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028

GEOTHERMAL POWER GENERATION WITH TWO-PHASE FLOW TURBINES

APPLICATION TO THE MOUNT MAKUSHIN RESERVOIR
UNALASKA ISLAND, ALASKA

PROPOSAL FOR A TECHNO-ECONOMICAL FEASIBILITY STUDY

FOREWORD

A total flow concept, known as two-phase expansion is presently being developed by GEOPHASE, an association grouping three, privately owned, companies, GEOTHERMA S.A. (GSA), BERTIN & Cie (BEC) and ATELIERS BOUVIER (AB). These partners with complementary expertise and experiences in the fields of geothermal energy (GSA), electrical engineering (BEC) and turbine manufacturing (AB) are dedicating R&D and industrial development efforts to power generation from geothermal sources at higher efficiencies and lower costs than those demonstrated by conventional processes.

The present proposal addresses a feasibility study which would be worth undertaking to assess the technical and economical feasibilities of applying two-phase flow turbines to electricity generation from the geothermal deposits recently identified at the Mount Makushin site.

GENERAL

The development of the geothermal reservoir identified at shallow depth at Mount Makushin, Unalaska Island, Alaska may prove an attractive alternative to a diesel fired power plant in meeting the Island's future energy demand.

At first glance the data available from the testing of well M1 which are summarised in Table 1 suggest that geothermal production from a well of commercial size, sunk at a depth of 2000 ft (600 m), would be (a) technically feasible, (b) economically viable, and (c) environmentally safe.

(a) technical feasibility

Commercial exploitation of high flow, low salinity, medium temperature (below 300°F) geothermal fluids is routine practice world wide. So is electricity generation via conventional conversion (flash - single or dual) cycles. In addition the process would be greatly simplified by avoiding reinjection into the reservoir of the condensate and separated liquid which could be dumped instead into a surface stream.

(b) economic viability

Thanks to this favourable setting - shallow wells with large productive capacities, no reinjection holes - mining costs would be kept at a minimum. A light drilling rig could be used thus saving the construction of a road that would be required by deep drilling equipment.

(c) environmental acceptability

It is expected that dilution of the heat depleted brine by the nearby fresh water stream would be sufficient to prevent saline contamination. Given a geothermal discharge of 900 lbs/hr (4 cf/sec) and stream and condensate salinities (as chloride contents) of 50 ppm and 3000 ppm respectively a minimum stream flow of 22 cf/sec would keep the downstream salinity below the legal 500 ppm mark required for salmon migration.

It is noteworthy that the elevation of the geothermal site respective to the nearest surface stream might turn the rejection of the condensate into an asset by adding a hydropower of 170 kWe (assumptions : head: 600 ft (183 m), flow rate: 4 cf/sec (112 l/sec), hydraulic turbine efficiency: 0.85).

The economics would shape more favourably should a new power generation concept allow for (a) conversion efficiencies greater than those achieved by conventional technologies (flash and binary cycles), and (b) a power plant, modular in design, providing easier shipping and assembling and higher plant reliability and operational flexibility.

The two-phase flow turbine developed by GEOPHASE is a total flow based process which aims at recovering the energy of both the vapour and liquid phases of the geothermal brine.

It is targeted towards the following performances and design features: (a) thermo-mechanical efficiency of 50%, and (b) a plant assembled from 2 MWe rated prepacked units. These features would, in the case of the Mount Makushin reservoir, result in (a) a net installed capacity of 10 MWe for a single well, and (b) a power plant consisting of five prepacked modules shipped to the site via helicopters. This would significantly cut down investment costs (mining and road infrastructure) and upgrade the plant capacity factor.

TWO-PHASE EXPANSION. AN OVERVIEW

Geothermal conversion processes presently use either flash or binary (named also Organic Rankine Cycles, ORC) cycles (see Figure 1). Our proposed process is based on a total flow concept. The two-phase mixture expands through specially designed inlet nozzles. Subsequently the kinetic energy of the jet is transmitted to an impulse turbine of the Pelton Wheel type which converts it into mechanical energy.

Figure 2 depicts the principles of the process (here a water condenser is shown; however either an air or a combined air-water condenser could be used).

The nozzle and the turbine are sketched in Figure 3. Various views and close-ups of the present prototype and bench test are displayed in Appendix 1.

Our process differs from existing total flow concepts such as the helical screw expander and the bi-phase turbine. The helical screw expander has not proven efficient for ratings in excess of a few hundred kilowatts due to its limited volumetric expansion ratio. The bi-phase concept is in fact a combined dual flash and two-phase expansion system. It uses a steam separator and a two-phase nozzle, on the hot water line, which drives a rotary turbine acting also as a low pressure separator.

In contrast to conventional conversion schemes the advantages of this process are the following:

a) There are no problems of thermo-chemical nature occurring at the hot source side of the heat exchanger such as scaling and precipitation which are major problems in ORC's.

b) Almost all of the available enthalpy of the brine is recovered while in a flash cycle only the latent heat of the vapour is used.

c) The concept is easy to operate and maintain.

d) Whatever the size of the components, the two-phase expansion concept is cost effective.

The process is designed as a modular system with two or more units in parallel. For instance a total mass flow of 400 tons per hour (approximately 900 000 pounds per hour as is projected for the Mount Makushin reservoir) can feed five parallel units of the type described in Appendix 2.

A cursory calculation based on rough production figures anticipated at Mount Makushin from preliminary testing of well M1 (Ref. D. Campbell and M. Economides, 1983) is attached in Appendix 2.

PRESENT STATUS AND FUTURE DEVELOPMENT OF THE CONCEPT

Presently the process has reached the stage of a probative test engine rated at 50 to 250 kwe depending upon brine inlet conditions with a total conversion efficiency of ca 30%. Yet it needs to be optimised and validated via specific engineering design studies and pilot testing on actual geothermal sites.

As can be seen in Appendix two future prototype developement is oriented towards the design, manufacturing and field implementation of an industrial prototype. This implies that the following phasing be set up within the next three years :

a) Improvement of the present prototype (in progress);

b) Implementation of nozzles and brine conditioners allowing for a two phase inlet (in progress);

c) Assessment of technological problems (scheduled late 1984);

d) Appraisal of thermochimical shortcomings associated with brine supersaturation in various mineral species (early 1985);

e) Detailed technico-economical calculations applied to a variety of candidate geothermal sites(in progress through 1985)

f) Pilot field studies on two selected geothermal sites in contrasted thermodynamic and chimical environnments, one with a low salinity and medium enthalpy brine, the other with high temperature and salt content. Power ratings would range from 0:5 to 2:5 Mwe which is about the size of a unit skid mounted module (scheduled mid 1985 to 1987)

This programme will allow for (a) an industrial development start up by late 1987, and (b) an overall system efficiency of 50% (nozzles : 90%, turbine : 60%).

