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IMPROVED ENERGY RECOVERY ON A SULPHURIC ACID PLANT

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1. INTRODUCTION

Sulphuric acid plants produce large quantities of heat and normally waste heat boilers recover about 55% of the total heat released as steam. This can be used to drive the blower on the plant, generate electricity or be exported for process use on the site. The heat from cooling of the absorber and drying tower acid circulation systems which amounts to about 35% of the total heat has in the past not usually been recovered. Cast iron serpentine coolers which are commonly used for this duty can give rise to many problems particularly when seawater is used as the coolant.

With the ever increasing cost of energy and development of heat exchange systems for sulphuric acid cooling the recovery of heat particularly from the absorber tower circuit has become increasingly attractive. This is particularly so where there is a use for low grade heat. In 1980 as part of an energy saving campaign at Leith Fertiliser Works studies were carried out on the benefits to be achieved from the recovery of heat from the acid cooling circuits of a 75,000 tonnes H_2SO_4/year sulphuric acid plant. The economics of installing a heat recovery system on the absorber tower circuit looked worthwhile and it was decided to replace all the existing serpentine coolers on the plant with plate heat exchangers. The installation was commissioned in June 1981 and good operating experience had been obtained from the heat exchangers/coolers. Reliable performance has also been achieved from a shell and tube heat exchanger, without energy recovery, on acid cooling duties on another sulphuric acid plant.

This paper reviews design parameters, economics and operating experience on the two installations.

2. BACKGROUND

The SAI Fertiliser Works at Leith manufactures a range of ammonium nitrate based granular compound fertilisers, prilled ammonium nitrate and powdered ammonium phosphate ('PhoSAI'). The back-up production facilities include nitric acid, phosphoric acid and sulphuric acid plants. The two sulphuric acid plants are of the sulphur burning contact type and their waste heat boilers supply a large proportion of the process steam demand for the site. Oil fired boilers make up the deficit of the steam requirements.

No.1 Plant was originally rated at 58,000 tonnes H_2SO_4/year and No.2 Plant at 30,000 tonnes/year but their output has been progressively increased to the present level of around 115,000 tonnes H_2SO_4/year. Both plants had cast iron serpentine acid coolers with seawater as the coolant on the absorber/drying tower acid circuits. The seawater was discharged to drain. The coolers were a source of significant plant downtime, high maintenance costs and plant output was being limited due to the difficulty of maintaining effective distribution of water over the coolers. There were therefore other incentives apart from heat recovery in terms of potential increased plant output and reduced maintenance costs to replace the coolers.

The first step was taken in 1979 when it was decided to replace the existing coolers on the smaller plant (No.2) with an anodically protected shell and tube heat exchanger to cool the acid for both the absorber and drying towers of the plant. Following this in 1981 plate heat exchangers were installed in the larger plant (No.1) to cool the separate absorber and dryer tower acid circuits and recover heat from the absorber acid circuit. This heat is used to pre-heat boiler feed water for the waste heat boilers on both sulphuric acid plants and the oil fired boilers on the site so reducing the amount of oil generated steam required for this purpose. There was no justification for heat recovery on the dryer tower acid circuit which operates at lower temperatures.

3. ACID COOLING WITH A SHELL AND TUBE HEAT EXCHANGER (No.2 PLANT)

In 1978 production from the two sulphuric acid plants at Leith was insufficient to meet the company's acid requirements and the shortfall had to be met by purchased sulphuric acid. As the seawater cooled cast iron serpentine coolers in No.2 Plant were restricting output it was decided to investigate the possibility of their replacement with a modern heat exchanger acid cooling system.

Chemetics, a subsidiary of Canadian Industries Limited, had developed an all-welded high alloy stainless steel shell and tube heat exchanger for sulphuric acid cooling. As is well known the corrosion rate of stainless steels such as 304L and 316L when exposed to concentrated sulphuric acid is very dependent upon the acid temperature. Relatively small rises in temperature can increase the rate of corrosion very markedly and failure of a shell could occur in a very short time if some form of corrosion protection is not provided. Chemetics by the use of anodic protection on the heat exchanger shell keep the corrosion rate to a very low value so achieving an extended shell life.

Generally the materials of construction used in these exchangers are dictated by waterside considerations and not by the acid side. The proposed installation at Leith proved to be no exception because while there were a number of sulphuric acid plants operating successfully with coolers of this type the majority used freshwater for cooling purposes with the water tubes constructed from 316L stainless steel. There was only limited experience with seawater cooling on Chemetics heat exchangers and there was concern about the rate of corrosion and likely life of the water tubes when

when operating on seawater at Leith. Apart from assessing the likely corrosion resistance of different alloys to seawater particular attention was given to the standard of surface finish that could be achieved on the internal bore of tubes as manufactured. Freedom from defects on the bore of the tubes was very important because of the risk of deposits of scale or marine growth forming in the defects which could lead to crevice corrosion and eventual perforation of the tubes. From experience in other locations using seawater it was considered that crevice corrosion would be the main hazard and it was clear that rigorous quality control during manufacture of the tubing would be essential.

Having evaluated fully the corrosion resistance of various alloys and standards of fabrication and inspection used by Chemetics it was decided to go ahead with installation of a shell and tube cooler to the following specification:

Tubes	- Avesta 254 SMO (a high molybdenum alloy specially developed for seawater cooling applications. Analysis of 20% Cr, 18% Ni, 6.1% Mo, 0.7% Cu, 0.020% C)
Shell	- 304L stainless steel
Tubesheets	- 904L stainless steel
Shellside	- Acid with anodic protection
Tubeside	- Seawater, 3 pass

A simplified flow diagram of the cooler installed on Leith No.2 Plant is shown in Figure 1. A single circulation tank receives acid from both the dryer and absorber towers and it is then pumped through the acid cooler. The temperature of the acid in the circulation tank is 85°C. A proportion of the total acid circulation is cooled down to the dryer inlet temperature of 60°C while the acid required for the absorber tower is mixed with the balance of the uncooled circulation and enters the absorber tower at 75°C.

