THE SUCCESSFUL DE-BOTTLENECKING OF AN AMINE CONTACTOR USING THE LATEST ANALYTICAL TECHNIQUES

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ABSTRACT

The Miskar Gas Field lies within the Miskar production concession located 100 km Offshore Tunisia in the Gulf of Gabes. Hydrocarbons from the field are brought onshore and processed to meet Tunisian Gas Grid specifications at the Hannibal Gas Plant located near Sfax. The field has been operated 100% by BG Tunisia since 1995. It provides the largest supply of indigenous gas in Tunisia.

In order to extend the Miskar field production plateau, BG Tunisia intends to drill a number of infill wells into the reservoir. The new wells will alter the gas composition envelope that will enter the Hannibal plant. This will result in an increased duty on the gas plant's processing equipment, primarily in the areas of acid gas removal and disposal.

WorleyParsons were commissioned by BG Tunisia to identify the work-scope required to upgrade the existing Hannibal sour gas facilities to permit processing of the increased quantity of H2S/CO2. The overall project is known as the Hannibal Sour Gas Project (HSGP). As part of the scope evaluation the project team has used the latest analytical techniques including radioactive scanning and Computational Fluid Dynamics (CFD) to quantify existing column performance.

Part of the HSGP addressed the throughput of the existing amine contactors. At Hannibal there are two identical parallel contactors each designed to process 148 kNm^3/h mmscfd of sour gas. The main duty of the acid gas removal unit is to reduce the CO2 level to below 100 ppmv to prevent CO2 freezing in the downstream cryogenic nitrogen removal unit

The contactors contain IMTP® #50 Random packing; a proprietary product of Koch-Glitsch. The packing capacity was checked and confirmed with the vendor. The required increase in flow for the revamp is 16%. Koch-Glitsch rated the packing capability to be well in excess of this.

During site tests in May 2005 the contactors flooded at only 10% increase in flows, well below the theoretical packing capacity. It was also noticed in the site tests that there was high gas entrainment resulting in a high flash gas rate in the downstream flash drum.

The results from the site tests were analysed to find the cause of the flooding. The initial analysis narrowed down the probable causes of flooding to the distributors and the gas inlet nozzle. These causes were investigated further using radioactive scanning in further site tests and also by using CFD.

The radioactive scanning by Tracerco found that the flooding started at the redistributor. Severe foaming was also found below the gas inlet nozzle.

The CFD analysis by Koch-Glitsch found that with the original inlet gas arrangement, with a flush gas nozzle, produced large rotational gas movements between the bottom of the packing and the liquid level. This is a probable cause of flooding and gas carry under to the flash drum. The CFD analysis was continued with the modelling of a gas inlet device. A great improvement in performance was noted

As a result of the analysis the following changes were made to the contactors:

- Replace distributor/redistributor trays
- Install gas inlet device

The installation of the gas inlet device meant that the packing had to be shortened by 0.4m. This loss of packed height was expected to be more than compensated for by the improved gas distribution.

These changes were implemented during shutdown in May 2006 and the subsequent site tests showed a significant improvement in contactor performance both in terms of capacity and hydrocarbon entrainment.

Contents

Appendices

1.0 Introduction

The Hannibal gas plant in Tunisia is operated by BG Tunisia. The plant processes gas from the offshore Miscar field and provides over 50% of Tunisia's natural gas. New sour wells are to be brought on line in the in the near future. The resultant increase in gas flow and sour gas content will impose additional duty on the acid gas removal unit.

WorleyParsons performed a study on the whole of the acid gas removal facilities however this paper will concentrate on the amine contactors.

There are 2 identical contactors in parallel. The contactors are 2.59m in diameter and contain IMTP® #50 Random Packing in 2 beds of 6.1m each.

The rated performance of the Amine Contactors is defined in Table 1.1 at the original and revamp conditions and for the vendor's maximum rating. When calculating jet flood for systems with foaming tendencies, foam factors are used to de-rate the capacity.

There is some question as to what foam factor should be applied to random packing. For trays in a heavy foaming system such as an amine contactor it is usual to use a factor in the range 0.75 to 0.80. The packing capacity calculation was checked and confirmed with the vendor. The Koch-Glitsch maximum efficient capacity correlation for random packing recommends a foam factor of 0.95 for the pressure drop and hydraulic capacity correlations in this well-known foaming application.

Table 1.1 compares the use of foam factors of 0.81 (conservative value) and 0.95 (as advised by Koch-Glitsch)

Table 1.1 Amine Contactor Performance

	Sour Gas Flow to Amine Contactor kNm^3/h	Rich Amine Flow from Amine Contactor m^3/h	% Flood (foam factor 0.81)	% Flood (foam factor 0.95)
Original Design	148	453	75	64
Revamp Design	172	524	82	70
Koch-Glitsch Maximum Rating	189	754	n/a	79

The required increase in flow for the revamp is about 16% for both sour gas and amine. Koch-Glitsch rated the packing well in excess of this, over 25% for the gas flow and over 50% for amine flow. For the revamp case the predicted flood (using a foam factor of 0.95) is just 70% so it is predicted to be adequate capacity for the revamp.

2.0 Site Tests - May 2005

The site tests on the contactors in May 2004 were to test the maximum capacity of each contactor. The tests were performed using the parallel contactors to minimise loss of production from the plant. The sour gas and amine feeds to the contactor that were being tested were increased at the same time as the feeds to the parallel contactor were reduced.

The contactors were found to have a much lower capacity than expected. This is shown in Table 2.1

Table 2.1 Amine contactor revamp requirement

	Sour Gas Flow to Contactor kNm^3/h	Amine Flow from Contactor m^3/h
Original design	148	453
Revamp design	172	524
Koch-Glitsch max rating	189	754
Contactor A test (flood)	162	492
Contactor B test (flood)	164	498

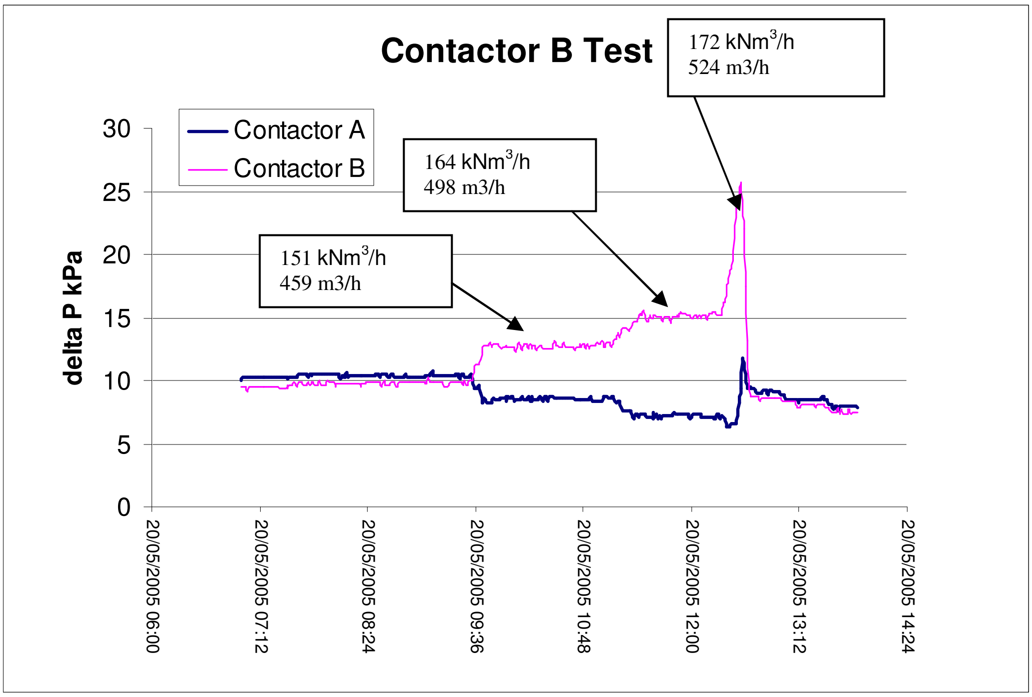
The contactors were expected to meet the revamp conditions comfortably; the Koch-Glitsch packing rating was much higher than the revamp requirement. However while performing the tests the contactors flooded at only about 10% higher flows than the original design.

