TURBOCOMPRESSORS FOR GEOTHERMAL PLANTS

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SUMMARY

Paper shows functional and constructional characteristics of Ansaldo's turbocompressors built since 1980 to nowaday for ENEL's 20 MW geothermal power plants.
Special remarks are made for centrifugal compressors of the geared kind; it is last Ansaldo's generation in this field of turbomachinery.
Mention is made for natural steam and gas mixture chemical and physical properties in different geothermal areas. Diagram showing convenience between ejectors and compressors non-condensable gas extraction system are made.

USE OF TURBOCOMPRESSORS IN GEOTHERMAL PLANTS

The utilization of "soffioni" steam in turbogenerator sets of the former Soc. Larderello plants (Italy), has been accomplished in different ways.
Flow diagrams 1, 2, 3 show the cycles used, depending on the several cases.
Diagram 1 is a typical example of direct utilization. The natural jet steam enters into the turbine, possibly after having crossed a water separator, and discharges at a little higher pressure than the atmospheric one, to be supplied to chemical plants for the extraction of chemical substances contained in the steam. Such an arrengement does not require condensers and the plant is very simple.
The specific steam consumption (SSC) of a 4,000 kW set is about 20 kg per kWh.
In diagram 2, the jet steam is conveyed to steam transformers, or evaporators, from which it leaves in a condensed state.
By means of a water pump the condensate is supplied to the secondary circuit of the same transformers; the purified steam, produced at about 2 atm.abs., is piped to the turbines and then discharged into the jet condensers at a pressure of about 0,10 atm.abs. The heat transferred to the circulating water is dispersed by evaporation in the cooling towers. In this case, a considerably smaller amount of gas passes through the turbine, with respect to the following cases. Gases are extracted from the condenser by a reciprocating pump and discharged into the atmosphere. In this case the SSC is reduced to about 13 kg/kWh.
In diagram 3 the steam issuing from the "soffioni" is directly supplied to the turbine which discharges into a jet condenser at a pressure of 0,10 ÷ 0.08 bar abs.
In this third case, the gases contained in the steam flow through the turbine and reach the condenser from which, after cooling, they are extracted by centrifugal compressors driven by electric motors or main steam turbines.
The compressors in this diagram, however, absorb a considerably higher power than the reciprocating pumps of diagram 2.
Despite this, for the same inlet steam conditions the specific steam consumption is only 8 Kg/KWh
A variation of diagram 3 provides, for the natural steam piping, for a cyclone or a tower for cleaning steam with water or water and sodium carbonate solution

The separated water entrains with it almost all of the boric acid contained in the natural steam and is used for chemical plants.
Diagram 3 is the most widely used in the geothermal plants of the Larderello area.
The choice of the most appropriate cycle for a specific plant, may depend also on the percentage by weight of the incondensable gases contained in the endogenous steam. Generally, when the gas percentage is below 10%, diagram 3 is used; when gas percentages ranging from 10 to 50%, diagram 2; with gas percentage over 50%, diagram 1.

Characteristics of incondensable gases contained in endogenous fluid

In the following table, the chemical-physical characteristics of endogenous mixture of Larderello (Italy), The Geysers - California (USA) and Wairakei (New Zealand) geothermal plants, are reported.
Some of these gases, as CO_2, H_2S, NH_3 and H_3BO_3, in solution in the steam condensate are corrosive.
The corrosiveness is accentuated also by the presence of O_2 from the infiltration air in bodies under vacuum, or from deaeration of the injection water in jet condensers and coolers.

The materials used for the construction of the plant are the fallowing:

- austenitic stainless steel
- ferritic stainless steel
- carbon steel
- meehanite cast iron

for gas and for condensate

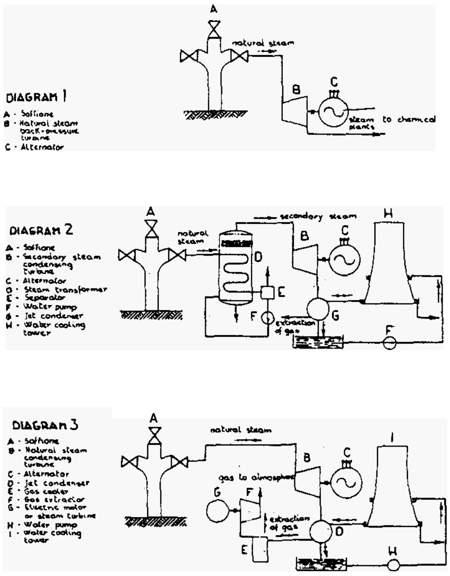


Fig 1

<u>Characteristics of incondensable gases contained in endogenous fluid</u>

In the following table, the chemical-physical characteristics of endogenous mixture of Larderello (Italy), The Geysers - California (USA) and Wairakei (New Zealand) geothermal plants, are reported.