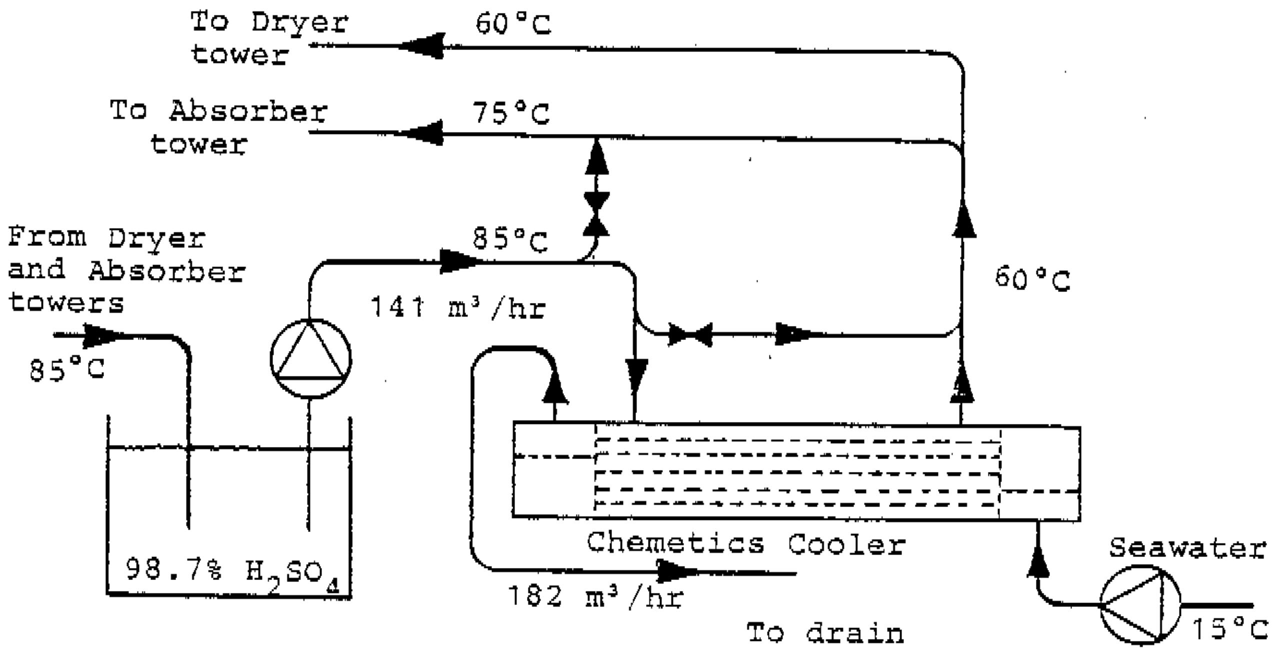


Figure 1 - Flow diagram of acid cooling system on No.2 Sulphuric Acid Plant

The new cooler (Figure 2) was installed with the minimum of disturbance to operation of the Plant. Because of its compactness (5 m long x 0.6 m diameter) it was possible to erect the heat exchanger adjacent to the existing acid cooler banks while the plant was in production and it was commissioned during a 24 hour shutdown.

The installed cost of the cooler etc was £85,000 in 1978.

