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AN AIR INGRESS MONITOR FOR TURBINE CONDENSERS

ITS DEVELOPMENT AND VALIDATION

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AN AIR INGRESS MONITOR FOR TURBINE CONDENSERS- ITS DEVELOPMENT AND VALIDATION

ABSTRACT

One of the major causes of inefficiency in turbine condenser operations is the presence of excess air in the system. Resulting condenser under performance can affect the power plant heat rate adversely, which adds to operating costs. Plant operators as well as efficiency and maintenance engineers need to know air ingress or inleakage levels and trends if excesses are to be contained and thus limit condensing surface air blanketing or binding.

Air ingress is currently assessed by several methods including monitoring the airflow on the discharge of the air extraction plant, or by using an additional air injection technique. The first category involves the measurement of a very low air flow which may contain an Unknown quantity of water vapour, while the second requires stable operating conditions during the test period. Each method has its inherent and practical disadvantages for the continuous monitoring of plant performance.

To overcome these disadvantages, Chell Instruments, with co-operation from the UK's major power producer, has designed an instrument to monitor the air content in real time between the condenser and the air extraction equipment. High accuracy measurements of the steam/air flow parameters using a refined averaging Pitot tube are processed using a Self-contained microprocessor controlled instrument to compute and display the airflow rate.

As part of the validation exercise, the instrument was firstly installed in a test pipeline where it was exposed to controlled flow rates of air under vacuum conditions and then the instrument was moved to various power stations where its performance in the real conditions of an air/steam mixture was examined. The AIM responded well to Changes in airflow. It was more difficult to confirm the absolute level of airflow rate as there were shortcomings with the comparative methods available, however, encouraging results were obtained.

INTRODUCTION

The Heat-Rate of a turbo-generator unit is very much a function of the top and bottom-end temperatures of the operating cycle. The bottom-end temperature, the temperature at which the exhaust steam from the turbine is condensed back into boiler feed water, is determined by the operation of the steam condensing plant. The condenser therefore is an important item of plant when considering the efficient operation and any improvement in heat rate of one's power unit. It tends however, very much to be neglected.

The condensing temperature is more commonly recorded as the condenser backpressure, the saturation pressure corresponding to the condensing temperature. A deviation in condenser backpressure of 0.3 in.Hg from normal conditions will increase heat rate by 50 Btu/kWh. This means that for a 400 MW coal fired unit with an 85% capacity factor and a \$2.50/MBtu fuel cost, the average yearly penalty would be \$375,000, reference 1).

For a given condenser design the condensing temperature of the steam is primarily determined by the temperature and flow rate of the cooling water -- the temperature being governed by the ambient conditions and the flow a result of the pumping capacity available. When the expected condensing temperature is not achieved at a particular load, usually seen as a shortfall in the target condenser pressure, it is generally assumed the condenser is suffering from one or both of the following:

- Waterside fouling.
- Air blanketing or binding

Unless on-line cleaning systems are installed very little can be done to pursue the fouling question until a plant outage occurs, when visual inspections on the cooling water side can take place and remedial action be taken where necessary. If air binding is suspected, resulting in a loss of active surface area in the condenser tube nest or bundle, then it is more often than not assumed to be an excess air ingress or inleakage problem. This may however, not always be the case.

It is true that the more air the air extraction plant has to handle the higher the air extraction pressure at which it operates particularly with rotary air pumps. When the air extraction pressure reaches a particular limit where full steam penetration of the tube bundle cannot be sustained, the condensation process takes place over a reduced surface area with a consequent increase in the condensing temperature and hence pressure. Moving from condition 1 to condition 2 in Figure 1 demonstrates this point. However, the same reduction in condensing surface area would still occur with the corresponding extraction (suction) pressure regardless of the cause of the deterioration of that pressure. Poor (high) pump water operating temperature due to excess steam carry over, or inadequate cooling, could produce a poor pump suction pressure despite an acceptably low air flow rate.

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Any reduction in steam penetration of a tube bundle leaves the inactive tubes air blanketed. The relationship between pump suction pressure, condenser pressure and air blanketing was demonstrated by Rowe (reference 2) where an identical condenser pressure variation and same shape of air blanketing was observed whether additional air was bled upstream of the condenser tube bundle or downstream of the condenser directly into the air suction manifold just upstream of the air pumps. It is the effect of the air on the pump performance rather than its passage through the condenser that is the dominating factor.