Collaboration at this stage with experts and/or consultants of the Alaska Power Authority is sought.

b) Two phase conversion technology

This item deals with the thermodynamics and electrical engineering of two phase expansion cycles, engines and satellite equipment. It is also relevant to the manufacturing, packing, assembling and operation-maintenance implications of the process in the Unalaska environnment. The programme will consist of the following sequence :

- design of two phase injectors,
- turbine design and regulation which includes the following parts :
  - impulse turbine (Pelton wheel) proper,
  - gear box and alternator
  - fly wheel (*)
  - speed governor (*)
  - electronic regulator and control panel
  - transformer

(*) Attention is drawn to the fact that, because of the size of the existing Unalaska grid, it is likely that the geothermal power plant will be 'self-controlled' (e.g. it will drive its own frequency instead of being regulated by the grid). Accordingly flow will be regulated which is best achieved via automatically actuated valves set at nozzle inlets.

- selection of condenser (air, water, hybrid) and ancillary equipment
- system's overall energy balance for various performance levels

This technology assessment will yield a preliminary design of the plant for a set of candidate alternatives regarding the ratings of power generation modules and type of condenser and regulation.

c) Logistics and economics

This section includes :

- a civil engineering study
- an appraisal of logistics (size, weight, pre-packing, shipping, assembling of drilling rig and power generating equipment

workover facilities)

- an evaluation of capital investment and plant running costs
- a comparison with a reference diesel plant case

It will enable to select the best suitable plant alternative with respect to logistics, plant reliablility, operation and maintenance and, last but not least, costs.

In addition to the usual standard DCF calculations we offer to do a <u>life cycle costing analysis over 30 years</u> and compare the two phase geothermal figures to those derived from a rate base analysis for diesel generation.

COST ESTIMATE

Geophase will provide a staff of three senior engineers experienced in geothermal, mechanical and electrical engineering and one economic analyst for completion of the afore mentioned work programme. Geotherma will act as operator for Geophase.

The feasibility study will include one trip to Alaska for site inspection and local cost, labor, civil engineering and logistics enquiries. Contacts will also be taken with relevant federal and state agencies for all matters relevants to development, energy and environment policies and regulations. Specific enquiries will also be carried out in west coast states for cost of specialized(satellite)equipement manufacturing, assembling and shipping.

The breakdown of costs is as follows :

A. <u>Personel costs (based on a daily cost of US $ 450)</u>.

a) Geothermal reservoir and drilling-production assessment 22 days x 450	9 900 US $
b) Two phase technology assessment 45 days x 450	20 250 US $
c) Appraisal of logistics and economics;life cycle costing analysis 35 days x 450	15 750 US $

B. Miscellaneous costs

Transport (air fare), living allowance (12 days), report preparation (10 copies)	4 500 US $
C. Grand total	50 400 US $

This proposal will be valid for 90 days from the date of submittal.

TABLE 1

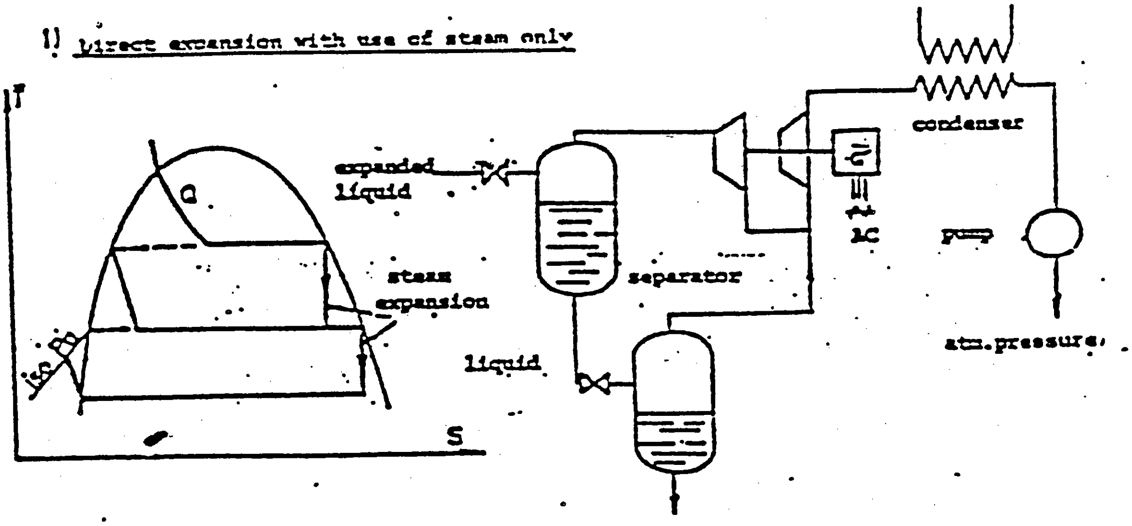
Geothermal Fluid Characteristics and well Head Flow Properties

(well assumed of commercial size)

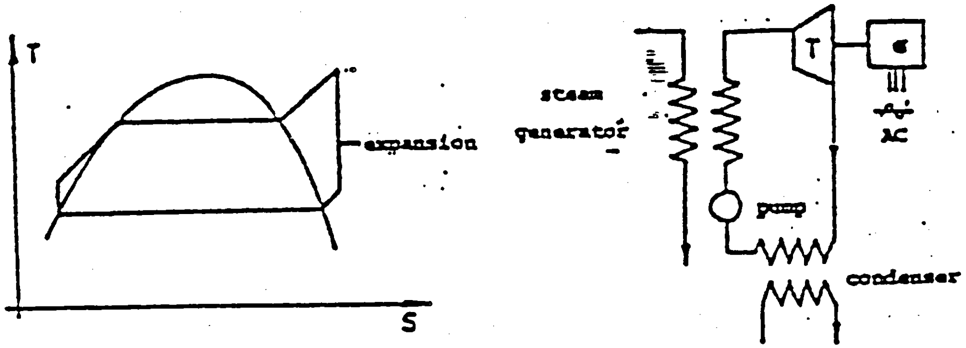
Pressure	60 psia (4.15 bars)
Temperature	293°F (145°C)
Total Mass Flow Rate	880,000 PPH (400 tons/hour)
Steam Quality	0.2
Salinity	0.7% as T.D.S.
Noncondensable Gas Content	Assume negligble.

Source : D. Campbell and M. Economides, 1983.
M. Economides, 1984.

