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THE CLEANING OF AIR COOLED CONDENSERS TO IMPROVE PERFORMANCE

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ABSTRACT

Air-cooled condensers were first introduced into the U.S. power industry in the early 1970's, but only began to increase in popularity during the last decade. The rising importance of this new and different technology for the condensing of steam has led to the need for a better understanding of the associated design, application, performance monitoring and cleaning requirements.

This paper identifies the basic configuration of air-cooled condensers in the power industry and some of the problems they encounter, especially fouling problems. Monitoring the performance of air-cooled condensers is an important task and the major criteria involved are identified.

To rectify degradations in performance associated with external fouling, a number of cleaning procedures are described. Included among these are details of a new *automated* cleaning technology that has been successfully applied, and some of the performance improvements that have resulted from the use of this technique are presented.

Keywords: Air-cooled Condensers, Performance Monitoring, Cleaning, Maintenance

INTRODUCTION

Over the past 30 years there has been a growing and competing demand for water for both domestic and industrial use and this has brought an increased interest in the use of air as a cooling medium in place of water. In the utility industry, the conventional use of water to condense the exhaust steam from turbogenerators sometimes results in a level of thermal pollution of lakes or rivers that has raised the objections of environmentalists, and has forced some plants (e.g. a combined cycle plant in Athens, NY) to adopt air cooling in order to obtain project approval. Many countries with abundant coal reserves also find mine-mouth power generation very attractive but may not have economically priced cooling water supplies available at those sites. In such cases, dry cooling is very appealing. Thus, some of the advantages in using air for cooling include:

- The ready availability of air – no need for piping or pumping systems
- No environmental impact and few fouling problems
- Air-cooled systems require less maintenance

However, there are a number of important disadvantages, among which are:

- Air has a low thermal conductivity, low density and low heat capacity
- Plain tubes are impractical and heat transfer enhancement by the use of fins is essential
- Air cooled heat exchangers are larger than their water-cooled equivalents and require substantial support structures and a larger footprint
- Where ambient temperatures are high, a large heat transfer area is required
- Fan-driven air-cooled heat exchangers are noisy and may therefore introduce local environmental pollution

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- The cost of an air cooled condenser system tends to be greater than that of a wet cooling tower system of equivalent capacity
- During peak summer conditions a heavy energy penalty may be incurred

Indeed, the EPA has reservations concerning the universal adoption of dry cooling systems due to their comparative inefficiency in heat removal and the associated increase in emissions. However, there are circumstances that make the air cooled condenser the only practical choice.

In the utility industry, the earliest applications for the air-cooled condensing of exhaust steam were modified air-cooled heat exchangers similar to those already in use by the process industries. Eventually, air-cooled condensers designed for the utility industry evolved into a configuration that recognized the special needs of condensing a large volume of low pressure vapor as well as the removal of non-condensibles. Meanwhile, air-cooled heat exchangers are sometimes used to offset the thermal pollution resulting from the cooling water discharge from steam surface condensers. For instance, the Plant Branch station of Georgia Power is passing a parallel stream of river or lake water through a set of air-cooled heat exchangers in which the temperature of the water stream is reduced by as much as 20 Deg.F. (Blankinship, 2001)(1)

AIR COOLED CONDENSERS

The current configuration of air-cooled condensers has evolved into the typical A-frame design of Figure 1.0 originally developed by GEA Energietechnik Gmbh. Berger(1992)(2) indicates that not only does this design facilitate condensate draining and collection but it also ensures that there are no dead zones in the heat transfer surface, that there is a high operating stability during load transients, while it also eliminates freezing even with ambient temperatures as low as –58 Deg.F (-50 Deg.C). Note that three panels in the center of the condenser constitute the deaerator and counterflow condenser and are of a different design from the parallel flow condenser panels located on either side of these center panels.

Figure 2.0 shows those sections in which the panels on both the left hand and right hand sides of the condenser consist of parallel flow condenser sections only. The exhaust vapor from the low pressure stage of the turbogenerator is brought to the upper header and between 70% and 90% of the vapor condenses in these parallel flow tube banks, the condensate and vapor flowing downwards together into the lower header. A duct connects this header to the lower header of the right-hand bank of tubes and the condensate from both tube banks is collected in the duct, from which it is withdrawn for recirculation back to the turbogenerator system.