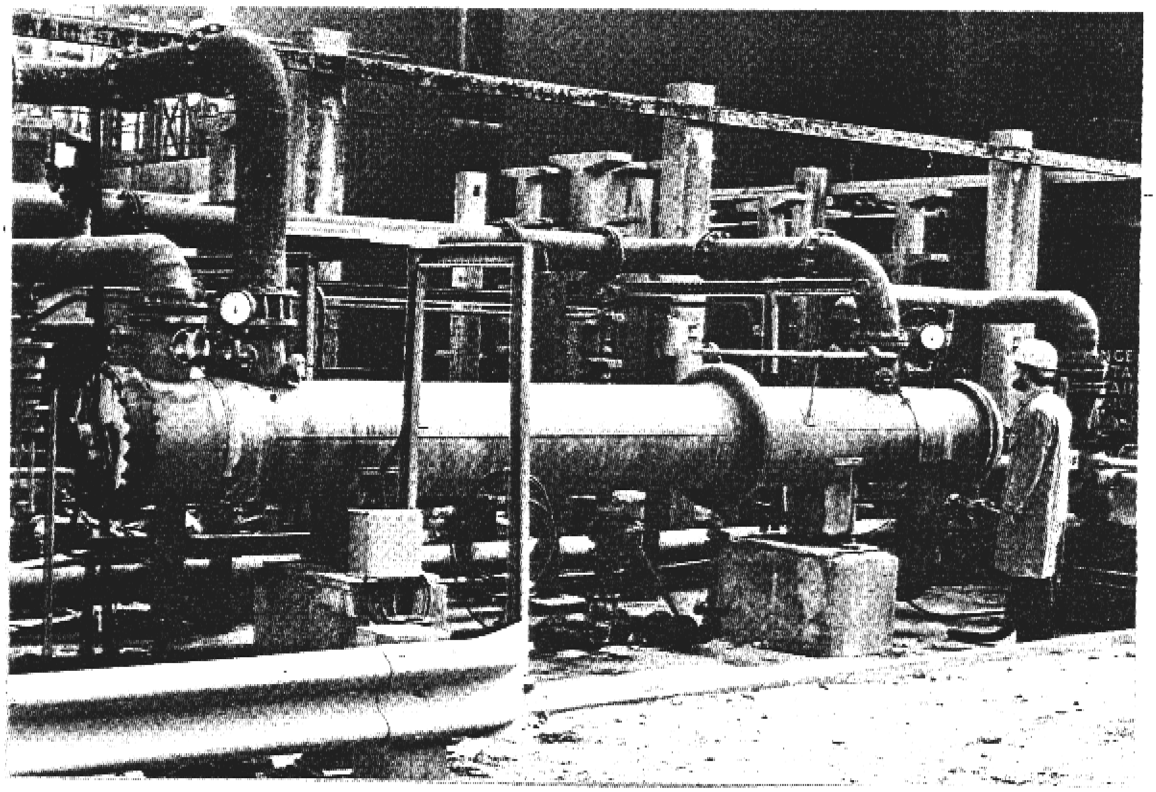


Figure 2 - Shell and tube cooler on No.2 Plant

(a) Design aspects

i] Prevention of corrosion :

In addition to anodic protection on the acid side, steps are taken to minimise corrosion on the seawater side. The unit has a high velocity seawater flow through the tubes to minimise formation of scale and marine growth which could lead to crevice corrosion. In addition the high circulation rate of seawater ensures that the tube wall temperatures are maintained as low as possible. To maintain this high velocity at all times control of acid temperature is by use of an acid bypass around the cooler while maintaining full seawater flow. The seawater is filtered and chlorinated for part of the year in order to minimise biological growth which could lead to fouling of tubes, and hence elevated seawater temperatures and corrosion problems. Because of the need to have high velocities through the tubes, the seawater flow through the Chemetics cooler is double that used previously on the serpentine acid coolers.

If the plant shuts down for any reason, seawater is immediately drained from the cooler. The shell is then flushed out with fresh water so that there is no possibility of having stagnant seawater within the unit at elevated temperatures.

ii] Leak detection :

Acid pressure is maintained above seawater pressure so that should a failure occur, the pH monitoring equipment in the seawater system will give an alarm allowing remedial action to be taken immediately.

iii] Operating experience :

Since its installation in September 1979 operation of the shell and tube acid cooler has been virtually trouble free. The anodic protection unit has worked very effectively and there is no evidence of corrosion on the acid side. The tubes handling seawater are also in good condition. As a direct result of removing the acid cooling restrictions on the Plant output has been increased by some 30% giving a pay-back in less than one year after taking into account the extra operating costs for pumping seawater etc.

4. ACID COOLING AND ENERGY RECOVERY WITH PLATE HEAT EXCHANGERS (No.1 PLANT)

The objectives in considering replacement of the existing acid coolers with a cooling/energy recovery system were threefold:-

i] To preheat boiler feed water for boiler plants on the site up to a temperature of 80°C and so reduce the amount of steam required for this purpose.

ii] To increase the acid cooling capacity of the plant.

iii] To reduce plant downtime and maintenance costs associated with acid cooling.

In any heat exchange system for pre-heating boiler feedwater using heat from an acid cooling circuit there is a risk of contamination of the boiler feed water with sulphuric acid. In order to reduce this possibility to an absolute minimum it was decided that the duties of acid cooling and pre-heating of boiler feed water should be carried out in separate heat exchangers linked by a closed circuit of softened water. In this arrangement heated water from the acid cooler is used to preheat the boiler feed water in a secondary heat exchanger. A trim heat exchanger with seawater cooling is also provided in the closed circuit for temperature control purposes.

Three alternative cooling/heat recovery schemes using this basic design concept were considered. One used anodically protected shell and tube heat exchangers similar to the unit installed on Leith No.2 Sulphuric Acid Plant and two used plate heat exchangers without anodic protection. Following detailed examination of the alternative schemes it was decided to instal the plate heat exchanger system developed by Alfa Laval.

Conventional plate heat exchangers were used and Figure 3 shows an exploded view of a typical unit. Heat transfer occurs in a pack of corrugated metal plates. Flow ports, at the corners of each plate, are arranged so that two liquids flow in alternative channels and heat transfer occurs through each plate. Gaskets, bonded into grooves around the edges and the ports determine the flow pattern and seal the channels. The plates are mounted between upper and lower carrier bars and are compressed against a fixed cover by means of a moveable end plate and horizontal tie bolts. Fluid connections are located on the fixed cover. As in all plate heat exchangers the cooling water and acid sides are easily exposed for cleaning and maintenance, all within the length of the frame.

