SINGLE TRAY RAIN TYPE CONDENSERS

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Abstract

Following the request for information on single tray rain type condensers, a literature survey was undertaken by the SMRI to obtain design criteria for this type of condenser. A number of rain condensers are at present in operation in the South African sugar industry and generally their performance has been successful. These condensers regularly return approach temperatures of less than 3° C while a conversion of an old cascade condenser to a rain type can be done at a cost of only one tenth of a new condenser. Some of the sources of reference, the design criteria concluded from these sources and the tests conducted on various single tray rain type condensers are described.

Introduction

During 1976 NB approached the SMRI for design data to improve their existing evaporator condenser which was performing poorly. Typical fourth vessel vacuum conditions were 565-590 mm Hg. There was considerable literature available in the QSSCT proceedings and by using these articles and having observed the successful use of the type of condenser at GH, NB modified their existing tray type condenser to a rain type with some success. Vacuum conditions improved to 640 mm Hg and after subsequent removal of the Stillman separator to 666 mm Hg. In order to be able to cater for any similar problems which could arise in the future the SMRI proceeded to develop a design programme for rain type condensers.

Literature survey

As an introduction to the study and to obtain design criteria a literature survey was undertaken. Some of the conclusions drawn by various research workers are mentioned below:

In 1969 Stewart and Mulvena[1] came to the conclusion that the single plate, rain type condenser is more efficient than the plate and tray type, has less pressure loss, is less prone to surging and is simple to manufacture. However they indicated that the condensers must be designed to prevent hold-up of incondensible gases. Their tests on rain type condensers indicated that the stream of water from the rain tray did not fall unbroken to the base cone, but that in the volume below the tray violent mixing of vapour and water droplets took place.

In 1970 the above authors[2] indicated how they set up a pilot plant condenser to assist with obtaining design criteria for rain type condensers.

In 1970 Hill[3] proposed a means of overcoming the surging often experienced by rain type condensers by increasing the number of incondensible gas chimneys. Hill further indicated that the excess water exit from the tray should be sufficiently large to accommodate all the injection water should the tray block. This would prevent water being drawn into the vacuum manifold.

The conclusions from the pilot plant and other condenser tests were reported by Stewart[4] in 1971. He reported that most of the condensation took place on the wall of the condenser. The diameter of a suitable condenser need not be larger than the vapour inlet pipe provided that the vapour velocity does not exceed 61 m/s (200 ft/sec). The rain tray should be located at least 1,8 m (6 ft) above the vapour inlet pipe and water should flow down the wall of the condenser. The pilot plant operated satisfactorily with a tray-to-vapour-pipe height of 2,4 m (8 ft) while the Plane Creek condenser also tested by Stewart had a clearance of 1,8 m (6 ft). Stewart felt that the incondensible gas chimney should be centrally located and that its size should be about 16% of the cross sectional area of the condenser. The performance of the condenser was not influenced by the tray hole size, and the approach temperatures measured during the tests ranged from 1,1-9,4° C (2-17° F).

Ziegler[5] reported in 1976 that his experiments indicated that a base cone with an angle of 70° to the horizontal would handle more than twice the water rate of a 30° cone without bridging and hence allow an easy removal of waste water. Both the SMRI and NB designs are based on the above sources of reference.

Design parameters

The first SMRI design had a body cross-sectional area 1,5 times larger than the vapour pipe. The vapour pipe was sized using a maximum vapour velocity of 61 m/s (200 ft/sec) and evaporation rate from the pan or last effect vessel as detailed in Table 1. The rain tray which is positioned 2,44 m (8 ft) above the vapour pipe consists of a perforated tray surrounded by a weir. The portion of the tray directly beneath the injection water pipes was made solid to prevent excess water being forced through this section of the tray.

