

EXPERIENCES WITH MECHANICAL DRAFT COOLING TOWERS IN INJECTION WATER SERVICE

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Abstract

Almost every sugar factory has facilities for cooling injection water. This service is an extremely exacting one and the majority of operators will at some time or another have experienced difficulties in this regard. This paper provides some guidelines that will be of assistance in selecting tower internals, more particularly in respect of configuration and the types of material to use. The question of performance guarantees is also discussed. Test results and experiences, covering a variety of packings, are presented, together with comment on methods of evaluation.

Introduction

Almost every sugar factory has facilities for cooling injection water. These facilities fall basically into two categories: spray ponds and mechanical-draft cooling towers. However the choice between these two is made, be they on economic, space or environmental grounds, the cooling tower should show advantages. The only rider here is that performances must come close to specification and this is not always the case.

Half of Hulett's six raw sugar factories have cooling towers; a fact which has enabled a certain amount of knowledge to be gained on the score of tower internals. By putting these experiences together, it has been possible to come to some broad conclusions as to what requirements are best suited to the very exacting service of cooling injection water in sugar factories. A tentative list follows:

- due to the quality of the water, biological growths are difficult to control without incurring high chemical costs. Packings should therefore be specified such that growths do not represent a potential hazard.
- developing logically on the above theme, it is a prerequisite that packing configurations incorporate:
 - (a) a very open structure which provides minimal opportunity for blockage to occur.
 - (b) a very robust assembly technique that avoids combs, clips etc. as a means of holding the components together.
 - (c) a well thought out method for supporting the packing/distribution manifold that will totally eliminate excessive point loadings.
- injection water is generally soft and corrosive and hence materials of construction should be selected that are durable in such an environment. Based on this criterion, plastic must be regarded as preferable to asbestos cement sheeting.
- the supplier makes no provision in his tender for any fall-off in tower performance after commissioning. This type of situation will almost certainly occur due to operation under non-optimum conditions or due to a deterioration in the condition of the tower internals. Disregarding for the moment the question of who should rightfully be responsible for contingencies of this type, the only valid recommendation that can be made is for the operator to incorporate a safety margin into his design. This margin should be big enough to ensure satisfactory performances over an extended period.

Turning next to the matter of equipment performance, an analogy could perhaps be made with the purchase of a heat exchanger. In this case the client provides data on terminal temperatures and heat load, and, in return, gets a piece of equipment that is designed to give satisfactory performance even under unfavourable conditions. The approach that is adopted here is for the supplier to build a safety factor into his design; this being accomplished by way of shell-and-tube-side fouling resistances. The position is very different when a cooling tower is being purchased:

- the guarantee only applies to clean equipment and the acceptance test run will normally be performed within a few days of commissioning.
- a "measuring tolerance" must be taken into account. This involves making a deduction from any performance shortfall against guarantee (if present).
- tests must be carried out under favourable conditions.

These three items may be perfectly reasonable in themselves but this is not really the point at issue. What is involved appears to be more a matter of principle; namely the right of the customer to get what he orders. The extremely competitive nature of the cooling tower supply industry will ensure that there is no giveaway against specifications but, by the same token, suppliers should realise that their own best interests are served by building-in a safety factor to cover all known and/or reasonable contingencies.

External conditions influencing the specification of cooling installations

Water cooling is essentially a service operation. This being so, a cooling installation must be designed to handle what it receives from process under a variety of circumstances.

The well designed cooling system will be based on two prime considerations that are determined externally:

- heat load
- water temperature requirements of the consumer.

Heat load merits scant comment, being determined by mass and heat balances over the processing equipment, notably condensers attached to the evaporator and pan boiling stages. In the case of heat balances, equations of the following type apply:

$$Q = v(s - c_w t_{w1})$$

Water temperature in the condensers is very important as this represents one of the determining factors in respect of the vacuums attained in the processing equipment.

Absolute pressure in pans and evaporator last vessels usually averages out at about 15 kPa (25.5° Hg), which corresponds to a saturation temperature of 54°C. For efficient counter-current rain condensers, an *effective* approach temperature of 5°C is a realistic figure. This value includes an allowance for pressure drop across vapour piping and entrainment separators; a factor which is often overlooked. Condenser water outlet temperature, which is also the cooling system inlet temperature, will thus approximate to: 54 - 5 = 49°C.

In the case of cocurrent condensers, water temperatures will have to be considerably lower to achieve equivalent results in

the processing equipment. However, units of this design are outmoded and only the above value for countercurrent condensers is applicable to the ensuing discussion.

Factors affecting water circulation rate

Actual values have been given in the preceding section as the influence of system temperatures on water circulation rate is best demonstrated by reference to a practical example.

In the raw sugar factories, operation with river water on a once through basis is fairly uncommon as a result of both environmental and water availability factors. This leaves spray ponds and mechanical draft cooling towers as the two common methods for obtaining condenser water in a suitable condition.