Therefore, when faced with a condenser performance shortfall that is assumed to be the result of air blanketing, it is advantageous to know whether the inadequate air suction pressure causing the air blanketing is a result of a high air flow rate, or some other deficiency in the air extraction plant. Some method of air ingress measurement is therefore highly desirable to determine whether an air leak search is necessary.

METHODS OF AIR INGRESS MEASUREMENT

Air ingress measurement on steam condensing plant has been a long-standing frustration of power station engineers. Several methods have been available and to some extent can be reasonably reliable, but they have their drawbacks.

Rotameters fitted on the exhaust side of air extraction plant are suitable if the airflows through each unit are within their limited measurement range and reasonably steady. In reality, the flows tend to pulsate, with the moisture content of the air adding to the stiction of the float, and even flooding the chamber.

Also used on the downstream (exhaust) side of the air plant is the orifice box. This is a chamber with a selection of orifice places across which the airflow differential pressure is measured together with the operating temperature, from which the airflow rate is computed. The differential pressures are generally very small - in the order of tenths of an inch water gauge - being measured with delicate inclined manometers.

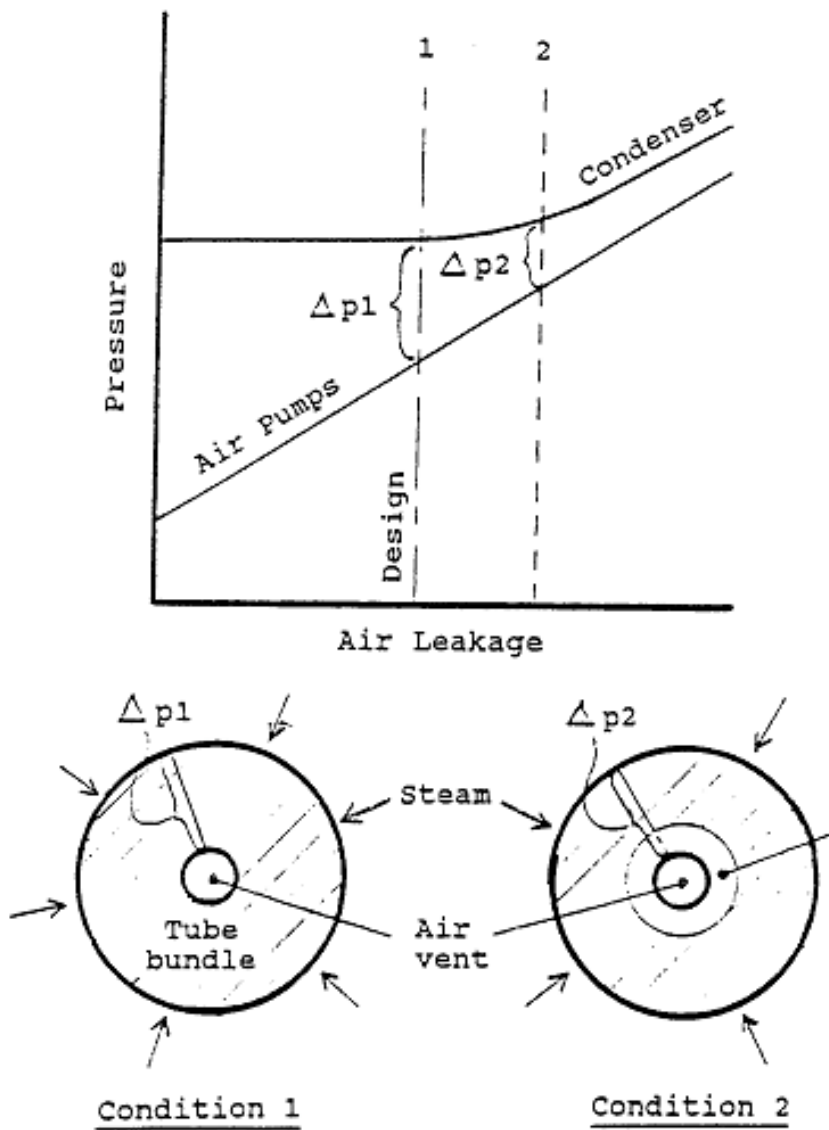


Figure 1. Air blanketing caused by excessive air leakage.

Both the rotameters and the orifice box by necessity create a flow restriction making them unsuitable for permanent service. They are generally only opened to the flow when a measurement is to be made. Other downstream methods have been tried but also have their disadvantages; e.g. rotating vane devices tend to have a limited service life due to the wetness of the airflow attacking the bearings.