The table and diagram below show in detail tests performed on the B contactor.

Table 2.1 Amine Contactor Site B Test Performance

20.05.05 B Contactor test	Comment	Sour Gas Flow to A Contactor kNm^3/h	Sour Gas Flow to B Contactor kNm^3/h	Amine Flow to A Contactor m^3/h	Amine Flow to B Contactor m^3/h
Start of Test		140	144	438	438
Test 1		134	151	420	459
Test 2		121	164	390	498
Test 3	B Flood	113	172	372	524

Diagram 2.1 Amine Contactor B Train Site Test pressure variation



The Sour Gas and Lean Amine flows were increased in 3 steps with the differential pressure across the column measured. At each increase in flow there was an increase in differential pressure across the column. The differential pressure was stable until the flows were increased to 172 kNm^3/h and 524 m^3/h respectively, at which point the pressure increase rose continually and did not fall until the flows to the column were reduced. The column therefore floods between the points of tests 2 and 3. It was found from further tests that the flood point was very close to test 2 (164 kNm^3/h, 498 m^3/h).

Another area of concern from the test runs was the high flash gas rates from the rich amine flash drums. The normal flash gas rate was twice the original design gas rates and as the feed gas and amine rates were increased by about 10% the flash rate further doubled.

3.0 Test Run Analysis

There were two main areas of concern in the operation of the contactor

- Premature flooding
- High level of flash gas in the downstream flash drum

The results for these observations are analysed in this section

3.1 Contactor flooding

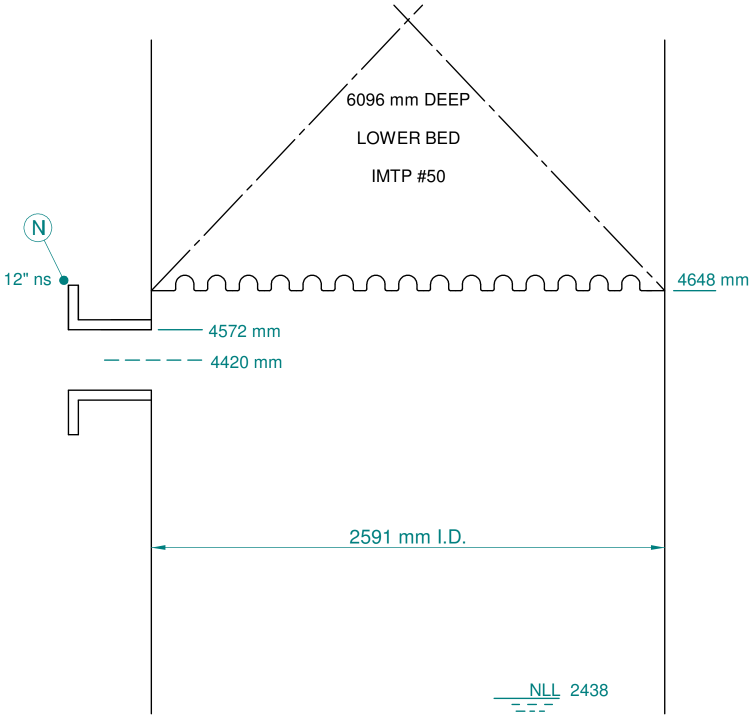
Five potential causes of the early flooding were identified

3.1.1 Gas Inlet Nozzle

There are 2 distinct problems with the gas inlet nozzle, its location and size

The gas inlet nozzle is located directly underneath the bottom packing support plate, with only around 100 mm from the top of the nozzle to the bottom of the support plate as shown in Sketch 3.1.1

Sketch 3.1.1 Gas inlet nozzle



This is not good design practice as the momentum effect of gas inlet so close to the bottom of the packing is likely to result in uneven gas distribution through the packing.

Table 3.1.1 Inlet Gas Nozzle Sizing

	Mass flow	Density	Volume flow	Inlet velocity and momentum	
Case:	kg/hr	kg/m^3	m^3/sec	m/sec	pv2
Original design	154,236	60.7	0.706	10.8	7,042
Test Run (note 1)	169,200	65.1	0.722	11.0	7,893
Revamp	181,879	71.4	0.707	10.8	8,318

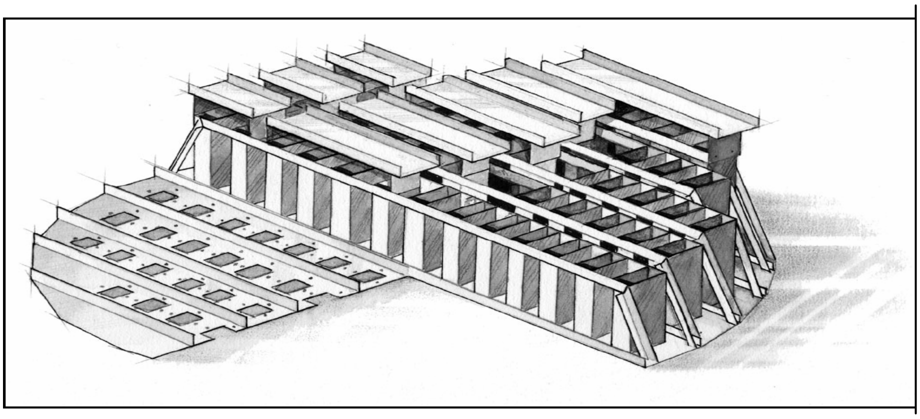
The inlet nozzle should have had a distribution device. The nozzle would be undersized even with a distribution device (vapour distribution tray or gas inlet device) but as a flush nozzle (with no distribution device) 12" is grossly undersized

The combination of the high inlet momentum and proximity to the bottom bed will cause mal-distribution and channelling at the bottom of the bottom bed. This in turn can lead to localised flooding. The packing vender flooding calculations assume perfect distribution but poor distribution will de-rate the column. The bottom of the bottom bed is the most critical in terms of loading (see section 3.1.4) so it is distinctly possible that this may be a cause of the flooding.

