RECIRCULATION SYSTEM ELECTRIC SUBMERSIBLE PUMPS – A WINNER FOR PERMIAN BASIN OPERATORS

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ABSTRACT

The recirculation electric submersible pump system was introduced to industry in 1995. Subsequently, the system's utility has been demonstrated in numerous installations; the vast majority of which have occurred in the Permian Basin area of west Texas / southeast New Mexico. The system can be used to: (1) minimize gas interference with the pump (2) maximize well drawdown (3) increase fluid flow past the motor in low volume wells, and (4) eliminate shrouds. The primary goals of most all existing installations have been either to avoid gas interference with the pump and/or to minimize producing fluid levels.

This paper provides a basic description of the recirculation system. Sample output from a new recirculation pump sizing applet is presented. The benefits of the technology to Permian Basin operators are demonstrated through several case histories. These examples include applications of the technology in both 5.5-in. and 7-in. casing wells.

SYSTEM DESCRIPTION AND PURPOSE

The recirculation electric submersible pump (ESP) system was introduced to industry in 1995. Wilson, et al' described the initial field trials which occurred in southern Oklahoma. The system has since been patented.* Although descriptions of the system have been presented previously,[1,3-6] another will be given here for completeness sake.

A standard electric submersible pumping unit consists of the following downhole rotating equipment:

1. centrifugal pump,
2. seal section,
3. electric motor.

In comparison to a standard ESP, the recirculation ESP (Fig. 1) requires only the following additional components:

1. recirculation pump,
2. recirculation tubing and connective assembly,
3. motor tailpipe and protective clamp assembly.

The recirculation pump is a small pump stage-wise (usually a #1 or #2 housing pump is sufficient), is of the same series as the main production pump, and imparts only a small horsepower adder to the system. The recirculation pump serves as the system intake and is volumetrically larger than the main pump stage. For example, the main pump may be rated nominally at 1000 BFPD while the recirculation pump might ideally be rated around 2200 BFPD. This is to ensure that an "excess" amount of fluid is produced, beyond the target or desired formation inflow. Practically speaking, the "excess" fluid is recirculated within the wellbore such that the intake volume for the recirculation pump is comprised of the formation inflow plus the recirculation volume. It is important to note that the recirculation pump operating point is influenced by the size of the recirculation tube. If the tube is too "restrictive", then the pump will operate on the left side of the curve; whereas, if the tube is too "big", then the pump will operate to the right side of the pump curve. The recirculation pump, therefore, produces a larger gross volume of fluid than the main pump, a portion of which is tapped off before much pressure has been added. The recirculation tubing is connected to the recirculation pump via a port that is tapped into the discharge head of that pump. The recirculation tubing is welded or threaded into a "cap" or "tubing head". The cap is then fit into the recirculation pump head. To round out the system, the recirculation tubing is usually banded or connected to a ±4 ft. motor tailpipe sub and protective clamp which serves to stabilize the assembly and provide some extra protection in cases where there is a close fit between the equipment and the casing ID.

The recirculated fluid flows down the recirculation tube and exits the tube below the motor, setting up a flow loop around the motor. The fluid volume recirculating around the motor mixes with the formation inflow so that the steady-state motor operating temperature rise is maintained at reasonable levels. (That is, a mixing occurs between "new" fluid and "old" fluid; the same fluid does not keep getting recirculated!) Intuitively one might expect that forced flow via a shroud would result in a somewhat cooler motor operating temperature than a recirculation system (computer simulations seem to support this). Nevertheless, the recirculation system provides a viable alternative to shrouds in submersible pump operations when motor cooling is likely to become an issue due to the completion configuration.

A significant benefit of the recirculation system is that it allows a larger OD ESP motor (hence less costly motor) to be run in a given casing size as opposed to a smaller, shrouded motor. In order to fit the 450-series motor (see Nomenclature section) in the 5.5-in. casing, a special "flat-radiused" tube was developed. This style of tube is required only in situations where space is at a premium. Otherwise, a larger OD common line pipe, etc. can be used as the recirculation tubing. Figures 2-4 show cross-sections of various styles of recirculation flat-tubes that have been used. All of these tubes incorporate "crush rods" for protection in tight clearances.

In addition to providing an alternative to the use of motor shrouds, the recirculation system can be used to:

1. minimize gas interference by setting below perforations,
2. minimize dynamic fluid levels by setting below perforations,
3. provide supplemental flow past the motor in low volume wells.