Operators will be familiar with the physical aspects of these two facilities but perhaps will be less well aware of the differences in operating results that are achievable. In mechanical draft towers, a real measure of control over air rates is possible and hence the temperature of the circulating water can be lowered to a level close to the wet bulb; this being the minimum level obtainable. The difference, referred to as the approach to wet bulb or simply the "approach", is one of the main design criteria for cooling towers and usually has its economic optimum in the range 6–8°C. In this regard, the requirements of the process may be over-riding and lower figures demanded.

The position in respect of spray ponds is distinctly less favourable and results will depend very much on the prevailing climatic conditions. Typically the "approach" level achieved in this type of facility is around 13–15°C.

The implications of the above two sets of figures for water circulation rates are interesting, as evidenced by the following table:

TABLE 1
Effect of type of cooling installation on water circulation rate

	Wet bulb (°C)	App- roach (°C)	Cold water temp (°C)	Hot water temp (°C)	Cool- ing range (°C)	Circulating rate (%)
Reference	1	2	3=1+2	4	4-3	
Cooling tower	26	7	33	49	16	100
Spray pond	26	14	40	49	9	180

From the above comparison it is apparent that approximately 80% more water must be pumped through a spray system in order to accomplish the same overall task. The net consequence is that much larger equipment is required all round and higher operating costs are incurred.

Additional factors that should favour the use of cooling towers are lower maintenance costs and improved space/environmental considerations.

Operation of mechanical draft cooling towers

Water loadings are normally set in the range 2,5 – 12,5 th⁻¹m⁻² of tower cross sectional area. The actual rate that is used will be determined by process requirements and the type of packing that is selected.

Superficial air velocities range between 1,2 and 2,5 ms⁻¹ (5 – 10,5 t h⁻¹m⁻²). A higher velocity is not favoured for two reasons: it

- creates a requirement for more elaborate entrainment or "drift" eliminators, which inevitably means higher pressure losses
- causes higher pressure losses in the packing itself.

The consequences of both these effects will be to increase the fan power rating and tend to move the conditions in the direction of non-optimum operation.

On the basis of the above figures, it is apparent that a gas/liquid ratio (λ) in the range 0,7 to 1,5 will normally apply.

Evaluating cooling tower performance

In direct contact processes involving air and water, both heat and mass transfer occurs simultaneously. This is already a fairly complex thermodynamic system and it is made considerably more so by the great variety of tower internals and techniques of operation that are employed by designers to achieve their objective. What this implies is that the meaningful evaluation of direct contact cooling equipment is not an easy task. In this paper two approaches are dealt with; both of which have their own particular area of application:

- fundamental approach
- empirical approach.

Fundamental approach

Because of its importance industrially, the air/water system has been extensively researched over many years.

Accordingly to the literature¹, "the most generally accepted theory of the heat transfer process occurring in cooling towers is that developed by Merkel. This analysis is based upon enthalpy potential difference as the driving force. Each particle of water is assumed to be surrounded by a film of air and the enthalpy difference between the film and surrounding air provides the driving force for the cooling process. In the integrated form, the Merkel main equation is:

$$K_v \left(= \frac{KaV}{G_w} \right) = \int_{tw_2}^{tw_1} \frac{c_w dtw}{i^* - i} \quad (1)$$

where K_v is a dimensionless group, sometimes referred to as the evaporation number, which characterises the air/water system defined by the right hand side of the equation.

"Figure 1 illustrates the air and water relationship and the driving potential which exists in a counterflow tower. An understanding of this enthalpy/temperature diagram is important in visualizing the process that occurs in a cooling tower.

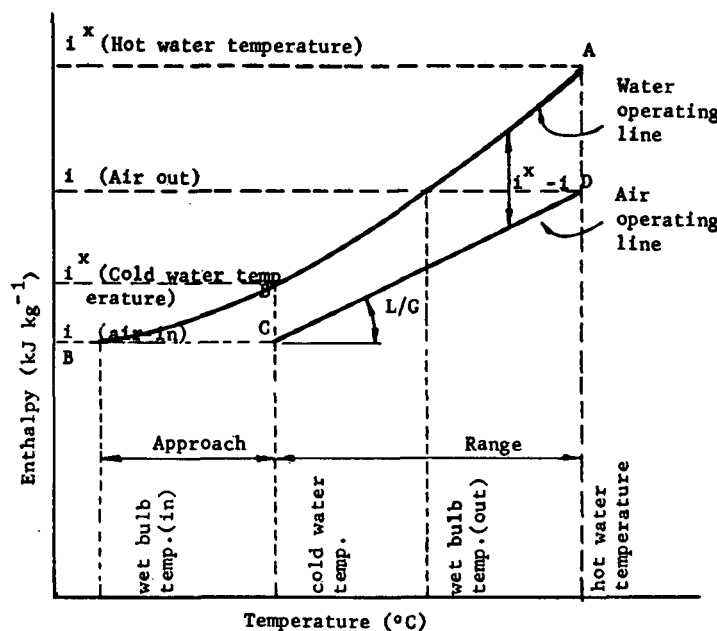


FIGURE 1 Cooling tower process heat balance.