3.1.2 Redistributor

Physical design comprises 60 gas risers from base plate with hats and 349 liquid drain holes of 17.98 mm diameter in the base plate. (See Sketch 3.1.2)

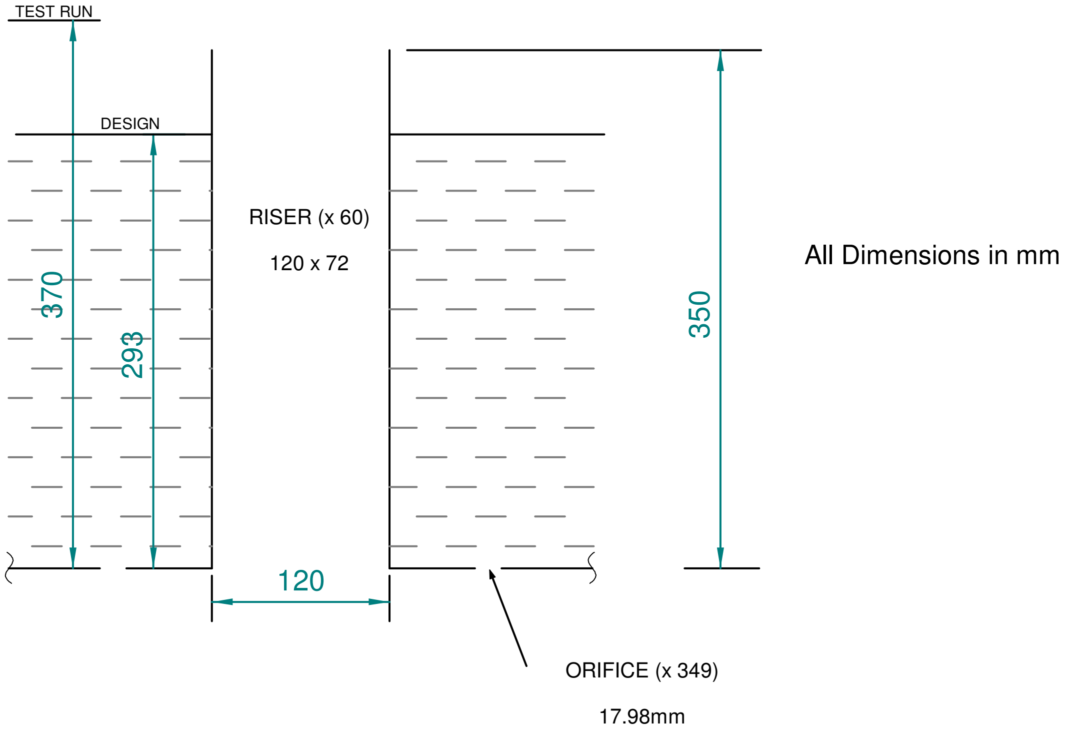
Sketch 3.1.2 Sketch 3.1.2 INTALOX® Model 117 Redistributor



The original design made no allowance over the normal flow for the design flow. (448 m^3/h) (i.e. design flow = normal flow)

The initial design, at normal flow had a riser clearance above the liquid level of only 57 mm out of the 350 mm riser height under perfect conditions (i.e. no fouling or out of level effects). This is shown in the following diagram

Sketch 3.1.3 Koch-Glitsch re-distributor tray operation



Such a small riser clearance leaves very little margin for any increase in flow and, as experienced during the site test when the height of the liquid column on this tray was found to be 370mm (see Table 3.1.2 below), gives the potential for liquid levels to be above the top of the riser, causing liquid to attempt to flow down the riser counter current to the gas flow and leading to flooding.

Table 3.1.2 Redistributor

	Flow (m^3/h)	Riser height (max 350 mm)
Redistributor design	447	293
Normal operation	459	315
Max theoretical flow	477	350
Max flow tests	499	Overflow (370)
Revamp requirement	524	Overflow

There is a good correlation between predicted and test run data. The maximum predicted flow before liquid overflow down the riser is 477 m^3/h which shows that the redistributor design is likely to be a contributor to the observed flooding at increased flow.

3.1.3 Distributor

Physical design comprises 60 gas risers from base plate (no hats) and 349 liquid drain holes of diameter 17.48 mm in the base plate. The drain holes are of slightly smaller diameter to account for a lower liquid flow rate at the top of the column.

The INTALOX® Model 116 Distributor is of similar design to the type 117 redistributor (Sketch 3.1.2) but excluding riser hats.

Similarly to the redistributor design, the original design made no allowance over the normal flow for the design flow.

3.1.4 Packing

This comprises 2 off 6.1m beds of IMTP® #50 Random Packing on bed support/ gas injector plates

Even using a conservative foam factor of 0.81 shows flooding at only 81% – indicating extra capacity. Koch-Glitsch use a less conservative foam factor of 0.95 so predict even more additional capacity.

Table 3.1.4 Capacity profile of packing

	% Floods:		
	Bottom of Bottom bed	Bottom of Top bed	Top of Top Bed
Koch-Glitsch Foam Factor = 0.95	69	62	61
Foam Factor = 0.81	81	73	71

The conditions for Contactor a during the evaluation were

- Sour gas feed = 164 kNm^3/h
- Lean amine rate = 499 m^3/hr
- Sour gas feed: 65.7 bara, 44℃, CO_2 12.74%, H_2S 667 ppm
- Treated gas: 65.6 bara, 49℃, CO_2 224 ppm, H_2S 0 ppm

The acid gas absorption profile was assumed as 90% in the bottom bed and 10% in the top bed.

The table shows that flooding is more likely at the bottom of the bottom packed bed.

The top bed has about 10% extra capacity. If flooding therefore occurs in the top section of packing first, it will be due to another cause other than simply packing capacity.

Koch-Glitsch confirmed that use of a structured packing would help alleviate flooding by around 10%, although it is not normally used for such high liquid loading applications.

3.1.5 Bed Support

Koch-Glitsch rated the supports and found that there was more than adequate area and therefore the bed supports should not be limiting (if clean and unobstructed).

3.2 Gas Entrainment/Absorption

The liquid rate is high relative to the column diameter. The hold up time at the bottom of the column is low. The surge volume from the NLL (2.43m) is 15 m^3 (including head). This gives the following surge hold up times.

Table 3.2.1 Capacity hold-up

Flow (m^3/h)	Hold up (min)	Velocity (m/min)
450	2.00	1.43
500	1.80	1.58
524	1.72	1.67

The liquid velocity down the column is quite high, about 1.5 m/minute. This will prevent smaller gas bubbles from disengaging from the liquid, as the velocity increases then larger bubbles will be carried under.

An earlier revamp recognised there was a problem and put IMTP® #50 Random Packing in the bottom head with the object to coalesce the smaller bubbles. It has been questioned about how effective this is but as the packing has 97% voidage it does not significantly reduce the hold up so it was decided to keep it.

Another factor is the size of the gas inlet nozzle and the high momentum of the inlet gas. The NLL is 1.8m below the inlet nozzle. If the liquid level increases significantly above the NLL there will be a high probability of foaming as the liquid is subjected to a jet of inlet gas.

3.3 Conclusions

As a result of the initial site tests it was decided to further analyse the problem. Further site tests would be carried out with radioactive scanning. In parallel to this a CFD analysis was undertaken to study the gas inlet nozzle

4.0 Radioactive Scanning – August 2005

Tracerco were contracted to study the contactors in operation by use of radioactive scanning. Radioactive scanning is a way to be able to “see” inside the column while the column is operating.