		ENEL former LARDERELLO (Italy)	THE GEYSERS (California)	WAIRAKEI (New Zealand)
- Suction pressure	atm	2 — 11	5.5 — 11.5	4.5 — 13
- Suction temperature	°C	130 — 230	170 — 190	145 — 195
- Cooling water temperature (Winter-Summer)	°C	20 — 35	27	15 — 21
- Condenser vacuum	"Hg	2½	4	1½
- Incondensable natural gas percentage	%	4 — 30	0.4 — 0.6	0.15 — 0.3
- Gas composition: percentage by weight				
CO_2		97.2	78.9	97.14 — 97.387
H_2S		1.997	5.1	2.64 — 1.967
CH_4		0.353	5.1	0.06 — 0.141
H_2		0.0847	0.8	0.02 — 0.028
N_2		0.361	N_2 Ar 2.9	0.14 — 0.478
He, Ar, Ne, H_3BO_3	cm³	25	NH_3 7.3	-

<u>EXTRACTION PLANTS OF INCONDENSABLE GASES</u>

Diagram 3 of a condensing plant includes the .following parts:
- a jet condenser and a cooler for incondensable yases;
- an extraction plant for the said gases;
- a condensate pumping plant;
- a condensate cooling tower, natural or farced draught, in geothermal areas where no water sources are available;
- a plant for pumping cold injection water into the condenser and coolers.

The cost of this equipment is justified by the higher power production. Incondensable gases can be extracted by stearn ejectnrs, vacuum pumps, or centrifugal compressors.

The choice depends primarily on the gas flaw to be removed from the condenser. In Wairakei plants (New Zealand) either steam ejectors or rotary compressors are used. In the Geysers plants (California), the gases are extracted by steam ejectors. In the Larderello plants area, where the percentage of gases contained in natural steam is higher, it is advantageous to use centrifugal campressors.

The capacity of an extractor depends on:

- the incondensable gas percentage contained in the steam;
- the quantity of infiltrated air in the bodies under vacuum (determined on the basis of experimental data of similar plants):
- the weight of the incondensable gases dissolved in the deaerated injection water in the condenser (obtainable from tables);
- the injectian water capacity and temperature and, therefore, on the quantity of steam saturating the mixture of the aforecited gases:
- the pre-estabilished vacuum degree.

Fig. 2 illustrates the diagram of the steam specific consumption calculated for a 15,000 kW turbogenerator unit, as a function of the pressure at the turbine exhaust and of the incondensable gas percentage contained in the natural steam.

Fig. 3 gives the values of the in-take mixture capacity, and the power absorbed by a centrifugal compressor. as a function of the same variables as Fig. 2.

Fig. 4 gives the specific steam consumption of the unit, as well as the consumption of the ejector, as a function of the aforecited variables, for the same 15,000 kW unit, but equipped with a two-stage ejector.

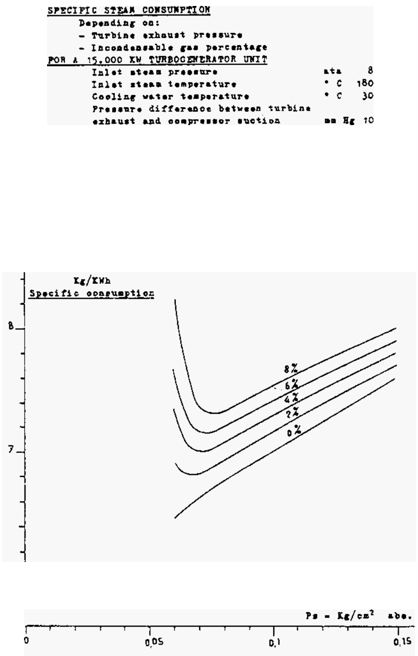


Fig 2

FUNCTIONAL AND CONSTRUCTIONAL FEATURES OF TURBOCOMPRESSORS

Turbocompressors used in geothermal plants are only of the centrifugal type, even if the value of capacity at suction would suggest the application of axial type turbocompressors.
The latter can not be used in geothermal plants, because of the physical and chemical characteristics of the mixture at suction. A low Reynolds number at the compressor suction would imply the adoption of large axial blades and, their efficiency could not be maintained, because of fouling due to some components of the mixture.
Centrifugal compressors are more suitable for the following reasons than axial flow machines:

-Their stage pressure ratio is greater. Hence fewer stages are required and the cost is less.