A number of incondensible gas chimneys protrude through the tray to allow the escape of these gases. The cross-sectional area of these chimneys is at least twice that of the incondensible gas pipe. The sizing of this pipe was based on information provided by Hugot[6] and using a vapour velocity of 12 m/s. The weir height, percentage tray open area and solid central area are calculated to allow a certain percentage of the cooling water to flow over the weir and down the body wall at maximum condensing rate. To ensure that some water always flows down the walls and to prevent incondensed vapour from passing through the annular gap, water passes through holes in the weir at tray level.

The injection water quantity is based on a minimum approach of 3,0°C. The tail pipe height and diameter are also based on information obtained from Hugot.[6]

The following evaporation rates were taken for the calculation of vapour loading to the condenser.

TABLE 1
Evaporation Rates

Pan type	Condenser vapour loading	
	kg m^{-2} s^{-1}	lbs ft^{-2} h^{-1}
Footing	0,0218	16
A	0,0163	12
B	0,0136	10
C	0,0109	8
Refinery	0,027	20

Modification details

Some leading dimensions of condensers built (IL) and modified (NB, SZ and TS) are given below:

TABLE 2

Mill	Pan Capacity m^3	Condenser Body dia. (m)	Percentage Tray Open Area	Tray-Vapour Pipe Height (m)	Pan Duty
SZ	34	1,89	7,6	2,4	Refinery
SZ	17	1,45	6,6	1,8	Refinery
SZ	31,2	1,45	14,3	1,8	Refinery
NB	Evaporator	2,13	7,2	2,7	
IL	32	0,8	23,0	2,44	B
TS	28,3	1,22	9,6	1,5	A

Operational testing

During 1978/79 measurements were made at the four factories using rain type condensers with which the SMRI had been involved. The data required were as follows:

Tv = temperature of vapour corresponding to absolute pressure in condenser.
Ti = temperature of injection water.
Tw = temperature of waste water.
Ta = temperature of incondensible gases.
Tvap = actual measured temperature of vapour entering condenser.
= Tv + superheat from BPE.

Temperature measurements at NB, SZ and IL were made with thermocouples located in mild steel oil bath sockets while at TS probes as detailed in Fig. 1 were used.

Absolute pressures were monitored with an absolute pressure transmitter except at TS where a mercury manometer was used.

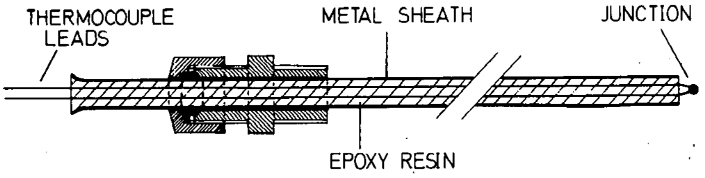


FIGURE 1 Thermometer Probe.

Noodsberg

One of the first single rain tray condensers to be used was designed by Noodsberg.

This involved the conversion of a cascade type condenser on the evaporator to a rain type condenser using the existing body shell. The base cone was altered to improve water drainage and a new peripheral water manifold was built. As this existing body had a fairly large diameter the rain tray initially suffered from poor water distribution but by observation through port holes the injection water piping was modified to overcome this problem. Initial observations indicated that the modified condenser was performing considerably better.

An attempt was made to improve further the condenser performance by fitting two horizontal perforated baffles. This attempt to increase water residence time did not however improve the condenser performance and the baffles were subsequently removed. These modifications were carried out during a normal scheduled maintenance stop. During the 1978 season condenser temperatures were recorded to gauge its efficiency. Mild steel oil bath type sockets, and thermo-couples connected to a multipoint recorder were used for these measurements. The injection water to the condenser was regulated by an absolute pressure-sensing controller with a manual by-pass. With the injection water controller regulating, an approach temperature of about 10° C was returned, however when the water was manually regulated, the condenser was more efficient and an approach temperature of 4° C was returned. Figs. 2 and 3 show portions of the temperature recorder chart for controller and manual regulation of the injection water respectively.

