1984

Performance Evaluation by Analog Study of a Two Stage Reciprocating Compressor Handling Complex Hydrocarbon Gas Mixtures

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PERFORMANCE EVALUATION BY ANALOG STUDY OF A TWO STAGE RECIPROCATING COMPRESSOR HANDLING COMPLEX HYDROCARBON GAS MIXTURES

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ABSTRACT

A two-stage reciprocating compressor was designed to handle two different compositions of crude overhead gas (i.e. a complex hydrocarbon mixture containing heavier hydrocarbons identified as pseudo-cuts) available from two different sources. The thermodynamic properties and flash calculations were done with the help of a computer program developed especially for this purpose on a DEC 10 Computer System.

Special care was taken during the design stage to ensure that condensation does not occur at the inlet of the cylinders or inside the cylinders. Coolers and Separation devices were sized so as to remove the condensate effectively before the gas stream enters the cylinders of respective stages. Piping layouts were kept such as to prevent any accumulation and consequent carryover of condensate to compressor cylinders. Piston rings and sealing rings were made of filled PTFE grades in view of the dry service.

Upon completion of the designs of the main compressor alongwith pulsation suppression devices, heat exchangers, separators and finalization of the layouts, the whole system was simulated on an Analog Simulator so as to assess the performance of this compression plant.

The Analog study utilizing guide-lines in API 618 Design Approach 3 was done at Southwest Research Institute, USA on the SGA Analog Simulator. The study duplicated the compressor, vessels, heat exchangers and piping system in between the first major vessel at compressor suction at the upstream side and the second stage separator on the down stream side. Various test conditions were included in the study to represent various operating parameters of the compression plant.

Some modifications to the original system were applied so as to minimise certain undesirable acoustic characteristics, such as higher pressure pulsations and pressure drops than that suggested by API, found in the original system. The resulting pressure pulsations and acoustic shaking forces were found to cause stresses on piping and bottles within acceptable limits.

Performance analysis of the modified plant system indicated only marginal deviations from ideal PV card.

INTRODUCTION

Analog study of a Reciprocating Compressor system at the design stage itself, by simulating the compressor alongwith the vessels, heat exchangers, piping etc. on to an active Analog Simulator, has been widely accepted in the industry as a reliable means for ensuring the optimum performance of the plant. Such Analog study considers the generation of flow and pressure pulsations inside the compressor and its dynamic interaction with the piping system connected to the compressor. API standard 618-1974 Design Approach 3 gives the necessary guidelines for such an Analog study. Experience has proved the effectiveness of these guidelines so that these are specified by most of the major users.

THE APPLICATION

The compressor application involved compressing crude OVHD Gas i.e. a complex hydrocarbon mixture containing C_2, C_3, C_4, C_5 and heavier hydrocarbons identified as pseudo-cuts indicating their molecular weights, sp. gravity and boiling point. Two different alternative compositions (see table I) were specified and the working pressures also varied in the two cases viz. from 1.4 kg/cm^2 abs. suction pressure to 9.5 kg/cm^2 abs. dischargepressure in case I and from 1.37 kg/cm^2 abs. suction pressure to 5.5 kg/cm^2 abs. discharge pressure in case II. There were 2 nos. compressors Unit A and Unit B, of which only one was to run at a time and the other was intended to be a standby unit.

MIXTURE PROPERTIES

A especially developed computer program, based on Soave-Radlick-Kwang and UNIFAC methods was used for predicting the various thermodynamic and transport properties of this hydrocarbon mixture and for doing flash calculations to estimate the amount of condensate to be taken out of the compressed gas stream after it emerges from the cooler. An accurate estimation is very vital for sizing of compressor plant as the amount of condensate may be substantial.

THE COMPRESSOR

Based on the pressure ratios involved and keeping in view the optimum interstage pressure temperature conditions, a two stage compressor, with suitably sized cylinders to handle the required capacity, was designed. The interstage cooler and separator and the final stage cooler and separator were designed to take care of the case I design conditions, while at the same time also ensuring reasonably good working in case II conditions.

Separators were made of proprietary vane-pack design to ensure effective condensate removal (under various load conditions). Piping layouts were made so as to prevent any accummulation & consequent carryover of condensate to compressor cylinders.

In view of the non-lubricated application piston rings and rider rings and rod packing rings in carbon graphite filled PTFE grade were used. Compressor suction and discharge valves of proprietary double damping (mechanical) design were used to ensure low pressure drop through valves.

THE ANALOG STUDY

The Analog study utilizing API 618 Design Approach 3 guideline was done at Southwest Research Institute on the SGA Analog Simulator. The study duplicated the compressor, vessels, heat exchangers and piping system in between the first major vessel at compressor suction viz. Knock out drum and the final stage separator. A schematic view of the system is shown in fig. 1.