-Centrifugal impellers are less sensitive to fouling than axial flow blades.

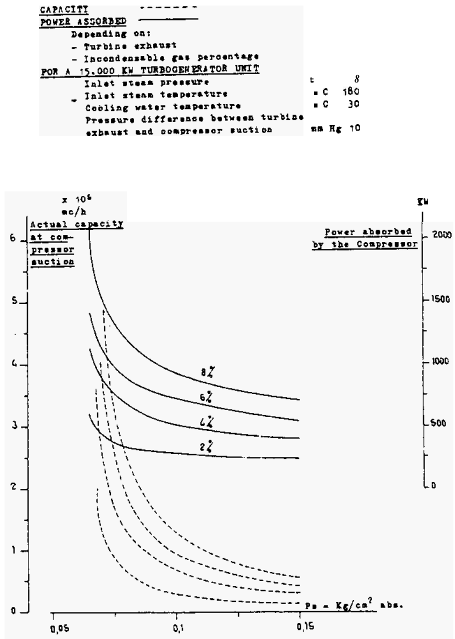


Fig. 3

Ansaldo's turbocompressors for ENEL's 20 MW geothermal plants have evolved since 1980 as follows:
there are two types of modular compressors namely
1) M-1R (multistage, multishaft, 1 intercooler) the oldest and
2) G3 - 11 (geared, 3 shafts, 1 intercooler). The baeic object common to both was to meet the entire range of requirements given in the following table with the minimum number of components arranged by simple and fast changes in the machine configuration.

Steam Mass flow rate	= 55-120 t/h
% endogenous gas	= 2 - 1 2 %
Pressure at condenser outlet	= 0.07 bar abs.
Water cooling temp.	= 25 °C
Gas inlet temperature	= 26 °C
Gas mass flow rats	= 1600÷13500 kg/h
Pressure at compressor discharge	= 1.1 bar. abs.

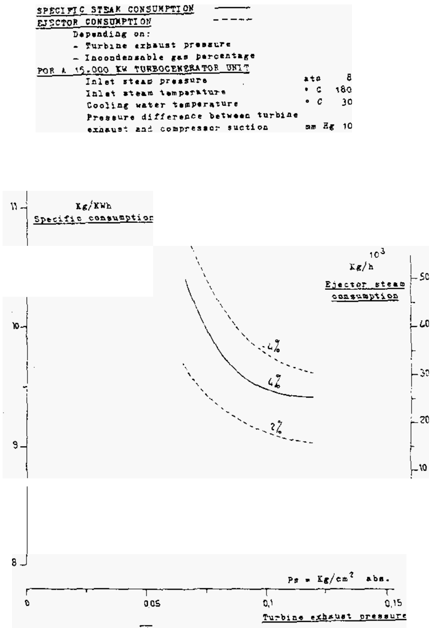


Fig. 4

The M-1R turbocompressors are formed by two bodies operating in parallel as shown in Fig. 5. The entire mass flow rate field is covered with 4 different configurations made in al.I cases of:

1 common low pressure casing
1 common high pressure casing
1 common law pressure shaft
1 common high pressure shaft
1 common gearbox
7 low pressure impellers
6 high pressure impellers

A typical sectional view of a compressor unit of type 1 is shown in fig. 6.
This drawing refers to configuration no. 1 which has the biggest flow rate. All the other configurations are obtained by changing impellers a5 indicated in fig. 5.
On discharge from the low pressure stage, the gases (endogenous gas, air and saturation vapour) are conveyed to the intercooler, where the heat accumulated during the compression is removed by cooling water. The cooler is of the jet type with injection of water to cool the counter flowing gases. Gas cooling takes place simultaneously with a partial condensation of the steam contained in the mixture of gases evacuated from the