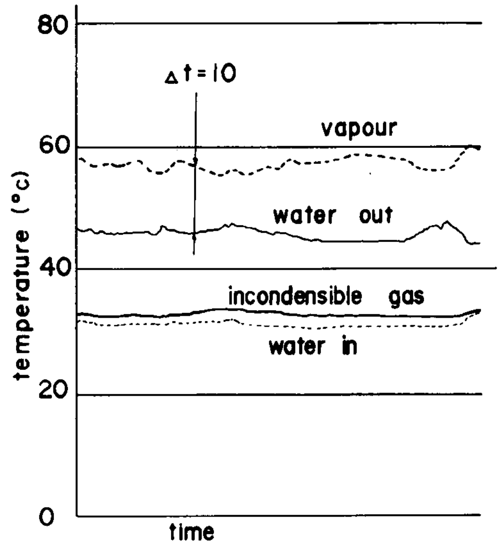


FIGURE 2 NB Temperature Recording — Automatic Control.

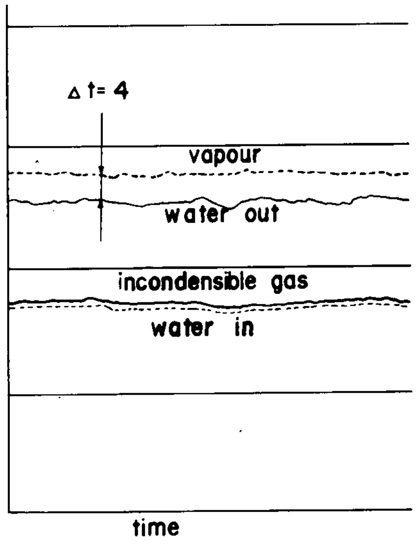


FIGURE 3 NB Temperature Recording — Manual Control.

Prior to modification approach temperatures of 20° C had been recorded.

Sezela

The first conversion using the SMRI rain type condenser design was on three refinery pan condensers at SZ.

All three condensers were of the cascade type with cast iron internals and shell. The stainless trays were fabricated and installed, after the removal of cast iron internals, during the 1977/78 off crop period. The injection water entry was converted from a side entry to overhead entry.

Fig. 4 shows a drawing of the rain tray fitted to the inside of the cast iron shell. The tray was supported on mounting lugs which formed an integral part of the body shell.

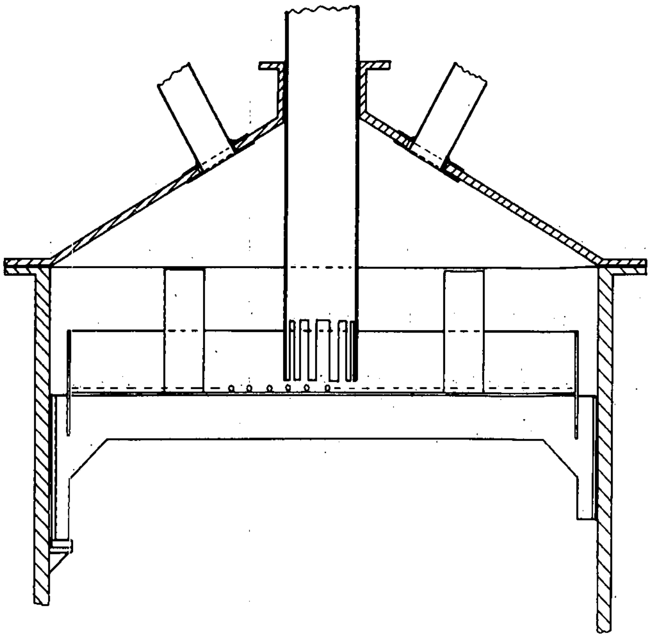


FIGURE 4 SZ Condenser Modification.