All the downstream devices require of course, a reliable exhaust air collection network, either with several local measuring devices, or one device at the end of a piping system, and most importantly, require air tight air extraction plant. If any pump has its own inleakage of air due to poor seals for example, this extra leak would be included in the measurement, masking the true value through the condenser. The problem of extra air also exists with extraction plant that has air-motivated ejectors in the system.

Air pump calibration curves can be used requiring knowledge of the operating suction pressure and seal/cooling water temperature of each pump. The problem here knows how much wear and tear of the pumps has changed the operating characteristics. A 20% reduction in performance of air extraction plant is not uncommon.

The real drawback however, is that none of these methods lends themselves easily to continuous on-line monitoring, an operator's dream!

A method that has been pursued, perhaps rather slowly, but in the belief that it should be possible, is the measurement of total air flow in the main air extraction or suction pipe between the condenser and the air extraction plant. If the mixture of air and steam flowing in the pipework is considered as two perfect gases, Dalton's Law of Partial Pressures can be used to establish the steam to air mass ratio. Measurement of the total flow in the pipe by some means therefore allows the two component flows to be individually assessed.

Dalton's Law requires measurements of temperature and static pressure of the flowing mixture. With the steam partial pressure assumed equal to the saturation pressure corresponding to the measured temperature, the air partial pressure is then obtained by subtraction. There are no real problems here, but it is with the measurement of the total mass flow that the method can stumble. The flow, being under high vacuum conditions, gives a very small pressure head - again in the order of tenths of an inch water gauge - with which to measure and compute the flow velocity. Moisture in the flow causes problems such as blockage in the pressure lines of conventional pitot-static probes and damage to sensitive instruments like hot-wire anemometers.

However, it is from these basic measurements that the Chell Air Ingress Monitor, AIM, has evolved. The development has concentrated on the reliable and accurate measurement of the flow differential pressure drop, and the on-board data processing to give continuous on-line outputs.

THE AIR INGRESS MONITOR, AIM

As already stated in section 2, it is the measurement of the flow differential that poses the more difficult problem. An earlier investigation at a power plant had already shown the difficulties in monitoring and displaying continuously this small pressure drop on the discharge side of the air pumps. Orifice plates, venturis, single point pitots and thermal devices had already been eliminated in favour of an averaging pitot.

A trial installation of five pitots - on the four air pump discharges and the commoned header discharge pipe - connected to a rotary selection valve and very low range differential transducer, was partially successful, but highlighted the difficulties of making measurements in a wet environment. The small pressure lines from the pitots would block with water and even the sensing ports on the pitot tube body would close with a film of water. The holes were made bigger and elongated (with no apparent difference in measurement) and even an air purge was tried. Despite some progress it was decided to move to the pump suction side to eliminate the rogue air from bad pump gland seals and to use the larger flow velocities in the higher ratio steam/air flow at the lower densities.

A second-generation single averaging pitot was used incorporating an integral resistance temperature device, RTD, and ports to measure absolute and differential pressures using MKS Baratron transducers. These three signals were monitored by a personal computer, which included a steam table package where partial pressures and densities were deduced before formulating the steam air ratio and airflow rate.

Once the basic principal had been established, it was a matter of refining both the hardware and the software to a point where all the software was loaded onto an EPROM and the hardware could be made compact for a permanently mounted instrument and even a portable version. [Figure 2](#) shows the calculation flowchart on which the Chell AIM'S processing is based, and [Figure 3](#) shows a typical fixed Installation.

To enable the successful measurement of air inleakage several precautions were necessary. Sensible routing of the piping to allow self-draining alleviated steam condensing in the pressure lines, while temperature stabilising the differential pressure transducer at an elevated temperature not only overcomes the possibility of condensation but also improves measurement accuracy. A class "A" 4- wire platinum resistance thermometer with an accuracy of 0.35-F together with the high accuracy (better than 0.5% of reading) pressure readings allows reliable information to be extracted from the curve fitted look-up steam tables in the software.