Historically, one way to produce gassy wells with ESPs has been to sump the unit before perforations and rely on natural annular gas/liquid separation. In such situations, the ESP must be shrouded or, now, a recirculation unit can be considered. In low bottomhole pressure wells, it is often desirable to set the pumping unit as deep as possible to draw down the working fluid level as much as possible. Setting an ESP below the perforations can enable this strategy yet the motor must be cooled. Finally, the recirculation system can be used to increase flow past the motor in small volume / large casing applications or provide required cooling flow at unit startup in cases where a high static fluid level / low well productivity combination put the ESP motor at risk of premature failure due to transient motor temperature spiking.

HISTORICAL DEVELOPMENT

The initial driver for the development of the system was the desire to run an unshrouded 450-series ESP below perforations in a 5.5-in. casing well to avoid scaling tendencies between the motor and shroud.' From 1995 to 2001 installations consisted of either 375 or 450-series motors with common round tubes or the custom recirculation tube. These units were run in 5.5-in. and 7-in. casing. The main limitation with these systems was that imposed by the available horsepower in 375 and 450-series motors. In 2001 a step change was implemented when Centrilift installed 500-series recirculation systems in two 7-in., 23 lb. casing wells. These systems utilized 513-series pumps and seal sections, and 562-series motors with the flat tube as shown in Fig. 3. The systems represent the highest volume/horsepower recirculation systems run to date. (The applications for these units are briefly described in well case histories 3 and 4 below.) Although theoretically it is possible to utilize the recirculation system with any series of ESP equipment, from a practical standpoint, it is most applicable to 300,400 and 500-series equipment.

SYSTEM SIZING TOOLS

Two software tools are available to size a recirculation pump application. The first of these tools is the Centrilift in-house sizing program, AutographPCB. This program is used to size a variety of pump systems, including ESP, both electric submersible and rod-driven progressive cavity pump units, surface pumping systems, and downhole oil/water separation units. The program is, in effect, a specialized NODAL program which solves for the required pressure boost required downhole at the desired rate and stated wellhead pressure requirements. Ultimately, this NODAL solution translates into a specific pump sizing. The program can account for well IPR performance and tubing performance but does not include the surface facilities network as that is beyond the consideration of the pump supplier in most cases; we generally are provided with the required wellhead pressure. The program is very robust and offers various fluid property correlations as well as tubing flow correlations. The program has the ability to not only provide a "steady-state'' pump sizing, but can also simulate transient conditions which occur at startup or are imposed due to running speed changes, well PI changes, tubing leaks, and various other conditions. As with most any predictive software tool, the output results are only as good as the input. The AutographPCB program is used to perform the main pump sizing in a recirculation system just the same as in a standard ESP application. There is no increased difficulty in applying the recirculation pump system from a sizing standpoint.

Prior to 2001, the recirculation pump sizing was perhaps more art than science based on utilization of a standard recirculation pump stage. However, in 2001, due to the potential for larger volume and horsepower systems and different styles of recirculation tubes, it was decided to develop a recirculation pump applet which would function in coordination with the main sizing program. The recirculation pump applet utilizes certain information from the AutographPCB sizing file and requires very minimal additional user input. The only required input includes:

1. proposed recirculation pump and number of stages,
2. length and ID of proposed recirculation tube.

The applet is written in MS Excel. The program iterates to find a coupled match between a viable operating point (flow and head) of the recirculation pump and recirculation flow based on the backpressure exerted (i.e., frictional pressure) by the recirculation tube. The program also calculates the estimated motor operating temperature and the estimated intake and discharge volumes for the recirculation pump; this enables the user to check whether the selected recirculation pump will likely operate within its nominal range. The aforementioned output parameters are displayed on the same screen as the input parameters, which results in an economical one-page output. A sample of the applet input/output is shown in Fig. 5. The simple nature of the applet allows the user to quickly run sensitivities on various recirculation tube IDs and lengths, and possible recirculation pumps to ascertain the best solution for a given application. Obviously, in smaller casing, the choices per recirculation tube style may be limited such that the only sensitivity is on the type of recirculation pump and the number of stages. The utility of the recirculation applet will now be demonstrated through some theoretical examples.