Figure 3.0 shows those sections in which the tube banks are of the counter flow condenser type (otherwise known as a dephlegmator or, alternatively, deaerator). Ducting also connects the two lower headers of these panels together and residual vapor from the parallel flow condenser flows through this duct and upwards into the counterflow condenser, the condensate from this vapor flowing downwards. Connected to the upper header of the counterflow condenser is a steam jet ejector, by means of which any non-condensibles accumulating in this header are evacuated from the condensing system.

Since the use of air for cooling eliminates the use of local water, the cost of cooling water and its treatment are avoided.

Against this advantage must be weighed the large diameter exhaust steam piping which is difficult to accommodate; while the extended volume of the system under vacuum makes it more prone to air inleakage and also extends the time required to evacuate the system during startup. Further, to minimize the pressure drop, the condensing units must be located close to the turbine.

Another disadvantage is that the fans on air-cooled condensers can be noisy and the noise level from a particular unit should be investigated during the design stage, as well as the noise levels from fan belts, gear boxes and similar features of the installation.

Fouling Tendencies

The external surfaces of the finned tubes on air-cooled condensers are very prone to fouling from pollen, dust, insects, leaves, plastic bags, bird carcasses, etc. Not only is the air flow affected but also the heat transfer coefficient, the deterioration in performance increasing unit operating costs. In severe cases, fouling can also limit the power generation capacity of the turbogenerator.

Further, under high ambient air temperatures, operators will sometimes spray water on the heat exchanger to reduce surface temperature. Unfortunately, depending on the quality of water used, this sometimes leads to a new scale formation on the tube fins. Note that air-cooled condensers operated in this way are not to be confused with Wet Surface Air Cooled Condensers, the behavior of which is to be discussed in a forthcoming issue of ASME Power Test Code PTC.23(3).

PERFORMANCE CALCULATION PRINCIPLES

Several standards exist for calculating the performance of air-cooled heat exchangers and it would seem to be approaching an exact science. Among these standards are ASME PTC.30(4), API Standard 661(5) and

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the Standards for Air-cooled Heat Exchangers published by the Air-cooled Heat Exchanger Manufacturers Association(6).

However, there are no standards at this time for calculating the performance of air-cooled condensers, nor can the standards for air-cooled heat exchangers be applied. One main difference is that, while air-cooled heat exchangers with their fans are built as discrete units, the fans provided with air-cooled condensers are not uniquely associated with a corresponding bank of tubes. Thus, when a fan is switched off or its speed reduced, not only is the air flow to all tube banks in the condenser reduced but the distribution of the air among the tube banks can also change. Some air-cooled condensers are also equipped with programmable logic systems that adjust fan speeds, vanes, etc. automatically to ensure that subcooling of the condensate does not occur but this, again, affects the distribution of the air. Fouling of the tube surfaces can also affect air distribution. Finally, local meteorological and ambient conditions have their own effects on the performance of air-cooled condensers.

Kroger(7) outlines in detail a method for calculating the performance of air-cooled condensers from first principles, based on an extensive knowledge of the condenser design data. Unfortunately, this data is not readily available and the calculations are complicated. The following is, therefore, an attempt to gage the performance of air-cooled condensers empirically, using a selected set of operating conditions as the frame of reference.

It is suggested that there be two references cases, both assuming that the turbogenerator is running at full load. Case(a) would be with all air-cooled condenser fans running at full speed and Case(b), also with the turbine at full load but with the fans running at half speed. The reason for having two reference cases is that, in cold weather, it may not be desirable to run the fans at full speed. The condenser should be calibrated when clean for both of these cases, using at least the set of instrumentation indicated in Figure 4.0, the values being averaged across all banks. Among the criteria to be captured for the reference cases, against which subsequent performance can be compared, are:

- Pressure of air at inlet to tube banks - P_{ai}
- Pressure of air leaving tube banks - P_{ao}
- Pressure drop across the tube banks –
  $\Delta P_{tb} = P_{ai} - P_{ao}$ (1)
- Corresponding air inlet temperature - T_{ai}
- Corresponding air outlet temperature - T_{ao}
- Vapor saturation temperature - T_s
- Condenser backpressure - P_s
- Pressure of air at fan inlet - P_{fi}
- Pressure of air at fan outlet - P_{fo}
- Pressure drop across the fans -
  $\Delta P_{fan} = P_{fo} - P_{fi}$ (2)
- Fan speed - N_{rpm}
- Condenser duty –
  $Q = W_{cond}*(H_{vap} - H_{liq})$ (3)
- Ambient air temperature - T_{amb}
- Effective modified heat transfer coefficient:
  $U_{mod} = A_{eff} * U_{eff}$ (4)

Using this combined function means that the effective surface area of the tube banks does not need to be known. Assuming that the log mean temperature difference can be calculated from:

$$LMTD = (T_{ao} - T_{ai}) / \text{logn}((T_s - T_{ai}) / (T_s - T_{ao})) \quad (5)$$

Then $$U_{mod} = A_{eff} * U_{eff} = Q / LMTD \quad (6)$$

Meanwhile, the operating data can be presented in several ways:

- One curve that is often available is shown in Figure 5.0, in which the condenser duty is plotted against inlet dry bulb temperature for various values of condenser backpressure. The curve in Figure 5.0 is used when all fans are running at full speed and a similar but different curve is usually available for fans running at half speed. These are in fact condenser capacity curves and can be calibrated against measured conditions when the unit is first started up and while the finned-tube banks in the condenser are still clean. Putman(8) has shown how, subsequently, current condenser duty can be calculated from present backpressure and turbogenerator load, using the low pressure stage expansion lines included in the thermal kit data provided by the manufacturer of the turbogenerator. This may be compared with the condenser duty calculated in accordance with equation (3) above.

- Another form of data presentation is shown in Figure 6.0, in which condenser backpressure is plotted against the percent of design air flow and for various values of the ambient air temperature. The air flow can be estimated from fan characteristic curves using the pressure at the inlet to the tube banks mounted in the A-frame. The actual backpressure can then be compared with that expected at 100% air flow for the current ambient air temperature. The avoidable condenser loss corresponding to this deviation in backpressure can be estimated using, again, the expansion lines included in the thermal kit

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data for the low pressure stage of the turbogenerator.

Of course, the performance of an air-cooled condenser can become degraded not only by the external fouling of the finned tubes but also by any internal fouling from the condensate (e.g. ammonia corrosion) or by air ingress into the condensing vapor. Harpster(9) has suggested a way of distinguishing between the effects of fouling and air ingress, using instrumentation applied to the air removal system, injecting known amounts of air or nitrogen into that part of the system operating under vacuum and noting the change in effective heat transfer. The air removal system instrumentation can subsequently be used to estimate the contribution of air ingress to the change in the effective heat transfer coefficient.

CLEANING TECHNIQUES FOR AIR-COOLED CONDENSERS(10)

The three principal methods for cleaning the external surfaces of air-cooled condensers are as follows:

- Fire hose
- High pressure handlance
- Automated cleaning machine

Fire Hose

While the volume of water consumed is high, a fire hose offers only a low washing effect because of the low pressure involved. The galvanized surfaces of the tubes and fins are not damaged by this method. Unfortunately, in order to perform cleaning the plant must be taken out of service and scaffolding erected. The process may also be time and labor intensive depending on unit design and accessibility.

It has also been found that use of the fire hose only leads to small performance improvements even if the surfaces seem to be optically clean. The reason is that only a portion of the fouling material is washed off while the remainder is pressed between the fin tubes and can not be washed out by this method. Furthermore, once compressed, the fouling material not only hinders heat transfer but also obstructs air flow.

High Pressure Handlance

The high pressure handlance method offers low water consumption and a high water pressure. Unfortunately, the latter can cause the galvanized surfaces to become damaged or even cause the fins to be snapped off. Again, the plant must be taken out of service and scaffolding erected in order that cleaning can be performed. Unit accessibility will affect cleaning productivity.

As with the use of a fire hose, this procedure only leads to small performance improvements and, once the fouling material has been compressed, it hinders heat transfer and obstructs air flow.

