THE GAS TURBINE AS A NEW FEATURE IN A LARGE AIR SEPARATION PLANT

P. C. Keith, Jr.*
Hydrocarbon Research, Inc.
New York, N. Y.

In December, 1962, Hydrocarbon Research, Inc. (HRI), placed in service an 800 ton/day air separation plant located just south of the Houston ship channel, Texas, and just west of the Shell Oil Refinery on La-Porte Road.

This plant provides oxygen and nitrogen to meet the requirements of a major chemical manufacturer. To give a little history, the plant design is a simple low pressure cycle employing reversing heat exchangers for feed air preparation, and radial inflow expansion turbines to accomplish the refrigeration duty.

Combustion gas turbines

The plant is unique among those currently being operated, in that combustion gas turbines are employed as prime movers for the air feed compressors. The machinery that was selected for the service were General Electric, frame size 3, dual shaft turbines, with a NEMA rating of 7,500 brake horsepower at the output shaft. The maximum allowable output shaft speed is 6,300 rev./min. The output shaft is directly coupled to a Clark Brothers 6H4 four-stage intercooled centrifugal compressor. Two such units are installed.

Each turbine is fitted with a waste heat recovery system in the form of unfired steam boilers. Inlet temperature to the boilers is held at 915° F, and stack temperatures run normally 400° F.

Each boiler has a rated capacity of 40,000 lb./hr., 450 lb./sq.in. gauge steam, with total temperature of 550° F.

Dual fuel system

The combustion turbines are equipped with a dual fuel system, which, we believe, is truly unique. Start-up of the turbines is effected on 1,050 Btu natural gas. With an automated pushbutton shift, the turbine is switched to 330 Btu tail gas (hydrogen plus CO) from the acetylene plant which the oxygen plant services. This is the normal running operation.

Automatic switchback to natural gas is accomplished in the event of failure of the process gas supply. The over-all thermal efficiency experienced to date is about 86%, that is, 86% of the fuel energy to the plant is recovered as gas turbine power or steam.

The significant features of these two turbines are the dual shaft design in conjunction with automatically controlled variable inlet nozzle on the low turbine. When so equipped, the gas turbine will automatically maintain the exhaust temperature at 915° F, regardless of variations in load and ambient conditions.

Uniform steam load

One of the problems that we were faced with in design, was maintaining a uniform steam load, regardless of the actual output shaft horsepower required at any given time. Field experience has confirmed the design predictions, i.e., maximum steam production and minimum gas turbine fuel consumption occur when the turbine exhaust temperature is held at the maximum design level.

The low pressure turbine is freewheeling, of course, and extracts the energy remaining in the combustion gases for the driven load, which in this case is the process air compressor. The machine described will at least partially compensate for load and ambient temperature swings, and is a conventional two-shaft machine, with the exception of the addition of the variable inlet nozzle on the low pressure turbine, which does permit control of load division between the high and the low pressure sections.

Nozzle and load governors

A nozzle governor which senses turbine exhaust temperature will automatically position the nozzle so that the supply compressor runs at that speed which will deliver the amount of combustion air to maintain 915°F exhaust temperature. A separate load governor holds the low pressure load turbine at a predetermined set speed by controlling fuel flow.

Finally, a helper steam turbine is solidly coupled to the gas turbine. This serves as the cranking engine for the start-up, and can supply additional power as required, particularly when high ambient temperatures prevail which reduce available gas turbine horsepower. It also helps complete the plant steam balance by utilizing excess steam when we have it, allowing us to reduce the gas turbine fuel consumption. We can put about 800 gross horsepower back into the system on steam.

*Presently with American Air Liquide, Inc., New York, N. Y.

