GAS CLEANING

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Gas cleaning is one of the oldest processes that condition natural gas for market. Also it is the most neglected and ignored of the gas conditioning processes, but not without cause. No management group will admit to selling dirty gas. Like the itch, no one admits the affliction and to even discuss the possibility is to be indelicate! It has seemed reasonable to assume that if dirt cannot be seen, then it does not exist--a comforting assumption which, unfortunately, is untrue.

Every operating gas company has pipeline dirt problems and these vary only in the degree of severity. Usually, they are called by other, more palatable names such as low transmission efficiency, scored cylinders, oil-poisoned adsorbent, excessive lube oil consumption, poor measurement, entrainment losses, et cetera.

Since the early days of the industry, gas scrubbers have been used for the intended purpose of removing extraneous material from gas. The term "scrubber" derives from the early belief that gas needed to be washed with oil to be clean. Scrubbers have been built in a variety of forms and their performance has ranged from poor to acceptable. In an effort to distinguish between these and the more recent devices that are truly capable of fine separations, the latter are called "gas cleaners."

Gas cleaners have attained a reasonably advanced state of development although significant improvements would be welcome at this time. They are to be found in increasing numbers protecting compressor stations, pipelines, town border stations, injection wells and processing plants. But many older scrubbers, and some newer ones, need to be rebuilt or replaced.

Pipeline Dirt

Pipeline dirt is defined here as all matter other than gas in a gas mixture. It may comprise solids, or liquids or both. Fine particles of solid matter may be dispersed in gas as a powder, or they may be dispersed in water or hydrocarbon liquid as a slurry. Some solids that have been identified include formation cuttings, drilling mud, desiccant dust, construction dirt, sand, mill scale, red iron oxides, iron carbonate, iron sulfide, welding slag, eroded steel cuttings, salt crystals, plug valve grease, et cetera.

Liquids found in gas pipelines include free water, hydrocarbon condensate, crude oil, absorption oil, glycol, amine solutions, lubricating oil et cetera. These collect in sags in the line and are moved downstream in slug flow by the gas as more liquid collects. Slugs can be removed with relative ease in line drips or scrubbers before they travel far in pipelines and gathering systems. Of greater concern is the removal of very finely dispersed matter, known as "particulate matter", which is carried by a flowing gas stream. Dispersions of liquid particulates are often called "aerosols."

The concentration of pipeline dirt in a flowing gas stream may be so small that it escapes notice. In well-maintained pipeline systems, dirt may move at a rate of two pounds per million standard cubic feet. So a major pipeline system handling one billion cubic feet per day would move one ton of dirt. In severe cases, the dirt content may range upward to 400 pounds per million cubic feet. Dirt movement is continuous and its concentration varies as system loads change. Pipeline operating techniques often include on-stream "pigging" to maintain maximum flow efficiency and this is backed by adequate scrubber capacity at receiving, compressor and border stations. However, substantial quantities of very small particulates pass on through most of these devices to accumulate in distribution systems and create one of the industry's most vexing problems.

Pipeline dirt problems are easy to ignore because fine particulate matter cannot be seen with the naked eye. Yet these materials are the cause of such difficulties as broken compressor valves, scored cylinders and rods, low transmission efficiency, poor measurement, erosion of regulators, fouled appliance controls and plugged pilot lights. Unfortunately, no method has been developed for absolute measurement of the particulate content of a flowing gas stream despite sustained efforts by the American Gas Association, operating companies and manufacturers. Evaluation of gas cleaner effectiveness depends on operating records and a variety of relative measurement methods that have never been standardized and are subject to question.

Particulate Size and the Micron Scale

In order to grasp the pipeline dirt problem, a realistic concept of the size of particulates is necessary. Here the micron scale is useful. One inch equals 25,400 microns and one millimeter equals 1000 microns. Rarely is it possible for the human eye to see a particle that is ten microns in diameter without using a good magnifying glass or microscope.(2)

An average strand of hair is approximately 100 microns in diameter. A No. 200 sieve mesh will pass a 74-micron particle while a No. 400 mesh sieve will pass one of 37-micron average diameter. White blood cells of humans average 25 microns diameter while red blood cells are slightly less than eight microns diameter. Particulates larger than 10 microns in diameter are said to be coarse. Smaller sizes are called "fine" particulates.

Fine particulates may accumulate in sufficient quantity to be seen as a cloud because, in aggregate, they reflect light. Tobacco smoke is a common example of a dense dispersion of particulates whose diameters range from 0.25 to 1.0 microns.

