Evaluation of pipeline-drying techniques

by Andrew J Barden[1], Marvin D Powers[1], and Philip Karklis[2]

[1]Nowsco Pipeline Services, Inc, Houston, TX, USA
[2]Nowsco UK Ltd, Northampton, UK

The Pipeline Pigging Conference

Hilton Hotel
Jakarta, Indonesia

May 27-30, 1996

Organized by
Pipe Line & Gas Industry
and
Pipes & Pipelines International
with the support of the
Australian Pipeline Industry Association

EVALUATION OF PIPELINE-DRYING TECHNIQUES

INTRODUCTION

Pipeline drying and, in broader terms, pipeline precommissioning, can have a significant effect on both the short- and long-term reliability of a pipeline system. It comes at the completion of construction and is the final, often-overlooked, preparation of the pipeline before it enters service. In many instances it is the last time that the internal condition of the pipeline system will be considered for several years, and in many cases that next time is too costly and too late. The pipeline that was put into service dirty and wet will have corroded, eroded, the isolation valves won't seal and it will have probably cost between 5% and 10% more to operate in the intervening years due to poorer flow characteristics. Combined with the end user customers who are dissatisfied with poor-quality, below-spec., product, this begs the question "Shouldn't these problems have been sorted out before we put this pipeline into service?" The answer is undoubtedly 'yes', and this paper will attempt to evaluate the different techniques available.

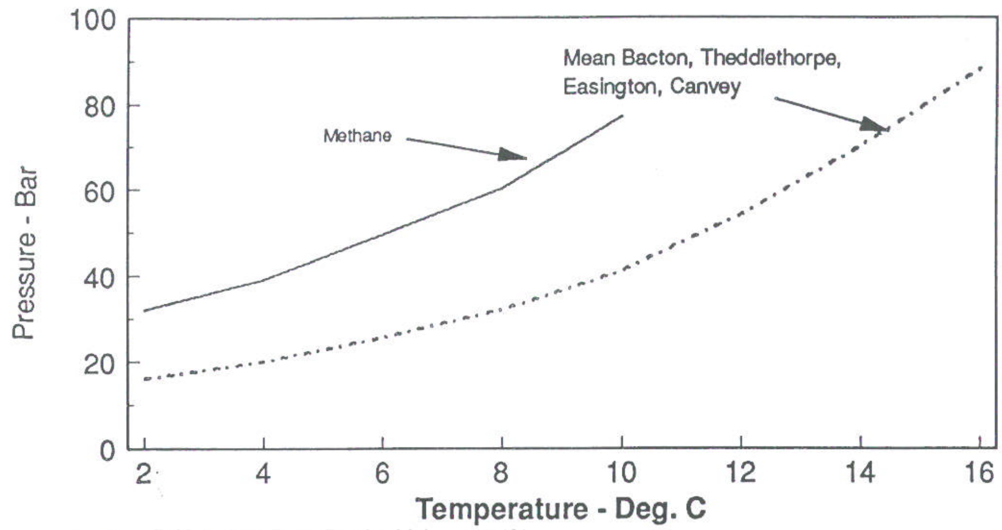
WHY DO WE NEED TO DRY GAS PIPELINES?

There are a number of reasons why gas pipelines need to be dried and these vary, depending on the product and its use.

Many gas pipelines need to be dried to prevent hydrate formation. This applies not only to natural gas but to products such as ethylene, carbon dioxide, ethane, etc. Hydrate is a white crystalline substance formed at a combination of pressure and temperature which causes the gas to react with water. It will typically appear as snow in a pipeline and can easily occur in sufficient quantities to block a line and, in particular, to cause valves, regulators, and instrument pipework to freeze. Fig.1 shows a typical hydrate-formation curve for several gases and their pressure and temperature dependency. Hydrates will easily decompose by increasing the temperature or decreasing the pressure.

Many products react with water to form acids and other corrosive compounds which would very quickly corrode the steel of the pipeline. This is the case with pipelines carrying chlorine, carbon dioxide, and with 'sour' natural gas which contains traces of carbon dioxide or hydrogen sulphide.

Petrochemical pipelines need to be dried because they are carrying extremely high purity products which are in the intermediate stage of a chemical process which cannot tolerate the presence of water. Such products are ethylene, propylene, and butene.



