Nitrogen Flow Optimization System for CAB (NOCOLOK) Furnaces

Erik Claesson, Håkan Engström, Torsten Holm, AGA AB, Sweden
Kent Schölin, Finspong Aluminium AB, Sweden

(Paper presented at VTMS Conf., England, May 1995)

Synopsis

A system for continuous control of the atmosphere in CAB (Nocolok) furnaces is developed. The system, named ContiControl-CAB, optimises the nitrogen flow and keeps the furnace atmosphere oxygen concentration constant during brazing. Laboratory tests and theoretical calculations were performed to find the optimum levels for oxygen concentration and dewpoint. The results from field tests using the ContiControl to control production furnace atmospheres under real conditions showed that the nitrogen consumption was reduced by 20-35 %. The residual oxygen content in the atmosphere was controlled to be below a certain set point. With this system the customer keeps track of the atmosphere variations as regards flow rate and oxygen concentration, which improves quality assurance.

1 Introduction

In Controlled Atmosphere Brazing (CAB), the atmosphere control usually is limited to registrations of dew point and/or oxygen concentration. Very often the controlling is done based on optical inspection of the brazing result and from this the nitrogen flow is adjusted. There is, however, no closed loop atmosphere control, which means that the users use excessive amounts of nitrogen to ensure their process. Still, this does not mean that the quality is assured. During production unforeseen things could happen, such as unstable predrying, that influences the atmosphere. The objective with this project was to develop an atmosphere control system which eliminates these quality assurance shortcomings and at the same time minimizes nitrogen consumption. The outcome is a system called ‘ContiControl-CAB’. It is a closed loop system that continuously analyses and controls the oxygen concentration by regulating the nitrogen flow.

2 Experimental

2.1 Laboratory tests

A laboratory study was performed to investigate how the atmosphere oxygen and water vapour concentrations affect the brazeability. These tests were made in a batch CAB furnace at Finspong Aluminium, Sweden, and are described elsewhere [1]. The results from these tests indicated in what way the furnace should be controlled and also the regulating parameters to be used.

2.2 ContiControl system description

ContiControl is an active flow rate control system based on the requirement that a certain setpoint for the oxygen concentration is maintained within the brazing furnace. The nitrogen flow rate is always minimized to maintain this oxygen concentration set point. If the actual O_2 concentration is higher than the set point then the nitrogen flow rate is increased. If the actual O_2 concentration is lower than the set point then the nitrogen flow rate is decreased. Flow rate adjustments are continuous and stepless by use of mass flow controllers.

Separate set points for the O_2 concentration are used for idling and production respectively. A somewhat higher set point can be used for idling, which results in a lower nitrogen consumption during that period. During idling, it is a requirement just to maintain good enough atmosphere conditions for enabling quick reconditioning time when starting production again.

The ContiControl also has a dewpoint alarm function. There are several reasons having dewpoint as an alarm function instead of as a regulating function. First, if the dewpoint approaches too high a level, it is normally because there is an external error such as insufficient drying of the coolers, water leakage from the cooling system on the mesh belt etc. Secondly, dewpoint analysis is difficult both due to slow response time and due to the risk of corrosion of the dewpoint sensor. The alarm level in ContiControl is set so that there is an alarm before the dewpoint reaches an unacceptably high level.

The complete ContiControl system is contained in one cabinet and contains three major parts:

– Gas Flow Control System for the Nitrogen
– O_2-Analyzing System
(Dewpoint meter is an option)
– Control panel