A radioactive source is held one side on the column and a detector on the opposite side. The amount of radiation that passes through the column is dependent on the density of material between the source and the detector. Therefore, in areas of low density, such as vapour spaces, most of the radiation passes through and there is a high signal. In areas of high density, such as liquid on the distributors, very little of the radiation passes through and there is a low signal. Because the contactors operate at high pressure, over 70 barg, the vessel walls are relatively thick, over 100 mm, which is near to the limit for obtaining meaningful results as the sensitivity is reduced in the signal output.

The tests were carried out in three stages:

- A scan down the columns during steady operation
- Separate ‘pinpoint scans’ at selected locations at flooding conditions
- Chord scans below vapour inlet

4 Steady State Scanning

The scan is shown in Appendix 1

Contactors A and B are shown on the same plot, Contactor A in black (dark) and Contactor B in green (light). The Contactors behave similarly.

The scans show high liquid level on distributors. The vapour phase above and below the distributor is shown clearly with the liquid up to the top of the distributors.

The main surprise was the high density readings immediately below the gas feed. The cause of this may be high liquid level or foam. This was investigated further with the chord scans.

4.1 Scanning during transient conditions leading to flood

Initial tests were carried out to flood the contactor A by just increasing the liquid flow and keeping the gas flow constant. No flooding occurred; this was probably due to the liquid over-flowing the distributors and running down the chimneys.

Further tests were carried out as before with the gas flows increased at the same time as the amine. Flooding was induced suggesting that the gas velocity was sufficient to push the liquid back up the risers to start the flooding.

The scan recordings for this run are shown in Appendix 2. 4 points were scanned during the increase of loadings up to flood:

- Gas inlet (green, top)
- Liquid outlet line vapour content (blue, second)
- Redistributor (red, third)
- Top distributor (black, bottom)

The test clearly showed flooding at the redistributor tray. The dip in the line (showing a weaker signal due to liquid build up) exactly coincided with the increase in pressure drop in the column and recovery of the column after flooding.

The liquid outlet scan showed a marginal increase in intensity as the column flooded. This shows a slight increase in gas content due to entrainment.

The scan for the gas inlet shows some instability as the column floods.

Although the distributor and redistributor are of similar designs it was the redistributor that flooded. It is likely that both distributors were overflowing however the gas velocity in the redistributor is greater than the top distributor, as the gas flow is greater at the middle of the column than at the top. Thus the redistributor would be the first to prevent the amine from coming down the chimney and therefore start to flood.
The test was repeated on Contactor B with similar results.

4.2 Chord scans below vapour inlet

The scan recordings for this run are shown in Appendix 3.

The chord scans show heavy foam liquid near the gas feed, and clear vapour away from the feed point. The unevenness in levels shows that this is foam and not high liquid level. It was anticipated that the CFD analysis would reveal the cause of the foaming.

5.0 CFD Analysis

Koch-Glitsch performed the CFD Analysis. The model considers vapour phase flow only. The inlet piping, which has a 90 degree bend in the vertical plane close to the contactor, was also modelled. The packed bed was modelled as a simplified porous zone. The bottom boundary of the model was the normal liquid level.

The analysis was produced in two stages

- Existing design with flush nozzle
- With inlet flow device

5.1 CFD with Existing design with flush nozzle

The existing arrangement was modelled to investigate operating problems of flooding and foaming

The model results are shown in the Appendices

Appendix 4 - Velocity Contours Side Cross-section
Appendix 5 - Velocity Contours End Cross-section
Appendix 6 - Velocity Vectors

The model predicts that the high momentum gas inlet with an elbow close to the column inlet creates strong rotational flow in the column in the region beneath the packed bed. The inlet gas stream from inlet pipe enters the column at high velocity and crosses the column to the far wall of the vessel with a velocity of 5-6m/s.

The inlet stream divides into two, part of the stream continues downwards to the lower boundary of the model (NLL) and the second part continues up into the packed bed. As a result, there is non-uniform distribution of the gas to the packed bed. Beneath the bed, the gas reaches a velocity of around 2.5 m/s at the normal liquid level

Diagrams of the scans are contained in Appendices 4 to 6 and are explained below:

Appendix 4 - Velocity Contours Side Cross-section

This diagram shows the high velocity gas inlet from the nozzle and the gas hits the far wall. The gas spreads out up to the packing but also down the wall, also at high velocity. The dark area is an area of zero velocity, which is the eye of a vortex formed.

Appendix 5 - Velocity Contours End Cross-section

This is the view of the cross section from a different angle, looking straight on to the inlet nozzle. It can be seen that there is a vortex formed on either side of the nozzle.

Appendix 6 - Velocity Vectors

This diagram shows clearly the flow direction of the inlet gas. There is downward flow on the wall opposite the inlet nozzle and upward flow towards the inlet nozzle. This flow pattern is a close match to the foam shape detected by the scanning in Appendix 3.

The strong rotational movement may explain why significant foaming has been measured beneath the packing in actual operation.

The rotational effects beneath the bed possibly cause more problems than the level of maldistribution within the bed, if they are creating foaming. IMTP® #50 Random Packing rates at around 82% flood. If liquid is in fact being entrained into the packing, then the percent flood at the bottom of the bed could be noticeably higher.

5.2 CFD with an Inlet Flow device

The system was remodelled to investigate the effect of adding a type 768 EVENFLOW^{TM} Inlet Device in place of the flush inlet nozzle.

The model results are shown in the Appendices

Appendix 7 - Velocity Contours Side Cross-section
Appendix 8 - Velocity Contours End Cross-section
Appendix 9 - Velocity Vectors

The diagrams can be directly compared to the diagrams in Appendices 4-6 to observe the benefit of installing an inlet device. Without the inlet device most of the gas entering the vessel hit the opposite wall and turned downwards towards the bottom of the vessel, creating strong rotational movement below the feed nozzle. With the inlet device, this movement was largely eliminated. There was no downward flow on the wall opposite the inlet. However there was still a slight downward flow down the sides of the vessel, but of a much lesser magnitude (less than 2 m/s compared to 5 m/s).

Diagrams of the scans are contained in Appendices 7 to 9 and are explained below:

Appendix 7 - Velocity Contours Side Cross-section

This diagram shows a dramatic improvement compared to Appendix 4. The turbulent gas flow between the packed bed and the liquid at the bottom of the vessel has been eliminated.

Appendix 8 - Velocity Contours End cross-section

Again this shows a dramatic improvement. Turbulence has been greatly reduced particularly near the liquid level and entry into the packing.

Appendix 9 - Velocity Vectors

This diagram slows slight downward flows toward the edges and upward flow in the middle but again the turbulence was much less than without the inlet device.

The CFD showed an improvement in the gas flow with more gas flowing straight into the packing which resulted in greatly reduced rotational movement below the feed. This provided a more even flow to the packing which will greatly improve its efficiency. The reduction in rotational movement will reduce the tendency to foam and to entrain gas into the rich amine.

6.0 Modifications

As a result of the studies the following main conclusions were:

- The most likely cause of the premature flooding is the distributors. The calculations predicted that these would flood at 500 m^3/h and this was observed during the site tests. The scanning results clearly showed the flooding initiated at the redistributor.

- There is severe foaming at the bottom of the contactor, as observed by the scanning. This is almost certainly caused by the design of the inlet gas nozzle, which creates a strong rotational movement of gas as observed by the CFD analysis. It is also likely to cause heavy gas entrainment in the rich amine either by foaming or vortex formation. There is also concern that the strong rotational gas flow will cause mal-distribution to the packing and possible carry up of liquid/foam would promote flooding.