Source: British Gas Data Book : Volume 1 (A)

Fig.1. Hydrate formation curve for methane and average North Sea natural gas (Ref.1).

The techniques available for drying pipelines fall into two broad categories: (a) those that simply address the prevention of hydrate formation by suppressing the hydrate formation temperature well below ambient temperatures, and (b) those that physically remove all water from the line.

Many chemicals such as methanol, glycol, ammonia and sodium chloride will act as an anti-freeze by lowering the hydrate-formation temperature below ambient; however ammonia and salt will cause other problems with corrosion and for this reason methanol and glycol tend to be the most common drying agents used. These drying agents are typically applied by running a pig train through the pipeline at start-up. This is often known as a swabbing operation.

The techniques in common use for physically removing the water from a pipeline are air drying and vacuum drying. Nitrogen drying has also been used in the past, but the principles of the technique are the same as air drying and it is usually more expensive.

The above techniques specifically concentrate on drying the pipeline, with the exception of the air-drying technique which can include significant cleaning as part of the drying process. With both chemical swabbing and vacuum drying, the cleaning of the line must be addressed as a separate issue. This is normally done as part of the flooding operation either by simply using water and brush pigs (with some success) or, in some cases, by gel or chemical cleaning. This is important in assessing the overall suitability of the technique for the particular application. Pipeline cleaning is another important topic in itself and is not covered fully in this discussion.

Each of the drying techniques is now covered in detail, highlighting the pros and cons of each system.

METHANOL AND GLYCOL SWABBING

Methanol and monoethylene glycol are usually used for pipeline drying operations (or more accurately, for hydrate suppression), but the other alcohols and glycols such as ethanol, propanol, and triethylene glycol can be used just as effectively. Before looking in detail at the chemical swabbing process, let us first take a closer look at hydrates themselves.

Hydrates are a class of compounds known as clathrates; a lattice of host water molecules, with gas molecules in the cavities of the lattice which stabilizes the compound. The hydrate-formation

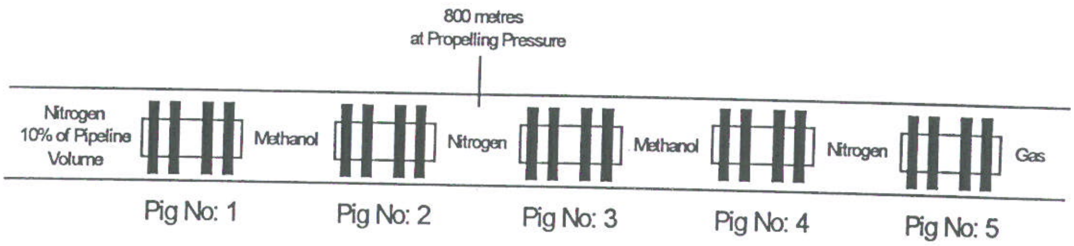


Fig.2. Typical methanol-swabbing train for previously-dewatered pipes.

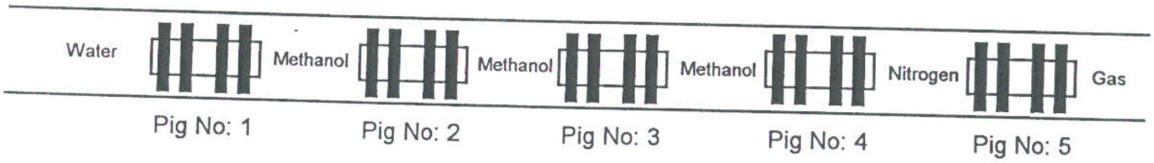


Fig.3. Typical methanol-swabbing train for water-filled pipes.

curves shown in Fig.1 are the minimum conditions of temperature and pressure which must be achieved before the hydrate will form, and usually some seeding or further sub-cooling is required before crystallization will start. Hydrates will only form when water is present in the liquid phase.

The addition of an anti-freeze to the water lowers the hydrate formation temperature in much the same way that it lowers the freezing point of water. The lowering of the hydrate formation temperature is given by the following equation (Ref.1):

$$D = KW/M(100-W)$$

where K = a constant (2335 for methanol)
M = molecular weight (32.04 for methanol)
W = percentage inhibitor in solution by weight
D = lowering of hydrate formation temperature (°F)

Thus it can be seen that a 50% solution of methanol in water will give a 72°F reduction in the hydrate formation temperature which will, in most cases, be well below any likely ambient temperatures.