With these criteria in mind, it should be noted that the best contemporary gas cleaners can remove virtually all particulate matter of 4-micron diameter and larger. Aerosols are more difficult to remove than solids and some recent advances in demisting techniques have reduced the diameter of particulates removed below 4 microns. Pad-type or cartridge filters have capabilities in the order of 1.0 micron diameter and larger where dirt loading requirements are small and where no aerosols are present in the gas. While these figures may seem impressive, recent studies (4,6) on dust problems in distribution systems indicate that the size distribution of the particulate matter ranges from 0.5 to 2.0 microns average diameter. It follows that effective removal of particulate matter in this range must be the goal of designers and users of gas cleaning facilities.

Mechanisms of Separation

Pipeline dirt is separated from flowing gas streams by several mechanisms which include gravitational settling, centrifuging, impingement, and diffusion (1, 10). Gravitational settling assists in the removal of large particles of pipeline dirt and it is augmented to a considerable degree by application of centrifugal force and centrifugation plays a significant role in causing fine particulates to impinge on collection targets such as fine fibres, wires and aerosols. Warner and Scauzillo (9) have shown that diffusion plays a significant role in the removal of aerosols classified as fine particulates. Ionization techniques have not been applied to natural gas cleaning because of safety considerations. Sonics have been employed to coalesce particulate matter in laboratory studies but no instance is known where this technique has been applied to cleaning pipeline gas.

In addition to the mechanisms listed above, filtration is a principal mechanism for removing solid particulates. However, filtering devices are not effective for removal of aerosols.

Contemporary Gas Cleaning Equipment

Contemporary gas cleaners may be classified into five basic types: gas-liquid separators, coalescer-separators, oil-bath scrubbers, centrifugal scrubbers and dust filters. All types may assume the physical form of a vertical cylindrical vessel, a horizontal cylindrical vessel or a sphere as dictated by the application and by the design details of the internals. The better versions of all types employ a primary separation section to remove the bulk of the coarse particulates and minimize the dirt loading on the fine separation stage in whatever form it may appear.

Basic differences in these five types are to be found in their fine separation stages. In gas-liquid separators, fine separation is effected by means of a highly efficient mist eliminator. In some forms, this mist eliminator may also function as a filter of sorts for solid particulates which, if allowed to accumulate in excessive amounts, may plug the element, make its primary function ineffective and, ultimately, result in its destruction.

In coalescer-separators, fine separation is accomplished by passing the gas through a high-density fibre mass at a velocity sufficient to impinge the fine aerosol on the fibres to form larger droplets which are blown off the downstream side of the coalescer. Larger diameter particles can be caught more effectively by the mist eliminator set downstream from the coalescer element. The coalescer may be either a fibrous pad or a replaceable cartridge. Most pads are removable and can be cleaned and returned to service. Cartridges can be back-flowed three or four times prior to replacement. Where solid particulate matter is present, either dry or in slurry form, the coalescer functions as a filter to remove this material but, unless removed, it will plug the fibrous mass, increase the pressure differential across it and, ultimately, result in its destruction. A recent development is the use of a blotting stage between coalescer and mist eliminator to unload the latter and increase its effectiveness (7).

Oil-bath scrubbers are one of the oldest forms still in use. They are designed to clean gas by impinging solid particulates on wetted surfaces or on aerosols whose average diameters are only slightly larger. The objective here is to make a slurry from the solids, to reject these by settling and to return the liquid to the contact zone for recirculation. Since most scrubbers of this type are self-energized and are circulated internally, the oil employed rarely has opportunity to settle its dirt. Comprehensive tests on scrubbers of this type have revealed that clean oil must be used if clean gas is to be produced (3). This is done best by an external circulating system which provides space and time for settling, followed by full-stream filtration of the liquid prior to its return to the scrubber. An effective oil-bath scrubber must have a highly efficient mist eliminator capable of rejecting droplets which contain solid particulates as nuclei. Because high liquid loading is inherent in the design of these units, mist eliminators are self-washing where clean oil is used but they must be substantial in area to accommodate these loadings.

Centrifugal scrubbers employ multiple cyclones in parallel to remove either solid or liquid particulates as small as four microns diameter under rated conditions of operation (3). Generally known as "Aerotec" tubes, these are relatively small and of standard size which can be semi-mass produced. Each comprises two concentric tubes. The top of the annulus is closed but gas enters the upper annulus via tangential inlets and flows centrifugally downward in the annulus at high velocity. Particulates are expelled from the lower end via a cone nozzle while the carrier gas turns 180 degrees and rises through the inner tube to discharge from its upper end. The vessel must be divided into three compartments by two diaphragms. Dirty gas enters the center compartment, passes through multiple cyclones set in parallel, discharges its dirt into the lower compartment and the clean gas passes through the inner tubes to the upper compartment en route to the vessel outlet. Within the capacity range of the tubes, efficiency appears to be limited by re-entrainment of particulates smaller than four microns diameter. This device functions best where gas flow is constant at design capacity. At higher rates, pressure drop is excessive. At lower rates, efficiency declines rapidly. Units designed for removal of solid matter do not function well on aerosols and vice versa, because of density differences of the particulate phases.