To rectify the problems the following actions were taken:

6.1 Replace Distributor/Redistributor Trays

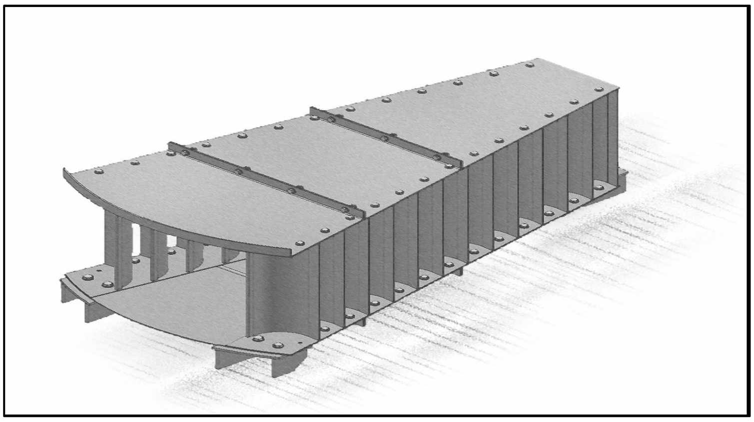
The existing distributors were designed for 447 m^3/h liquid flow with no margin. The new flow requirement is 524 m^3/h. The new distributors were designed with a flow margin of 20%. Although it is unlikely that the packing could handle this extra 20%, designing with this margin ensures an adequate height between the liquid level and the top of the risers at normal flow.

Consideration was given to drilling more/larger holes in the existing distributors. This was discounted because of the extended shutdown time this would take and the inaccuracies of manual drilling on site would lead to poorer flow distribution.

6.2 Installation of an Inlet Flow Device

It was decided to install the Model 768 EVENFLOW ™ Inlet Device Inlet Device, as modelled in the CFD analysis

Diagram 6.2 - Model 768 EVENFLOW ™ Inlet Device



As noted in the CFD analysis it was necessary to shorten the lower packed bed by 500 mm to gain 600 mm free space above the top of the inlet nozzle. The amine licensor, Dow, accepted the loss of packed height in the column and provided a simulation for the new conditions with a reduction in the contactor bed height. In reality it was thought that 5.6m of packing with good gas distribution would probably perform better than the existing 6.1m with poor gas distribution.

7.0 Final site test - June 2006

The revamp Contactors were carried out in May 2006 and the Contactors were tested in June.
The results from the tests are summarised in the Table 7.1 and Diagrams 7.1 and 7.2

Table 7.1 Capacity Summary

Maximum conditions	Contactor A post revamp	Contactor B post revamp	Contactor A pre revamp	Contactor B pre revamp	Revamp Target
Amine Flow (m3/h)	551	546	492	498	524
Sour Gas Flow (kNm^3/h)	165	170	162	164	172

Diagram 7.1 Pre –Revamp Amine flow, Flash gas Flow and Column DP (kPa)

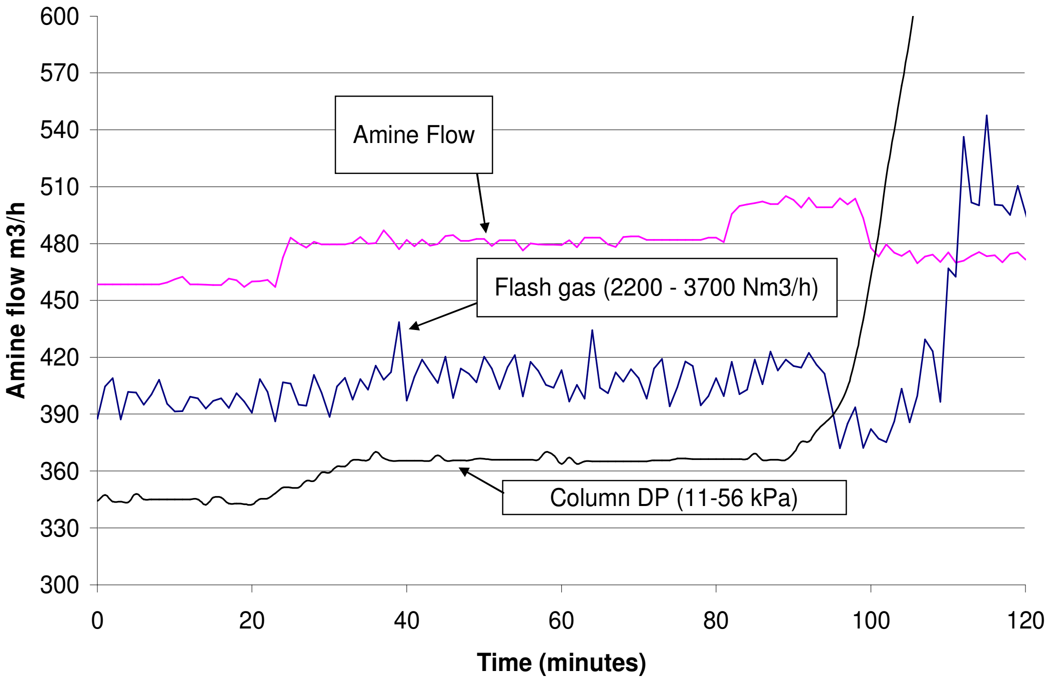
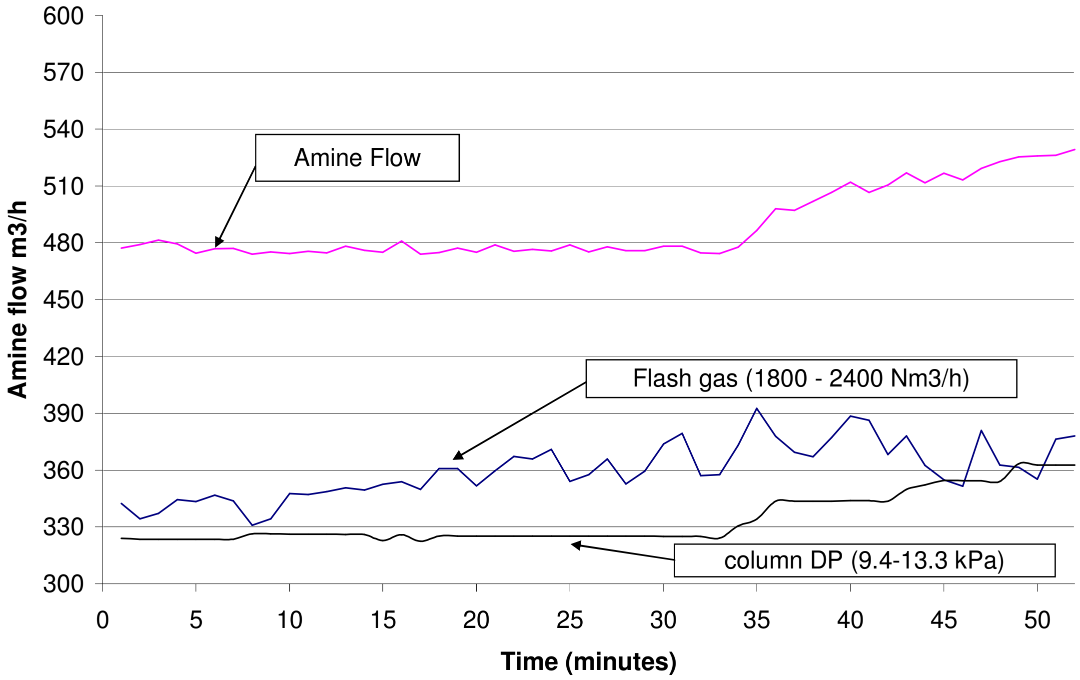


Diagram 7.2 Post–Revamp Amine flow, Flash gas Flow and Column DP (kPa)



The results from the Contactor tests were encouraging, flowrates of gas 170 kNm3/h, amine 546 m3/h were achieved. The revamp design is 173 kNm3/h and 524 m3/h so the gas flow was within 2% of design and the amine flow was exceeded by over 3%. Unfortunately the flows could not be increased further due to problems meeting the CO2 specification that were not connected to the hydraulics of the column and which were already being addressed as the part of the overall sequenced debottlenecking plans.