The chemical-swabbing process consists of running a series of batches of hydrate-inhibiting fluid down the pipeline to absorb the water in the system and leave a film of residual liquid of a high enough concentration of inhibitor such that hydrates will not form. All the hydrating fluids are hygroscopic and fully miscible with water. The process has two main variations, depending upon whether the pipeline is bulk dewatered as a separate operation or whether this is included in the chemical swab.

Onshore pipelines are usually bulk dewatered sectionally as they are hydrotested, and the line will be chemically swabbed upon the completion of all the tie-ins. Here, a five-pig train is typically used (Fig.2). This consists of two slugs of inhibitor which are separated by slugs of nitrogen when the inhibitor is methanol because of its flammability. The fifth pig simply sweeps up residual liquid. The pig train is usually propelled with gas so that the line is commissioned and ready to go straight into operation on completion of the swabbing activity. Alternatively, for smaller lines, the train can be pushed with nitrogen if gas is not available, but this makes the operation more expensive. Air should not be used to propel the train because even if nitrogen is used as a buffer around the pigs, a flammable atmosphere of methanol vapor and air will exist in the rest of the pipeline due to the remnant methanol film. This could easily ignite during subsequent operations.

For offshore pipelines, the swabbing process is usually undertaken as a once-through operation including the bulk dewatering. Here, a pig train similar to that shown in Fig.3 is used. The increase in the number and size of methanol slugs being designed to cope with the greater by-pass of water which can be expected in this situation.

The size of the methanol slug is normally calculated in accordance with an empirical formula (Ref.2) which suggests the following slug sizes:

volume (litres) = 0.7 x dia.(mm) x length (km)

For an onshore pipeline, two slugs of this length would be used, whereas for an offshore pipeline using the once-through approach, three slugs would be used. Whilst this calculation might seem simplistic, the result required is not that difficult to achieve when one bears in mind the effect on hydrate formation temperature as little as a 50% solution will have. The success of the operation is in fact based upon the weight of methanol in the last slug (Ref.2).

Total volume of liquid pigged out from both slugs as a percentage of the volume of methanol introduced %	Weight percent of methanol in each of the last two samples of the last slug. To be not less than: %
60	70
70	65
80	60
90	50

The above methodology can be used to prevent hydrate formation and is often used in lines that are going to be run 'wet' and have methanol injected into the gas stream continuously. It is, however, also possible to use this method as the basis for actually drying the pipeline.

Although the above acceptance criteria allows acceptance with as little as 50% methanol in the last slug, Nowsco has found that levels as high as 95% are common and levels of 99% are not unusual. This means that there is very little free water left in the line and that it will evaporate very quickly as dry gas is fed through the line, usually over just a few days. On large, looped, transmission systems where the facility to mix gas is available, this means that the line can be dried out over a few days, and by mixing with other dry gas, the specification is hardly affected. So whilst the swabbing process does not in itself produce a negative dewpoint condition or a clean pipeline, it is usually feasible to achieve a negative dewpoint in a very short period of time.

It is worth discussing the safety, handling, and environmental issues which are sometimes cited as reasons for not undertaking methanol swabbing. Methanol is a highly-flammable liquid and burns with a colourless flame. It does require special handling precautions, but these are generally no worse than those for gasoline. From an environmental standpoint in countries where methanol reprocessing is available, there is little or no environmental impact at all. Reprocessed methanol is used which is usually delivered to site, injected into the pipeline, collected at the other end with some water contamination, and then delivered back to the supplier to be reprocessed. All the methanol is totally recyclable. The very small quantity of methanol vapor which gets vented into the atmosphere is small in comparison with the amount of diesel exhaust fumes generated by the other drying methods.

The main advantages of methanol swabbing can be summarized as follows:

It is undoubtedly the quickest commissioning method on all but the very smallest pipelines. The duration is governed only by the pigging velocity and hence gas flow.

The length of pipeline that can be dried by this technique is limited only by the capabilities of the pigs. (The longest pipeline in the world was dried using this technique.)

It can be used onshore and offshore, though on larger offshore lines equipment space requirements may become prohibitive.

It is the only method which commissions the line at the same time as "drying" it.
It is still effective in low ambient temperatures.