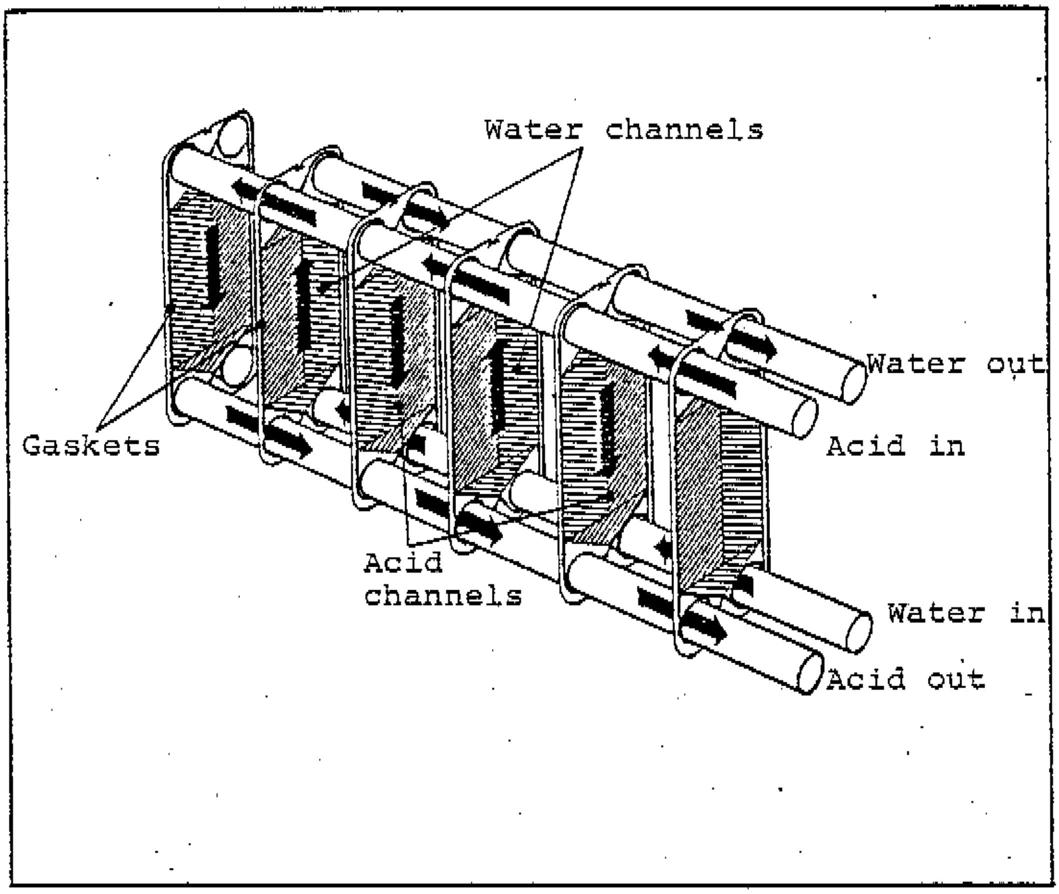
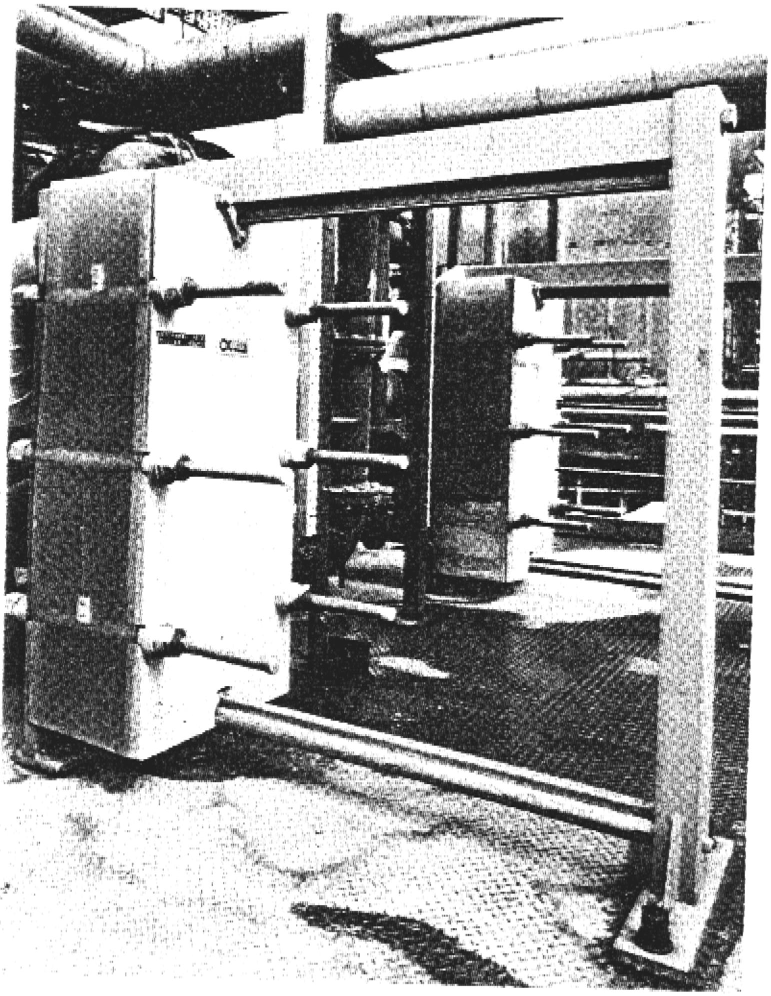


Figure 3 - Exploded view of plate heat exchanger

Figure 4 shows the two acid coolers at Leith.



Absorber Acid
Plant coolers
on No.1 Plant

A simplified flow diagram of the plate heat exchanger system as installed at Leith is shown in Figure 5. Acid (98.7% H_2SO_4) from the absorber tower discharges into a brick lined tank from where it is pumped through two plate heat exchangers in parallel to cool the acid from 92°C to 70°C. The plate exchangers are of Hastelloy C construction with Viton gaskets. A proportion of the cooled acid bypasses the absorber tower and is returned to the pumping tank in order to limit the temperature of the acid going to the coolers to 92°C. The absorber acid is cooled by an intermediate loop of circulating softened water. From the acid cooler the heated water flows through the boiler feed water heater which pre-heats feed water for the sulphuric acid plant waste heat boilers and the oil fired boilers on the site from 10°C to 80°C. The water heater is a single plate heat exchanger with AISI 316 plates and ethylene propylene rubber gaskets. A further plate heat exchanger (trim cooler) with seawater as the coolant is provided in the circuit for temperature control purposes. This is to deal with any fluctuations in the circulating water outlet temperature of the water heater caused by changes in demand for boiler feed water preheating. Temperature control to the required level for entry to the acid cooler heat exchanger is achieved by means of an automatic valve on a bypass around the cooler. The trim cooler is a single plate heat exchanger with titanium plates and butyl gaskets.

