A REPORT UPON

AN INVESTIGATION OF PUMPING CONDITIONS

AND RESULTS OF TESTS OF PERFORMANCE OF

THE ALBERGER-CURTIS STEAM TURBINE CENTRIFUGAL PUMPING UNIT

IN THE CITY WATER WORKS PUMPING STATION

SACRAMENTO, CALIFORNIA.

JUNE 29, 1915.

Department of Engineering

Office of City Engineer

Sacramento, California.

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by

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June 29, 1915.

GENERAL TABLE OF CONTENTS

TABLE OF CONTENTS.

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APPENDICES

REPORT

Fundamental Considerations and Pumping Conditions

Capacity of Pumping Engines and Present Water Consumption.

The Alberger-Curtis steam-turbine centrifugal pumping unit, which is under immediate discussion in this report, has not yet been accepted by the city. Unless and until such acceptance is had it obviously cannot be considered to be a part of the permanent pumping equipment of the city water works pumping station.

The present regular equipment of the station consists of four pumping units with rated capacities as follows:-

Table No. 1

CAPACITIES OF PUMPING ENGINES CONSTITUTING REGULAR EQUIPMENT

SACRAMENTO WATER WORKS PUMPING STATION

Name of Pump	Date of Erection	Type	Rated Capacity * Mill. Galls. per Day.
Snow	1904	Trip. Exp. Vert. Crank and Fly Wheel	10.0
Allis	1895	Comp. " " " " "	5.5
Holly	1873	Quadruplex Incl. " " " "	4.5
Dpw	1903	Tandem Comp. Duplex, Horizontal	2.0
		Total Nominal Capacity =	22.0

* These figures make no allowance for slip which, in the several units, may be conservatively taken as follows:- Allis and Snow Pumps (with plungers and valves in good condition), 5%; Dow and Holly Pumps, 15%. On account of the gritty and turbid condition of the water supply, it is a difficult matter to maintain the pumps in good condition, the tendency being to grind down the plungers and pistons and to wear out the glands, stuffing-boxes and valves.

It will be seen from the table above that the total actual pumping capacity, after making due allowance for slip, (say 10%, as an average figure), is about 19.8 million gallons per 24 hours. Except for the steam-turbine centrifugal unit under consideration, no additions have been made to the equipment at the pumping plant since 1904.

The consumption of water in the city has been steadily advancing for many years and has now reached the maximum rate of at least 22.0 million gallons

per 24 hours, as supplied from this plant. It is apparent that this volume of water can only be furnished by operating all of the regular pumping equipment at rates considerably in excess of its nominal capacity. When the water mains are extended into the annexed territory, which is now being done under contract No. 57 (for the furnishing and installing of riveted steel and cast iron water pipe, valves, hydrants and other appurtenances in the streets, alleys and rights-of-way in the City of Sacramento), the demands for water will be largely and rather suddenly increased. That further pumping equipment is urgently required demands no demonstration. Such equipment, however, must be of a proper type and must be capable of efficient and reliable operation under all of the physical conditions which obtain with respect to the pumping station and the requirements of pumping. In view of these physical conditions which prevail at the pumping station, the proper type of pumping equipment should be most carefully considered before any further installations are made.

The following table presents figures of water consumption in millions of gallons per 24 hours for the period 1910-1914, inclusive, in terms of average per year, average for maximum month, total for maximum day and rate per day for maximum hour.

Table No. 2.

STATISTICS OF WATER CONSUMPTION IN SACRAMENTO, 1910-1914.

Year	Water Consumption *- Mill. Gallons per Day. Average per Year	Aver. for Max. Month	Max. Day	Max. Hour
1910	12.7	16.4	19.9	---
1911	12.1	13.5	14.8	20.0
1912	12.7	15.1	17.0	20.5
1913	13.6	16.5	17.7	22.0
1914	13.4	16.0	17.9	21.8

* These figures are 90% of the total pumpage as estimated from the displacement or rated capacity of the pumps and thus allow 10% for slip, as a rough average correction. It is probable that the average slip of the pumping station equipment was larger, during the early years of the period, than the figure assumed.