At the flows that closely match the revamp conditions the DPI was stable, below 15 kPa. Therefore all indications are that the contactors are hydraulically sound at the revamp conditions.

Diagrams 7.1 and 7.2 (shown to the same scale) also show a significant reduction in the flash gas resulting from the entrainment of hydrocarbons. The new inlet device, as demonstrated in the CFD analysis, provides a stable flow regime at the bottom of the column to reduce entrainment.

8.0 Acknowledgements

Many thanks to the following companies for both their permission to use their work in this paper and for their help on the project

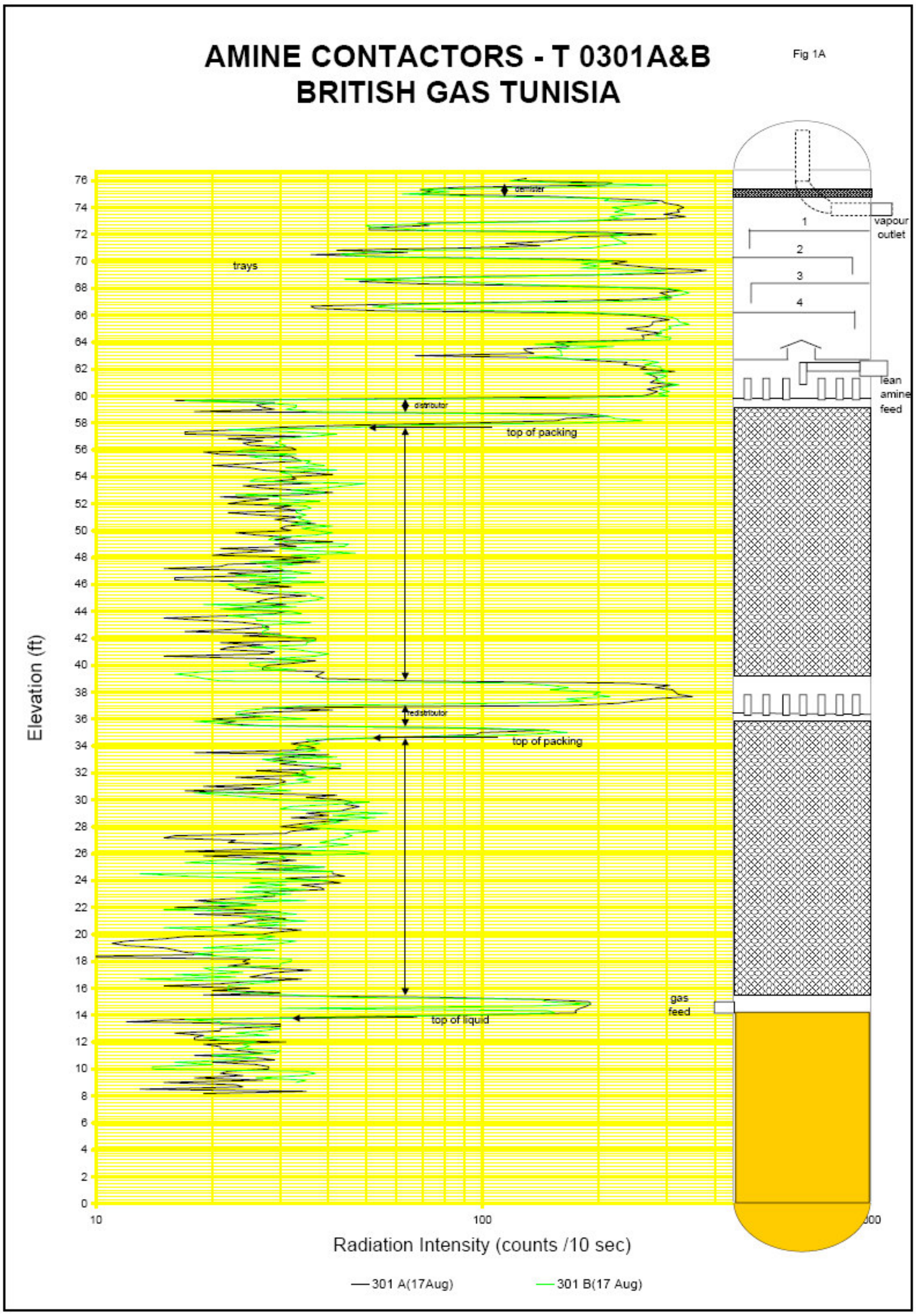
- Koch-Glitsch UK
- Tracerco (The Tracerco Process Diagnostics Group is an internationally based service organisation within Johnson Matthey plc.)

