



TECHNICAL REPORT

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**THE EFFECTS OF SUB-COOLING IN
HEAT EXCHANGE PROCESSES**

Summary

Sub-cooling of condensate and partial flooding types of systems for the removal of condensate from heat exchange systems are suggested as having operational and heat conservation values from the following sources:

1. Noise reduction (open discharge systems)
2. Aesthetic appearance (open discharge systems)
3. Reduction in radiation loss from condensate return lines
4. Reduction in heat loss by the trap
5. Reduction in radiation loss from trap lead in lines
6. Sensible heat utilization
7. Reduction in flash steam loss

An analysis of the factors involved indicates that any probability of gains from these sources must be balanced against the realities of losses from the following:

1. Reduction in heat transfer rate from partial flooding
2. Reduction in air removal capabilities
 - a. Reduced steam temperatures
 - b. Insulating layers of air
3. Enhancement of corrosion from condensate ahead of traps
4. Enhancement of corrosion from condensate after traps
5. Corrosion damage in deaerators
6. Boiler tube fouling
7. Water hammer damage
8. Increased freezing risks

A summary of the various probable sources of savings does not uncover any sizeable savings, but possibly some loss instead.

1. **Reduction in heat loss from condensate return line**
 Less than 1/2#/hr. per 100 ft. of 3" line
2. **Reduction in heat loss of trap**
 - a. **Live steam loss - None by inverted bucket or sub-cooled traps**
 - **Some from all other types of traps**
 - b. **Radiation loss - Less than 0.1#/hr. per trap**
3. **Heat loss reduction in trap lead in line**
 Less than 0.1#/hr. in 15 ft. of 1" line
4. **Sensible heat savings**
 - a. **Closed pressurized return - none**
 - b. **Open discharger or vented return**
 Actual loss of heat because of accumulative inefficiencies from partial flooding heat transfer rate reductions and from retarded air removal
5. **Flash steam reduction**
 1. **Heat exchanger**
 - a. **Closed pressurized return - None**
 - b. **Discharge to sewer or vented return**
 1 BTU/# per °F sub-cooled
 2. **Tracer**
 - a. **Closed pressurized return - none**
 - b. **Discharge sewer or vented return**
 1/4 to 1/2#/hr. per trap

If any advantages from sub-cooling remain from these sources after careful analysis, they will be greatly negated and exceeded by the probability of increased corrosion due to increased CO₂ absorption by the sub-cooled condensate. E. S. Monroe of E. I. DuPont in Delaware states, "The numerous leaks that develop where corrosion takes place often result in excessive steam and condensate leaks that defeat energy conservation faster than maintenance can take care of them"

The summary of a report by Dearborn Chemical Ltd. of Canada states the case very effectively:

DEARBORN CHEMICAL COMPANY LTD.

SUMMARY

In steam heating condensate svstems with high CO_2 potential present in the steam, very corrosive conditions can occur. These conditions are encountered in unit heaters and heat exchangers operated in a flooded condition where the CO_2 is not vented **and** as a result accumulation will take place in the vapour phase. The CO_2 redissolves and forms very aggressive condensate.

By using and selecting traps that can vent CO_2 , a substantial reduction in corrosion can be realized thus extending the reliability and service life of equipment.

An inverted bucket type trap and thermodynamic trap were found to reduce corrosion in unit heaters and exchangers due **to** their ability to vent CO_2 . The reduction in corrosion was based on the iron levels monitored in the condensate.

1.0 Introduction

The object of this paper is to attempt a deeper insight into the various factors involved in how the sub-cooling of condensate before discharge from heat exchange processes can affect the efficiency and the overall cost of operation and maintenance of the process. In this paper, simplified calculations and a simple heat exchanger model are used to illustrate these points.

In some cases the practice of oversizing heat exchangers, especially reboilers, and the concern for tight temperature control have influenced the use of variable level partially flooded modes of operation. Additionally, the recent interest in energy conservation has brought forth claims and generated interest in the possibility of heat loss savings through the use of sub-cooling types of steam traps rather than discharging condensate at or close to saturation temperature. In either case the operation suggests backing up condensate into the heat exchange system. No matter how much a superficial examination of the results of sub-cooling condensate may suggest advantages, the backing up of condensate into any heat exchange system can have detrimental effects which should be scrutinized very closely before this mode of operation is considered.

For many reasons including product load variations, heat exchangers such as reboilers at various times will have heat exchange capacities far in excess of the requirements of the process. As a consequence, the removal of condensate through steam traps is complicated by reduced steam pressures, and temperature control in the exchanger will be difficult to maintain. In these instances, automatic level control systems were designed for condensate removal. The level control permits adjustment of condensate level for partially flooding the exchanger to bring the heat exchange capacity closer to that required by the existing process requirements. In this way, steam pressure is kept high enough for continued condensate discharge, and temperature swings from erratic condensate removal are eliminated. Although the method of condensate removal is one of modulating level control as contrasted to condensate temperature control which is the basis for condensate removal with sub-cooling steam traps, both modes of control require that condensate be held back in the system at all times. It is this characteristic that makes the two methods common and which suggests that any discussion of the effects of sub-cooling steam trap operation will apply to partially flooded level control operation also.

2.0 Sub-Cooling Steam Traps

Sub-cooling steam traps are automatic condensate removing valves which are actuated by temperature sensing devices. In essence, they are designed to be condensate temperature control valves, however water and steam both can exist in the same space at the same temperature at the same time. Since the purpose of a steam trap is to discharge condensate without permitting steam to pass, a temperature actuated valve must close before condensate in the trap reaches steam temperature. There must be condensate in the trap and behind the trap for some distance in order to insure that steam does not pass.

How far below steam temperature the valve must close depends upon many mechanical characteristics of each type of trap which affect the rate at which the valve can respond to condensate temperature changes. The degree of temperature suppression necessary to prevent steam loss and the rate of condensate flow will determine the extent of the back up of condensate behind the trap and into the system. Likewise, the extent of the back up of condensate into the system will determine the effects that the sub-cooling operation will have on the process. There are both theoretical advantages and practical disadvantages in sub-cooled operation.

Before we look at these, let's look at the types of devices available as sub-cooling steam traps.

There are several basic types of sub-cooling traps:

1. Thermal Expansion
2. Balanced Pressure Bellows
3. Bi-Metal
4. Wafer or Diaphragm

2.1.0 Thermal Expansion Traps

These devices are designed to control condensate temperature at a constant suppressed temperature well below steam temperature. Their mode of control is a modulating proportional band around a suppressed set point temperature.

Some actuators are flexible chambers filled with a fluid or solid, such as wax, which will expand in volume as temperature rises. The expansion causes extension or contraction of the actuator moving the valve to or away from the seat. In some cases the expansion and contraction of a solid metal actuator moves the valve. Changing condensate flows will change condensate temperature slightly and the actuator will move the valve to accommodate the flow change.

Temperature set-point is adjustable.

2.1.2 Balanced Pressure Bellows Traps

These devices are designed to close at some temperature below steam and to open again after condensate has sub-cooled sufficiently. Their mode of operation normally is intermittent on-off.

The actuator is a flexible thin wall metal bellows partially filled with a volatile fluid under vacuum. When cool, the internal vacuum permits the bellows to be compressed pulling the valve away from the seat. As temperature of the condensate approaches steam, the vacuum in the bellows permits the fluid within the bellows to volatilize before steam temperature, the pressure within the bellows equals the condensate pressure, and the spring rate of the bellows

extends its length moving the valve to the seat. This pressure balance requirement permits the valve to open and close before steam temperature regardless of pressure.

Depending on the manufacturer, the temperature suppression may be from 5⁰F to 100⁰F, but in most cases, the valve will open at 15⁰F to 20⁰F below saturation, and it will close again at 10⁰F to 15⁰F sub-cooling.

2.1.3 Bi-Metal Traps

In these devices a bi-metal thermostat senses temperature and provides the force to move the valve. A simple bi-metal element can be set to sense only one temperature so it could not function over a broad range of pressure change. To accommodate various pressure ranges, traps have been designed to include multiple bi-metals, pressure opposed thermodynamic assisted movement, and spring opposed movement with varying degrees of success. In general, control is erratic and unpredictable.

The attempt is to achieve a proportional band control in which condensate temperature in the trap varies around an initially set suppressed temperature as the flow rate changes. The desired end is a modulated continuous flow of condensate at a set temperature below saturation over a broad pressure range. Because of many difficult mechanical variables, practice has not achieved the desired end in all cases.

Bi-metal traps are designed to hold 10⁰F to 50⁰F below saturation.

2.1.4 Wafer or Diaphragm Traps

By design the actuator in these traps is essentially a single convolution bellows. Its form is a thin wall hollow wafer with a flexible diaphragm bottom. It also is partially filled with a volatile liquid under vacuum. In the cold state the diaphragm is flexed upward away from the seat, and condensate pressure pushes the wafer away from the seat. As condensate temperature rises toward steam the vacuum in the wafer permits the fluid in the bellows to volatilize. The expansion of the fluid flexes the diaphragm downward to the seat closing the valve. The action essentially is on-off.

In appearance the wafer and seat resemble the flat seating surfaces of a disc trap. The same problems of positively sealing two flat surfaces and of the close passages between the wafer and seat will exist.

Depending on the manufacturer and type, fixed suppression temperatures from 10⁰F to 108⁰F are available.

2.2.0 Sub-Cooling Theory

Sub-cooling traps are designed in an attempt to maintain a relatively constant condensate temperature below steam temperature. The attempt is not to permit steam to reach the trap maintaining a leg of water behind the trap at all times to seal the valve from steam. The resultant constant back up of condensate into the system has many effects, and some in theory are cited as benefits.

1. Noise reduction
2. Aesthetic appearance
3. Reduction in radiation loss from condensate return lines
4. Reduction in heat loss by the trap
 - a. Live steam loss
 - b. Radiation loss reduction
5. Reduction in radiation loss from trap lead in lines
6. Sensible heat utilization
7. Reduction in flash steam loss

On the surface the list looks like a formidable advantage to potential users, but deeper analysis shows that many factors influence whether or not any advantages may accrue from sub-cooling.

1. Type of application
2. Type of condensate return system
3. Degree of sub-cooling
4. Feedwater conditions
5. Feedwater treatment
6. Actual steam trap operating characteristics

As with all good things which because of external factors seem to have realized their time of advantage, sub-cooling operation has its practical detrimental side also. The same operating characteristics which seem to provide advantages also present problems which can far outweigh or negate advantages.

1. Reduction in heat transfer rate
2. Reduction in air removal capabilities
 - a. Reduced steam temperatures
 - b. Insulating barriers
3. Enhancement of corrosion ahead of traps
4. Enhancement of corrosion after traps
5. Increased freezing risks
6. Water hammer damage
7. Corrosion damage in deaerators

8. Boiler tube fouling

Any consideration of the good effects of sub-cooling operation assumes the achievement of consistent reduced temperature operation with relatively constant levels of back up of condensate into the system. Actually many mechanical factors difficult to control in the design of temperature sensing and actuating devices influence the degree of suppression necessary to achieve a consistent seal as well as the stability of the seal. However, in order to investigate the reasonableness of the claims to advantage themselves, we will consider all sub-cooling devices as reliable, repeatable, and consistent in their ability to sub-cool. Under these ideal terms let's look at the various advantages and disadvantages of sub-cooling operation.

3.0 Noise Reduction

The discharge of hot condensate is always accompanied with the formation of some amount of flash steam as the condensate passes out of the valve. The sudden expansion of the condensate into flash steam increases the velocity of the flow, and noise is the result. The amount of flash steam produced will decrease as the temperature of the condensate decreases, therefore sub-cooling of the condensate will reduce the noise level of the discharge of any quantity of condensate.