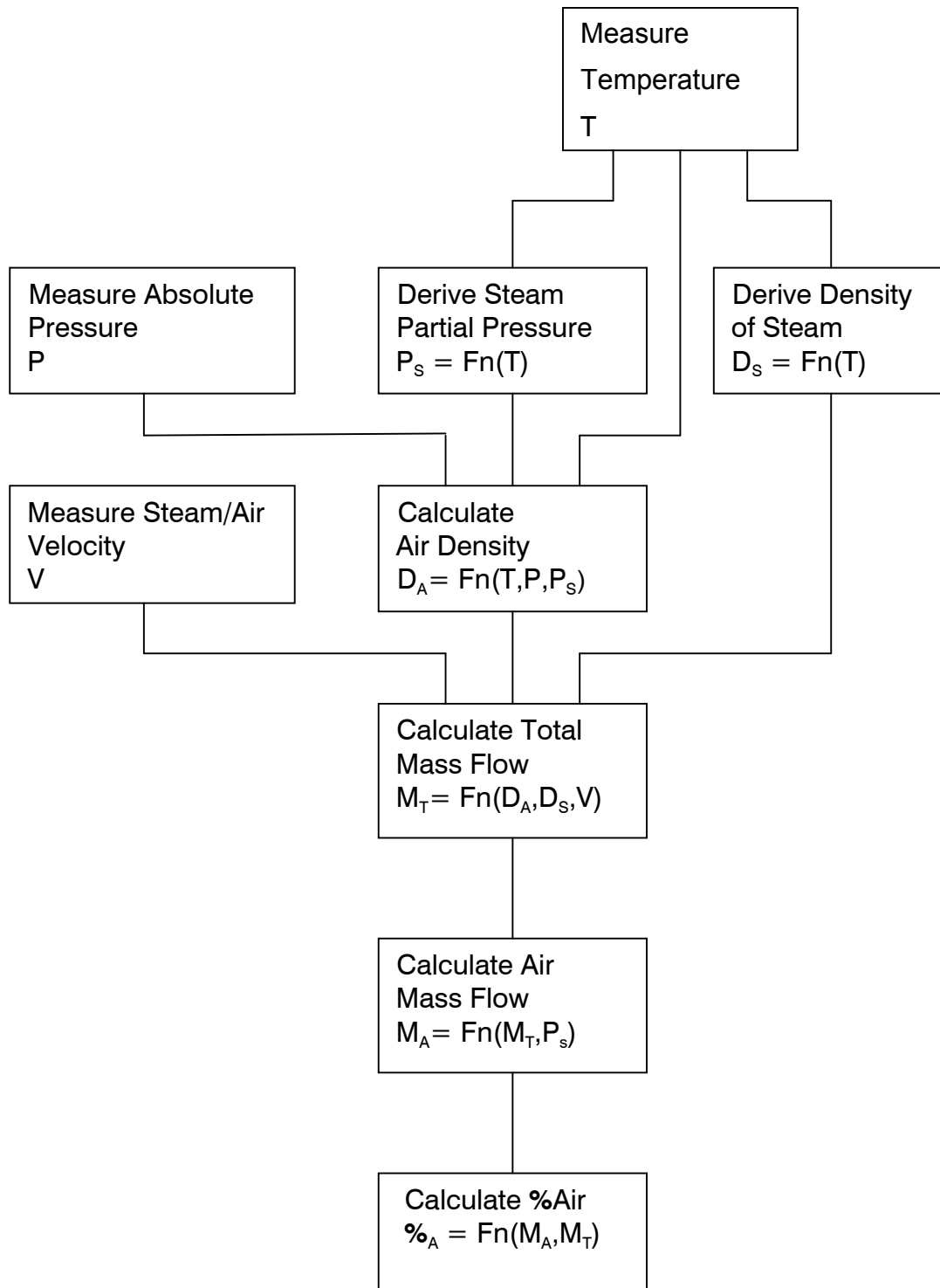


Figure 2. Air Ingress Monitor - Calculation flowchart.