Automated Cleaning Machine

The automated cleaning machine, an example of which is shown in Figure 7.0, uses a significant volume of water; but at a pressure that, while allowing for effective surface cleaning, avoids damaging galvanized surfaces and fins. The main components of the system include a nozzle beam, a tracking system, and a control panel. The water contains no additives. The nozzle beam is optimally matched to the tube bundle geometry, with a constant jet angle. Optimizing the geometry of the nozzle beam involves determining the proper nozzle distance to the surface, the jet energy and the selection of the appropriate nozzle design. Variations in nozzle beams are shown in Figures 8.0 and 9.0. The constant jet angle also ensures that there is no damage to or snapping off of tube fins, regardless of the material from which they are fabricated. Furthermore, the carriage on which the nozzle beam is mounted moves at a constant speed and so allows the fouling to be removed effectively and uniformly across the heat exchange elements of the condenser. Because the fouling material is removed, air flow is no longer obstructed.

An important advantage of the automated cleaning method is that cleaning can be performed during operation while the unit is still on-line. Further, there is no need for scaffolding and labor requirements are minimized.

The automated cleaning system can be applied in three principal forms:

a. Permanently installed system complete with PLC controls, one system being supplied for each side of the condenser as previously shown in Figure 7.0.

b. Semi-automatic system in which only the guide rails are permanently installed, the nozzle beam carriage being moved from section to section as the cleaning progresses as shown in Figure 10.0.

c. Portable service unit, together with a portable nozzle beam carriage and control unit. The cleaning service is performed in-house or by a qualified service provider as shown in Figure 11.0.

PERFORMANCE IMPROVEMENTS FROM CLEANING

Data from several power plants equipped with air-cooled condensers show that, after cleaning to remove external fouling, it was possible to operate the unit with the fans running at half-speed rather than full-speed.

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The lower auxiliary power consumption resulted in a reduction in operating costs.

In another plant, condenser cleaning resulted in the generated power rising from 15 MW to 18 MW.

To clean an air-cooled condenser installed in a 400 MW power plant located in the United Kingdom, a semi-automatic cleaning system was used. An analysis of the heat rate deviation curve for this unit showed that a 1 in.Hg improvement in turbine back pressure was equivalent to savings of $188.00/h accompanied by an increase in generation capacity of 4 MW.

Turbine back pressure before cleaning = 3.40 in.Hg.
Turbine back pressure after cleaning = 2.62 in.Hg.
Back pressure reduction = 0.78 in Hg.

Savings at a 75% load factor

= 0.78 * 188.00 * 7 * 24 * 0.75 = $18,476/week

The data was taken at an ambient temperature of 59 Deg.F and it was found that the air flow before cleaning was 78% of its design flow rate.

CONCLUSION

In the power industry, the reduced availability of water as the cooling medium for the condensation of exhaust steam, combined with an increased emphasis on environmental considerations, has made the selection of an air-cooled condenser a viable alternative to the traditional steam surface condenser. Although their capacity is sometimes limited by ambient conditions, their selection can avoid a number of other problems, not the least being acceptance by permitting authorities. Further, because the external surfaces of the finned tubes on the air-cooled condenser are prone to fouling, an effective cleaning system is required. One such system has been demonstrated. Finally, there is a need to develop new standards for acceptance test procedures and for calculating their performance under a variety of operating conditions.