Due to operating and gas conditions a $\pm$ 10 percent deviation in the velocity of sound was included in the investigation. This is easily accomplished by the Analog by varying compressor speed by the correct percentage. Thus frequencies appear that do not correspond directly to integral multiples of compressor speed, the amplitudes of which are valid, however, and will occur at compressor excitation frequencies for the analogous operating and gas conditions studied. Operation at various capacity steps was studied at both case I and case II conditions. Table II lists the test conditions evaluated during the study as these conditions involved the highest pulsation levels in the system.

Acoustic characteristics data was recorded on the original suction and discharge piping systems for both stages of compressor for unit A and unit B based upon case I and case II operating conditions. Undesirable acoustic characteristics found in the original system were pulsations in the piping exceeding API guidelines and pressure drop through the originally installed orifices in compressor nozzles exceeding API guidelines and thus adversely affecting compressor cylinder performance. For getting lower pulsation levels and reduced pressure drops so as to improve compressor performance certain modifications were considered during the study which included increasing orifice diameter, installation of fresh orifices, deletion of a few orifices and increasing the pipe diameter at certain locations (Fig. 2). The modified system offered a better compromise on pressure drops, pulsations and the compressor cylinder performance more or less meeting API guidelines.

A mechanical evaluation, with the help of a digital computer, of the compressor volume bottles was considered to determine the adequacy of supports with a view to have overall system vibration control. The overall shaking forces were found to be low in amplitude and the supports were adequate so that no undesirable vibration of the vessels could be there.

The mechanical evaluation also included the analysis of the piping response. With the addition of a few pipe supports the overall vibration levels of the piping at different points were brought to acceptable limits so as to cause cyclic stresses well within the limits specified by API.

The performance of the modified compressor system as indicated by the P.V. diagrams obtained from the simulator at different test conditions is indicated in Fig. 3 to 6.

CONCLUSION

The performance of the compressor system can be very well evaluated at the design stage itself by simulating the system on to an Analog Simulator and doing the acoustical analysis followed by a mechanical evaluation on a digital computer. Modified versions can also be evaluated for the ultimate performance so as to optimize the system at this stage itself, rather than going for some change when the compressor system poses some problem while commissioning at site.

REFERENCES

i) "Reliability and Performance Assurance in the Design of Reciprocating Compressors and Pump Installations" by W. Von Nimitz, 1974 Purdue Compressor Technology Conference.

ii) "Role of Analog Study towards better performance of Reciprocating Compressor Plants" by S.N. Dwivedi and W. Von Nimitz, Seminar on Compressor Performance and Improvements (8th - 9th May 1983), Allahabad, India.

iii) "Application Criteria for Compressors Handling Natural Gas containing heavier hydrocarbons" - by J.S. Pandey and S.N. Dwivedi, Seminar on Compressor Performance and Improvement (8th - 9th May 1983), Allahabad, India.

TABLE I

GAS COMPOSITIONS

Component	CASE I Mol.Frn.	Mol. Wt.	API	Boiling (°F)point	Mol.Frn.	Mol. Wt.	CASE II API	Boiling (°F)point
C 1	-	-	-	-	-	-	-	-
C 2	0.082	30.1			0.018	30.1		
C 3	0. 33	44.1			0.186	44.1		
C 4	0.223	58.1			0.331	58.1		
C 5	0.0337	72.1			0. 29	72.1		
Pseudo 1	0.0319	68.8	105.9	69	0.0478	88.4	73.8	157
2	0.0446	74.8	85.4	102	0.0373	95.6	69.1	185
3	0.0589	81.6	71.7	137	0.0198	104	64.7	215
4	0.0618	89.1	62.2	172	0.0093	113	60.4	245
5	0.0349	97.2	55.0	207	0.0036	123	57.6	275
6	0.0145	106.0	49.4	242	0. 001	133	54.7	305
7	0.0002	115.0	55.8	256	0.0002	144	52.1	355
8	0.00022	116.0	44.7	277				
9	0.0009	121.0	53.4	277				
10	0.0001	125.0	41.0	309				
11	0.0004	133.0	49.8	312				
Water	0. 083	18.0	-	-	0. 056	18	-	-
	1.000	54.9			1.000	61.4		