Most traps discharging to atmosphere where noise results are on steam main drains and steam tracers. They normally have been grossly oversized so that when they open intermittently, large amounts of condensate relative to actual condensate flow requirements are discharged. As a consequence, the noise level of most traps discharging near steam temperature has been high. However, if trap capacity is matched more closely to actual requirements, discharges will be longer and greatly diminished in sound level.

Additionally, the normal 20° to 30° temperature reduction in condensate does not alter the amount of flash steam produced sufficiently to reduce noise level appreciably below that of a properly sized trap operating near saturation temperature.

4.0 Aesthetic Appearance

In this instance also the production of flash steam is the consideration. Oversized traps operating at or near saturation temperature send large clouds of condensate and flash steam billowing into the atmosphere. The appearance is one of unattractive, potentially destructive, and apparently wasteful discharge of vapor.

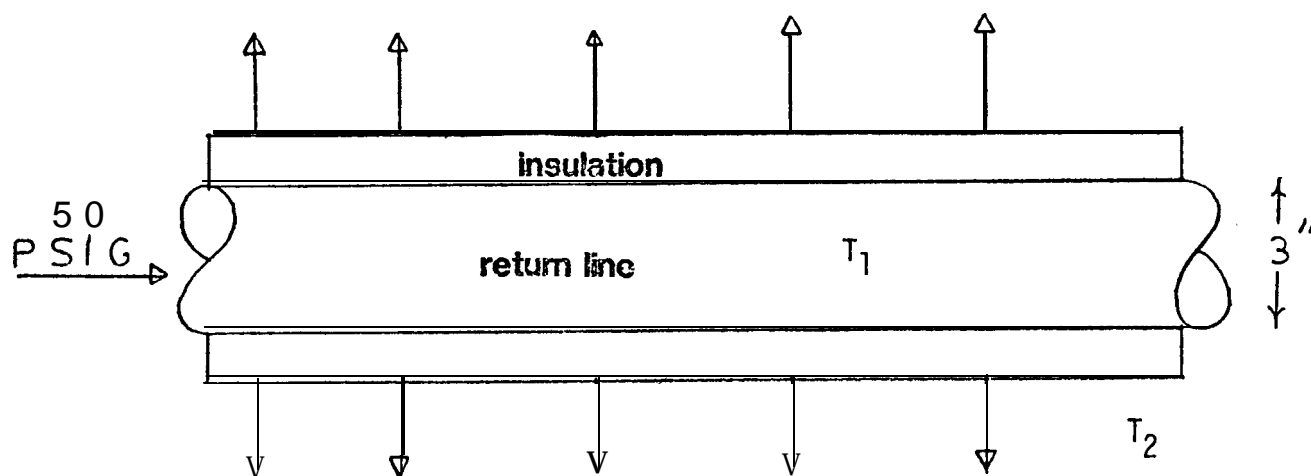
Again, properly sized traps will produce less unsightly discharges, and the 20° or 30° sub-cooled discharge will not reduce this volume enough to be sufficiently more attractive.

5.0 Reduction in Radiation Loss From Condensate Return Lines

If condensate is being returned to the boiler for reuse in making steam it flows through a piping system to the condensate receiver. Enroute some heat is lost from the pipe. Sub-cooling of the condensate before it passes

into the return line can reduce this loss. For purposes of keeping an analysis simple, let's assume that the loss is strictly radiation and the condensate temperature is a constant in the entire return line. Admittedly, this will result in an exaggerated picture of the effect of sub-cooling which must be adjusted to reality. Assume a 3" condensate return line and 20°F sub-cooled temperature across the entire length. A nominal 10 psig condensate return line pressure is also assumed.

REDUCED CONDENSATE RETURN LINE RADIATION



HLS: Heat loss savings

HLS: $H_{sat} - H_{sc}$

H_{sat} : Radiation loss at steam temperature

H_{sc} : Radiation loss 20 degrees sub-cooled

HLS: Less than 2.5#/hr. per 100 ft. of pipe.

See Calculation I

This is not a very large steam loss savings, when we also consider that our assumptions greatly exaggerated even this small result.

6.0 Reduction in Heat Loss by the Trap

All steam traps lose some amount of heat in their operation. All will radiate heat from their metal surfaces, and some will permit live steam loss as a consequence of their operating characteristics.

6.1 Live Steam Loss by the Trap

All steam traps which, as part of their operating characteristics, have a consistent water seal between the steam and their valves theoretically will have no live steam loss. This is equally true of all types which consistently sub-cool and of inverted bucket types. All other types have some operating characteristic peculiarity which assures some degree of live steam loss.

6.2 Radiation Loss by the Trap

All traps will have some amount of radiation loss from their bodies. Uninsulated bodies will radiate more. The amount of radiation is proportional to the surface area of the trap and the temperature of the trap.

Since the vast majority of traps are used in steam main drain and steam tracing applications, a comparison of the difference in radiation losses between sub-cooling and saturation temperature traps will be considered. Let's compare the smallest sub-cooling trap versus the smallest inverted bucket trap.

RADIATION LOSS REDUCTION

HLS: Heat Loss Savings

HLS: $H_{ib} - H_{sc}$

H_{ib} : IB radiation loss

H_{sc} : Sub-cooled radiation loss

HLS: Less than 0.1#/hr. per trap

Inverted bucket can be insulated to reduce loss.

See Calculation II

Again this is an extremely small difference which can be made even smaller if the inverted bucket trap is insulated. Because insulating the sub-cooling trap would slow down its reaction to temperature changes, this is not advisable.

7.0 Heat Loss Reduction in Trap Lead In Lines

Again we will assume a constant temperature along the length of the line for simplicity, and that total loss is from radiation.

Assume an uninsulated line 15' long, 1" in diameter with steam pressure 50 psig.

HLS: Heat Loss Savings

HLS: $H_{sat} - H_{sc}$

HLS: Less than 0.1#/hr.

See Calculation III

8.0 Sensible Heat Savings

If condensate is returned to the boiler for reuse through pressurized returns, the suggestion of sensible heat savings through sub-cooling is ludicrous. Any heat taken from the condensate in the heat exchanger simply reduces the temperature of the condensate returned to the deaerator or to the boiler. In order to return the condensate to the temperature at which it can be boiled, the heat removed in the process has to be replaced in the boiler so that the net result is no heat savings.

The high cost of water and energy today dictates that as little condensate as possible be wasted so that the number of heat exchangers discharging to sewer are few and diminishing and vented return systems are being eliminated. Nonetheless, even in those cases, the claims for sensible heat savings are dubious. Essentially the claims are based simply on the amount of heat which can be transferred to a process from some degree of sub-cooling of condensate before it is removed from the heat exchanger. On the surface the analysis seems simple and straight forward, but the simple statement ignores many factors which actually have an adverse effect upon heat exchanger efficiency.

Reduced heat exchange rate due to partial flooding of heat exchange surfaces requires that higher steam pressure be used when sub-cooling than with total steam operation.

Retarded air removal through sub-cooled steam traps concentrates air in heat exchangers causing temperature reductions and insulating films on exchange surfaces both of which require raising pressure above that required for full steam operation.

Higher steam pressure requirements mean more energy usage.

In order to understand the effects of all of these factors, let's consider a simple model of a parallel flow shell and tube heat exchanger with steam in the 1" diameter coils.

$$W = \text{Water flow} = 30,400\#/hr. = 60.8 \text{ GPM}$$

$$T_{in} = \text{Water temperature in} = 45^{\circ}\text{F}$$

$$T_{out} = \text{Water temperature out} = 195^{\circ}\text{F}$$

$$P_s = \text{Steam Pressure} = 50 \text{ psig}$$

$$Q = \frac{H}{h L}$$

$$Q = \text{Steam flow required at 50 psig}$$

$$H = \text{Heat required}$$

$$H = W \times c \times (T_{out} - T_{in})$$

$$hL = \text{Latent heat 50 psig steam}$$

$$C = \text{Specific heat of water} = 1 \text{ Btu}/\# \text{ } ^{\circ}\text{F}$$

$$Q = \frac{W \times C \times (T_{out} - T_{in})}{hL}$$

$$Q = \frac{30,400 \times 1 \times 150}{912}$$

$$Q = \frac{3,283,200}{912}$$

$$Q = 3,600\#/hr.$$

Superficially the amount of sensible heat savings with 20^oF sub-cooling of condensate in the heat exchanger would be.

$$HLS = \text{Heat Loss Savings} = Q \times S.H. \times \Delta t_{sc}$$

$$= 3,600 \times 1 \times 20$$

$$= 72,000 \text{ Btu/hr.}$$

$$= 80\#/hr. \text{ of 50 psig equivalent steam}$$

$$= 2.22\%$$

This is too simple a statement since other factors enter into how much steam actually has to be used.

8.1 Efficiency Loss Due to Partial Flooding

When condensate is backed up into the heat exchanger in order to use sensible heat, part of the heat exchange surface formerly covered with steam is now flooded with condensate. The rate of heat exchange from the hot water is lower than that from steam and the temperature of the condensate drops as heat is extracted so that less temperature difference is available to promote heat transfer. The result is less heat transfer area for steam and reduced heat transfer rate from the condensate. In order to regain the required heat transfer rate, steam temperature has to be increased by raising steam pressure. Higher steam pressure means less latent heat available and increased steam usage.

Let's analyze how high the pressure must be raised to compensate for 20°F sub-cooling.

EFFICIENCY LOSS FROM PARTIAL FLOODING

- Product Temperature Rise from 72,000 Btu/Hr. Sensible Heat: 2.4 degrees F
- Flooded Coil area: 9.9 Sq. Ft.
- New Steam Temperature Required: 307 degrees F
- New Steam Pressure Required: 60 psig
- Total Steam Required at 60 psig: 3,552#/hr.

See Calculation IV.

Our Steam savings has now shrunken from 80#/hr. to 48#/hr., and steam temperature has risen to 307°F. We now are sub-cooling to 287°F compared to the original steam temperature of 298°. We are down to 11°F sub-cooling below the original 50 psig steam operation. But this is only part of the story. There is the effect of retarded air removal to be considered.

8.2 Efficiency Loss Due to Retarded Air Removal

8.2.1 Steam Temperature Reduction

On start-up a thermostatically operated trap will be wide open permitting full flow of cold air which occupies the lines and heat exchange system ahead of the condensate. After the air is gone and condensate has heated to the suppressed temperature set point, nothing can pass through the trap until it has cooled to the suppressed temperature. This is also true of the air that is constantly passing over with steam into the system. As the steam condenses, the air is left behind in the system to collect behind the condensate where it

remains as a mixture of steam and air. The air-steam mixture will have a lower temperature than pure steam at a given pressure so that as the air content in the steam concentrates the mixture temperature drops. Whenever the air-steam mixture is sufficiently concentrated, it's temperature will drop to the suppressed set point and this mixture can pass through the trap, but there are two important points to be considered.

First, it is a mixture of air and steam that is being discharged. In order for any thermally operated valve to vent air it must also vent steam. The amount of steam loss due to thermal air venting varies with many factors so that it cannot reliably be predicted or calculated, however, in order to drop steam-air mixture temperature 20°F below 50 psig saturation, the mixture must be 30% air. Conversely every time air is vented 70% of the discharge is steam.

Second, in order to sub-cool 20°F, a 30% air-steam mixture must exist at the interface. Air is present in the system at all times. If the mixture is 30% at the interface, it isn't difficult to expect 10% as an average throughout the heat exchanger. A 10% air-steam mixture will cause a 7-10°F lower steam temperature at 60 psig. In order to regain sufficient steam temperature to maintain heat rate the pressure would have to be raised to at least 70 psig.