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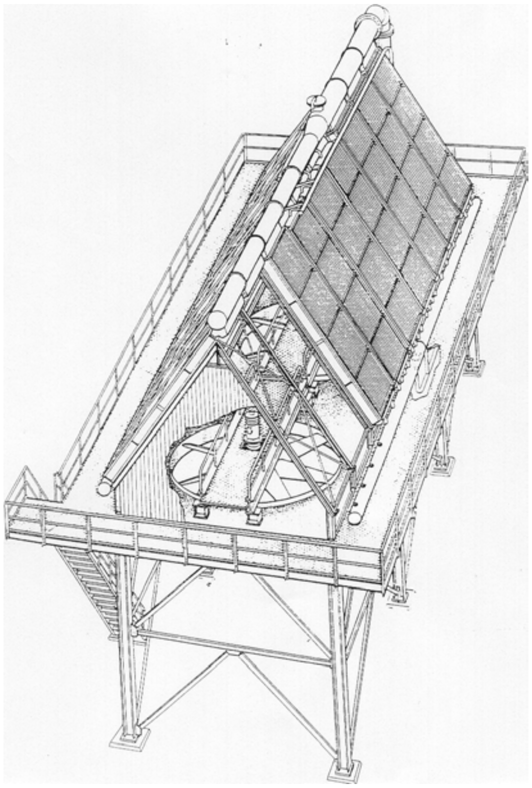
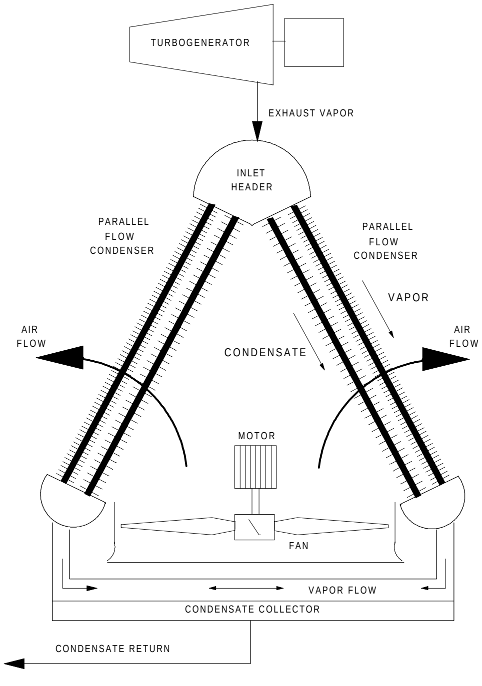
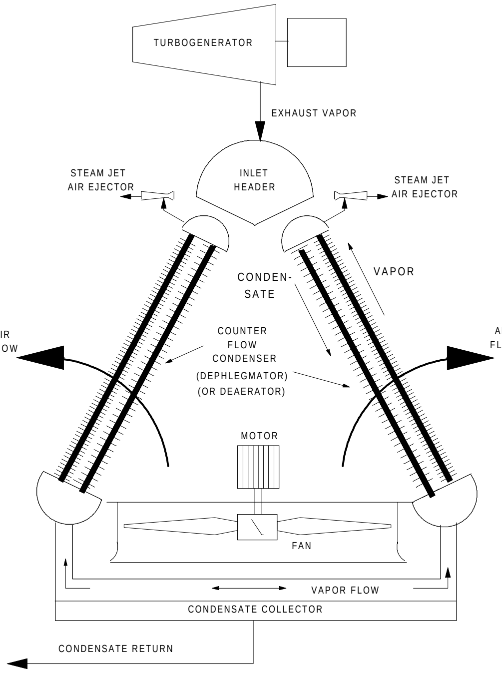


Figure 1.0 – General View of Air-cooled condenser



AIR-COOLED CONDENSER
PARALLEL FLOW SECTIONS
FIGURE 2.0



AIR-COOLED CONDENSER
DEAERATOR SECTION
FIGURE 3.0

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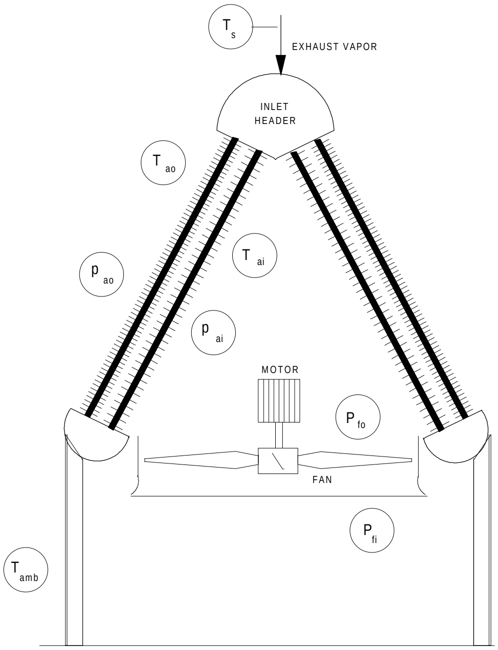
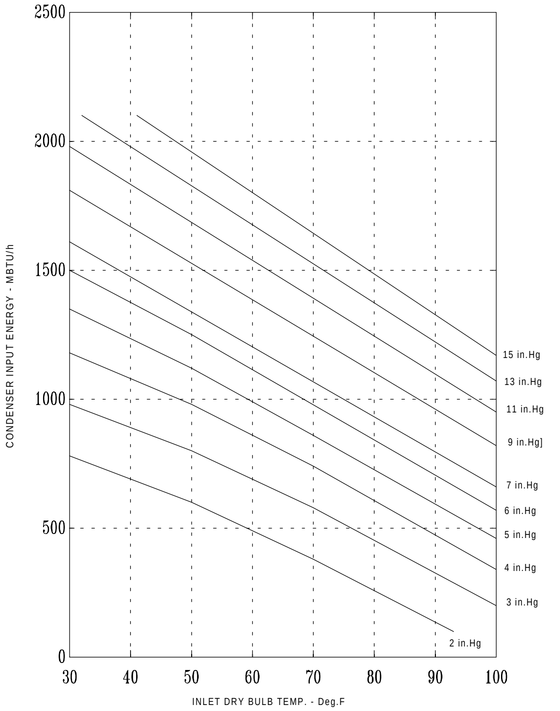