It was initially feared that the vapour pipe to tray height of only 1,8 m which was less than the prescribed 2,44 m, would adversely affect the condenser performance. The condenser performed fairly well returning approach temperatures of between 1° C and 4° C when the injection water was controlled. As before, this approach is based on temperature measurement using mild steel oil bath temperature sockets and thermo couples connected to a multipoint recorder.

The need to control accurately the injection water is evident in Fig. 5 which shows a partly supervised boiling cycle. The approach temperature was reduced from 14° C to 3° C during the early part of the boiling cycle with negligible effect on the pan pressure (based on vapour temperature measurement). During the latter part of this cycle the approach temperature was 1° C.

During the 1977/78 off crop period, the joints of pan segments were sealed using the "Furmanite" process. It has been reported by the SZ process staff that the combined effect of the modified condenser and sealing was to increase the average seasonal brix of the first and second massecuites by approximately 0,5 brix as well as reducing the cycle boiling time by 17-20%.

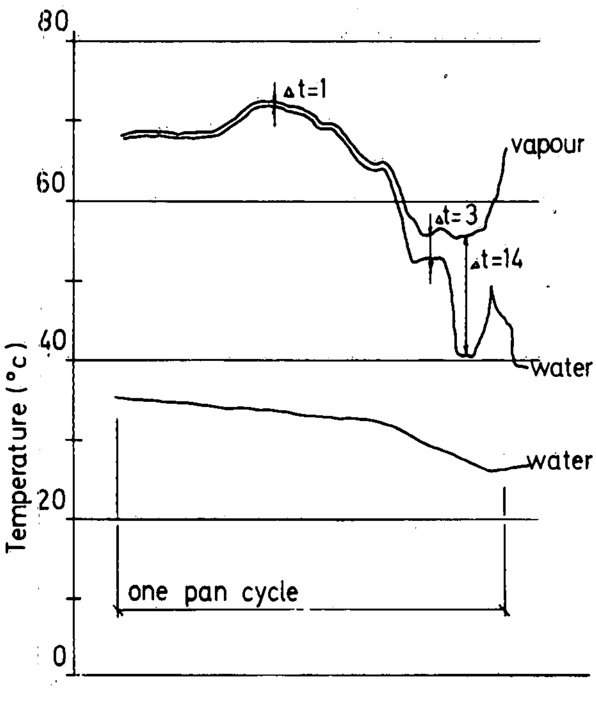


FIGURE 5 SZ Temperature Recording.

Illovo

The first complete condenser based on the literature survey done by the SMRI was installed at IL.

The condenser was connected to a B-pan. Tests done on this condenser to date have on occasions been disappointing. However when the condenser was recently examined it was found not to be to the design specification. The disc which should have been positioned beneath the injection water pipe was omitted as were the holes at the weir base.

The temperature recorder whose thermo couples were fitted into mild steel oil bath sockets often indicated that the vapour temperature fluctuated greatly. However the controller and absolute pressure recorder indicated that the pan pressure was fairly constant. Fig. 6 shows temperature recordings taken from the pan and condenser with the absolute pressure controller set to regulate injection water to return a pressure of 13,5 kPa abs. in the pan. It can be seen from the temperature tracings that the difference between the vapour and tail pipe temperature was 3°C. This vapour temperature was measured about 2 m ahead of the condenser entrance.

An accurate assessment of the condenser performance cannot be made until it is altered to meet the design details. As shown in Fig. 6 this condenser operates satisfactorily at its designed operating pressure, however when made to operate at lower pressures its performance was occasionally irregular.