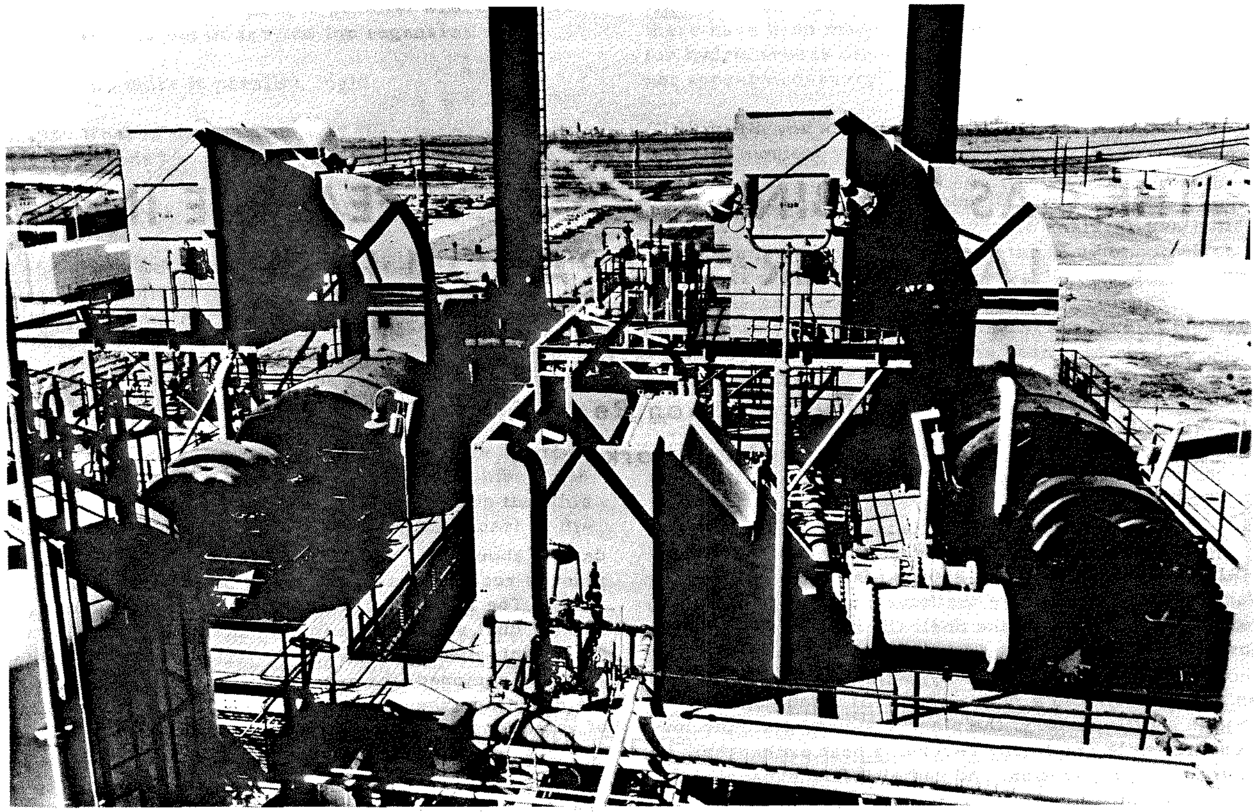

Figure 1. Gas turbine compressor trains at the Bayou Oxygen Co.

Explosion in the exhaust ducting

During a routine start-up in the winter of 1963, we experienced an explosion in the exhaust ducting of our B turbine. The explosion ripped out a section of the waste heat boiler sheathing, but no other significant damage was found and no injuries resulted. An investigation disclosed the reason for the mishap to be maloperation, coupled with failure of the fuel control system.

The turbine was being started in normal fashion on 1,050 Btu natural gas, and after cranking speed was reached, the combustion control was placed in the fire position. Lightoff did not occur. The operator should have continued to advance the firing sequence through to a purge cycle prior to attempting restart. Instead, the control was moved back through the fire position, at which time the turbine lit off, with a waste duct full of an air-methane mixture. The explosion described then resulted. Since the accident, interlocks have been fitted to the control, making a reoccurrence impossible.