Figures 6-8 show the input well data, pump, and motor screens from a "main-pump'' sizing for a theoretical recirculation pump application. In this theoretical well, we have 7-in. casing and are interested in utilizing 400-series ESP equipment so that a fairly large diameter recirculation tube can be run with the unit. The motor screen reflects the estimated motor operating temperature of 210 °F if a shroud were employed. Table 1 presents the results of a sensitivity performed on specific recirculation pumps. In these cases the recirculation tube was chosen as a 1-in. OD (0.902-in ID) tube with a defined 39 ft. length (recirculation tube length does not change since the net equipment length starting at the recirculation pump head does not change). The information in the table suggests a considerable volume of fluid will be recirculated through the 1-in. tube regardless of the recirculation pump chosen, resulting in a small estimated swing in motor operating temperature (216-222 °F). However, only the FC2700 pump will operate within its nominal range. The FC2700 is the best choice for the recirculation pump, with the added benefit that it is the largest volumetrically and is best suited to handle any free gas which makes its way to the pump intake due to its mixed flow construction.

Fig. 9 shows the motor sizing screen from our same theoretical well with the exception that we now wish to run a 562-series motor in the 7-in. casing. Obviously we cannot use a motor shroud in this scenario and are now forced to use a flat recirculation tube. The same possible recirculation pumps as in the previous example are considered with the addition of a larger stage quantity possibility for each pump to see what effect that has overall. Table 2 data show that the recirculated volume will be considerably less using the flat tube (Fig. 3) as opposed to the larger tube of the previous example, with a commensurate higher motor operating temperature. Also, some increase in recirculated volume is noted for each type of pump when the stage quantity is increased. Any of the pumps would suffice for the application; however, the FC1600 would be operating more optimally (to the right of BEP) within its nominal range, plus the resulting estimated motor operating temperature is less. In this example, the 15-stage FC1600 would likely be chosen as the recirculation pump. Overall, given a choice between the equipment selection scenario from the first and second sensitivity studies, the best option from purely the viewpoint of motor operating temperatures would be the smaller motor / larger recirculation tube scenario. Admittedly though, in this fictitious case the horsepower requirements do not demand the larger OD motor. Of course, if the motor horsepower requirements were ±300 hp or above, the larger motor / flat recirculation tube scenario might be the only option. As always, equipment cost would be a consideration in any final selection.

The recirculation applet assumes a round geometry for the recirculation tube. This is significant since the friction loss characteristics for such tubes are generally well known and available. For the custom flat tubes, we currently estimate the friction loss in terms of an equivalent round tube. However, a testing program is now underway to empirically determine friction loss characteristics for the most common flat tubes we utilize. This information will be incorporated into the applet and should greatly increase the predictive capabilities of the program.

CASE HISTORIES

Seven brief case histories of the recirculation ESP system are presented below. The first four cases have been summarized from lengthier discussions previously given in the literature. The latter three cases have not been previously presented.

Case #1

While on rod pump this 5.5-in. casing well experienced 13 combined rod and tubing failures over an 18 month period. This resulted in 47 days of downtime and $80,000 in well servicing and repair costs. Prior to producing the well on rods, attempts at utilizing shrouded slimline motor ESPs were unsuccessful due to motor bums resulting from scale formation between motor and shroud. **A** recirculation ESP system consisting of 400-series equipment and flat recirculation tube increased oil production and gas production in the well by 79% and 56%, respectively. In addition, artificial lift equipment runtime was increased to over 6 months. Please see reference 3 for more details of this installation. Some well and reservoir information for this case and for case history #2, immediately below, may be found in Table 3.

Case #2

The problems and circumstances for this 7-in. casing well were almost identical to that described in case #1. The well had 17 rod and tubing failures while on rod pump during a 21 month period prior to the recirculation ESP system installation. Three well workovers immediately prior to the recirculation system installation cost over $34,000. **A** 400-series recirculation system with 1-in. round tube was installed in the well. This system pushed runtimes beyond 7 months and increased both oil and gas production in the well by 180%. Please see reference 3 for more details of this installation.

Case #3

A shrouded 450-series ESP motor and pump system had been set below perforations to “de-water” this 7-in. casing gas well. The 5.5-in. motor shroud limited the motor size to 450-series and very aggressive re-rating of the motor was necessary due to the horsepower requirements. This aggressive re-rating was lead to undesirable runtimes due to failures resulting from high motor operating temperatures. The operator desired to run a 500-series recirculation system (3500 BFPD main pump and 380 horsepower motor) which would allow 562-series motors at standard rating to be employed in the application. The recirculation system was sized to essentially produce the same amount as the previous shrouded units; however, the larger motor recirculation system, with flat tube, has increased the runtime over the shrouded small motor systems and has resulted in an estimated $2500 per month lower equipment lease costs and electricity costs while maintaining the rates from the previous shrouded operating scheme. Runtime has improved as well (in excess of 250 days) over the shrouded systems. Please see reference 6 for more details of this case. Some field and well data for this case and for case #4, immediately below, may be found in Table 4.