Appendices

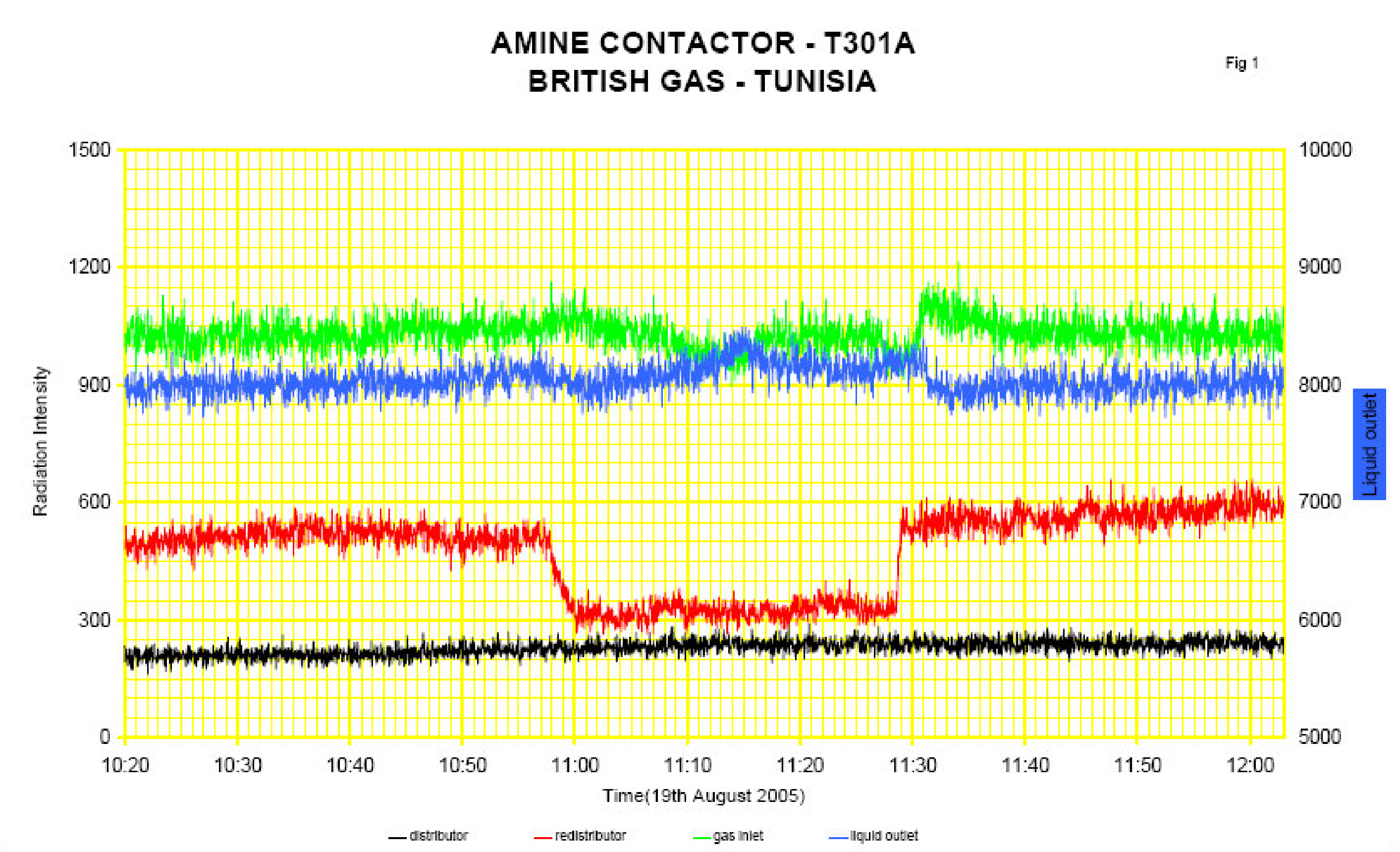
1-3 Tracerco Plots

4-6 CFD Diagrams without a flow inlet device

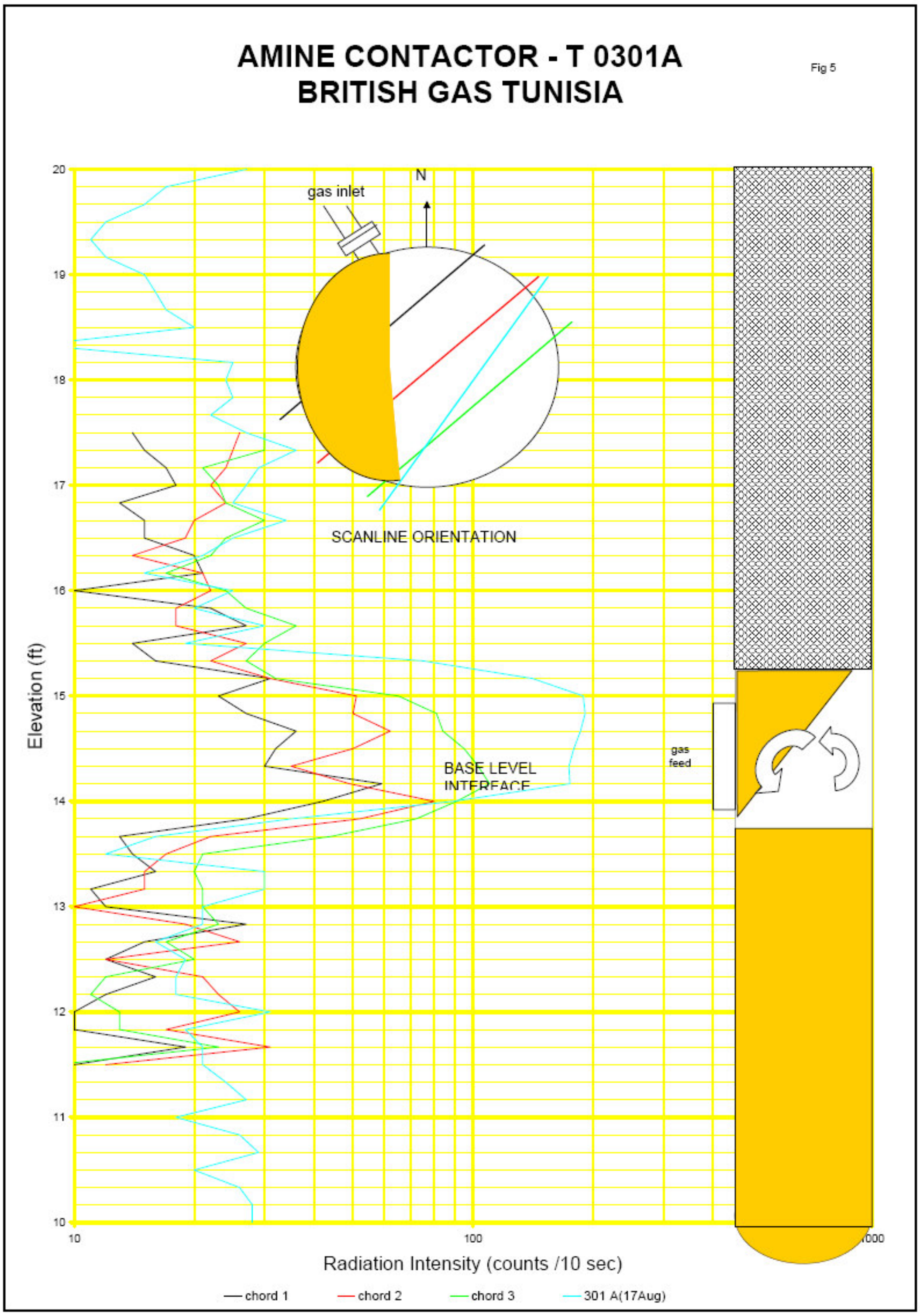
7-9 CFD Diagrams with a flow inlet device



Appendix 1 - Scan down the columns during steady operation



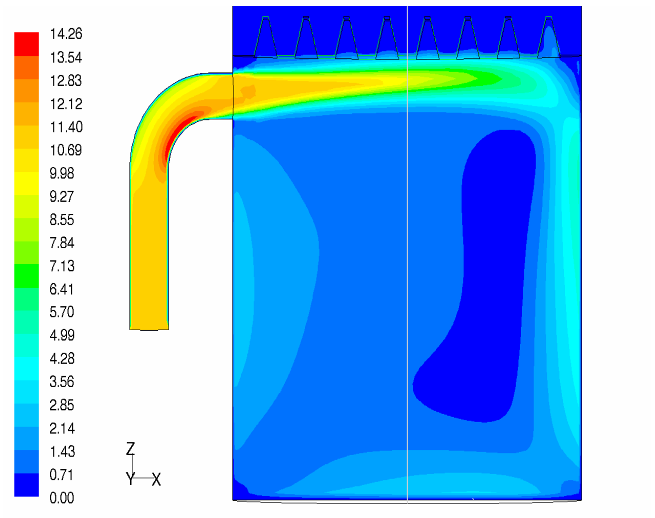
Appendix 2 - Scanning during transient conditions leading to flood