AIR-COOLED CONDENSER

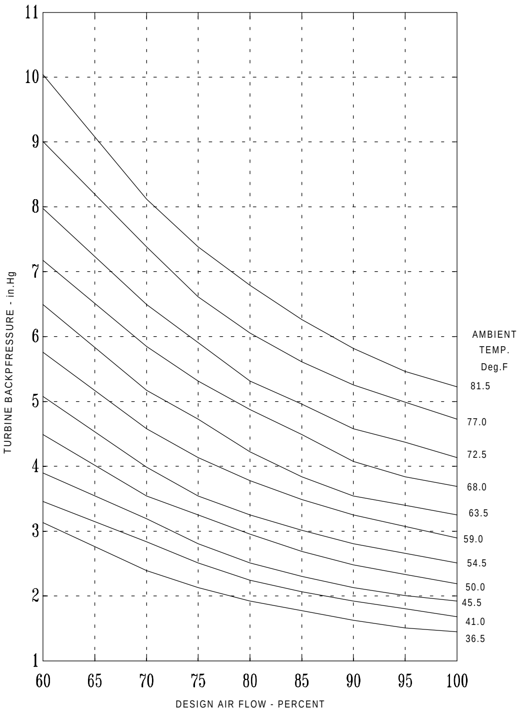
INSTRUMENTTAION

FIGURE 4.0



CONDENSER CHARACTERISTICS
ALL FANS AT FULL SPEED

FIGURE 5.0



CONDENSER BACKPRESSURE CHARACTERISTICS

FIGURE 6.0

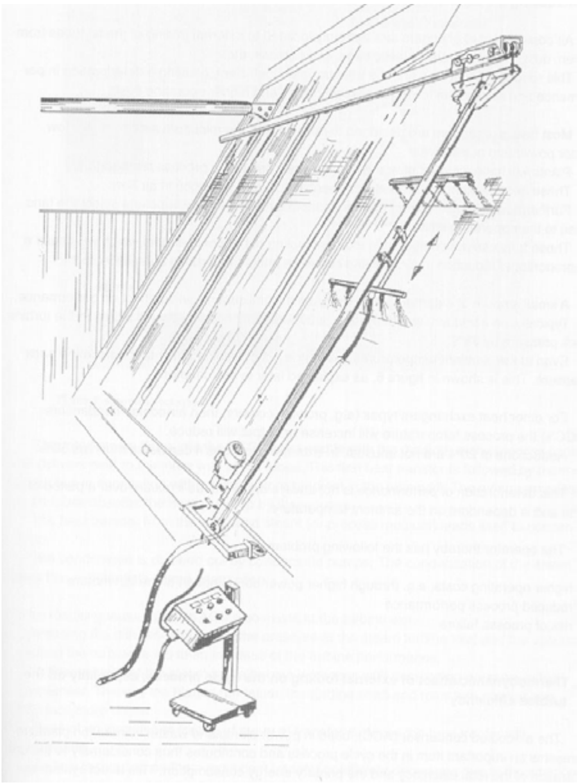


Figure 7.0
Automated Cleaning Machine

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Figure 8.0 Variation in Nozzle Beam

Figure 9.0 Variation in Nozzle Beam

Figure 10.0 Semi-Automated System

Figure 11.0 Portable System

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