1) Direct expansion with use of steam only



2) Rankine cycle with auxiliary fluid



3) Cycle proposed : two-phase expansion

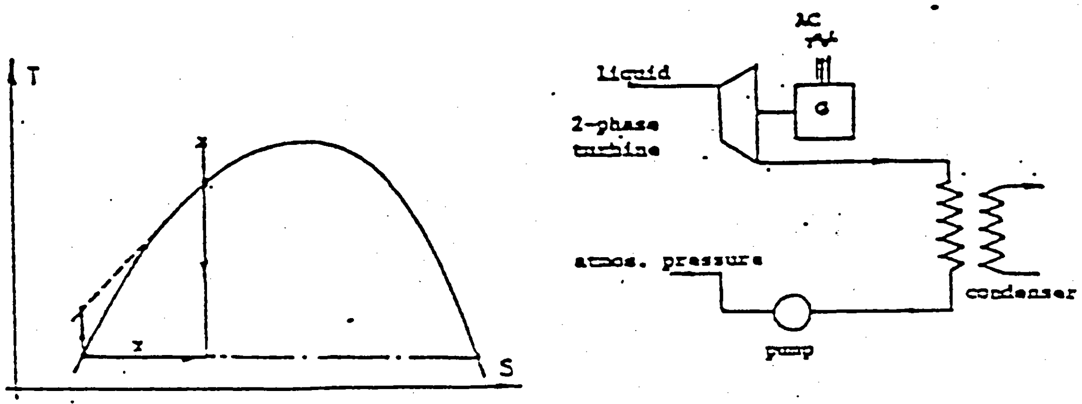


Figure 1 Geothermal Conversion Cycles

SYSTEM DIAGRAM

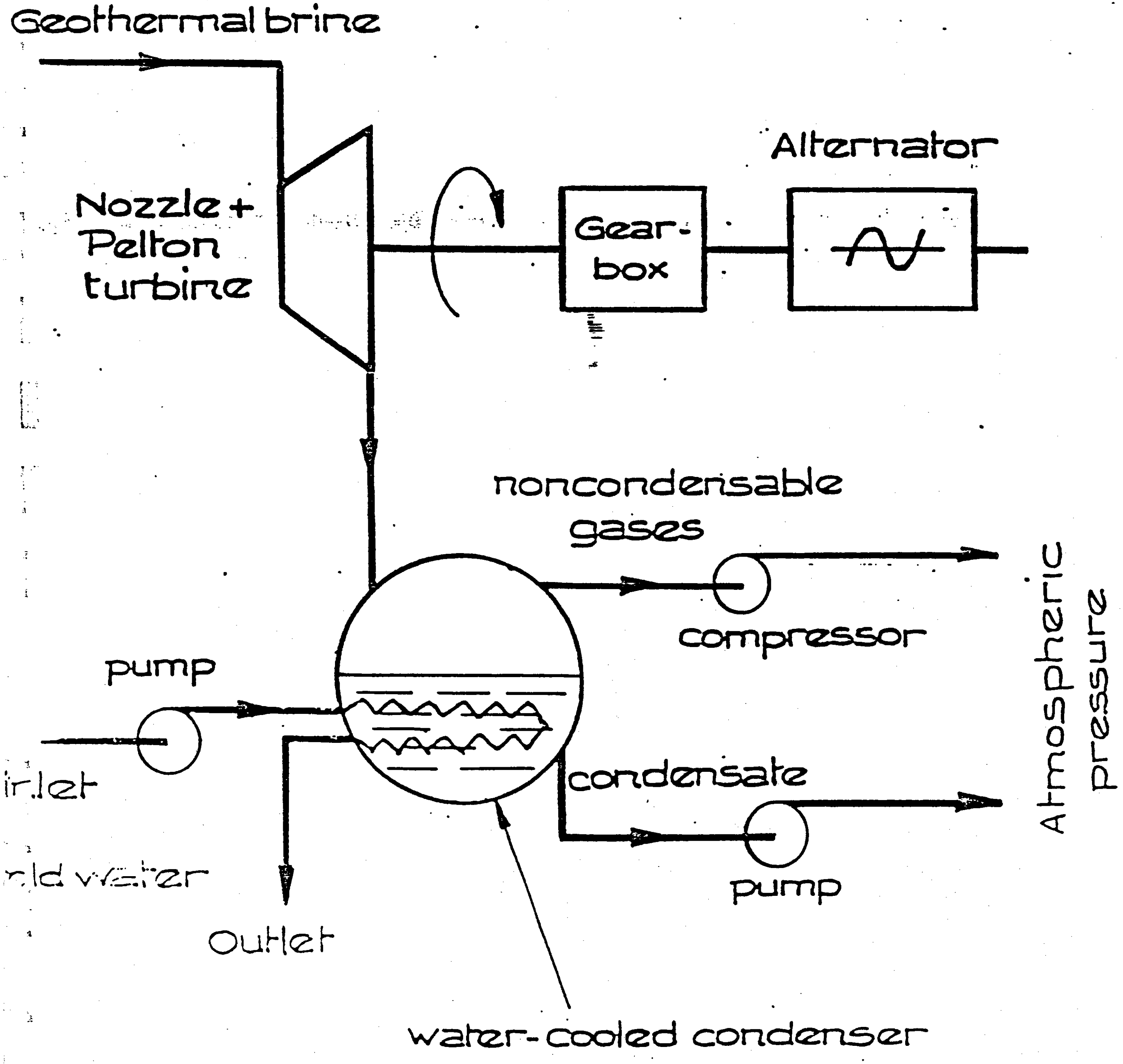
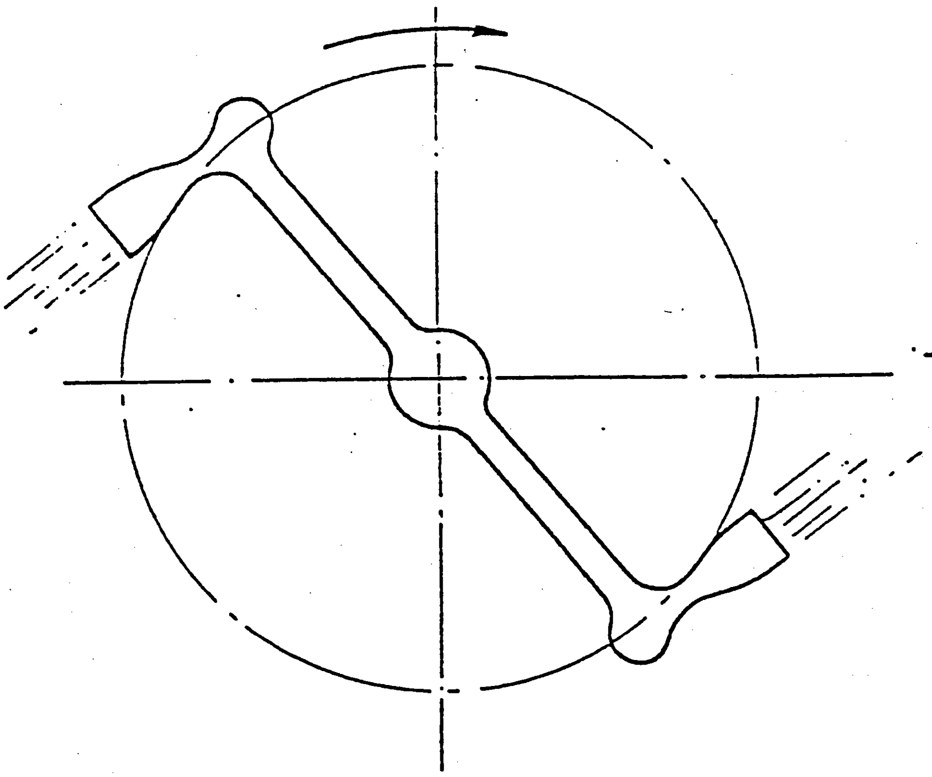
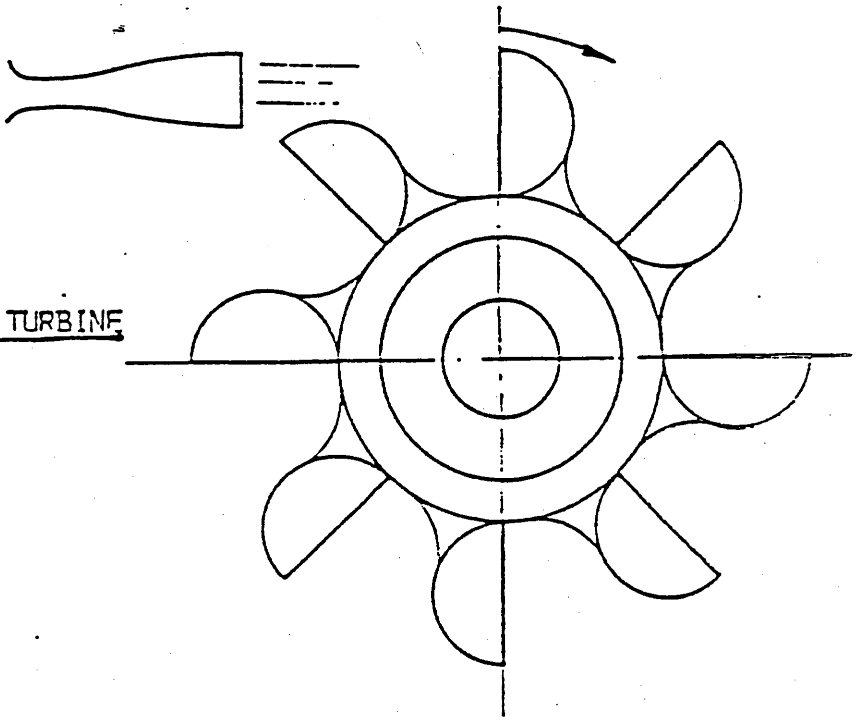