The main disadvantages of methanol swabbing can be summarized as follows:

Negative dewpoints cannot be achieved using this technique alone, and as such it is not the preferred method for sour-gas lines, high-purity petrochemical products, etc.

Due to the flammability of both methanol and gas, the operation makes the pipeline "live" whereas the other drying techniques are effectively carried out still in the construction phase. This can impact on other activities, especially if hot work, etc., is still required at the worksite.

The flammability of methanol does make the operation more hazardous than the other drying techniques.

AIR DRYING

Air drying is a broad term which can cover a wide range of activities from simply blowing air through the line to running hundreds of pigs through the line. The specific technique which will be covered in detail here is that developed and patented by Pipeline Dehydrators Inc (now a part of the Nowsco group) in the USA. The technique evolved from the drying of high-purity petrochemical and carbon dioxide lines and has subsequently been used extensively on the drying of natural gas transmission lines. The technique is particularly suited to onshore lines which can be dried sectionally, and has the advantage of optionally cleaning the line to a standard higher than the other drying techniques.

The basis of the technique is to run a series of light (2lb/ft^3) polyurethane foam swabs through the pipeline with super dry air with a dewpoint of -90°F. These pigs are launched on a regular basis so that at any one time a long pipeline will contain many pigs. To facilitate this, special low-pressure, quick-action, launchers are used which allow a swab to be loaded and launched in less than a minute and with minimal or no disruption to the flow of dry air. The swabs initially absorb large quantities of water and ensure that water in the pipeline is continually spread out in a thin film, thus facilitating evaporation into the dry air stream. The pipeline dries from the launch end, and gradually progresses in a front down the pipeline. Pigs are usually received in a bottomless receiver thus ensuring that the air is only just above atmospheric pressure. The lower the pressure, the more water vapor the air can absorb, and the quicker the pipeline will dry. The swabs will continue to come out with progressively less water but with the air still saturated with vapor at the ambient temperature of the pipeline. This will continue as the pigs become drier until the dewpoint of the air finally starts to fall. This is actually quite rapid once the free water has been removed. Typically a dewpoint of -20°F is achieved as the pigs are received in a dust dry condition. In addition to measuring this outlet dewpoint, the appearance of the dust gives a strong visual indication that the line is beginning to dry.

At this point all free water has been removed from the line. The line can now be cleaned by removing the rust and millscale from the line as dust. With the line being free of water, no further oxidation will take place, so the line will be left rust free immediately prior to going into service. This cleaning process is achieved by running a series of power brush pigs through the line with the dry air. Usually six such pigs is all that is required.

The power brush pig is very aggressive, being coated with flame-hardened steel bristles approx. 3/8" long. These pigs scratch loosely-adhered millscale and rust from the pipewall, but will not physically remove it all from the pipeline. However, this debris is such a fine dust that it can be readily removed by running additional foam swabs through the line. The swabs are an open-cell polyurethane foam and will readily absorb dust in much the same way that they absorb water. The first swabs to follow the cleaning pigs will push out huge clouds of dust and the dust will not only penetrate but will sometimes saturate the swab to the core.

As the cleaning operation progresses, the dust cloud will slowly diminish and the dust penetration will reduce to a fraction of an inch until eventually the swabs are received in almost the same condition as that in which they were launched. At this point the pipeline will be as clean as physically possible without chemically cleaning the line, and it will typically be dry to a dewpoint of -40°F. This is inevitable as the rust and millscale hold some moisture and trap additional moisture between it and the surface of the steel. So once this water-bearing debris has been removed, the dryness of the line automat7ically increases.

Further reductions in the dewpoint can be achieved by simply continuing to blow air through the line, but for gas transmission lines, this dewpoint is usually adequate as it relates to a water loading of 6.4lbs/MMscf. A typical gas transmission pipeline specification is 7lbs/MMscf. The pipeline is now ready for the introduction of natural gas. The commissioning of petrochemical or volatile liquid pipelines is usually preceded by purging with nitrogen to ensure there will be no flammable mixtures formed during start-up.

It is very important in using this technique to have enough air available to do the job properly, and people often underestimate this requirement. With so many pigs in the line at once, it is important that pigs do not stick or catch each other. A large air flow is critical to avoid this potential problem. This is especially the case with the power-brush pigs which are designed to by-pass, and so can easily stop if sufficient air is not available.