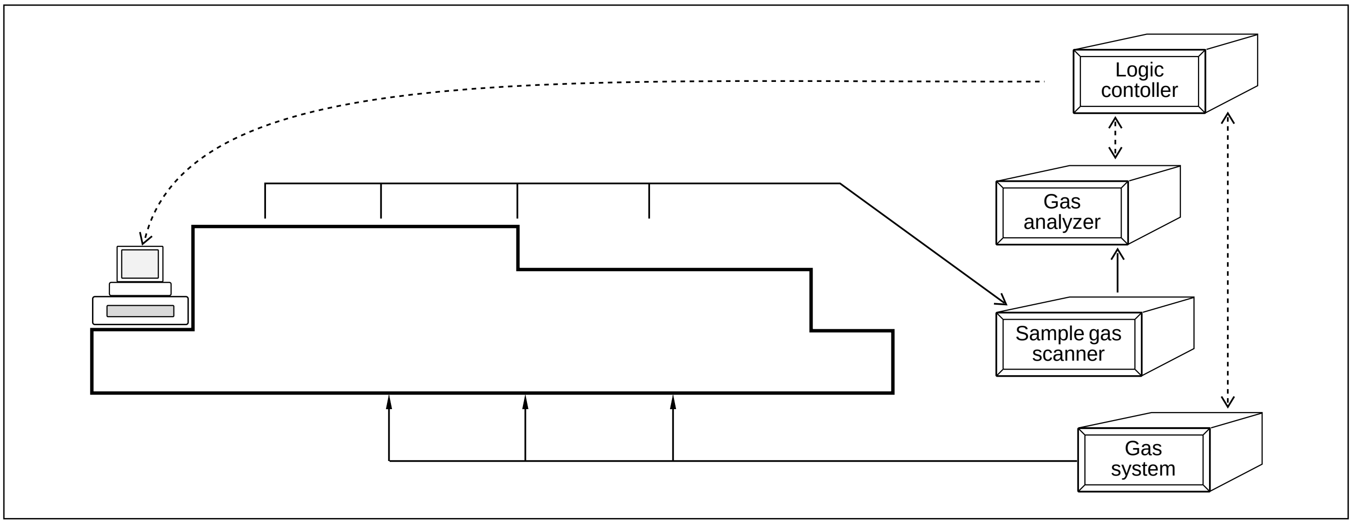

Fig 1 Principle block diagram for ContiControl

2.3 Field test

The ContiControl system was installed and evaluated at two different production furnaces for controlled atmosphere brazing. Oxygen analysis was initially performed in empty furnaces to establish the oxygen concentration profiles along the furnaces. This also helped to find the best point for oxygen analysis for the flow control. Brazing was then made with the ContiControl connected to the furnaces, see figure 1. The flow control was performed at one of the major nitrogen inlets. The other gas inlets were supplied with constant flow of nitrogen. The sample gas scanner indicated in figure 1 is an option.

3. Results

3.1 Analyzing techniques

An O_2 analyzer using an electrolytic cell was used and found to function well. However, future oxygen analysis in situ would be a way to completely eliminate the clogging problem. This is to be further studied.

Dewpoint analysis is difficult because the analyzing sensor is corroded by the flux vapours. The dewpoint is, however, an important parameter regarding the brazing quality [1]. A way to prolong the sensor endurance is to measure the dewpoint during short times and with short intervals, and to purge the sensor with nitrogen after each analysis.

Clogging of the gas sampling line is a potential problem. To be considered are the gas sampling gas outlet position and design of the sample gas line. A high analyzing gas velocity is required in order to yield short response time.

3.2 Laboratory tests

Basic relations between brazeability and atmosphere oxygen concentration and dewpoint were obtained in the laboratory tests [1] with results summarized in figure 2.