Case #4

This case was quite similar to case #3 above with the exception that the operator was able to work over the well to add pay prior to installing a 562-series motor flat tube recirculation system in this 7-in. casing well. The operator knew that increased water production would also result; however, the ability to run a standard-rating 562-series motor of sufficient horsepower enabled significantly more hydrocarbon production to be realized in this “co-production” project. The deployed unit included a 6100 BFPD main pump with a 570 horsepower motor. The well hydrocarbon revenue increase was estimated by the operator at over $200,000 per month based on a doubling of oil production and a 50% increase in gas production.

Case #5

This 5.5-in, 17 lb. casing well had a severe dogleg at 1,000 ft. MD which caused a 456-series ESP unit to become stuck in the hole during the installation attempt. The operator was then limited to setting a slimline ESP above 6,030 ft. MD which severely restricted production. The operator then inquired about a recirculation system for this well. **A** slimline (375-series) motor recirculation unit with 400-series pump was able to pass through the dogleg and was set below perforations at 7,200 ft. MD. This enabled the operator to increase drawdown on the well thereby increasing production and revenue. There was an estimated incremental hydrocarbon revenue of $432,000 per year. General data for this well are located in Table 5.

Case #6

The wells located at this lease are very pressure sensitive and the more fluid a well carries above the perforations, the less oil it makes. Traditional ESP systems set above the perforations had been used to produce this well; however, offset wells operated by another company have responded well to recirculation pump technology. Therefore, operator decided to try the recirculation system to see if similar benefit would result for this well. The operator set a 562-series motor recirculation system with flat tube much further down into the perforated interval and achieved a considerable increase in oil production. The estimated incremental hydrocarbon revenue due to the 58 BOPD increase in production is $500,000 per year. General data for this well are located in Table 6.

Case #7

Conventional ESP system in this 5.5-in., 17 lb. casing well experienced severe operational difficulty due to excess gas volume at the pump intake, resulting in cycling and gas locking problems. A 450-series motor recirculation system with flat tube was installed 400 ft. below the top gas producing interval. The recirculation system is operating smoothly without cycling and has increased production, resulting in incremental revenue of $342,000 per year for this well. General data for this case are located in Table 7.

CONCLUSIONS

The recirculation electric submersible pump has proven to be a viable and valuable addition to the well operator's "toolbox" of artificial lift systems, particularly as demonstrated in the Permian Basin where the majority of installations have occurred. Case histories described in this paper indicate that the system has provided tangible economic benefit to operators in various scenarios ranging from alleviating running problems in deviated wells; to mitigating motor horse-power limitations and thus allowing larger and less expensive ESP equipment to be deployed instead of smaller, shrouded units; to allowing changes in completion strategy to add pay and increase production; to mitigating operational difficulties; to picking up additional oil production by setting lower in the perforated interval. In summary, the recirculation pump can yield good results where conditions dictate its potential applicability. Relevant sizing tools exist which can, in conjunction with good well data, yield proper equipment sizing

NOMENCLATURE

Generally, 400-series ESP equipment = ESP equipment with OD $\geq$ 4.00-in. and $<$ 5.00-in.
500-series ESP equipment = ESP equipment with OD $\geq$ 5.00-in. and $<$ 6.00-in.
Specifically, xxx-series pump (or other equipment) = x.xx-in. maximum unit OD

BEP = centrifugal pump best efficiency point
BFPD = barrels fluid per day
BOPD = barrels oil per day
ID = inner diameter
IPR = inflow performance relationship
OD = outer diameter
PI = productivity index

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Table 1

Sensitivity Results for Recirculation Example #1

Pump	No. Stages	Qip	Qmin	Qbep	Qmax	Qrecirc	Mtr Temp
FC1600	15	2482	991	1646	2082	1172	222
FC1800	8	2590	991	1783	2477	1276	220
FC2200	8	2935	1487	2280	2775	1606	217
FC2700	8	3174	1487	2627	3767	1834	216

Table 2

Sensitivity Results for Recirculation Example #2

Pump	No. Stages	Qip	Qmin	Qbep	Qmax	Qrecirc	Mtr Temp
FC1600	15	1719	990	1643	2078	443	252
	31	1875	991	1645	2081	593	247
FC1800	8	1565	989	1780	2473	296	271
	17	1698	989	1781	2474	423	253
FC2200	8	1611	1484	2275	2770	340	268
	16	1752	1485	2277	2772	475	250
FC2700	8	1633	1484	2622	3760	361	263
	16	1778	1485	2624	3763	500	250

