons of fresh water used for steam generation purposes. The count on the counter was checked almost every week and the checks are present on the appendix A. Although it cannot be this describe the real need of water is used for steam generation since the working hours of the boilers wasn't standard, there was weekends that the production of the factory was in operation and was days that production work in 1 shift or in 2 shifts. In order to extract validated data from this counter there is a need of count the same time the working hours of steam boilers. For this reason, is better to have an online counter system that will record also the working hour of the boilers and be connected to the Environmental Monitoring System of the Company.

As part of this project, it was also measured the temperature of water into the feed water tank in order to compare with the temperature into the return tank which is supplied by feed water tank.

The temperature of the feed water tank was measured 5 different times of the year and the temperature didn't have such big different. The measurements are present on the Table 9: Feed water temperature below

A/A	Date	Measurement
1	13/04/2022	19.69 °C
2	16/08/2022	22.50 °C
3	07/10/2022	21.28 °C
4	13/01/2023	18.64 °C
5	30/04/2023	19.17 °C

Average temperature on feed water tank	20.26 °C

Table 9: Feed water temperature

The feed water flow into the preheater tank that is used also for the return loop as temporary storage area. The temperature of return steam loop (in water condition) is average at 60°C and is preheated to 90°C (with steam) before pass from the boiler and transits to high pressure steam. Since the refill quantity of water is near to 10 tons per day its better to check the possibility to preheat the water with solar panels so it will get at higher temperature to preheater tank.

For this purpose, it was measured a water heating of a solar panel and a 200L tank. During March 2023 it was measures the temperature of the tank at morning (06:00 – 07:00) and the temperature of the water inside the tank the midday (12:00-13:00). The mean temperature of the water was 18.4 °C at morning checks and mean temperature at midday checks was 58.3 °C. It is verry important to note that the tank was also in use during the day. Although is assumed that 1 solar panel is heating 200 L of water from 18.4 °C to 58.3°C, these numbers are similar to the temperature of the feed water tank and to the return loop temperature. This mean that with 20-25 Solar panels the feed water tank can preheated to the temperature of the return loop and with this way it will need to increase from 60°C to 90°C and not more.

Chapter 9 – Conclusions

In this thesis, the steam generation and distribution loop of a pharmaceutical company was study. For this purpose Remedica Ltd a pharmaceutical company in Limassol give the opportunity to study a real system. At first chapters the basic operation principles and types of heat exchangers and steam boilers was present and then a brief description of steam usage in Remedica Ltd. During this thesis is it was study and understand the usage and parts of the loop and some point that could change in order to decrease energy losses and increase energy efficiency of the system detected.

9.1 Recommended improvements

During this study it was detected some point that could increase the efficiency of the system and some of this point was direct transfer to the company. The recommended modifications /correction to the system is present below.

1. Thermal insulation of steam tubes and valves

As we have previously seen, during study, thermography has been performed of the steam distribution loop. Thermography has indicated a number of cases where the thermal insulation of the piping and/or circuit valves was deficient and in need of improvement. In this particular paragraph, we calculate the energy savings estimated to be brought about by strengthening the thermal insulation of the piping / valves, with a 40mm thick thermal insulation material and thermal conductivity. Jacket-type or and blanket type thermal insulation could be used for the valves, as shown in the images below

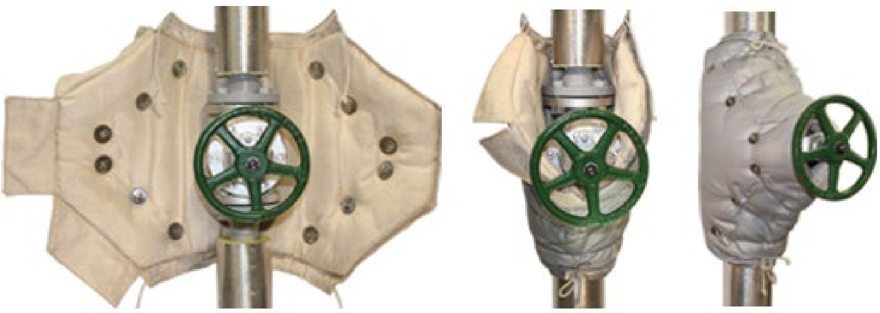


Image 1: Jacket type thermal insulation[22]

Image 2: blanket type thermal insulation[22]

2. <u>Thermal insulation of hot water tanks</u>

As it presents there are some water tanks that are used for hot water that are not thermal insulated and this have as a result the temperature loses that mean energy loses.

3. <u>Periodically check on the loop.</u>

This proposal is to avoid any thermal leaks due to destroyed thermal insulation or steam leaks due to pipeline. These checks could be the same for other systems of the company as the compressed air or the cold water that come from chillers and the water supply.

This is a point that Remedica already implement and at begin found a lot of issues but now problems are reduced and solve earlier.

4. <u>Installation of solar panels for feed water</u>

As it described feed water inserted into the loop at 20°C and mixed with returned water which is at 60°C and is preheated to 90°C. Due to the fact the quantity of feed water inserted into preheated tank is about 10 tons per day it is important to preheat it in order to need less energy for heating at 90°C. Solar panels is a good solution that will preheat free the feed water decreasing the energy need for heating.

5. Replacement of old steam pipelines

It has been found that several of the steam pipes are quite old and corroded. The steam leaks that have been detected in the system are almost all from these pipes. This indicates to us that these pipes have worn out and need to be replaced. The replacement is required for 2 reasons, 1st because there will be a leak at these points, possibly very soon, and 2nd because there is definitely internal oxidation, where residues circulate in the distribution network and end up in the boiler, thus reducing its performance, and there is a need for more blow down which means more loss of hot water (loss of water - loss of its heating energy).

