

Direct amine heating - a case study

Indirect heating of amine has been the traditional method in order to minimise the risk of overheating. Two amine waste heat reboilers, which heat amine directly, have been supplied to Tunisia by Foster Wheeler. They incorporate a number of features to ensure uniform heating, based on a flow model study

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In 1994, Foster Wheeler supplied two amine waste heat reboilers (AWHR) to the Hannibal Gas Treating Plant in Tunisia. The plant is owned by British Gas and is located 20km south of Sfax. Gas is piped to the plant from the off-shore installation in the Miskar gas field, situated 125km offshore in the Gulf of Gabès.

The feed gas contains a substantial amount of carbon dioxide and trace amounts of hydrogen sulphide which have to be removed in order to meet the sales specification of the gas. The CO₂ and H₂S removal process is based on the use of a recirculating amine wash: pre-heated and filtered sour gas is passed through an absorber vessel where it is washed with the amine solution. This reduces the concentration of CO₂ and H₂S to acceptable levels.

The rest of the plant is concerned with the regeneration of the CO₂/H₂S-rich amine solution by a combination of pressure reduction and heating. This is where the AWHRs come in.

The heating of amine is a sensitive process since the medium is susceptible to coking and degradation if exposed to excessive temperatures. Indirect heating processes have conventionally been employed to minimise the risk of overheating.

A unique feature of the AWHRs is that they heat the amine directly: the site has two 20MW gas turbines which generate power for the plant, and British Gas decided to utilise the turbine exhaust gases to provide heat to the amine solution. Careful consideration had to be given to the design of the AWHRs to ensure that overheating of the amine would not occur.

The AWHRs are all convective heaters. Turbine exhaust gases are ducted through to the tubed waste heat recovery section and out of the integral stack. The coil through which the amine solution flows is of horizontal tube design and consists of small-bore tubes arranged in multiple parallel streams.

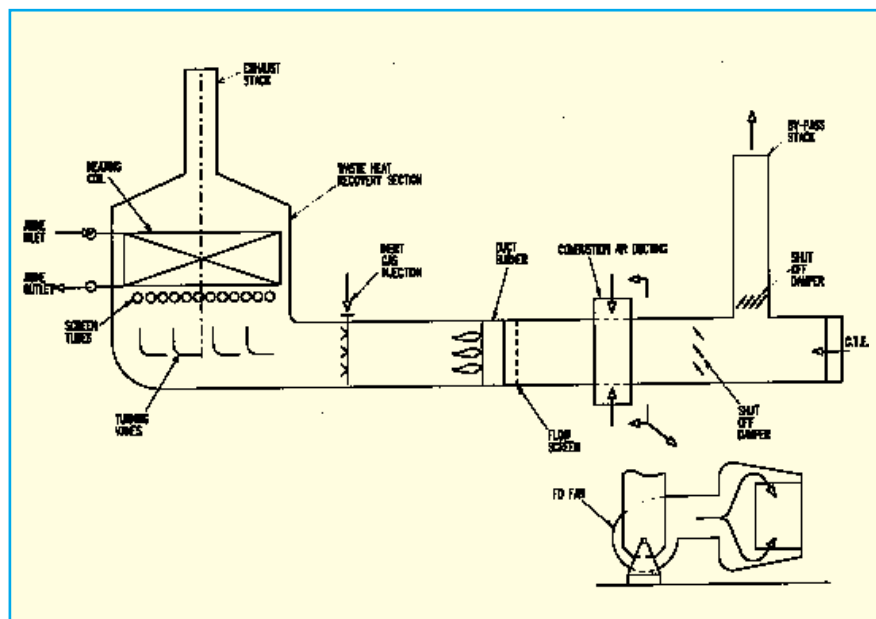


Figure 1 Basic layout of amine waste heat boilers

Tube metallurgy is TP316L stainless steel. A bypass stack is located just downstream of the turbine exhaust and dampers allow GTE flow through to the waste heat recovery section or divert it to bypass. Figure 1 shows the basic arrangement.