TEMPERATURE REDUCTION DUE TO AIR IN STEAM

Pressure (psig)	Steam Temperature (°F)	Temperature Air Steam Mixture		
		10%	20%	30%
60	307	300	292	283
70	316	308	300	291

Total Steam Required at 70 psig: 3,578#/hr.

Steam Temperature 70 psig: 316

Sub-cooled Condensate Temperature: 296

Steam Temperature at 50 psig: 298

Let's determine the new steam flow requirement at 70 psig to compensate for partial flooding and lowered steam temperature due to air.

$$\begin{aligned}
 Q &= \frac{Hs}{hr} \\
 &= \frac{3,211,200}{898} \\
 &= 3578\#/hr.
 \end{aligned}$$

This doesn't tell the complete story either. Since we have raised pressure, the temperature of the condensate being thrown away has risen to 296°F from 298°F. We have raised condensate temperature 180F to save 20°F in sub-cooling. At this point it is almost a trade-off, but there is still one additional heat exchange loss to overcome.

8.2.2 Insulating Effect of Air

As heat exchange takes place and steam condenses, the air left behind migrates toward the heat exchange surfaces where it collects in microscopic films as a barrier to further heat exchange. Air is an extremely effective insulator.

$$\begin{aligned}
 .01" \text{ air} &= 0.20" \text{ in water} \\
 &= 15.5" \text{ steel} \\
 &= 11.0 \text{ ft. of copper}
 \end{aligned}$$

In order to overcome the heat transfer resistance of thin films of air, steam temperature must be raised to maintain heat flow rate. Even a film of 0.00001 of air average thickness in a heat exchanger can have a marked effect on pressure requirements:

HEAT TRANSFER RESISTANCE FROM STEAM TO WATER THROUGH 0.00001 IN AIR

$$R_t: R_{wa} \text{ plus } R_a$$

R_t : total resistance

R_{wa} : total resistance without air

R_a : air film resistance = x_a/k_a

x_a : air film thickness: 0.00001/12 ft.

k_a : 0.0104

R : 1/U

1/ U_t : 1/ U_{wa} plus 1/ U_a

U_{wa} : 140

1/UT: 1/Uwa plus ka/xa

Ut: 138.5

New Steam Temp. Required to Overcome Resistance: 334 degrees

New Steam Pressure Required: 99 psig

New Steam Flow Required: 3650#/hr.

Heat in Condensate at 99 psig Sub-cooled 20 degrees F: 1,054,100

Heat in Condensate at 50 psig: 964,800 Btu/hr.

Cost of Sub-cooling: 82,330 Btu/hr. 145 #/hr. of 50 psig steam

See Calculation V

To overcome the effects of 20°F sub-cooling in the form of lost heat exchange surface, temperature reduction due to air, and a very thin 0.00001" layer of air, steam temperature had to rise to 358°F and pressure to 99 psig.

We now must use 3,708#/hr. of 99 psig steam to maintain the same heat load as with 3600#/hr. of 50 psig steam. We now must throw away 318°F condensate to sub-cool 20°F. We now throw away 3,708#/hr. of 338°F water instead of 3,600#/hr. of 298°F water. Sub-cooling 20°F has cost us 170,500 Btu/hr. to use 72,000 Btu/hr. of sensible heat. This is hardly an efficient trade off.

8.3.0 Heat Transfer Rate Testing

Comparisons of the performance of heat exchangers drained by inverted bucket traps to that when drained by sub-cooling bi-metallic traps were made in Armstrong Machine Works laboratories. A small heat exchanger was supplied with 150 psig steam and cooling water was passed through the exchanger. The rate of cooling water flow and the temperature rise of the water established the heat transfer rate with each trap. The exchanger was run repeatedly with inverted bucket and bi-metallic traps, the heat transfer rates were established, and a comparison of the differences was made.

In all cases, because of the partial flooding of heat exchanger surface, and poor air removal, the heat transfer rate was lower with the sub-cooling trap by substantial amounts as shown in Figure 1.

In a study of the effects of steam traps on heat exchanger efficiency done by Jerry Roy of Union Carbide, South Charleston, West Virginia, sub-cooling traps were not even considered because of air removal problems experienced in a Canadian plant. His direct quote is "They tried thermostatic traps in process services and found that calandrias had a tendency to become vapor bound with non-condensibles.

8.4.0 Sensible Heat Savings in Steam Tracing

Steam tracers can be described as miniature heat exchangers. Although each tracer uses only 10 to 30#/hr. of steam, because there may be thousands of tracers in a large plant, their cumulative consumption is the same as a single large heat exchanger.

Just as in the case of a heat exchanger, if the condensate from the tracers is returned to the boiler through a pressurized return, the removal of sensible heat from the condensate will not result in any heat savings. That same amount of heat would have to be put back into the colder condensate in the boiler to make steam.

Where tracers discharge to sewer, the condition is slightly different. Here the analogy to a large heat exchanger subject to efficiency losses due to partially flooded sub-cooled condensate operation may not apply depending on the design of the system.

Usually, existing steam tracing systems have been greatly oversized as a safety factor to insure against freezing or fluid thickening even when live steam is used. Normally the heat exchange surface is more than necessary and the steam pressure is higher than required. In these cases, if sufficient courage and the capability existed to reduce steam pressure, steam usage could be minimized with live steam operation. If steam pressure can't be reduced, sub-cooling operation probably could be instituted with no penalty in steam usage and possibly some small savings.

Sub-cooling operation with 20°F suppression and a 20#/hr. steam consumption would appear to save 400 Btu/hr. per trap. This is a very simplified look at the matter which ignores many factors, but it may be reasonable to suggest to 1/4 to 1/2#/hr. 50 psig equivalent savings for each trap.

In reality this may be a rather small return for the investment of the potential maintenance problems associated with sub-cooling operation.

When the design of new systems is considered, the situation is different. The use of tracers full of steam drained with traps discharging condensate at or near steam pressure will permit smaller and fewer tracers operating at lower steam pressure than if sub-cooling were used. The installation will be less expensive, and the tracer system will use less steam.

9.0 Flash Steam Reduction

As discussed previously, the discharge of condensate at any temperature greater than saturation temperature for the pressure at the trap outlet will result in the formation of flash steam. The higher the temperature of the discharged condensate, the greater the volume of flash steam produced.

In newer plants, the condensate return systems have been designed so that this flash steam is vented into lower pressure steam systems where the heat content is used, and the lowest pressure condensate system discharges to a deaerator or pressurized receiver where the flash steam heat is used to heat make-up boiler feedwater so that virtually no heat is lost. Any reduction in flash steam discharge from sub-cooled traps would have to be replaced by

live steam in the feedwater heating or deaerating processes.

In older plants with condensate discharging to atmosphere a reduction in heat lost as flash steam is a possibility. It is usually only in steam main drain and tracer applications that discharge to sewer occurs. The large amounts of water and heat involved in wasting heat exchanger condensate usually dictates saving it for reuse.

Let's examine the reduction in flash steam to be expected from a typical tracer trap discharging 20#/hr. of condensate from 50 psig steam

$$\begin{aligned} \text{HLS} &= Q C \Delta t \\ &= 20\#/hr. \times 1 \text{ BTU}/\#^{\circ}\text{F} \times 20^{\circ}\text{F} \\ &= 400 \text{ Btu/hr.} \\ &= 0.44\#/hr. \text{ of } 50 \text{ psig steam equivalent per trap} \end{aligned}$$

10.0 Conclusion

Aside from various nebulous mechanical and maintenance advantages claimed, the case for partially flooded sub-cooling trap condensate discharge is argued on the basis of possible heat loss savings. A summary of the various probable sources of savings has not uncovered any large amount of savings, but possibly some loss instead.

A. Reduction in Heat Loss from Condensate Return Line

Less than 1-2#/hr./100 ft. of line

B. Reduction Steam Loss by Trap

1. Live Steam Loss - None

2. Radiation Loss - Less than 0.1#/hr. per trap

C. Heat Loss Reduction in Trap Lead in Line

Less than 0.1#/hr. in 15' of 1" line

D. Sensible Heat Savings

1. Heat Exchanger

a. Closed pressurized return system - None

b. Discharge to sewer or vented return -

Actual loss of heat because of accumulative inefficiencies from flooding and retarded air removal.

2. Tracer - 1/4 to 1/2#/hr. per trap

E. Flash Steam Reduction

1. Heat Exchanger

- a. Closed pressurized return - none
- b. Discharge to sewer or vented return - 1 Btu/# per
°F sub-cooled

2. Tracer

- a. Closed pressurized return - none
- b. Discharge to sewer or vented return - 1/4 to 1/2#/hr. per trap

On the basis of heat loss savings the conclusions are:

Partially flooded sub-cooled condensate discharge from heat exchangers whether to closed returns or to drains is of no practical advantage.

Sub-cooling operation of steam tracing traps discharging to closed pressurized returns is of no advantage.

Sub-cooling operation of steam tracing traps discharging to open drains may save 1/4 to 1/2#/hr. per trap.

Based on heat loss savings alone the case for sub-cooled trap operation is a definite no for any large capacity heat exchange application, but some small savings may be possible with steam tracing. Nonetheless, there are other factors involved in the analysis which relate to potential costs hidden in the use of sub-cooling types of traps.

11.0 Corrosion Enhancement with Sub-cooling Traps

Corrosion can occur even with the purest water. There are available free hydrogen ions in pure water which will cause iron and copper to go into solution eating the metal surfaces. As the metal goes into solution, the free hydrogen ions are tied up and the corrosion subsides. The corrosivity of a still body of water is therefore limited. However, if the water is flowing fresh or if any source of new free hydrogen ions is added to the water, corrosion can continue unchecked. Such is the case of condensate corrosion and especially of condensate corrosion aided by sub-cooling trap or flooded heating surface operation.

11.1 Carbonic Acid Formation

All boiler feedwaters contain elements which are or which produce non-condensable gases when the water boils. These gases are transported out of the boiler into the steam system along with the steam

Primarily these gases are oxygen and CO₂. All water has some dissolved oxygen, but normally the oxygen is tied up chemically or removed by mechanical means such as deaeration before it can enter the boiler.

On the other hand, all feedwaters contain carbonates and/or bicarbonates which, in the boiler drum volatilize along with the water forming CO₂ which, as a gas, passes freely into the system with the steam. Unlike steam the CO₂ is non-condensable so that it remains behind in the steam space as the steam condenses. Here it combines with more steam and CO₂ concentrating the mixture if it is not removed by some means. It is this concentration of CO₂ which is the air that affects heat exchange so greatly.

As a gas, other than for the extreme effect on heat transfer, the CO₂ is relatively inoffensive. But, if it is allowed to cool below saturation temperature in contact with water, it will dissolve in the water forming carbonic acid. The higher the concentration of CO₂ and the lower the temperature of the condensate, the more concentrated the carbonic acid becomes. The carbonic acid provides a continuing supply of free hydrogen ions to promote and to continue corrosion of iron and copper. The higher the CO₂ concentration forming the carbonic acid the higher the free hydrogen ion availability and the greater the corrosivity of the condensate.

A typical river water will contain in excess of 100 ppm of bicarbonate and carbonate compounds, and a typical pure lake water will contain 50 ppm. The normal industrial feedwater treatment for boilers under 600 psig will remove or neutralize only hardness compounds leaving the carbonates and bicarbonates untouched. The best treatment usually will not reduce the carbonate and bicarbonate levels lower than 10 to 20 ppm. The conversion rate of carbonates and bicarbonates is:

1 ppm carbonate yields 0.35 ppm CO₂

1 ppm bicarbonate yields 0.79 ppm CO₂

It is apparent that even the best boiler waters will release 3 to 16 ppm of CO₂ into the steam system.