“The operating line is shown by the line BA (also the equilibrium line for saturated air) and its length is fixed by the inlet and outlet water temperatures. The air operating line begins at point C and is based on conditions applicable at the base of the tower i.e. air enthalpy corresponding to the entering wet bulb temperature, and temperature corresponding to, that of the cold water. The initial driving force is therefore $(i^* - i)$. A simple heat balance over the tower gives:

$$Lc_w(tw_1 - tw_2) = G(i_1 - i_2)$$

$$\text{or } \frac{L}{G} = \frac{i_1 - i_2}{tw_1 - tw_2} \quad (2)$$

“This equation shows that the slope of the operating line in Figure 1 can be estimated from the liquid to gas ratio L/G . As this ratio will be known for any given set of operating conditions, it becomes an easy matter to locate point D, representing the conditions at the top of the tower.”

The integral of equation (1) is represented by the area ABCD in Figure 1. This value is known as the tower characteristic (or evaporation number) and, as shown above, is a function of the gas/liquid ratio, λ . The actual relationship takes the form:

$$K_v \approx \lambda^m \quad (3)$$

and to this end Figure 2 has been included to show this effect in the case of one tower design. The exponent “m” has been found to lie between 0,5 and 0,85 and varies in accordance with the type of packing used. It is, for instance, bigger for film packings than for splash trays. Another noteworthy feature from Figure 2 is the dependence of the evaporation number on the cooling range. Experiments have shown that K_v becomes smaller with increasing inlet water temperatures when all other conditions remain constant. Plausible arguments have been put forward to account for this effect².

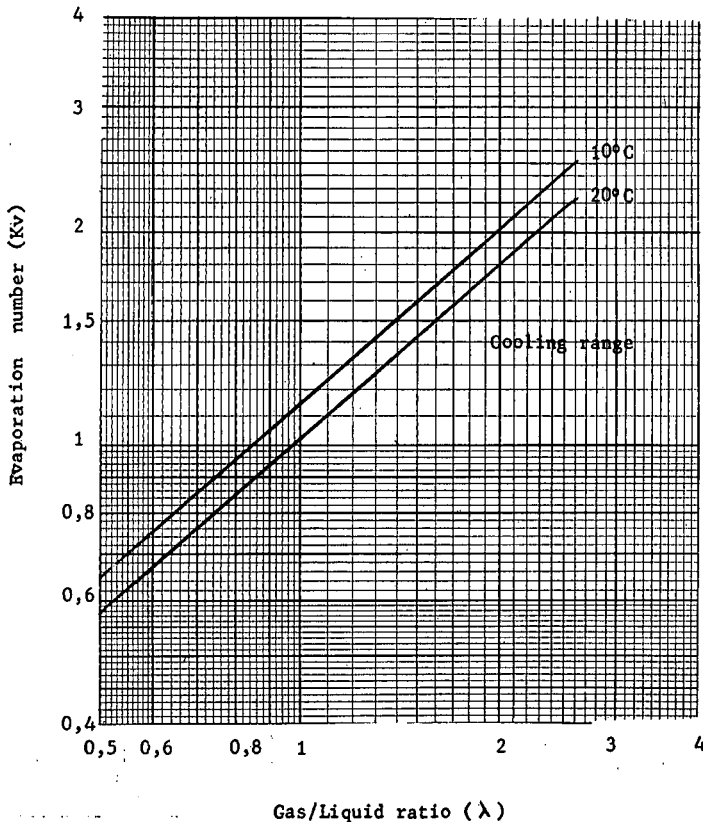


FIGURE 2 Influence of gas/liquid ratio and cooling range on the evaporation number.

The evaporation number can be determined by numerical integration of equation (1) using the Tchebycheff method¹.

Moving on from the theory to the more practical aspects of tower performance evaluation, it is noteworthy that this technique has in fact been used to produce the results that are presented in Table 3A/3B. That this is so is due to the fact that the evaporation number concept is gaining increasing acceptance in specific areas of application and within established limits and also because it is recognised as being particularly suitable for the sorting out of empirical data.

Unfortunately a final decision has yet to be made by the recognised authorities on the acceptability of the evaporation number concept as a suitable measure for performance guarantee purposes. Until such time as this happens, other methods of evaluation will continue to have a role to play.

Empirical approach

It is generally accepted practice to carry out performance evaluations on cooling towers in accordance with the recommendations of DIN 1947, put out by the German Federation of Engineers³. This is a most comprehensive document that lays down rules for the performance of acceptance test runs, the format for test reports, tolerances and guarantees. In respect of these items, only the last two are regarded as relevant to this paper.