The environmental acceptability of the technique can be improved by using a specially-modified receiving trap fitted with large dustbags. This considerably reduces the amount of dust escaping to the atmosphere. It is important that the dust bags are sized with enough surface area to filter out the dust expected otherwise the bags can become blocked and burst.

The downside of this particular technique is that it is limited in the length of line that can be dried in one section because of the durability of the foam pigs. Drying length limitations are not usually a problem onshore, but give the technique limited use in the offshore environment. However, a variation of the technique which does not use pigs has recently been used, with reported success, by Statoil in Europe to dry one of its major offshore transmission lines.

The main advantages of the air-drying technique can be summarized as follows:

- all free water is removed from the pipeline.
- very low dewpoints can be achieved down to as low as -90°F.
- the line can be cleaned at the same time to a higher specification than any of the other drying processes.
- the process gives relatively-short drying times.
- the process is very efficient in high ambient temperatures.

The main disadvantages of the air-drying technique can be summarized as follows:

- the length of section to be dried is limited. This is dependent on diameter, but for a 30-in pipeline, 100 miles would be a typical maximum.
- a large area is required for equipment on large-diameter lines.
- the technique consumes large amounts of fuel to run compressors.
- the process generates a large amount of debris both in terms of used swabs and dust from the pipeline; however, these can be disposed of in an environmentally-friendly manner.
- the process is not particularly well suited to offshore pipelines.

VACUUM DRYING

The vacuum-drying process, as with the air-drying process, physically removes all the water from the pipeline. In air drying it is blown out and in vacuum drying it is evacuated out. The vacuum-drying process relies on the fact that the boiling point of water varies with pressure, so that whilst water boils at 100°C at atmospheric pressure (1013mbara), at 8.72mbara it will boil at 5°C. So, by reducing the pressure in the pipeline down to the saturated vapour pressure (svp) for the ambient temperature, we can cause the water to 'boil' and remove it from the pipeline as a gas with a vacuum pump.

The vacuum-drying process can be split in to three main phases (see Fig.4):

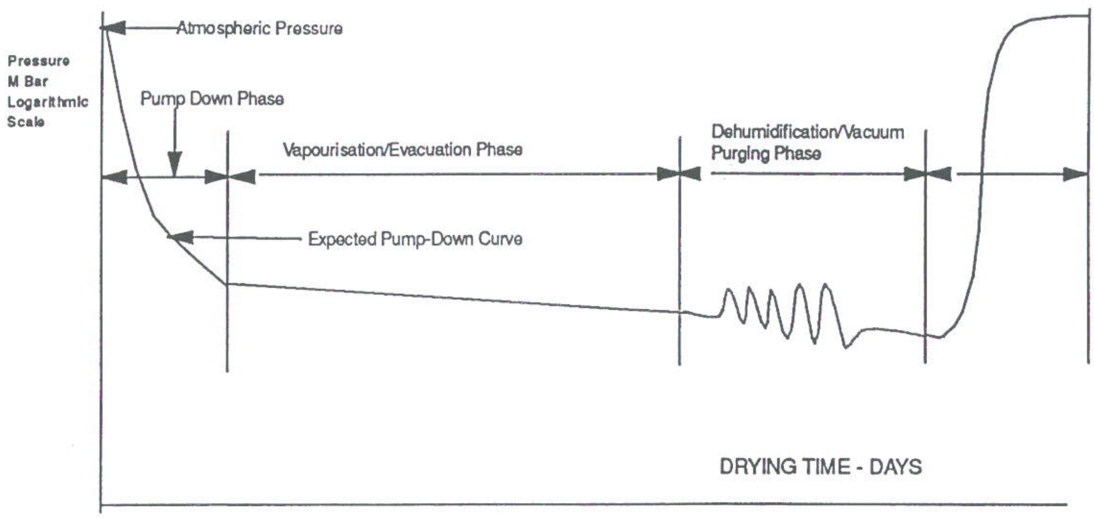


Fig.4. Typical vacuum-drying operation.

---

evacuation - pump down
evaporation - vaporisation
final drying - dehumidification

Evacuation

In the first phase, the pipeline pressure is drawn down from atmospheric to the saturated vapour pressure(svp), which will vary according to the ambient pipeline temperature. During this phase it is mostly air that is being removed from the pipeline. A leak test is usually undertaken during this first phase to check for leaks which should be repaired or, if small and untracable, quantified for later use in the soak test.