Table 3

General Data for Cases 1 & 2

Parameter	Value
County, State	Gaines, Texas
Formation	Wolfcamp
Well static pressure, psig	350-500
Producing GOR, scf/stb	160-200
Water cut, %	89-91
Bottom hole temperature. F	145-150
Oil gravity, API	41-42
Casing size & weight	5.5-in., 17 lb. / 7-in., 26 lb.
Tubing size	2.875 in.
Well producing interval, ft TVD	9200 - 9500

Table 4
General Data for Cases 3 & 4

Parameter	Value
County, State	Lea, New Mexico
Formation	Cisco & Canyon
Well static pressure, psig	1000-1200
Producing GOR, scf/stb	6,100-22,500
Water cut. %	92-93
Bottom hole temperature, F	156
Oil gravity, API	43
Water specific gravity	1.03
Casing size & weight	7-in., 23 lb.
Tubing size	2.875-in. / 3.5-in.
Well producing interval, ft TVD	7400 - 7800

Table 5
General Data for Case 5

Parameter	Value
County, State	Gaines, TX
Formation	Upper, Middle, Lower Clearfork
Well static pressure, psig	2175 (est.)
Producing GOR, scf/stb	521
Water cut, %	74.5
Bottom hole temperature, F	140
Oil gravity, API	42
Water specific gravity	N/A
Casing size & weight	5.5-in., 17 lb.
Tubing size	2-7/8"
Well producing interval, ft TVD	6030 - 7200

Table 6
General Data for Case 6

Parameter	Value
County, State	Gaines, TX
Formation	Wolfcamp
Well static pressure, psig	866 (est.)
Producing GOR, scf/stb	160
Water cut. %	91
Bottom hole temperature, F	140
Oil gravity, API	32.8
Water specific gravity	1.04
Casing size & weight	7-in., 26 lb.
Tubing size	2 7/8"
Well producing interval, ft TVD	9060-9270 Open Hole

Table 7
General Data for Case 7

Parameter	Value
County, State	Ward, TX
Formation	Cherry Canyon
Well static pressure, psig	1563
Producing GOR, scf/stb	8914
Water cut. %	92.0
Bottom hole temperature, F	130
Oil gravity, API	N/A
Water specific gravity	1.03
Casing size &weight	5.5-in, 15.5 lb.
Tubing size	2-3/8"
Well producing interval, ft TVD	6306 - 6392