(a) Performance guarantee

In terms of his tender document, the supplier guarantees that under mutually agreed atmospheric conditions (pressure, temperature and air humidity) and subject to a predetermined cooling range and water rate, the tower will achieve a specified cold water temperature. The “approach” is implicit in this definition.

What is really being called for is a measure of how the water temperature responds to a specific heat load in the tower under given air conditions. As it is extremely unlikely that the test conditions will correspond to the design point, it is necessary for the supplier to provide a set of curves that covers the full range of possible operating conditions. Within prescribed limits, each point on the guarantee curve is assumed to be adequate for judging the fulfilment of the guarantee.

In order to arrive at a consistent assessment of the tower performance, the cooling range actually obtained during the tests is adopted as the determining factor in estimating the cold water temperature to be achieved in terms of the guarantee. Figure 3 gives an example of a guarantee curve. This particular curve has been used in the acceptance test run presented in detail in Table 2.

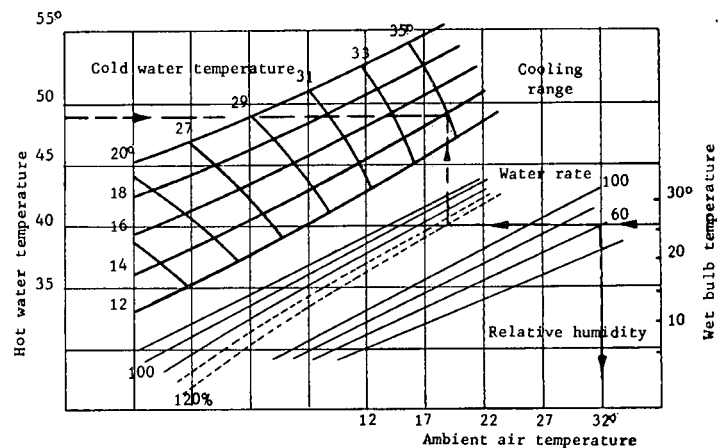


FIGURE 3 Suppliers guarantee curve.

When conducting tests, the operating conditions must lie within the following limits around the design point unless, of course, other arrangements have been agreed contractually.

water rate	$\pm 10\%$
cooling range	$\pm 10\%$
power output of fan drives	
(a) with speed control or variable blades	$\pm 5\%$
(b) for non-variable fans	$\pm 20\%$
operating pressure head at the nozzles	$\pm 2\text{ m ws}$
wind velocity at fan height	
(a) tower height less than 30 m	max. 4 m s^{-1}
(b) tower height between 30–50 m	max. 5 m s^{-1}

In some cases the order for a cooling tower makes provision for penalties for non-fulfilment of the guarantee. Penalties are customarily of the type “ $\alpha\%$ of the contract price per $y^\circ\text{C}$ above the guaranteed cold water temperature up to a maximum of $z\%$ of the contract price.” In addition to this the client always has his normal rights in law in the event that defective goods are purchased.

(b) Tolerances and adjustments

Two categories of tolerance are generally spoken of:

- constructional tolerance
- measuring tolerance

Provided the supplier is made aware of the local conditions applying to the contract, he has no rightful claim based on uncertainties encountered in the design and calculation of the tower. Accordingly, a constructional tolerance is not admissible.

On the other hand, it is claimed that the difference (δ) between the measured value of the cold water temperature and the guarantee value estimated from the suppliers curves is subject to uncertainties which accrue from so-called “measuring errors”. For this reason the DIN rules allow the deduction of a “measuring tolerance” (δ_i) from the mean difference (δ_m) between the measured and guaranteed cold water temperatures. This measuring tolerance is composed of individual tolerances that apply to the measurements of all variables, i.e. flow rates and temperatures and also includes a scatter error tolerance to cater for, amongst other things, the randomness of the deviations of individual data sets about the mean.

The size of the measuring tolerance is dependent on both the quality of the measuring equipment used and the number of corroborative measurements that are made. The figure will normally lie in the range $0,4 - 0,8^\circ\text{C}$.

In addition to tolerances, direct adjustments are made to the guaranteed cold water temperature to account for the following circumstances:

- deviations from the specified fan power input (Nm)
- deviations from the guaranteed water nozzle pressure (h_d)
- wind velocities above limits (negotiable)

Examples of diagrams which are used in the estimation of tolerances/adjustments are to be found in the standard reference³.

Choice of cooling tower internals

Half of the six main sugar factories in the Hulets Group have mechanical draft towers for cooling injection water. All these installations use Asbestos Cement (AC) sheeting to provide basically a film-type cooling effect. Latterly, the internals of one cell in a nine cell installation have been replaced by a splash packing for evaluation purposes.