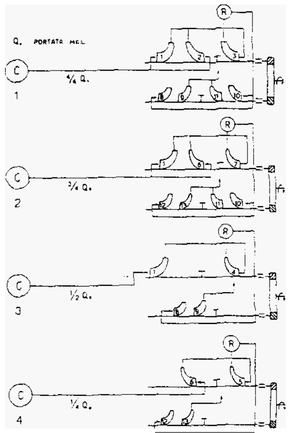
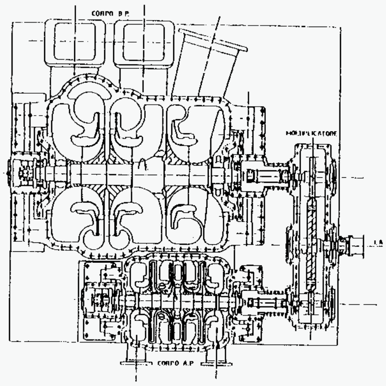


Fig. 5

condenser. The last stage of compression discharges directly to the atmosphere at a temperature ranging between 150°C and 200°C.
It is important to note that, with high cooling it is possible to reduce the compressor power, since this is affected by the temperature of the gases at the inlet of each stage. On the other hand. excessive cooling may cause the carry-over of water droplets, which may produce corrosion in the compressor casing and fouling in the first impellers and in the diffusers. Generally the set is shut down for cleaning after about 7000 hours of aperation.
The carry-over of water droplets from the coolers may be reduced to the minimum by placing layers of Raschig in the cooler· below and above the water sprayers,or better by dimensioning adequately the coolers, so as to have very low speeds inside.
The components of the compressor are shnwn in fig. 7. They consist of the following parts:

1 Low pressure body
2 High pressure body
3 Speed increasing gear
4 Low speed shaft (RPM = 3000)
5 Low pressure coupling (RPM = 7400)
6 High pressure coupling (RPM = 13220)
7 Inlet law pressure flanges
8 Outlet low pressure flange
9 Inlet high pressure flanges
10 Outlet high pressure flange
11 Support bearings
12 Base plate



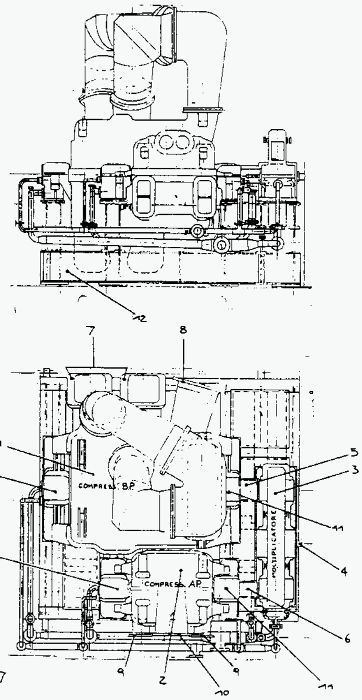


Fig. 7

In the low pressure body is clear- a double flow followed by a single flow. After this there is the intercooler not shown in the drawing. The high pressure is made of two stages double flow. The impeller diameters for each body are the same for each configuration. Variation of capacity is obtained by either single or double flow and with right width of rotating and static: channels (impellers and diffusers). The two rotors are connected to a speed increasing gear by means of toothed gear. coupling, the whole group is connected with another toothed coupling to the steam turbines which drive the generator directly.

The total weight for this compressor is about 39 tons.

The turbocompressors above described have been exceeded by the aforementioned G3-11 gas exausters. The entire mass flow rate requirements are covered with five different configurations (see fig. 8).

Each configuration is provided for a wide range of gas ma55 Flow rate at the same outlet pressure condenser. This is obtained changing impellers and diffusers channels width without any other modifications; it is a meaningful possibility in yeothermal application saw that it is always quite difficult to fix the exact gas per-ceritaqe contained in geothermal steam. It means that even with the machines already built it will be possible, with minimum modifications, obtain the right geometry for true mass flow rate without efficiency penalties.

Those kind of compressors (see fig.10) are made of open type impellers provided with three dimensianal profile backward lined vanes and axial. inlet, overhanging joined at the ends of the pinon shafts, of the speed increasing unit. with a HIRTH type coupling.