At design conditions, 114.2kg/s of amine solution enters the AWHR at 123°C and is heated to 136°C. The design duty of each AWHR is 28.7MW. The heat supplied by the gas turbine is insufficient for the duty required, so a burner with several evenly spaced horizontal runners is located in the ducting as a supplement to fire the GTE.

During shutdown of the gas turbine, ambient air is supplied to the duct burner by a local forced draught fan and the unit operates on auxiliary firing alone. Additionally, two inert gas streams are disposed of by injecting them into and mixing them with the flue gases downstream of the burner. Uniform heating of the amine had to be ensured under all these conditions.

In order to avoid coking and degradation problems with the amine, the film temperature has to be restricted. This means keeping the heat flux densities low. A maximum allowable film temperature of 166°C was specified and flux rates had to be kept below 25kW/m² in order to achieve this. It could not be assumed that totally uniform conditions would exist in the AWHR since there were a number of potential sources for creating localised hot spots:

1. Maldistribution of the turbine exhaust gases.
2. Maldistribution of air from the forced draught fan.
3. Maldistribution of the flue gases from the duct burner.
4. Poor mixing of the inert gases with the flue gases from the duct burner.
5. High levels of radiation to the first tube rows.
6. Flame impingement.
7. Overfinning.

If not properly considered and addressed, any of the above may have

given rise to excessive flux rates and high film temperatures.

Points 5, 6 and 7 were addressed in the design of the tube bank and ducting arrangement. A dummy row of tubes is located just upstream of the tube bank to act as a radiation shield. Amine does not flow through these tubes.

The possibility of flame impingement on the tubes was avoided by ensuring an adequate discharge length of ducting after the burner, and turning the duct through 90 degrees so that the tubes are not directly in line with the burner flame.

After the dummy row of screen tubes, the waste heat recovery section has three bare tube rows followed by finned rows of increasing density. The first finned section has only 39 fins per metre (one fin per inch), 9.5mm high, which is very low. Finning on fired heater tubes is generally a minimum of 79 fins per metre (two fins per inch) and 12.7mm high, but this would have resulted in unacceptably high fluxes in this case.

Further up the tube bank, the finning increases to a maximum of 157 fins per metre (four fins per inch), 12.7mm high.

Maldistribution of air flow from the FD fan was partially addressed by designing the ducting from the fan to the main ducting to give top and bottom entry of

Velocity distribution at gas turbine discharge					
Duct test locations	1	2	3	4	Row average
1	82	39	140	191	113
2	67	37	136	203	111
3	99	56	66	194	104
4	37	25	92	200	88
5	-22	-47	101	199	58
6	74	74	168	192	127
Column average	56	31	117	197	

NB. Data is expressed as a percentage of the mean velocity, looking in the direction of flow.

Table 1

the air into the main ducting across the whole width of the duct. This gives better distribution than introducing the air through the side of the duct, where it is likely to be heavily biased to one side of the ducting.

The remaining concerns about poor mixing and maldistribution were addressed by carrying out a flow model study. The objective of the study was to determine the arrangement of ducting and flow distribution devices required to ensure the following for operation of the AWHR in waste heat mode (supplementary fired turbine exhaust gases) and

fired heater mode (auxiliary fired ambient air):

—Uniform distribution of air/turbine exhaust gases into the duct burner. A target criterion of 15 per cent root mean square (RMS) deviation from the mean velocity was specified

—Adequate mixing of the inert gas streams with the flue gases from the duct burner before entry to the waste heat recovery section. A target temperature variation criterion of $\pm 28^{\circ}\text{C}$ was specified at entry to the tube bank and $\pm 11^{\circ}\text{C}$ after the three rows of bare tubes

—Uniform distribution of the flue gases

in the waste heat recovery section. A target criterion of ± 30 per cent variation in flow was specified at entry to the tube bank and ± 15 per cent after the three rows of bare tubes. A one-sixth scale three-dimensional model, geometrical-ly similar to the proposed full size AWHR, was constructed from Perspex. The model extended from the turbine exhaust through to the stack on top of the waste heat recovery section. All interconnecting ducting was modelled along with the air ducting from the FD fan and the bypass stack.