Biological considerations

The conditions prevailing in a raw sugar factory tower are near ideal for the development of biological growths; namely,

a warm, wet environment, pH in the acceptable range and a plentiful supply of nutrients. These factors contribute to raising the significance of biological considerations from the nuisance level to perhaps the single most important factor affecting the choice of cooling tower internals.

Cooling tower suppliers have a very wide selection of packings on offer, which is reasonable in the light of the range of operating requirements that are encountered. For the sugar industry, however, the selection should be narrowed down to those few packings that provide a very open structure which, in practical terms, offer no scope for blockage. In other words, the operator must exclude from his list the very compact, high performance packings that at first sight appear so attractive. Any decision along these lines will obviously find its end result in higher capital expenditures but this is the price that must be paid for satisfactory operation over the long term. Against this, it must be recognised that extra costs at the initial stages will soon be recouped by way of better performances from both the tower and processing plant and lower operating costs.

In regard to the latter point, it is almost a prerequisite for a well specified tower that chemical usage is limited to small quantities of lime for pH control. The fact that some of the installations seen in the industry are obliged to spend tens of thousands of rands annually on chemicals for biological control is testimony to the fact that equipment has been wrongly specified or supplied.

Corrosion considerations

Commenting in general, it would seem fair to say that AC sheeting is not a suitable material for service in injection water cooling towers in the sugar industry. There are sound reasons for coming to this conclusion:

- circulation water is basically condensate and therefore soft,
- circulating water is subject to intermittent contamination by organic material originating in the process. Since there is very little buffering action provided by the water, acid conditions of some severity (pH 4–5) will be present at such times. Furthermore continuous pH control of injection water is rarely practised and the duration of these periods of low pH could be fairly lengthy depending on the frequency of testing.

In the above circumstances, leaching of the lime content of the AC sheeting is promoted and its mechanical strength inevitably suffers. In this context, the results of tests carried out by the sheeting suppliers on samples of 4 mm flatsheet withdrawn after only half a year's service elicited the following comment:

- assuming unchanged operating conditions, the life expectancy of the sheeting would be approximately 2 years,
- applying the same corrosion rates to 6 mm flatsheet, the life expectancy would rise to around 6 years,
- using 6 mm corrugated sheeting (big 6) instead of flatsheet would add about 2 more years to its estimated lifespan.

These are not promising results. While they probably err on the pessimistic side they are regarded as order of magnitude correct, based on Hulets' experiences to date.

Packings I/II

These layouts involve 3 tiers of AC sheeting, in stacked pairs as shown in Figure 4, giving an effective vertical packing height of 2 400 mm. Each tier is supported at its extremities on beams running at right angles to the sheets. Individual sheets are located by combs (top and sides) and spacer buttons (lower edge).

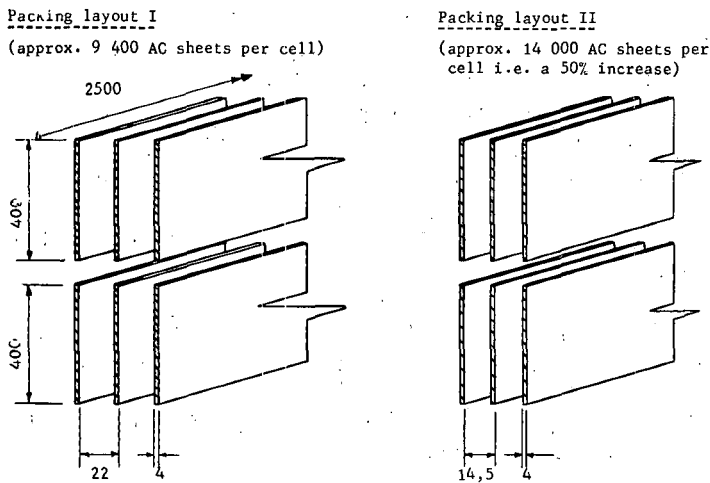


FIGURE 4 Packing layout I/II.

Each of these packings was a season or less in service. Experiences with them were not good; chronic blockage problems being encountered with both arrangements. Possible reasons for this are:

- size of pitch between sheets. The “gap” between adjacent sheets was 18 mm initially and subsequently 10,5 mm; dimensions which were definitely too small.
- the method of stacking sheets vertically in pairs. With this method, the pairs rarely matched up over their full length and hence any material displaced from the upper sheet tended to lodge on the top edge of the lower sheet in the narrow space between the pairs. It is thought that most problems originated from this source.

Turning next to the mechanical considerations, these packings were found to be unsatisfactory in a further two important respects:

- individual sheets were located by means of a system of combs and button spacers. With this technique, any bad workmanship at the installation stage inevitably showed up in the tilting of the sheets. Particularly in these circumstances (but possibly in other circumstances too) the combs tended to work themselves loose.

- individual sheets were supported at their extremities on concrete beams. A knife edge contact over a short length may be adequate in normal circumstances but taken together with adverse factors such as water quality, non-permanent fittings and the extra load on the sheets due to biological growths, this configuration proved unequal to the task.