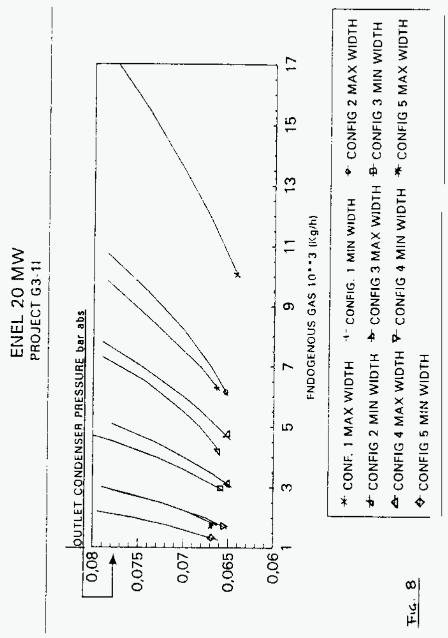


Fig. 8

The main advantages of G3-I1 over the previous M1-R type are as follows:

- Very compact construction with compressor completely integrated with gear box (see fig. 9)

- N° 3 pinions driven, this means the availability of 3 different rotation speeds with the possibility for a better choice of impeller diameter for every configuration (improved of efficiency)

- Axial flow at the inlet of each impeller with optimum distribution of incidence angle.

- Very low mechanical losses due to the elimination of axial thrust bearings for pinions shafts. All axial thrusts are transported on idler and low speed shafts throw "thrust collars" (see fig. 11)

- Opened high efficiency impellers with three dimensional blades.
Impellers are fixed at the end of the pinion with "HIRTH coupling" (see fig. 12/13). This permits a perfect centering of the impeller and avoids instability problems as well as vibrations arising from shrinking phenomena between shaft and impeller. Such coupling allows easy removal and assembly after a long period of operation and no rebalancing of the rotor/impeller unit after reassembly is required. This very precise coupling is associated with the fact that there is one casing for every impeller which permits low clearances between the impeller and the stator and hence higher efficeiicy.

- The need for just one tooth coupling against three couplings used in M-1R compressor.

- Fewer impellers far every configuration. 3 impellers for configurations 1, 2 and 3 and 4 impellers for configurations 4 and 5.

The weight of biggest machine is = 40tons. Power absorbed vary from 380 to 1600 Kw going from configuration N° 5 to configuration N° 1.
The compression has one intermediate cooler of the same kind of M-1R before described.
Outlet temperature from last stage is around 240°C.
The compressor is protected with an antisurge system cnmletely automatic made of two indipendent line with two indipendent regulators each one operate an antisurge valve (see drawing 14 with schematic P&I).

Materials used are consequently our long experience in yeothermal field construction. Main components are made of:

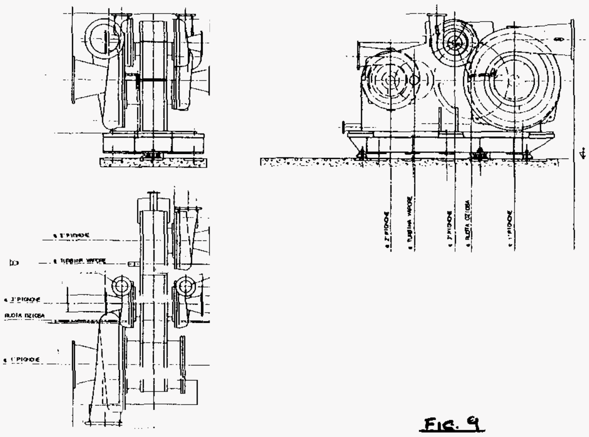
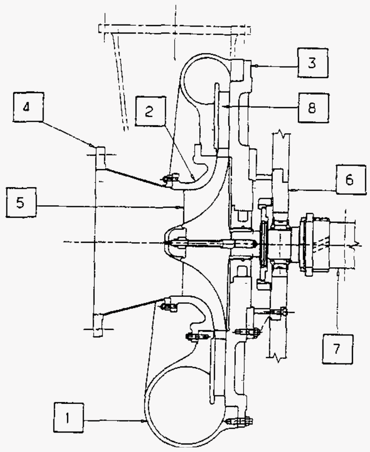


Fig. 9



1 CASING
2 INLET NOZZLE
3 CASING RING
4 SUCTION
5 IMPELLER
6 SUPPORT CASING RING
7 PINION
8 IMPELLER BLADED DIFFUSER

Fig. 10

Casing: Meehanite cast iron

Impellers: Alloy stainless steel 16% Cr-4,5% Ni (17-4 PH)