The dummy row of tubes upstream of the waste heat recovery section and the three bare rows of tubes were modelled using wood dowels. The pressure loss over the rest of the tube bank was simulated by sheets of perforated plate.

The louvre dampers, burner runners, inert gas spargers and internal structural members were all modelled in detail so that their interference with the gas flow could be simulated. The exhaust of the gas turbine was also replicated so that the gas flow distribution into the ducting could also be accurately imitated.

Kinematic similarity between the model and the full sized AWHR can be assumed providing that the Reynolds number is above 20000 in both cases. This is the minimum for fully turbulent flow. For the thermal mixing tests, the density and momentum ratios of the inert gases and flue gases were maintained.

The flow was evaluated at various test locations: velocities, pressures and temperature measurements were taken at discrete points located at the centres

Comparison of initial and final flow and temperature distributions				
Test location	RMS deviation % of mean velocity		Temperature variations	
	Initial	Final	Initial	Final
Before burner	55.1	13.8	N/A	N/A
WHRS entry	48.5	19.9	+50/-39	+18/-13
After three bare rows	16.3	12.5	N/A	+14/-10

Table 2

of equal areas of the test section. In this way a grid of readings was obtained across the whole duct cross section at each test location. The data was normalised, ie converted to a percentage of the mean velocity, and the RMS deviation from the mean was calculated and used as a measure of uniformity. Flow direction was assessed by means of a cotton tuft attached to the tip of the velocity probe.

The flow from the gas turbine was very poorly distributed across the duct and heavily biased to one side. In some areas the flow was reversed, as demonstrated by Table 1. With the initial AWHR configuration, this resulted in correspondingly poor flow distribution into the duct burner (55 per cent RMS deviation from the mean), the waste heat recovery section (48.5 per cent RMS) and after the three bare tube rows (16.3 per cent RMS).

There is an inherent improvement in the flow through the tube bank because of the straightening effect of the tubes themselves.

Similar maldistribution problems were also observed with the air flow

from the forced draught fan. RMS deviations of 37.7, 56.2 and 43.5 per cent were measured at the duct burner entry, waste heat recovery section entry and after three bare rows respectively.

Thermal mixing tests simulating the injection of the inert gas streams into the flue gas flow also indicated temperature variations well outside the specified target criteria with the initial sparger arrangement. The model was retested with several different designs of flow screens installed just upstream of the burner in an attempt to improve the flow into it. The final design consisted of a variable area perforated plate complete with vertical straightening vanes. The open area of the plate was reduced in regions of high flow to force the gases into areas starved of flow and hence correct the maldistribution.

The improvement in flow distribution is shown in Table 2.

To improve the flow into the waste heat recovery section, tests were carried out with various turning vane arrangements installed in the 90 degree bend section of the ducting. From these tests, an arrangement consisting of eight