During both seasons progressive collapse of the packings was in evidence.

Test results appear in Table 3A. Test 1 was carried out within a fortnight of the tower commissioning date. Comparison of the tower evaporation number with the design figure gives a measure of its under-performance. The decision by the suppliers to increase the packing surface area by 50% during the 1975 off-crop was a mistake. This conclusion is best reflected in the results that were achieved (Test 2). The tower was subsequently taken off line for an extended period for a thorough cleaning and this action was followed immediately by the acceptance test run (Test 3). On this occasion, results very near to the design point were achieved. However, the improvement was only short-lived and this packing was itself replaced at the end of the 1976 season.

Packing III

This layout involves 3 tiers of AC sheeting. Supporting arrangements are essentially similar to Packings I/II except that individual sheets are located by spacer strips as demonstrated in Figure 5.

Choice of this packing to replace arrangements I/II was motivated by several factors, *inter alia*:

- need for greater pitch between sheets to avoid blockages.
- desire to compensate for loss of packing surface area, and indirectly performance, by whatever means possible. The use of corrugated sheets best met this need as increased turbulence was created thereby and the area per unit volume was greater than for flatsheets at the same pitch.

Experience with this packing has been satisfactory when viewed from the standpoint of potential to foul up. This finding indicates that a packing pitch of around 50 mm is above the threshold level at which biological growths have the mechanical strength to effectively bridge between sheets.

TABLE 3A
Performance tests on mechanical draft cooling towers
1. Empangeni Installation¹
(Commissioned October 1974)

	Film packing I		Film packing II ²		Film packing IIIA		Film packing IIIB	
	Design point	Test (1)	Test (2)	Test ³ (3)	Design point	Test (4)	Design point	Test (5)
Number of data sets	—	8	8	14	—	18	—	12
Inlet temp. (°C)	50	50,0	49,9	46,2	52	52,3	51	54,9
Outlet temp. (°C)	34	36,0	36,2	30,8	36	37,7	35	40,5
Cooling range (°C)	16	14,0	13,7	15,4	16	14,6	16	14,4
Outlet temp. (°C)	34	36,0	36,2	30,8	36	37,7	35	40,5
Wet bulb temp. (°C)	27	22,6	18,1	18,4	27	18,8	27	23,9
Approach (°C)	7	13,4	18,1	12,4	9	18,9	8	16,6
Tower duty (% design)	100	87,5 ⁴	87,1	100,9	100	103,1	100	96,3
Water loading (th ⁻¹ m ⁻²)	14,2	14,2 ⁴	14,4	14,9	14,2	16,0	14,2	15,2
Gas/liquid ratio	0,70	0,70 ⁴	0,74	0,66	0,70	0,67	0,70	0,63
Evaporation number	1,23	0,68 ⁴	0,54	1,14	0,91	0,52	1,05	0,48

Notes: 1. Consisting of 2 cells each with a 90 kW fan. Tower duty 52 000 kW.
2. Same design point applies as per Packing I.
3. Acceptance test run.
4. Design water flow assumed.

In respect of mechanical considerations the only point that merits special comment is the method used to locate the sheets. This aspect is demonstrated in Figure 5 and involved tailor making spacers as follows. Oversized sheeting (11 mm thick) was manufactured, cut into 100 mm wide strips and laminations made up comprising 4 strips rivetted together. The spacers were then glued to both ends of one side of each sheet prior to being installed. In the installed position, the loaded edges of individual sheets were protected from crimping over by the presence of the solid mass of strips between each sheet. This packing arrangement has proved to be both cheap and easy to install and the finished product gives every indication of being good for many years' service.

The replacement programme for the tower internals was carried out in two phases, with only 2 tiers of packing being installed prior to the start of the season. Test 4 reflects the results. During the second half of the season a third tier was added and a final evaluation carried out (Test 5). The results of these tests are disappointing from a performance point of view, but as discussed earlier, the configuration has satisfactory features. In order to bring the performance of this installation into an acceptable range it is probable that a further cell will be added during next off-crop.

Packing IV

In this arrangement (Figure 6), the distribution manifold is supported on concrete pedestals resting directly on the packing,

which is, in turn, supported on precast concrete beams. Successive sheets are turned through 90° and considerable mechanical strength is imparted thereby.

This layout makes for many narrow passages where displaced material can lodge and with time, cause blockages.

The support method for the distribution manifold is inherently unsound. Settlement of the concrete pedestals into the packing results in occasional failure of the distribution arms.

This installation has been operational for 12 years, the same packing being in service throughout this time. Current results, reported as Test 6, are not good and testify to the poor general condition of the internals. Softening of the AC sheeting, partial blockage of the packing and damaged distribution arms are all contributory factors.

It is planned that the tower internals will be replaced during next off-crop and it is unlikely that the same type of packing will be chosen.