Inadvertent shutdowns

In general, experience with these turbines has been very satisfactory. We did have a number of problems with respect to inadvertent shutdowns of the machinery during the early months of operation. A lot of these were due to a rather peculiar temperature profile in the waste heat duct. The exhaust end of the turbine is on temperature control. This temperature is measured at 12 points around the duct by a device which averages the temperatures and feeds a signal to a controller which holds this average at the 900°F level.

Due to as yet unexplained vagaries of instrument and electrical manufacture, this device tries to hold a lower temperature, thereby reducing fuel to the turbine prematurely and shutting the unit down. This has not been solved as yet although G. E. is working on the problem.

Pressure drop

We had originally designed also for 10 in. of water pressure drop through the unfired waste heat boiler. In point of fact, we are running somewhere between 21 and 25 in. of pressure drop, which is costing us something in the neighborhood of 200 horsepower on the turbine. Despite this loss, we have been unable to justify, at least for the time being, additional expense in opening up the tube spacing in these boilers. This is a problem which those of you who contemplate this installation or already have it in will find: a little bit of excess pressure drop on the low pressure side will sharply cut in to your available horsepower at the output shaft.

We have been able to maintain the available turbine horsepower at better than 97 to 98% of original performance by a periodic cleaning, that is, every 10 days to two weeks. We employ ground walnut or pecan hulls. There is a specific trade name for this, but it's nothing more or less than ground up nuts that you throw into the turbine air intake. It removed the material that accumulates on the compressor and turbine blading.

The over-all performance of these machines has been good. We would suggest that the complication of having to operate on two fuels of such widely varying heating value (one ought to be sure that the game is worth it before trying this) is a nuisance and presents some serious operating problems. Our experience shows that if we can operate on natural gas essentially continuous, or even this low Btu fuel gas continuously, we confirm the manufacturer's statements that these things can be as reliable or more reliable than a conventional steam plant.

Continuous hydrocarbon analysis

I'd like to depart for just a moment from the turbines and add a little bit of information on this particular installation for the benefit of those people who have had problems with continuous hydrocarbon analysis.

We have had over the years a lot of frustration in the measurement of the hydrocarbon content of the various process streams in an air separation plant.

I would like to recall to the minds of the poeple here the work that was done by L. Coleman of Rohm & Haas, at Deer Park, Texas, in the development of a continuous multistream automatic hydrocarbon analyzer. You will recall that he had done a substantial amount of work with a company in Houston called the Well Logging Equipment Manufacturing Co., WEMCO. We had tried a couple of competing brands of hydrocarbon analyzers employing a chromatographic column. Our experience was essentially unsatisfactory. We could not get any real repeatability. Sensitivity was poor. Operating staff had no confidence in the equipment at all. For all practical purposes it was of no value.

Chromatographic analyzer

We went to WEMCO and purchased one of the commercial instruments which had been developed as a result of their work with Rohm & Haas at Deer Park. It is a chromatographic hydrocarbon analyzer using a hydrogen flame ionization cell. It uses air as a carrier purified catalytically. The hydrogen source which they recommend we use is ordinary bottled hydrogen which is passed through a palladium diffusion cell. We can measure methane, ethane, ethylene, propane, propylene, butane, and, of course, acetylene continuously from as many as 5 streams on two automatic programs. The full-scale deflection of the instrument for acetylene is 1 ppm.

We have now operated this instrument in excess of 9 months. The repeatability is excellent. It has been very nearly maintenance free. Wet laboratory analysis confirms that the results that we're getting from this instrument are extremely good. The most gratifying thing about this particular story is the fact that our operating staff has now begun to have confidence in a unit of this type.

DISCUSSION

GLASS—Monsanto: I'd like to ask you about your hydrocarbon analyzer. You said it was a chromatographic analyzer, analyzing continuously. You mean that your're getting chromatograms off of it on a repetitive basis, don't you?