TABLE II

ANALOG STUDY TEST CONDITIONS

	CASE I	CASE I	CASE II	CASE II
Test Number	1	2	1	2
Initial Suction press. (Ata.)	1.4	1.4	1.37	1.37
Final discharge press. (Ata.)	9.5	9.5	5. 5	5. 5
Unit Flow (Nm^3/hr)	4613.8	2306.9	4355	2177.45
Compressor loading	100%	50%	100%	50%
(a) Pockets Open	None	None	None	None
(b) Single active cylinders	None	HE-2 CE-1	None	HE-2 CE-1
No. of units in parallel	1	1	1	1
Piping Configuration	Flow through intercooler	Flow through intercooler	Flow bypassing intercooler	Flow bypassing intercooler

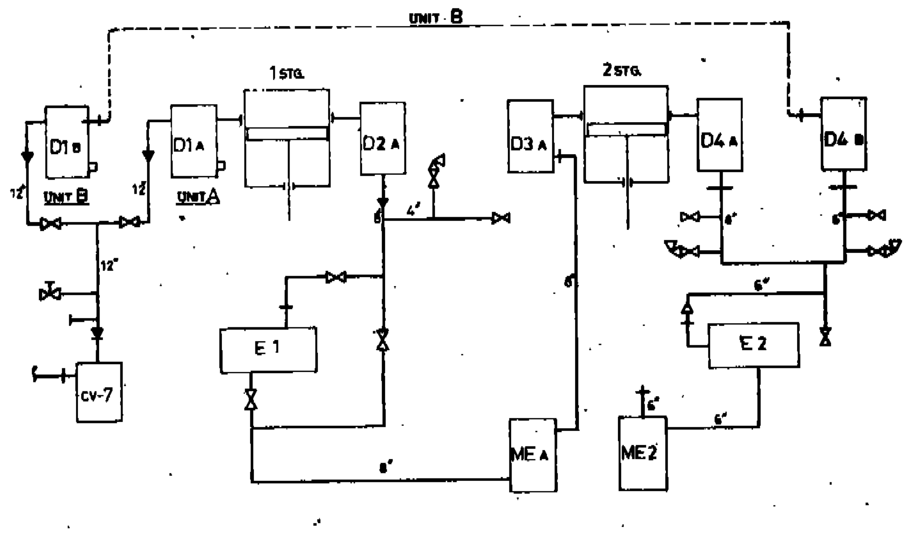