Packing V

The preceding sections have dealt exclusively with film-type packings. The picture that emerges is not favourable and hence Hulett's have taken a hard look at the alternatives. One alternative that is presently receiving attention is the splash packing, this being an obvious choice on account of its very

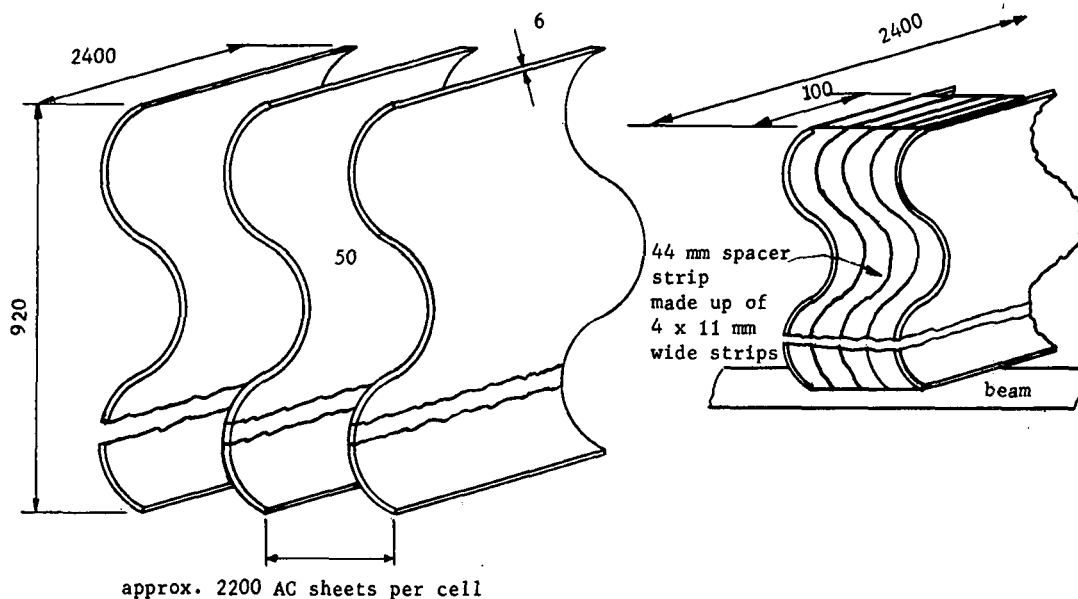


FIGURE 5 Packing layout III.

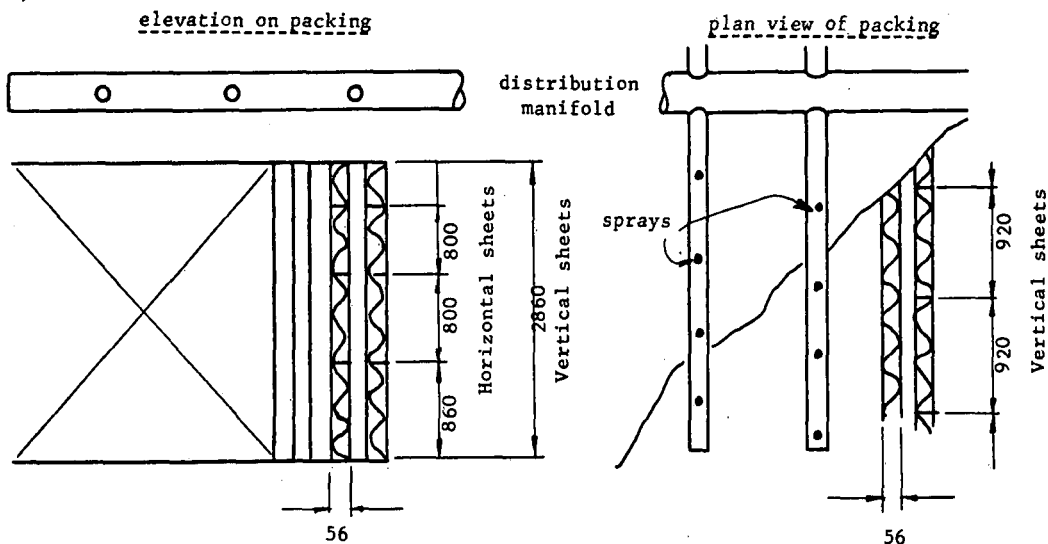


FIGURE 6 Packing layout IV.