Dust filters employ either fibrous cartridges or pads in pressure cases fitted with by-passes and quick-opening closures to facilitate rapid change of the filter elements. These are made of various materials such as molded fibre glass, felt, cellulose, fine wire and a wide variety of fine-stranded synthetic fibres, all reinforced by wire or by resin impregnation to minimize compaction and resultant pressure differential increase. In cylindrical cartridge form, radial flow is from outside to inside in most petroleum industry applications in order to present maximum filter cake area, maximum dirt-loading capacity and maximum resistance to rupture due to excessive pressure differential. In service, particulates penetrate the fibrous mass until they lodge and form the base of the filter cake that builds on the surface of the element. When flow is reversed to remove the filter cake and reduce pressure drop, the success of this operation depends on removal of the particulates that penetrated the fibres. Effectiveness declines with each successive back-flow operation until the filter element no longer responds and must be replaced. If solids are filtered from a slurry, they are more difficult to remove by back-flowing so the useful life of filter media is reduced where aerosols are encountered. The economic feasibility of dust filters depends on the dirt concentration of the gas and the dirt loading capacity of the filter elements. Applications are limited by the cost of filter replacements and the labor required to change them. High dirt loadings may dictate use of some other type of gas cleaner such as an oil-bath scrubber.

Some of the absolute filter papers developed for the Atomic Energy Commission have been used successfully in filter cartridges for service where solids loading is very light.

Mist Eliminators

Mist eliminators are essential to all gas cleaners, except dust filters, and they must be selected and sized with care. Also, they are used to clean gas from absorbers and to minimize absorbent loss in gasoline plants, dehydrators and various gas treating plants.

The vane type mist eliminator is perhaps the oldest device still used by the industry since it has been available in various forms for more than thirty years. Gas passes through this element in a horizontal direction. Enclosed at the top, bottom and sides, the gas flows through multiple, narrow, vertically-disposed channels, each fitted with a series of alternating vertical vanes which project outward into each channel. Gas flows against the edge of these channels and the baffling effect causes flow to be reversed to pass around the edge. The centrifugal force generated causes the aerosol particulates to impinge on the wetted surfaces of the vanes. These form liquid films which drain by gravity into a sealed catch basin at the bottom of the element whence it drains to the liquid reservoir provided in the vessel. This device can be mass-produced in a variety of unique forms. It is relatively inexpensive, and it has large capacity per unit volume of shell space occupied. It handles high liquid loadings quite well at pressure differentials of 10 inches of water or less.

It has some serious disadvantages. Rarely is it capable of removing aerosols whose diameters are less than 40 microns, so it cannot be considered effective in truly fine separations, even when used with a coalescer designed to produce droplets large enough to be caught by the vanes. Drop size decreases appreciably with flow rate both above and below the coalescer design rate where size reaches a maximum so that such a unit would be quite inflexible. Several instances are known where vane-type mist eliminators, located in suction scrubbers on reciprocating compressors, have broken up as the result of destructive acoustical pulsation causing serious damage to compressor cylinders.

Fibrous pads comprising a knitted and crimped mesh made from a wide variety of materials are generally recognized as the most effective form of mist eliminator developed to date. Available in carbon and stainless steels, as well as numerous other corrosion resistant metals, fibreglass and many synthetic yarns in various mixtures, these are knitted in a variety of patterns and the mesh is crimped before forming into pads of variable density, thickness and shape. Thickness may range from 4 to 36 inches. Pads may be rolled in circular form to fit vertical cylindrical vessels, or made into pads of other geometric shapes, all fitted with top and bottom grids to provide support and means for firm attachment. Density varies, as desired, from 3 to 40 pounds per cubic foot (5). Free volume ranges from 90 to 99.4%. Surface area ranges from 50 to 600 square feet per cubic foot. Wire diameter ranges from 0.003" to 0.011". Wire is used to reinforce glass and synthetic fibre masses of much finer strand diameters to prevent excessive compaction.

Capacity of fibrous mesh pads can be calculated from a special form of packed column flooding equation (5) to determine average free-space velocity at flowing conditions. This is divided into flow rate at flowing conditions to compute the surface area required. Effective performance range is from 30 to 110% of the rated capacity (5). For ultra-fine separations, this relationship must be refined to take diffusional forces into account (9).