The heat exchange system was designed to pre-heat 33 M^3/hour of boiler water from 10°C to 80°C. If however boiler feed water demand should peak above this level the additional flow required bypasses the energy recovery heat exchanger. If demand is below 33 M^3/hour the excess preheated water recycles through the feed pump back to the inlet of the water heater.

Typical temperature conditions for the system are given below:

Absorber tower	- Acid in	- 70°C	
	- Acid out	- 100°C	
Absorber acid	- Acid in	- 92°C	Water loop in 27°C
Coolers	- Acid out	- 70°C	Water loop out 82°C
Water heater	- Boiler water in	- 10°C	Water loop in 82°C
	- Boiler water out	- 80°C	Water loop out 54°C
Trim cooler	- Seawater in	- 15°C	Water loop in 54°C
	- Seawater out	- 30°C	Water loop in 27°C

Under these conditions approximately 2.5 mw is recovered from the absorber circuit.

The acid on the drying tower circuit is cooled from 50°C to 40°C in a separate plate heat exchanger using seawater as the coolant which discharges to drain. In this case Hastelloy C plates with Viton gaskets are used.

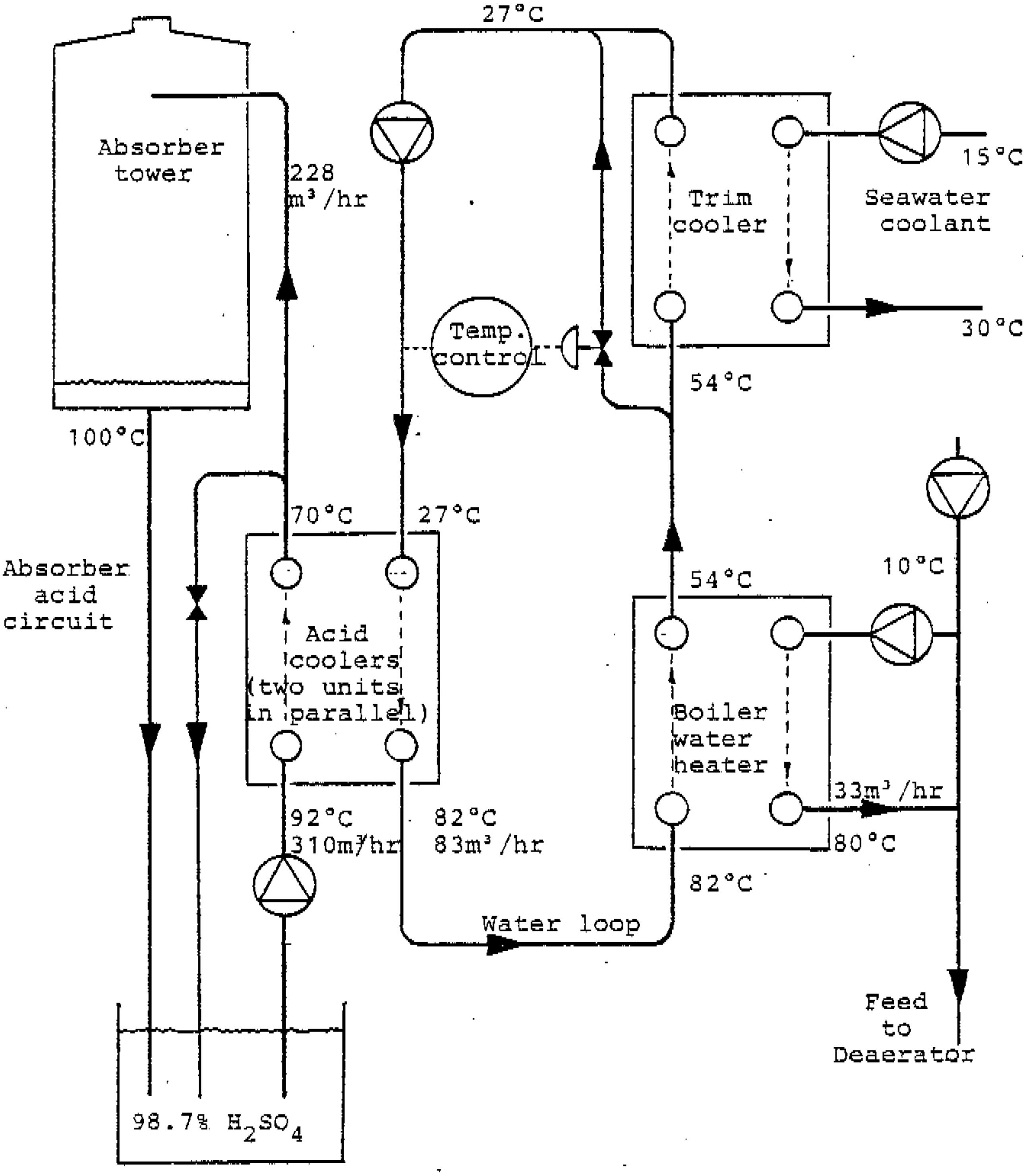


Figure 5 - Absorber Acid Cooling/Energy Recovery System on No.1 Sulphuric Acid Plant.

The cooling/heat exchange system which is shown in Figure 6 was partly erected off site in modular fashion. The old cast iron serpentine coolers were then demolished and the new heat exchangers erected in the same location. The work was carried out during a five week shutdown of the plant. The new plate heat exchangers are very compact and occupy only a fraction of the space required for the old serpentine coolers. The total cost of the installation in 1981 was £250,000 of which £95,000 was for the heat exchangers.