Summary and Conclusions.

Fundamental Considerations and Pumping Conditions.

The present regular equipment of the Sacramento City water works pumping station comprises four pumping units of various types, capacities and efficiencies. The total nominal capacity of the pumps is 22.0 million gallons per day. The actual working capacity is perhaps 19.8 million gallons per day. The Alberger-Curtis steam-turbine centrifugal pumping unit, which has been under immediate consideration in the foregoing report, has a nominal capacity, under certain restricted conditions, of 15.1 million gallons per 24 hours. This pump has not yet been accepted by the city and hence cannot at this date be considered to be a part of the regular pumping equipment of the station. (See page 2 - 3).

The consumption of water in that portion of the city (namely, the area included within the limits of the city prior to 1910) supplied from the pumping station in question has been increasing during recent years. This increase has been more real than apparent because the condition of the pumping engines is undoubtedly much better to-day than it was several years ago and the "slip" has therefore been reduced significantly. The maximum rate of use of water for short periods during the past five years has probably been in the neighborhood of 22.0 million gallons per day. This figure is certainly considerably in excess of the working capacity of the pumps constituting the regular pumping station equipment, as noted above. The maximum short-period rate of use of water in the area supplied seems to be about 63% greater than the average rate. (See page 3).

The lowest level reached in recent years by Sacramento River was 2.6 feet on the gauge. This stage occurred on Sept. 23, 1913. In each of several years in the early history of the city the river reached the zero mark, at least. It is not safe to assume that zero stage will not again be reached,

and perhaps in the npt distant future. The center line of the shafts of the centrifugal pumping unit has an elevation of 22.8 feet above the zero of the river gauge. The pump derives its supply of water through the Allis and Holly suction pipe system. If the inevitable losses of head (entrance, velocity, friction, at elbows, valves, etc.) are added to the water lift, the total suction lift at low stages of the river becomes much greater than the centrifugal pumping unit can possibly operate with. Centrifugal pumps are, as a class, notably unfit for service under high suction lift conditions and those applying to the present case are nothing less than absurd and impossible. This whole matter has received painstaking consideration in the foregoing report, with the result that the following conclusion became unavoidable:- "Such conditions can mean only one thing, namely, that this pumping unit, if accepted by the city, would be of no valuve whatever when the river reaches its lower stages, or, say, anywhere below 10 feet on the gauge, because it could not then safely and reliably be operated." (See pages 4 - 9).

The steam-turbine centrifugal pumping unit has been designed to operate at a pressure of about 125 lbs. per sq. in. at the throttle. This necessitates a pressure of about 130 lbs. per sq. in. at the boilers. The pressure normally carried at the boilers when the reciprocating pumping engines, only, are in operation ranges between 115 and 120 lbs. per sq. in. The contract for the turbine centrifugal unit stipulates that the supply of steam shall be in a dry, saturated condition. (See page 10).

Nature and Conditions of Contract and Specifications for Pumping Unit.

The contract for the pumping unit in question was made under date of Sept. 18, 1913 with C. F. Braun and Company, constructing mechanical engineers, San Francisco. The foundations and condenser sump were to be furnished by the city; the pumping unit and auxiliaries and piping connections by the contractor. The contract provided that the unit should be capable:-

(a) of pumping 10500 gallons per minute (15,100,000 galls. per 24 hrs.) through a total head (suction + discharge) of 135 feet

or (b) of pumping 7000 gallons per minute (10,000,000 galls. per 24 hrs.) through a total head (suction + discharge) of 205 feet.

The pumping unit was to comprise two centrifugal pumps which were to be so designed and cross-connected that they could be operated independently or in parallel with the capacity noted in (a) above and so that they could be operated in series or tandem with the capacity noted in (b). The efficiency of the pumps in the first case was to be 76%; in the second, 67%. (See pages 10 - 12).