KEITH: Yes. What I mean by continuous is: we don't have a continuous trace of any particular contaminant, but the unit will automatically continue to cycle through all of our streams; full cycle time on the four streams which we analyze is less than 20 min. The best that we could achieve on any other of the units which we had installed was somewhere in the order of 40 to 50 min., and even then we would usually get a confusion between the methane and acetylene peak or the propane-acetylene peak, depending upon the length and type of column that had been installed.

GLASS: You mean you're getting four streams within 20 min. for this many compounds?

KEITH: Yes, sir, that's right. We're getting methane, ethane, ethylene, propane, propylene, acetylene, butane from four separate streams on a continuous trace in 20 min.

GLASS: Would you care to point out what locations in your cycle you are monitoring?

KEITH: We are currently monitoring the cold end of the exchangers. We are monitoring the low pressure column bottoms and we're measuring the product gaseous oxygen. I'm not sure whether we're measuring the high pressure column bottoms or the effluent from the hydrocarbon absorbers, but I think we're measuring one of the two.

GLASS: I see. What about the appearance of hydrocarbons in your product oxygen? Did you see some there? Can you tell us other than, say, methane or the lighter hydrocarbons, if you can see acetylene there?

KEITH: We will occasionally see a bump on the trace. This is a conventional Brown Electronik recorder. And we might see a deflection of two chart divisions which might tend to indicate maybe two tenths of a part per million. This is confirmed by wet tests. We don't measure any acetylene. When I say we check the performance of the unit, we make up our own samples from lecture bottles and mix them in a vessel of a known volume. We can introduce this manually into the instrument, and it will check within one chart division, which is very close.

PAPENFUSS—Olin Mathieson: Would you care to comment on the configuration of turbine exhausts and air intakes a bit? Physical location of either, what type of air intake you use and what means you have of disposing of your gas engine exhaust?

KEITH: Yes, this we recognize as a problem, unfortunately. The exhaust stacks are at an elevation of I would guess 80 to 90 ft. They are located to the east of the turbine compressor inlet. In other words, the alignment of the turbine is: the process compressor is at the east end, and at the other end of the string is the waste heat boiler and the stack. The process air inlet is co-located with the process air compressor. The compressor turbine inlet is located approximately midway between the process air inlet and the exhaust stack.

The elevation of both the compressor air inlet filter and the process air inlet filter is about 35 ft. We haven't experienced, to date, any feedback, that we can pin down, of either heat or stack gases in either the compressor air inlet or the process compressor inlet.

PAPENFUSS: Now if I gather correctly, what you're saying here: your discharge elevation is approximately 90 ft. on the turbine exhaust gas, and your air intake is approximately 30 ft. elevated.

KEITH: Right.

PAPENFUSS: What would you say approximately is the distance between the two?

KEITH: Certainly no more than 50 ft.

JONES—Canadian Industries, Ltd.: Two or three little points: Is no swing in temperature, say 120 or 140° F, would this substantially modify the backup steam requirements in order to accommodate changes in power availability as a consequence of changing ambient air temperature in the turbine?

KEITH: This has been quite a problem. This is one of the reasons that we had to go to this temperature control system on the turbine—to maximize steam production by holding high exhaust temperature. With this temperature control we are able to maintain a fairly steady level of steam production the year round. Of course, during very hot weather we simple can't get the horsepower out of the unit.

We are in the process now of air conditioning the intake to the compressor turbine. We are air conditioning it by putting in an evaporative cooling system which, even though it's located in Houston, during those portions of each day when you're most affected—that is, during the hot portion of the day—we can realize sufficient cooling to, at least in large part, maintain high available horsepower from the turbine.

JONES: Is it conceivable that in the winter time, if this were, shall we say, associated with ammonia plant air compression, that increased mass flow through the air compressor might offset to some degree the larger power availability from the turbine with lower intake temperature?

The other point in connection with the string is: with the intercoolers on the air compression, have you encountered any problems with condensates knocked out of the air passing through the centrifugal machine, at either intercooler points or labyrinth seals or any similar locations?