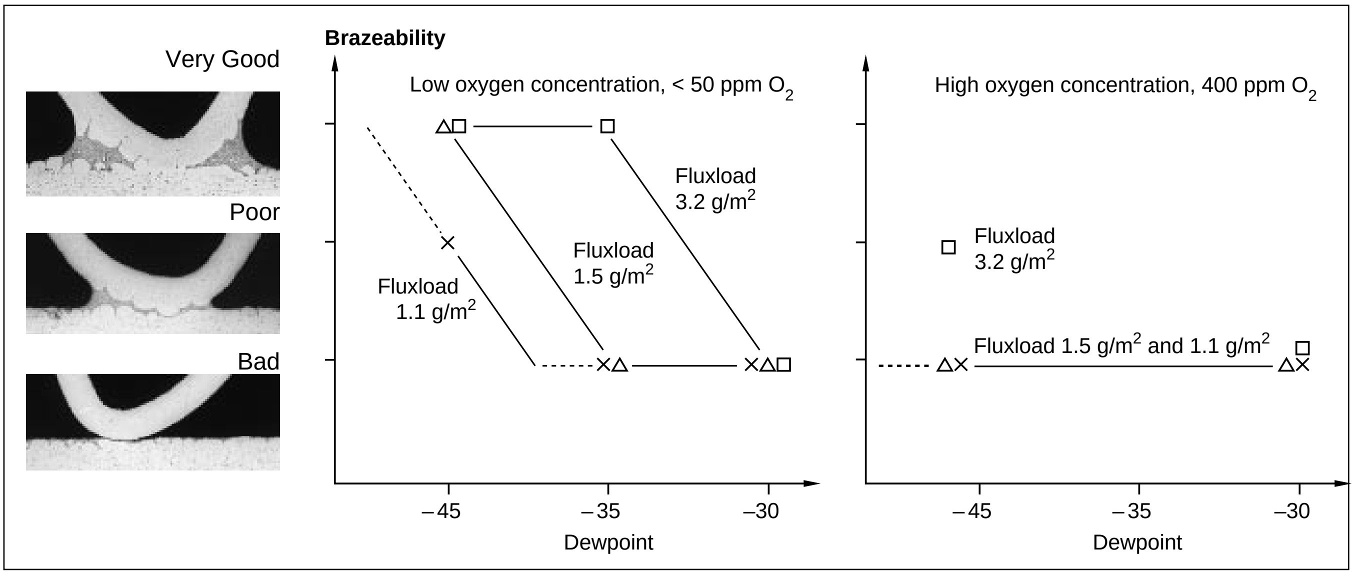

Fig 2 Relation between brazeability and atmosphere concentrations of O_2 and H_2O.

At the low oxygen level (< 50ppm O_2), the dewpoint has a considerable effect on brazeability. As shown in figure 2 there is a strong relation between flux load and required dewpoint for good brazeability. A critical maximum dewpoint level was found to exist at about –35°C for the flux load 3,2 g/m^2 and at about –45°C for the flux load 1,5g/m^2. For the lowest flux load, 1,1 g/m^2 the brazing results were judged as poor for all tests.

At the high oxygen level (400 ppm O_2) ‘No’ or ‘Poor’ brazeability was obtained for all combinations of flux loads and atmosphere dewpoints. Thus high oxygen concentrations have a considerably negative effect on the brazeability.

3.3 Field test

Furnace 1

Oxygen analysis made at different positions in the furnace, during production, show high concentrations especially near the inlet but also close to the outlet of the furnace, figure 3. In the brazing zone the oxygen level is much lower. Thus it is clear that oxygen is entering the furnace through the openings.