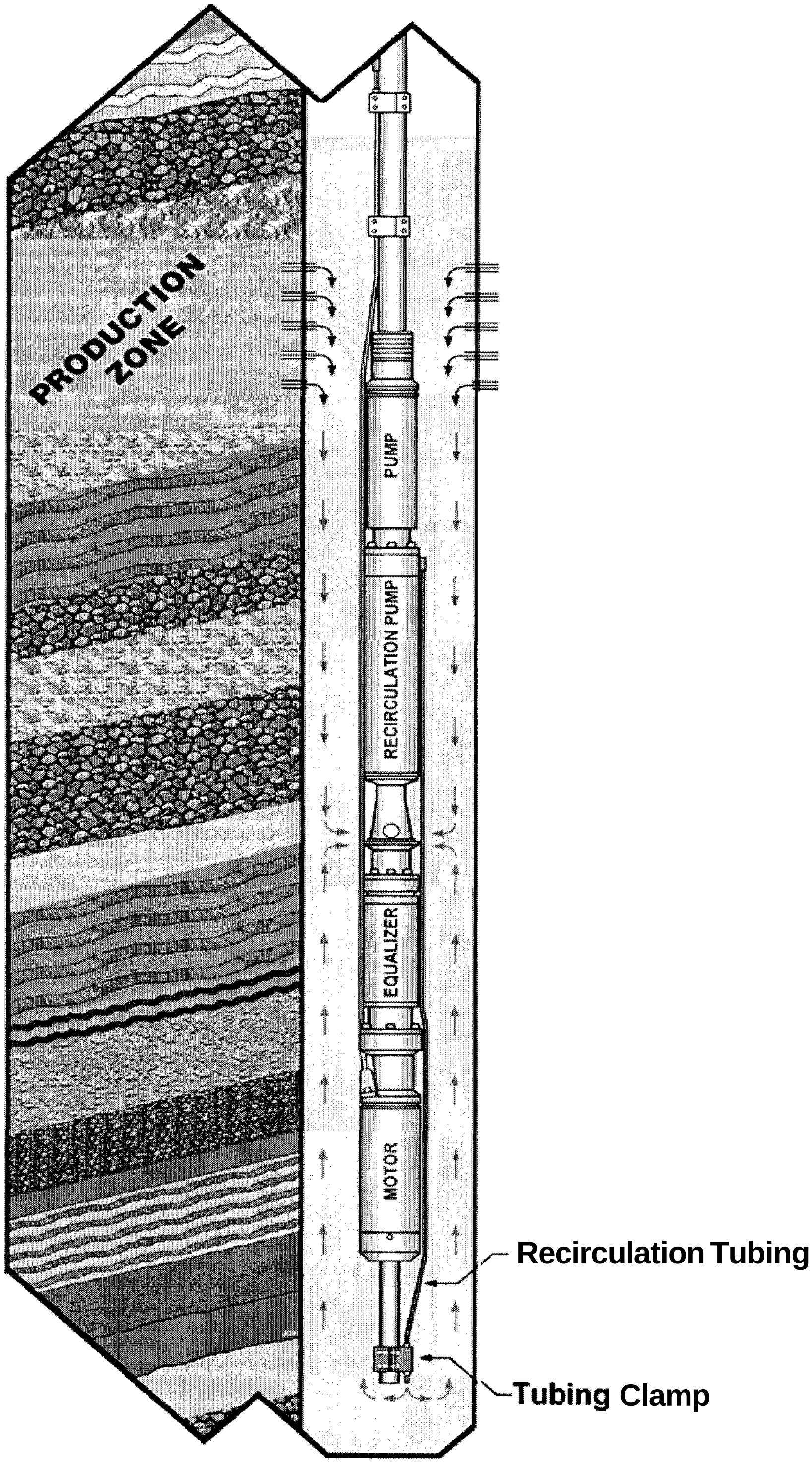

Fig.1 Recirculation System

Figure 2 – Recirculation Flat Tube (original style)

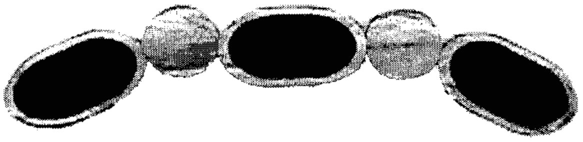

Figure 3 – Recirculation Flat Tube ("Midland" style)

Figure 4 – Recirculation Flat Tube ("Argentine" style)