KEITH: On lower temperatures the available gas turbine horsepower increases more rapidly than the required air compressor brake horsepower. Therefore, there is always enough power to drive the compressor; however, turbine exhaust temperature falls sharply (unless other measures are taken) with steam production and, consequently, over-all thermal efficiency deteriorates very badly.

In answer to the second question, we are experiencing some of what appears to be condensate corrosion problems in the air compressor intercoolers. We are experiencing this at two locations, separated by about 1,200 miles: one is electric drive and one is gas turbine drive. We don't yet know what the answer is. In both cases they are copper finned tube coolers. We are investigating those problems of corrosion as a result of peculiarities in the condensate that comes out.

JONES: The last point is: could you tell me how noisy the installation is?

KEITH: That's a very good point which I want to bring up; I'm glad Mr. Jones mentioned it. When you're standing up on the operating platform next to the combustors, if you have someone standing next to you, you're going to have to bend over and shout in his ear for him to hear you. However, as soon as you get 20 ft. away from the machines, you can pretty well converse in normal tones. We have had no problem with noise as a function of these gas turbines. They run at a speed which subtends a frequency of sound which is not annoying. We can work around them and we can operate them with no trouble. However, our blower loaded expanders are quite another kettle of fish.

PFLASTERER—U. S. Steel: You answered one of the questions about that evaporative cooler: I assumed that you were going to have to do that. Could you tell me something about the steam helper turbine: what is the size of the unit?

KEITH: The steam helper turbine is an Elliot turbine. It is capable of developing about 800 horsepower gross.

PFLASTERER: Does this normally, then, have to be on all the time in order to deliver your 7,500 horsepower rated output?

KEITH: No, it does not, except during high ambient temperature conditions.

PFLASTERER: Is this a topping-type turbine?

KEITH: No, it's a full condensing steam turbine. We have condensing steam turbines on our oxygen service and we use the same condenser for the helper turbine exhaust.

PFLASTERER: Do you find any operating problem starting up your centrifugal machines, the direct coupled units, because of the rather limited operating range of the gas turbine drive itself?

KEITH: We haven't had any trouble to date. Because it is a two-shaft turbine a lot of our starting problems are solved for us when we can simply start the turbine end of the gas turbine and bring that up to speed or nearly up to speed, and then by opening our nozzle rings we can bring the process air compressor up to speed.

Anonymous: First, could you comment further on this waste heat boiler, what went wrong with the pressure drops, and second, did this contribute in any way to the explosion by making it harder to purge or something like that?

KEITH: I think the problem probably originated in the requirement that we were looking to get something in the neighborhood of a 50° approach on the tail end of this thing. The people who built the boilers simply missed it a little bit on design. There's not much else we can offer by way of explanation. When you're talking of a net difference of say 8 to 10 in. of water drop, that's not a great deal. It becomes a question of capital. I haven't seen any calculations as to what we would have to do in order to reduce the pressure drop by essentially half.

I would suggest that one not be too overanxious to reduce pressure drops because, after all, this is what makes the system work, and if you're going to reduce the pressure drop, you're going to have to reduce your gas velocities accordingly, which means your heat transfer rate is going to go down and your capital is going to go up probably geometrically.

To answer your second question: no, the explosion that occurred in the duct was entirely a function of the fact that air and methane were present in volume quantities in the waste heat ducting when the unit lit off. It didn't light off the first time. It did when he backed the control through the fire position. We can't attribute this explosion to the design of the waste heat boiler.

JONES: Could you tell me what the turndown characteristics are on the installation overall: 80% or something of this sort, perhaps?

KEITH: Is this on the turbine or on the plant itself? Well, since we have two turbines we can't operate at half capacity. However, the turndown on the turbine itself is limited to an output speed of probably, as I recall, no less than about 4,800 rev./min., which allows us to back off in the neighborhood of 60% of design load operation—no less than that, though.