6. Installation of online counters

It is important to have some measurements of the steam production system which will be recorded so that conclusions can be drawn for further improvement of the system.

This improvement would concern the required steam production, temperature and pressure control. The amount of water supply could be controlled in parallel with the use of the steam boiler and depending on the amount you release from the system through the blowdown, leaks would be detected immediately and the appropriate people would be informed via SMS.

Appendix A – Feed Water counter values

At the table below is written the real measurements of fresh water added to the system and an average daily consumption during these days. The 1st weeks the counter write high values since was a lot of leaks that repaired after the checks. The counter was installed at 15/03/202 after request for this study.

Fresh Water counter values.

A/A	Date	Measurement	Different from previous measurement	daily average consumption (tons)	
1	15/3/2022	0	0		Installation of the counter
2	21/3/2022	110	110	18,33333333	
3	28/3/2022	278	168	24	
4	4/4/2022	419	141	20,14285714	
5	12/4/2022	527	108	13,5	
6	19/4/2022	655	128	18,28571429	Various leaks - on distribution loop
7	27/4/2022	762	107	13,375	
8	3/5/2022	827	65	10,83333333	
9	10/5/2022	911	84	12	
10	17/5/2022	999	88	12,57142857	
11	24/5/2022	1084	85	12,14285714	
12	31/5/2022	1166	82	11,71428571	
13	8/6/2022	1251	85	10,625	
14	14/6/2022	1318	67	11,16666667	
15	21/6/2022	1401	83	11,85714286	
16	28/6/2022	1470	69	9,857142857	
17	5/7/2022	1536	66	9,428571429	
18	12/7/2022	1600	64	9,142857143	
19	19/7/2022	1669	69	9,857142857	
20	26/7/2022	1743	74	10,57142857	
21	5/8/2022	1854	111	11,1	
22	16/8/2022	1971	117	10,63636364	

23	23/8/2022	2059	88	12,57142857	
24	30/8/2022	2146	87	12,42857143	
25	6/9/2022	2248	102	14,57142857	leak detected on return loop
26	20/9/2022	2400	152	10,85714286	
27	27/9/2022	2464	64	9,142857143	
28	5/10/2022	2568	104	13	
29	11/10/2022	2634	66	11	
30	25/10/2022	2792	158	11,28571429	
31	3/1/2023	3505	713	10,18571429	
32	10/1/2023	3583	78	11,14285714	
33	17/1/2023	3649	66	9,428571429	
34	24/1/2023	3716	67	9,571428571	
35	8/2/2023	3819	103	6,866666667	
36	14/2/2023	3862	43	7,166666667	
37	22/2/2023	3922	60	7,5	
38	28/2/2023	3960	38	6,333333333	
39	7/3/2023	4024	64	9,142857143	
40	15/3/2023	4097	73	9,125	
41	21/3/2023	4143	46	7,666666667	
42	2/4/2023	4230	87	7,25	
43	30/4/2023	4432	202	7,214285714	

Average daily consumption of fresh water	11,29981705

Table 10: Fresh Water counter values

Appendix B - Steam generation system Photographs

Below is presented pictures of the steam generation system of the company.

Image 4: Boiler 1

Image 3: Boiler 2

Image 5: Boiler 3

Image 6: Feed water tank

Image 7: Steam distribution manifold

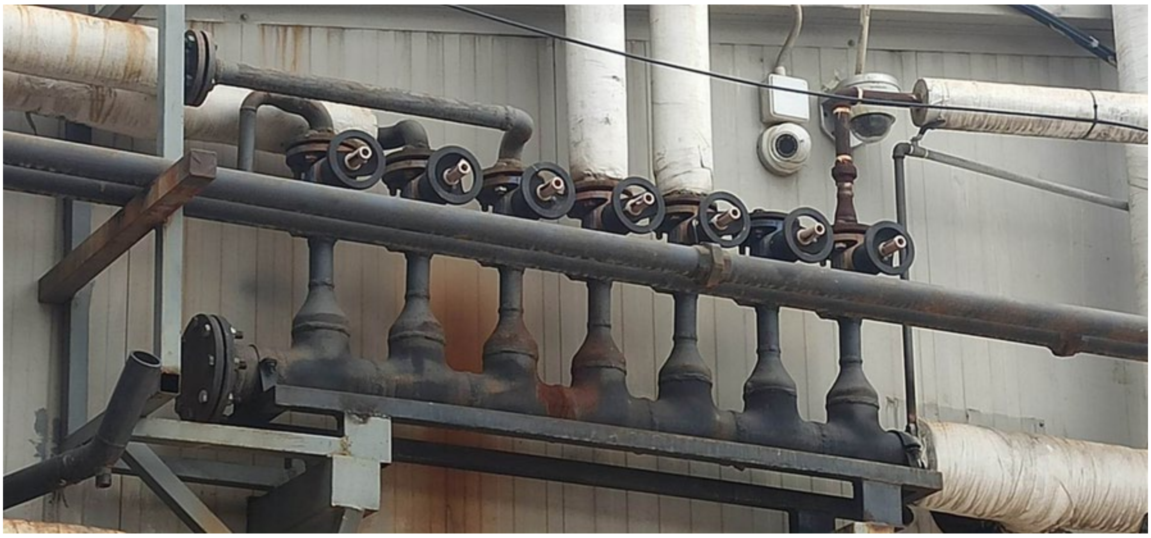


Image 8: return loop manifold

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