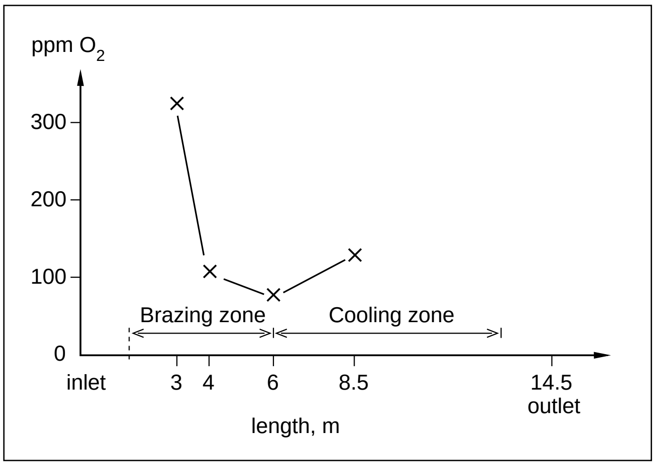

Fig 3 Oxygen analysis in different zones of furnace 1

Figure 4 shows the oxygen concentration level in the brazing zone at 600°C during a production cycle and at a constant nitrogen flow (without regulating). Initially the oxygen concentration increases (point B in figure 4), due to drag in of air with the parts to be brazed. After some time the oxygen concentration is lowered down to an equilibrium level obtained at about 80 ppm which remains during the production cycle (point C). This equilibrium oxygen concentration is lower than the one measured with empty furnace (no production) because oxygen is consumed in reactions with the flux. When production is finished the oxygen level increases again to the same level as before starting production.

Figure 5 shows the same sequence as figure 4 but with regulating of the nitrogen flow using a set point of 200 ppm for O_2. As can be seen in figure 5 the flow rate increases initially during start up in order to get the oxygen concentration down as fast as possible to the set point value, 200 ppm. After a while, the flow is reduced

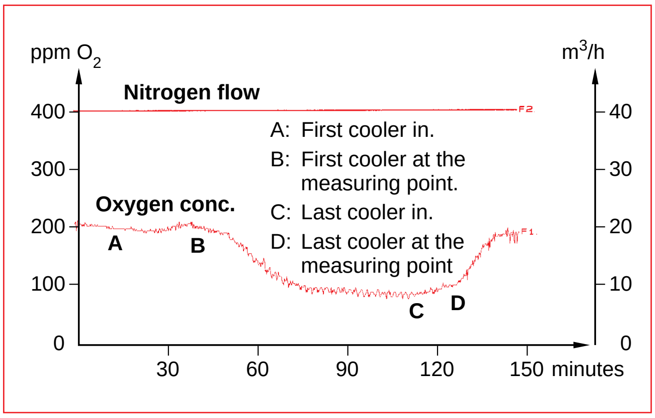

Fig 4 Oxygen level as function of different steps throughout a production cycle at constant flow of nitrogen.

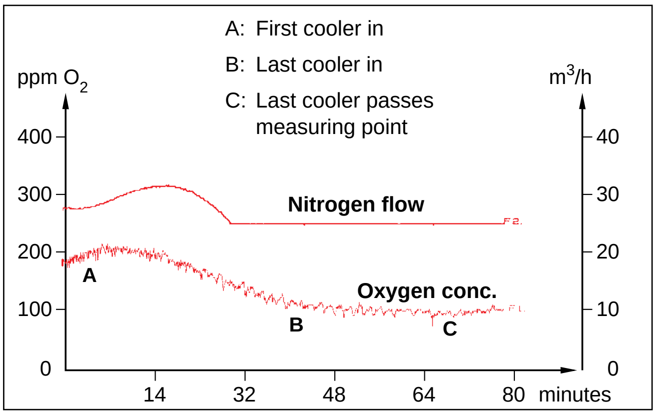

Fig 5 Oxygen level as function of different steps during a production cycle when regulating with ContiControl.

to a minimum (=preset value) as long as the oxygen level is below set point.
The brazing result when using ContiControl was the same as during normal production with constant nitrogen flow. No leaking radiators were produced and an overall fault rate of zero percent.

This mesh belt furnace was originally running with a constant nitrogen flow of 40 m^3/h, independent of the kind of radiator brazed. The flow distribution is shown in table 1, which also shows the flow distribution after installing ContiControl. Regulation was made in zone 3. With the ContiControl system in action during production the average nitrogen flow was decreased to a level of 26 m^3/h, corresponding to 35 % reduction. A constant oxygen concentration level at about 100 ppm in the brazing zone was maintained during the whole cycle.