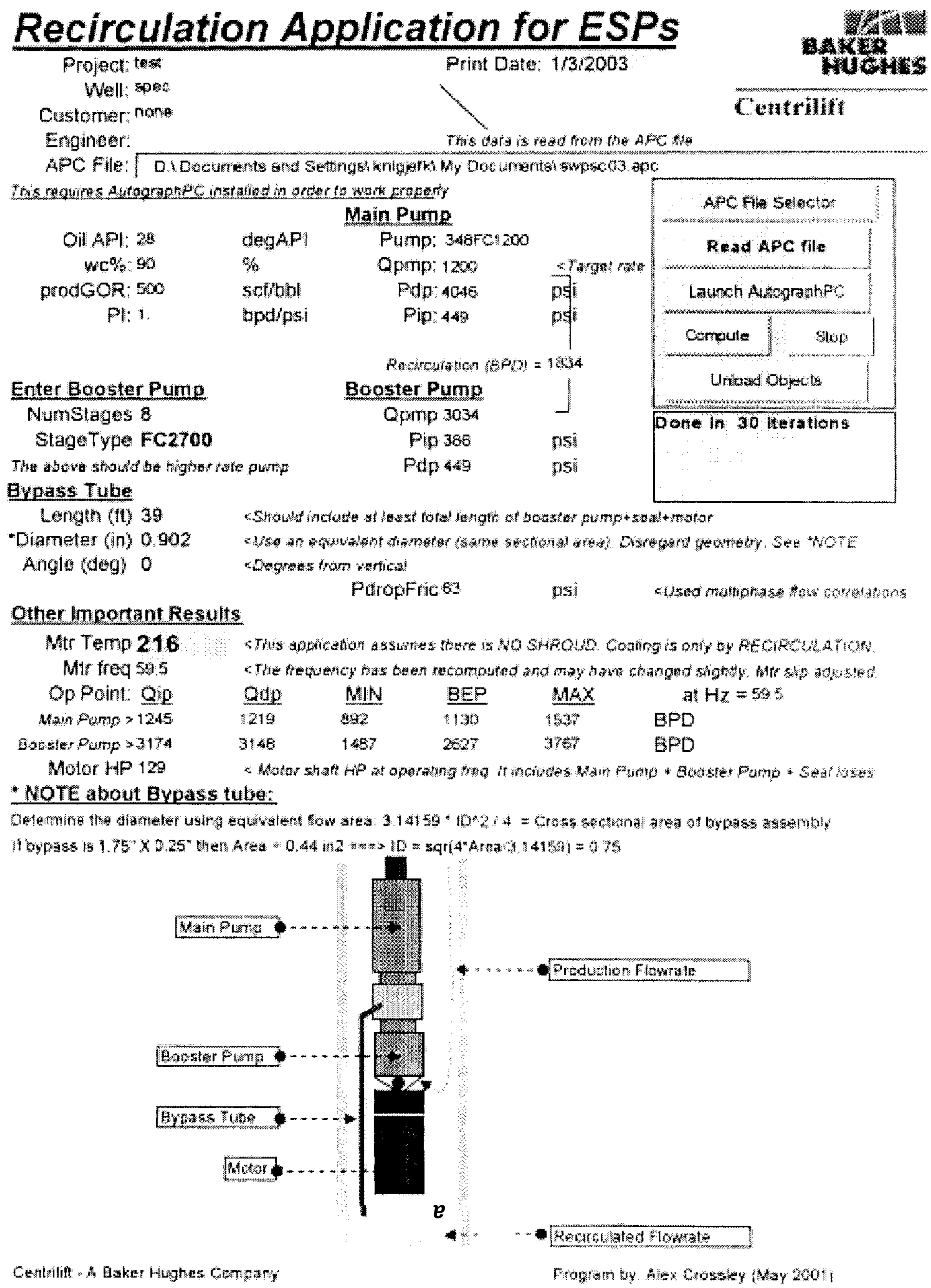

Figure 5 – Recirculation Pump Sizing Applet I/O Screen

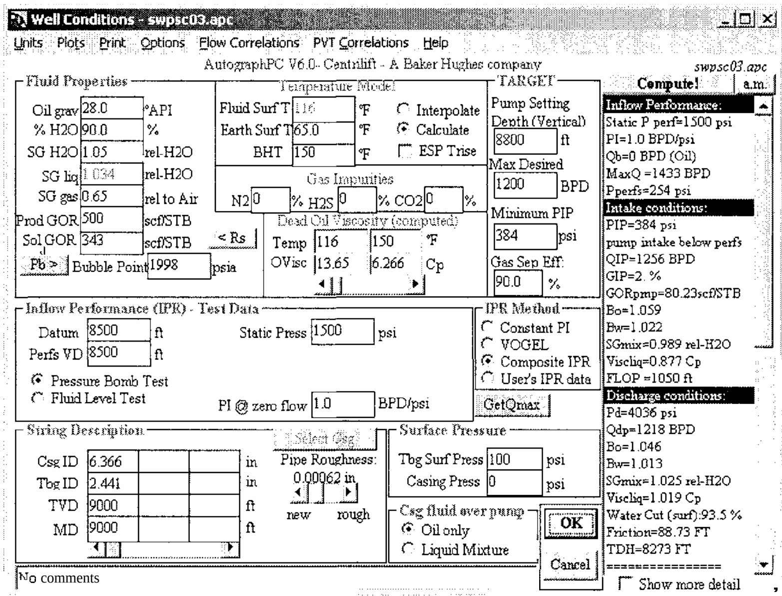

Figure 6 – Theoretical Example Input Screen

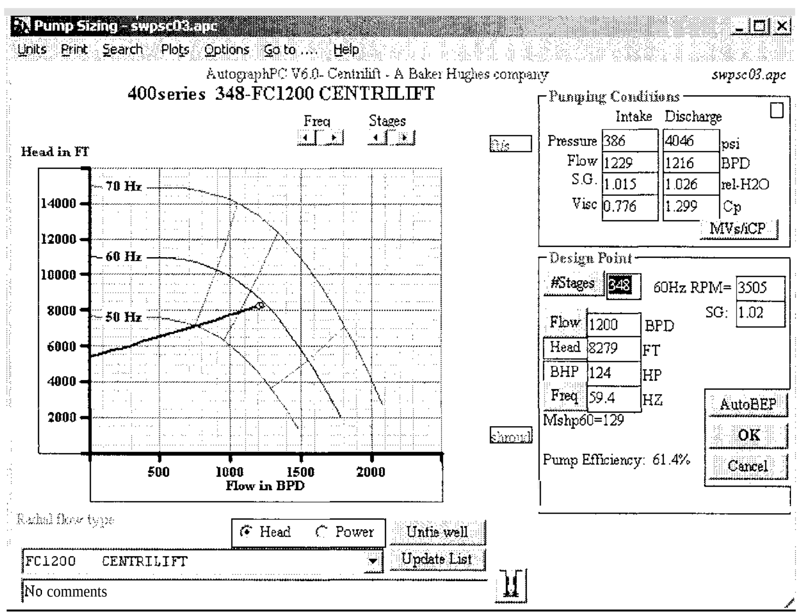