The contract reads that the steam consumption of the turbine shall be not less than 19 lbs. of dry, saturated steam per H.P. hour. This statement is, of course, absurd and was clearly intended to read not more than 19 lbs. of steam per H.P. hour. Knowing the contract efficiency of the pumps and assuming that maximum steam consumption is stated in the contract, it becomes possible to compute the minimum contract duty of the pumping unit. This would be as follows:-

(a) 79,200,000 ft. lbs. per 1000 lbs. of dry, saturated steam when the unit is operating with the pumps in parallel under a total lift of 135 feet

(b) 69,800,000 ft. lbs. per 1000 lbs. of dry, saturated steam when the unit is operating with the pumps in series under a total lift of 205 feet.

(See pages 11 - 12).

The specifications for the pumping unit were filed, and adopted by the City Commission under date of June 6, 1913. They appear to be indefinite and inadequate with reference to the efficiency both of the pumping unit itself and of its auxiliaries. The stipulation with respect to suction lift took cognizance only of the water stages in the river and neglected the extremely important matter of losses of head in the suction pipe systems. These losses become very large and significant when large volumes of water are required to pass through the pipes. (See pages 12 - 14).

General Description of Pumping Unit and Auxiliaries.

For purposes of record, a complete description of the steam-turbine centrifugal pumping unit and its auxiliaries, including the features of capacity, general design, sizes and dimensions, etc., has been presented in the foregoing report. It is believed to be unnecessary to repeat the facts here. (See pages 14 - 18).

The contract price of the pumping unit and its auxiliaries is $17,000, of which 75% or $12,750 have been paid by the City. Including the cost of extras, of foundations, testing, etc., the total cost to the City of this equipment, were it to be accepted, would be fully $21,200. The contractor has furnished two bonds, with the Aetna Accident and Liability Co., of Hartford, Connecticut, as surety, dated Sept. 24, 1913, as follows:- material and labor bond, $8,500.; performance bond, $4,250. (See pages 18 - 19).

The pumping unit was delivered in Sacramento late in May or early in June 1914, about 8-1/2 months after the contract was signed. The apparatus was first turned over with steam on August 9. The steam turbine was faultily designed and built and two accidents befell the roter in the third or lowest stage. It was not until February 9, 1915, nearly 17 months after the contract was signed, that the unit and its connections were really in a condition for continuous operation. Between Feb. 9 and Mch. 11, 1915, the pump was operated for 26 entire days and for 0.4 to 22.0 hours on each of 5 other days. A complete history of the erection and the operation of this pump to date has been presented in the foregoing report. (See pages 19 - 24).

Description of Tests of Pumping Unit.

A partial test of the steam-turbine centrifugal pumping unit was made on April 16 but because of some distortion and leaks which developed in the discharge line, the test was discontimued. For several reasons this test, in so far as it was completed, was unsatisfactory and the results secured were disregarded. A second, reliable and complete test was conducted on May 3. The

tests were planned to demonstrate, in every important feature, so far as the physical conditions of the station and its equipment would permit, the performance of the pumping unit itself and to give some idea of the general station duty. The pumping unit was tested under four principal conditions as follows:-

(1) 20-foot suction lift, 50 lbs. per sq. in. discharge pressure
(2) 20-foot suction lift, 80 lbs. per sq. in. discharge pressure
(3) Highest attainable suction lift, 50 lbs. per sq. in. discharge pressure
(4) Highest attainable suction lift, 80 lbs. per sq. in. discharge pressure.

It was found to be impossible to operate the pump under condition (3) for more than a very brief interval because the volume of discharge was too small to supply the city and the pressure at the pump fell from 47 to 22 lbs. per sq. in. in 15 minutes, so that it was deemed unwise and unsafe to continue that phase of the test longer. A complete outline showing the scope of the test and the methods of observation has been given in the foregoing report. (See pages 24-34).

Discussion of Results of Test of May 3, 1915.