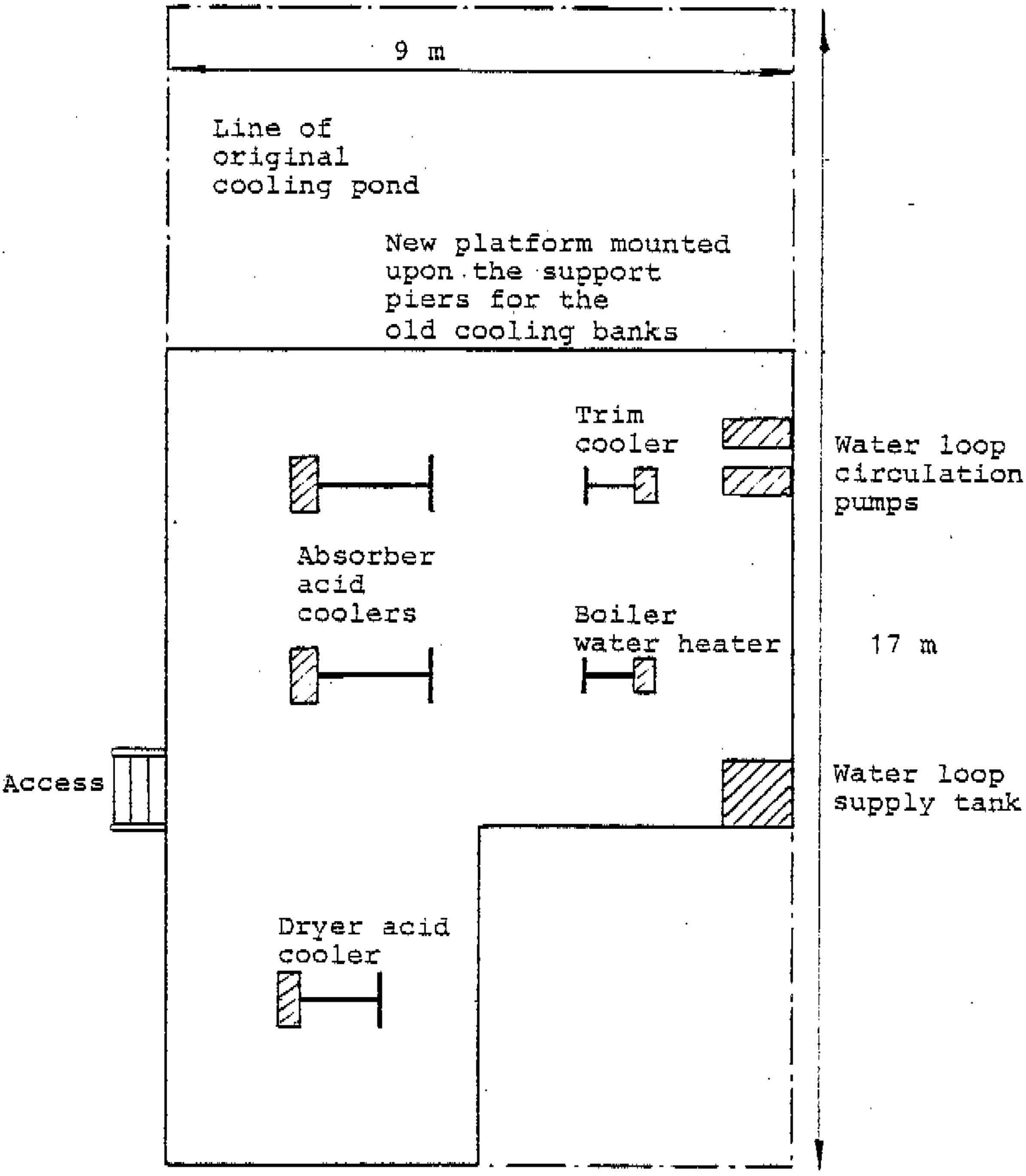


Figure 6 - Plan of acid cooling area, No.1 Plant.

(a) Design aspects

i] Expected plate life :

Prior to the installation of plate heat exchangers the acid temperature ex the absorber tower to the serpentine coolers was around 100°C and there were problems with acid leaks from the pipes and joints. At this temperature the corrosion rate on Hastelloy C plate exchangers would be at least 0.2mm/year in relation to a plate thickness of 0.7mm. For the Leith installation the design acid inlet temperature to the plate cooler was fixed at 92°C. This was a balance between having a reduced temperature for minimal corrosion and extended plate life and a higher temperature for improved energy recovery. The corrosion rates at 92°C are estimated to be 0.1mm/year reducing to 0.01mm/year at the outlet section of the cooler where the temperature is 70°C. Each year by reversal of the direction of fluid flow and by inter-changing the channels through which the acid and water flow the higher level of corrosion due to acid at 92°C is spread more evenly throughout the heat exchanger. Under these circumstances the estimated average corrosion rate over a period of four years is 0.11mm giving an expected plate life of over 12 years. The changes in acid and water flows outlined above can be achieved without disturbing the plate pack or modifying the pipework. Since failure of gaskets usually occurs due to the inability to re-seal a disturbed joint the rotation of the acid and water port duties without dismantling the plant pack should result in a gasket life of over four years.

ii] Prevention of contamination of boiler feed water :

As mentioned earlier the use of an intermediate heat exchanger for preheating boiler feed water minimises the possibility of contamination of boiler feed water with sulphuric acid or seawater. However to reduce the risk even further the pressures in the various acid and water circuits are arranged so that possible acid or seawater leakage paths would flow away from boiler feed water. This is indicated in Figure 7. In addition the intermediate loop is monitored for pH changes and losses or gains in fluid so that a leak would be detected quickly.