11.2 Effects of CO₂ Concentration

The concentration of free hydrogen ions in solution is measured as its pH. The pH of seven is neutral, and any pH under 7 is acidic. Each unit change of pH below seven is a ten fold increase in the corrosivity of the solution. The pH of carbonic acid will vary directly with the concentration of CO₂ as shown in figure 2. For instance, only 20 ppm of CO₂ will reduce pH to 5.5, and this small concentration of CO₂ causes a highly corrosive condition as shown in figure 3.

A 20 ppm CO₂ concentration solution flowing in a 1" steel pipe at only 100#/hr. will result in corrosion eating away the metal surface at a rate of 0.032" per year. Additionally, the rate of corrosion will be concentrated more greatly in heat exchange areas and points of stress such as bends, joints, fittings, and threads. Since a 1" pipe has a nominal thickness of only 0.133", we can expect it to develop leaks in its thickest parts in less than four years. In a heat exchanger with its stress points and hot surfaces, trouble would appear much more quickly.

11.3 CO₂ Concentration Due to Sub-Cooling and Partial Flooding

If partially flooded operation or sub-cooled steam trap methods are used for removing condensate, conditions for the concentration of CO₂ in the steam system and dissolved in the condensate in the system, in the condensate lines, and in the trap are accentuated.

For instance in order to sub-cool 50 psig condensate 20°F, air cannot be discharged by the trap until the air-steam mixture at the steam condensate interface is 30% air, mostly CO₂. The entire steam system has CO₂ in the steam and at the steam condensate interface where the CO₂ concentration is highest, the CO₂ will enter into solution with the sub-cooled condensate. The result is high concentrations of carbonic acid and low pH in the flooded portion of the heat exchanger, in the lines to the trap, and in the trap itself. Corrosion is the natural result.

In an effort to determine typical pH depressions which sub-cooling of condensate might produce, some experiments were conducted in Armstrong Machine Works' plant and laboratories in New Braunfels, Texas. Different types of traps were installed on long steam main drain lines, they were operated with condensate naturally condensed from steam from our plant boiler, and samples were taken from in front of the traps at time intervals to be analyzed for pH. The results were startling as figures 4 through 8 vividly illustrate. In all cases, within a few hours of sub-cooled operation, the pH of the condensate took a dramatic drop. Regardless of the fact that neutralizing amines were being fed to maintain a general condensate system pH above 8.0 to 8.3 and that steam condensed right after the boiler had a pH near 8.0, the pH of the sub-cooled condensate dropped into the highly corrosive range of 5.5 to 6.0.

Under the same conditions the condensate from ahead of traps which discharged at or near saturation temperature remained at a pH of 7.5 to 8.0.

Subsequently, the investigation was taken into typical refineries and petrochemical plants in the Eastern and Southeastern United States and in Ontario, Canada. In all cases regardless of the source of feedwater, regardless of feedwater treatment methods, and regardless of condensate treatment, the pH of the condensate taken from the lines ahead of the traps was at the highly corrosive range below 6.0.

While in one of the plants in Sarnia, Ontario, we met Mr. Grant Hall, Area Manager for Dearborn Chemical of Canada. Grant was there conducting studies of corrosion levels in heat exchangers which were being operated partially flooded and on tank heating coils being drained by sub-cooling thermo-static traps.

11.4 Dearborn Chemical Sub-cooling Corrosion Effect Investigation

In this plant, expensive neutralizing amine feed was used to maintain general condensate system pH at a level of 8.3. Nonetheless, the color of condensate being discharged from various heat exchangers and tank heating coils was creating a red river as it flowed to the sewer. This alarmed the Dearborn people.

Samples of the condensate from ahead of the traps and in the reboilers tested at pH's from 5.0 to 5.9, and the iron content was as high as 5 ppm. After the analysis and deep consideration of all of the factors involved, Dearborn advised that the condition was being caused by CO₂ concentrations in the sub-cooled condensate which were being directly caused by the sub-cooling. Steam traps which discharge condensate at or near saturation temperature were installed in test cases, and the results were compared. The pH ahead of the traps rose to 8.0 or higher, CO₂ concentration was markedly reduced, and the iron content of the condensate was reduced to less than 0.5 ppm.

At the suggestion of Dearborn, the refinery is now investigating means to eliminate sub-cooled traps on all heat exchangers and to begin operating reboilers without partially flooding. In the words of the Dearborn representative, if they didn't, they could expect to have their reboilers and tank coils down around their ears in no time. They are heeding the warning.

Sub-cooling of condensate will transfer the corrosion problems usually encountered in the return system after the traps to the steam system ahead of the trap. This naturally will make the steam system ahead of the traps as great a maintenance problem as the condensate system has been in the past. Not only that, but sub-cooling will also increase the problems normally found in the return system.

12.0 Increased Condensate Return System Corrosion

Sub-cooling of condensate is cited as beneficial in reducing the heat loss from flash steam and condensate lines, but in doing so it presents increased corrosion hazards.

As hot condensate containing CO₂ in solution flashes to the lower return line pressure, the CO₂ volatilizes also. In the dissolved form the CO₂ was corrosive, but as it flashes to vapor, it becomes inoffensive. Additionally with the condensate at a high temperature, the CO₂ which passes through the trap as air will remain a vapor and not be dissolved in the condensate. In these ways, the corrosivity of the condensate flowing in the return lines will be kept to a minimum.

Whenever sub-cooled discharge of condensate into the return lines takes place or when condensate is cooled for any reason, corrosivity of the condensate is greatly increased beyond the minimum achievable with hot condensate and flash steam. The CO₂ in solution ahead of the trap will remain in solution after the trap, plus any CO₂ coming through the trap as air will go into solution as it contacts the CO₂ condensate in the return line. An increased CO₂ level in the condensate from these two sources will reduce the pH radically, and the corrosion rate in the return system will increase dramatically endangering lines, receivers, pumps and especially threatening the deaerator.

13.0 Deaerator Corrosion

Most of the deaerators in use today mix returned condensate with makeup

water. If the condensate is sub-cooled radically it has a high dissolved CO₂ content which then comes in contact with dissolved O₂ in the raw makeup water. A combination of CO₂ and O₂ is 40 times as corrosive as CO₂ alone. The result is premature deterioration of deaerator internals.

Another consideration of corrosive condensate is the amount of the products of corrosion being concentrated in the deaerator in solution as iron carbonate and the natural carry-over of these products into the boiler drum and tubes.

14.0 Boiler Tube Fouling

As the corrosion laden water passes through the boiler tubes, the water is boiled, and the iron carbonate precipitates. This iron carbonate is like a cement; it adheres to the internal surfaces of the tubes causing insulating layers. The result is loss of heat exchange in the boiler tubes which will permit overheating of the metal and eventual failure by ruptures at the softened hot spots.

15.0 Conclusions

After careful consideration of the effects of partially flooded operation and condensate drainage with sub-cooling traps on heat exchanger efficiency, on steam and condensate losses due to leaks caused by corrosion thus induced, and on the increased equipment maintenance and replacement costs caused by increased corrosion, the arguments for use of sub-cooling condensate drainage methods sound extremely hollow. Even if some positive heat loss savings could be proven in any specific case, leaks and the increased maintenance costs because of corrosion damage to equipment, lines, traps condensate return systems, deaerators, and eventually boilers, will far outweigh any possible savings.

Although the above analysis concentrated primarily on heat exchanger applications, the implication would seem to suggest that similar problems can be expected with the application of sub-cooling steam traps on steam main drain and steam tracing applications. An analysis of condensate samples taken from ahead of sub-cooling traps in several plants in Canada are shown in Figure 9. Iron contents ranged from 0.007 to 40.0 ppm, and copper contents ranged from 0.10 to 2.85 ppm. This is evidence of advanced corrosion in most cases.

In order to further define the corrosive effects of sub-cooling condensate in drip and tracer applications, Armstrong Machine Works along with competent water treatment companies and interested industrial plants will conduct field tests to establish typical corrosion rates of both copper and steel.

Concluding we quote an industry authority who has for many years been warning against the dangers of sub-cooling condensate. Mr. Elmer S. Monroe of E. I. DuPont in Delaware, "Any possible savings achieved through sub-cooling of condensate will sooner or later be exceeded by the losses from leaks caused by the corrosion due to sub-cooling."

I. Reduction in Return Line Radiation

$$\mathbf{H_{sat} = U_{sat} A \Delta T_{sat}}$$

H_{sat} = Heat loss at saturation temperature

$$\mathbf{U_{sat} = U \text{ at } 10 \text{ psig saturation temperature} = 3.0 \text{ Btu/ft}^2/\text{°F/hr.}}$$

$$\begin{aligned} \mathbf{\Delta T_{sat} = \text{Temperature difference } 10 \text{ psig saturation} \\ \text{to } 0^{\circ}\text{F assuming } 0^{\circ}\text{F ambient}} \\ \mathbf{= 240^{\circ}\text{F}} \end{aligned}$$

$$\mathbf{H_{sc} = U_{sc} A \Delta T_{sc}}$$

H_{sc} = Heat loss at 20°F sub-cooling

$$\mathbf{U_{sc} = U \text{ at } 20^{\circ}\text{F sub-cooling below } 10 \text{ psig saturation} = 2.8 \text{ Btu/ft}^2/\text{°F/hr.}}$$

$$\begin{aligned} \mathbf{\Delta T_{sc} = \text{Temperature difference } 20^{\circ}\text{F sub-cooled to } 0^{\circ}\text{F}} \\ \mathbf{= 220^{\circ}\text{F}} \end{aligned}$$

$$\mathbf{HLS = H_{sat} - H_{sc}}$$

HLS = Heat Loss Savings

$$\begin{aligned} &= U_{sat} A \Delta T_{sat} - U_{sc} A \Delta T_{sc} \\ &= A (U_{sat} \Delta T_{sat} - U_{sc} \Delta T_{sc}) \\ &= A (240 \times 3.0 - 2.8 \times 220) \\ &= \frac{104 \text{ Btu/hr.}}{\text{Sq. Ft.}} \end{aligned}$$

$$\mathbf{1 \text{ sq. ft. of } 3'' \text{ pipe} = 1.091 \text{ ft.}}$$

$$\mathbf{HLS = 104 \times 1.091}$$

$$\mathbf{= 113 \text{ Btu/hr. per ft. of return line}}$$

$$\mathbf{= 0.12\#/hr. \quad 50 \text{ psig equivalent steam per ft. of pipe}}$$

$$\mathbf{= 12\#/hr. \quad \text{per } 100 \text{ ft. of pipe with uninsulated pipe}}$$

$$\mathbf{= 2.4\#/hr. \quad \text{per } 100 \text{ ft. of insulated pipe}}$$

II. Reduction in Trap Radiation Loss

$$H_{IB} = U_{sat} A_{IB} \Delta t_{sat}$$

$$H_{IB} = \text{Heat loss from IB}$$

$$U_{sat} = U \text{ at saturation temperature } 50 \text{ psig} = 2.7 \text{ Btu/ft}^2/\text{°F/hr.}$$

$$A_{IB} = \text{IB surface area} = 0.25 \text{ ft}^2 \text{ Armstrong 1811}$$

$$\Delta t_{sat} = \text{temperature difference } 50 \text{ psig saturated to } 0^\circ\text{F} = 298^\circ\text{F}$$