Gas labyrinth seal: Stainless stell 316L

Bladed diffuser: Stainless steel 316L

Gearbox casing: Carbon steel

Pinions: Alloy steel DIN 17 CrNiMo6

Idler wheel and shaft: Alloy steel DIN 30 CrNiMo8

Hull wheel and shaft: Alloy steel DIN 30 CrNiMo8

Gas intercooler: Stainless steel AISI 316L

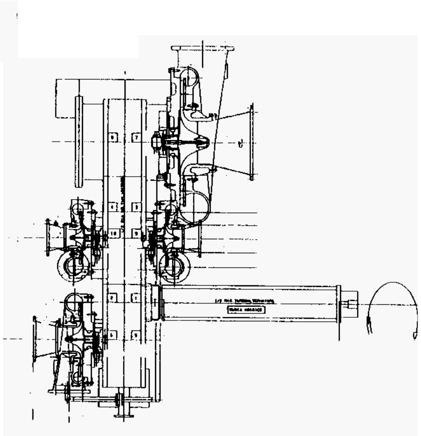


Fig. 10 / Bis

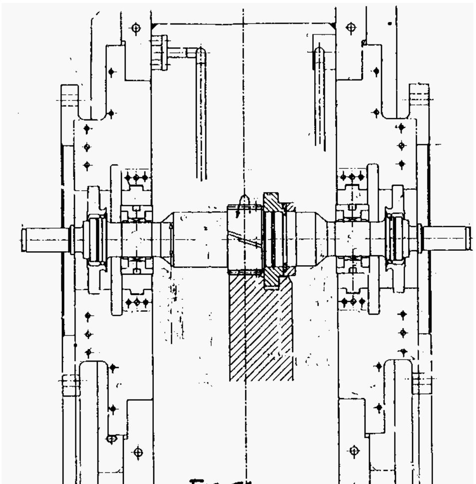


Fig 11

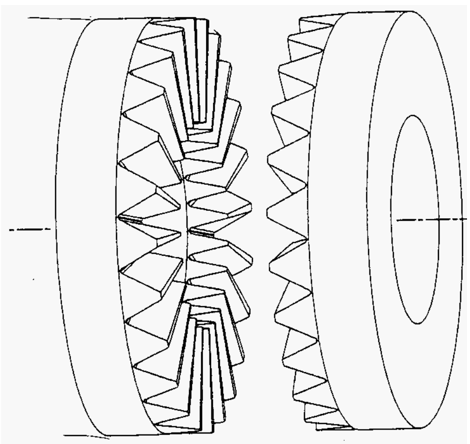


Fig 12

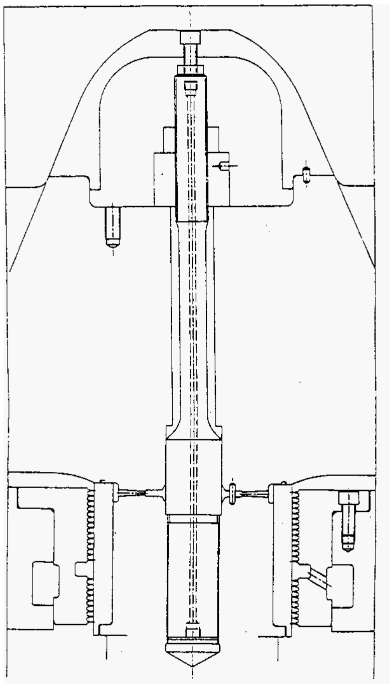


Fig. 13

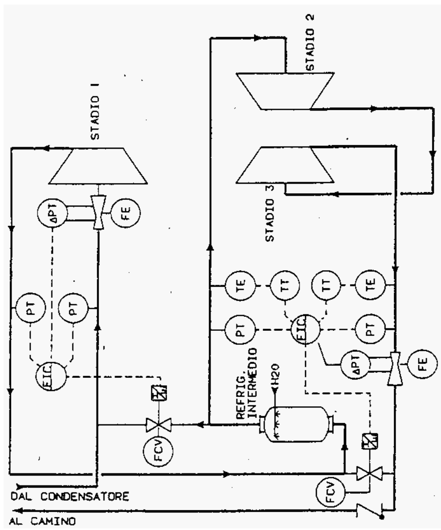


Fig. 14