The function of the fibrous pad is to provide targets whose diameters approach those of the particulates which must impinge the fibres. When impingement occurs, the resulting film flows downward to other fibre contact points where other droplets have drained, forming larger droplets more readily influenced by gravitational forces. A single fibrous pad is both coalescer and mist eliminator. Considerable quantities of liquid collect and are held in the lower layers of the pad to assist in the coalescing of aerosols carried into the pad from below. Excess liquid falls from the bottom of the pad. The upper portion of the pad is quite devoid of liquid accumulations and it functions as the mist eliminator. For removal of free water, hydrocarbon condensates and light crude oil mists, a 6-inch pad thickness will provide excellent mist extraction. For glycols, amines and organic treating solutions, greater thickness and special materials are required, sometimes using two or more pads of different materials. In certain instances it may be desirable to separate two pads so that the first can function as coalescer while the second comprises the mist eliminator. As a rule-of-thumb, the coalescer pad would have half the area, or twice the free-space velocity, of the mist eliminator pad.

Configuration of a fibrous pad is very important if effective performance is to be achieved. It must be installed in horizontal position with gas flow upward through the mesh. Only in specialized applications and with the approval of the mesh supplier should a mist eliminating pad be installed in any other position. Numerous applications are known where fibrous pads are installed in a vertical plane with gas flowing normal to the pad in a horizontal direction. Unless this pad were unusually thick, (determined from vessel diameter, liquid loading and physical properties of the liquid) it will function solely as a coalescer that passes larger droplets of liquid through with the gas. In general, designs employing this configuration are incapable of fine separation.

Experience has shown that single fibrous mist eliminator pads that are properly designed and applied are capable of effecting removal of 4 to 6 micron aerosols. Multiple pad installations, particularly those with a blotting stage between coalescers and mist eliminators, are capable of 1 to 3 micron performance.

Test Methods and Performance Evaluation

Inability to obtain an absolute measurement of the pipeline dirt content of a flowing gas stream is hindering the development of more effective gas cleaners and the evaluation of existing facilities. Many methods have been proposed. Some have been developed to a certain degree of usefulness including gravimetric methods, slide sampling and counting, and various photometric and light-scattering techniques. The greatest obstacle is the ability to analyze a total flow stream and measure its particulate content under flowing conditions, or to obtain a true sample of that stream and its contents. It is significant that the AGA Pipeline Research Committee suspended research on gas cleaning about five years ago pending solution of this problem. The solution still pends.

Meanwhile, a number of operating and manufacturing companies are proceeding to develop evaluation programs for gas cleaners. Currently, most of these are concerned with solids removal because these techniques are simpler (8). Evaluation programs for aerosol removal are being developed by the author. The objective is to devise interim test methods for evaluating gas cleaner performance and to make purchasing and application more effective.

Conclusions

In summary, it is urged that operating company management recognize that gas cleaning problems exist. The only variable is to be found in the degree of severity which may reflect the quality of operation.

Distribution companies deserve clean gas now and in the future but their problems today may have come to them twenty or more years ago. Elimination of pipeline dirt, be it liquid or solid, will continue to be an integral part of their operations but better gas cleaning practices now will abate this problem in the future.

An acceptable, uniform method for absolute measurement of the dirt content of flowing gas streams is one of the industry's most pressing needs. Efforts to achieve this objective deserve full support of the industry.

Operating companies should evaluate the effectiveness of their gas cleaners by tabulating operating records that reflect valve breakage, packing failures, rod and cylinder scoring on reciprocating compressors; burned blade tips on gas turbine drives, loss of efficiency on adsorption driers and quick-cycle hydrocarbon recovery units due to lube oil contamination, frequency and severity of crude oil contamination and salt accumulation in gasoline plants and gas treating systems, loss of transmission efficiency due to accumulation of lube oil and other pipeline dirt deposits in pipelines, absorption oil and lube oil consumption, frequency and nature of erosion in regulator settings, frequency and nature of measurement problems caused by pipeline dirt, and the frequency and nature of pipeline dirt problems encountered in distribution systems. Analysis of these data will provide many answers concerning the effectiveness of existing gas cleaners.

Before buying a gas cleaner, study the application with great care and make a special effort to give the designer the best design parameters available. These data will provide sound design and adequate performance at a reasonable cost.

Remember that, to date, there is no single gas cleaner design that is best for all applications. Recommendations and quotations should be studied and evaluated with care so that quality of performance is considered as well as price.

With equipment costs rising and deliveries uncertain, give thought to rebuilding older, inefficient gas scrubbers with new, efficient internals and realize appreciable savings in delivery time and cost. In some cases, no piping changes will be required so that additional savings can be realized.

Finally, it seems safe to predict that if the gas industry develops more interest in gas cleaning and demands better facilities, these will be forthcoming.

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