$$H_{sc} = U_{sc} A_{sc} t_{sc}$$

$$H_{sc} = \text{Heat loss from sub-cooled trap}$$

$$U_{sc} = U \text{ at } 20^\circ \text{ sub-cooled } 50 \text{ psig} = 2.6 \text{ Btu/ft}^2/\text{°F/hr.}$$

$$A_{sc} = \text{sub-cooled trap surface area} = 0.15 \text{ ft}^2 \text{ Wafer type}$$

$$\Delta t_{sc} = \text{temperature difference } 20^\circ \text{ sub-cooled to } 0^\circ\text{F} = 278^\circ\text{F}$$

$$HLS = H_{IB} - H_{sc}$$

$$HLS = \text{Heat Loss Savings}$$

$$U_{sat} A_{IB} \Delta t_{sat} - U_{sc} A_{sc} \Delta t_{sc}$$

$$2.7 \times 0.25 \times 298 - 2.6 \times 0.15 \times 278$$

$$93 \text{ Btu/hr.}$$

$$0.10\#/hr. \text{ of } 50 \text{ psig equivalent steam}$$

III. Trap Lead-in Line Radiation Reduction

$$HLS = H_{sat} - H_{sc}$$

$$= U_{sat} A_{sat} \Delta t_{sat} - U_{sc} A_{sc} \Delta t_{sc}$$

$$A_{sat} = A_{sc}$$

$$U_{sat} = 3.3 \text{ Btu/ft}^2/\text{°F/hr.}$$

$$\Delta t_{sat} = 298^\circ\text{F}$$

$$U_{sc} = 3.2 \text{ Btu/ft}^2/\text{°F/hr.}$$

$$\Delta t_{sc} = 278^\circ\text{F}$$

$$A = \frac{\text{Length}}{2.904} \text{ ft}^2$$

$$\begin{aligned}
\text{HLS} &= A (3.3 \times 298 - 3.2 \times 278) \\
&= \frac{15}{2.904} (3.3 \times 298 - 3.2 \times 278) \\
&= 480 \text{ Btu/hr.} \\
&= 0.53\#/hr. \quad \text{equivalent 50 psig steam uninsulated} \\
&= 0.1\#/hr. \quad \text{insulated}
\end{aligned}$$

IV. Efficiency Loss Due to Partial Flooding

Determine Heat Exchanger Surface Area

$$H_s = U_s A_s \Delta T_{avg}$$

H_s = Heat required from steam = 3,283,200/btu/hr.

$$A \Delta T_{avg} = \frac{(t_s - 45) + (t_s - 195)}{2} = 178^{\circ}\text{F}$$

$$\begin{aligned}
A_s &= \frac{H_s}{U_s A \Delta T_{avg}} \\
&= \frac{3,283,200}{140 \times 178} \\
&= 132 \text{ ft}^2
\end{aligned}$$

Assuming 72,000 Btu/hr. extraction from the flooded portion of the coil,, determine temperature rise in the heated water due to sensible heat.

$$H_{sc} = W \times S. H. \times \Delta t$$

S. H = Specific heat of water = 1 Btu/#^oF

$$A t = \frac{H_{sc}}{W \times S. H.}$$

H_{sc} = Heat due to sub-cooling = 72,000 Btu/hr.

$$\Delta t = \frac{72,000}{30,400}$$

$\Delta t = 2.4^{\circ}\text{F}$ = Product temperature rise due to sub-cooling condensate

Determine flooded area:

$$H_{sc} = U_{sc} A_{sc} \Delta T_{avg}$$

U_{sc} = 70 Btu/ft²/^oF/hr. From Nixon Heat Exchanger Handbook

$$\Delta T_{Avg} = \frac{(298 - 45) + (278 - 195)}{2} = 104^{\circ}\text{F}$$

$$\begin{aligned}
 A_{sc} &= \frac{H_{sc}}{U_{sc} \Delta t_{Avg}} \\
 &= \frac{72,000}{70 \times 104} \\
 &= 9.9 \text{ ft.}^2 \\
 &= 7.5\%
 \end{aligned}$$

Determine new steam temperature required to maintain total heat rate of 3,283,200 Btu/hr.

$$H_T = H_s + H_{sc}$$

$$\begin{aligned}
 H_s &= H_T - H_{sc} \\
 &= 3,283,200 - 72,000 \\
 &= 3,211,200 \text{ Btu/hr.}
 \end{aligned}$$

$$H_s = U_s A_s \Delta t_{avg}$$

$$u_s = 140 \text{ Btu/ft}^2/\text{°F/hr. from Nixon Heat Exchanger Handbook}$$

$$A_s = 122 \text{ sq. ft.}$$

$$A \Delta t_{avg} = \frac{(T_s - 45) + (T_s - 192)}{2}$$

$$\begin{aligned}
 A \Delta t_{avg} &= \frac{H_s}{U_s A_s} \\
 &= \frac{3,211,200}{140 \times 122} \\
 &= 188^\circ\text{F}
 \end{aligned}$$

$$(T_s - 45) + (T_s - 192) = 188$$

$$T_s = 307^\circ\text{F}$$

$$P_s = 60 \text{ psig}$$

The total steam requirement now at 60 psig is approximately

$$\begin{aligned}
 Q &= \frac{H_s}{hr.} \\
 &= \frac{3,211,200}{904} \\
 &= 3,552\#/hr.
 \end{aligned}$$

V. Efficiency Loss Due to Insulating Effect of 0.00001" of Air Film

Determine reduction in heat rate due to 0.00001" layer of air

$$RT = R_{wa} + R_a$$

RT = Total heat exchange resistance

R_{wa} = Resistance without air

$$R_a = \text{Resistance with air} = \frac{X_a}{K_a}$$

X_a = Air thickness

$$K_a = 0.0104$$

$$RT = R_{wa} + \frac{X_a}{K_a}$$

$$RT = \frac{1}{UT}$$

$$\frac{1}{UT} = \frac{1}{U_{wa}} + \frac{K_a}{X_a}$$

$$U_{wa} = 140 \text{ Btu/ft}^2/\text{°F/hr.} \quad \text{From Nixon Heat Exchanger Handbook}$$

$$\frac{1}{UT} = \frac{1}{140} + \frac{0.00001}{0.0104 \times 12}$$

$$U_T = \frac{1}{0.0075432}$$

$$U_T = 138.5 \text{ Btu/Hr./°F/Sq. Ft.}$$

Determine steam temperature necessary to regain heat rate.