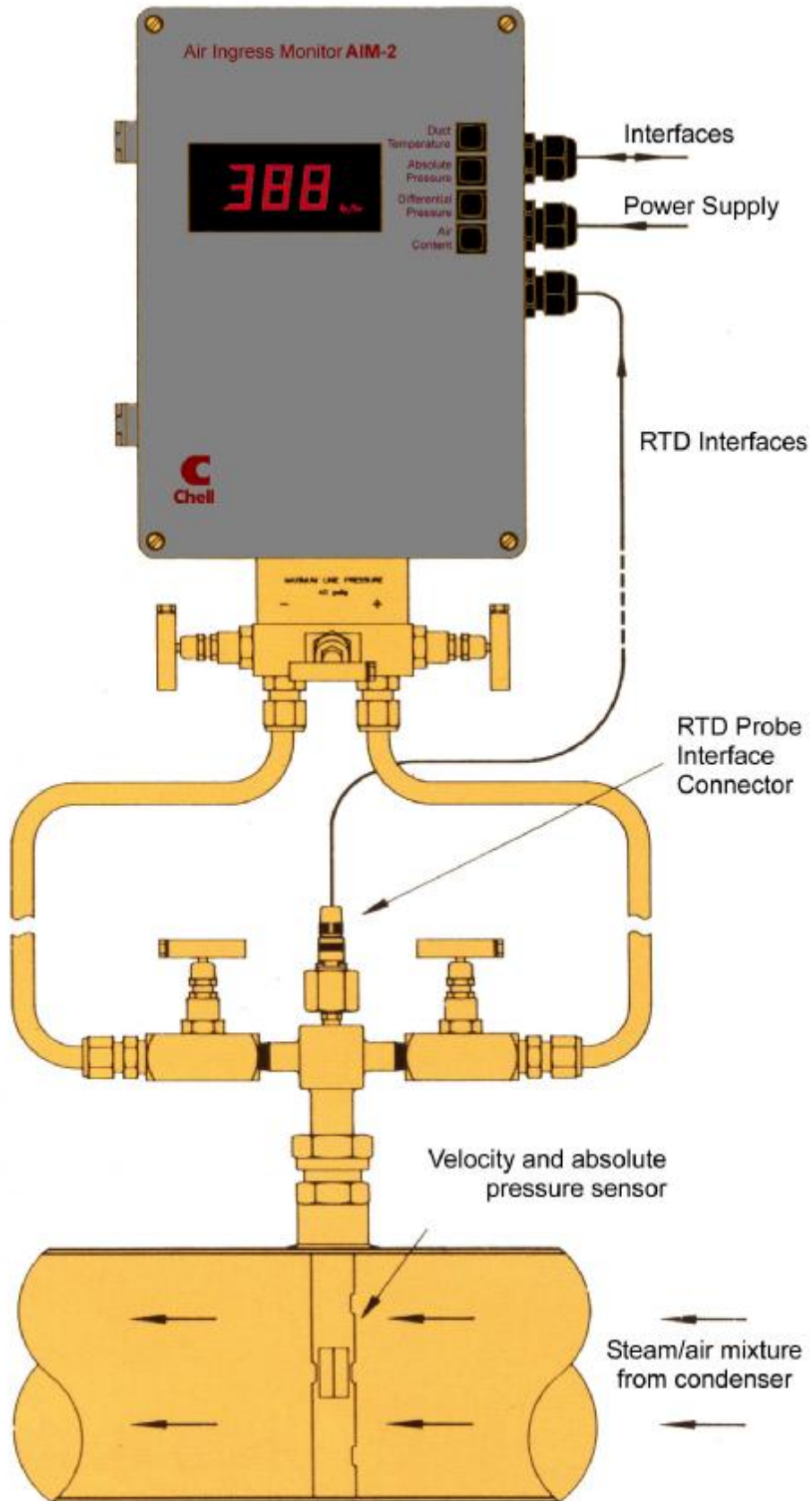


Figure 3 – AIM Installation

Several factors can influence the stability of the mixture flow in the extraction pipework. Condenser and air extraction plant dynamics for example can alter the steam carry-over from the condenser. Such instabilities can give rise to a 'noisy' flow and it's measurements. Signal filtering techniques are therefore employed in the on-board microprocessor system. The air ingress is computed in real time with an uncertainty of typically 2 scfm (9 lb/hr). It is displayed using high brightness LED's with an up-date approximately every 3 seconds, and is available as a 4-20 mA analogue output for remote display. The mixture temperature, absolute and differential pressures or percentage air content can also be displayed on selection and are all available for integration with total plant monitoring systems via RS-232C or RS-485 optional interfaces.

AIM VALIDATION

As part of the validation exercise, the Chell AIM was firstly installed in a test pipeline where it was exposed to controlled flow rates of dry air under vacuum conditions. Step changes in flow rates of air were induced through calibrated nozzles installed on a manifold at the head of the pipeline. The AIM followed precisely these steps up to 90 scfm (400 lb/hr). Due to the nature of the rig, the absolute pressure in the pipeline increased substantially with each additional airflow until it went beyond a sensible limit for these tests. So the next step was to install the monitor in the air extraction line of a power plant turbo-generator unit with real steam/air mixtures.