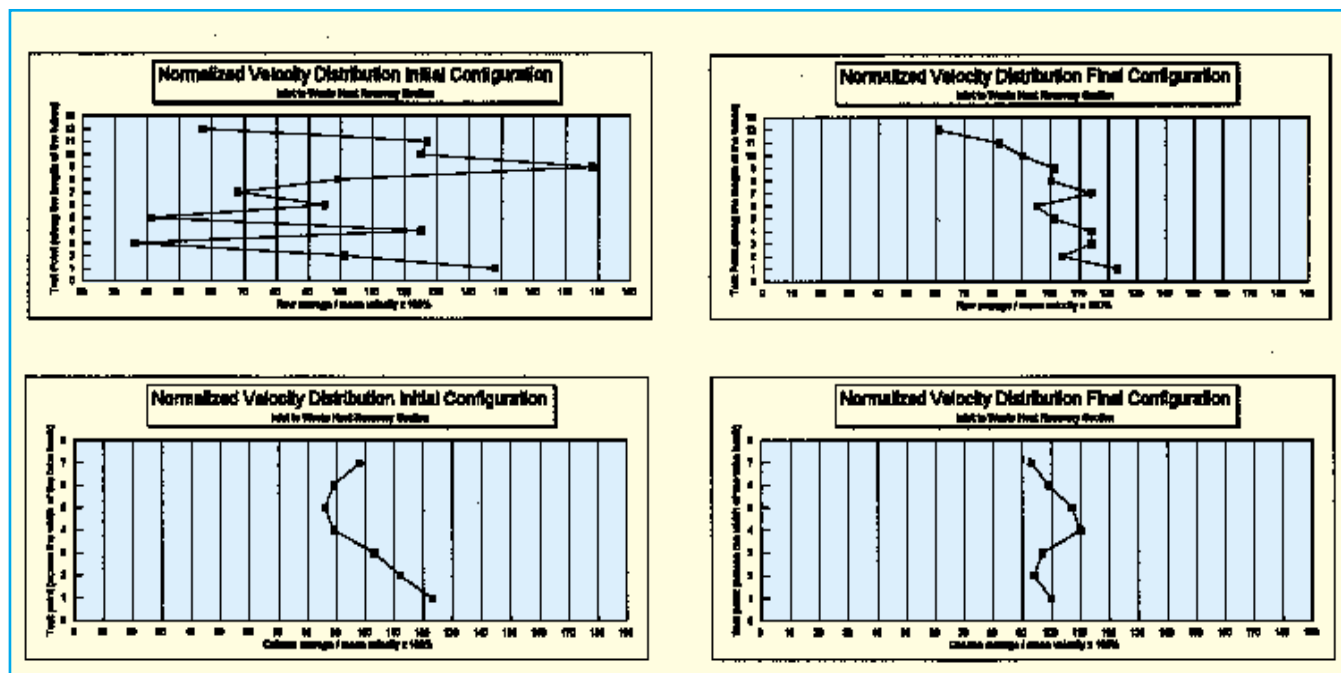


Figure 2 Normalised initial and final velocity distributions at WHRS inlet

curved vanes and two straight ones was found to give uniform flow into the tubebank, without gas injection through the spargers.

The tests with the turning vanes also indicated that the addition of the inert gases through the spargers disturbed the pattern of flow into the waste heat recovery section. Further tests were carried out with different hole configurations in the sparger legs. It was found that increasing the number of holes in each sparger to reduce the exit velocity of the inert gas gave improved mixing and better temperature distribution.

Quantitative assessment of the mixing was carried out by heating the simulated inert gases to approximately 40°C above the temperature of the flue gases, which were at ambient in the model. The temperature distributions were measured using a matrix of thermocouples across the duct test section.

In addition to quantitative testing, mixing was also visually assessed using sulphur dioxide and ammonia. A white smoke is formed when contact between these two gases occurs. SO₂ was introduced into the sparger flow and NH₃ into the simulated flue gas flow so that a visual appraisal of the mixing could be made.

With the finalised flow devices installed and the revised gas sparger configuration, the model was retested for varying degrees of clockwise and counter-clockwise turbine exit swirl angles to investigate the effects on the flow pattern.

The improvements gained by the addition of the flow screen and turning vanes, and the revised sparger configuration are shown in Table 2. RMS velocity deviations from the mean were drastically improved from 55.1 to 13.8 per cent at the burner entry and from 48.5 to 19.9 per cent at the waste heat recovery section entry. Improvements were also made in the flow distribution after the three bare tube rows but this was less pronounced because distribution was initially quite good, anyway.

The normalised velocity distributions at entry to the waste heat recovery section, before and after the addition of the flow devices, are shown in Figure 2. It can be seen that the improvement is more pronounced along the length of the tubes where peak variations have been reduced from 178/36 per cent of the mean to 123/61 per cent.

The basic flow devices resulting from the model testing were translated into practical designs for fabrication while maintaining the essential flow improving properties. The completed AWHRs were shipped to Tunisia from Pembroke Dock, UK, in 1994, and the gas plant was commissioned the following year. The units have since operated satisfactorily with no amine degradation problems attributed to the AWHRs while operating within the design parameters originally specified.

Conclusion

Foster Wheeler's Fired Heater Division is currently applying the experience gained with these waste heat recovery units to a contract for two such units, with heat transfer oil as the process medium. Similar concerns over high film temperatures and localised hot spots also apply to the thermal oil, and ways of improving flue gas flow distribution have been investigated in a similar study.

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