	Flow m³/h				Total Flow / Furnace Volume
	Zone 1	Zone 2	Zone 3	Zone 4	
Before	8	14	14	4	13.8
After	6	0	18 (Mean) 15-35 (Regulating interval)	2	9.0

Table 1 Flow distribution before and after installation of ContiControl in furnace 1

Another result was that the personnel experienced a good overlook of the atmosphere being more aware of the quality of the total brazing production.

Furnace 2

The furnace had three nitrogen inlets; in the preheat, the brazing and the cooling zone respectively. Based on tests with different flow distributions and related oxygen analysis the regulating of the flow was made in the cooling zone. The span of flow for regulation was 30 (minimum) to 50 m³/h (maximum). The other two inlet flows were kept constant but changed as compared to the original settings, see table 2. When comparing the total flow divided by furnace volume for furnace 2 and furnace 1 respectively it is clear that furnace 2 had a lower atmosphere exchange factor, which can be attributed to the longer length of furnace 2.

	Flow m³/h			Total Flow / Furnace Volume
	Preheat Zone	Brazing Zone	Cooling Zone	
Before	23	40	37	6.8
After	25	10	30-50	5.1

Table 2 Flow distribution before and after installation of ContiControl in furnace 2

Figure 6 shows oxygen concentration and nitrogen flow for both cases; constant nitrogen flow and flow regulation with ContiControl respectively. The possibility, with support of ContiControl, to change and optimize the flow distribution has been utilized. It is clear from the figure that the amplitude in oxygen concentration, caused by a disturbance, is very much reduced with the ContiControl regulation. It is also clear that the nitrogen consumption is reduced.

It was demonstrated that external conditions may disturb the atmosphere quality very much. Figure 7 shows the influence from factory door openings on oxygen concentration and related nitrogen consumption. When two doors are open there is a greater disturbance compared to when only one door is open. In the same figure are also shown disturbances caused by the cooling fan (see Discussion). When both doors are closed and the fan is off the oxygen concentration is constant, below 20 ppm, throughout the whole production cycle.

At off-production hours the total flow was set at a low constant level of 35m³/h just to maintain good atmosphere conditions.

Based on 53 hours of continuous production the following observations were made:

– The average nitrogen consumption was 75,5m³/h when using ContiControl compared to 100m3/h when using steady flow rate, thus a reduction of 24,5%.

– The start up time to reach the set point of 20 ppm was approximately 1 hour after having changed to a regulated flow (65 - 85 m³/h) with the new flow distribution. The start up time was the same as when starting with a constant flow of 100m³/h

The brazing result was examined by microscopy and revealed in all cases very good joints. The flux load used was 1,3g/m³ (compare with figure 2).

4 Discussion

The oxygen concentrations had in both cases a minimum in the brazing zone at the point of highest temperature. However, the measuring points used in regulation were placed differently in the two cases. In furnace 1, the sampling point was placed at the start of the brazing zone and in furnace 2 very close to the temperature maximum in the brazing zone. The position of the sampling point was chosen to avoid direct influence in the readings from nitrogen inlets. Thus, the absolute oxygen concentration levels from the two cases can not be directly compared.

Furnace 1 was short, total length 14,5 m, which means that disturbances in oxygen concentration are quickly transferred into the furnace. Therefore, the nitrogen flow regulating interval has to be relatively wide in order to eliminate these disturbances and to assure a high atmosphere quality. By using a wide regulating interval, a positive consequence is high gas savings with ContiControl, in this case 35%. This furnace had controlled gas inlets at the entrance and exit ends, which improved the atmosphere stability. Also external disturbances were small as compared to furnace 2.
Furnace 2 had a length of 35 m, thus much longer