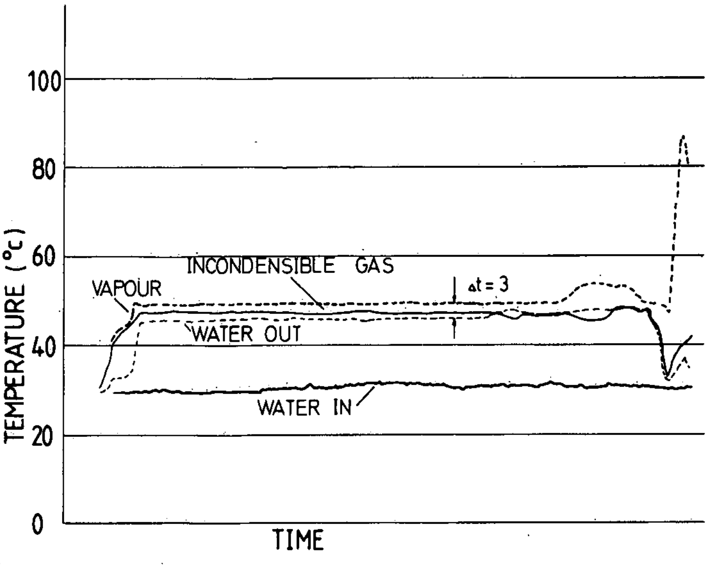


FIGURE 6 IL Temperature Recording.

Tongaat

Following the successful conversion of the old refinery pan condensers at SZ a similar conversion was done on an A pan at TS whose condenser internals were ready to collapse.

As the perforated plate with the required hole size and pitch was not readily available the rain tray was drilled and fabricated by the TS workshop staff. The total cost of the conversion including fabrication and installation amounted to R400 for material (430 stainless steel) and 70 man-hours.

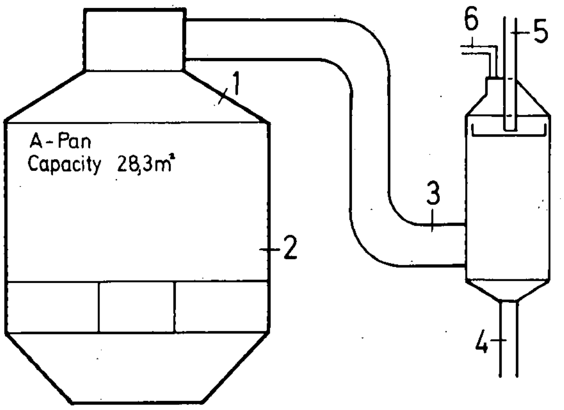
This condenser had a vapour pipe-to-tray height very much less than any of the previously tested condensers so a more detailed performance examination was undertaken. A mercury manometer, to measure pan pressure, and a thermometer calibrated against a standard mercury in glass thermometer were used to determine the condenser approach temperature. Table 3 shows the results obtained from these measurements. Thermo couples connected to a multipoint recorder were used to monitor the temperature at various points in the pan condenser. The position of these thermo-couple probes and a tracing from the recorder are shown in Figs. 7 and 8 respectively. The position marked "A" on Fig. 8 coincides with approach temperature measurement 9 of Table 3. The degree of super-heat and boiling point elevation are indicated in Table 4. Even though the vapour temperature just before it entered the condenser was lower than the vapour temperature measured in the roof of the pan it was still superheated.

Notes: (Refer table 3)

1. The following corrections were made:
   (i) All mercury columns were corrected to 0° C.
   (ii) The barometric pressure was measured in the laboratory on the ground floor and 1,5 mm Hg was allowed for difference of barometric pressure between laboratory level and pan station level.
2. Most of the above data was provided by the TS process staff.

Conclusion

The tests conducted to date clearly indicate that single tray rain type condensers will return good approach temperatures.



Condenser details

tray-vapour pipe height = 1,5 m
percentage open area of tray = 9,6%
condenser body diameter = 1,22 m

FIGURE 7 TS Thermometer Probe Location.

One of the main advantages of this type of condenser is that it is simple and cheap to fabricate. It is relatively simple to convert an existing cascade condenser to a rain type and condenser. Based on the information provided by the TS engineering staff a conversion would be approximately a tenth of the cost of a new cascade condenser. The SMRI has a computer program to speed up the rain type condenser design process. This program is to be up-dated in the light of the information obtained from the above tests.