Figure 2. Two-phase Flow Expansion System Diagram.

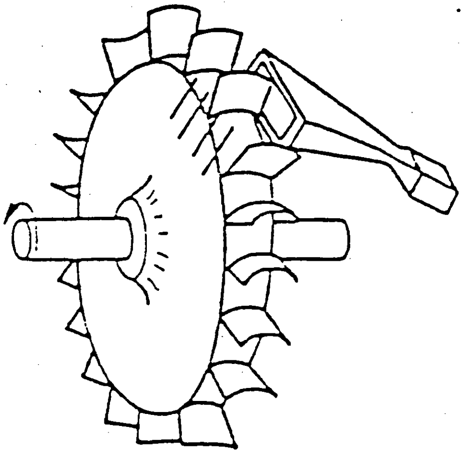
TWO-PHASE TURBINES



HERO TURBINE



PELTON-TYPE TURBINE



RATEAU-TYPE TURBINE

VIEW OF THE
TWO-PHASE FLOW
TURBINE AND NOZZLES

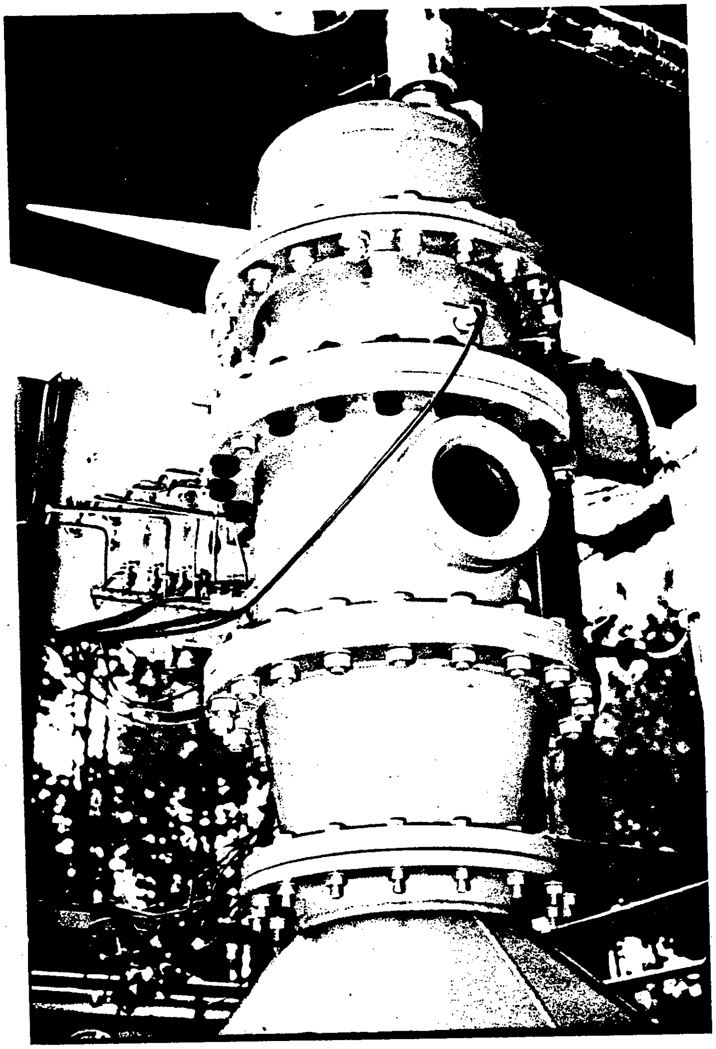
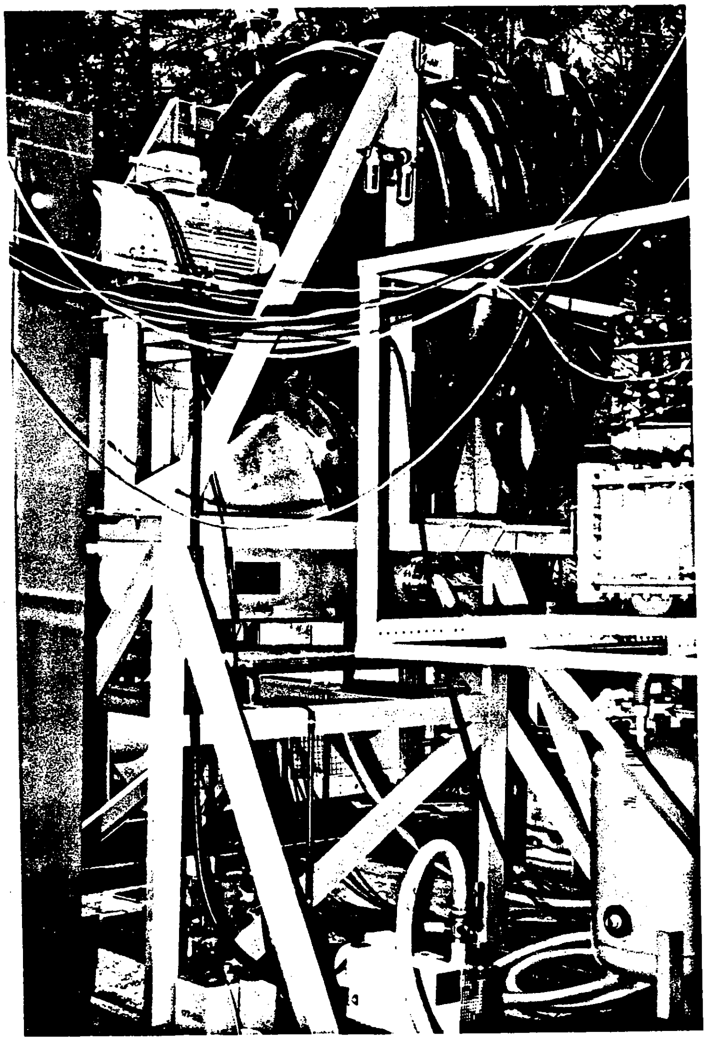