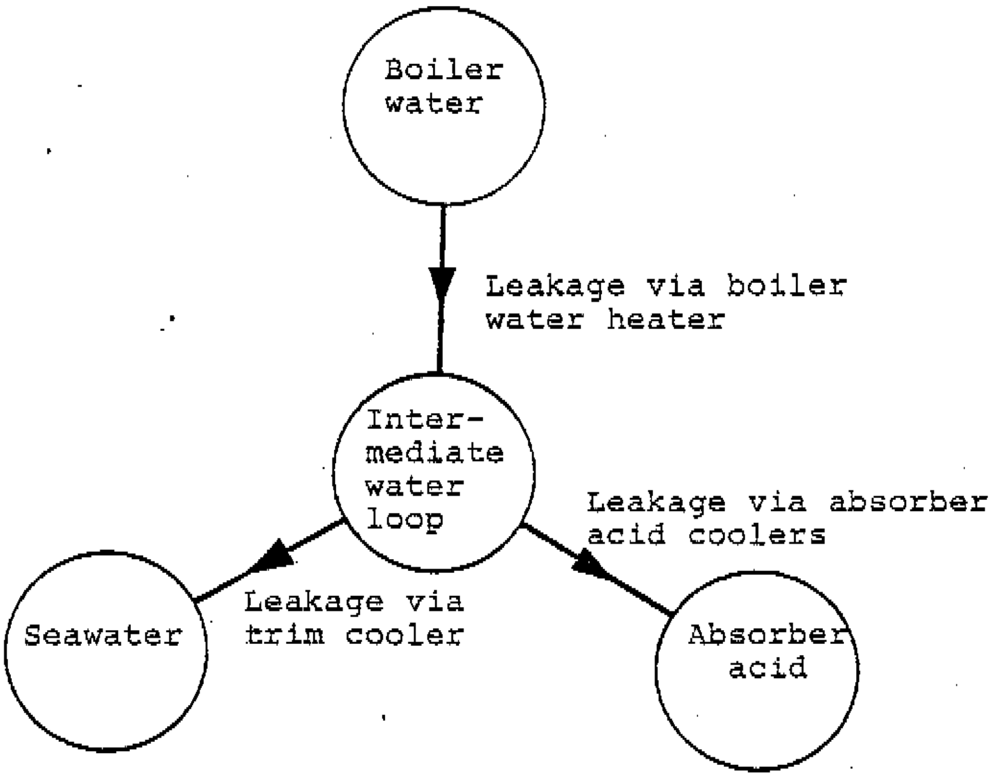


Figure 7 - Leakage paths in the event of plate perforation.

iii] Boiler water preheat temperature :

The boiler water preheat temperature is maintained at 80°C independent of plant load. This is achieved by keeping the acid temperature to the acid coolers at 92°C over a wide range of plant outputs. Control is achieved with a bypass on the intermediate water loop which alters the flow through the trim cooler and hence the heat lost by it. Control of seawater flow to the trim cooler was rejected as an option since at low plant loads this would lead to the seawater outlet temperature from the coolers being in excess of 45 - 50°C and scaling might occur.

iv] Protection against choking and fouling :

With the fine clearances between the plates in the heat exchangers, steps have to be taken to minimise the possibility of choking resulting from the ingress of debris for example from degraded brick work from the absorption tower. Backflushing arrangements are provided so that any debris caught in inlet ports can be flushed out and discharged through a separate return line. The acid is filtered before returning to the pumping tank. A backflushing arrangement is also provided on the seawater side of the trim cooler. Seawater is chlorinated during part of the year to minimise the possibility of marine growth and fouling of the heat exchange surfaces.

(b) Operating experience

Operation of the plate heat exchanger cooling system which was commissioned in June 1981 has been virtually trouble free. The problems associated with inadequate cooling especially in summer have disappeared and it has been possible to run the plant at higher production rates for longer periods. The number of plant shutdowns caused by acid cooler problems has decreased dramatically and the cloud of steam which hung over the old coolers has disappeared. In addition the new cooler system has led to improved start-ups of the plant as optimum acid temperatures can be reached more quickly than with serpentine coolers.

The design operating conditions have been achieved in practice and boiler feed water is heated from 10°C to 80°C reducing oil demand by 1700 tonnes/year. This gives a reduction in oil consumption worth £200,000 per year - a pay back in just over a year on the capital cost of £250,000. In addition there are benefits in terms of higher plant output and lower maintenance costs.

5. FURTHER DEVELOPMENTS

Since the installation of the plate heat exchanger system at Leith welded plate heat exchangers with anodic protection for sulphuric acid cooling and heat recovery at elevated temperatures have been developed. Welded plates have replaced the Viton gaskets on the acid side which have in the past been a limit on the temperature of operation and it is now possible to have acid inlet temperatures in excess of 100°C. This is similar to the temperatures achieved with shell and tube heat exchangers with anodic protection which have been in operation for some years. There are also installations using Teflon heat exchangers either of the shell and tube type or immersion coils for sulphuric acid cooling and heat recovery.

As well as recovering energy from the acid cooling circuits of a plant it is also important to look at the energy a plant consumes particularly through the main air blower which is of course a reflection of the pressure resistance through the plant. At Leith it will be necessary to replace the absorber tower on No.1 Plant in the near future and the opportunity will be taken at that time to instal a new tower with a lower pressure drop - so reducing the energy absorbed by the blower.