The capacity of the pumping unit under the four test conditions noted above was carefully determined. In no case did the pump deliver at its nominal, guaranteed rate. The deficiency under the several test conditions was as follows:-

(1) 4.7% with 19.9 ft. average suction lift and 50.3 lbs. per sq. in. average discharge pressure .

(2) 9.0% with 20.1 ft. average suction lift and 80.5 lbs. per sq. in average discharge pressure.

(3) 32% with 28.1 ft. average suction lift and 33.3 lbs. per sq. in. average discharge pressure.

(4) 48% with 27.1 ft. average suction lift and 81.3 lbs. per sq. in average discharge pressure.

In case (3) the suction lift was raised to simulate the conditions which would obtain if 15,000,000 gallons per 24 hours were being drawn through the Allis-Holly suction pipe system with a river stage represented by 5.4 feet on the gauge, or 2.8 feet above the stage reached by the river on Sept. 23, 1913. In case (4) the suction head was increased to represent the conditions which would prevail if 10,000,000 gallons per 24 hours were being drawn through the suction

pipe system in question with a river stage represented by a gauge reading of 0.4 feet. (See pages 34 - 36).

The steam requirements of the pumping unit were also determined under each of the four conditions above referred to. It may properly be assumed that the guaranteed steam requirements are not more than 25.0 lbs. of dry, saturated steam per H.P. hour when the pumps are operating in parallel with a total lift of 135 feet and not more than 28.4 lbs. per H.P. hour when the pumps are operating in series or tandem with a total lift of 205 feet. The percentage of steam in excess of the stated figures, required under the several test conditions, was found to be as follows:-

(1) 22.4% with 19.9 ft. average suction lift and 50.3 lbs. per sq. in. average discharge pressure.

(2) 30.6% with 20.1 ft. average suction lift and 80.5 lbs. per sq. in. average discharge pressure.

(3) 80% with 28.1 ft. average suction lift and 33.3 lbs. per sq. in. average discharge pressure.

(4) 63% with 27.1 ft. average suction lift and 81.3 lbs. per sq. in. average discharge pressure.

(See pages 36 - 37).

From the guaranteed maximum steam requirements stated above it is possible to compute the minimum duty of the pumping unit. Per 1000 lbs. of dry, saturated steam the unit should perform 79,200,000 ft. lbs. of work when the pumps are operating in parallel with a total lift of 135 feet and 69,800,000 ft. lbs. when the pumps are operating in series with a total lift of 205 feet. The corresponding values in terms of ft. lbs. per B.T.U. are 900 and 790. The deficiency in duty below the stated figures was found, under the several test conditions, to be as follows:-

(1) 18.4% per 1000 lbs. steam and 18.3% per B.T.U. with 19.9 ft. average suction lift and 50.3 lbs. per sq. in. average discharge pressure.

(2) 23.6% per 1000 lbs. steam and 18.4% per B.T.U. with 20.1 ft. average suction lift and 80.5 lbs. per sq. in. average discharge pressure.

(3) 54% per 1000 lbs. steam and 46% per B.T.U. with 28.1 ft. average suction lift and 33.3 lbs. per sq. in. average discharge pressure.

(4) 39% per 1000 lbs. steam and 39% per B.T.U. with 27.1 ft. average suction lift and 81.3 lbs. per sq. in. average discharge pressure.

(See pages 37 - 38).

A complete tabulation of test conditions and results of the test of May 3 are presented in Table No. 9, page 41. Diagrams showing certain principal test conditions and the performance of the pumping unit thereunder have also been presented in the foregoing report. (See pages 38 - 45).

Fuel Requirements of Centrifugal vs. Reciprocating Pumping Units.

It has been a matter of serious complaint that the fuel oil requirements for the operation of the pumping station are extraordinarily greater when the steam-turbine centrifugal pumping unit is in service than when the reciprocating pumping engines are in service. From the records maintained at the pumping station by Mr. Ehret it has been possible to determine the excess fuel requirements when the centrifugal unit is in service and, hence, the excess cost of its operation. This matter has been discussed at length in the foregoing report and various tables and diagrams have been presented by which the regular equipment and the new centrifugal unit have been compared in this particular. The general conclusions of this study may be stated as follows:-

(1) about 122 gallons or 2.9 bbls. more of fuel oil are required, other things being equal, to pump one million gallons of water through a total lift of 98 feet with the centrifugal pumping unit, only, in service than with the Snow and Allis Pumps in service.