$$H_T = A_s \times U \times \Delta T_{Avg.}$$

$$A \Delta T_{Avg} = \frac{H}{A_s U}$$

$$= \frac{3,211,200}{122 \times 138.5}$$

$$= 190$$

$$\Delta T_{avg} = \frac{(T_s - 193) + (T_s - 195)}{2}$$

$$190 = \frac{2T_s - 389}{2}$$

$$T_s = 334^\circ\text{F}$$

$$P_s = 99 \text{ psig}$$

HEAT EXCHANGER PERFORMANCE I.B. vs BIMETALLIC TRAP

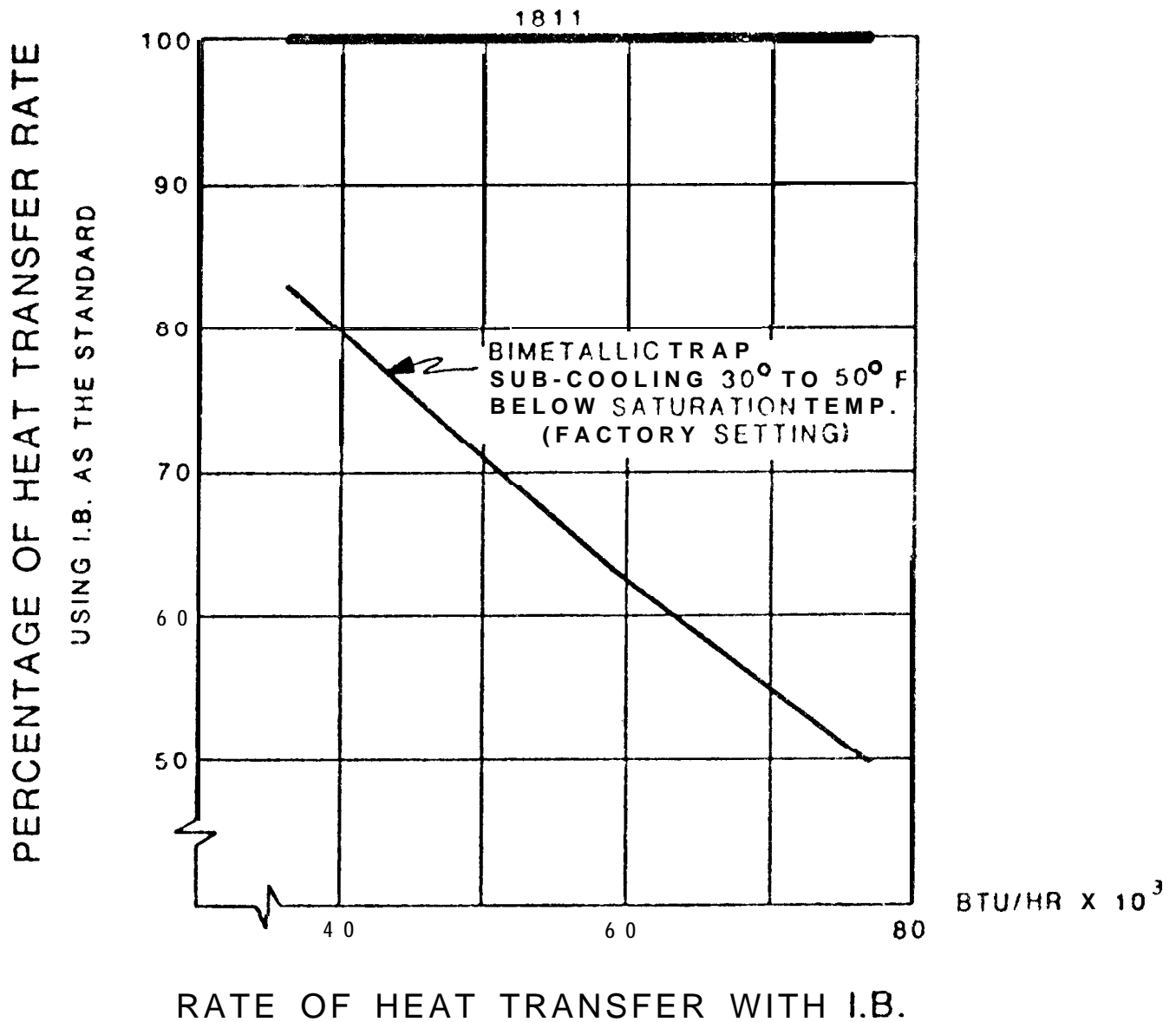


Figure 1

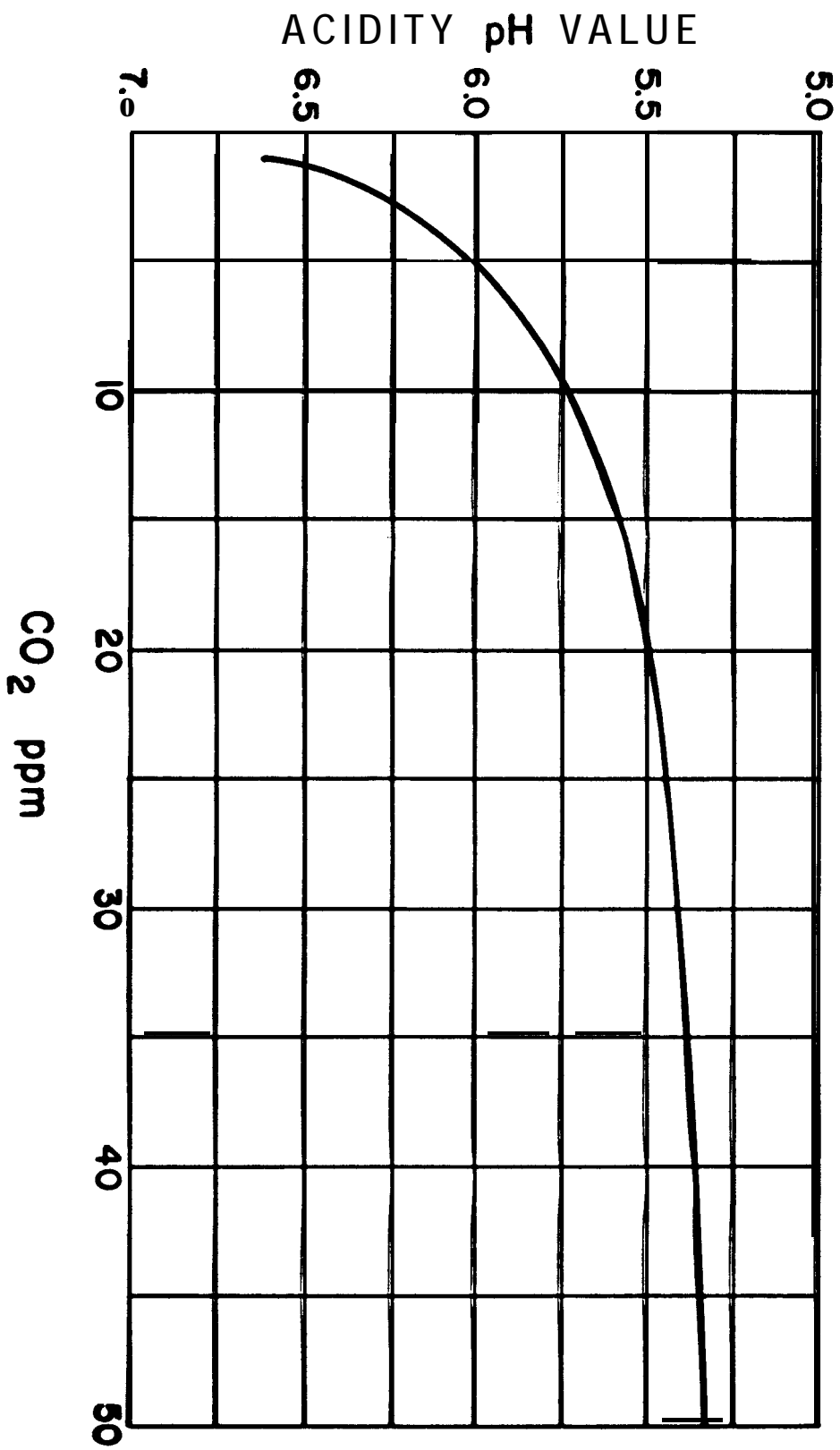


Figure 2

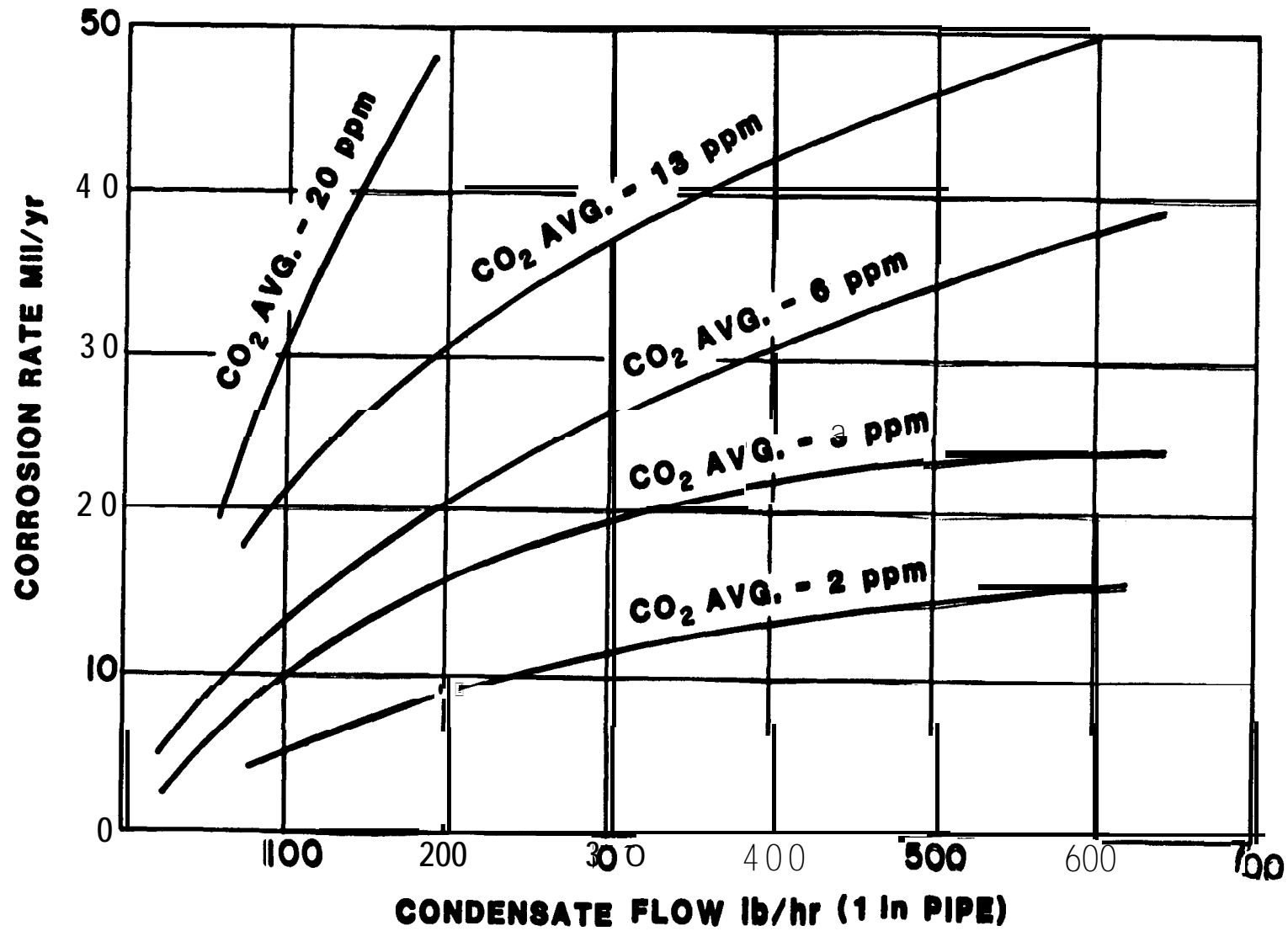


Figure 3

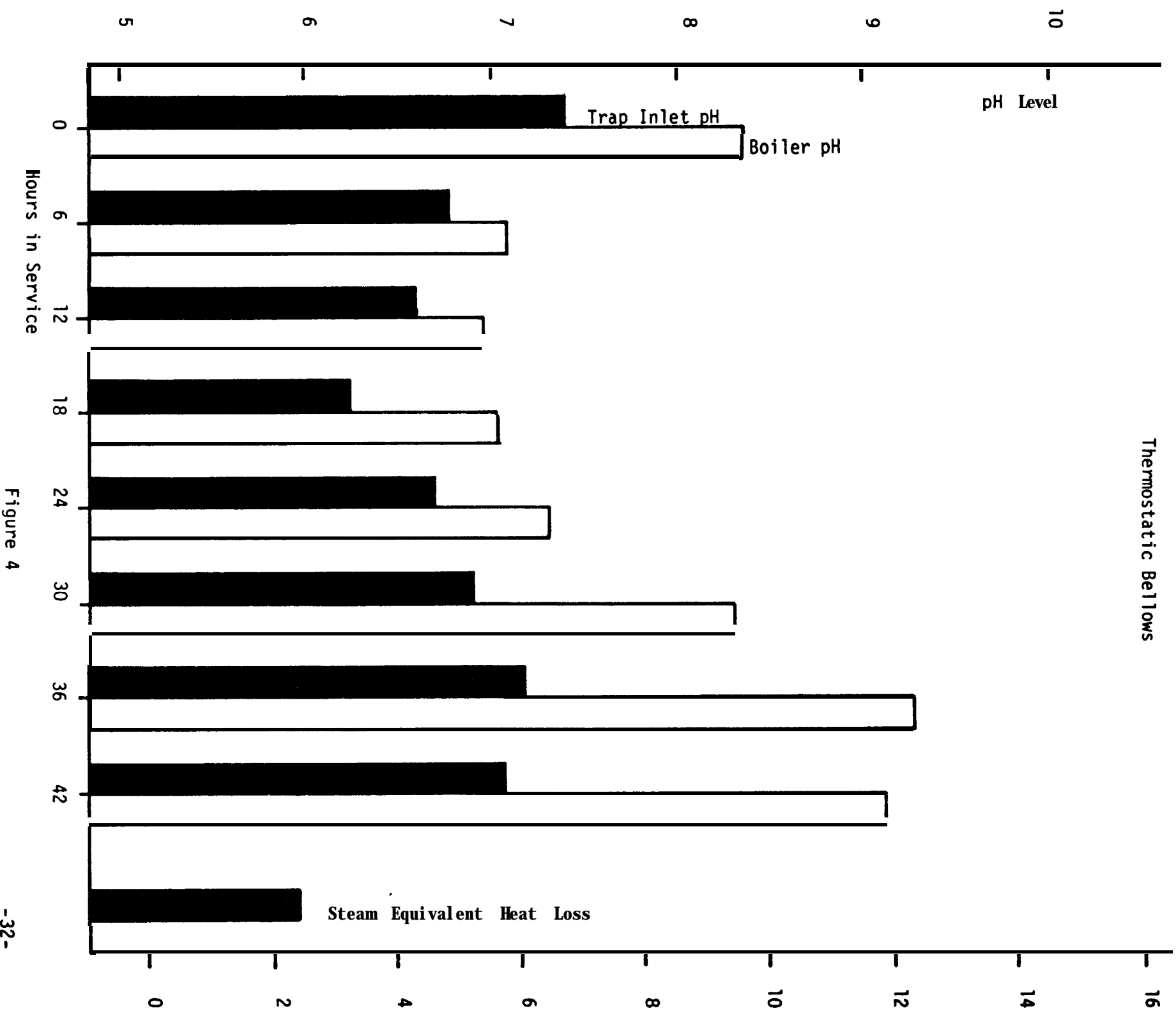
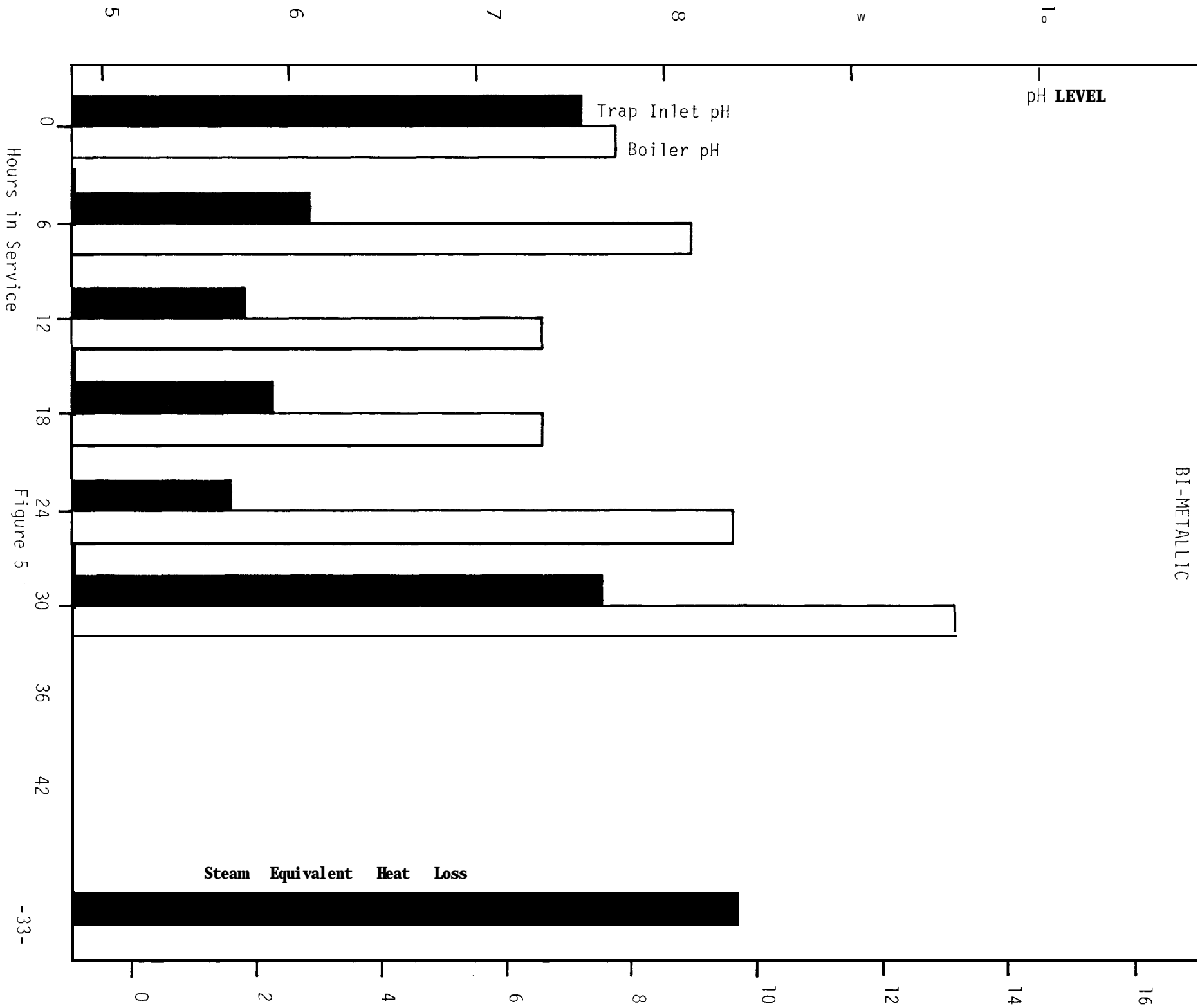