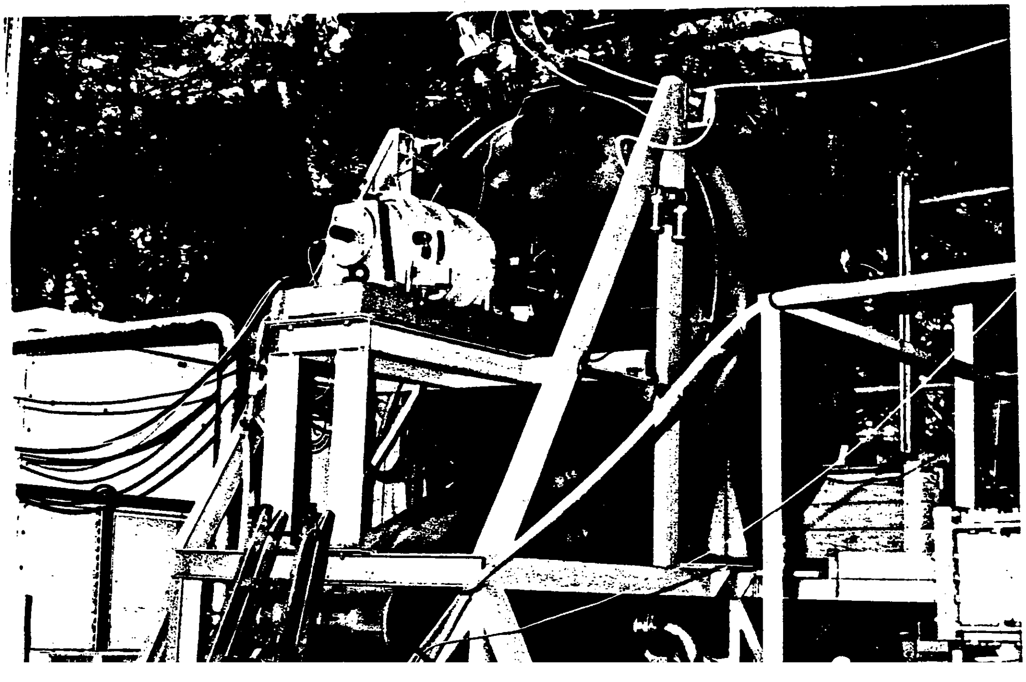
Fig.1. : View of the Nozzle Bench Test.

Fig.2. : Close Up of the two-phase jet (mist) at nozzle outlet



<u>Fig.3.</u> : Turbine Bench Test (turbine - nozzle housing, Foucault current brake condenser)

<u>Fig.4.</u> : General view of the Turbine Bench Test



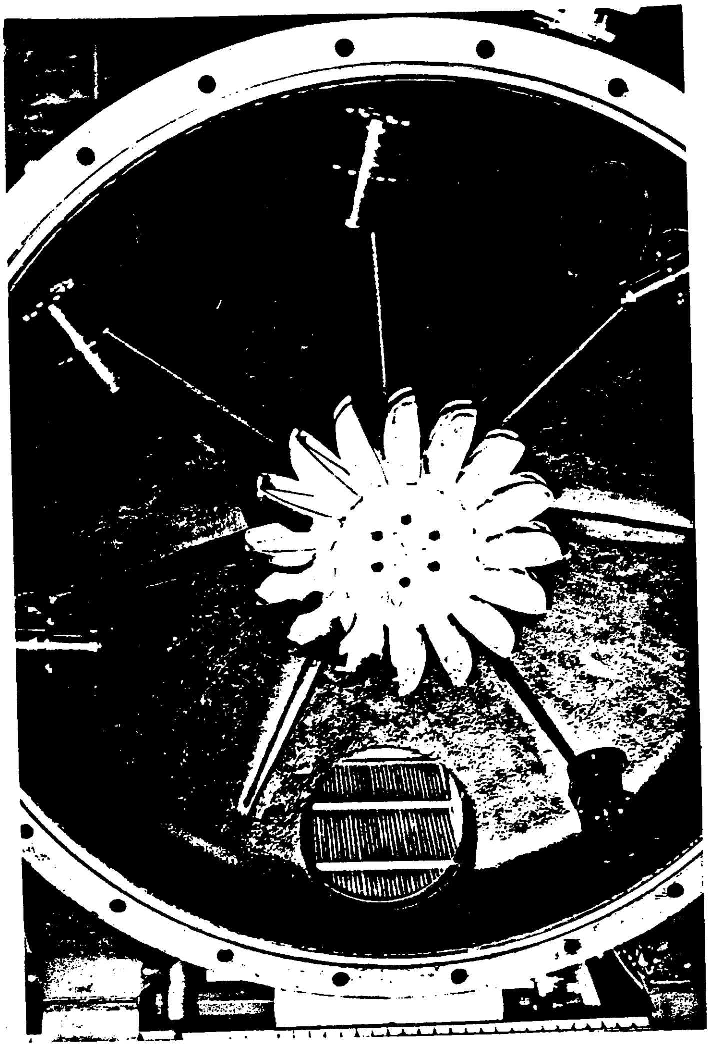


Fig.5. : Inside View of the Turbine and Nozzle Housing.

Here a 6 nozzle holper and a 100KW turbine (Relton wheel) are shown, Housing dimensions are Ø 1.70m I.D. Turbine size is Ø 50cm, weight 100kg. Future design will deal with a housing more compact in size to reduce disc friction losses