FIG.1 SCHEMATIC ORIGINAL SYSTEM

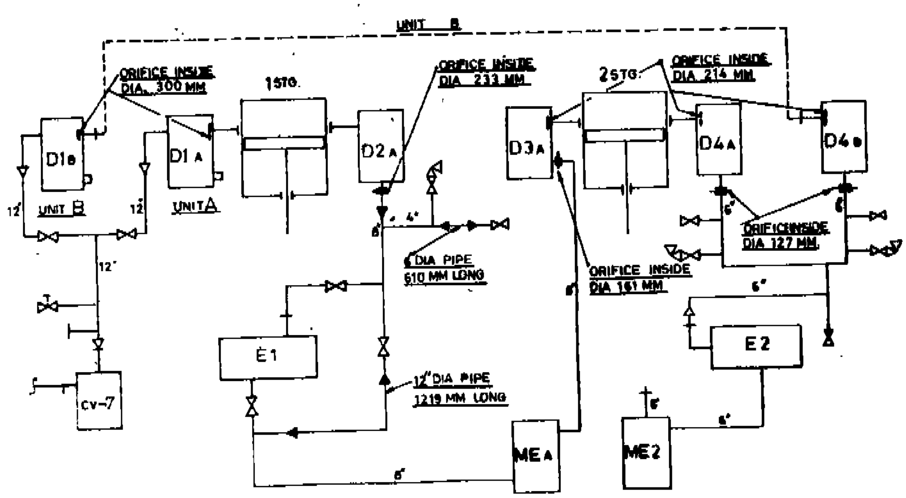

FIG 2 SCHEMATIC MODIFIED SYSTEM

PERFORMANCE ANALYSIS
CASE 1 MODIFIED SUCTION
& DISCHARGE

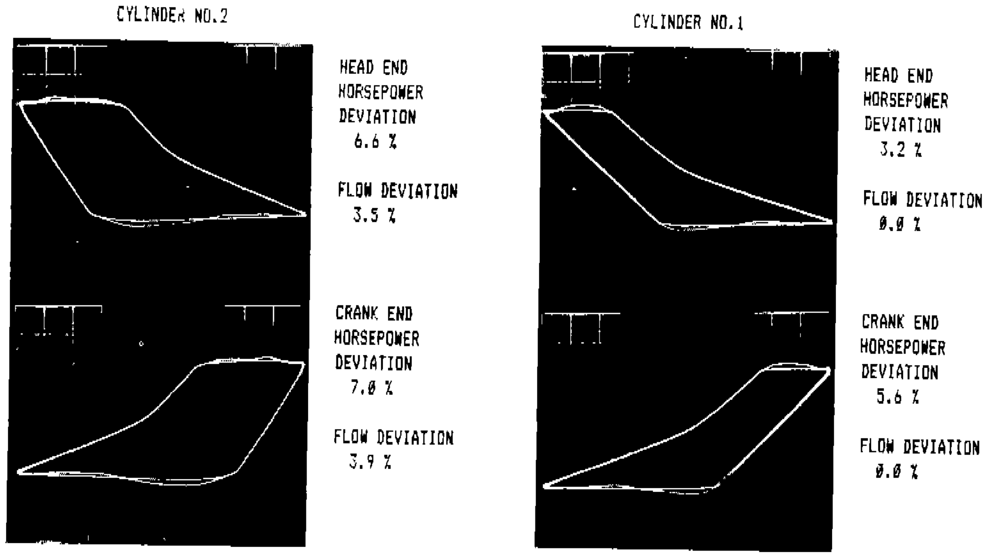

FIG. 3

PERFORMANCE ANALYSIS
CASE 2 100% LOAD MODI-
FIED SUCTION & DISCHARGE

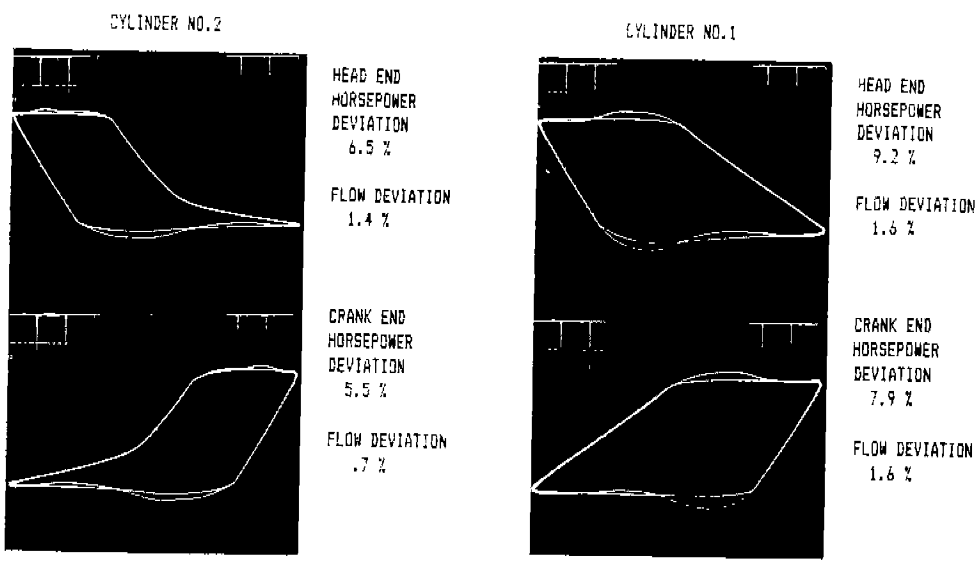

FIG. 4

PRESSURE VOLUME CARDS
2 ND. STAGE (50%) LOAD

CYLINDER 1

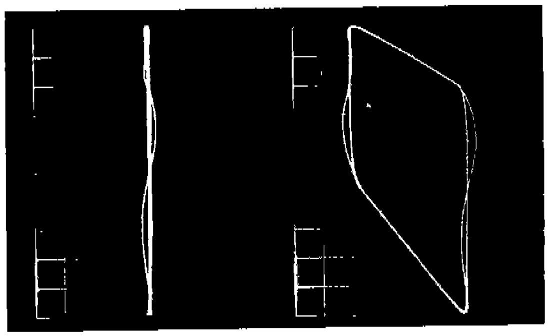

FIG. 5

PRESSURE VOLUME CARDS
1ST. STAGE (50%) LOAD

CYLINDER 2

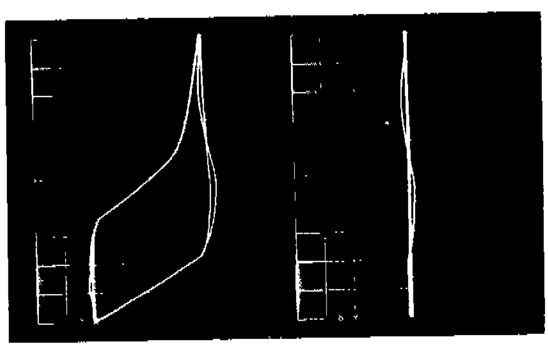

FIG. 6