6. CONCLUSIONS

The replacement of the cast iron serpentine coolers on the two Sulphuric Acid Plants at Leith with shell/tube and plate heat exchangers for acid cooling and heat recovery has been successful. The benefits are summarised below:

(a) Substantial savings in fuel have resulted from the installation of a heat recovery system.

(b) Increased sulphuric acid output has been achieved as a result of improved plant availability and increased cooling capacity.

(c) Maintenance costs on the acid coolers have been reduced.

(d) Better control of acid temperatures has been possible leading to improved operation of the plants particularly during start up periods.

TA/82/4 Improved energy recovery on a sulphuric acid plant, by G.B. WHYTE, Scottish Agricultural Industries PLC, United Kingdom

DISCUSSION : (Rapporteur P. ORPHANIDES, PFI, Greece)

Q - Mr. A.M. HUNTER, Syricon Ltd, United Kingdom

Would Mr. Whyte tell us why SAI selected a Chemetics cooler for their N° 2 plant and not plate exchangers, and for their N° 1 plant plate exchangers and not a Chemetics cooler?

The design studies we have undertaken and installations we have designed, utilizing both types of exchanger, indicate that for a plant of the capacity of N° 2 plant plate exchangers would probably be a more economic choice. The shell and tube unit would be more attractive at high plant capacities and particularly where heat recovery is involved.

A - While what Mr. Hunter says is probably correct as far as design studies are concerned the situation at Leith was somewhat different.

Chemetics worked very closely with us on the installation of the Shell and tube heat exchanger on N° 2 plant. They were interested in getting further experience with a cooler operating sea water and the whole package they proposed for the cooler system was very attractive to us. On hot plant we fully considered the alternatives of Shell and tube and plate heat exchangers taking into account limited availability of sea water for cooling, the limitation of the absorber and temperature to around 92° C and capital costs etc... As you know we finally decided on Alfa Laval plate heat exchangers.

I think that one cannot generalize on what should or should'nt be installed and every project should be evaluated on its own merits.

Q - Mr. L.J. HENDRIKS, UKF, Netherlands

1. In many places in the world, the quality of the cooling water is for our purposes "too good" due to waste-water treatment, etc... (even for brackish-river water).
   Biological growth is becoming more and more an important disturbing factor.
   To minimize this effect you chlorinated for a part of the year the sea-water.

   Is this operation continuous or interruptible?
   Are you starting this operation at a certain distinct sea-water temperature level?

2. In your paper is mentioned the use of Teflon-Spaghetti-Heat exchangers.

   Why did you select plate-heat exchangers instead of Teflon Immersion-Coils?
   Was the choice based on:
   - Lower investment cost?
   - Maintenance cost?
   - Production reliability?

   Can you give an indication of the project, based on:
   - Lower maintenance and
   - Better operation performance?
   Excluded: Energy Saving!

A - 1. After several years experience we have found that we require to chlorinate the sea water during the period April to September each year. This is when the sea water temperatures are higher and biological growth is prevalent but we do not check the water temperatures before starting chlorination of the water.

2. We selected Alfa Laval plate heat exchangers following an evaluation of alternative options taking into account several factors including the plant operating conditions at Leith, experience of plate heat exchangers operating under similar conditions elsewhere, capital cost, etc... We did not evaluate Teflon immersion coils but I would have reservations about their reliability when operating under the conditions pertaining at Leith.

3. It may be possible to justify the installation of plate heat exchangers purely on lower maintenance costs and better operational performance but this will depend upon other limitating factors on a particular plant. For example the presure drop through the plant may be critical and to take full advantage of potential increased output a new blower would be necessary - but this would require an economic evaluation.

Q - Mr. E. GONTHIER, Prayon-Rupel, Belgium

Why do you use a by-pass after cooling the acid to keep the temperature at 92° C?

We feel that, as long as hydrodynamic flow conditions in the tower allow a fluctuation, it is preferable to increase the acid flow in the tower and to adjust the acid temperature in the pumping tank with the outlet temperature in the tower. This would have the following advantages:

- a lower ΔT in the tower
- limited variations around the optimum absorption conditions
- a uniform temperature at the pump aspiration.

A - I'am sure that the questioner purpose is correct but we had limitations with equipment on an existing plant and we decided to limit the corrosion rate on the absorber cooler by controlling the acid inlet temperature to 92° C.

Q - Mr. D. BHAGA, Chemetics, Canada

By using higher acid handling capability of anodically protected acid cooler it would have been possible to recover 20% more heat (10° C to ∿ 95° C). Why did SAI opt for recovery heating boiler feed water only to 80° C?

A - As I stated in my reply to Mr. Hunter we were concerned about running our N° 1 plant with acid from the absorber tower at a temperature of ∿ 100° C because of corrosion problems throughout the plant. The heat recovery installation in the sulphuric acid plant is only part of an energy reduction programme throughout the works and in the future we should have additional waste heat available from a new plant we propose to install.

So hence another reason for restricting energy recovery from this installation.

Q - Mr. R. GUYARD, Chemetics, Canada

You mention a 0.11 mm/year corrosion rate and a 12 year plate life. What is the thickness of the plates? We consider half thickness as the reasonable limit for practical equipment life.

A - The estimated corrosion rate of 0.1 mm/year given in the paper is at a temperature of 92° C. At 10° C the acid outlet temperature, the estimated corrosion rate reduces to 0.01 mm/year. By reversing the direction of fluid flow and by interchanging the channels through which the acid and water flow the estimated average corrosion over four years is 0.11 mm giving a total corrosion loss of 0.33 mm over 12 years. The plate thickness is 0.7 mm so that the expected corrosion over 12 years is about half of the plate thickness.