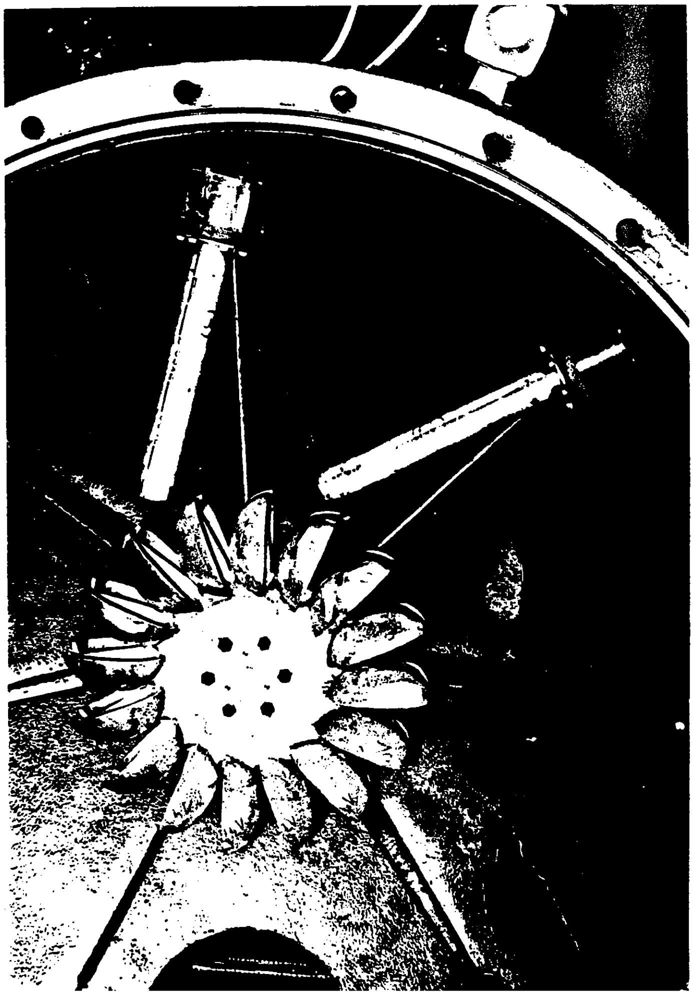


Fig.6. : Close Up View of a two nozzle turbine set

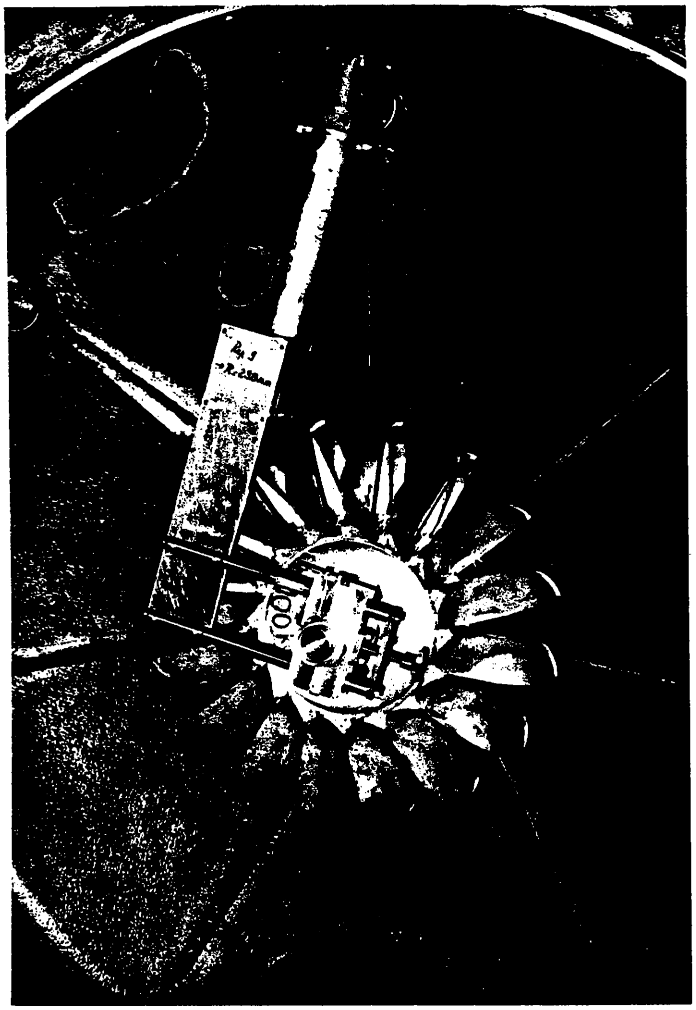
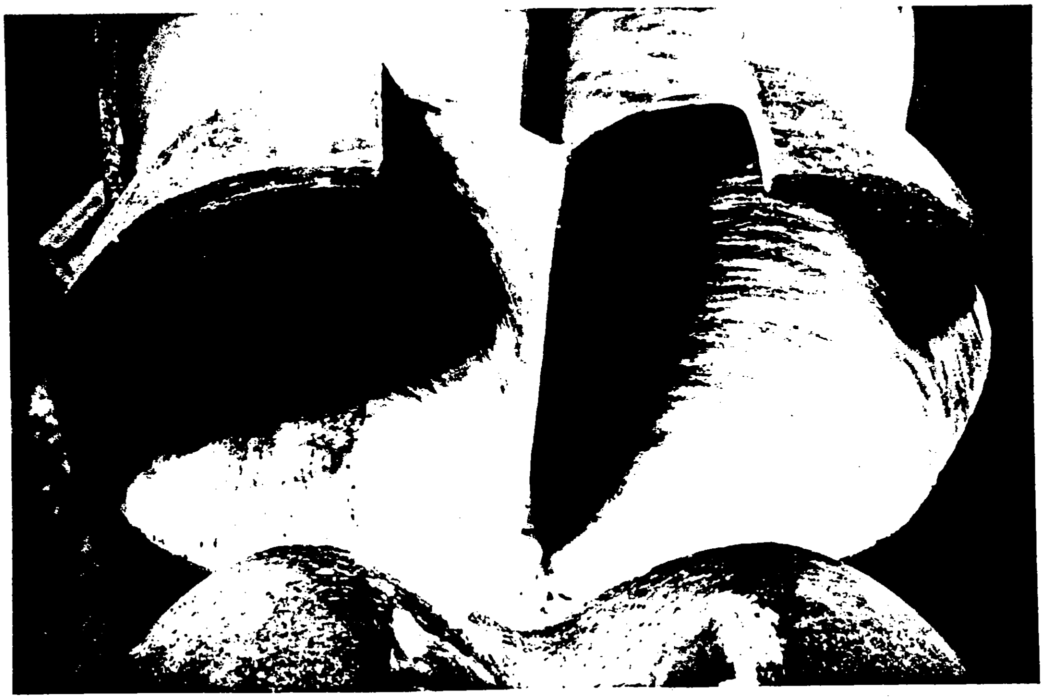


Fig.7. : Close Up View of the nozzle alignment device.

Fig.8. : Close Up View of the Pelton Wheel Bucketts.



APPENDIX 2

AN APPLICATION OF THE TWO PHASE EXPANSION CONCEPT TO THE MOUNT MAKUSHIN GEOTHERMAL RESERVOIR (UNALASKA ISLAND, ALASKA)

A PRELIMINARY CALCULATION BASED ON FIGURES ANTICIPATED

BY D. CAMPBELL AND M. ECONOMIDES

(9th Stanford Geothermal Reservoir
Engineering Workshop - Dec. 1983)

The following is an approximate approach and in no may is it intended as a design of the equipment. Instead it will supply a general idea of the projected power output, conversion efficiency and equipment size.

Table 1 outlines the characteristics of a production well of commercial size at the Unalaska reservoir, while Table 2 contains turbine outlet fluid featùres.

TABLE 1

Fluid Characteristics and Flow Rate at Wellhead of Commercial Size Well at Unalaska Reservoir

Pressure	**60 psia (4.15 bars)**
Temperature	**293°F (145°C)**
Total Mass Flow Rate	**880,000 PPH (400 tons/hour)**
Steam Quality	**0.2**
Salinity	**0.2% T.D.S.**
Noncondensable Gas Content	**Assume negligble.**

TABLE 2

Turbine Outlet Fluid Characteristics

Pressure	0.46 psi (.0316 bars)
Temperature	77°F(25°C)
Steam Quality	0.3
Vapor Density	$.023 Kg/m^3$
Mixture Density	$.077 Kg/m^3$
Theoretical Available Power (for 880,000 PPH)	22.34 MWe

Because the proposed equipment is presently in the prototype development stage, an assumed efficiency will be used in the calculation, the high value being 0.5 and the low being 0.35. The alternator efficiency is taken as equal to 0.97, corresponding to current industrial standards for similar power ratings. The calculations deal with five parallel units. In our example each unit consists of a Pelton Wheel, 1.6 m in diameter with a nominal rotating speed of 3800 RPM coupled with eight inlet nozzles with a terminal diameter of 270 mm.