National Power, the UK's major power utility, offered several sites for the instrument to be installed and validated. The mutual objectives were to observe the monitor's response to changes in air leakage rate, establish its absolute accuracy, and confirm its reliability and robustness for long term Installations in the field.

To observe the AIM'S response to changes in air flow rate, it was agreed with the utility to bleed known values of air into the condensing plant. This would also possibly provide a means of checking the 'as-found' or initial level of air leakage to the plant. It has been suggested by Bloomer ([reference 3](#)) that by plotting the partial pressure of the air in the air suction pipe against each additional air bleed and extrapolating back to the intercept with the air bleed axis, the initial value may be found, [Figure 4](#).

At the first site installation, air was bled into the condenser using calibrated sharp-edged orifice discs. Spot measurements of total air ingress taken from the AIM gave resultant increases, which followed the step changes remarkably well. [Figure 5](#), but the extrapolation method described above fell short of confirming the AIM indicated initial ingress rate of 66 scfm (310 lb/hr). The Bloomer method suggests that the extrapolation should be a straight-line extrapolation, but this is only likely to be true if the air suction temperature remains constant and other plant variants do not affect the air suction pressure – a feature fortuitously often experienced by Bloomer. Here, the resultant data gave a curve to the air partial pressure plot, making extrapolation unreliable.