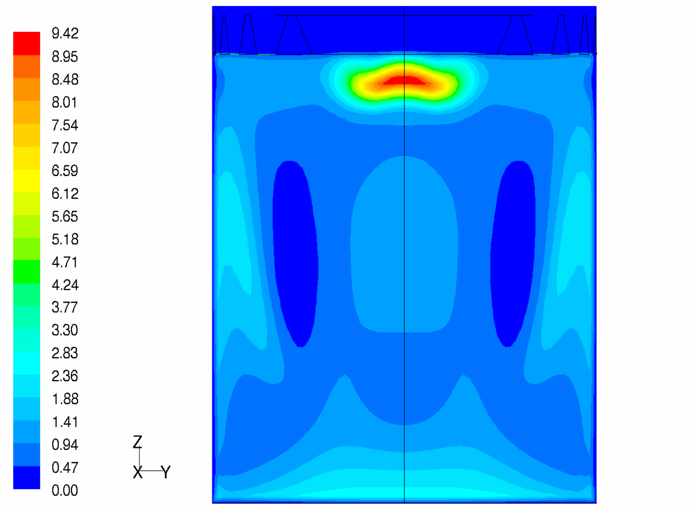
AMINE CONTACTOR - T 0301A
BRITISH GAS TUNISIA

Fig 5

Appendix 3 - Chord scans below vapour inlet



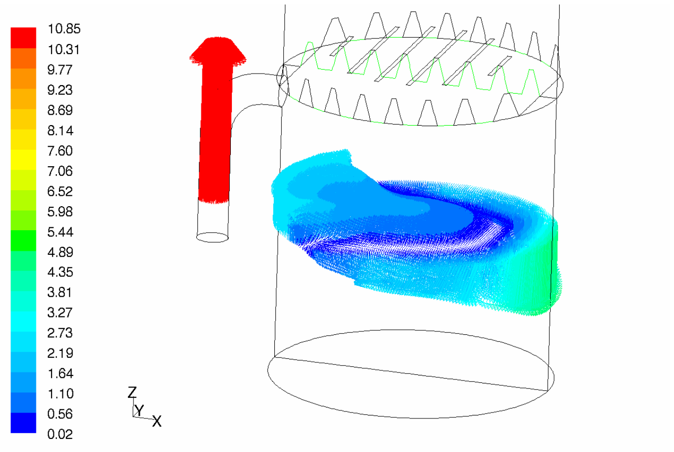
3 Slice y=0, detail, Amine Absorber T-0301, Koch-Glitsch UK
Contours of Velocity Magnitude (m/s) Sep, 2005
FLUENT 6.2 (3d, segregated, sstkw)



4 Slice x=0, detail, Amine Absorber T-0301, Koch-Glitsch UK
Contours of Velocity Magnitude (m/s) Sep, 2005
FLUENT 6.2 (3d, segregated, sstkw)

Appendix 4

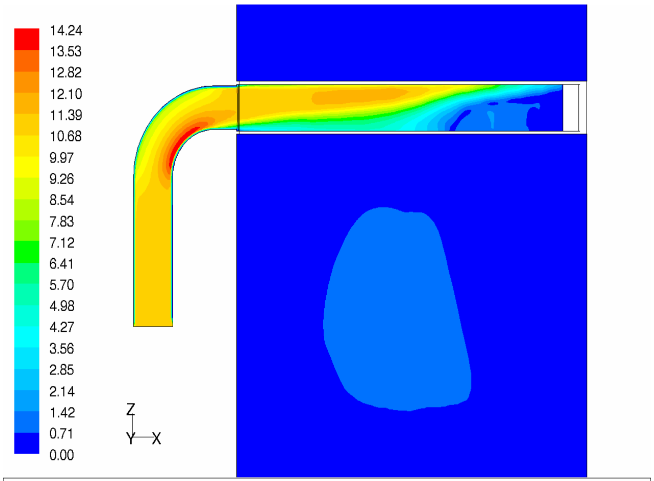
Appendix 5



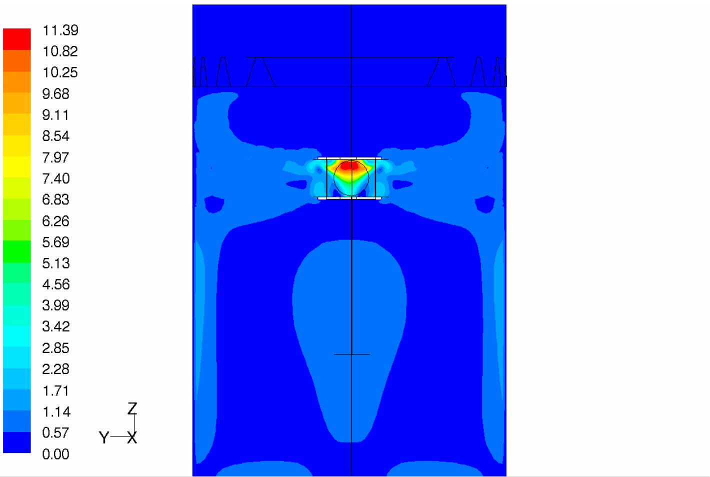
6 Slice z=3.3, Amine Absorber T-0301, Koch-Glitsch UK
Velocity Vectors Colored By Velocity Magnitude (m/s) Sep, 2005
FLUENT 6.2 (3d, segregated, sstkw)

Appendix 6

Appendices 4-6 CFD Diagrams without a flow inlet device



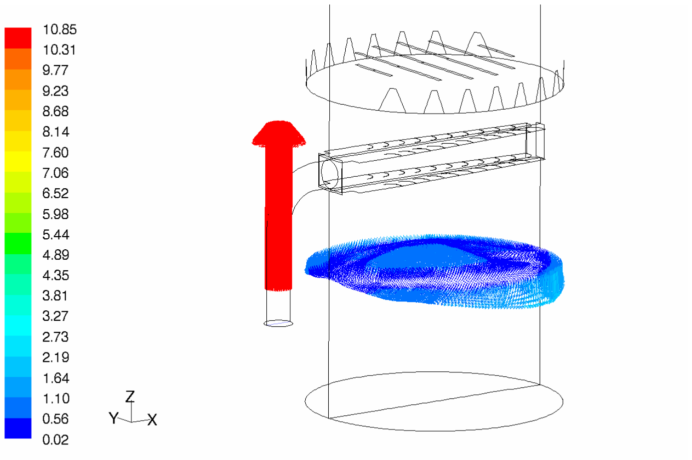
3 Slice y = 0, detail, Amine Absorber T-0301 + Evenflow, bottom bed displacement 500mm, KG UK
Contours of Velocity Magnitude (m/s) Dec, 2005
FLUENT 6.2 (3d, segregated, rke)



4 Slice x = 0, detail, Amine Absorber T-0301 + Evenflow, bottom bed displacement 500mm, KG UK
Contours of Velocity Magnitude (m/s) Dec, 2005
FLUENT 6.2 (3d, segregated, rke)

Appendix 7

Appendix 8



6 Slice z = 3.3, Amine Absorber T-0301 + Evenflow, bottom bed displacement 500mm, KG UK
Velocity Vectors Colored By Velocity Magnitude (m/s) Dec, 2005
FLUENT 6.2 (3d, segregated, rke)

Appendix 9

Appendices 7-9 CFD Diagrams with a flow inlet device