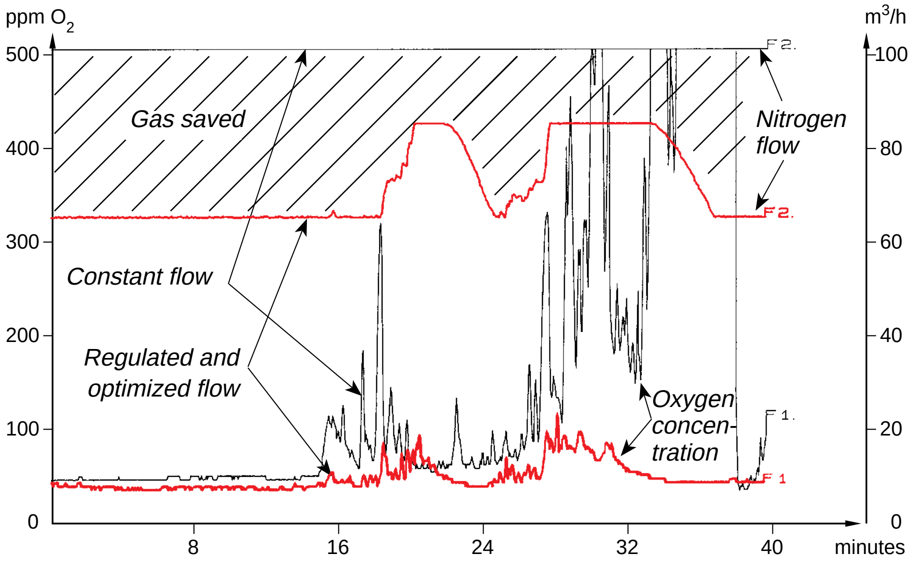

Fig 6
Effect of disturbances on oxygen concentration amplitude for constant and regulated nitrogen flow.

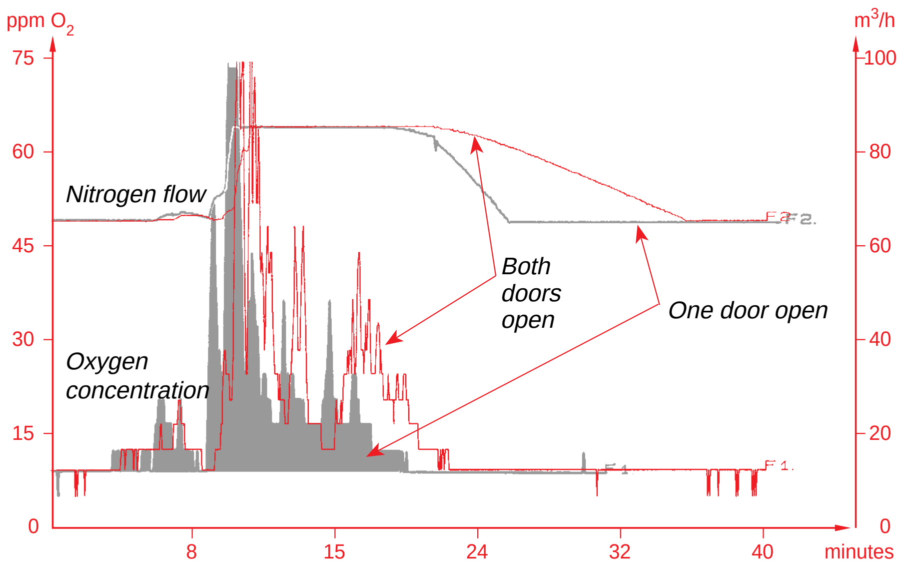

Fig 7 Effect of external disturbances on oxygen concentration amplitude for regulated and optimized nitrogen flow.

than furnace 1. In this case, the external disturbances were notable. There was a cooling station with a cooling fan directly after the furnace outlet. When this fan was started then the flow distribution in the furnace was disturbed so that oxygen penetrated into the furnace atmosphere. There were also disturbances from factory door openings, which created an overall air circulation in the factory. These effects are demonstrated in figure 7 which also show the positive effect from ContiControl in leveling this disturbances.