Condenser

Depending on local conditions either an air or water-cooled condenser may be utilized. A combined air/water condenser can also be envisaged as is illustrated in Figure 2. In this case a simple water condenser was sized considering the abundance of cold surface water in the Makushin region. The condenser would require 1 m^3/s of cooling water per unit and 1400 m^2 of heat exchange area per unit. As far as sizing is concerned the calculation has dealt with conventional technology and in no way is the condenser design to be considered as optimized. The achieved compactness ratio (Heat exchange area/unit volume of exchanger) is 66 m^2/m^3 could be markedly improved to at least 200-300 m^2/m^3.

Economics (In case of water condenser)

Table 3 summarizes the energy balance of the proposed scheme.

TABLE 3

Energy Breakdown in Total Flow Turbine

Items	System Efficiency (.35)	Efficiency (.50)
Alternator Power Output (KW_e)	1517	2167
Water Feed Pump Consumption (KW_e)	74	74
Condensate Pump Consumption (KW_e)	3	3
Net Power/Unit (KW_e)	1440	2090
Net Total Power (5 Units)	7200	10450
Specific Consumption (Brine Flowrate/KW_e)	122 PPH	84 PH

The costs of the individual system components are shown in Table 4.

TABLE 4

Cost of Individual System Components
(Per Unit in Thousand Dollars)

Turbine (Pelton Wheel Plus Nozzles)		126
Turbine Housing		9.9
Alternator		103
Gear Box		32.5
Condenser-Base Price		247
(Extra Cost, Stainless Steel)		(247)
Condenser Feed Pump		43.8
Condensate Pump		4.2
	Total	566.4 (813.4)

Installation Cost

To obtain the actual installation cost, the component costs is multiplied by a coefficient K_i which takes into account local as well as industry-wide logistics. In petroleum engineering this coefficient is equal to 3.5 However, in hydraulic engineering, which is closer to our field of application, K_i is equal to 2. Hence, in this calculation K_i is considered to vary between 2 (benign, normal conditions) and 4 (exceptinally hostile logistical and operational conditions). In the case of the condenser, the multiplier is applied on the base cost alone. Additions to the total cost because of specialty metals or coatings are applied thereafter in order to avoid artificial cost escalations.

Capital investment costs are summarized in Table 5 for all five skid mounted units.

TABLE 5

Total Investment Costs for Five Units of Total-flow Turbine System

Net Elective Power (KW_e)	**Efficiency (0.35)**		**Efficency (0.5)**	
Net Electric Power (KW_e)	**7.2**		**10.45**	
	$k_l = 2$	$k_l = 4$	$k_l = 2$	$k_l = 4$
Total Investment Cost ($ Million)	6.9	12.6	6.9	12.6
Unit Cost ($/$KW_e$)	960	1745	662	1202

Size and Weight

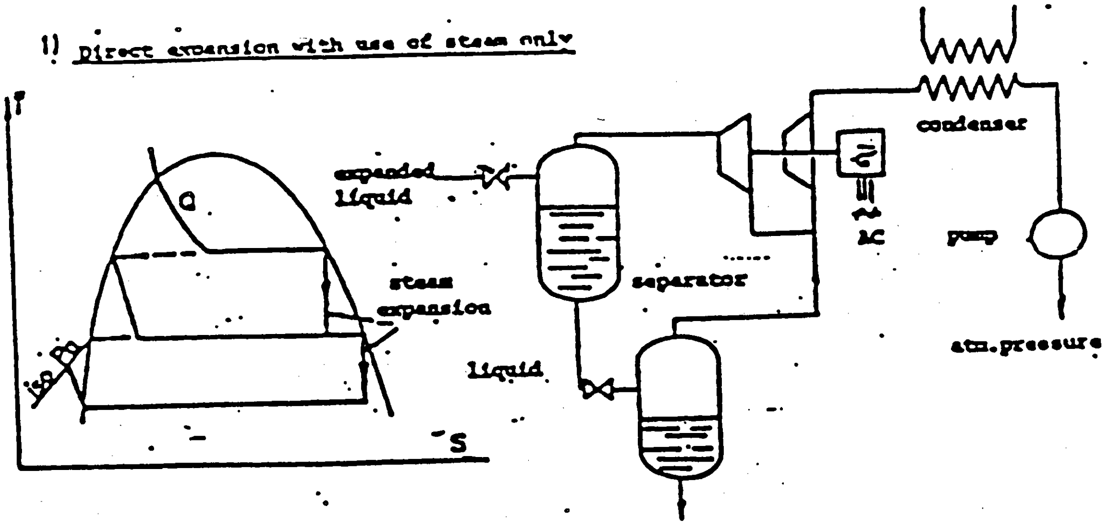
The turbine and turbine housing will have a diameter of 1.6 m and will weigh between 3-4 tons. An optimized design would most likely lead to a smaller and faster rotating turbine resulting in smaller size and weight.

Within the power range of interest (1-3 MW/unit) the ratio of 5 kg/KW_e is a generally accepted figure for the weight of the alternator. Hence, for each unit the weight should be between 7 and 10 tons. The weight of the gear box should not exceed 2 tons/unit. However, it should be readily emphasized that rotating speeds should be adjusted in order to reduce the weight of the gear box.

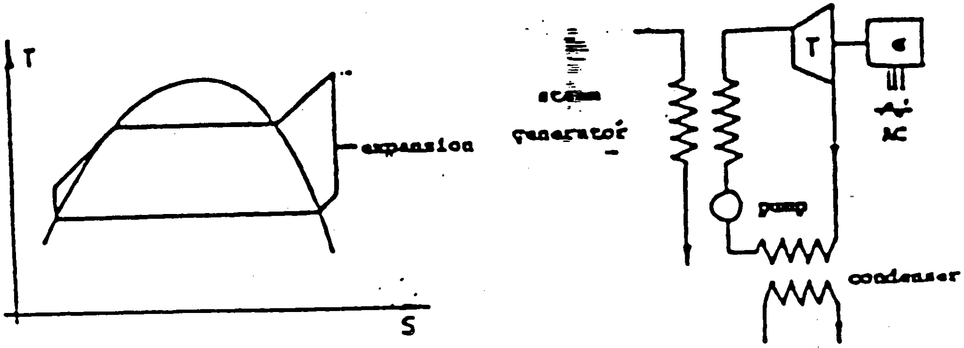
At the present design state the condenser weight and size are subjected to the greatest uncertainty.

For water condensers with a compactness ratio of 200 m^2/m^3 the resulting volume would amount to approximately 6 m^3. Given a weight of 2.5 tons/m^3, the condenser weight would be 15 tons/unit.