TABLE 3B
Performance tests on mechanical draft cooling towers
2. Amatikulu Installation¹
(Commissioned 1965)

	Film packing IV		Splash packing V				
	Design point	Test ² (6)	Design point	Test (7)	Test (8)	Test (9)	Test (10)
Number of data sets	—	2	—	2	3	6	4
Inlet temp (°C)	43,3	51,5	49	51,5	51,7	43,5	54,9
Outlet temp (°C)	29,4	40,9	33	35,5	35,5	32,1	37,1
Cooling range (°C)	13,9	10,6	16	16,0	16,2	11,4	17,8
Outlet temp (°C)	29,4	40,9	33	35,5	35,5	32,1	37,1
Wet bulb temp (°C)	23,9	26,1	26	26,1	21,7	24,8	27,0
Approach (°C)	5,5	14,8	7	9,4	13,8	7,3	10,1
Tower duty (% design ³)	100	92	100	75	64	48	72
Water loading (th ⁻¹ m ⁻²)	8,0	12,0	8,7	6,5	5,5	5,8	5,7
Gas/liquid ratio	1,03	—	1,06	1,02	1,20	1,14	1,18
Evaporation number	1,53	—	1,17	0,82	0,65	0,92	0,73

Notes: 1. Consisting of 9 cells each with 30 or 36 kW motors. Tower duty 92 000 kW.
 2. Data consistent with test (7).
 3. Prorata figures.

open structure which permits both visual inspection and cleaning of the trays whenever necessary.

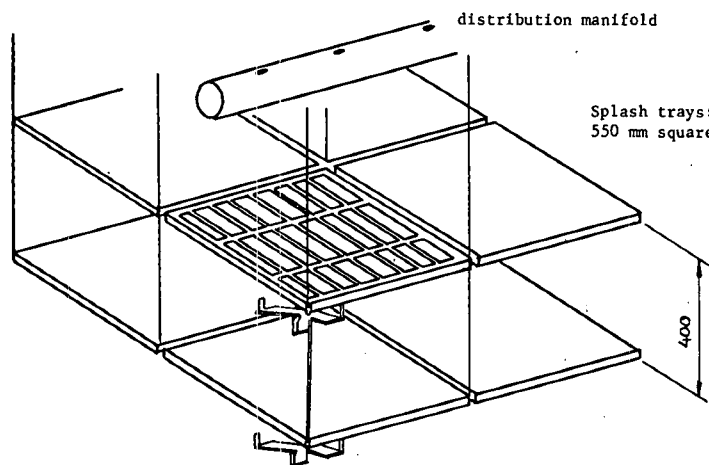


FIGURE 7 Packing layout V.

Figure 7 demonstrates the type of packing that is presently being tested at Hulett's Amatikulu factory. Further work remains to be done in this regard but first impressions are that the installation is neat and robust and that there is no tendency towards fouling of the trays. Equally important is the fact that the materials of construction are plastic (trays) and stainless steel (support wires). The criterion of durability of the packing is therefore likely to be met. On paper, an installation built around the splash principle will be more expensive than one using a high performance (film) packing. However, this discounts the effects of life expectancy and maintained performance on the results of the evaluation, and if these were to be included, it is fairly certain that the splash packing would show real advantages overall.

Due to height limitations imposed by an existing tower, it was possible to install only 11 tiers of splash trays instead of the 15 tiers that would have been optimum for this service.

A short series of runs were carried out towards the end of the season and are reported as Tests 7 – 10. These results are fairly consistent, with the exception of Test 8 which involved low wet bulb conditions. There is no ready explanation for this particular result. Based on the figures given in Table 3B

it is estimated that an increase in the number of tiers to 15 (which is possible if the distribution manifold is raised) would yield an "approach" of 8 – 9°C at the design heat load.

Taking all factors into consideration, the splash tray appears as a viable packing arrangement for use in injection water cooling towers in the sugar industry.

Acknowledgement

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REFERENCES

1. Perry, Robert H. and Chilton, Cecil H. (1973). Chemical Engineers' Handbook, McGraw Hill Inc, New York.
2. Spangemacher, K. (1970). Calculations of cooling towers with the aid of an evaporation number. Translation from Brennstoff-Wärme-Kraft bd 10 (1957) Nr 5 s 209–215.
3. V D I—Rules on cooling towers (1959). Performance Tests on Cooling Towers.

Nomenclature

- a = contact area of packing (m²m⁻³ active tower volume)
- c_w = specific heat of cooling water (kJ kg⁻¹ C⁻¹)
- G = gas rate (kg s⁻¹)
- G_w = specific water rate (kg s⁻¹ m⁻² tower X sectional area)
- i* = enthalpy of saturated air at water temperature (kJ kg⁻¹)
- i = enthalpy of air stream (kJ kg⁻¹)
- K = mass transfer coefficient (kg water s⁻¹ m⁻² surface area of packing)
- K_v = evaporation number (dimensionless)
- L = water rate (kg s⁻¹)
- Q = equipment heat load (kW)
- s = enthalpy of steam (kJ kg⁻¹)
- tw = water temperature (°C)
- v = vapour rate (kg s⁻¹)
- V = active cooling volume (m³m⁻² tower X sectional area)
- λ = gas/liquid ratio (–)

Subscripts

- 1 at inlet conditions
- 2 at outlet conditions