(2) About 0.33 gallons more of fuel oil per mill. ft. lbs. of work performed are required when the centrifugal pumping unit, only, is in service than when the Snow and Allis pumps are in operation.

(3) Assuming an average daily pumpage of 15 million gallons, the excess cost of fuel oil, under the conditions noted in (1) above, and assuming that oil costs $0.81 per barrel, would be about $35.30

(4) Per million gallons pumped under the conditions stated in (1) above, the excess cost of fuel oil is estimated to be about $2.35

(5) Per million ft. lbs. of work performed under the conditions of (1) and (2) above, the excess cost of fuel oil is estimated to be 0.63 cent.

These figures would, of course, be somewhat reduced if the operation of the

Holly pump be considered, as is the case in Table No. 11. (See pages 46 - 52).

Conclusions.

Holding in review the studies and investigations which have been made with respect to the physical and other conditions affecting the operation of the Sacramento City water works pumping station and basing judgment upon the results of comprehensive tests of the steam-turbine centrifugal pumping unit under consideration, and upon a painstaking examination of these results, it appears that the following conclusions may be advanced:-

(1) The present maximum rate of use of water in that portion of the city supplied from the City water works pumping station is dangerously greater than the working capacity of the present regular pumping equipment.

(2) The Alberger-Curtis steam-turbine pumping unit, which has recently been installed in the pumping station but not yet accepted by the city, is of no value whatever because at low stages of the river its operation would be entirely problematical and unreliable. Indeed, under the physical conditions which prevail with respect to its setting, it may be said that the pump is a menace because (1) it may give a false idea of security and (2) it causes a most serious congestion of the pumping station floor.

(3) The fact that this pumping unit is entirely unreliable and not to be depended upon at all at low river stages has nothing to do with the question as to whether or not it shall be accepted by the City. The sole determination upon which its acceptance must rest is that the contract provisions with respect to capacity and duty under certain stipulated conditions be fulfilled.

(4) The capacity of the pumping unit, as determined by the test of May 3, is fully 4.7% less than the guarantee under the contract conditions of 20 ft. suction lift and 50 lbs. per sq. in. discharge pressure, and fully 9.0% less than the guarantee under the contract conditions of 20 ft. suction lift and 80 lbs. per sq. in. discharge pressure.

(5) The steam requirements of the pumping unit during the test of May 3 were fully 22.4% more than what may logically be interpreted to be the guaranteed economy under the contract conditions of 20 ft. suction lift and 50 lbs. per sq. in. discharge pressure, and fully 30.6% more than the presumably guaranteed figure applying to the contract conditions of 20 ft. suction lift and 80 lbs. per sq. in. discharge pressure.

(6) The duty of the pumping unit in question, expressed in terms of ft. lbs. of work per 1000 lbs. of dry, saturated steam consumed by the turbine, was shown by the test of May 3 to have been fully 18.4% less than what may logically be interpreted to be the guaranteed duty under the contract conditions of 20 ft. suction lift and 50 lbs.

per sq. in. discharge pressure, and fully 23.6% less than the presumably guaranteed figure applying to the contract conditions of 20 ft. suction lift and 80 lbs. per sq. in. discharge pressure.

(7) Under the usual delivery pressure conditions the excess cost of fuel oil required for the operation of the pumping station when the steam-turbine centrifugal pumping unit, only, is in service, as compared with the fuel requirements when the Snow and Allis pumps are in service is as follows:- $2.35 per million gallons pumped; 0.63 cent per million ft. lbs. of work performed; $35.30 per day if 15,000,000 gallons are pumped.

Respectfully submitted,

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