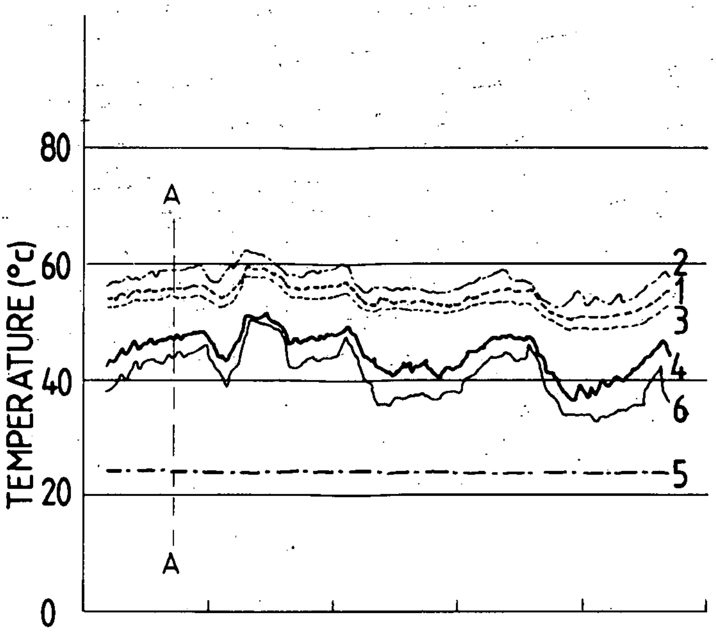


FIGURE 8 TS Temperature Recording.

1 vapour (pan)	2 massecuite	3 vapour (pipe)
4 waste water	5 injection water	6 incondensible gas

TABLE 4
Temperature Values

	°C	Measurement point/source
Massecuite . .	58,8	Point 2 Fig. 8
Vapour . . .	55,5	Point 1 Fig. 8
Vapour . . .	53,8	Point 3 Fig. 8
Waste water . .	46,8	Point 4 Fig. 8
Waste water . .	46,4	Ref. No. 9 11/1 Table 3
Sat. vapour . .	48,4	Ref. No. 9 11/1 Table 3
BPE	58,8 − 48,4 = 10,4° C	
Vapour superheat .	53,8 − 48,4 = 5,4 at condenser inlet	

TABLE 3

	Date	Waste water temp. °C	Vacuum mm Hg	Atmospheric mm Hg	Pan Vapour pressure mm Hg	Vapour temp. °C	Approach temp. °C
1 . . .	15,12	43,0	679,0	753,0	72,5	45,2	2,2
2 . . .	15,12	48,0	659,0	751,5	91,0	49,8	1,8
3 . . .	27,12	47,4	654,5	751,0	95,0	50,6	3,2
4 . . .	28,12	52,8	632,5	753,5	119,5	55,2	2,4
5 . . .	29,12	50,4	654,5	765,0	100,0	51,6	1,2
6 . . .	10,1	45,8	665,0	747,5	81,0	47,4	1,6
7 . . .	11,1	42,0	675,5	754,0	77,0	46,2	4,2
8 . . .	11,1	37,4	690,0	753,5	62,0	42,2	4,8
9 . . .	11,1	46,4	665,5	752,0	85,0	48,4	2,0
10 . . .	12,1	46,8	651,5	747,5	94,5	50,6	3,8
11 . . .	16,1	49,4	640,0	753,0	111,5	58,8	4,4
12 . . .	17,1	50,0	650,0	757,0	105,5	52,8	2,8
13 . . .	18,1	49,0	654,0	755,0	99,5	51,6	2,2
14 . . .	18,1	54,0	628,0	755,0	125,5	56,2	2,2
15 . . .	18,1	54,0	624,5	755,0	129,0	56,8	2,8
						Average	2,8° C

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