1) Direct expansion with use of steam only



2) Rankine cycle with auxiliary fluid



3) Cycle proposed : two-phase expansion

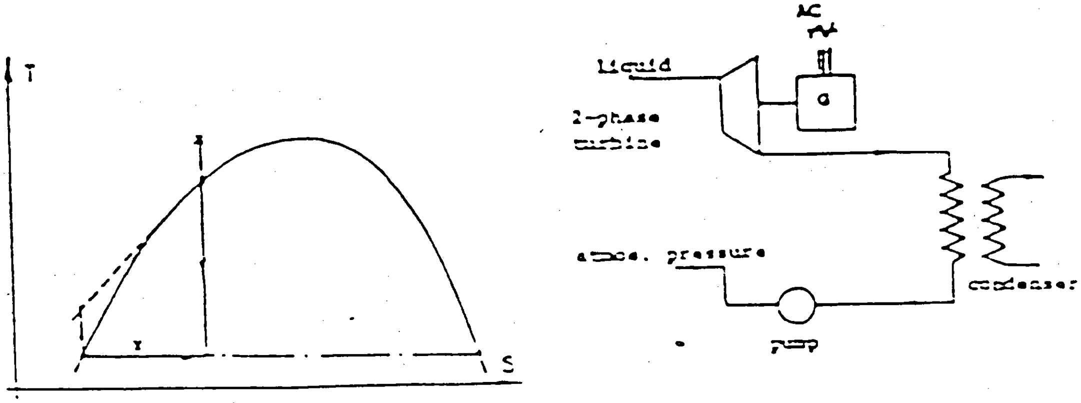


Figure 1 Geothermal Conversion Cycles

SYSTEM DIAGRAM

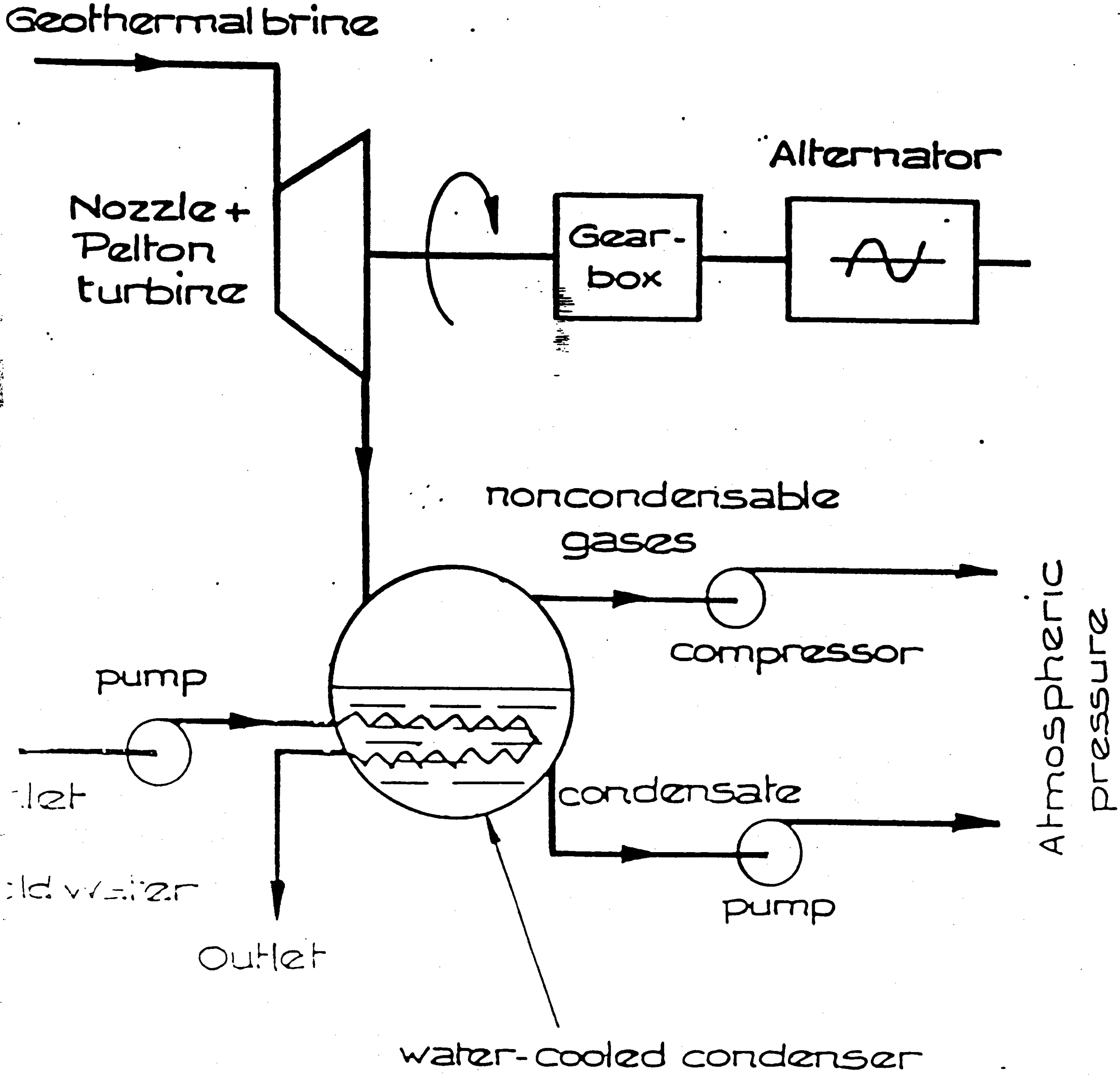


Figure 2. Two-phase Flow Expansion System Diagram.

TWO PHASE EXPANSION

PRESENT STATUS FUTURE PROTOTYPE AND INDUSTRIAL DEVELOPMENT

PRESENT STATUS

A test engine has been proofed on the bench test facility, illustrated in Appendix one, whose features are the following :

Thermal power : 600 kW

Saturating water flowrate : 0.9 kg/s

Turbine Ø 440mm with 6 injection nozzles

Electromagnetic brake : 100 kW (speed or power regulated)

The experimental outfit enables to monitor the following parameters :

Generating conditions (pressure, temperature, flowrate)

Condensing conditions

Number of nozzles and injection radius

Turbine rotating speed (U/C_o)

The present performances are :

Nozzle efficiency : 70 - 80%

Turbine efficiency: 30 - 40%

Maximum overall efficiency : 30%

Capital investment costs (drilling not included) : 350 to 700 US $/kWe depending upon generating conditions.

Marked improvements can be sought in the very near future regarding nozzle efficiency, reduction of disc friction losses in the turbine housing and limitation of losses occuring in the turbine bucketts.

They should allow to reach overall efficiencies close to 50% a target attainable within one year from now.

FUTURE PROTOTYPE DEVELOPMENT

The following R, D and D and industrial prototype development actions are scheduled within the next three years.

1. Prototype upgrading
   - Reduction of aerodynamic friction losses

- Reduction of buckett generated losses :
  - Increase of unit flowrate
  - Alternative buckett configurations

- Validation of injectors on a nozzle bench test

2. Testing of new injectors

- Two-phase inlet conditions (efficiency of 90%)

- Higher expansion ratios

3. Techno-economical analyses

- Detailed analysis of process implementation on actual geothermal sites

4. Detailed technology assessments

- Material definition (nozzles, turbine, ets...)
  - Erosion, corrosion, fatigue-corrosion, coating.

5. Thermochemical investigations

- Design and implementation of scale inhibition and abatement procedures and of a flash cristallizer upstream from the condenser.

6. Turbine factory testing

Power ratings varying from 0,2 to 2 MWe.

7. Pilot and Demonstration experiments on existing geothermal fields (Italy, Mexico)

- Low salinity, medium enthalpy brine.

- High salinity, high enthalpy brine.