Chemical equilibrium calculations using the Thermo-calc method have been performed (2) to illustrate possible reactions between the flux and the atmosphere, as seen in table 3. (The flux was treated as a mixture of solid phases because no model for the flux melt was available) It must be remembered that equilibrium calculations do not take reaction rates into account. Thus, the discussion below is only giving possible tendencies in reactions.

Gas	Equilibrium partial pressure, bar
$KAlF_4$	1,3 E-2
O_2	2,0 E-4
HF	1,5 E-4
H_2O	1,5 E-6

Table 3 Equlibrium calculation results for the gas phase. Conditions: – Temperature 600°C
– Inlet concentrations in the nitrogen: 200 ppm O_2, 80 ppm H_2O (dewpoint approximately – 45°C)

Vapour of $KAlF_4$ forms up to a concentration of 1,3 vol% in the atmosphere, thus up to substantial amounts. Analysis of deposits in sample gas lines has given the following result: 24% Al, 23 % K, 51% F (weight%). This corresponds roughly to the vapour KAlF4 to be deposited.

By reaction between H_2O and the flux, HF is formed. To minimize the formation of HF it is therefore of great importance to keep the dew point low in the furnace atmosphere. The equilibrium calculations indicate that the partial pressure of HF in the atmosphere (at 600°C) would increase from 100ppm to 1000 ppm when the inlet dewpoint in the nitrogen is increased from –48°C to –26°C. As H_2O is consumed by this reaction it would be the best to control that the atmosphere dewpoint is low enough in the first part (low temperature) of the furnace to ensure that water is not introduced into the brazing zone.

According to table 3 the equilibrium concentration of oxygen is fairly high, 197 ppm compared to 200 ppm in the inlet nitrogen. However it was found in the static laboratory batch furnace tests that the oxygen concentration dropped markedly during the brazing cycle. The equilibrium calculation does accordingly not agree with the experience. The oxygen levels given in figure 2 are the ones initially aimed for at the start of brazing, but at the end of the brazing cycle the O_2 concentration fell to a few ppm. One mechanism is probably that oxygen is consumed by dissolving as ions in the flux melt. Al_2O_3 may also form as a reaction product between oxygen and solid flux (before melting), which is supported by the equilibrium calculations.

Al_2O_3 could also form by oxidation from H_2O. Both oxidation of aluminium present in the flux and of the parts to be brazed must be considered. The amount of Al_2O_3 formed is dependant on the total concentration of oxygen in the atmosphere, calculated as atomfraction, thus, the total concentration expressed as ($2xO_2 + H_2O$).

It is shown that the flux is consumed by different reactions with water and oxygen. The lower the oxygen and water vapour concentrations are, the less flux is needed. To put it in another way, the total amount of flux in the furnace should be sufficient to react with the oxygen and the water vapour, and after this reaction enough flux must be left to dissolve the oxide. This means, in theory, that given an initial oxygen and dew point level, a higher flux load is needed if the furnace is loaded with fewer workpieces than usual. High flux loads will, however, lead to more gaseous species primarily $KAlF_4$ and in presence of water to HF, which leads to deposit and corrosion problems respectively.

5 Conclusions

Using the ContiControl-CAB system for closed loop flow control results in:

- Substantial gas savings of the order 20-35%
- Improved quality as the atmosphere oxygen concentration is supervised, controlled and maintained at the required set point. Disturbances in the atmosphere quality are leveled out.

The amount of oxygen in the furnace atmosphere, coming from O_2 or H_2O, must be maintained at low levels, the lower the better, in order to minimize flux consumption and oxidation of aluminium and to yield good brazeability. To minimize HF formation the dewpoint should be low, preferably below –45°C.

References

1. Stenqvist, T. Schölin, K. Engström, H. *Proc. BABS Conf Advances in Joining Tech,* Solihull, October, 1994

2. Jansson, B. *Personal communication.*