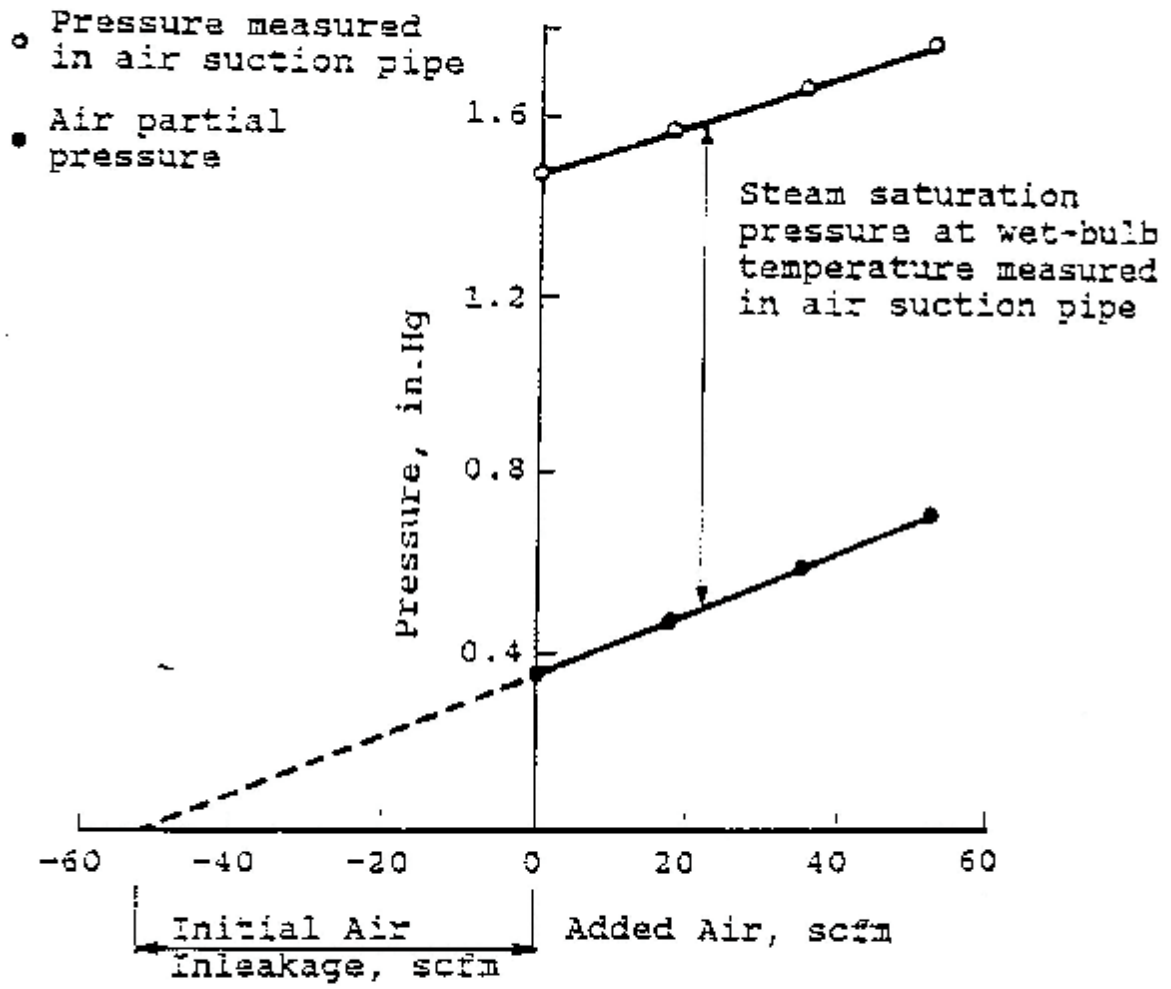


Figure 4. Extrapolation method of measuring air inleakage rate

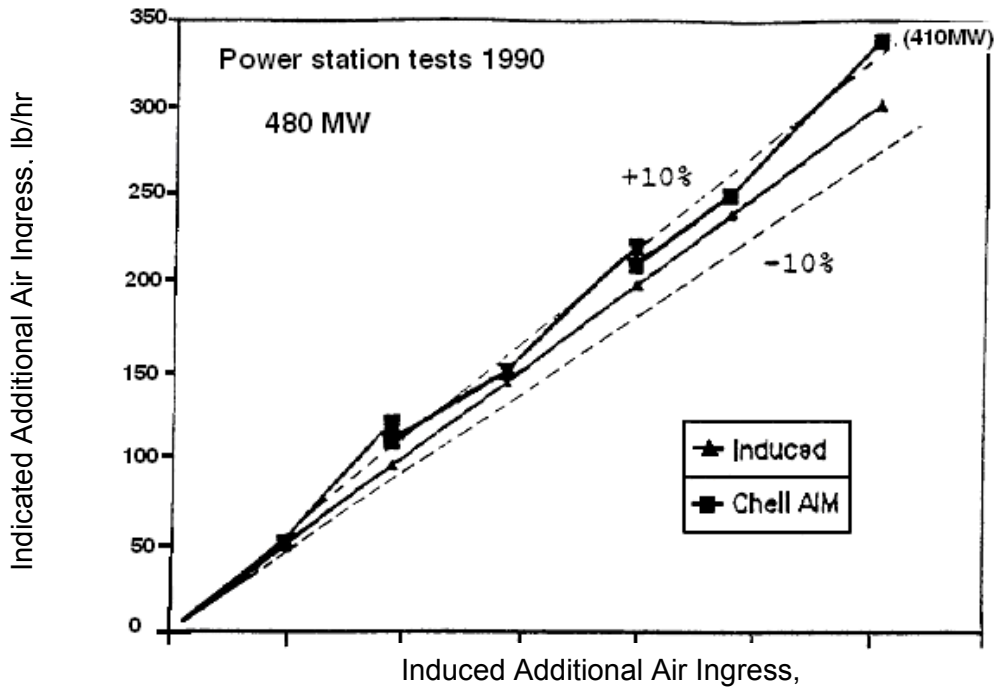


Figure 5. Comparison of the Chell AIM with additional air bleeds via choked orifices