Evaporation

As the pressure approaches the svp, water will start to evaporate and maintain the pressure equilibrium. Thus, as the pressure tries to fall, further water evaporates and as such the pressure stays constant. This vapour is sucked out of the line by the vacuum pump and more water evaporates to take its place. This process continues until all free water in the pipeline has evaporated.

Final drying

Once all the free water in the pipeline has evaporated, the pressure will start to fall as there is no more water to evaporate and maintain the equilibrium. All the air in the pipeline has, for all intents and purposes, long since been evacuated, and the pressure in the line can be assumed to be made up of only the vapour pressure of the water. Consequently the pressure in the pipeline can be directly correlated to the dewpoint. A pressure of 1.032mbara is equivalent to a dewpoint of -20°C; therefore, once this pressure has been obtained throughout the pipeline, it is clear that the pipeline is dry. On some long pipelines where friction plays an important part and slows down the drying process, this phase can be modified by purging through a dry gas under vacuum. This can speed up the water-removal rate for this final drying process.

A further check can be carried out in the form of a soak test. Here the pressure is shut-in and monitored for a period of time, typically 24 hours. If any free water is present, then it will evaporate and the pressure will rise back to the svp for the ambient pipeline temperature. It is at this point that the leak test carried out earlier becomes important so that it can be taken into account in evaluating whether water is present. At the end of drying it is possible to introduce product straight into the vacuum which contains basically no oxygen. However, this assumes that product is available, and in many cases the vacuum is filled with inert nitrogen gas to avoid any in leaks. Very-low dewpoints can be obtained by purging with nitrogen under vacuum prior to filling the pipeline.

The vacuum-drying process does require heat input into the system to evaporate the water, as in fact does the air-drying process. This is commonly known as the latent heat of vaporisation. This can be a problem in vacuum drying, as the water has to absorb this heat from the pipeline's surrounding environment, typically soil or seawater. In air drying, the air flowing into the pipeline continually brings energy into the system. The vacuum pumps for the operation must be sized appropriately, so that they are not causing water to evaporate faster than the system can absorb the heat of vaporisation. If this is not done, then ice can form inside the pipeline. This is much more of a problem in low ambient temperatures, whereas in warm climates this is rarely a problem.

Vacuum drying can be undertaken from only one end of a pipeline providing the other end is leak free. As such, vacuum drying is very well suited to drying subsea pipelines or tie-ins, whereas air drying is not. Vacuum drying also tends to require only a small equipment footprint and so although it can take longer to dry a pipeline with this technique, it can be less obtrusive, particularly offshore where space may be at a premium. Most vacuum pumps are also electrically driven so if power is already available, this can be a big advantage.

The way vacuum drying works relies on getting the pressure in the pipeline well below the svp for a particular ambient temperature. Pressure loss in the pipeline can have a big influence on both the feasibility and length of a drying operation, and therefore vacuum drying is not well suited to very long lengths of small-diameter pipelines.

The main advantages of vacuum drying can be summarized as follows:

All free water is removed from the pipeline.
Very low dewpoints can be achieved, down to -90°F (when used with nitrogen purging).
The equipment space requirements are generally very small.
The process produces no appreciable waste (some vacuum pumps produce a little waste oil).
It can be undertaken from one end of the line only, making it particularly suitable for some offshore pipelines.

The main disadvantages of vacuum drying can be summarized as follows:

No cleaning is carried out in the process.
Durations can be very long.
It is unsuited for long, small-diameter lines.

CONCLUSION

The three main drying techniques all have an application in different areas and in different circumstances. Recognizing that, basically, all pipelines will benefit in the long term from some sort of precommissioning, is in itself a major step forward. As well as the technical merit of each system there is inevitably a cost differential between the three systems. These costs can vary so much, depending on location, and length and diameter of line, that it is impossible within the confines of this paper to undertake a meaningful comparison; however, once you have decided you want to dry your pipeline, it is easy to get a contractor to give you a price for performing the different cleaning and drying techniques.

REFERENCES

1. British Gas Data Book: Volume 1(A).
2. British Gas Code of Practice for commissioning new and retested steel pipelines using methanol swabbing BGC/PS/PC1 - Jan, 1980.