Figure 7 – Theoretical Example Pump Sizing Screen

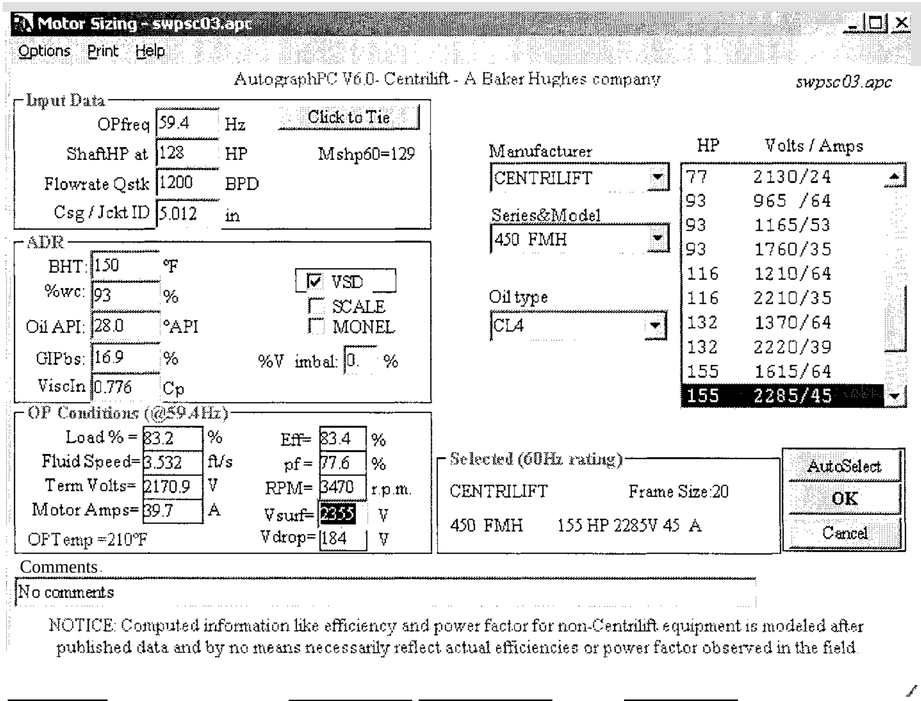

Figure 8 – Theoretical Example 450-Series Motor Sizing Screen

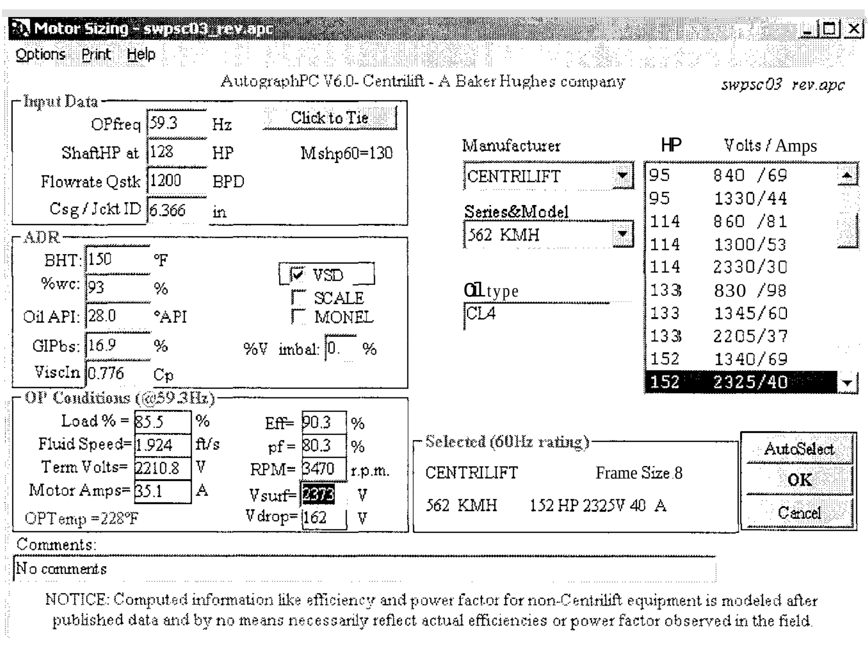

Figure 9 – Theoretical Example 562-Series Motor Sizing Screen