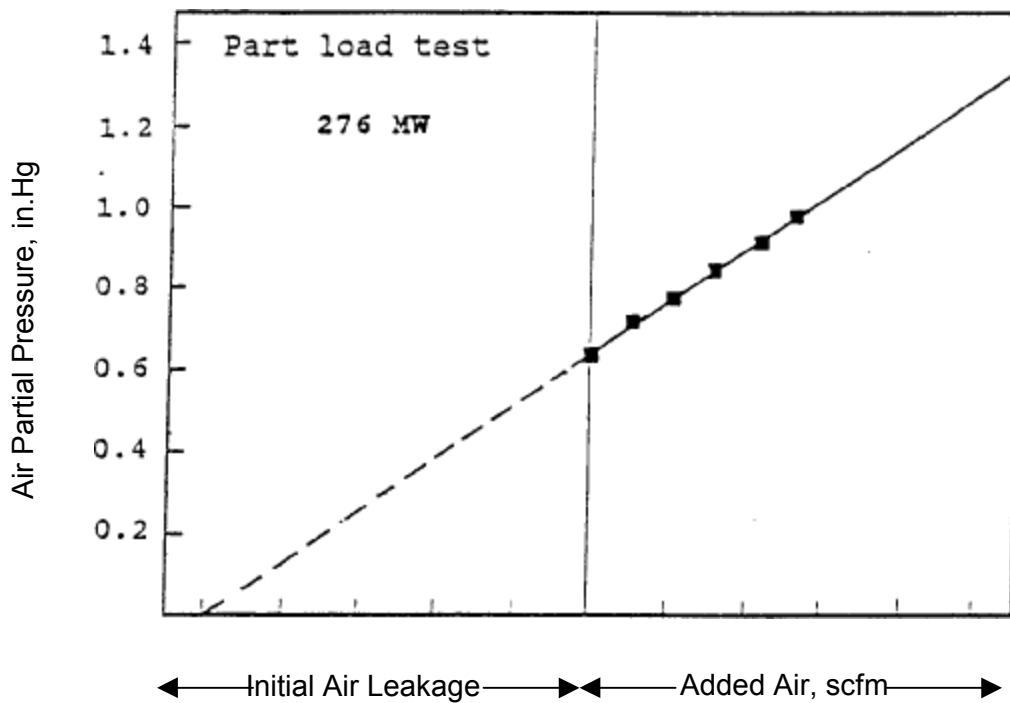


Figure 6. Estimate of initial air leakage using extrapolation method.

At a second site installation the air bleed test was repeated at part load (276 MW) as well as full plant load (507 MW). Changes in airflow rate deduced from averaged spot readings of the AIM corresponded satisfactorily with the bleed values, but at full load, the extrapolation technique again produced a slight curve, which could not convincingly be extrapolated. However, at part load a straight line data set gave an intersection of 96 scfm (440 lb/hr), encouragingly close to the AIM indicated value of 98 scfm (446 lb/hr), Figure 6.

It was also fortuitous that Helium injection, dilution and detection technique was being evaluated for air mass flow measurements under vacuum conditions at the same time as these tests. Despite saturation problems in the sensitive detection equipment as the test progressed, the initial Helium measurements of air flow rate were similar to the AIM at full load.

Additional installations have been set up to observe the AIM performance with various extraction pipe geometries and to monitor its robustness for long term installation. It goes without saying that the choice of installation position for the averaging pitot is important. Locations near branch pipes and bends are to be avoided and if it is suspected that the steam/air ratio is high or there is a lot of suspended water in the flow, the pilot should be installed for good drainage. Component durability has not been a problem over the 2-year period that the monitors have now been in service.

PRESENT APPLICATIONS

There are currently 12 power generation sites in the UK that have these instruments, some with multiple units, 5 sites in the US, and 2 further sites in Canada. A mix of permanently mounted and portable units are employed.

The fixed installations give a continuous display that not only keeps the plant operator advised of the current air inleakage rate but can be used to follow trends, particularly over periods of time that may influence the inleakage rate; for example part-load operation, or repair/maintenance procedures relevant to the plant, including of course air leak searches.

The portable version is attractive when several sensing heads are required to monitor the total airflow from a condenser, but it is not economic to have the processor on each head. Quick connect fittings allow an operator to walk round the plant with a portable processing unit and obtain spot measurements at each location.

Portability has also proven useful in a diagnostic application. Spot measurements with a portable AIM through temporary fittings at each of four air take-off points on a condenser in the UK identified an imbalance in the air flow through each extraction pipe. The pressure drop down the pipe with the greatest flow dominated the pressure profile of the whole condensing plant, so effort was put onto tracing the source of the airflow.

As a result of the validation work, present applications and discussions with the plant operators, a second upgraded version of the first commercial unit (the Chell AIM-1) will shortly be available. The Chell AIM-2 will incorporate digital configuration and calibration, Avoiding the need to open the instrument and change internal switches, and will have a self-test routine for increased confidence levels. Particularly useful on the portable version will be a front panel input zero to minimise wastage time to usable readings during the Warm-up period when first switched on.

Finally, during the validation period a useful facility added to the AIM was a limited ability to log and store on-board the measured and computed data. This feature has been improved and is a standard available option with the AIM-2 offering memory for 10,000 sets of readings.

It is now believed the Chell Air Ingress Monitor provides a reliable means of measuring both on-line and for special diagnostic purposes, the air flow rate at specific locations in the air extraction pipework of condensing plant. This can be integrated in several ways with power plant evaluation procedures with the eventual aim of improving the operational performance of the plant.

Patents UK 91 03298.7 and US 07/688,048 are pending on this technique.

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