Figure 4



BI-METALLIC

Steam Equivalent Heat Loss

Figure 5

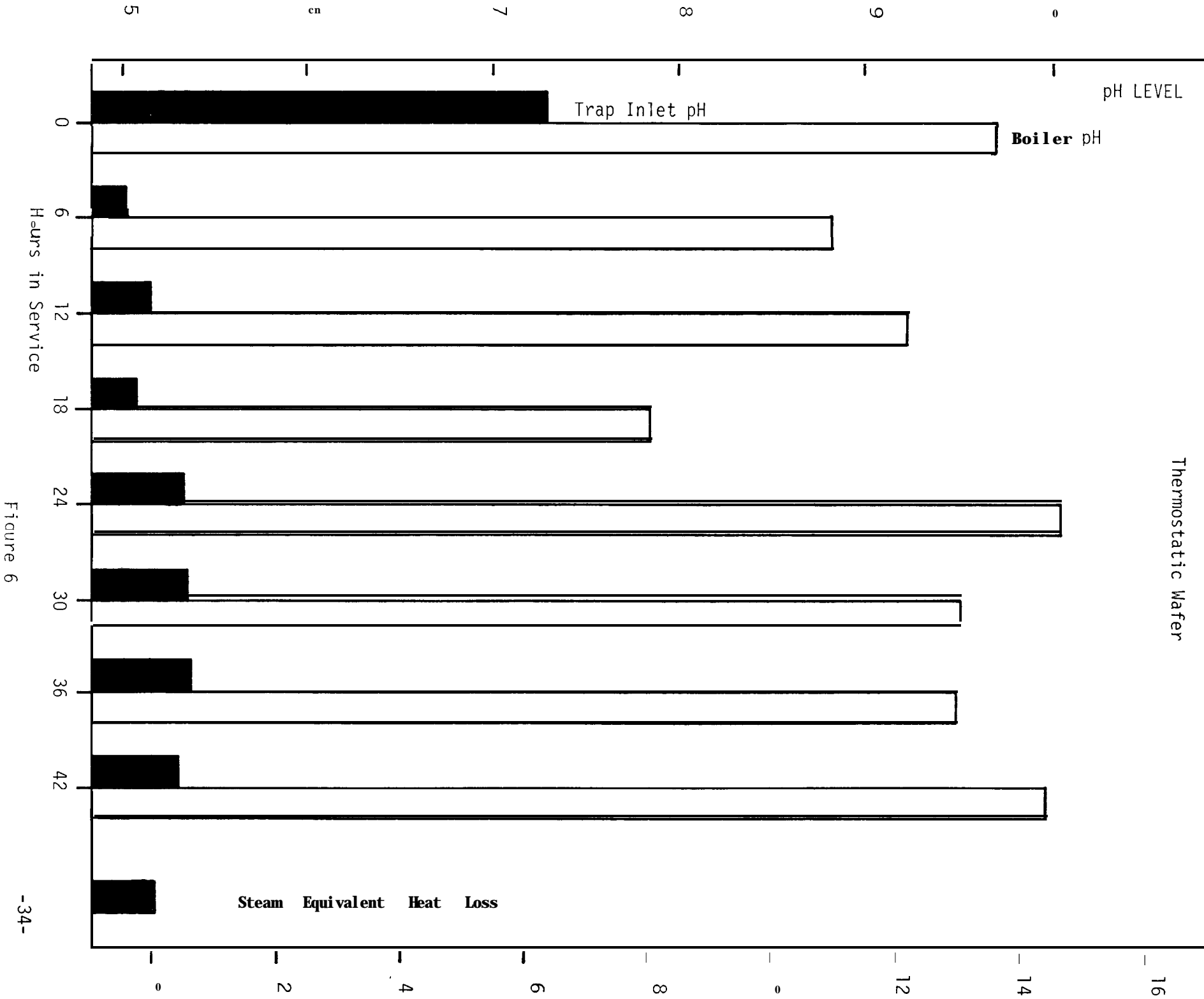


Figure 6

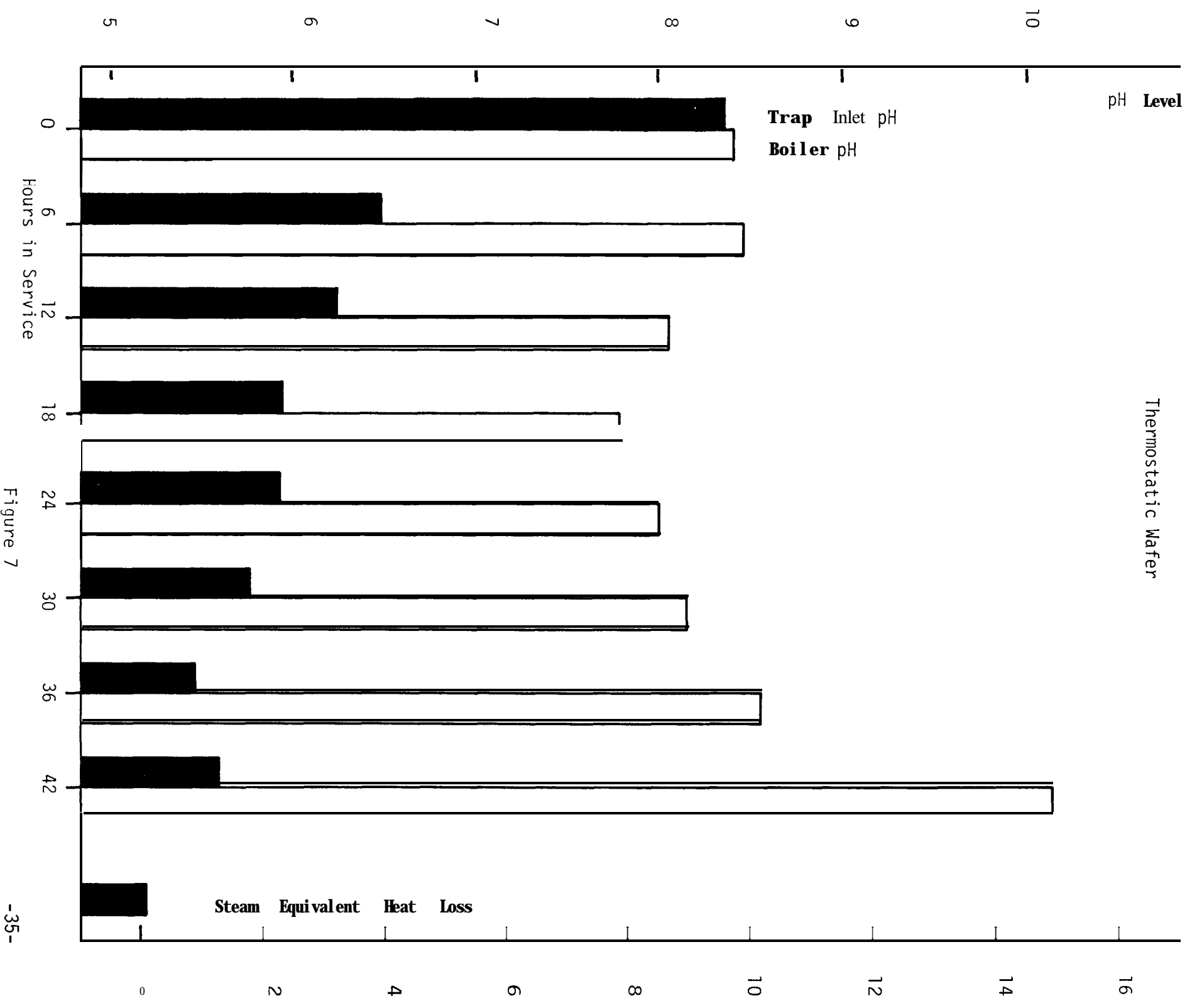


Figure 7

- 1 - Inverted Bucket
- 2 - Thermostatic Wafer
- 3 - Bi-metallic
- 4 - Thermostatic Bellows

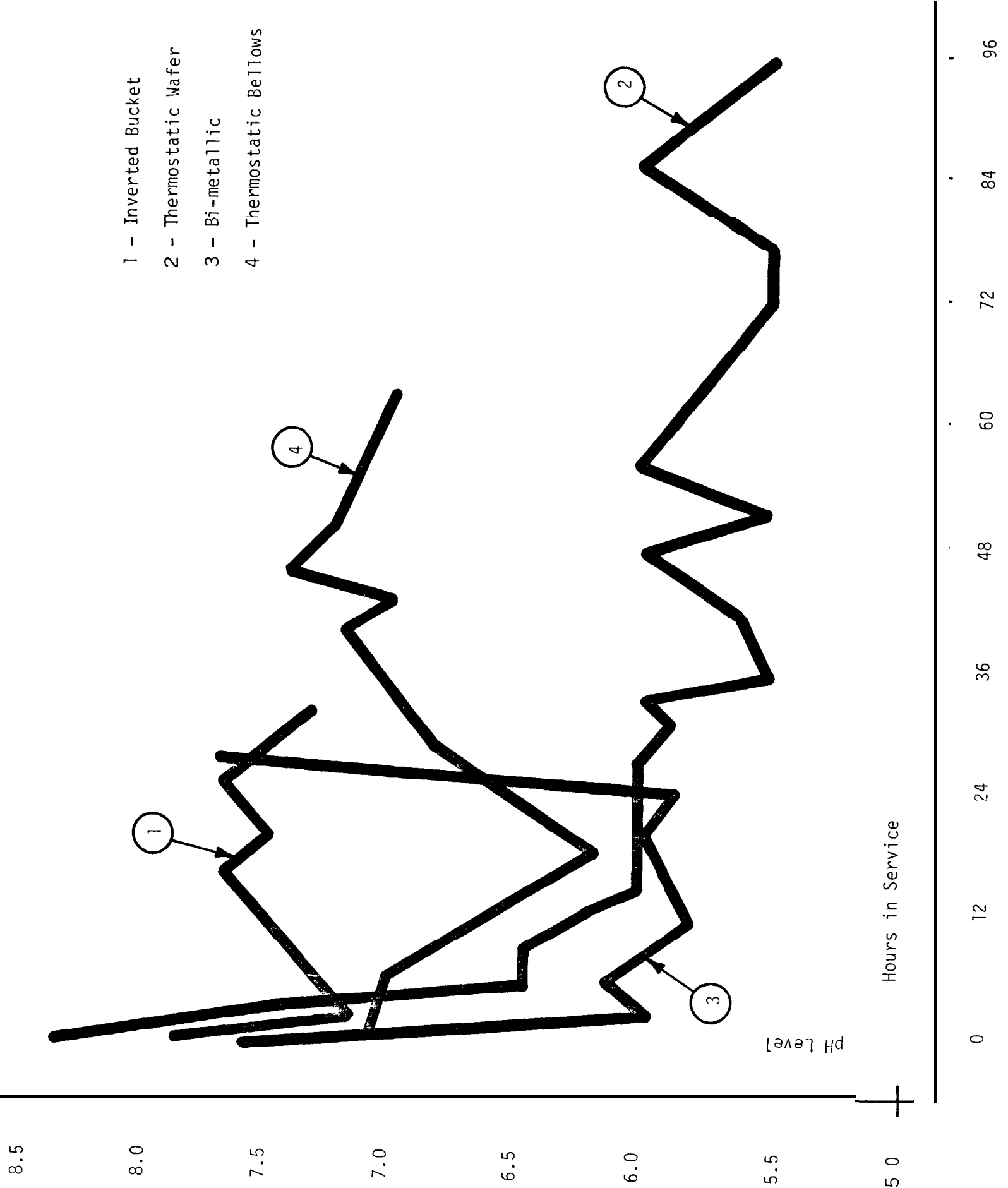


Figure 8

**ATOMIC ABSORPTION ANALYSIS
OF
SUB-COOLED STEAM TRACING CONDENSATE**

Imperial Oil, Sarnia, Ontario, Canada

cu = 0.29 ppm

Fe = 1.05 ppm

pH = 6.83

Gulf Oil, Clarkson, Ontario, Canada

Cu = 0.10 ppm

Fe = 0.12 ppm

pH = 6.27

Shell, Corunna, Ontario, Canada

Cu = 2.85 ppm

Fe = 40.0 ppm

pH = 7.03

Shell, Oakville, Ontario, Canada

Cu = 0.21 ppm

Fe = 0.007 ppm

pH = 6.0

Gulf Oil, Clarkson, Ontario, Canada

cu = 2.11 ppm

Fe = 25.0 ppm

pH = 7.27

Figure 9

SUMMARY

In steam heating condensate systems with high CO₂ potential present in the steam, very corrosive conditions can occur. These conditions are encountered in unit heaters and heat exchangers operated in a flooded condition where the CO₂ is not vented and as a result accumulation will take place in the vapour phase. The CO₂ redissolves and forms very aggressive condensate.

By using and selecting traps that can vent CO₂, a substantial reduction in corrosion can be realized thus extending the reliability and service life of equipment.

An inverted bucket type trap and thermodynamic trap were found to reduce corrosion in unit heaters and exchangers due to their ability to vent CO₂. The reduction in corrosion was based on the iron levels monitored in the condensate.

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INTRODUCTION

Severe corrosion occurs in high condensation systems where the CO₂ can accumulate in the vapour phase above the condensate in the unit. As condensation continues, the accumulated carbon dioxide will develop a partial pressure sufficiently high enough so as to permit re-solution of more and more carbon dioxide until equilibrium is attained, under which condition, the carbon dioxide content of discharged condensate will equal that of the incoming steam. The condensate formed will be very aggressive and corrosive.

Sub-cooling the condensate will allow more CO₂ to dissolve making it even more aggressive ^{*} 1

A survey was conducted to investigate areas in the steam condensate system where these conditions of severe corrosion could exist. The effect of trap design and selection was investigated to determine the effect on corrosion under these conditions.

The South Tank 874 and North Tank 879 heaters were studied to determine the effectiveness of an inverted bucket trap vs. a float and thermostatic spring trap to vent CO₂ and to determine their effect on corrosion.

- 2 -

The next area investigated was the North Fuel Oil Heater which was running partially flooded with condensate using a thermostatic trap which discharged sub-cooled condensate. The exchanger was then operated in an unflooded condition by using a thermodynamic trap to compare the effect on corrosion.

Note:

1. D.S. McKinney et al p7 - Article enclosed in Appendix A.

- 3 -

CASE I SOUTH TANK 874 HEATER

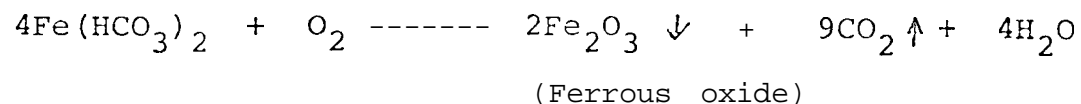
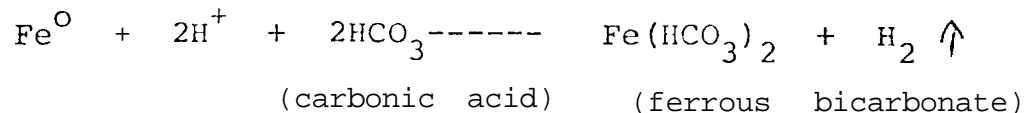
The South Tank Heater has an Armstrong Model 214 inverted bucket type steam trap. The trap was operating satisfactorily discharging at short regular time intervals. The condensate field test results of pH, specific conductance and lab analysis for iron values are summarized in Table No. 1. The average iron value was 0.575 parts per million (ppm) as $\text{Fe} \begin{smallmatrix} 0 \\ 2 \ 3 \end{smallmatrix}$

CASE 2 NORTH TANK 879 HEATER

On February 28, 1980, the tank heater trap operation was investigated. The type of trap used was a velan Model-MFT-2 Float with a thermostatic spring trap. The trap continuously drained a steady stream of sub cooled condensate. The condensate formed a bright red stream on the ground. The other tank heater was not operational for it had all ready failed in service.

The field test of the condensate conductivity was high, indicating a high amount of dissolved CO_2 being present.

When the CO_2 titration test was performed, the sample turned yellow as it was exposed to the air. The reaction occurring was the ferrous bicarbonate formed by the carbonic acid attack being reverted to the hydrated ferrous oxide precipitate.



Under these operating conditions, where the condensate was being sub cooled, a very aggressive condensate was being formed.

This is shown by the high iron level of 5.0 ppm for the February 28th, 1980, result in Table No. 2

The Velan float with a thermostatic trap was changed to an Armstrong Model 814 inverted bucket trap on March 5, 1980. Field Test results and lab results for March 6, 1980, on the Condensate conductivity and iron showed a substantial drop. The ferrous bicarbonate reversion reaction did not occur during the CO₂ titration test indicating the condensate formed was not as aggressive as indicated by the high iron level of 5 ppm.

The results summarized in Table No. 2 shows a significant decrease in corrosion as shown by the drop in iron levels. The mean value of the iron level was 0.576 ppm which is the same as the results obtained in South Tank 874 study.

DEARBORN CHEMICAL COMPANY LTD.

TABLE NO. 1 SOUTH TANK 874 HEATER CONDENSATE TEST RESULTS

Date	PH	Conductivity Micromhos	Iron as Fe ₂ O ₃
2/28/80	5.0	5.6	0.680
3/6/80	6.0	5.5	1.000
3/20/80	7.2	3.5	0.350
4/10/80	5.7	4.5	0.750
4/17/80	5.9	4.0	0.240
5/9/80	6.0	4.0	0.430

TABLE NO. 2 NORTH TANK 879 HEATER CONDENSATE TEST RESULTS

Date	pH	Conductivity Micromhos	Iron as Fe ₂ O ₃ ppm
2/28/80	6.9	15.0	5.000
3/6/80	5.9	6.0	1.450
3/20/80	5.9	6.0	0.630
4/10/80	5.6	3.5	0.750
4/17/80	5.8	4.0	0.350

TABLE NO. 3 NORTH FUEL OIL HEATER CONDENSATE TEST RESULTS

Date	PH	Conductivity Micromhos	Iron as Fe ₂ O ₃ ppm
2/28/80	6.2	5.0	0.700
3/6/80	5.8	7.5	1.430
3/20.80	7.4	1.4	0.100
3/3/80	6.3	3.0	0.100
4/10.80	5.7	3.5	0.080
4/17/80	5.8	3.5	0.060
5/9.80	6.9	2.0	0.400

CASE 3 NORTH FUEL OIL HEATER

The type of steam trap used for the fuel oil heat exchanger was a Triflex Model #16 Thermostatic trap. The iron levels shown in Table No. 3 for 2/28/80 and 3/6/80 indicate a very aggressive condensate being formed. The trap was changed to a Yarway Model #40 Thermodynamic Trap. The iron levels dropped significantly. The mean iron value was 0.148 ppm compared to an average of 1.065 ppm with the thermostatic trap in operation. The thermodynamic trap which vents CO₂ has significantly decreased the aggressiveness of the condensate and corrosion.

CONCLUSION

The corrosion in the North Tank 879 heater was significantly reduced by alternating the trap selection. When the heater had a float and thermostatic spring type trap, condensate was being retained longer by allowing only sub-cooled condensate to be discharged. Under this condition CO₂ gas would not be vented but would accumulate and dissolved into the condensate making it very aggressive. Changing to an inverted bucket trap allowed CO₂ gas to be vented eliminating it's accumulation. This resulted in less CO₂ dissolving into the condensate thus reducing it's corrosivity.

The North Fuel Oil Heater was being operating in a flooded condition using a thermostatic trap. Changing the trap to a thermodynamic trap allowed CO₂ to be vented as in the heaters with a substantial decrease in corrosion.

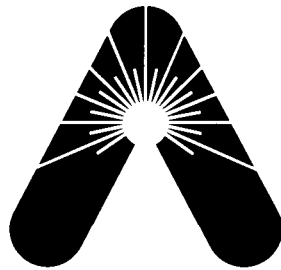
Claude Gauthier, P.Eng.
Dearborn Chemical Co. Ltd.

/pm

APPENDIX A

Studies of the Mechanism of Solution of CO₂ in Condensates
formed in Steam Heating Systems of Buildings.

Preventing the Solution of CO₂ in Condensates by venting
of the Vapour Space of Steam Heating Equipment



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